Marcellus Shale

Amy Bergdale

US EPA, Region 3, Environmental Assessment & Innovation Division, Office of Monitoring & Assessment, Freshwater Biology Team
Who is Marcellus??

• Brief History of Natural Gas
• Sources of Natural Gas
• Exploring the Marcellus Shale
• Waste Characteristics of the Marcellus Shale, including TENORM
• Reasonable Potential of the pollutants of concern: both aquatic and human health
• Reality of the Issue
Discovery of Natural Gas

1815 – Charleston, WV

The first Natural Gas well discovered by accident
Discovered in Appalachia

• World’s 1st commercial oil well in 1859, Titusville, PA.

• Natural gas was an accidental and underestimated by-product of the oil rush of 1850s.

• Large scale practice of natural gas was introduced in late 1800s by Joseph Pews and George Westinghouse for steel and glass industries in Pittsburgh.

• Local gas companies evolved from individual wells to an interstate supply acquired by Rockefeller’s Standard Oil.

• 1950s shifted supply from Appalachia to new discoveries of natural gas in Southwest and Gulf of Mexico.
Energy Consumption in the UNITED STATES, 2007

Note: Sum of components may not equal 100 percent due to independent rounding.
Energy Consumption

NATURAL GAS USE

- Pipeline Fuel: 2.6%
- Oil & Gas Industry Operations: 5.0%
- Electric Power: 26.4%
- Commercial: 13.9%
- Residential: 21.6%
- Vehicle Fuel: 0.1%

Annual U.S. Natural Gas Total Consumption

2008: 23.2 TCF

Source: U.S. Energy Information Administration

http://www.eia.doe.gov/basics/naturalgas_basics.htm
United States Gas Fields

United States Shale Gas Plays

- Shale Gas Plays
- Basins

Stacked Appalachian Plays
- Marcellus
- Utica
- Devonian (OH shale)

EIA Energy Information Administration
Office of Oil and Gas
### SOURCES of GAS

<table>
<thead>
<tr>
<th>Source</th>
<th>TCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asalouyeh, South Pars Gas Field - Iran</td>
<td>500</td>
</tr>
<tr>
<td>Urengoy gas field - Russia</td>
<td>385</td>
</tr>
<tr>
<td>Iolotan gas field - Turkmenistan</td>
<td>264</td>
</tr>
<tr>
<td>Barnett Shale - TX</td>
<td>2.1 - 30</td>
</tr>
<tr>
<td>Anadarko Basin – TX to KS</td>
<td>100</td>
</tr>
<tr>
<td>Haynesville Shale – Gulf Coast</td>
<td>250</td>
</tr>
<tr>
<td>Prudhoe Bay – North AK</td>
<td>28</td>
</tr>
<tr>
<td>Marcellus</td>
<td>168 - 516</td>
</tr>
</tbody>
</table>

![Proved reserves at end 2006](http://s.wsj.net/public/resources/images/P1-AP715A_NATGA_NS_20090429185625.gif)

Trillion cubic metres

- S. & Cent. America
- North America
- Africa
- Asia Pacific
- Europe & Eurasia
- Middle East

- 66.13
- 73.47
Marcellus Shale

Source: American Association of Petroleum Geologists
What is involved w/ Marcellus drilling?

VERTICAL VS HORIZONTAL
Marcellus Fracturing

Water-

Groundwater

Municipal

Surface

Proppant

– 30% of Water volume

Shale & Overburden

Additives

http://geology.com/articles/marcellus-shale.shtml
Additives

- Over 300 proprietary additives, including surfactants, biocides, wetting agents, scale inhibitors, organic compounds (benzene, toluene) etc

<table>
<thead>
<tr>
<th>Fracwater Chemistry</th>
<th>Wetting agent</th>
<th>Friction reducer</th>
<th>Biocides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetting agent</td>
<td>nonionic surfactants</td>
<td>anionic polyacrylamide polymer</td>
<td>dibromo nitrilopropionamide, glutaraldehyde, or n,n dibromosulfamate</td>
</tr>
<tr>
<td>Friction reducer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biocides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scale inhibitors</td>
<td>Either a Polyacrylate or a Phosphonate, such as aminotrimethylene phosphonate or phosphonobutane tricarboxylate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5lb/1000gal
5,000,000gal
25000 lbs
What is involved w/ Marcellus drilling?

LANDUSE ALTERATION & INFRASTRUCTURE

- Access Roads
- Well pads
- Transport vehicles
- Compression stations
- Cleaning stations
- Pipelines

(National Park Service, December 2008)

- 5,000,000 gal
- 3000 gal/truck
- 1667 trucks for water
- 1.5 million lbs of proppant
- 2000 lbs/truck
- 750 trucks for proppant
What is involved w/ Marcellus drilling?

- Vertical vs Horizontal
- Infrastructure
- Land Use Alteration
- Process
  - water
  - proppants
  - additives
  - shale & overburden composition
- Supporting Infrastructure
- Treatment
Characterizing the Waste

- Surfactants
- Organics
- TDS
  - 30,000 to 230,000+ mg/l
- Chlorides
  - 15,000 to 110,000+ mg/l
- Metals
  - Barium, Strontium
  - Selenium
- TENORM
  - Radium 226, 228
  - Gross alpha, beta
  - Uranium
  - Radon
Characterizing the Waste

Staged Flowback of Marcellus Well - WV

Chloride
Total Dissolved Solids
Specific Conductivity
What is in the Waste?

- waste treatment & disposal method
- waste storage method

- ↑ frac water
- ↑ produced water
- ↑ cuttings

- ↑ surfactants
- ↑ organics
- ↑ other toxic substances

- ↑ TDS
- ↑ metals
- ↑ TENORM

- ↑ Cl⁻
- ↑ Na⁺
- ↑ K⁺
- ↑ SO₄²⁻
- ↑ other ions

- ↑ radon
- ↑ U
- ↑ Ra₂²⁸
- ↑ Ra₂²⁶

- ↑ other radionuclides

- ↑ other toxic substances
What is involved with Marcellus drilling?

Treatment of Waste

- Underground Injection
- Thermal Evaporation
- Brine Treatment
- Dilution
What is involved w/ Marcellus drilling?

How much waste?

Average Horizontal Well –

• 5,000,000 gal H2O (not considering proppant and/or additive volume)

• Flowback ~60% injected volume

• 1,500,000 gal of waste

• Need 500+ trucks to transport
## Underground Injection - PA

<table>
<thead>
<tr>
<th>County</th>
<th>Injection Formation</th>
<th>Injection Pressure (psi)</th>
<th>Injection Volume (Bbls/Month)</th>
<th>API</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beaver</td>
<td>Huntersville/Oriskany</td>
<td>1300</td>
<td>21,000</td>
<td>37-017-20027</td>
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<tr>
<td>Clearfield</td>
<td>Oriskany</td>
<td>3240</td>
<td>4260</td>
<td>37-033-00053</td>
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<tr>
<td>Greene</td>
<td>Mine Void</td>
<td>0</td>
<td>150,000</td>
<td></td>
</tr>
<tr>
<td>Erie</td>
<td>Gatesburg</td>
<td>1570</td>
<td>45,000</td>
<td>37-049-24388</td>
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<tr>
<td>Indiana</td>
<td>Balltown</td>
<td>1930</td>
<td>3600</td>
<td>37-063-20246</td>
</tr>
<tr>
<td>Somerset</td>
<td>Oriskany</td>
<td>3250</td>
<td>27,000</td>
<td>37-111-20059</td>
</tr>
<tr>
<td>Clearfield</td>
<td>Oriskany</td>
<td>1450</td>
<td>4200</td>
<td>37-033-22059</td>
</tr>
<tr>
<td>Somerset</td>
<td>Huntersville/Oriskany</td>
<td>3218</td>
<td>30,000</td>
<td>37-111-20006</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>285,060</strong></td>
<td></td>
</tr>
</tbody>
</table>
Brine Treatment

- VOCs – blown off
- Oil & Grease, removed
- Metals, removed
- Does NOT treat TDS
- TDS in = TDS out
Thermal Evaporation

- VOCs – blown off
- Oil & Grease, removed
- Metals, removed
- TDS, removed
- By-products
  - Salt
  - Water
Dilution

Is Dilution the Solution?
Is there Reasonable Potential to cause harm?

Components of Water Quality Standard:
- Designated Uses
- Water Quality Criteria
- Antidegradation policy
- General Policies

Water Quality Criteria:

Numeric criteria
- Chemical
  - Aquatic life
  - Human health
  - Others (e.g., wildlife, sediment)
- Whole Effluent Toxicity
- Biological
- Narrative Criteria

Reasonable Potential -
Limitations must be established in permits to control all pollutants or pollutant parameters that are or may be discharged at a level that will cause, have the reasonable potential to cause, or contribute to an excursion above any state water quality standard [40 CFR 122.44(d)(1)(i)].
Calculating Receiving Water Concentrations Under Critical Conditions for Marcellus Waste

- Criterion for *protection of aquatic life* from chronic effects from Pollutant X (in our case we are using Chloride as our pollutant of concern)
Water leak from Washington County gas well kills fish

Thursday, June 04, 2009
By Don Hopey, Pittsburgh Post-Gazette

A leaking waste water pipe from a Range Resources Marcellus Shale gas well drilled in Washington County's Cross Creek Park has polluted an unnamed tributary of Cross Creek Lake, killing fish, salamanders, crayfish and aquatic insect life in approximately three-quarters of a mile of the stream.

The state Department of Environmental Protection said Range Resources reported the May 26 waste water discharge from a coupling on a 6-inch pipe running from a recently drilled well to a waste water impoundment. The DEP has taken water samples of the stream above and below the pollution release, said Helen Humphreys, a department spokeswoman, and, after those are evaluated, will determine the appropriate enforcement action.

The Range Resources wastewater pipeline connects three Marcellus Shale deep gas wells drilled in the 3,000 acre county-owned park.

Read more: [http://www.post-gazette.com/pg/09155/975107-113.stm#ixzz0HZotpuGY&C](http://www.post-gazette.com/pg/09155/975107-113.stm#ixzz0HZotpuGY&C)

"It's a gold rush, really. It's a boom," said Steve Rupert, an executive with Range Resources, which is drilling aggressively in the rolling farmland southwest of Pittsburgh. (Washington Post Aug. 15, 2008)
Determining a Critical Value (Cr)

Criterion for protection of aquatic life from chronic effects:

- **Qs** = Critical stream flow (7Q10) for chronic criterion
- **Qd** = Critical effluent flow from discharge flow data
- **Qr** = Sum of critical stream flow and critical effluent flow
- **Cs** = Critical upstream pollutant concentration
- **Cd** = Critical effluent pollutant concentration

\[
Cr = QsCs + QdCd
\]
Characterizing the Waste in PA

Chloride Brine Data from Western PA

Avg 65600 mg/L
Determining a Critical Value (Cr)

Upstream 
(Qs, Cs)

Downstream
(Qr, Cr)

Discharge (Qd, Cd)

\[ Cr = QsCs + QdCd \]

\[ Qr = 19162 \text{ mg/L} > 230 \text{ mg/L} \]

Ohio River, River Mile 40, U.S. Chester, WV
Background chloride 100mg/L
Large 100mgd (155cfs) Treatment Facility
7Q10: 2,060cfs
Max observed is 109000mg/L of 16 samples
Cd = 109000 * 2.5 = 272,500mg/L (assuming 99th percentile, default CV of 0.6)

Conclusion: The discharge would cause, have the reasonable potential to cause, or contribute to an excursion of the Chronic National Aquatic Life Criteria for Chloride
Determining a Critical Value (Cr)

\[ Cr = Q_s C_s + Q_d C_d \]

\[ Q_r \]

\[ Cr = 67,326 \text{ mg/L} > 230 \text{ mg/L} \]

Conclusion: The discharge would cause, have the reasonable potential to cause, or contribute to an excursion of the Chronic National Aquatic Life Criteria for Chloride.
What if diluted?

**Ohio River Receiving**

Cr = 19162 mg/L > 230 mg/L
Chronic Chloride National Aquatic Life Criteria

10% = 1916 mg/L
5% = 958 mg/L
1% = 192 mg/L
0.5% = 96 mg/L

< 230 mg/L

**S. F. Tenmile Receiving**

Cr = 67,326 mg/L > 230 mg/L
Chronic Chloride National Aquatic Life Criteria

10% = 6733 mg/L
5% = 3366 mg/L
1% = 673 mg/L
0.5% = 337 mg/L
Waste Disposal Methods

- waste treatment & disposal method

- underground injection
- dilution
- brine treatment

- brine waste
  - blown off VOCs
  - removed surface oil & grease
  - removed metals
  - salt cake
  - PM
  - N₂
  - NOₓ
  - SOₓ
  - VOCs
  - discharged to air
  - distilled
  - discharged to surface water
  - reuse

- thermal evaporation
  - ↑ oil & grease exposure
  - ↑ leachate & leakage

- waste storage method
  - retention ponds
  - storage tanks

- ↓ water availability
- ↓ waste volume

- ↑ groundwater contamination
- ↑ surface water contamination
- ↑ soil contamination

- other disposal methods
Visualize linkages b/n sources, stressors, and biological effects

Source = Marcellus gas drilling

Stressor(s) = i.e., Metals, TDS, etc.

Biological Effect(s)
What is in the Waste?

- **↑ frac water**
- **↑ produced water**
- **↑ cuttings**

**↑ surfactants**
- **↑ organics**
- **↑ toxic substances**

**↑ TDS**
- **↑ Cl⁻**
- **↑ Na⁺**
- **↑ K⁺**
- **↑ SO₄²⁻**
- **↑ other ions**

**↑ metals**
- **↑ radon**
- **↑ U**
- **↑ Ra²²₈**
- **↑ other radionuclides**

**↑ TENORM**
- **↑ other toxic substances**

**↑ other substances**
- **↑ other ions**

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**waste treatment & disposal method**

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**waste storage method**
Characterizing the Waste

Stage Flowback from Marcellus well - WV

- Gross Alpha Radioactivity
- Gross Beta Radioactivity
- Radium 226
- Radium 228
Defining Pollutant

• Pollutant – 40 CFR 122.2
  – Dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water
<table>
<thead>
<tr>
<th>Contaminant</th>
<th>MCL (year promulgated)</th>
<th>Source</th>
<th>Health Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined radium-226/-228</td>
<td>5 pCi/L (1976)</td>
<td>Naturally occurs in some drinking water sources.</td>
<td>Some people who drink water containing radium-226 or -228 in excess of the MCL over many years may have an increased risk of getting cancer.</td>
</tr>
<tr>
<td>(Adjusted) Gross Alpha</td>
<td>15 pCi/L (not including radon or uranium) (1976)</td>
<td>Naturally occurs in some drinking water sources.</td>
<td>Some people who drink water containing alpha emitters in excess of the MCL over many years may have an increased risk of getting cancer.</td>
</tr>
<tr>
<td>Beta Particle and Photon Radioactivity</td>
<td>4 mrem/year (look-up table) (1976)</td>
<td>May occur due to contamination from facilities using or producing radioactive materials.</td>
<td>Some people who drink water containing beta and photon emitters in excess of the MCL over many years may have an increased risk of getting cancer.</td>
</tr>
<tr>
<td>Uranium</td>
<td>30 µg/L (2000)</td>
<td>Naturally occurs in some drinking water sources.</td>
<td>Exposure to uranium in drinking water may result in toxic effects to the kidney. Some people who drink water containing alpha emitters in excess of the MCL may have an increased risk of getting cancer.</td>
</tr>
</tbody>
</table>
Reasonable Potential for Radionuclides??

<table>
<thead>
<tr>
<th>Radionuclides</th>
<th>Location</th>
<th>Flow Rate</th>
<th>Max Observed</th>
<th>Calculation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radium 226+228</td>
<td>Ohio River</td>
<td>2060 cfs</td>
<td>1005 pCi/L</td>
<td>1005 * 5.6 = 5628 pCi/L</td>
<td>398 pCi/L</td>
</tr>
<tr>
<td></td>
<td>S.F. Tenmile</td>
<td>3.75 cfs</td>
<td></td>
<td></td>
<td>1390 pCi/L</td>
</tr>
<tr>
<td>Gross alpha</td>
<td>Ohio River</td>
<td>2060 cfs</td>
<td>12500 pCi/L</td>
<td>12500 * 5.6 = 70000 pCi/L</td>
<td>4898 pCi/L</td>
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<tr>
<td></td>
<td>S.F. Tenmile</td>
<td>3.75 cfs</td>
<td></td>
<td></td>
<td>17289 pCi/L</td>
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</table>
Region 3 Treatment of Marcellus Waste, PA & WV

Underground Injection

COMING SOON - Thermal Evaporation

Brine Treatment

Dilution
2008 Events that Impacted Pittsburgh District Water Management

- **Summer/Fall.** Multiple requests for water withdrawals from Corps Reservoirs

- **August – December.** Low stream flows. Monongahela 10% of normal
2008 Events that Impacted Pittsburgh District Water Management

• **October 10.** Hatfield Power Plant Failed air emissions requirements, businesses not meeting state mandated criteria, intake concentrations higher than criteria, etc

• **October 22.** Start of Monongahela River high TDS Event. PA State Total Dissolved Solids (TDS) Drinking Water Criteria of 500 mg/l exceeded.

• **October 22 -27.** Special release from Stonewall and Tygart Reservoirs to mitigate elevated TDS in PA

• **November 7.** W PA Drought Watch Declaration

• **December 10.** Union Township issued a bottled water advisory, water supply of 850,000 affected

• **December 12.** High Runoff, TDS began to decrease
Drinking water of 800,000+ people

Elizabeth Conductivity '03-'05, '08 & '09
Region 3 Draft Permit Reviews – To Date

- 4 Proposed Treatment Facilities in PA
  - Monongahela River Watershed (3)
    - TDS impaired – applying 500 mg/l
  - W Br Susquehanna River (1)
    - Applying PA TDS Strategy
    - TDS loads up to 522,245 lbs/day (equivalent to 156,548 mg/l)
- 3 Existing POTWs accepting brine
  - Wilkes-Barre proposed TDS load up to 1,194,399 lbs/day
Proposed TerrAqua Facility

- W Branch Susquehanna River
  - Protect Warm Water Fishes
  - 28.5 Stream Miles to Milton PWS

- TDS In-stream Analysis –
  - Region 3 Objection
  - Analyzed in combination with Williamsport Central STP
  - “Far Field” => 500mg/l at Milton PWS
    - Allocated to 10 facilities in watershed
    - Loads as high as 522,245 lbs/day for TerrAqua
  - “Near Field” => 1800mg/l at Discharge
    - Calculated load of 1,344,541 lbs/day for TerrAqua
  - Far Field more Stringent
Biological Assessment of the Allegheny and Monongahela Rivers

PADEP and EPA, 2 yr grant (’08-’09)

• Evaluate conditions via probabilistic survey.
• Fish, fish habitat, macroinvertebrate, mussels, water chemistry, plankton, and sediment.
  • Data will assist in risk assessment from potential stressors.
• Aid in analyzing the potential seasonal and yearly variability.
  • PADEP can develop, implement, and test bioassessment methods to produce an unbiased estimate of the current ecological condition.
• PADEP can estimate or develop biological criteria, reference conditions, and water quality conditions in support of the CWA.
Protection measures form the first barrier to a multiple-barrier approach to drinking water protection.
RAIN Goals

• Provide information and tools to aid water suppliers in making decisions
• Improve communication between water suppliers about water quality events
• Install monitoring equipment at appropriate locations and provide operational training
• Develop a secure website to share information about water quality
• Improve communication between water suppliers, USACE and emergency responders
Concept For RAIN

- Coverage: Allegheny, Monongahela, Youghiogheny, and headwaters of Ohio Rivers
- Communication System
  - Spill Alert/Alarm notifications
  - Water supplier Roundtables
- Monitoring System
  - On-line, continuous monitoring equipment
  - Operator training
- Website Development
  - Water quality data – historical/current
  - Links (USGS, NOAA, NWS, USACE)
RAIN’s Monongahela TDS Project Site Selection Rationale

East Dunkard - Mon intake below Cheat River
Dunkard Valley - Mon intake below Dunkard Creek
Carmichael - Mon intake below Whiteley Creek
Brownsville - Mon intake below Tenmile Creek
Washington Twp - Mon intake below Redstone Creek
PAWC (A) - Mon intake in USACE Dam 3
PAWC (B) - Mon intake in USACE Emsworth Pool
McKeesport - Youghiogheny intake 1 mile from Mon
Pittsburgh - Furthest downstream intake on Allegheny
West View - First intake on Ohio River
RAIN’s Monongahela TDS Project Monitoring Effort

Ten RAIN Facilities
HACHSC1000
• Conductivity
• pH
• Temperature

Four Remote Tributary Sites
Hydrolab MS5Sonde
• Conductivity
• pH
• Temperature
RAIN’s Proposed Monitoring Effort

11-15 RAIN Member Facilities:

- HACH Source Water Panel
- Nitrate
- Ammonia
- Dissolved Oxygen
- UV Organics
- Suspended Solids-Turbidity
- ORP
Waste Characterization Study

- TDS
- Metals
- Organics
- TENORM

Phase I
Site specific, across Region

Phase II
Treatment of Waste, ‘cradle to grave’
Marcellus

• Brief History of Natural Gas
• Sources of Natural Gas
• Exploring the Marcellus Shale
• Waste Characteristics of the Marcellus Shale, including TENORM

Reasonable Potential of the pollutants of concern: both aquatic and human health

• Reality of the Issue
Questions to ASK

What are the characteristics of the WASTE?
How is the WASTE being treated?

What are the characteristics of the EFFLUENT?

What are the characteristics of your RECEIVING water?

Are we PROTECTING the AQUATIC LIFE USE?

Are we PROTECTING HUMAN HEALTH?
Marcellus Shale