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Review of Industry Methods for Sourcing and Storing Water, and Treating Re-used Water for High-Volume Fracturing Applications

B. W. (Buddy) McDaniel
Chief Technical Advisor – Stimulation
Halliburton – Duncan Technical Center

Major Points to be Discussed

- **Sourcing** of water
  - Concern for potable water supplies/limitations
  - Limitations on water quality acceptable for fracturing use
- **Transport** and **Storage**
  - Trucking or temporary pipeline
  - Offsite or rig-site area storage
- **Treatment** of original or flowback waters being reused
- **Disposal** concerns for water not reused
- **Downhole effects**
  - Concerns for potable water contamination
  - To tectonics and stress fields

Oilfield Has Changed Drastically

- Prior to 2003 in low perm formations, we would drill typically ~8 to possibly 30+ vertical wellbores per one-mile square area where now only 2-4 wells with long horizontal laterals
- **Resource shale formations** are now commercial oil and gas plays bringing **New era** of completion approaches to achieve economic viability using the ***Shale Completion Model***
- This combination of ***long laterals & high-volume multi-stage fracturing*** method has even been extended to very low permeability "conventional" reservoirs

- This has allowed ***previously non-commercial reservoirs*** to become **profitable**

Oilfield Has Changed Drastically

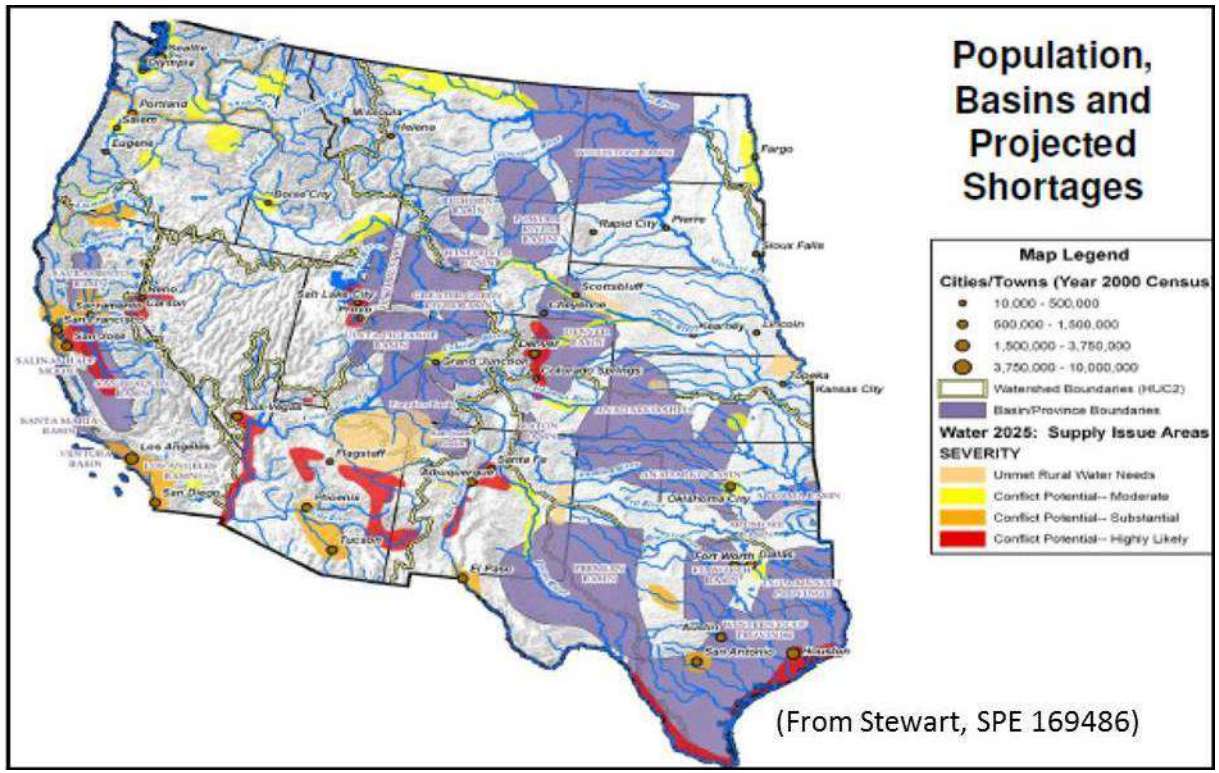
- **Environmental impacts** of this revolution are significant
  - Moved from single well pad to multi-well pads (enlarged area version of offshore platform approach)
  - Necessity of the **very large volumes of water** per well
  - **Large number** of this type of well being drilled
  - **Negative press**, supported by environmental protectionist groups and lack of understanding of oilfield industry
  - Much of oilfield had lived for many decades **without** feeling need to **make concerted efforts to enlighten general public** of our practices and concerns for environmental protection.
    - Drastically more trucking for water and proppant hauling **increased road wear** and **enhanced traffic congestion**
    - More wells drilled in/near **highly populated areas increased public view and concern** about our operations

Just How Much More in the Public Eye Can Fracturing Get?

DFW Airport!

Sourcing Water for Fracturing

- Using potable water or non-potable water
  - What is presently available? Regulatory limitations?
  - Does using potable water challenge human usage needs



  - Several challenges in US, more severe in other global areas (Many parts of SA, Australia, Northern Africa, China, most of Middle East)

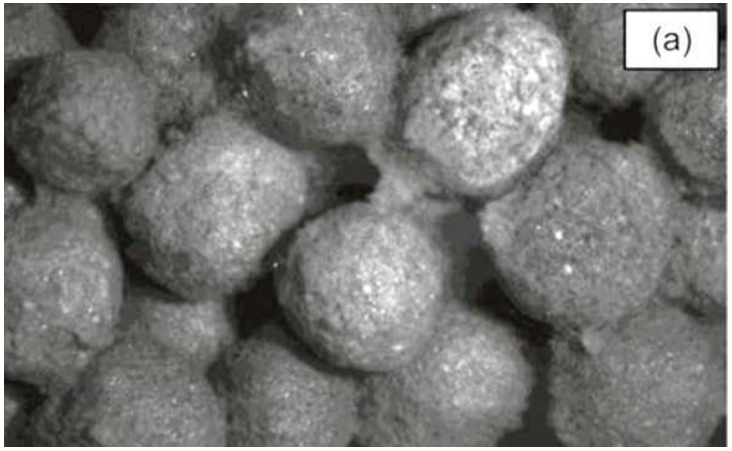
Sourcing Water for Fracturing

- **Compatibility** with type of treatment being pumped
  - Waterfracs (only Friction Reducer (FR) additive or low concentration of gel polymer
  - Linear gel polymer or Crosslinked (X-link) gel
  - Hybrid frac using WaterFracs initially and then switch to linear or X-link gel to carry higher proppant concentrations
  - Compatible with formation, or can be made compatible with low cost additives (typically clay compatibility concerns)
- **Cost** must be acceptable, including transportation expense
- Source water **should not introduce damage** to fracture conductivity or formations from solids, precipitation, scale formation, etc.; or issues must be controllable with low cost additives.

Compatibility with Formation and Type of Treatment System

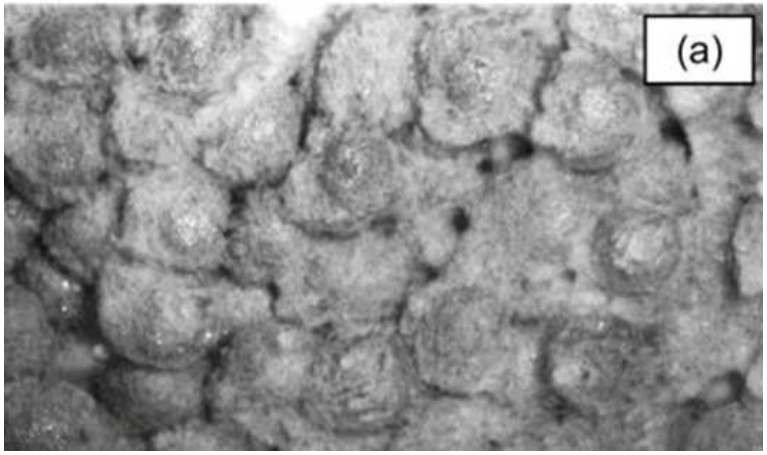
- Source water should not introduce damage to fracture conductivity or formations from solids, precipitation, scale formation, etc.; or issues must be controllable with low cost additives.
- Laboratory evaluations to if physical modifications require, such as (rate limiting) filtration, costly chemical titrations, or newer technology such as **Electrocoagulation**.
- Evaluate if specific formation being treated needs chemical additives to be compatible with formation
- Evaluate if additives needed to be compatible with Fracturing fluid system(s).

Flowing Untreated or Electrocoagulation (EC) Treated Formation Water through 20/40 Ceramic Proppant Packs for 30 min. (@ 160°F@2,000 psi stress)

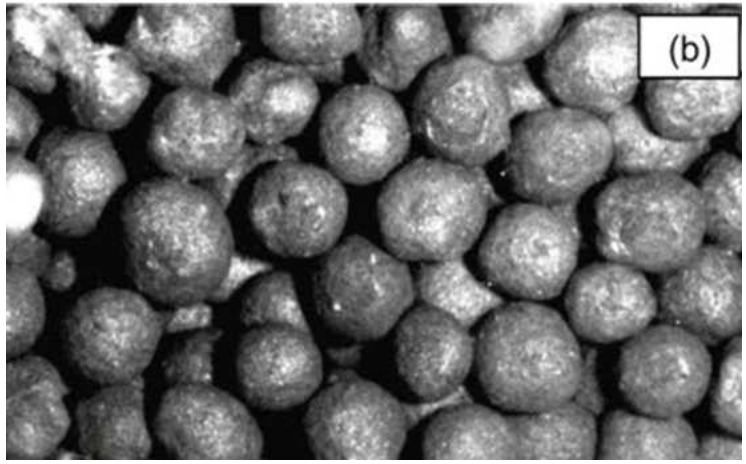


Untreated a Permian formation Water Sample

EC Treated Permian Water



An Untreated Marcellus formation Water Sample



EC Treated Marcellus Water

Untreated Marcellus Water contained >3x Total Suspended Solids (TSS) as the Permian water.

Ye et al. (2013) SPE 165085

Truck it or Pump it to Storage?

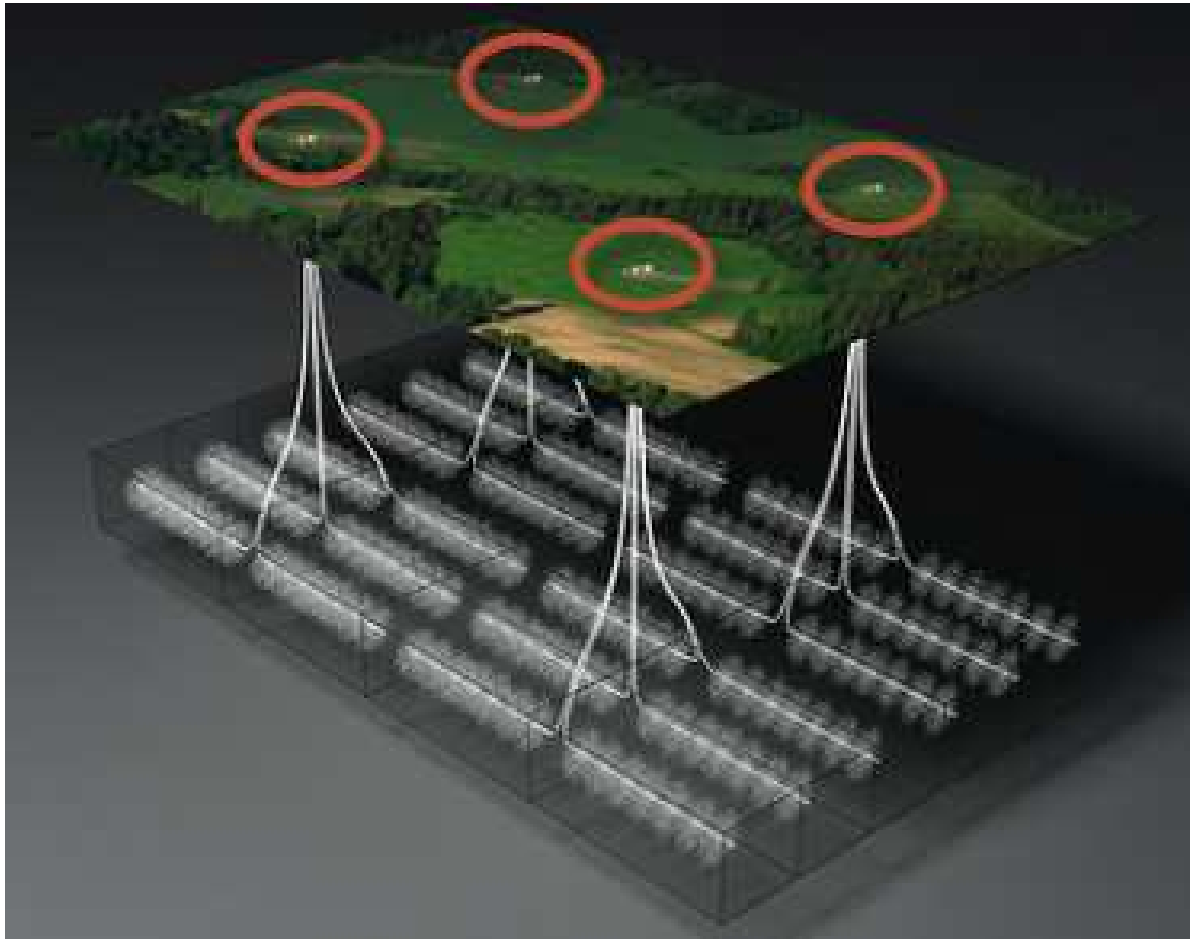
- The movement of water has been performed primarily by trucks, often requiring improvements to the roads built to connect well locations with public highways.
- Some operators have built transfer systems using piping (tubing or aluminum pipe) and centrifugal pumps, especially where location roads are very long or poor, and public roads are scarce. In some city areas truck traffic can be restricted.
- With n still required, or used e
- Often t

Store On Pad or Offsite

Pad Drilling Reduces Environmental Impact and Costs

In Northeastern BC, Canada Horizontal Well Pads First Taken to Extreme

By 2010 Pad Drilling becoming common, with Rigs on rails, then “walking” rigs…



Argentina Is a Good Non-North America Study

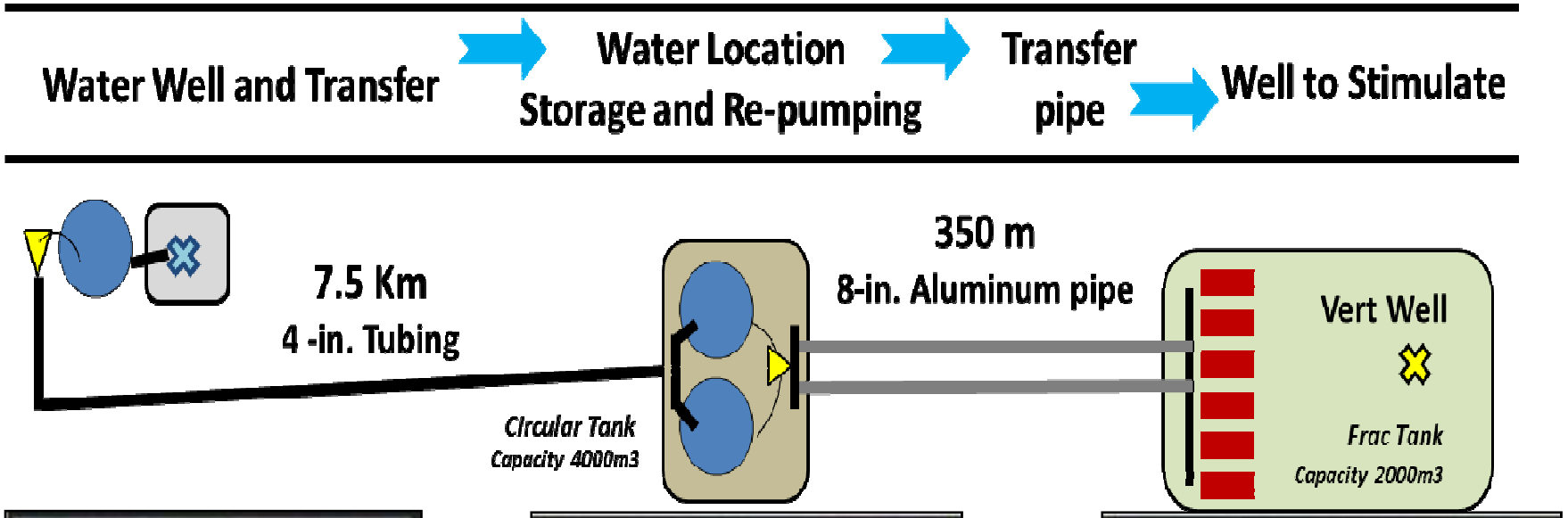
- A long history of using hydraulic fracturing applications in vertical completions
- Several candidate formations for application of long horizontal completions and massive volume multi-stage fracturing stimulations have become active in recent years, along with Australia, generally the most active outside NA
- Significantly less oilfield infrastructure in Argentina than in NA
- Meaningful Environmental regulations in place
- Excellent historical working relationships between oilfield service providers and well operators

Argentina a Good Non-North America Study

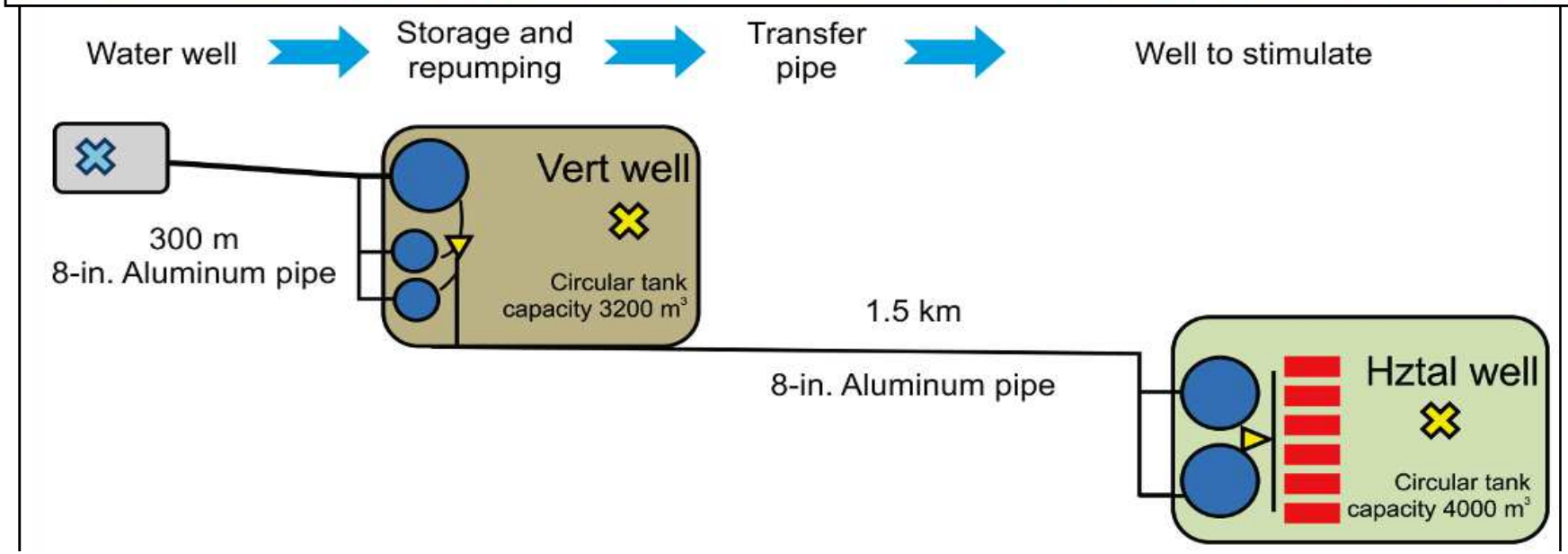
Logistics

- Substantial progress related to water management and logistics for sustainable development of Argentina's shale plays since 2009.
- Variety of water storage systems and methods for transferring water (trucks, pipe systems) have been used in the **Neuquén Basin** (most active shale play area)
- Methods have depended on stage or phase of activity (exploration or pilot phase),
  - Type of completion (vertical, horizontal, or recompletion wells)
  - Existing surface facilities in the fields
  - Geographical location, and proximity to available water sources

Water Delivery Plan for First Massive Frac in Argentina



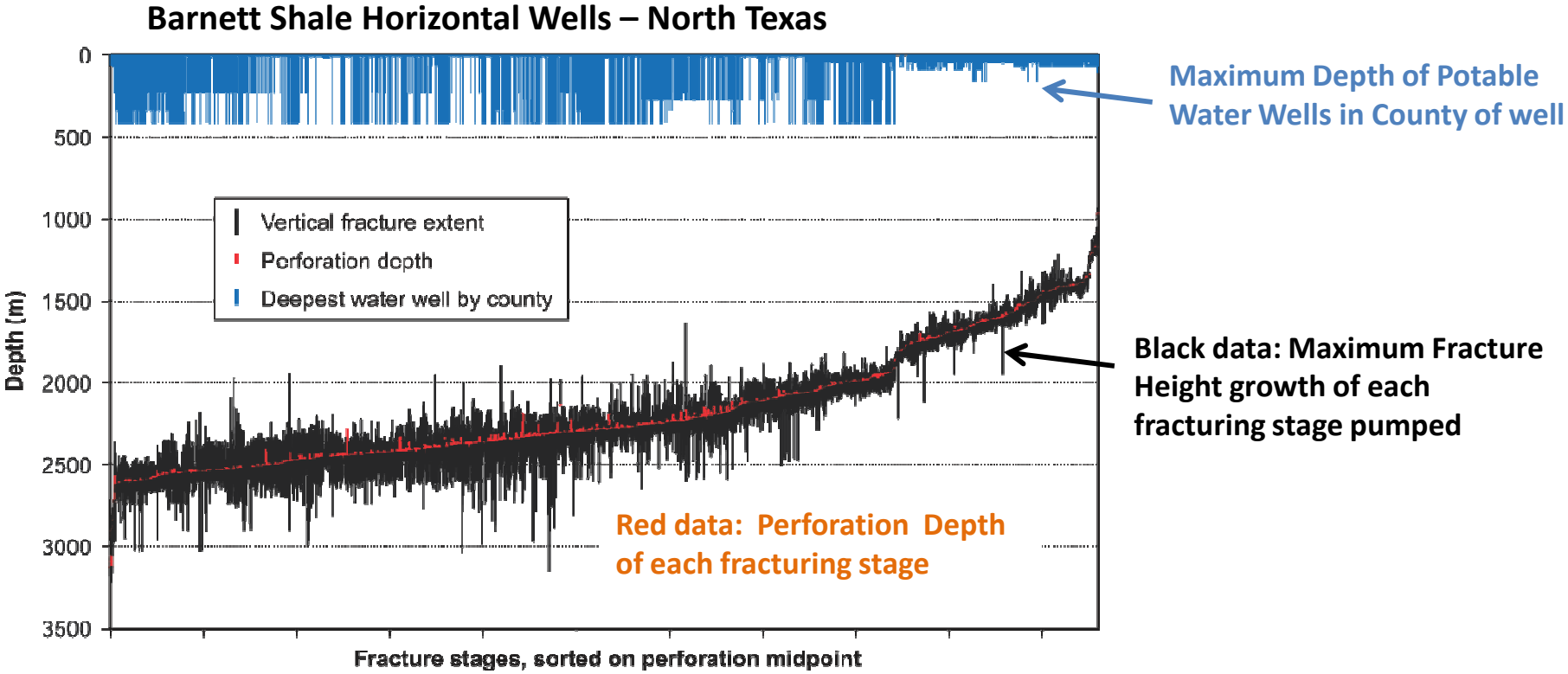
Water management plan for First Horizontal well completion



Argentina Examples

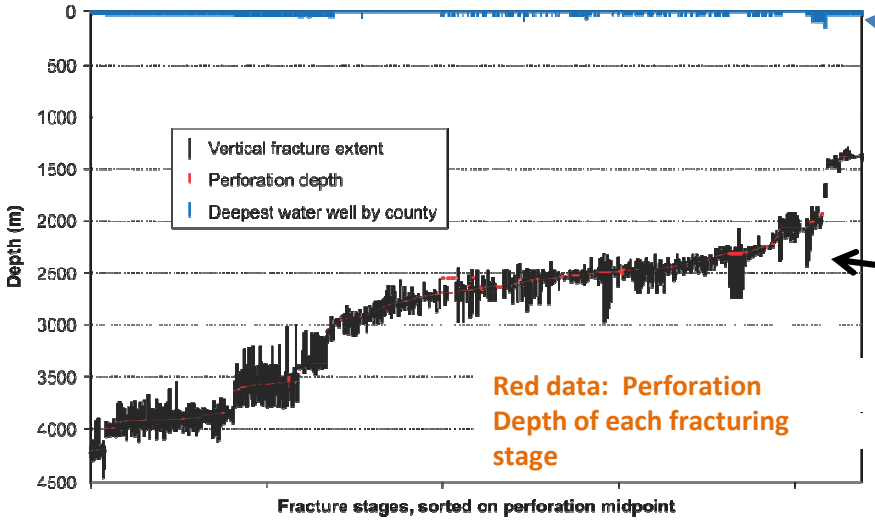
Potential Surface Seismic Concerns from Fracturing

- Many simplistic/inaccurate cartoon sketches were publicized showing **fracs on horizontal wells** would grow up into **potable water zones**
- Even showing **flaming water faucets** (actually from **biogenic** methane)
- Real data is drastically different (from Warpinski et al. SPE 174118)



Data from Other Major Shale Plays

Woodford Shale Wells in Oklahoma and Kansas *

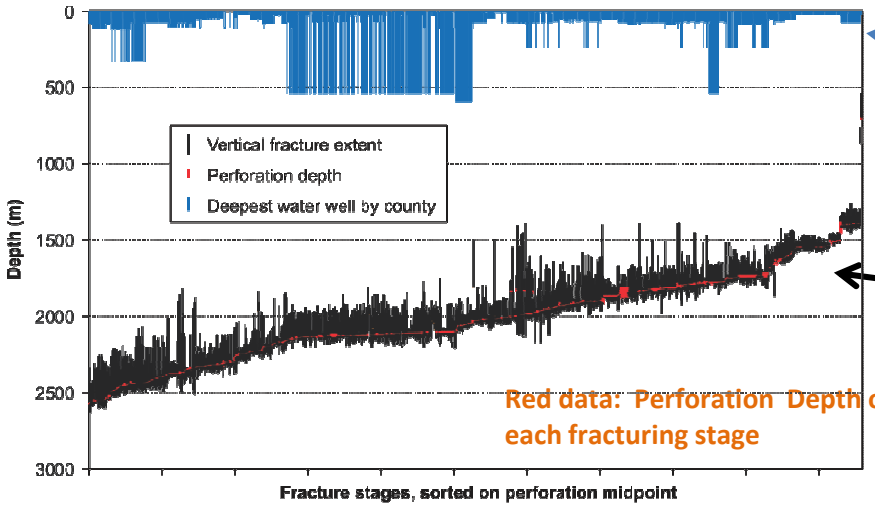


Maximum Depth of Potable Water Wells in County of well

Black data: Maximum Fracture Height growth of each fracturing stage pumped

Red data: Perforation Depth of each fracturing stage

Marcellus Shale Wells in Northeast US *



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*Warpinski et al. SPE 174118

Class II Deep Disposal of Water

USGS data lists ~150,000 Class II injection wells are used in connection with oil and natural gas activities across the US; ~40,000 are specifically disposal wells.

Increased volumes from fracturing operations has brought added public attention/concern in regard to environmental issues

- Surface leakage from well casing, wellhead, or surface piping - **This has increased site monitoring and site containment requirements**
- Injection causing induced seismicity to increase chance for fault slippage/earthquake
  - Initial permitting processes consider local geology. – USGS says only **0.55% disposal wells** have *potentially* been linked to seismicity
  - **0.15% of the ~150,000 Class II wells** have *potentially* been linked to seismicity
- Most states have developed **new pre-set rules** for reduced injection rates, or even injection shut-down, related to **nearby seismic activity**

Conclusions

- **The development of resource shale formations as commercial oil and gas plays has ushered in a new era of completion approaches to help ensure economic viability.**
- **The combination of long laterals with high-volume multi-stage fracturing treatments (Shale Completion Model) allows previously non-commercial reservoirs to become profitable.**
- **Environmental impacts of this revolution are significant,**
- **Sourcing and evaluation of water; Concern for potable water supplies/limitations**
- **Transporting and storage (Offsite or Rigsite) • Treatment of flowback waters being reused**
- **Disposal concerns for water not**
- **Downhole effects to tectonics and stress fields**

Thank You !

Questions ??