Water Management for Unconventional Oil and Gas Production

AWWA/NWRA Workshop

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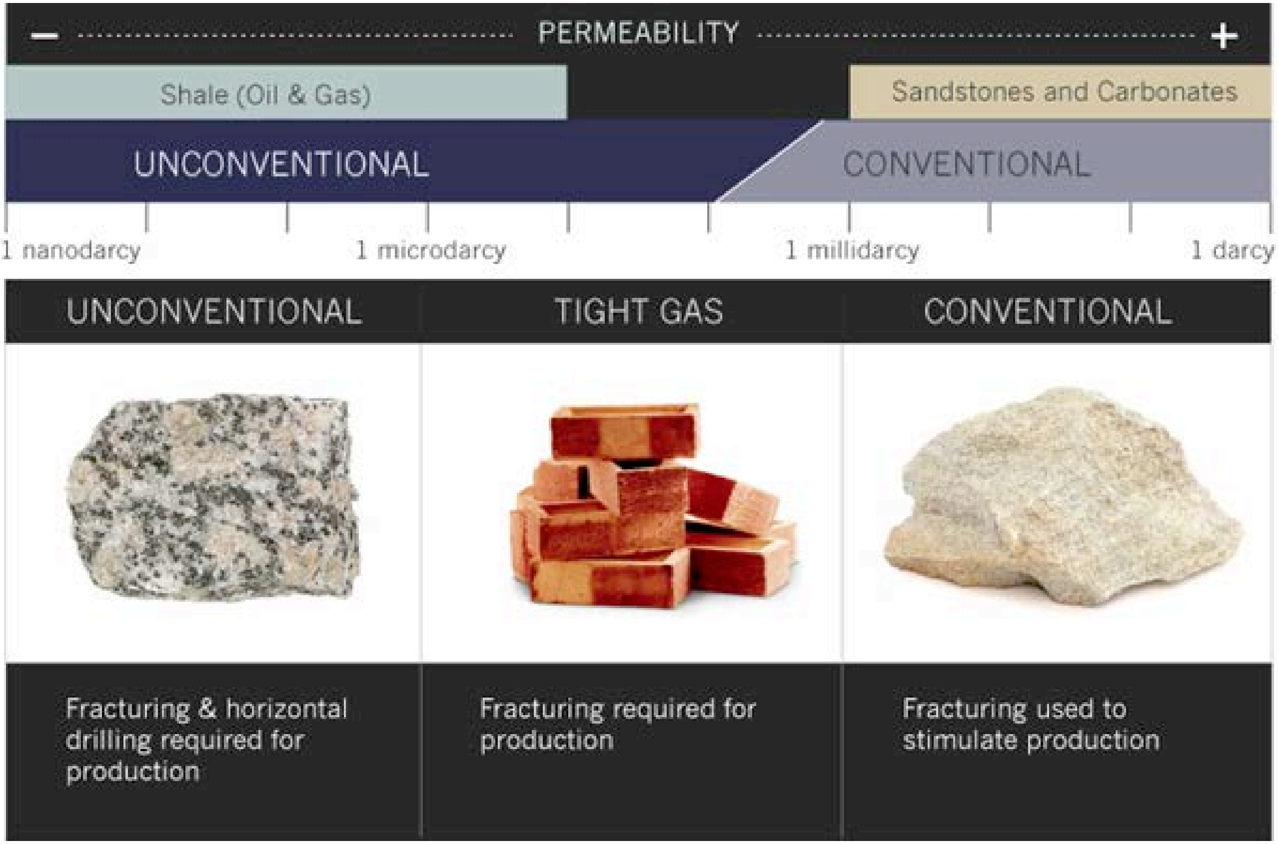
Overview

- Water use and scarcity in shale development
- Disadvantaged water resources for fracturing
- Water storage
- Groundwater protection
- Water management and treatment
  - Source water
  - Flowback and produced water
  - Water quality
  - Treatment technologies
- Wastewater disposal
- Opportunities for optimization
  - Reusing water between operators
  - Drilling and water infrastructure
- Water costs
- Conclusions

Hydraulic Fracturing

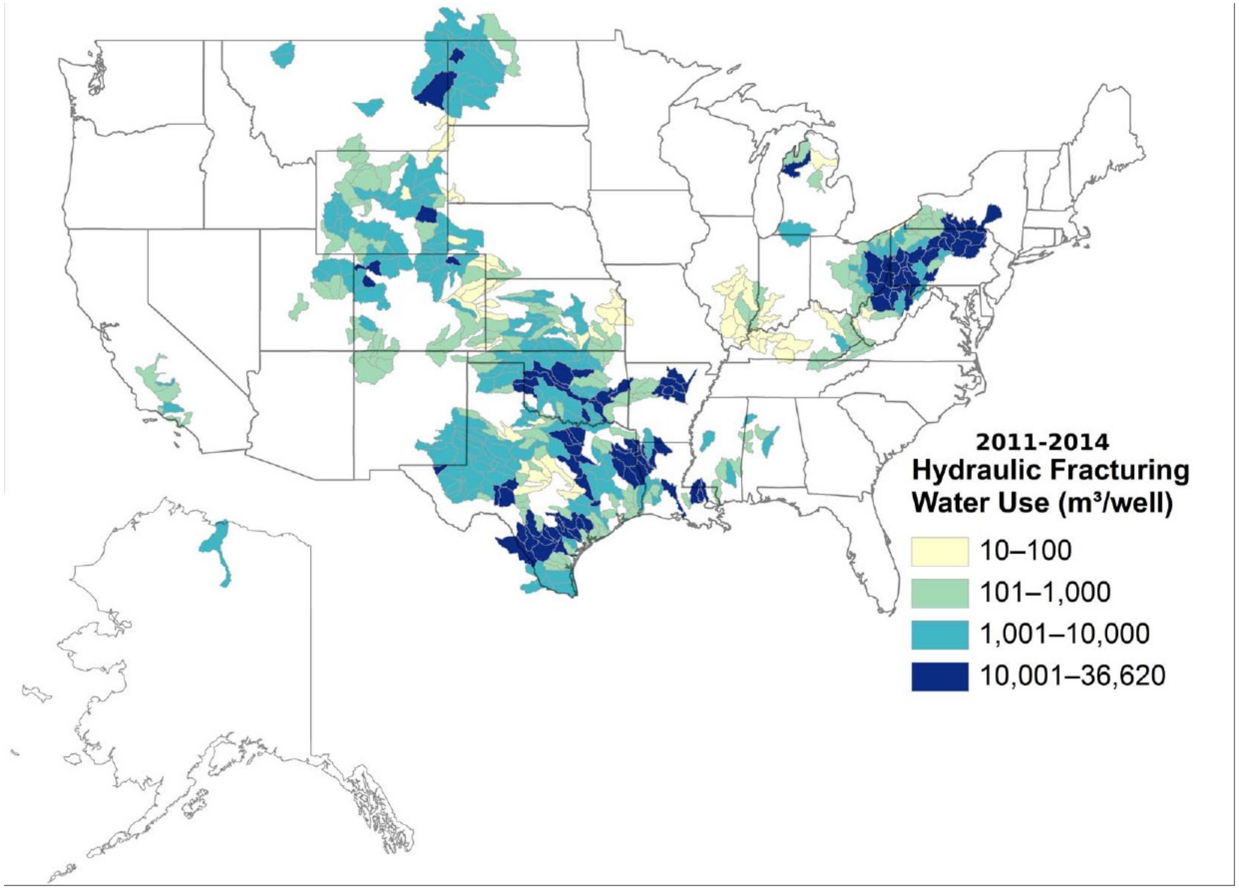
- High-pressure water-based fluid used to fracture low-permeability hydrocarbon formations
- Fracture fluid chemistry has changed significantly over the last 10 years.
- Evolution in water management shows how recycle and reuse can be utilized



OilPro.com

Water Use in Shale Development

- Water use varies significantly by shale play
- Complex water management



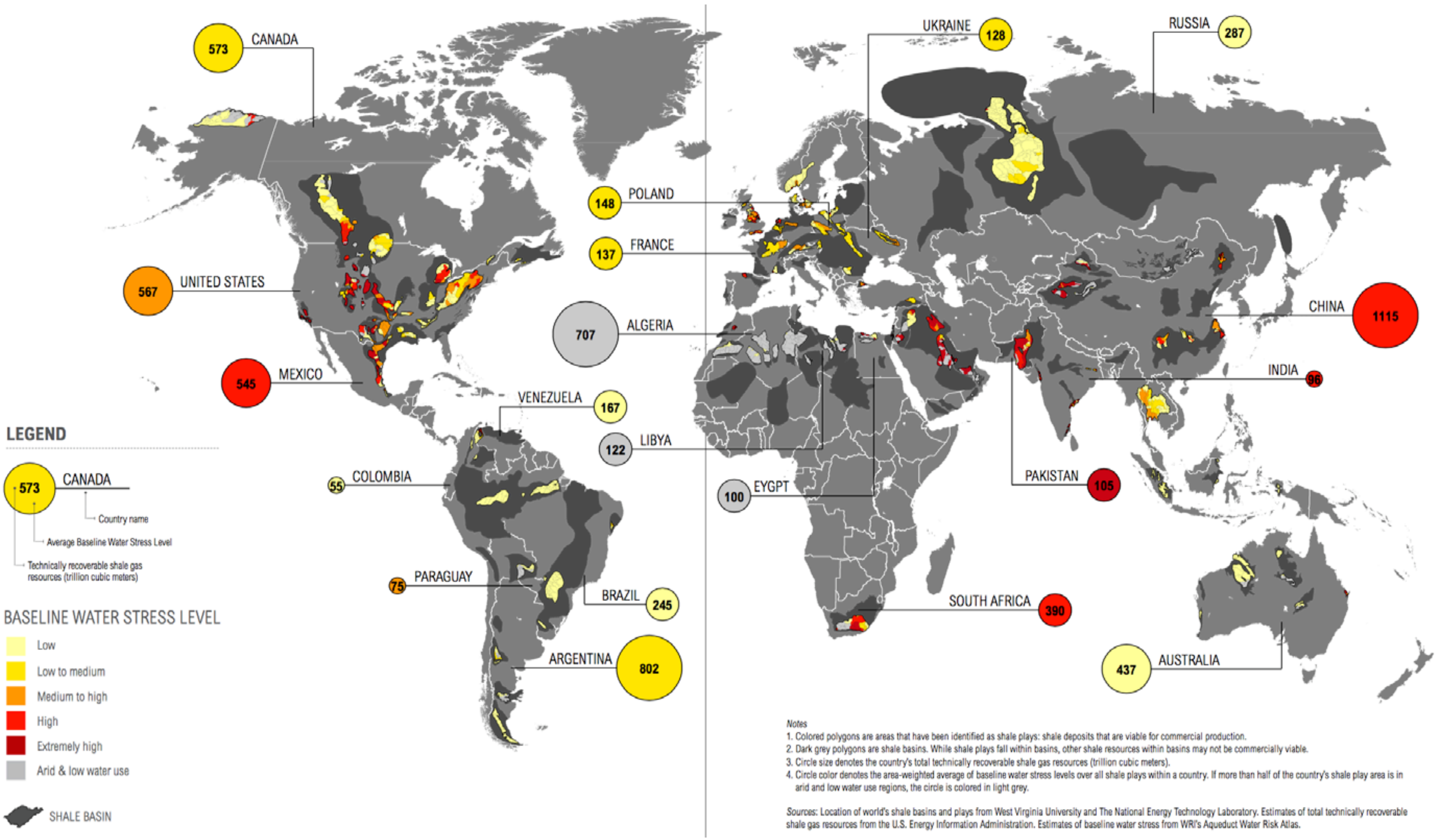
USGS, *Water Resources Res.*, 2015

North American Shale Plays

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

U.S. is now world's largest oil and natural gas producer

Water Stress and Shale Development



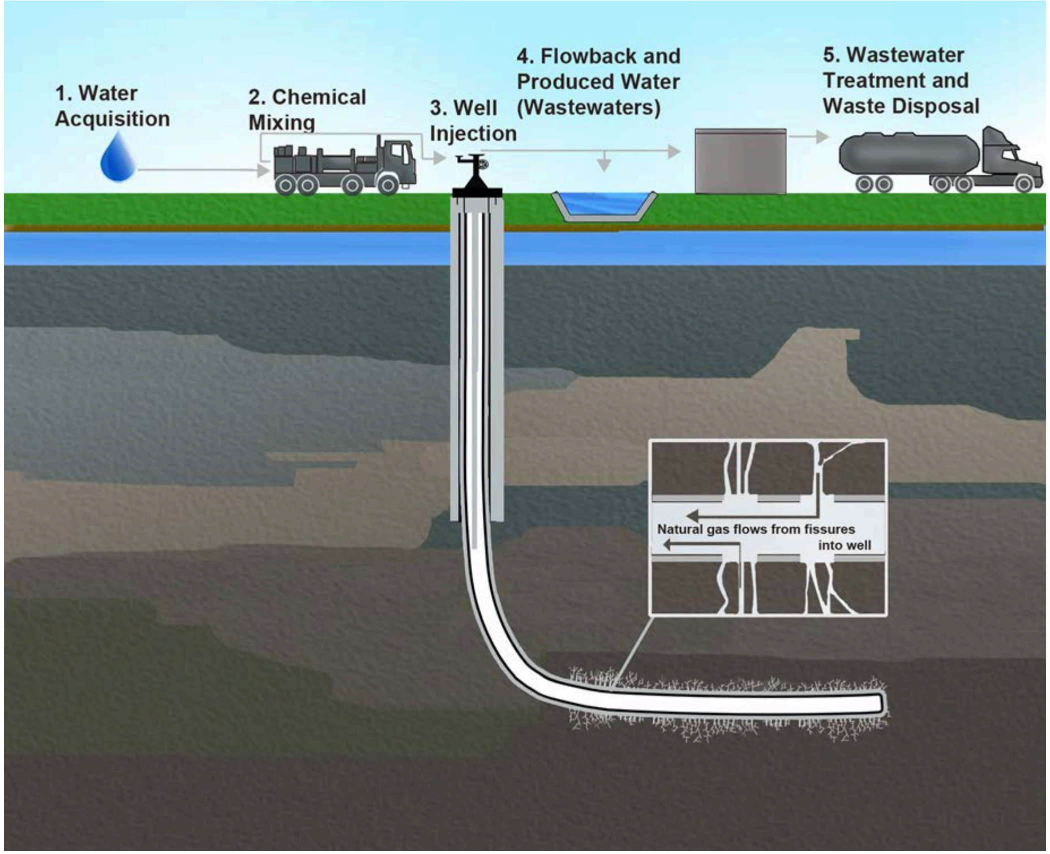
WRI, 2013

Water Scarcity Assessment

- Operators should understand water risks by assessing water scarcity
- Tools for modeling water stress. e.g.:
  - Aqueduct (WRI)
  - Global Water Tool (WBCSD)
- Water management plans should be informed by local water stresses in the development area
- Incorporate impacts of climate change and demand growth in assessing water resources
- Groundwater sustainability: are aquifers being over-drafted?
- Stakeholder engagement is critical for understanding water use in the watershed and understanding the value of water to stakeholders

Hydraulic Fracturing

- Water quality for fracturing has moved towards much higher TDS levels over the past 10 years
- Typical water use is 4-6 million gal per well
- Additives: sand (proppant), friction reducer, thickener, corrosion and scale inhibitor, acids and antimicrobials
- Injection fluid is 99% water and sand, 1% chemicals
  - Water can be highly saline
  - Match water quality with chemicals

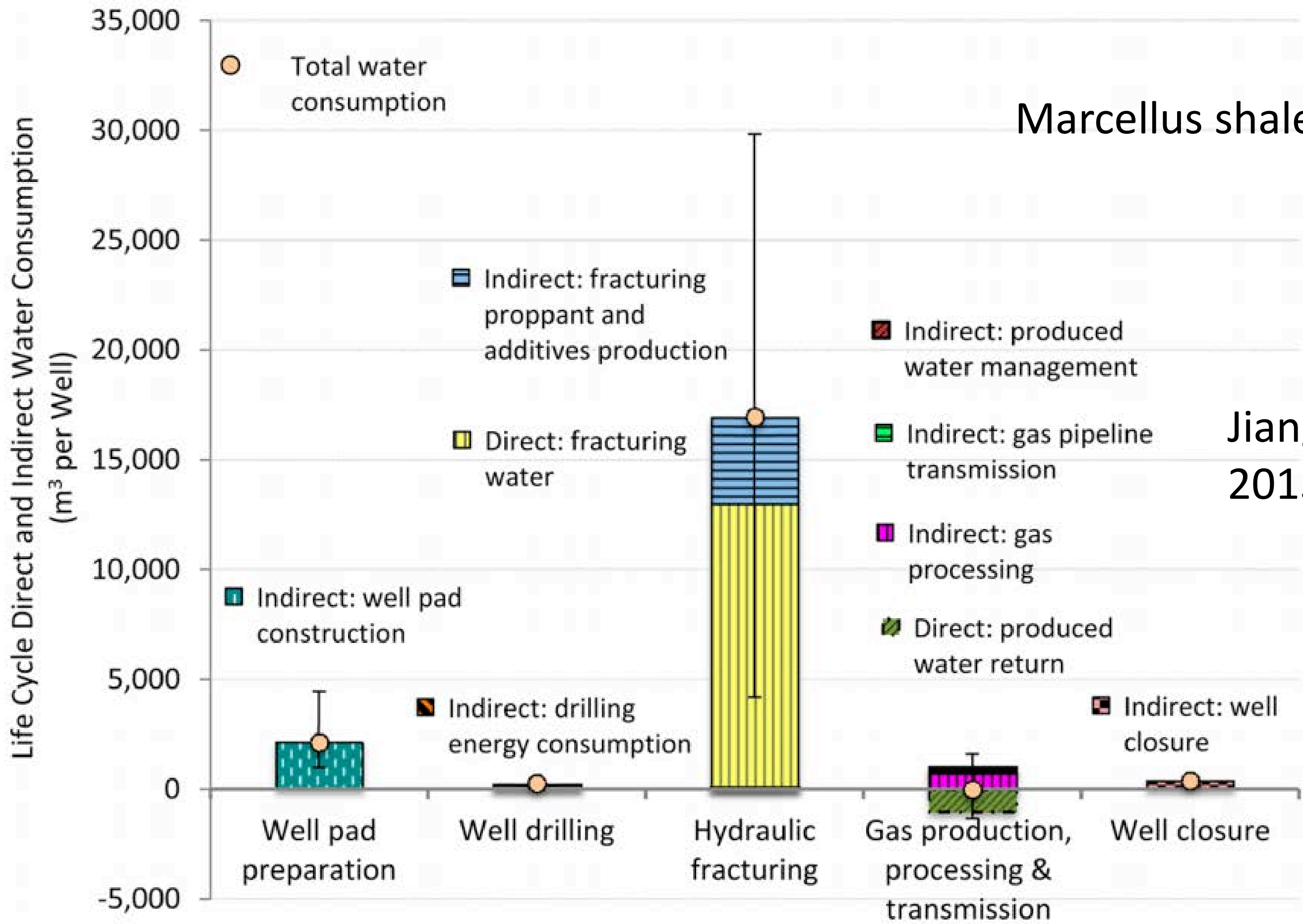


This picture is changing

- Water reuse (internally and externally)
- Salt recovery

Life-Cycle Water Use

- Hydraulic fracturing accounts for greatest water use in well life-cycle

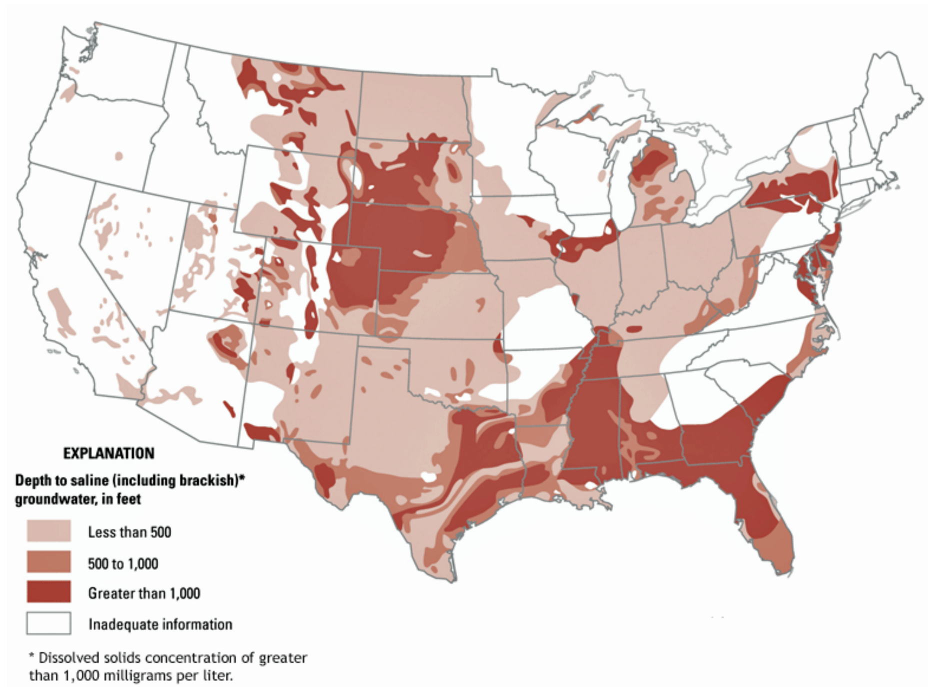


Marcellus shale well

Jiang et al, *Env. Sci. & Tech*, 2013

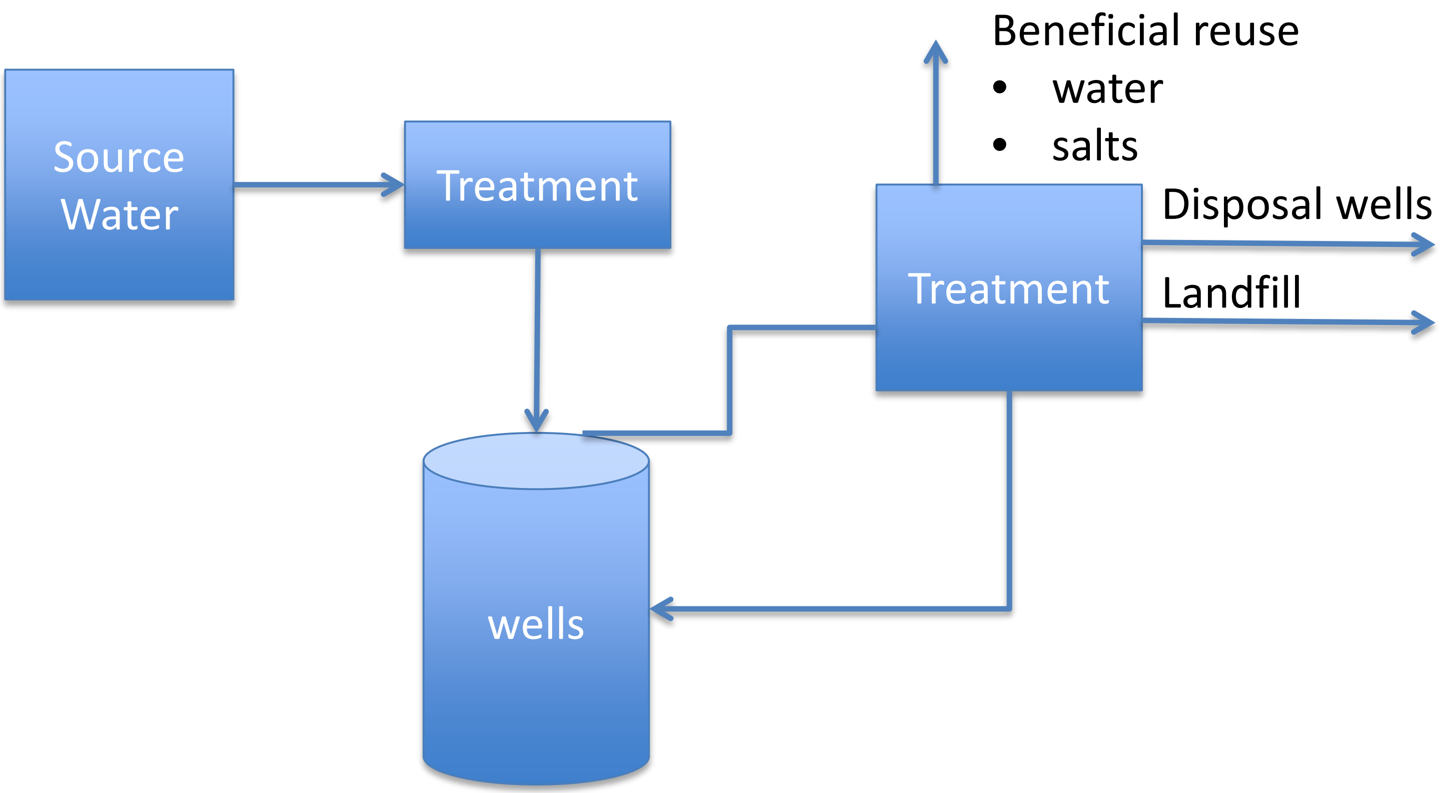
Use of Disadvantaged Water Resources

- Drivers
  - Water scarcity
  - Truck traffic
  - Supply reliability (e.g permits)
  - Public relations
- Treated flowback water
  - Common for Marcellus shale
  - Not common where injection well capacity is plentiful
- Brackish groundwater
  - Drought-proof water resource
  - Less competition and social/environmental impacts than freshwater
- Acid Mine Drainage water
  - PA SB 875 to incentivize (approved 6/2015)
- Treated municipal wastewater
  - Pioneeer in Odessa, TX (to be built)
  - Shell in British Columbia
  - Anadarko in Aurora, CO



Brackish water resources, USGS,

Water Treatment/Management



- Water management strategy varies greatly between unconventional resources plays
- Cost is usually dominated by transportation and treatment
- Mobile treatment units are common due to dynamic nature of water treatment needs (in space and time)

Source Water Treatment

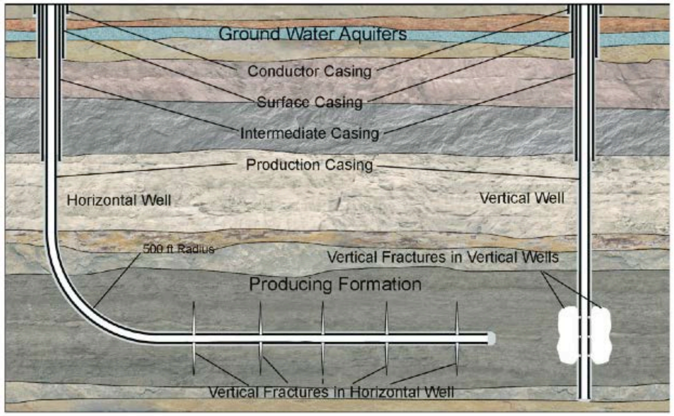
- Filtration
  - Remove TSS
  - Remove sulfate reducing bacteria and acid producing bacteria
  - Reduces scaling and corrosion potential
  - Reduces chemical demands in fracturing
- Aeration: prevent H_2S formation
- Biocides: kill bacteria
- ClO_2: remove bacteria, sulfides, particulates and insolubles
- Hardness removal (ion exchange)-e.g. Boron can cause problems with crosslinked gel formulation
- Sulfate removal
  - May cause scaling with Ba and Sr from formation

Water Storage: Tanks and Pits

- PA Department of Environmental Protection announced plans to ban temporary waste pits at Marcellus and Utica shale gas well sites (3/2015)
- Impoundments are prone to leaking, with potential groundwater contamination
- Impoundments also have VOC emissions and have negative impacts on wildlife
- Vertical tanks reduce the environmental footprint of well development

Groundwater Protection

- Shale formations are much deeper than drinking water aquifers
- Drinking water aquifer contamination can occur from surface spills, migration pathways in the well or sub-surface fractures or other wells
- Proper well design and mechanical integrity are critical
- Failure of the cement or casing or completion assembly surrounding the wellbore poses a risk to water supplies
- Cementing is critical
  - Proper cement placement and quality
  - Fully cemented surface casing that extends through the base of drinking water resources is critical
- If the annulus is improperly sealed, gases and fracturing fluids can access drinking water aquifers



Typical well construction, API

Source: EPA, 2015

Groundwater Protection

- Location of offset well relative to fracked well determines the likelihood of a “frac hit”(well communication incident)- migration pathway to drinking water
  - Frac hits most commonly occur on multi-well pads with inadequate spacing
  - Induced fractures must not intersect with existing fractures or permeable zones
- Older wells have more integrity problems…stresses from re-fracturing etc. (aging of steel casing and cement)
- Fluid migration along natural faults/fractures to drinking water zone is unlikely
- Monitoring
  - Baseline and post-completion groundwater testing (req’d in CO & WY)

Source: EPA, 2015

Flowback Water Quality Variability

Concentrations in mg/L

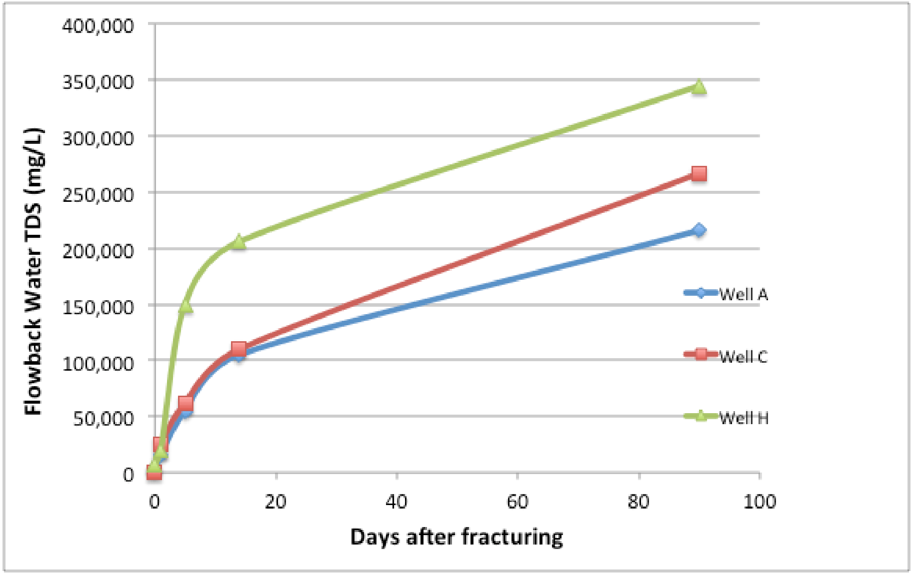
Sample	1	2	3	4	5	6	7	8	9
Bicarbonate	1,010	717	1,190	259	183	183	76	366	366
Chloride	19,400	29,400	10,000	6,290	59,700	87,700	153,000	96,400	58,300
Sulfate	34	0	88	67	0	0	0	670	749
Calcium	630	1,058	294	476	7,283	10,210	20,100	4,131	2,573
Magnesium	199	265	145	50	599	840	1,690	544	344
Barium	49.4	94.8	6.42	6.24	278	213	657	1.06	5.10
Strontium	107	179	45	74	2,087	2,353	5,049	178	112
Iron	5	26	8	14	27	3	68	26	34
Silica	34		41						
Boron	28	27	27	9	45	73	80	95	66
Potassium	192	273	79	86	977	1,559	2,273	2,232	1,439
Sodium	10,960	16,450	5,985	3,261	26,780	39,990	61,400	54,690	32,600
TDS	33,300	49,300	18,200	10,800	98,600	144,000	252,000	160,000	97,700
TSS	57	246	50	30	10	12	32	120	13,762
TOC	89	64	133	180	218	70	43	266	235

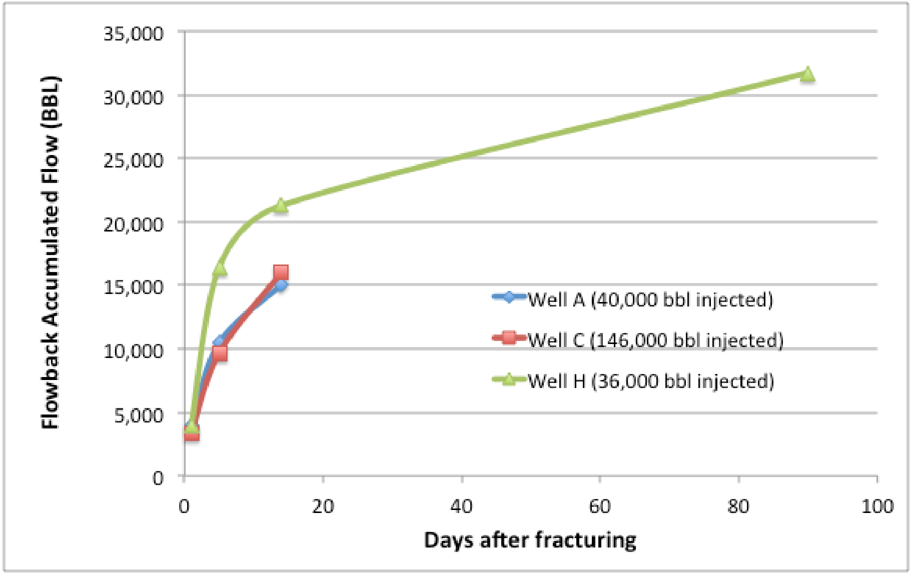
J. Häggström, Halliburton, 2011

- Huge variability in water quality from different wells
- Treatment technology needs to be robust to handle variations in water quality

Time and Location Dependence

Flowback water water quality and flowrate for 3 Marcellus shale wells (Hayes, 2009)





- Large variability in TDS over first 90 days
- TDS of initial flowback does not predict long-term TDS trends

- Injection volume not correlated with flowback volumes
- Logistics are challenging with such variability

Water Management Drivers

- Key drivers
  - Environmental sensitivity
  - Water availability and quality
  - Wastewater disposal options
  - Quality of flowback water
  - Volume of water required for fracturing and flowrates of flowback and produced water
  - Regulations and permits
- Economic analysis
  - Model water management scenarios to determine lowest cost alternatives
  - Account for environmental and social impacts in analysis
  - Risk management – consider liabilities and regulatory impacts of alternatives

Water Treatment Technologies

- Constituents of concern: TSS, metals, organics, radionuclides (NORM), frac fluid additives, TDS
- Hydrocarbon removal: hydrocylones, DAF, cartridge filtration, nutshell filtration, biological treatment
- Clarification
  - Chemical precipitation & settling
  - Filtration and membrane separation
- Electrocoagulation: remove solids, organics, bacteria and heavy metals
- Microbiological control: biocides, UV, ozone
- Softening: ion exchange, nanofiltration
- Desalination
  - Reverse Osmosis (up to ~ 50,000 ppm TDS)
  - Mechanical Vapor Recompression, Multi-Effect Distillation, Forward Osmosis, Membrane Distillation, Carrier Gas Extraction for brine concentration
  - Concentrated brine may have market value (e.g. drilling)
- Crystallization
  - Zero liquid discharge
  - Sell salt product

Reusing Water Between Operators

- Creating a market for water sourcing and reuse will facilitate efficiencies in the industry
- An example is Sourcewater
  - Start-up out of MIT
  - Web-based system for sourcing water, recycling water, and selling water
- Full-service water management companies handle sourcing, treatment, storage and disposal
  - Opportunity for these companies to share in costs of developing water infrastructure to service the industry
- Issues over liability must be managed
  - Texas HB 2767 shifts liability from producer to the recycler
  - Recycler is immune once water is sold to new producer

Wastewater Disposal

- POTW disposal used to be common but has been prohibited in PA and other places
- Wastewater disposal options include deepwell injection and dust suppression & deicing
  - Induced seismicity from injection into disposal wells
  - Env. concerns over land application
- May states prohibit brine transport in pipelines due to concerns over leaks and spills
- Wastewater pipelines used in North Dakota and recently approved in Texas
  - Reduce truck traffic
  - Must be monitored for leaks

Rodriguez, *J. Unconv. O&G Res.*, 2015

Drilling and Water Infrastructure

- O&G well drilling should be planned with water infrastructure development
- Need to drill on leases scattered over a wide area to maintain them can lead to sub-optimal water management
- Burdening individual O&G development projects with water infrastructure costs may make them cost-prohibitive
  - Better to make strategic investments in water infrastructure development
  - Systems-level development planning
- Truck traffic is major impact of shale development
  - Cost
  - Environmental impact
  - Safety (accidents) and traffic congestion
  - Damage to roads

Water Costs

- Reduce water costs by
  - Reducing truck traffic
  - Water reuse
  - Optimizing schedule for water delivery, use and disposal (waiting times can be very expensive)
- Bakken: water recycling can save $200-400K/well (Halliburton)

Producing Area	Total Water Cost ($/BBL)
Bakken	6-15
Eagle Ford	2-6
Permian Basin	3-8
Marcellus	4-20
Denver-Julesburg	4-8

O&G Facilities, 2014

Conclusions

- Industry has improved water management in many ways
- Shale development is highly dynamic
  - Opportunities for logistics optimization
  - Many treatment technologies to choose from: make fit for purpose
- Monitor groundwater quality and use well construction best practices
- Utilize frac tanks instead of pits for wastewater storage
- Many opportunities for water reuse
  - Water scarcity and disposal issues are drivers
  - Recover valuable materials (salts, metals, organics)
  - Emerging business models to reuse water between operators
- Opportunities to invest strategically in water infrastructure
  - Utilize pipelines instead of trucks
  - Centralized or mobile treatment facilities