AAEE Workshop

Marcellus Shale Water Management – An Operator’s Viewpoint

May 9, 2011
Key Points

Requirements
Conventional versus unconventional

Sources
Balancing regulatory considerations with operational flexibility

Treatment, Reuse, and Disposal
Down-hole performance, surface issues, and disposal

Storage
Tanks, pit, impoundments...

Transfer
Reducing truck traffic while ensuring integrity
Requirements

- 4 to 6 million gallons/well
- Pump Rates – 70 to 100 bpm
- Reliability/Seasonality
- Quality/Compatibility
- Location/Proximity
Simplified Fluid Design

Slickwater with scale inhibitor and bactericide

Water Quality

Shale permeability

Production mechanism

Water mobility

Challenge conventional rules of thumb

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional Limits</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.0 to 8.0</td>
<td>Fluid Stability, Scaling</td>
</tr>
<tr>
<td>Chlorides</td>
<td>&lt;20,000 mg/L</td>
<td>Fluid Stability</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt;20 mg/L</td>
<td>Fluid Stability</td>
</tr>
<tr>
<td>Ca, Mg, Ba, SO₄, CO₃, …</td>
<td>f(P,T,pH) (+/- 350 mg/L)</td>
<td>Scaling</td>
</tr>
<tr>
<td>Bacteria Count</td>
<td>&lt;100/100 mg/L</td>
<td>Bacteria Growth</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>&lt;50 mg/L</td>
<td>Skin</td>
</tr>
<tr>
<td>Oil &amp; Soluble Organics</td>
<td>&lt;25 mg/L</td>
<td>Fluid Stability</td>
</tr>
</tbody>
</table>

nanodarcy, nD, $1 \times 10^{-9}$ D

millidarcy, mD, $1 \times 10^{-3}$ D
## Requirements

**Water use per million btu of energy:**

- Deep shale natural gas: 0.60-5.80 gallons
- **Marcellus Shale gas – avg:** 1 gallon
- Nuclear (uranium ready to use in a power plant): 8-14 gallons
- Conventional oil: 8-20 gallons
- Synfuel-coal gasification: 11-26 gallons
- Coal (delivered power plant): 13-32 gallons
- Oil shale: 22-56 gallons
- Tar sands/oil sands: 27-68 gallons
- Fuel ethanol from corn: 2,510-29,100 gallons (irrigation)
- Biodiesel from soy: 14,000-75,000 gallons (irrigation)

**Shale gas production uses less water than any other significant energy source**

Source: U.S. Dept. of Energy
Requirements

Estimated Marcellus water use at expected peak drilling rate (3,000 wells per year)

Source: USGS, Pennsylvania Water Consumption
Sources

Water Network

Raccoon Valley Sportsman Club Pond
Nancy Stewart Impoundment (270,000 bbls)
Lehman Impoundment (150,000 bbls)

Cross Creek Lake (CC1) DEP Approved
DEP Approved

Rush (Proposed)
Best Impoundment (325,000 bbls)
Bednarski Impoundment (265,000 bbls)

S. Hewitt Road Metering Vault - DEP Approved

Zappi Impoundment (98,000 bbls)
Buffalo Creek 2
Buffalo Creek 1

Dutch Fork Lake
Hewitt (proposed)

Clingerman Impoundment (205,000 bbls)
Carol Baker Impoundment (325,000 bbls)

Worstell (proposed)
Johnston #1 Impoundment (130,000 bbls)

Plum Road Metering Vault
Chartiers Run (CR4) DEP Approved

Rex Road Metering Vault

Old Hickory Ridge Road Metering Vault - DEP Approved

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Sources – Surface Water

- PA receives 43” precipitation per year
- 5 million gallons = 1.8 inches of water over the drainage area of 1 well (~100 acres)
- If the productive area of the Marcellus takes 50 years to drill, annual water use over the productive area would be 0.04 inches of water per year (1/10th of 1% of annual rainfall)
- PA consumptively uses ~1.6% of its available water

<table>
<thead>
<tr>
<th>City</th>
<th>Avg Annual Precip</th>
<th>Avg Snow Annual</th>
<th>Avg # days of Precip</th>
<th>Avg # thunderstorm days</th>
<th>Avg # rain days</th>
<th>Avg # severe thunderstorm watches per year</th>
<th>Avg # tornado watches per year</th>
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</thead>
<tbody>
<tr>
<td>Allentown</td>
<td>45.17</td>
<td>32.9</td>
<td>125</td>
<td>31</td>
<td>1</td>
<td>1</td>
<td>10</td>
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<tr>
<td>Avoca</td>
<td>37.56</td>
<td>48.7</td>
<td>140</td>
<td>29</td>
<td>1</td>
<td>1</td>
<td>11</td>
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<tr>
<td>Erie</td>
<td>42.77</td>
<td>90.4</td>
<td>165</td>
<td>35</td>
<td>1</td>
<td>1</td>
<td>9</td>
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<td>Harrisburg</td>
<td>41.45</td>
<td>34.3</td>
<td>125</td>
<td>31</td>
<td>1</td>
<td>1</td>
<td>11</td>
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<tr>
<td>Philadelphia</td>
<td>42.05</td>
<td>21.1</td>
<td>117</td>
<td>27</td>
<td>1</td>
<td>1</td>
<td>8</td>
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<tr>
<td>Pittsburgh</td>
<td>37.85</td>
<td>43.5</td>
<td>153</td>
<td>35</td>
<td>1</td>
<td>2</td>
<td>12</td>
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<tr>
<td>Williamsport</td>
<td>41.59</td>
<td>41.7</td>
<td>141</td>
<td>34</td>
<td>1</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

- Pennsylvania Precipitation Average - 43.02 inches, 21st wettest in the U.S.
- Pennsylvania Tornado Average - 10.2 per year - 24th most in the U.S.
Sources – Surface Water

CONSUMPTIVE USE AND RENEWABLE WATER SUPPLY, BY WATER-RESOURCES REGION

EXPLANATION
Billon gallons per day
11.0 1995 Consumptive use
68.7 Renewable water supply
Consumptive use as a percentage of renewable supply

0 — 10
10 — 40
40 — 100
> 100

* Represents entire Colorado River basin
** Represents entire Mississippi River basin

~1.65%
~1.6%
Sources – Surface Water
Sources – Municipal
## Table 1 - Water Quality and Quantity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine Pool #1</td>
<td>1.9 billion gallons</td>
<td>Flow</td>
<td>80</td>
<td>45,553</td>
<td>1,638</td>
<td>gpm</td>
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<tr>
<td>Mine Pool #2</td>
<td>1.8 billion gallons</td>
<td>pH</td>
<td>2.8</td>
<td>8.6</td>
<td>5</td>
<td></td>
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<tr>
<td>Average Discharge Flow</td>
<td>935 gpm</td>
<td>TSS</td>
<td>2</td>
<td>656</td>
<td>29</td>
<td>ppm</td>
</tr>
<tr>
<td>Average pH</td>
<td>6.0</td>
<td>TDS</td>
<td>144</td>
<td>3,486</td>
<td>1,120</td>
<td>ppm</td>
</tr>
<tr>
<td>Average Alkalinity</td>
<td>112 mg/l</td>
<td>Chlorides</td>
<td>1</td>
<td>348</td>
<td>31</td>
<td>ppm</td>
</tr>
<tr>
<td>Average Acidity</td>
<td>52 mg/l</td>
<td>Sulfate</td>
<td>5</td>
<td>2,800</td>
<td>416</td>
<td>ppm</td>
</tr>
<tr>
<td>Average Total Iron</td>
<td>100.5 mg/l</td>
<td>Hardness</td>
<td>74</td>
<td>1,559</td>
<td>435</td>
<td>ppm</td>
</tr>
<tr>
<td>Average Total Manganese</td>
<td>1.1 mg/l</td>
<td>Iron (total)</td>
<td>0</td>
<td>238</td>
<td>19</td>
<td>ppm</td>
</tr>
<tr>
<td>Average Total Aluminum</td>
<td>0.6 mg/l</td>
<td>Magnesium (total)</td>
<td>2</td>
<td>525</td>
<td>47</td>
<td>ppm</td>
</tr>
<tr>
<td>Average Sulfates</td>
<td>7.62 mg/l</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PA DEP – Orphaned Mine Discharge Project
Sources – Alternative

Municipal

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.0-9.0</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td>30</td>
<td>ppm</td>
</tr>
<tr>
<td>5-Day BOD</td>
<td>30</td>
<td>mg/l</td>
</tr>
</tbody>
</table>

FYI, Reuse BOD = 49 to 7,175 mg/l
Sources – “Super Sources”
Treatment, Reuse, and Disposal

- 10-30% of frac water flows back to surface after frac; balance is bound in micro fractures in shale
- Water flowed back after frac contains salts and other naturally occurring dissolved minerals present in ancient sea water
- Water is gathered and removed from site by either truck or pipeline
- Management methods during 2011:
  - Recycle
  - Injection wells
  - Advanced treatment facilities
Recycling technology did not develop in other shale gas plays due to abundant opportunities for disposal by injection into deep rock formations.

Recycling in the Marcellus play has been driven by lack of other disposal options and regulatory framework.

Estimated that 75% of all Marcellus flowback water is currently being recycled.

Technology will continue to improve rapidly.
Range Reuses 100% of our Flowback in our SW PA Core Area

Potential Down-hole Issues
  Fluid Stability
  Bacteria
  Scaling

Non-issues as Supported by Well Performance

TDS Build-up Concerns
  Not an issue because of required dilution

Known Surface Issues…Aesthetics
  Solids
  Bacteria (anaerobic)
Keys to Remediating Surface Issues

Solids – Clarification/Filtration
Bacteria (anaerobic/SRBs)
Remove the Food Source
Maintain with Aeration

Pre-Aeration

Post-Aeration
Impoundments vs. Tanks
The Goal is Maintenance

Double Liner System with Runway
Permanent Fill/Withdrawal Manifold
Under-Drain Catch Basin System with Leak Alarm
Influent Weir Tank Battery
  – Solids and Condensate Capture
Aeration System
Bird Netting
Remote Level Monitoring System
Security/Privacy Perimeter Fencing
Minimize Trucking
Source water, 800 - 900 trucks per well
Flowback, ~180 trucks per well
Trucking = $0.85 - $0.95 / bbl / hour
Proximity is key

Pumping and Pipelines
Temporary
  Integrity
  Distance
Permanent network
  Link super sources to storage locations

Noise Mitigation
Water Transfer

- 3rd Party Engineer Develops Test
  - Pipe rating
  - Component ratings
  - Layout
  - Weather conditions
- Separate Testing Firm Executes
- Approximately 8 hours
- Any failure results in re-test
- Scheduled 3-7 days prior to Frac
- Procedure/test for each job
Thank You

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MyRangeResources.com

MarcellusCoalition.org

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