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

Requirements

Simplified Fluid Design

Slickwater with scale inhibitor and bactericide

Water Quality

Shale permeability

Production mechanism

Water mobility

<u>Challenge conventional rules of thumb</u>

Parameter	Conventional Limits	Considerations
pH	6.0 to 8.0	Fluid Stability, Scaling
Chlorides	<20,000 mg/L	Fluid Stability
Iron	<20 mg/L	Fluid Stability
Ca, Mg, Ba, SO_4, CO_3, …	f(P,T,pH) (+/- 350 mg/L)	Scaling
Bacteria Count	<100/100 mg/L	Bacteria Growth
Suspended Solids	<50 mg/L	Skin
Oil & Soluble Organics	<25 mg/L	Fluid Stability

nanodarcy, nD, 1 x 10^{-9} D

millidarcy, mD, 1 x 10^{-3} D

Requirements

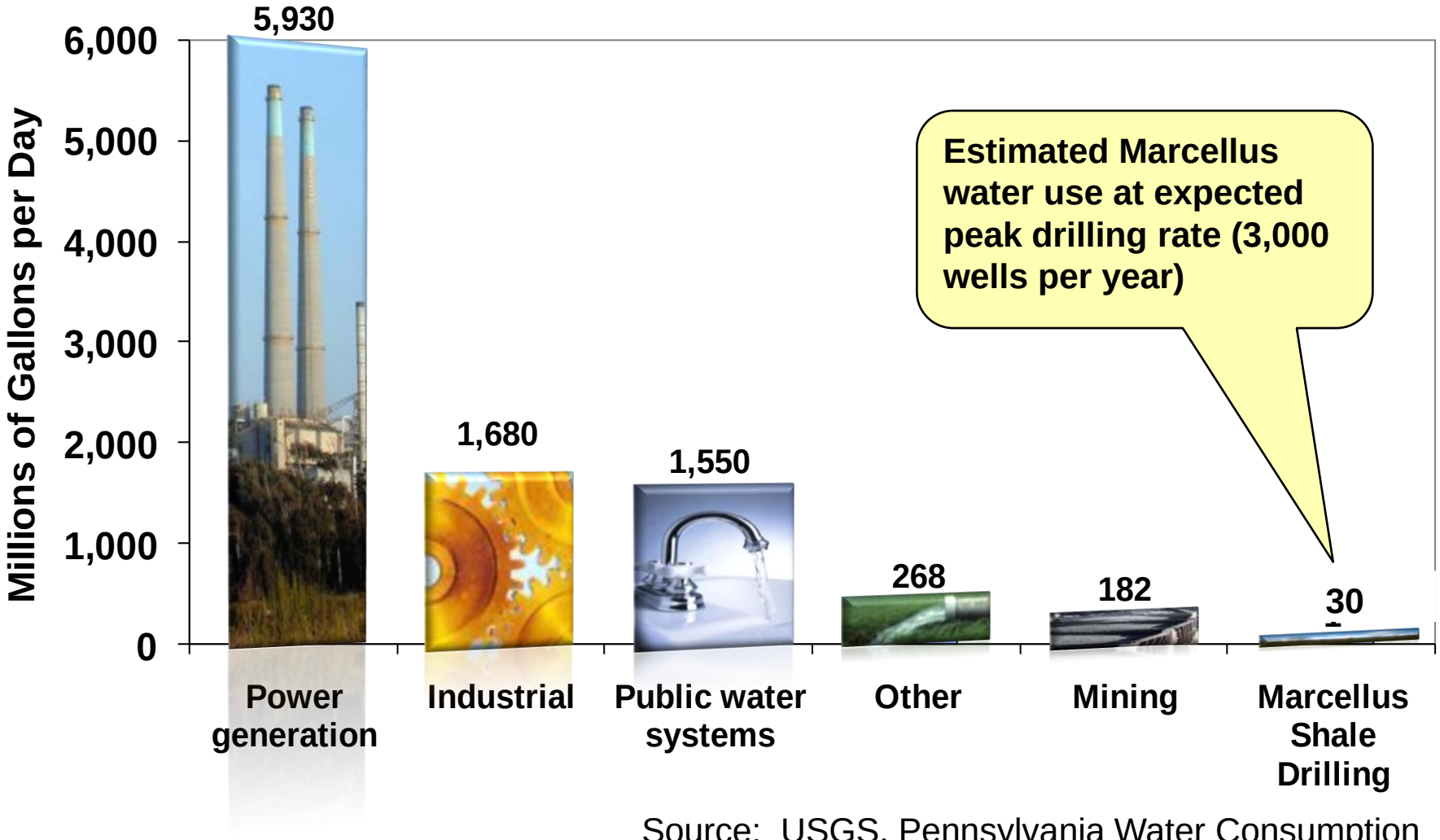
Water use per million btu of energy:

•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

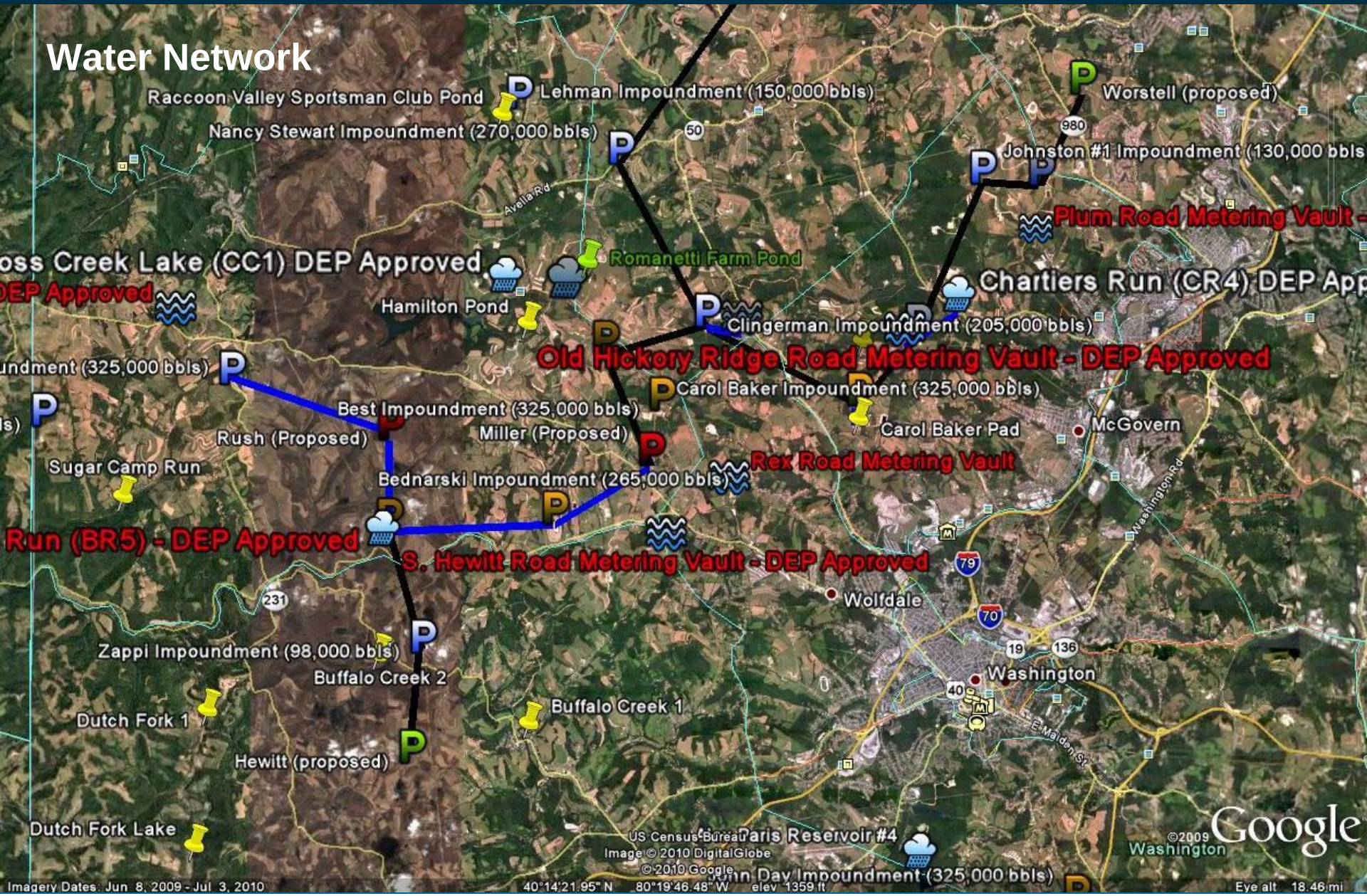
Source: U.S. Dept. of Energy

Requirements



Source: USGS, Pennsylvania Water Consumption

Sources

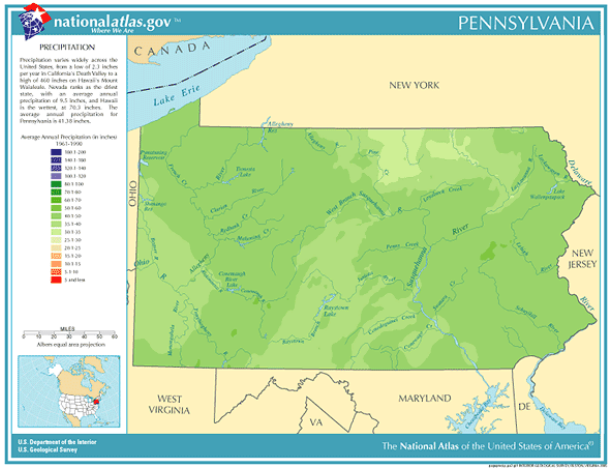

Water Network
Raccoon Valley Sportsman Club Pond
Lehman Impoundment (150,000 bbls)
Nancy Stewart Impoundment (270,000 bbls)
Worstell (proposed)
Johnston #1 Impoundment (130,000 bbls
Plum Road Metering Vault -
Romanetti Farm Pond
Hamilton Pond
Chartiers Run (CR4) DEP App
Clingerman Impoundment (205,000 bbls)
Old Hickory Ridge Road Metering Vault - DEP Approved
Carol Baker Impoundment (325,000 bbls)
Carol Baker Pad
McGovern
Best Impoundment (325,000 bbls)
Rush (Proposed)
Miller (Proposed)
Sugar Camp Run
Rex Road Metering Vault
Bednarski Impoundment (265,000 bbls)
S. Hewitt Road Metering Vault - DEP Approved
Wolfdale
Zappi Impoundment (98,000 bbls)
Buffalo Creek 2
Buffalo Creek 1
Dutch Fork 1
Hewitt (proposed)
Washington
Dutch Fork Lake
Paris Reservoir #4
Day Impoundment (325,000 bbls)
Washington
Google
Imagery Dates: Jun 8, 2009 - Jul 3, 2010
40°14'21.95" N 80°19'46.48" W elev 1359 ft
Eye alt 18.46 mi

Sources – Surface Water

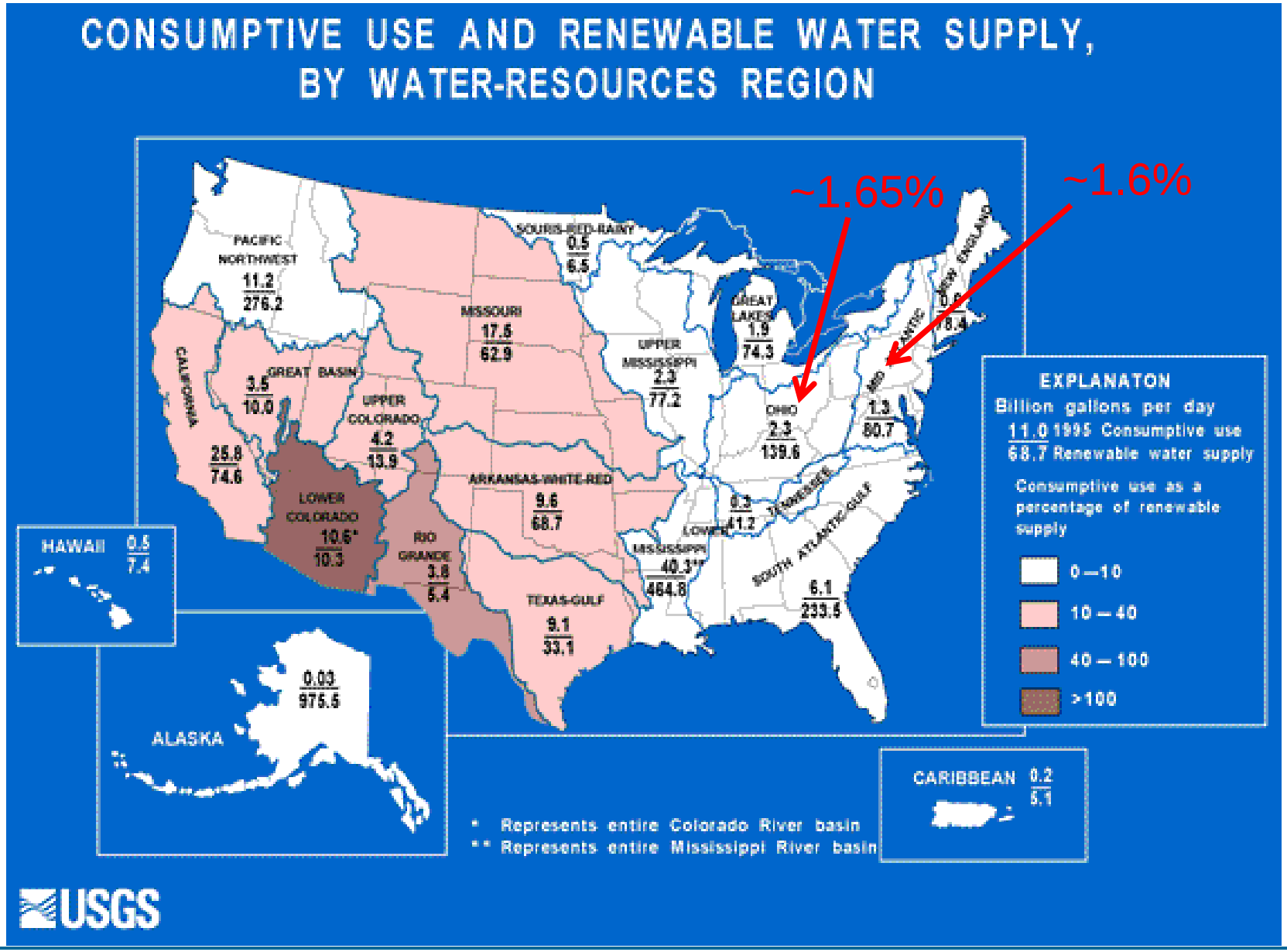
- PA receives 43” precipitation per year
- 5 million gallons = 1.8 inches of water over the drainage area of 1 well (~100 acres)
- If the productive area of the Marcellus takes 50 years to drill, annual water use over the productive area would be 0.04 inches of water per year (1/10th of 1% of annual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

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

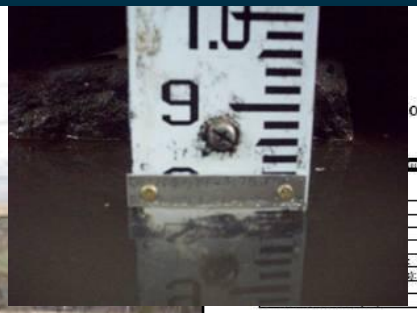
- Pennsylvania Precipitation Average - 43.02 inches, 21st wettest in the U.S.
- Pennsylvania Tornado Average - 10.2 per year - 24th most in the U.S.



Sources – Surface Water



Sources – Surface Water



on: CR4

	Charters Run/Charters Creek
	WWF
	Yes
	0.20

Method:
Follow Susquehanna River Basin Commission (SRBC) Policy No. 2003-01.

Footnotes:
(1) From USGS Stream Stats Data-Collection Station Report.
(2) From USGS Low-Flow Statistics for Pennsylvania Streams.
(3) From USGS Stream Stats Ungaged Report.

Step #1: Determine SRBC Passby Fl

Withdrawal Location
CR4: Extraction point associated with Paxton #3H (1.4 miles).

Step #2: Determine Q7-10 Flow Rate

Withdrawal Location
CR4: Near existing Water Withdrawal Location on Charters Run

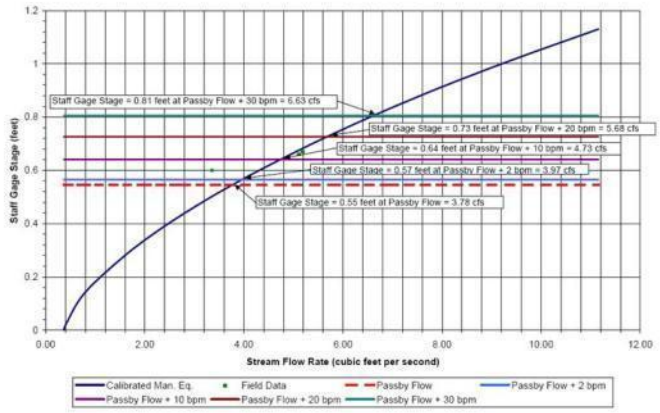
Step #3: Determine the Probability t

Flow Dur		
Probability of Exceedance		
P1		
P5		
P10		
P20		
P25		
P30		
P40		
P50		
P60		
P70		
P75		
P80		
P90		
P95	45	2.89
P99	29	1.87

available over 80 percent of the time.

FIGURE 4

Stage-Discharge Curve for Upstream Cross Section on Chartiers Run
Range Resources, Washington County, PA



Step #4: Determine the Months of the Year when the Total Required Flow will be Available

Monthly Data				
Month	Station Mean Flow[1] (cfs)	Weighted Mean Flow[2] (cfs)	Total Required Flow (cfs)	Is There Sufficient Flow?
January	334	19.26	3.97	Yes
February	441	25.41	3.97	Yes
March	587	33.83	3.97	Yes
April	458	26.39	3.97	Yes
May	327	18.84	3.97	Yes
June	211	12.16	3.97	Yes
July	151	8.70	3.97	Yes
August	145	8.36	3.97	Yes
September	99.4	5.73	3.97	Not Always
October	94.1	5.42	3.97	Not Always
November	130	7.49	3.97	Not Always
December	226	13.02	3.97	Yes

CONCLUSION:

On average, there should be sufficient flow in Chartiers Run at CR4 through out the year to allow a withdrawal rate of 0.19 cfs and maintain a SRBC passby flow of 3.78 cfs. However, there may be specific days during September through November when the flow rate goes below the required flow rate and a withdrawal could not be taken from the stream. A rule-of-thumb (2 X Weighted Mean Flow > Total Required Flow Rate) was used to determine the months when flow rates may be too low for withdrawal. An in-stream flow measurement will be required on a daily basis to confirm the stream flow rate and the availability of water for withdrawal.

4/24/2009 1 2.3.3 - CR4 Calculation

Sources – Municipal

Sources – Alternative

TABLE 1 – WATER QUALITY AND QUANTITY

Parameter	Value
Mine Pool #1	1.9 billion gallons
Mine Pool #2	1.8 billion gallons
Average Discharge Flow	935 gpm
Average pH	6.0
Average Alkalinity	112 mg/l
Average Acidity	52 mg/l
Average Total Iron	100.5 mg/l
Average Total Manganese	1.1 mg/l
Average Total Aluminum	0.6 mg/l
Average Sulfates	762 mg/l

Parameter	Min	Max	Average	Units
Flow	80	45,553	1,638	gpm
pH	2.8	8.6	5	
TSS	2	656	29	ppm
TDS	144	3,486	1,120	ppm
Chlorides	1	348	31	ppm
Sulfate	5	2,800	416	ppm
Hardness	74	1,559	435	ppm
Iron (total)	0	238	19	ppm
Magnesium (total)	2	525	47	ppm

PA DEP – Orphaned Mine Discharge Project

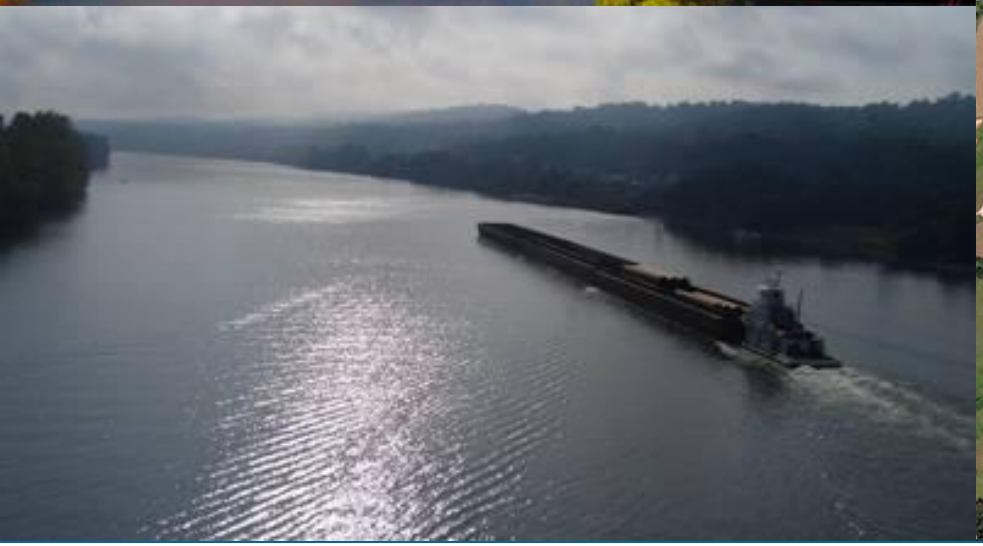
Sources – Alternative

Parameter	Value	Units
pH	5.0-9.0	
TSS	30	ppm
5-Day BOD	30	mg/l

EPA Secondary Treatment Standard

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

Rapidly Evolving Technology

- 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

Recycling

- 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)

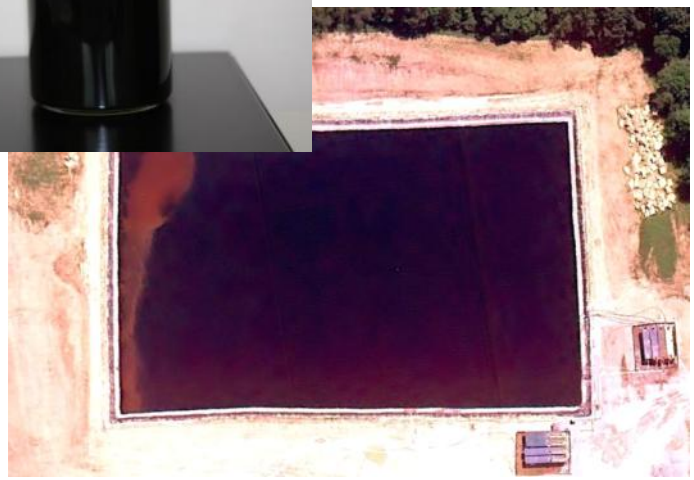
Keys to Remediating Surface Issues

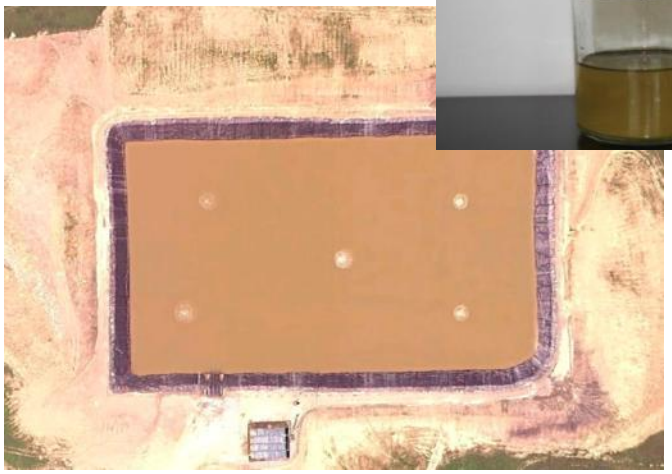
Solids – Clarification/Filtration

Bacteria (anaerobic/SRBs)

Remove the Food Source

Maintain with Aeration





Storage

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**

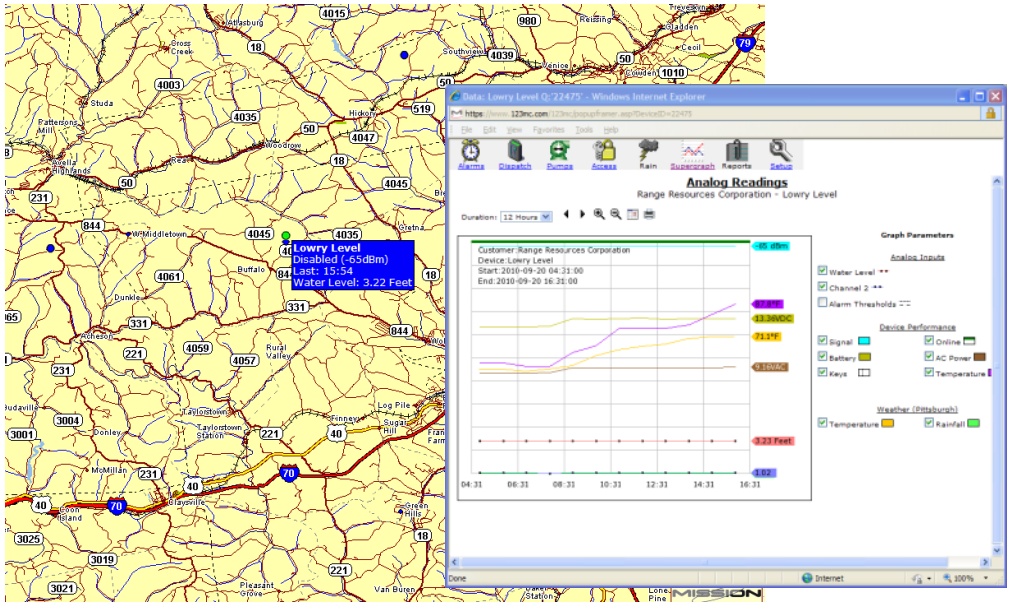
Storage

Aeration System

Bird Netting

Remote Level Monitoring System

Security/Privacy Perimeter Fencing



Water Transfer

Minimize Trucking

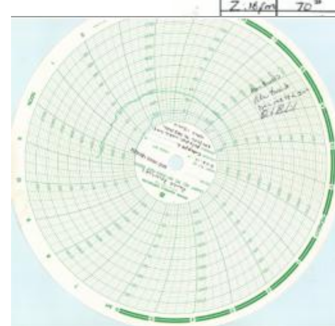
- Source water, 800 - 900 trucks per well
- Flowback, ~180 trucks per well
- Trucking = $0.85 - $0.95 / bbl / hour
- Proximity is key

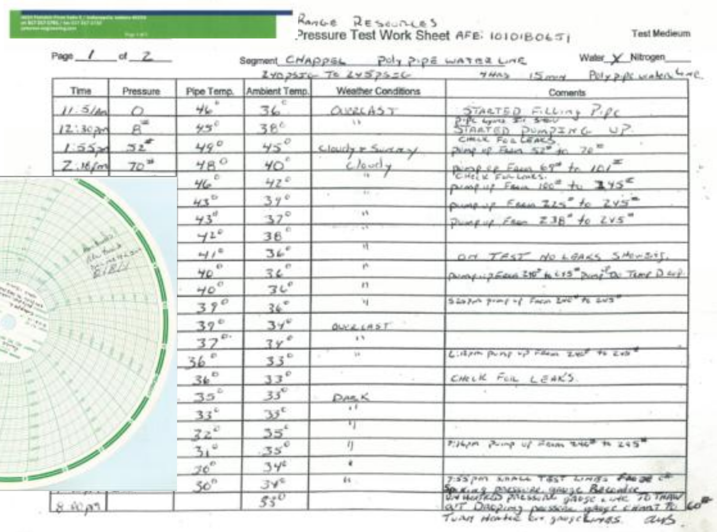
Pumping and Pipelines

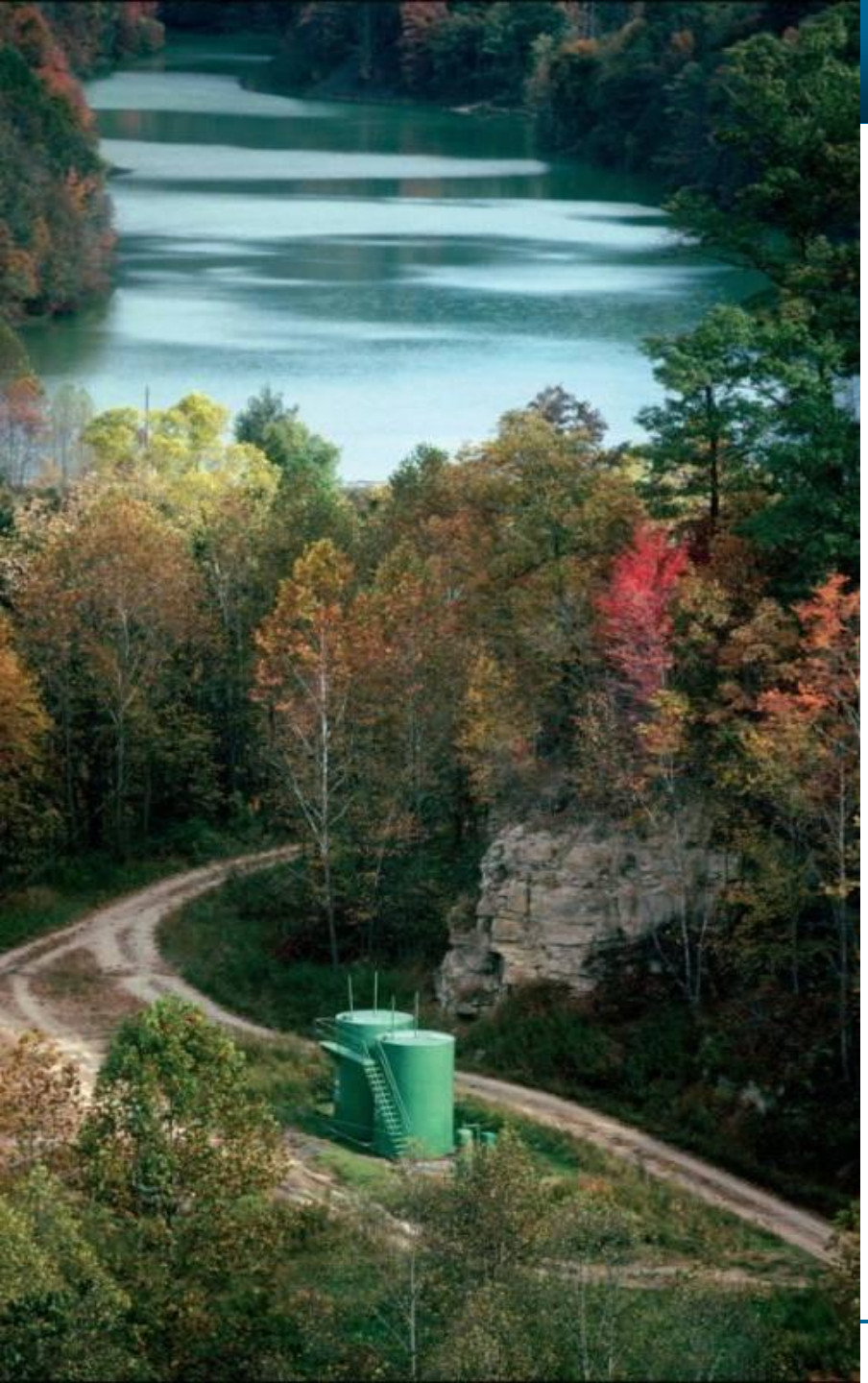
- Temporary
  - Integrity
  - Distance
- Permanent network
  - Link super sources to storage locations
- Noise Mitigation

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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