WATER SUPPLY, TREATMENT AND DISPOSAL IN UNCONVENTIONAL GAS DEVELOPMENT

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INFUSE
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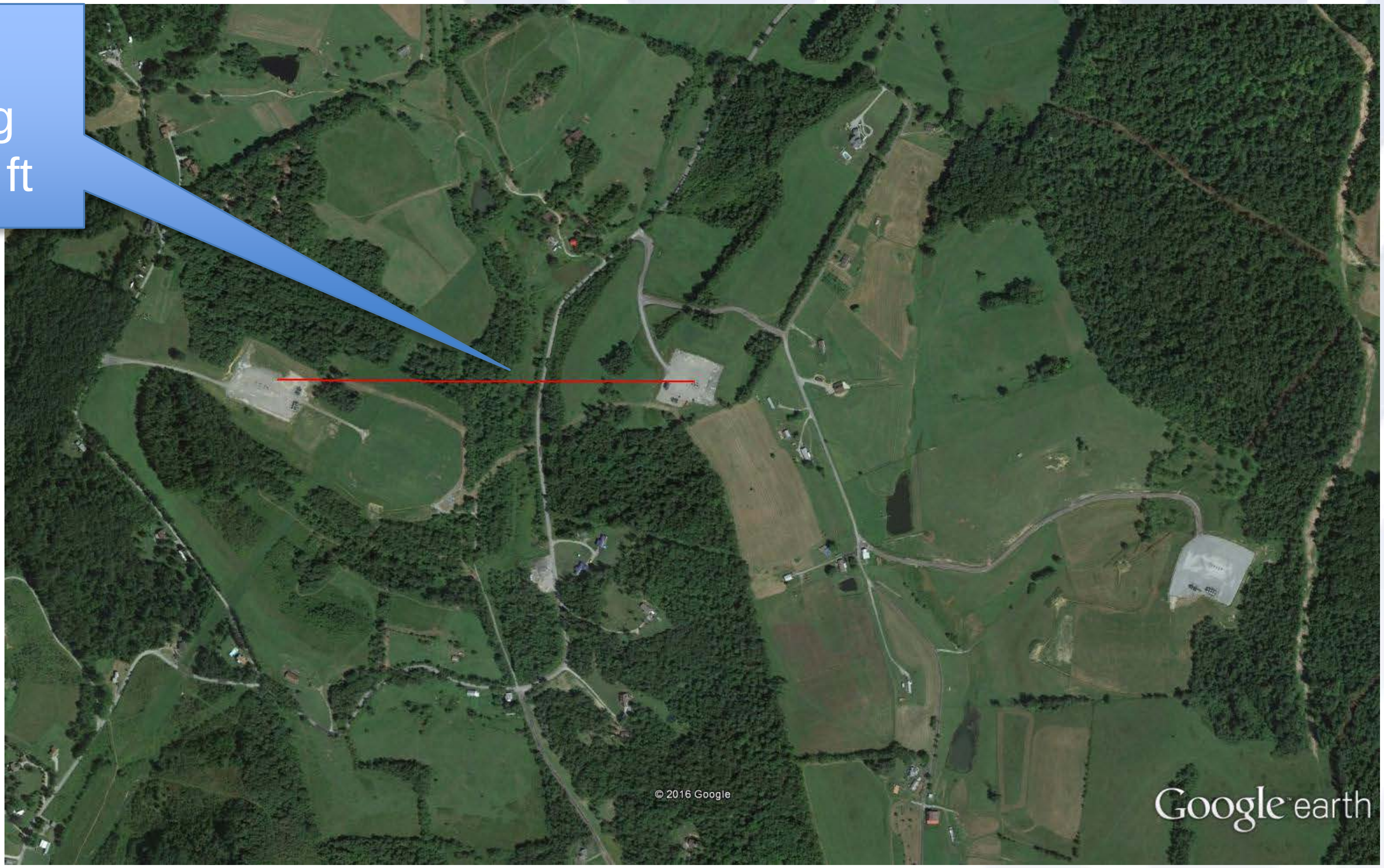
Water Withdrawals

Major sources:

- surface water
- municipalities
- recycled produced water

THREE WELL PADS: GREENE CO. PA

Well spacing ~ 2,500 ft



PRODUCING WELL SITE:
4 WELLS

- 2 hectares total
- access/service road
- Out slopes

- 1.2 hectares pad
- well heads
- separators
- condensate tanks

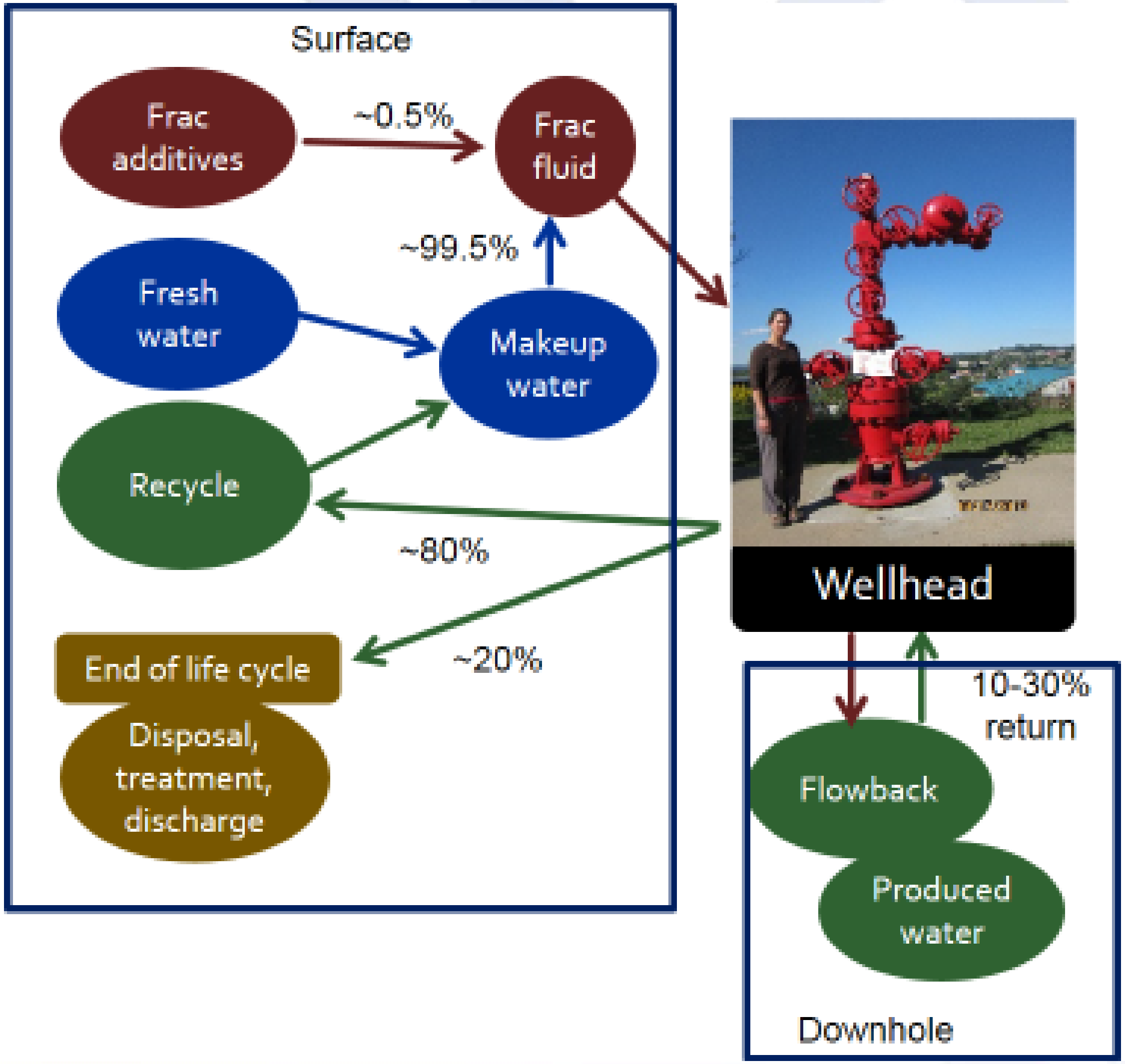
PRODUCING WELL SITE WITH FLOWBACK POND 6 HECTARES

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

Terminology: liquids

- **Makeup water**-impoundments/tanks
  - fresh water
  - waste water
- **Hydraulic fracturing fluid-**frac fluid
  ~ 16,000 to 19,000 m^3 injected
  - Makeup water +
  - Proprietary mixture of chemicals
  - Proppant
- **Flowback-produced water**
  Fluids returned from the well after frac
  ~70-90% lost in formation
- **Recycle**
  - Flowback-produced water used for makeup

Fluids at the well site

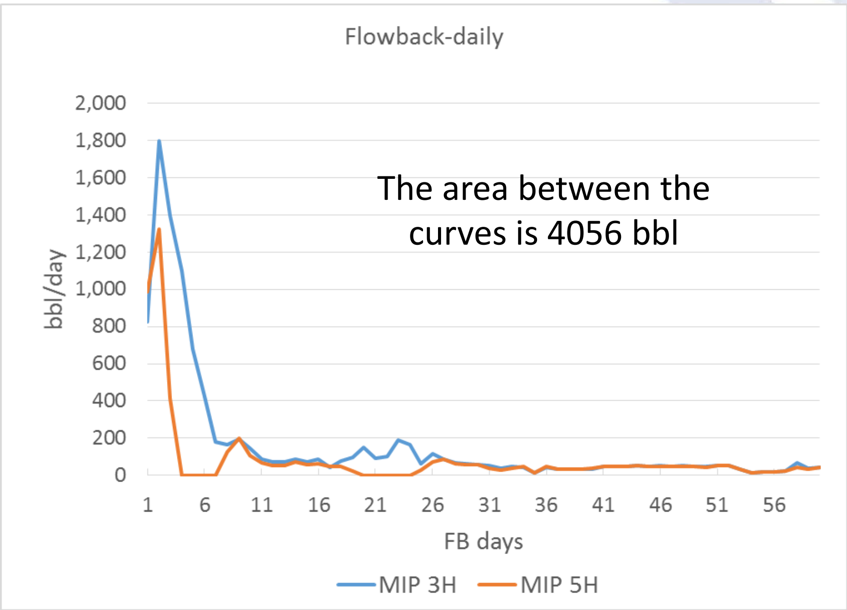


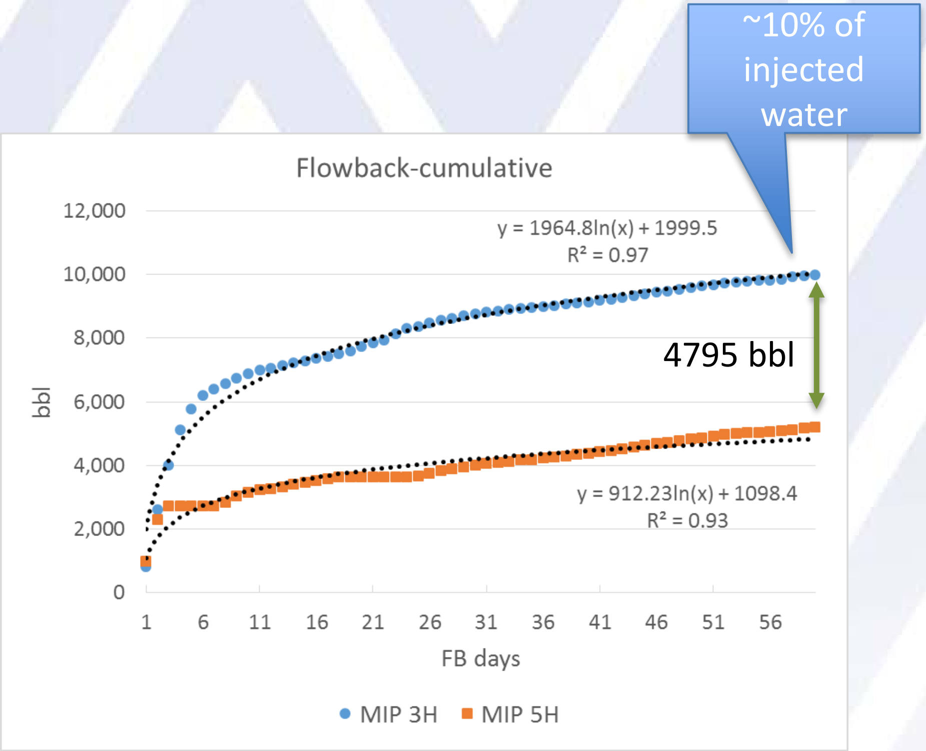
Flowback volumes: MIP 3,5H

3H produced 92% more water, 30% more gas

1 bbl=0.16 m^3

6.25 bbl/m^3





CHEMICAL CHARACTERIZATION

- Flowback/produced water
  - Recycled flowback + makeup water + additives
- Hydraulic fracturing fluid
- Drilling mud

Flowback day ~1,350

Produced water from old (MIP 4,6H) wells predominantly Na, Ca, Cl

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

* µS/cm

MSEEL data

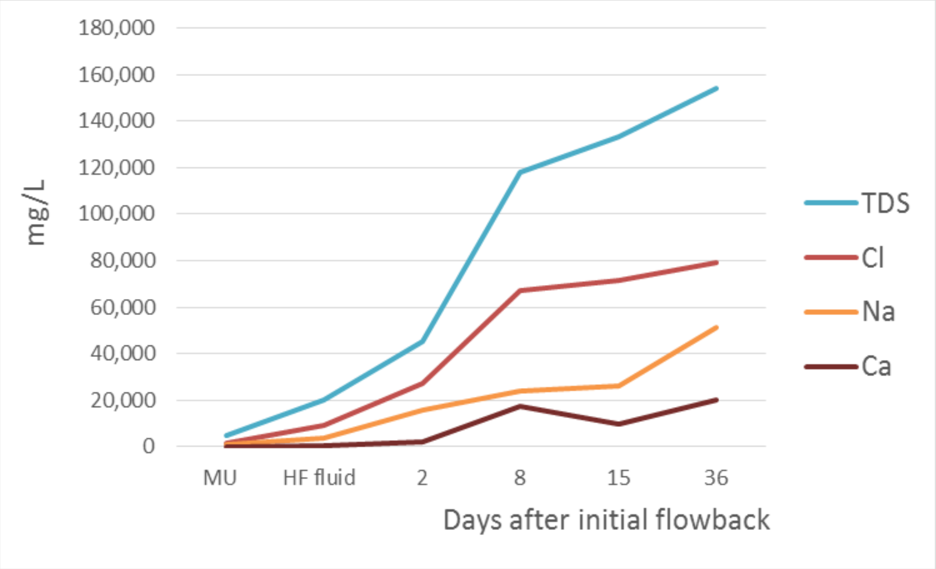
Nearly all parameters were higher in flowback than frac fluid

Pink: exceeds drinking water MCL

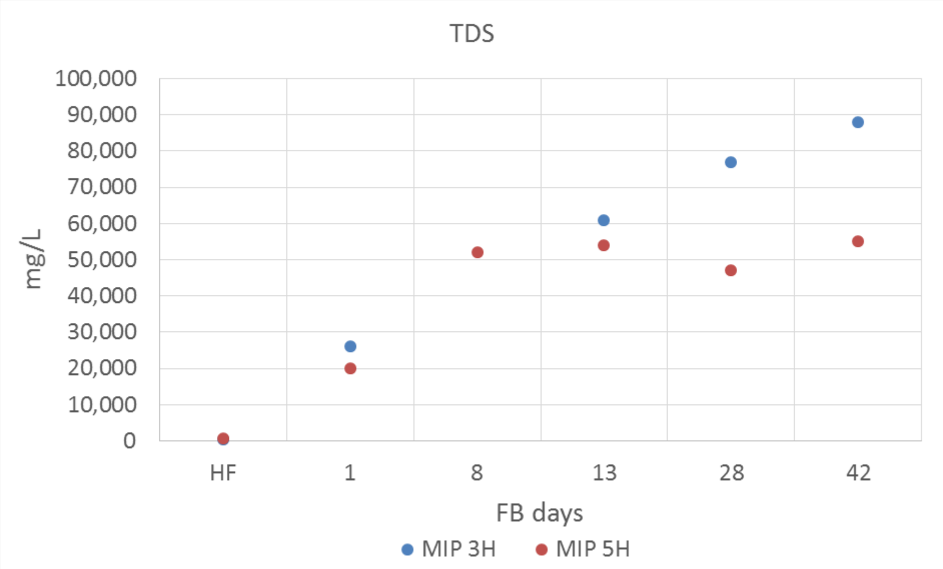
MDL		units	SDWA MCL	MIP 3H HF	MIP 3H FB day 42	MIP 5H HF	MIP 5H FB day 42
0.0011	Al	mg/L	0.05	0.42	0.00055	0.02	0.00055
0.0007	As	mg/L	0.01	0.00	0.35	0.00	0.35
0.0002	Ba	mg/L	2	0.04	2500	0.048	1100
0.4	Ca	mg/L		35.5	6800	34	2900
0.0001	Cr	mg/L	0.1	0.003305	0.05	0.00005	0.05
0.01	Fe	mg/L	0.3	1.996	140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

Flowback evolution-major inorganic ions

Ziemkiewicz et al., 2011

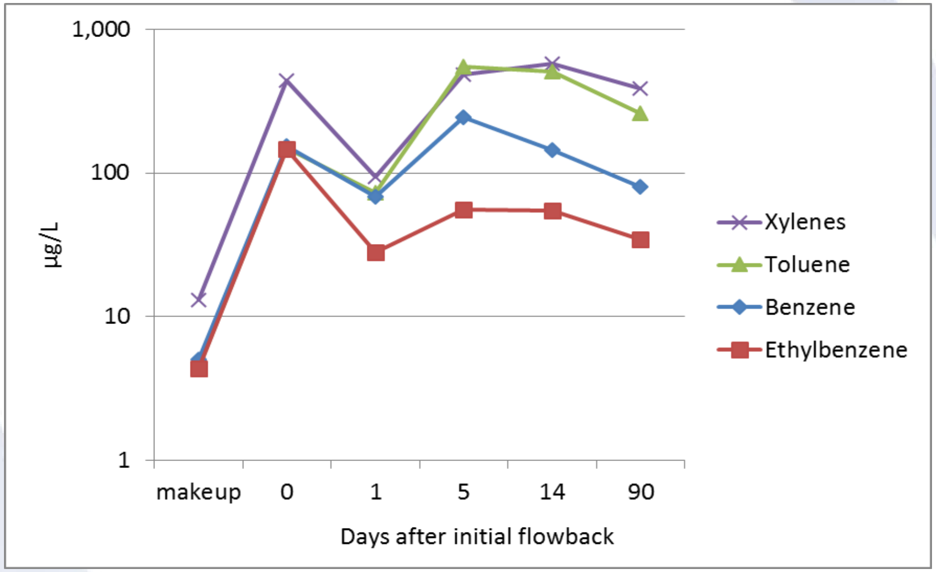


MSEEL

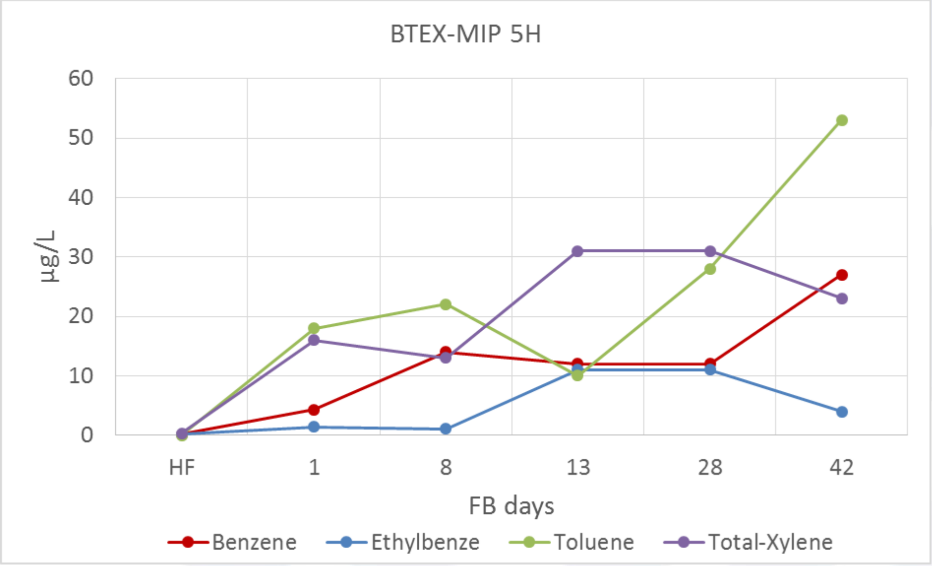


Flowback evolution-organics

Hayes, 2009



MSEEL



Flowback/Produced Water

- Extremely saline: 10,000 to 300,000 mg TDS/L
- Inorganics: Na, Mg, Ca, Sr, Ba, Cl, Br
- Organics: BTEX
- NORMs: α,β,^{226}Ra, ^{228}Ra,
- During flowback cycle
  - Discharge drops off rapidly
    - Initially 5,000 bpd to 175 bpd after 60 days
  - Ion concentrations increase
- Most of the contaminants come from the formation-not frac fluid

Terminology: solid wastes

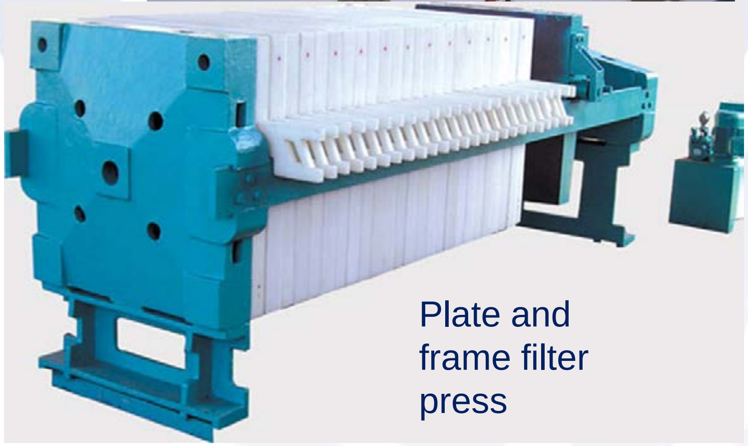
- **Drilling mud**
  - Returns to the surface with cuttings during drilling
  - Recycled after cuttings removed
  - To disposal after well completed
- **Drill cuttings**
  - Rock fragments-clay to fine gravel
  - ~500-800 tons/well or 25 to 50 truckloads
  - To disposal after separation from drilling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

Drilling wastes

Mud

Cuttings

Solids separation



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

Brazil nuts are about 12 pCi/g

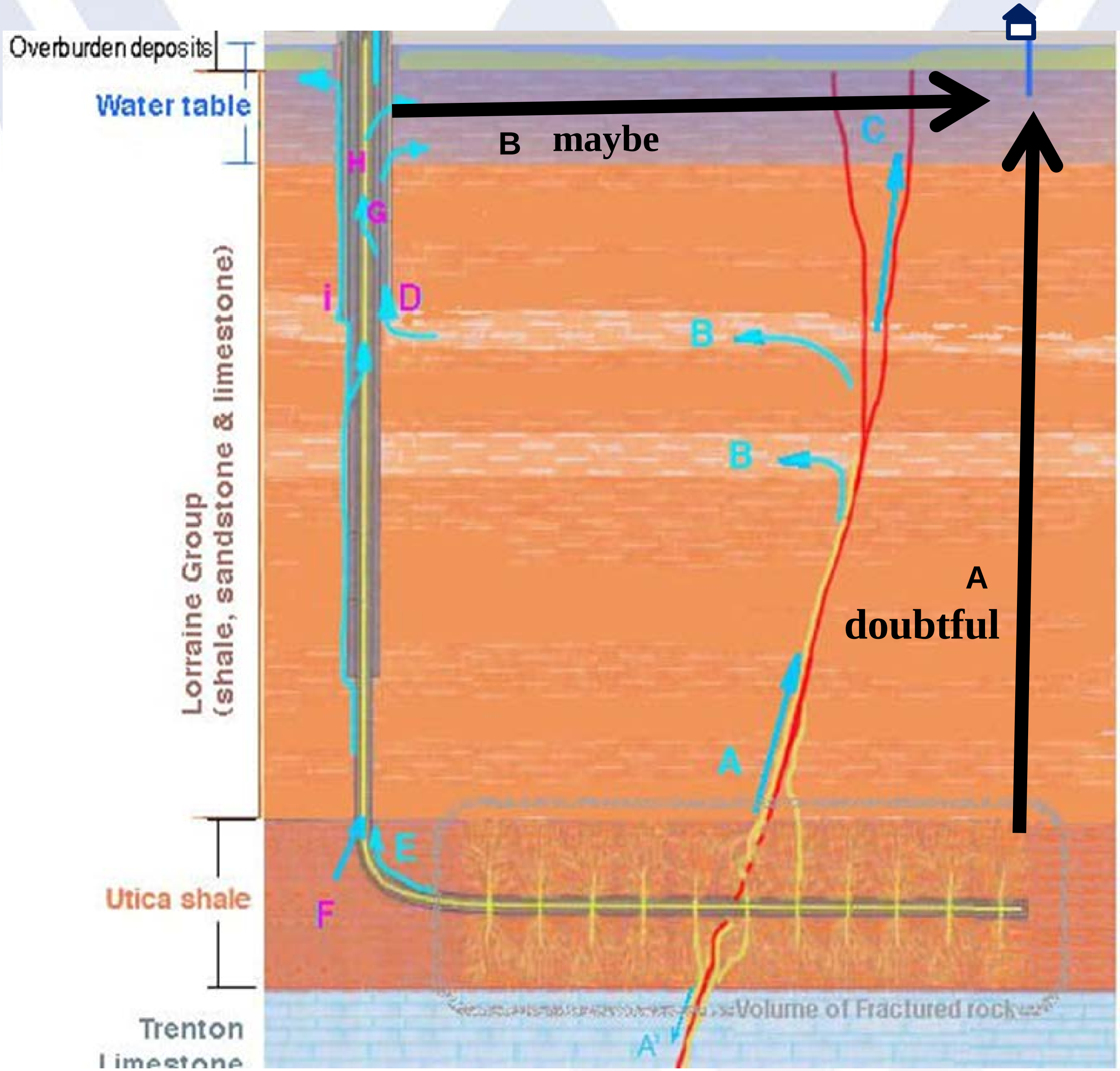
Radionuclides (pCi/g)

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

EXPOSURE PATHWAYS

A. HAS NOT BEEN DOCUMENTED

B. DOCUMENTED, RESULTS FROM POOR WELL INTEGRITY



Leakage: Avoidable sources of contamination

Bank failure under liner

Fuel leak at generator

Containing leaks

Roll-Off container leaking drill cuttings and fluid onto unlined drill pad

Good: A properly – constructed impoundment

Bad: Poorly installed plastic liner

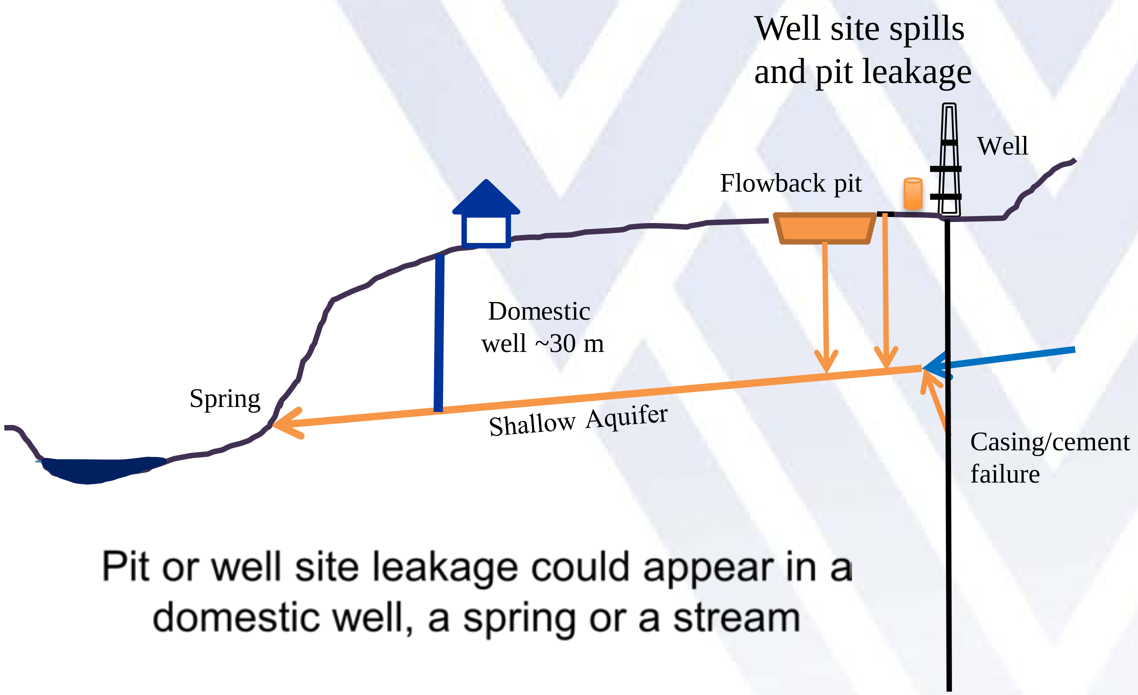
Unsupported pipe may break

Explosions are rare but this one resulted in a major release and fish kill-No secondary containment

Practical Risk Reduction:

Polymer liner across drill pad covered with gravel.
Secondary Containment around tanks

Most likely human/environmental exposure pathways



Pit or well site leakage could appear in a domestic well, a spring or a stream

Risk Reduction: leakage at the well site

Issues

1. Discharge of produced water to local water supply
2. Shallow groundwater contamination
3. On site spillage
4. Blowout during completion
5. Vertical well leakage
6. Deep contamination from horizontal leg

Solutions

1-3. Onsite containment, double HDPE liner, bermed, adequate to store 2 x maximum stage volume

4. Double BOPs
5. Well bore integrity
6. Never documented

Recommendations: reducing accidental releases of Produced Water

- Recycle/reuse flowback and produced water for frac water makeup
- On site containment:
  - Production casing integrity-testing prior to well completion
  - Drill pad-lined and bermed
  - Pits-construction/design/inspection according to State standards
  - Flowback lines to be properly installed/protected
- Transportation:
  - Tracking and accountability
- Solid waste characterization and disposal according to protective standards (RCRA?)

FOR MORE INFORMATION PLEASE CONTACT:

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