# Hydraulic Fracturing in Underground Sources of Drinking Water at Pavillion, WY

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**Photograph overlooking Pavillion Field**

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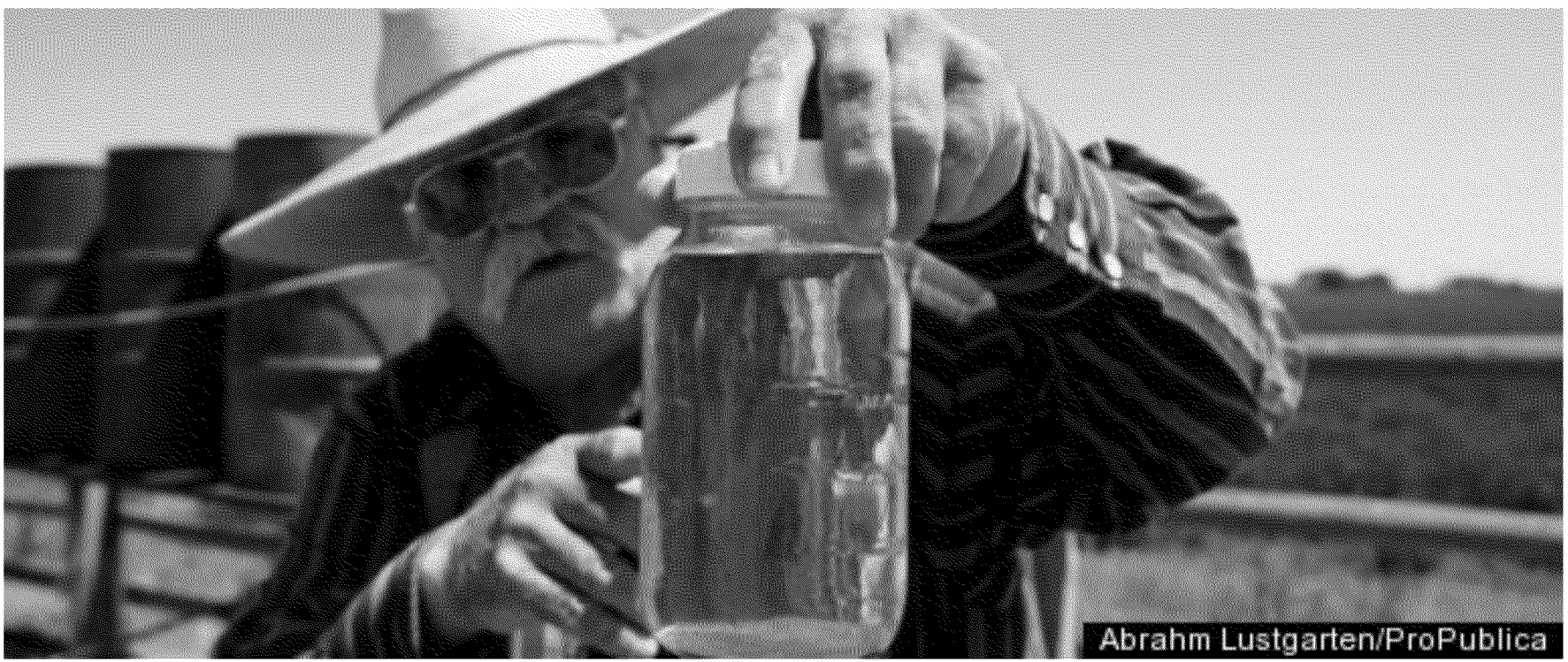
# Discussion on Potential Impact to Ground Water

- Ongoing debate over the impact of well stimulation, especially hydraulic fracturing, on ground water at Pavillion and elsewhere.
- Missing from this debate is recognition that stimulation fluids have been injected directly into underground sources of drinking water with potential associated ground water resource impact.



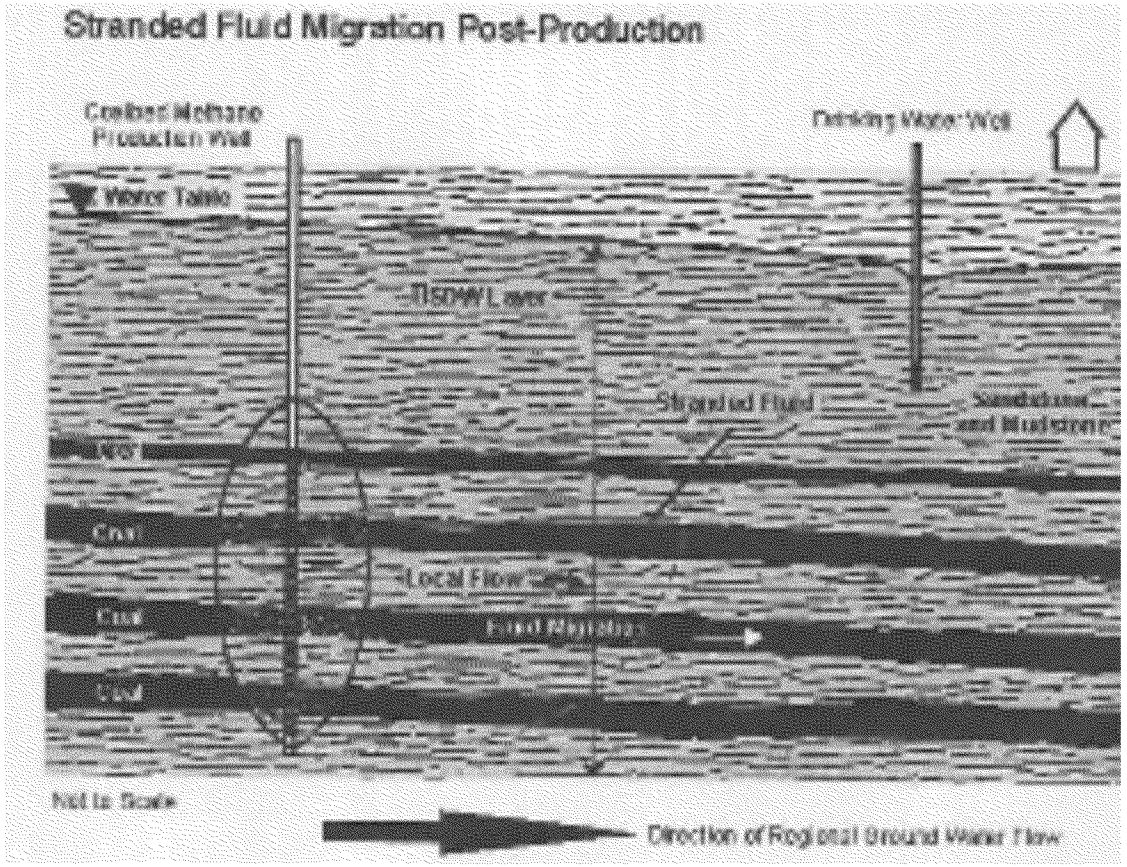

**Photograph of landowner holding jar of water from his domestic well at the Pavillion Field**

# Ground Water and Domestic Well Impact are not Synonymous Terms

There are two related but fundamentally different questions regarding ground water contamination.

1. Has contamination of ground water resources occurred? This includes depths and formations not currently used for water supply - a ground water resource.

2. Has contamination of domestic wells occurred?




**Source: EPA (2004)**

A domestic well investigation is not a ground water investigation.

# Definition of a USDW

**Underground Source of Drinking Water (USDW)** is defined in 40 C.F.R. 144.3 as a formation that currently or could supply drinking water, contains less than 10,000 mg/l total dissolved solids and is not an exempted aquifer.

The Energy Policy Act of 2005 excluded *"underground injection of fluids or propping agents (other than diesel fuel) pursuant to hydraulic fracturing operations"* from the term *"underground injection"* in the Safe Drinking Water Act.

- Injection of stimulation fluids directly into USDWs, regardless of volume and composition (with exception of diesel fuel) is not considered injection under federal regulations.
- Is "no injection" equivalent to no impact?

# Hydraulic fracturing in USDWs associated with CBM Production

**Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs**

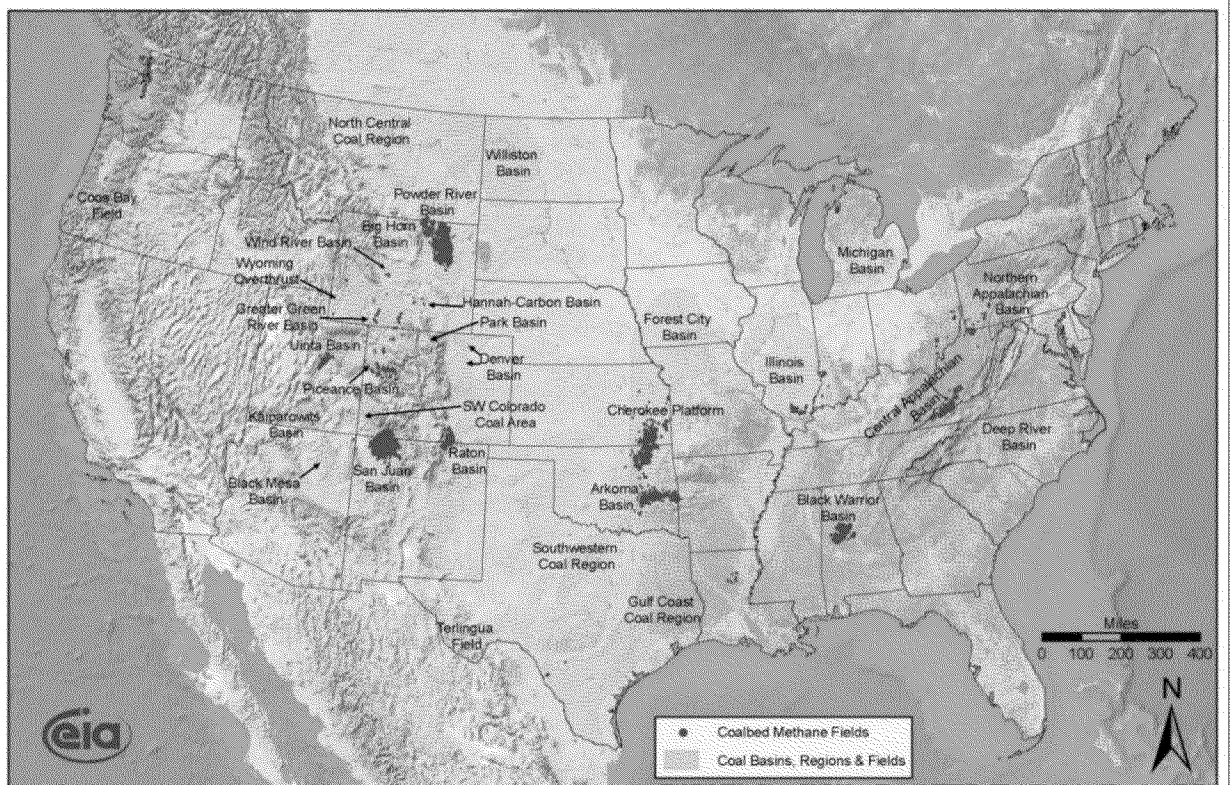
**Final**

*"In many CBM-producing regions, the target coalbeds occur within USDWs, and the fracturing process injects 'stimulation' fluids directly into the USDWs."* (EPA 2004).

In 2010, 9% of natural gas supply came from CBM (EIA 2012).

| Basin | Has hydraulic fracturing occurred in USDWs? |
|---|---|
| San Juan | yes |
| Black Warrior | yes |
| Piceance | unlikely |
| Uinta | likely |
| Powder River | Infrequently |
| Central Appalachian | likely |
| Northern Appalachian | yes |
| Arkoma | no |
| Cherokee | yes |
| Forest City | unlikely |
| Raton | yes |
| Sand Wash | yes |
| Pacific Coal Region | yes |

**Coalbed Methane Fields, Lower 48 States**

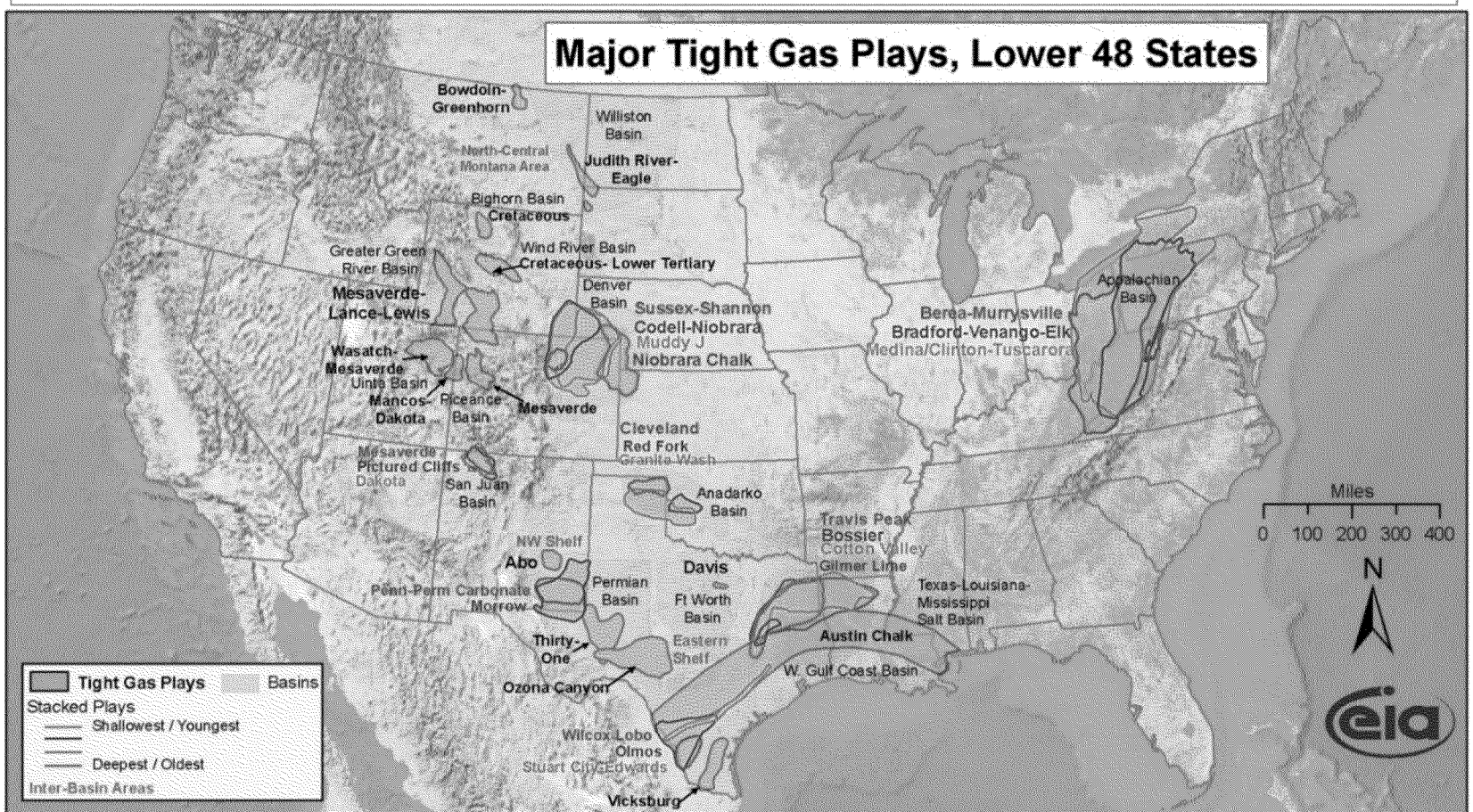



Source: Energy Information Administration based on data from USGS and various published studies
Updated: April 8, 2009

# Tight Gas Plays

In 2010, 26% of natural gas production came from tight gas plays (EIA 2012). Extraction from tight gas plays expected to increase 73% from 2012 to 2040 with share of total gas extraction remaining constant (EIA 2014).

Are stimulation fluids being injected directly into USDWs in tight gas plays? If so, what is the extent?




Source: Energy Information Administration based on data from various published studies
Updated: June 6, 2010

# What We are Doing and Why

## Research Objective

Document extent of stimulation and evaluate potential resource damage if present in USDWs in Pavillion Field.

## Why do this work?

- The Pavillion Field is a tight gas play. Stimulation into a USDWs in a tight gas play has not been documented at any location.
- The extent of stimulation (number of events, depths, fluids, etc.) into a USDW has not documented in detail at any well field including at CBM locations in 2004 EPA report.
- Potential impact of direct injection into USDW has not evaluated at any specific well field including CBM locations in 2004 EPA report.

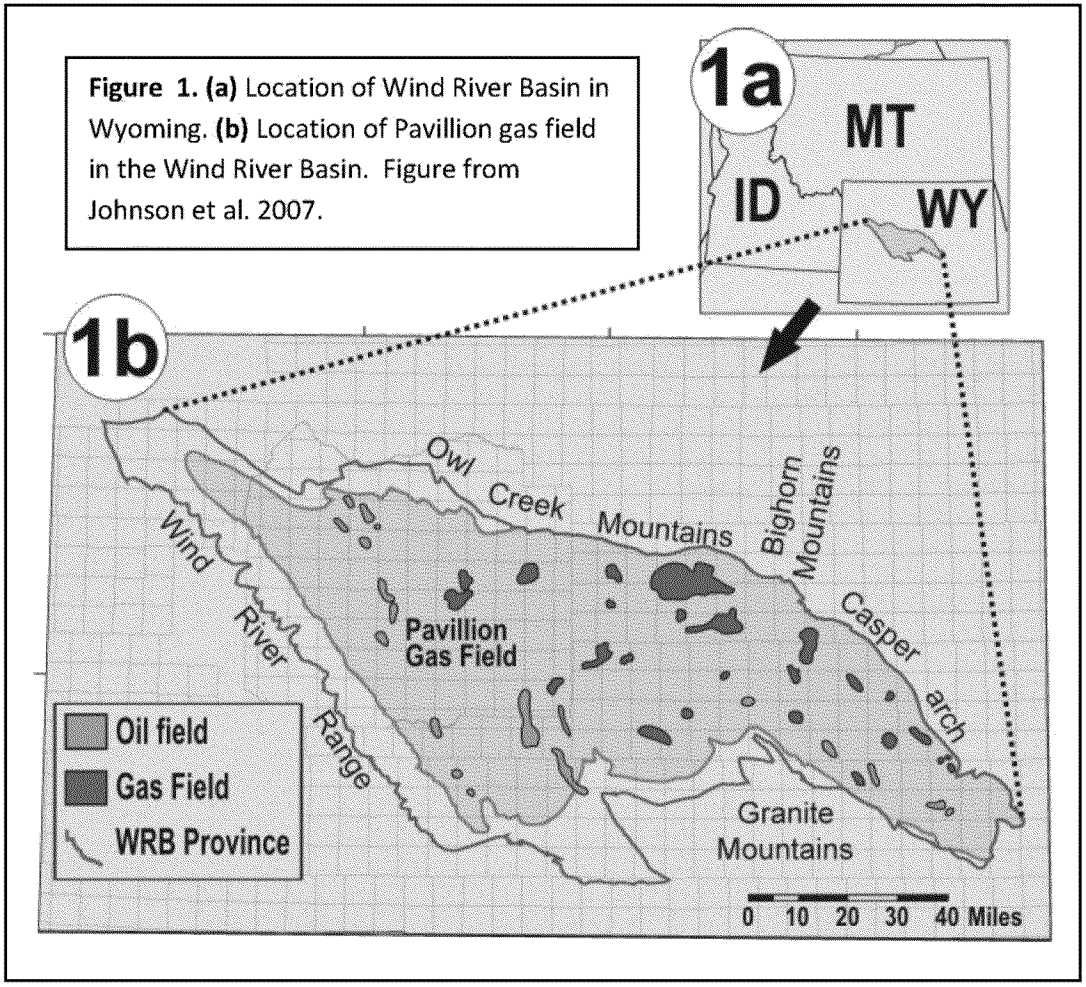
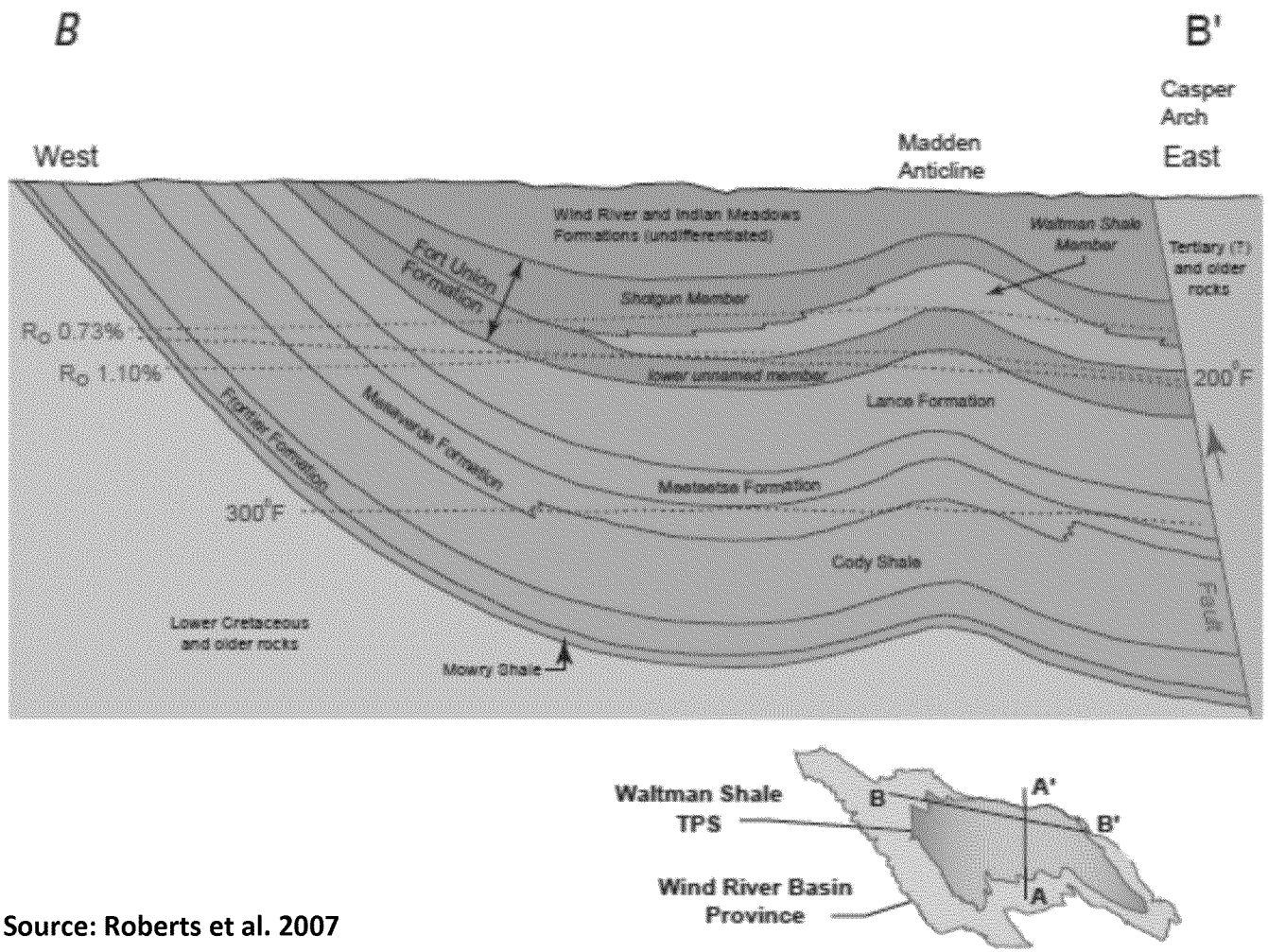



**Figure 1. (a)** Location of Wind River Basin in Wyoming. **(b)** Location of Pavillion gas field in the Wind River Basin. Figure from Johnson et al. 2007.

Note: The focus of the draft 2011 EPA report (DiGiulio et al. 2011) was to evaluate potential upward migration from intervals of stimulation – not impact in intervals of stimulation.

# Wind River and Fort Union Formations

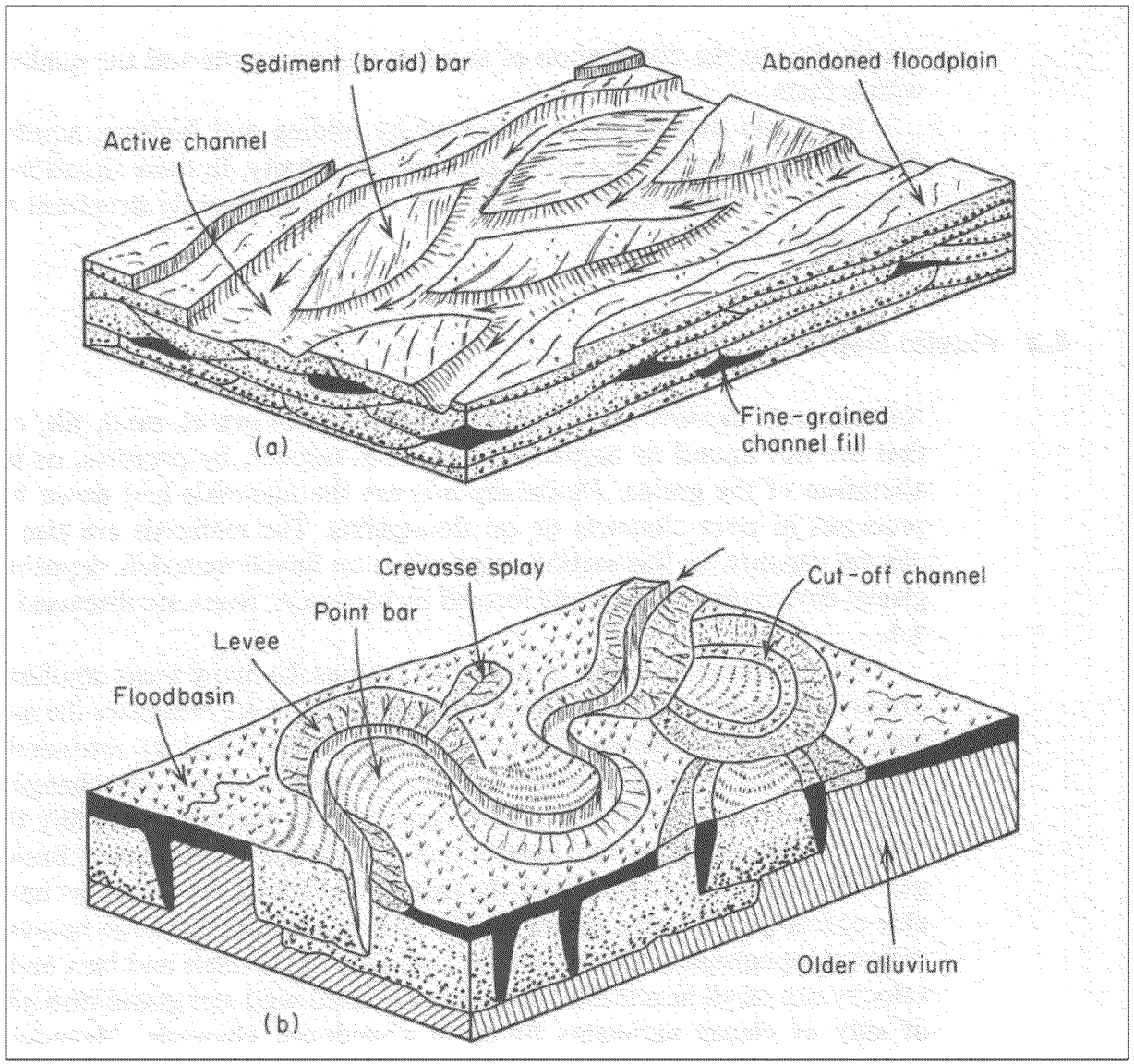



Source: Roberts et al. 2007

- Stimulation fluids were injected into the Wind River and underlying Fort Union Formations.
- Cretaceous age source rocks

# Fluvial Geomorphology

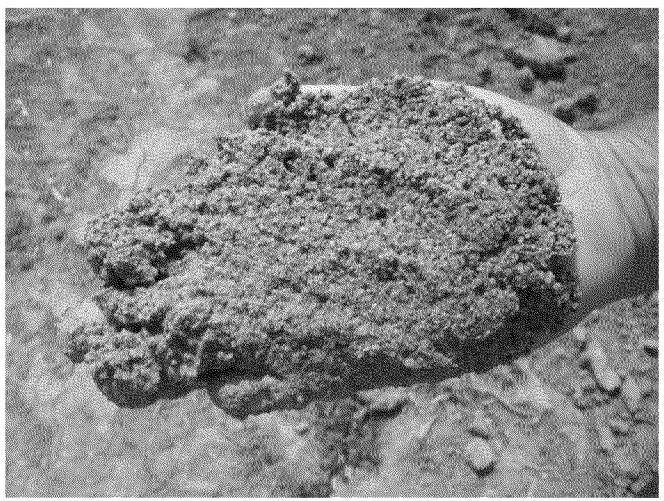
- Not monolithic sandstone units of low permeability
- Heterogeneous fluvial depositional systems. Contains connected, poorly connected, and unconnected water bearing sandstone units (McGreevy 1969). Units may be connected by fracture systems (Morris et al. 1959).
- These units surrounded by discontinuous low permeability sandstone, mudstone, and shale units.
- No extensive areal confining units.



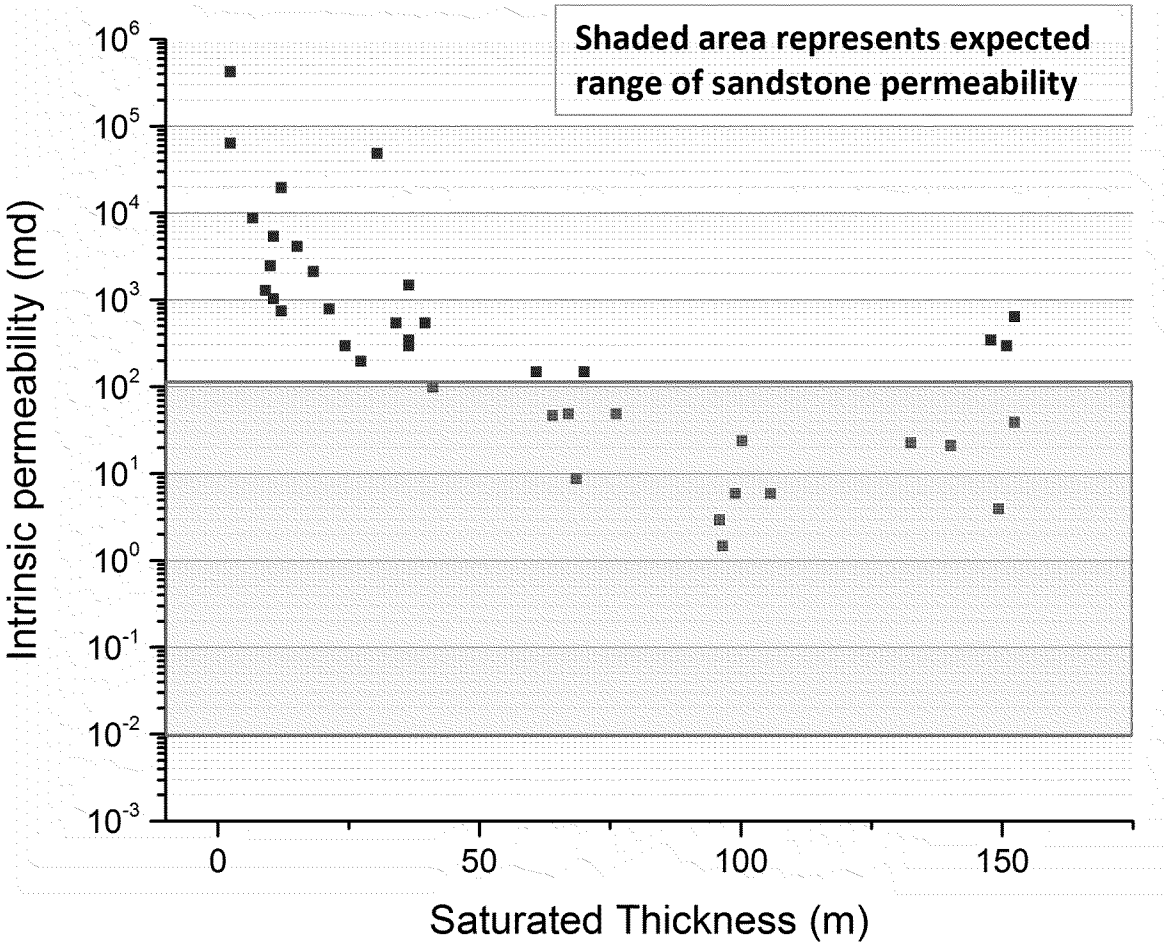

**Source: Freeze and Cherry (1979)**

# Presence of Permeable Water Bearing Zones in Wind River Formation

White coarse-grained sandstone targeted by local water well drillers and often referred to as "water sands" in Morris et al. (1959) present in Pavillion Field



**Source: DiGiulio et al. (2011)**




**Source: Data from Wyoming Water Development Office State of Wyoming Water Plan. Calculated from "permeability" (gpd/ft$^2$) using dynamic viscosity = 1.002E-02 g cm$^{-1}$ s$^{-1}$ and density = 1.0 g cm$^{-3}$**

# Attainment of USDW Criteria- Current Use of Wind River Formation, Potential Use of Fort Union Formation

**Wind River Formation**

- 5 municipal wells in Town of Pavillion supply 20,000 gpd and 7.3 million gallons per year (James Gores & Associates 2011)
- Supplies drinking water for domestic wells in Pavillion area (James Gores & Associates 2011)
- Major source of drinking water for the City of Riverton, WY (over 493 million gallons of water gallons extracted from 11 wells in 1965) (Whitcomb and Lowry 1968).
- Water yields ranging between 0.1 to 3,000 gpm and artesian zones with sufficient head to produce 200 gpm (WWDO 2003).
- Major source of drinking water throughout the Wind River Basin (Daddow 1996).
- The largest number of documented domestic well completions in Fremont County (Plafcan et al. 1995).

**Fort Union Formation**

- Total dissolved solids range from about 1,000 to 5,000 ppm (McGreevy et al. 1969).
- Wind River and Fort Union Formations defined as aquifers by Wyoming Water Development Office (WWDO 2003).
- Aquifer exemption required for injection of produced water into Fort Union Formation at Shoshone-Arapahoe 16-34 located 3.5 mi northwest of Pavillion Field (EPA 2013).

# Attainment of USDW Criteria– TDS and Major Ion Concentrations in Wind River Formation

| Parameter | Daddow (1996) Median (Range) | | Plafcan et al. (1995) Median (Range) | | Pavillion Area (EPA Data) Median (Range) | |
|---|---|---|---|---|---|---|
| **TDS** | **490** | (211-5110) | **1030** | (248-5100) | **925** | (302-4921) |
| **Ca** | **10** | (1-486) | **45** | (1.7-380) | **51** | (3.3-452) |
| **Mg** | **2.2** | (0.1-195) | **8.2** | (0.095-99) | **5.3** | (0.02-147) |
| **Na** | **150** | (5-1500) | **285** | (4.5-1500) | **260** | (42-1290) |
| **K** | | | **2.45** | (0.1-30) | **2.45** | (0.18-10.5) |
| **SO4** | **201** | (2-3250) | **510** | (12-3300) | **551** | (90-3640) |
| **Cl** | **14** | (2-466) | **20** | (3-420) | **21** | (2.6-78) |
| **F** | **0.7** | (0.1-8.8) | **0.9** | (0.2-4.9) | **0.9** | (0.2-4.1) |

Major ion chemistry in domestic wells in Pavillion Field is <u>typical</u> of the Wind River Formation (elevated TDS and SO4)

Secondary Standards
TDS = 500 mg/L
SO4 = 250 mg/L

# Attainment of USDW Criteria

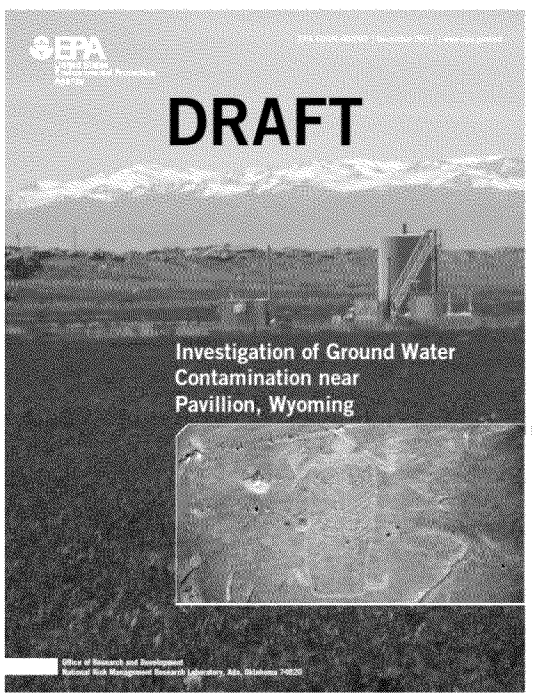
- *"The Wind River formation is considered both an aquifer and a USDW."*
- *"The Fort Union formation would also meet the definition of an aquifer and USDW as it contains fewer than 10,000 milligrams per liter (mg/l) of Total Dissolved Solids (TDS) and can provide sufficient quantity of groundwater to supply a public system."*

Pavillion Gas Well Integrity Evaluation

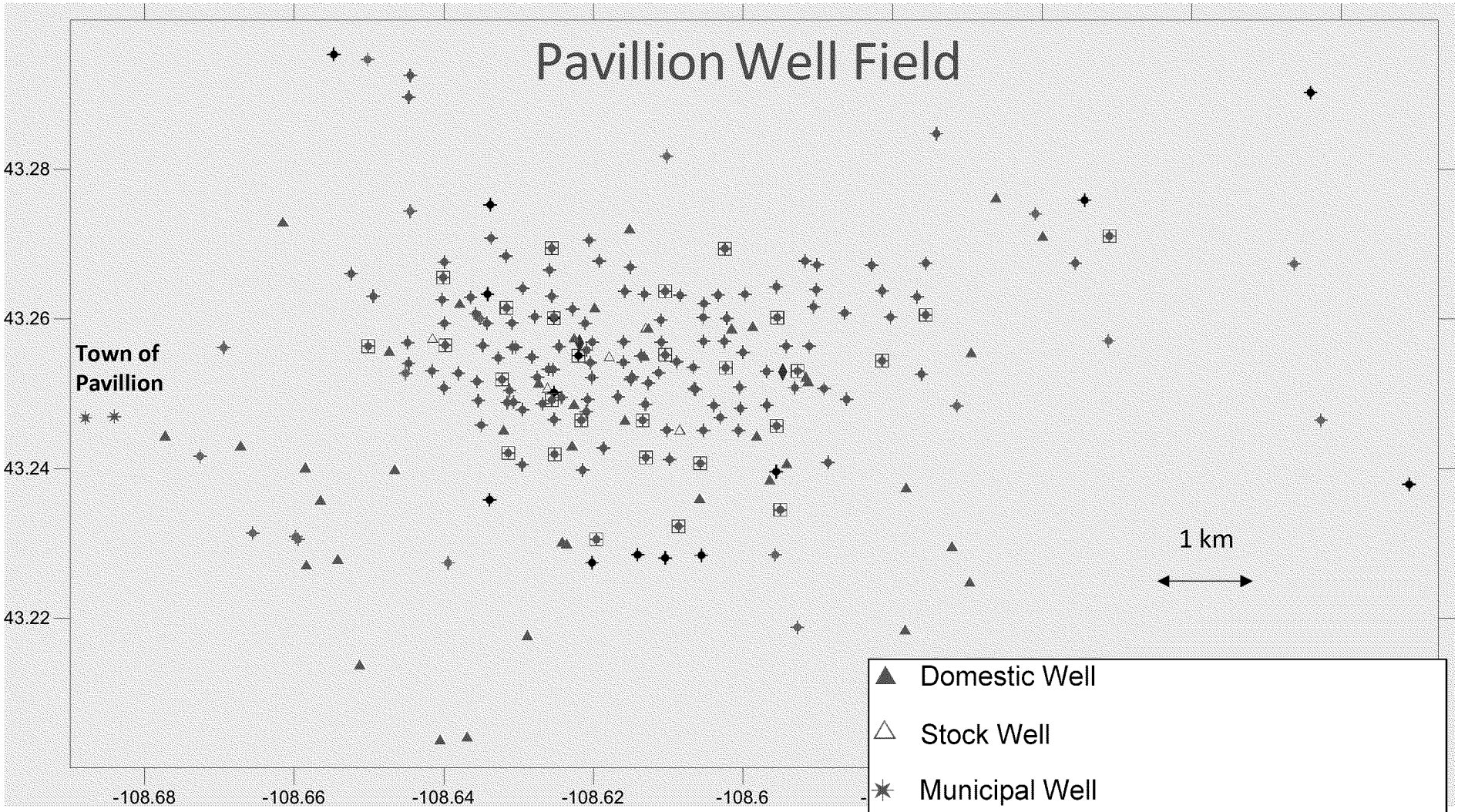
U.S. Environmental Protection Agency Region 8

July 25, 2013

*"The Wind River Formation meets the definition of an Underground Source of Drinking Water (USDW) under the United Code of Federal Regulations, Title 40, Section 144.3."*



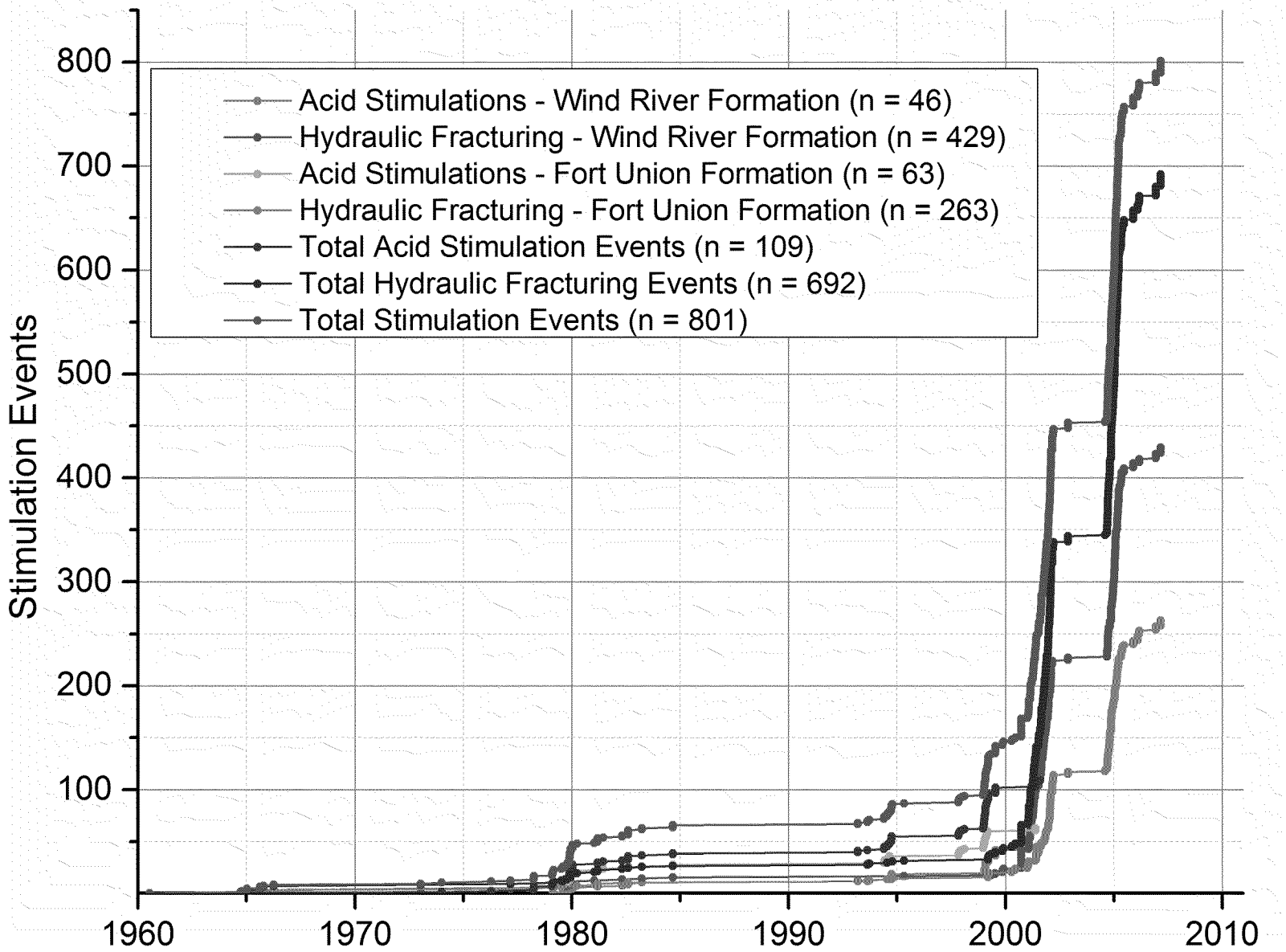

**DiGiulio et al. 2011**




**Source: WOGCC (2014)**

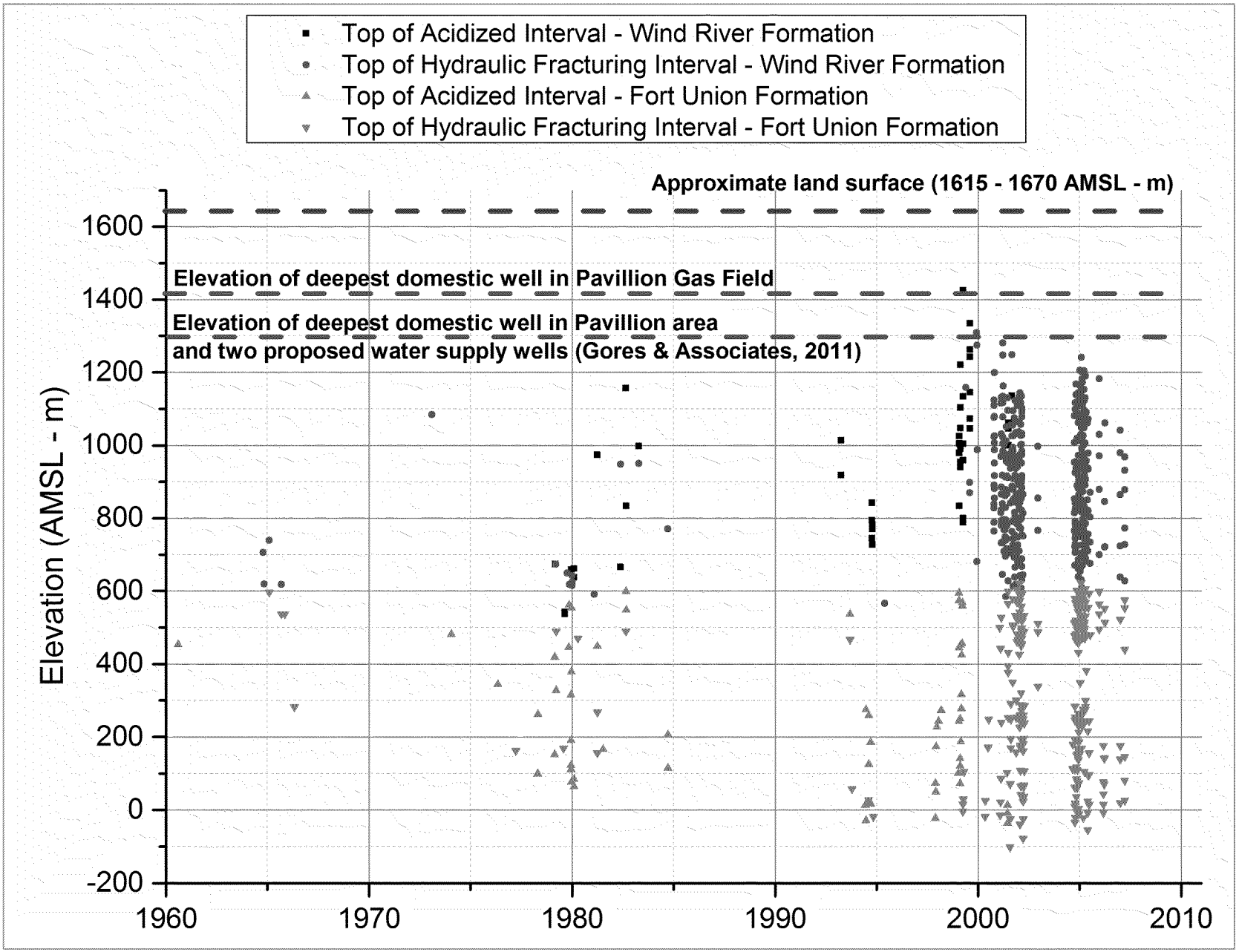
**139 stimulated production wells, 15 stimulated P&A wells, 18 non-stimulated P&A wells, 28 pit locations**

# Documented StimulationEvents as a Function of Time




**Source: WOGCC (2014)**

# Stimulation Elevations



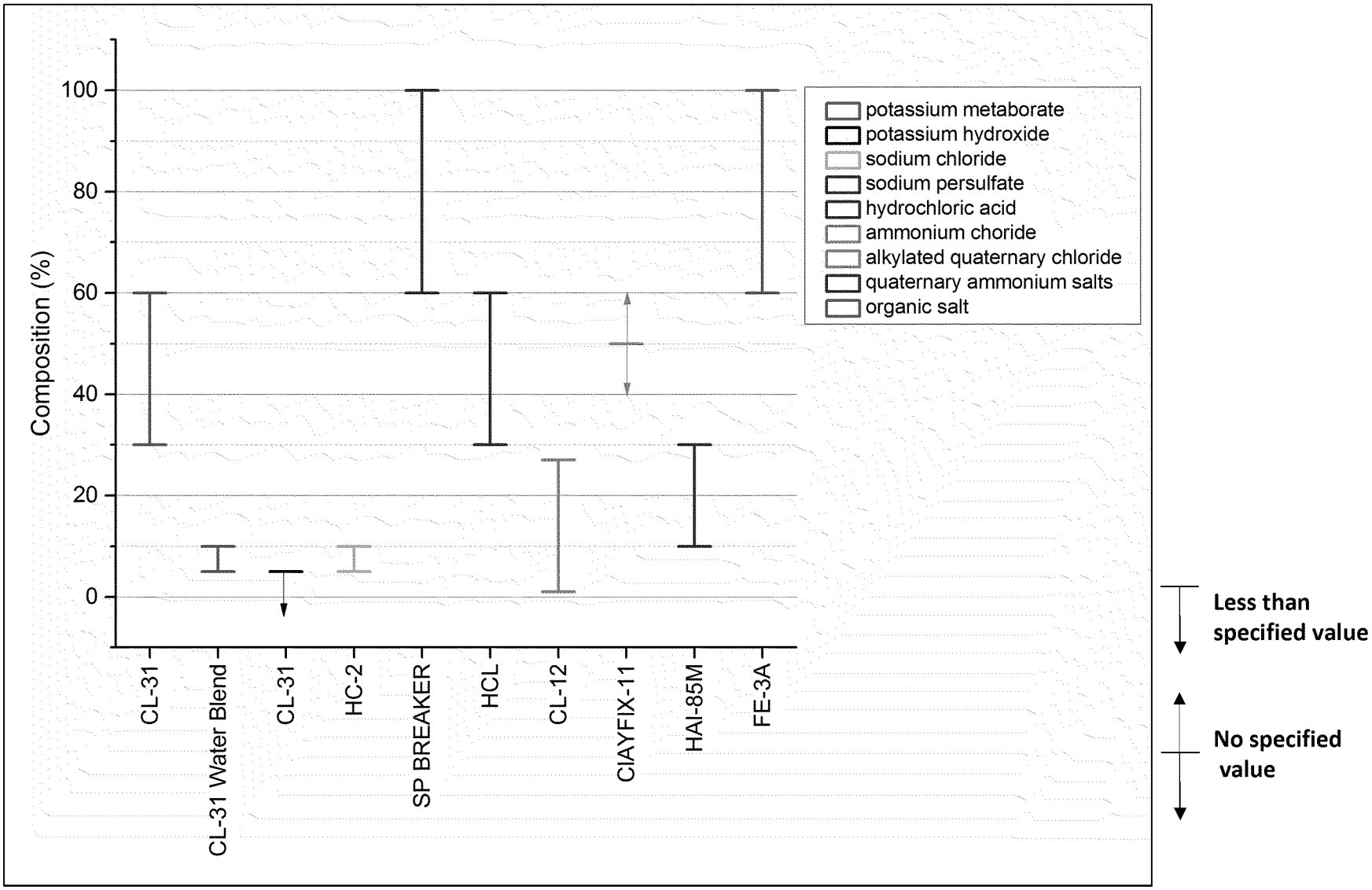

Source: WOGCC (2014)

# Common Descriptions of Fluids in Well Completion Reports

- diesel fuel (undiluted)
- 6% KCl solution
- $CO_2$ foam (some $N_2$) with additives
- slickwater
- 15% HCl with Musol solvent and other “additives”
- 10% methanol solution with “additives”
- “gel”
- “linear gel”
- “x-link gel”
- “salt water”
- “clear frac”
- “fluid”
- “clean fluid”
- Numerous undefined fluids (e.g., “YF125 PSD frac fluid”, “P-12 solvent”, “WF 130”, “WF 135”)
- [blank or nothing]

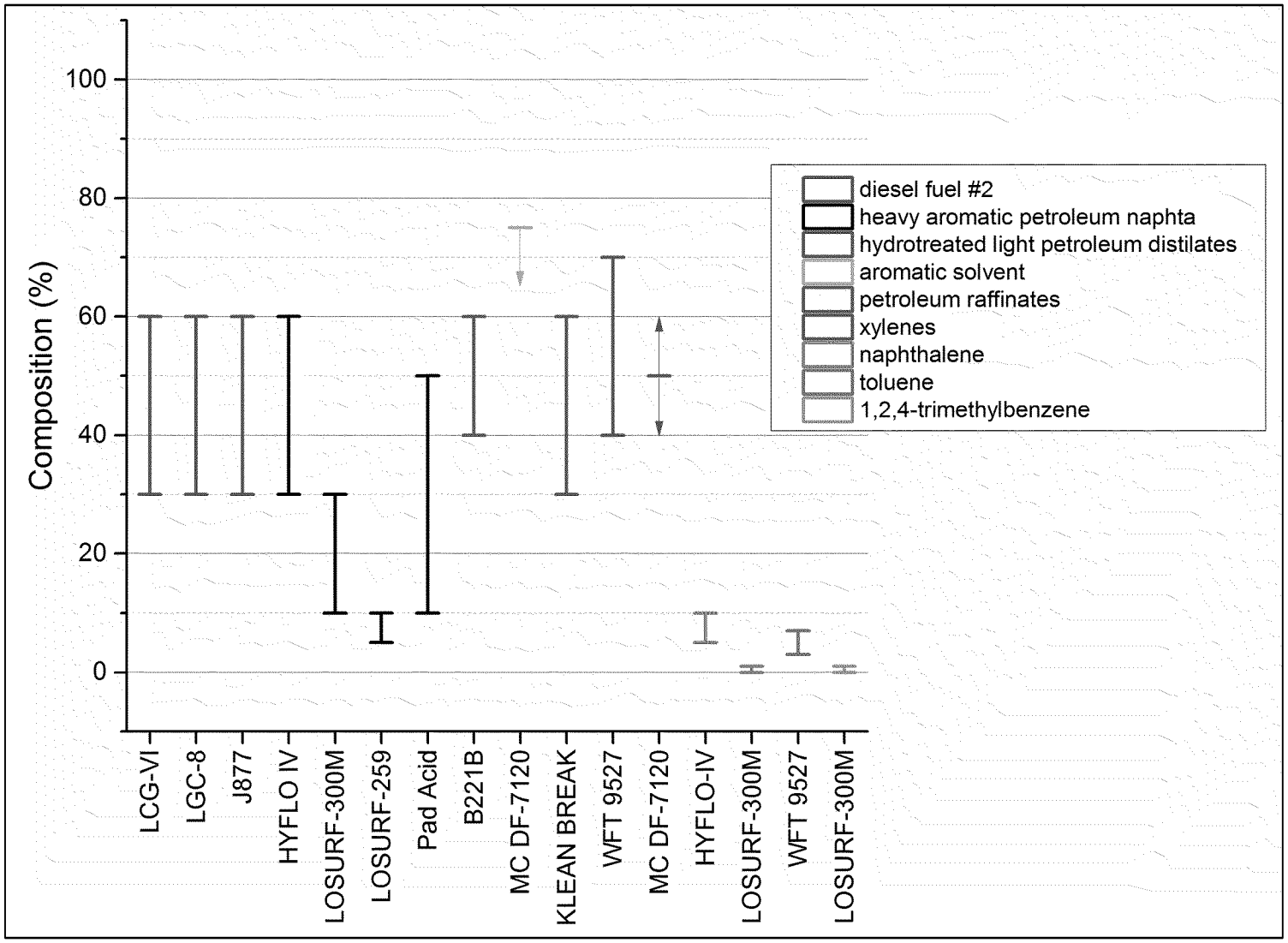
**Source: WOGCC (2014)**

# Information from Material Safety Data Sheets (MSDSs) – Major Ions




**Source: EPA (2010)**

# Information from Material Safety Data Sheets (MSDSs)– Diesel Range Organics and Aromatic Hydrocarbons

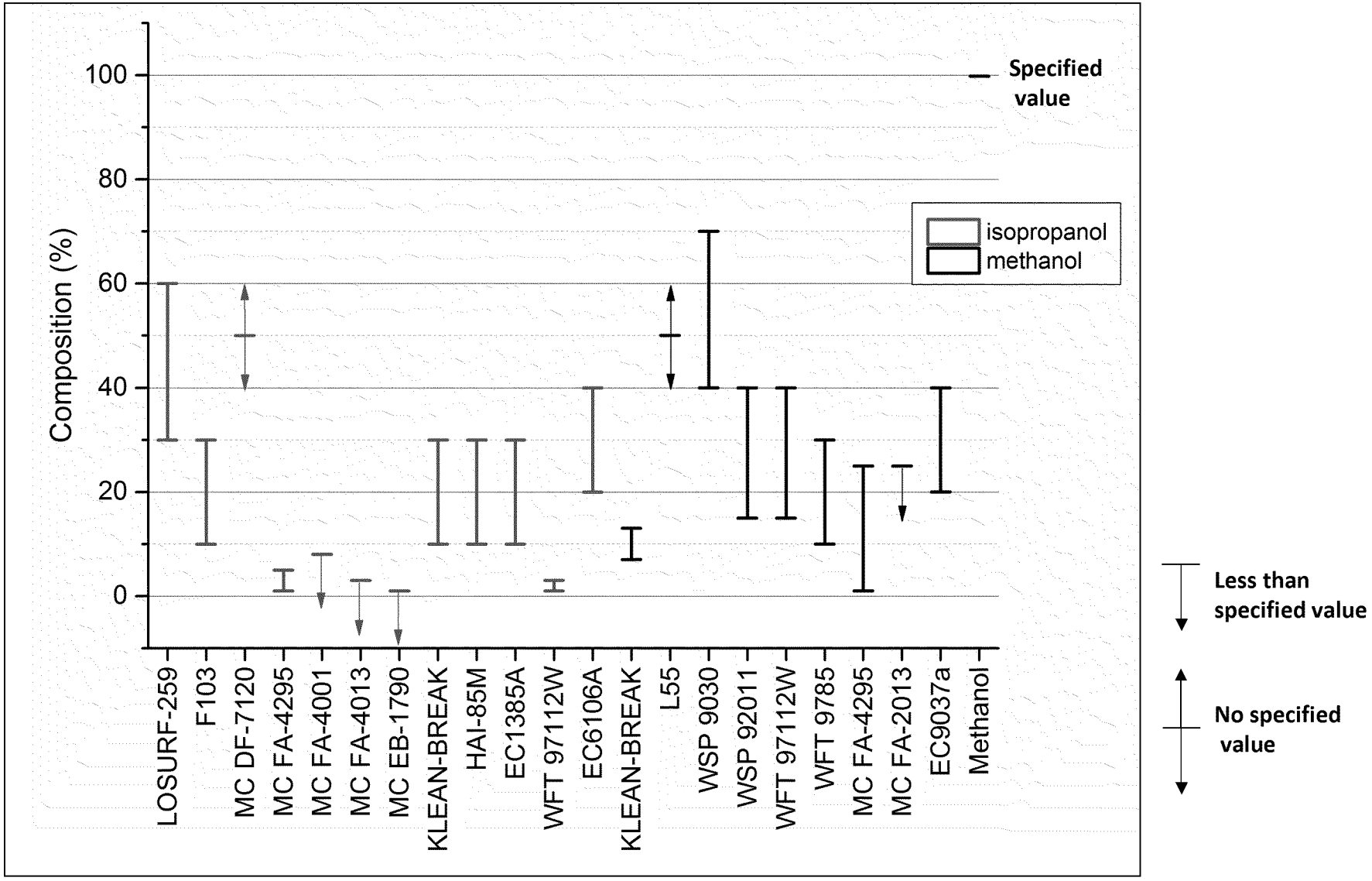



**Less than specified value**

**No specified value**

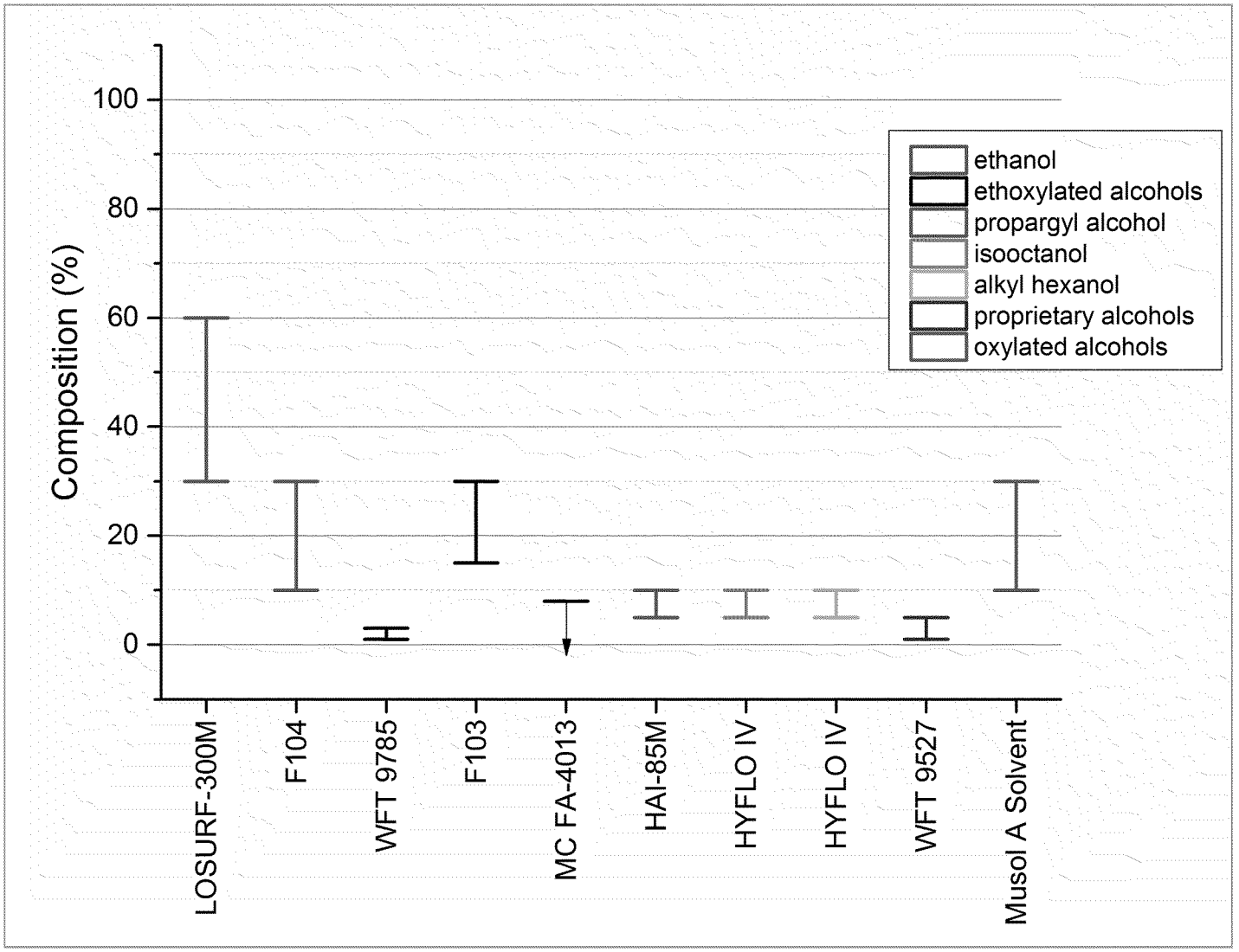
**Source: EPA (2010)**

# Information from Material Safety Data Sheets (MSDSs) – Isopropanol and Methanol




Source: EPA (2010)

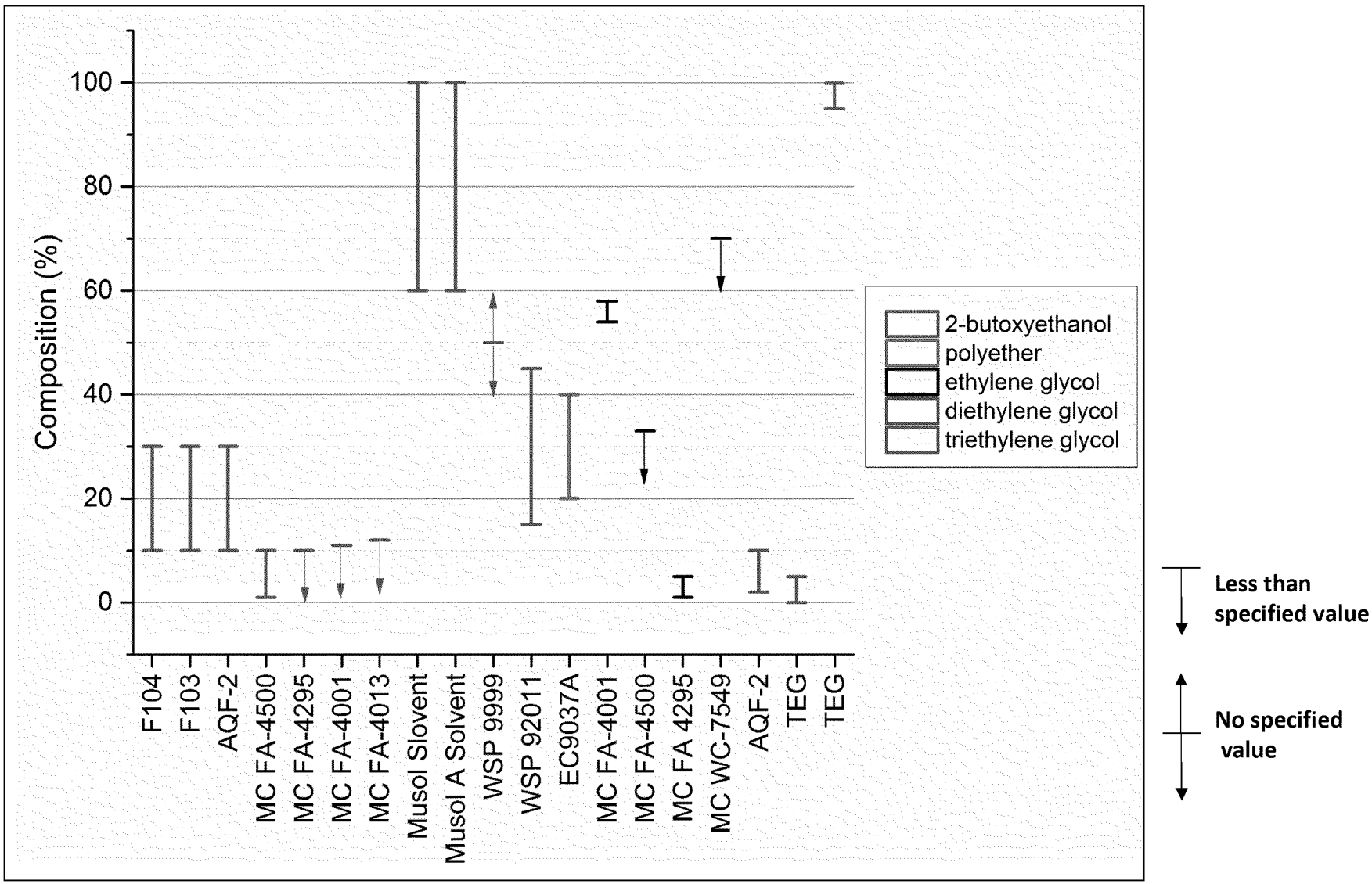
# Information from Material Safety Data Sheets (MSDSs)– Other Alcohols




Less than specified value

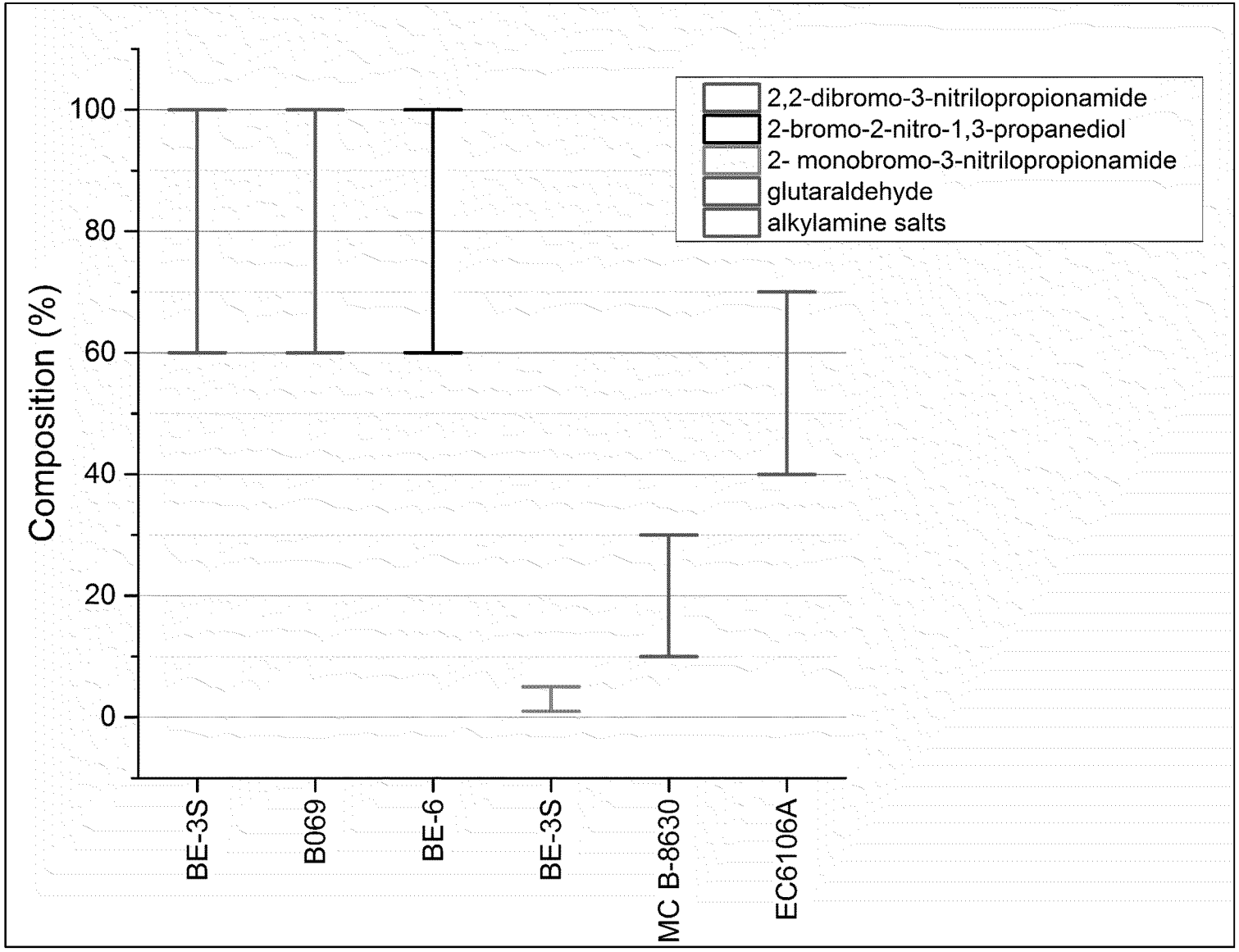
Source: EPA (2010)

# Information from Material Safety Data Sheets (MSDSs) Glycols and Glycol Ethers




**Source: EPA (2010)**

# Information from Material Safety Data Sheets (MSDSs) Biocides




**Source: EPA (2010)**

# Conclusions and ResearchQuestions

**Conclusions**

The Wind River and Fort Union Formations in the Pavillion Field meet criteria as Underground Sources of Drinking Water (USDWs).

Thousands of gallons of undiluted diesel fuel and millions of gallons of fluids containing numerous inorganic and organic additives were injected directly into these USDWs during hundreds of stimulation events.

First documented injection of stimulation fluids into USDWs in a tight gas play.

**Research Questions**

Has impact occurred in these formations?

Have stimulation fluids been injected directly into USDWs in other tight gas plays?

# References


Daddow, R.L. (1996). Water resources of the Wind River Indian Reservation, Wyoming. U.S. Geological Survey, Water-Resources Investigation Report 95-4223, 121 p. http://pubs.usgs.gov/wri/1995/4223/report.pdf

DiGiulio, D.C., R.T. Wilkin, C. Miller, and G. Oberley.(2011). Investigation of Ground Water near Pavillion, WY (Draft Report). U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Ada, OK. http://www2.epa.gov/sites/production/files/documents/EPA_ReportOnPavillion_Dec-8-2011.pdf

Freeze R.A. and J.A. Cherry (1979). Groundwater. Prentice-Hall, Inc. Englewood Cliffs, N.J. 604p.

Gores & Associates (2011). Pavillion Area Water Supply Level I Study, Final Report for the Wyoming Water Development Commission, October 2011. http://wyofile.com/wp-content/uploads/2012/02/PavillionWaterSupplyLI_exesum-2011.pdf

Johnson, R.C., Finn, T.M., Kirschbaum, M.A., Roberts, S.B., Roberts, L.N.R., Cook, T., and Taylor, D.J. (2007). The Cretaceous-Lower Tertiary Composite Total Petroleum System, Wind River Basin, Wyoming, Chapter 4 of Petroleum Systems and Geologic Assessment of Oil and Gas in the Wind River Basin Province, Wyoming. U.S. Geological Survey, Digital Data Series DDS–69–J. http://pubs.usgs.gov/dds/dds-069/dds-069-j/REPORTS/69_J_CH_4.pdf

McGreevy, L.J., W.G. Hodson, and S.J. Rucker IV. (1969) Ground-Water Resources of the Wind River Indian Reservation Wyoming, Water Supply of Indian Reservations. U.S. Geological Survey, Water-Supply Paper 1576-1.

Morris, D.A., Hackett, O.M., Vanlier, K.E., Moulder, E.A., and Durum, W.H. (1959). Ground-Water Resources of Riverton irrigation Project Area, Wyoming, U.S. Geological Survey, Water-Supply Paper 1375, 205 p. http://pubs.usgs.gov/wsp/1375/report.pdf

Plafcan, M., Eddy-Miller, C.A., Ritz, G.F., and Holland, J.P.R. (1995). Water Resources of Fremont County, Wyoming. U.S. Geological Survey, Water-Resources Investigations Report 95-4095, 133 p. http://pubs.usgs.gov/wri/1995/4095/report.pdf

Roberts, S., L.N.R. Roberts and T. Cook (2007). Geologic Assessment of Undiscovered Petroleum Resources in the Waltman Shale Total Petroleum System, Wind River Basin Province, Wyoming, Chapter 5 of Petroleum Systems and Geologic Assessment of Oil and Gas in the Wind River Basin Province, Wyoming. U.S. Geological Survey, Digital Data Series DDS–69–J. http://pubs.usgs.gov/dds/dds-069/dds-069-j/REPORTS/69_J_CH_5.pdf

U.S. Code of Federal Regulations, Title 40, Part 144.3 http://www.ecfr.gov/cgi-bin/text-idx?SID=7a6a2cc869faa49e5a8c355af200be44&node=se40.23.144_13&rgn=div8

# References Continued


U.S. Energy Information Agency (2009). Coalbed Methane Fields, Lower 48 States. http://www.eia.gov/oil_gas/rpd/coalbed_gas.jpg

U.S. Energy Information Agency (2010). Major Tight Gas Plays, Lower 48 States. http://www.eia.gov/oil_gas/rpd/tight_gas.jpg

U.S. Energy Information Agency (2012). Annual Energy Outlook 2012 with Projections to 2035. http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf

U.S. Energy Information Agency (2014). Annual Energy Outlook 2014 with Projections to 2040. http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf

U.S. Energy Policy Act of 2005. http://www.gpo.gov/fdsys/pkg/BILLS-109hr6enr/pdf/BILLS-109hr6enr.pdf

U.S. Environmental Protection Agency (2004). Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs, Office of Water Office of Ground Water and Drinking Water (4606M), EPA 816-R-04-003, June 2004. http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_coalbedmethanestudy.cfm

U.S. Environmental Protection Agency (2010). Expanded Site Inspection - Analytical Results Report, Pavillion Area Groundwater Investigation Site, August 30, 2010. http://www2.epa.gov/sites/production/files/documents/PavillionResultsReportAppendices.pdf

U.S. Environmental Protection Agency (2013). Pavillion Gas Well Integrity Evaluation, Region 8, July 25, 2013. ftp://ftp.epa.gov/r8/pavilliondocs/OtherDocuments/WellAndFieldPitsEvaluationJuly2013/GasWellIntegrityEvaluation25July2013Final.pdf

Whitcomb, H.A. and M.E. Lowry (1968). Ground Water Resources and Geology of the Wind River Basin Area, Central Wyoming. U.S. Geological Survey, HA-270, 13 p.

Wyoming Oil and Gas Conservation Commission (WOGCC) (2014). Well completion reports and sundry notices downloaded from http://wogcc.state.wy.us/

Wyoming Water Development Office, Wyoming State Water Plan, Wind/Bighorn River Basin Plan, Jan. 14, 2003. Data downloaded from http://waterplan.state.wy.us/plan/bighorn/techmemos/grnddet.html