PSE Bringing science to energy policy

GWC Getches-Wilkinson Center for Natural Resources, Energy, and the Environment

2018 Martz Summer Conference

# Reconciling Oil and Gas Development and Groundwater Protection: Lessons from Pavillion, WY

Dominic DiGiulio, Ph.D.

June 8, 2018

**Photograph overlooking Pavillion Field**

# Presentation Outline

- Very brief overview of why it is necessary to protect brackish groundwater
- Very brief overview of upstream (e.g. oil and gas field field) sources of groundwater degradation during oil and gas development
- Make the case for the need of clear robust state regulatory criteria to protect groundwater during oil and gas development
- Provide an example (Pavillion Field) why these criteria are necessary

# Groundwater resources are vital for economic development and the well being of citizens

Groundwater is the primary source of water for about ½ of the U.S. population.

43% of irrigation water comes from groundwater.


**Figure from Maupin et al. (2014)**

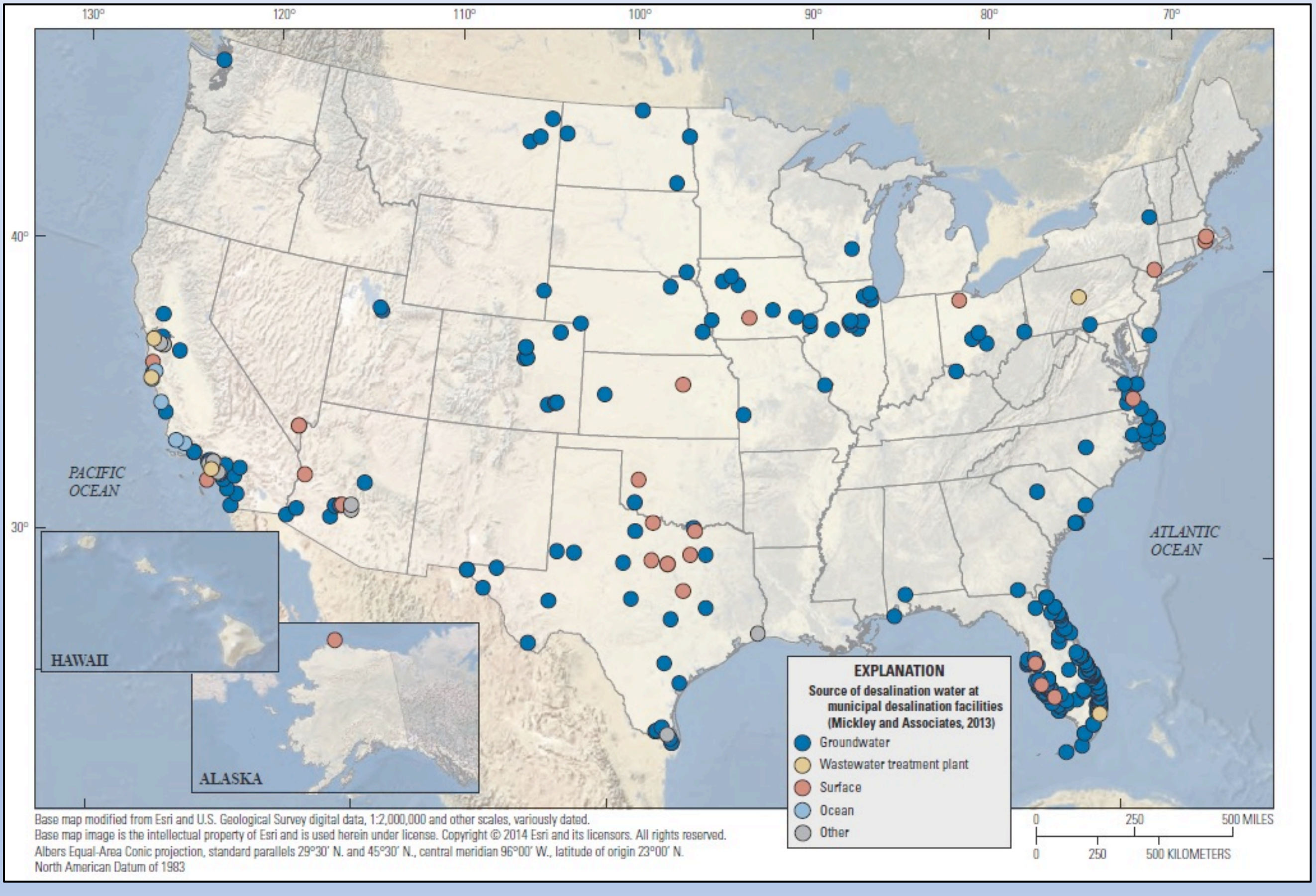
# Decreasing freshwater availability is causing an increased demand for direct and treated use of deeper brackish groundwater

The USGS (2017) defines brackish water as water having between 1,000 and 10,000 mg/L total dissolved solids (TDS).

Treated use: In 2010,there were 649 desalination plants in U.S.

67% municipal
18% industry
9% power
6% other.

Advances in membrane technology that have reduced the cost of desalination of brackish water.




From Stanton et al. (2017)

# Protecting fresh and brackish groundwater resources will only get more important in the future with climate change

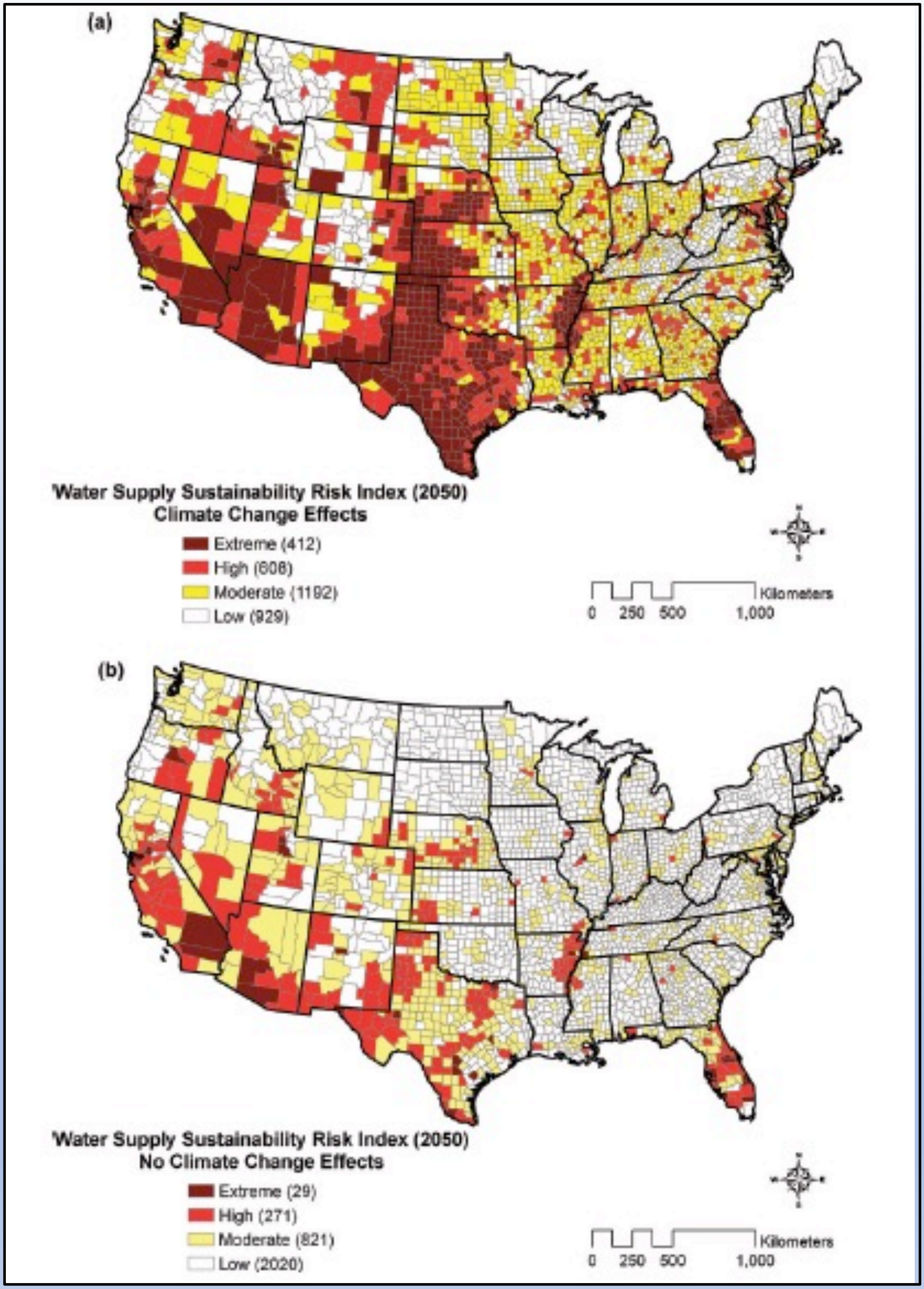



Figure from Roy et al. 2012

# There is an obvious need to protect fresh and brackish groundwater resources from all sources of degradation including those associated with oil and gas development.

**Causes and potential causes of degradation of groundwater resources include:**

- Disposal of oil and gas wastewater into fresh and brackish aquifers (1,142,Class II disposal wells with aquifer exemptions)
- Thousands of on and off pad spills of product and wastewater
- Seepage of wastewater from impoundments and pits (In 1984, there were at least 122,000 unlined pits in U.S.).
- “Beneficial” use (disposal of wastewater using aquifer recharge, irrigation, and road spreading.
- Injection of stimulation fluids vertically near formations containing fresh and brackish groundwater
- Injection of stimulation fluids into formations containing fresh and brackish groundwater.

PSE

# “Beneficial” use (e.g., disposal of wastewater using aquifer recharge, irrigation, and road spreading)

- Analytical limitations for compound identification
- Unknown physiochemical and degradation properties for many compounds
- Unknown toxicological properties for many compounds
- Need for field-based exposure assessment

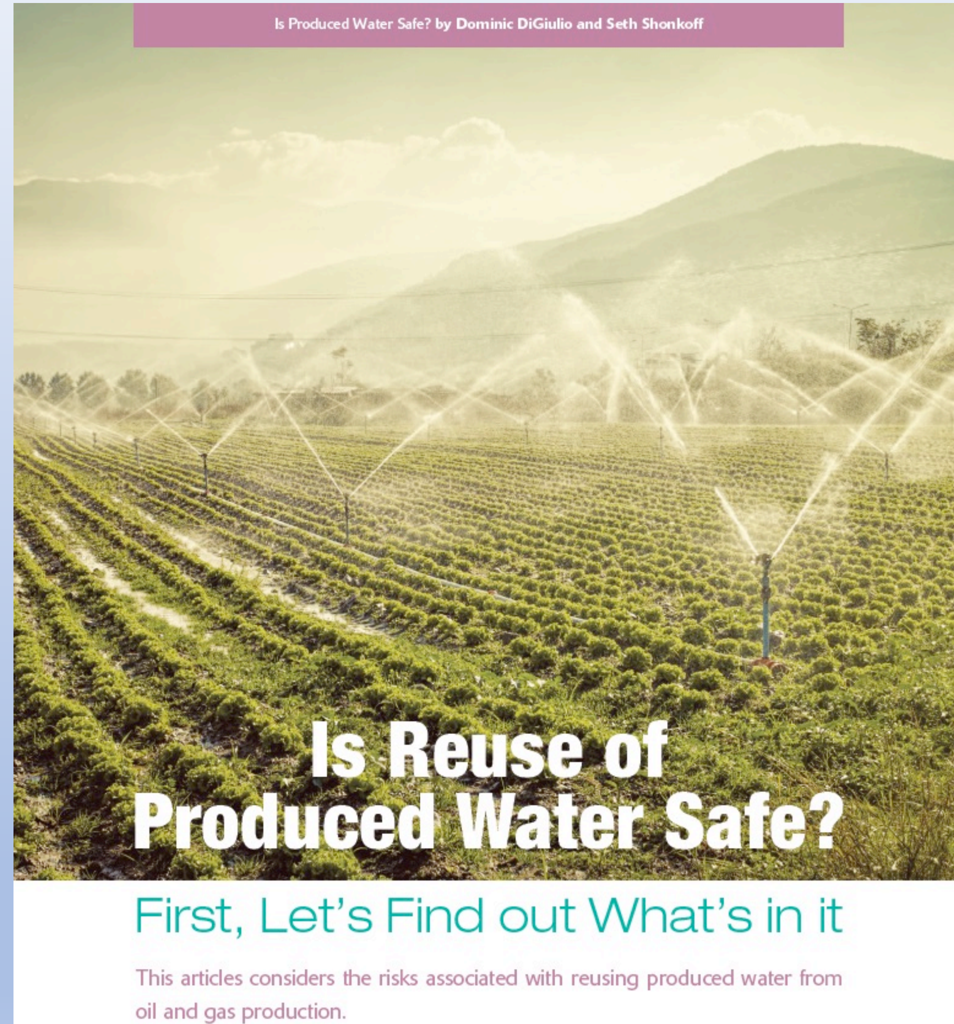



**Figure from DiGiulio and Shonkoff 2017**

PSE

# Injection of stimulation fluids vertically near formations containing fresh and brackish groundwater

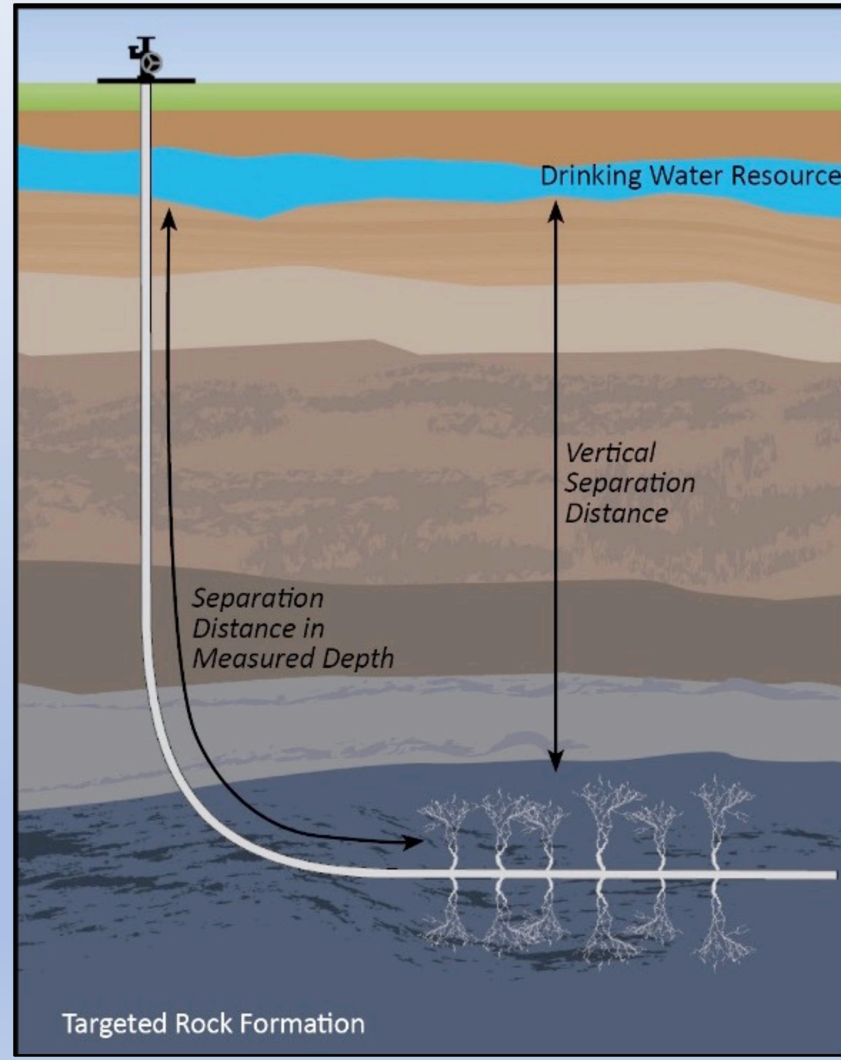
Environmental Science & Technology
Policy Analysis
pubs.acs.org/est

**The Depths of Hydraulic Fracturing and Accompanying Water Use Across the United States**

Robert B. Jackson,[*,†,‡,§] Ella R. Lowry,[†] Amy Pickle,[||] Mary Kang,[†] Dominic DiGiulio,[†] and Kaiguang Zhao[⊥]

## High volume hydraulic fracturing

- 6% fractured within 3000 ft of surface
- 3% fractured within 2000 ft of surface
- 1.3% fractured within 1000 ft of surface




PSE

**Injection of stimulation fluids into formations containing fresh and brackish groundwater (<u>focus of this talk</u>)**

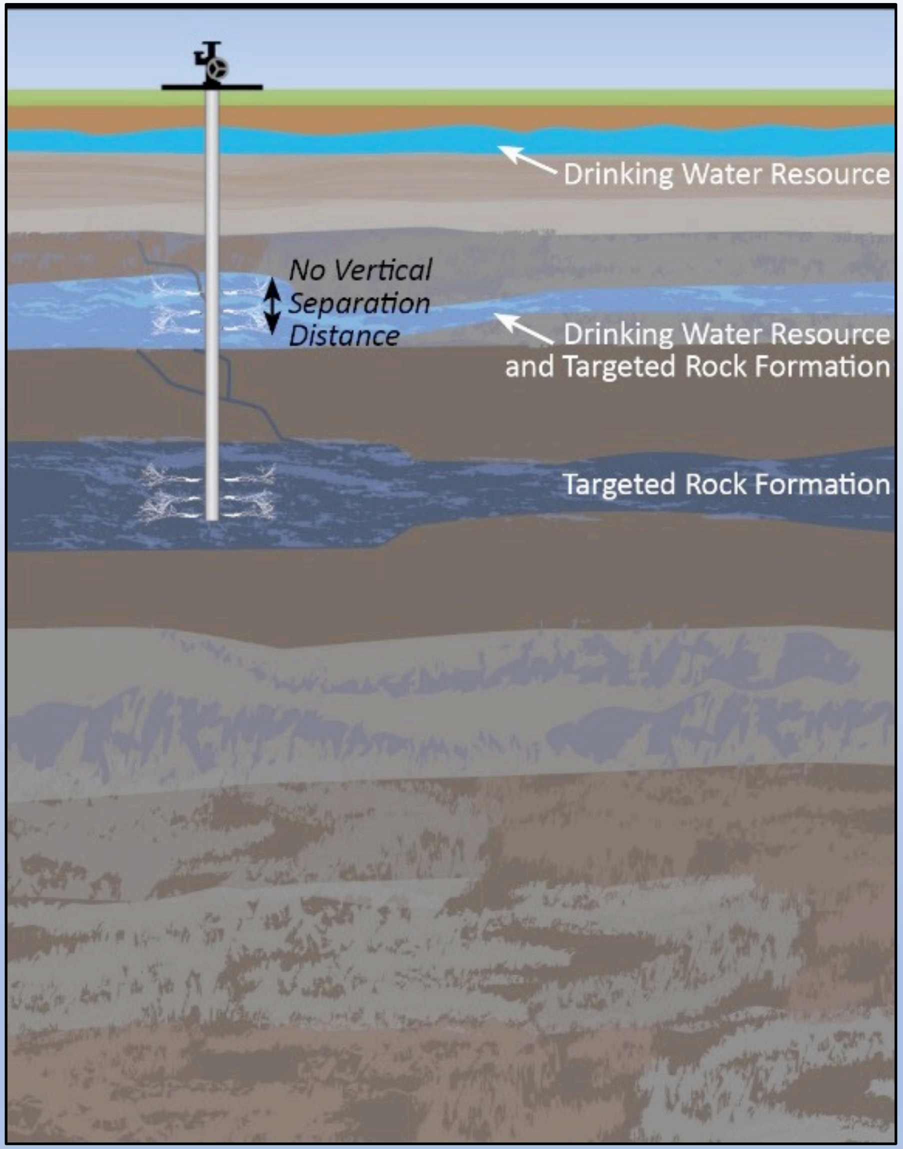



Figure from EPA 2016

# Groundwater protection starts with a clear, robust, regulatory definition of protected groundwater.

Under the Safe Drinking Water Act (SDWA), the federal definition for protected groundwater during oil and gas development is an Underground Source of Drinking Water (USDW).

An USDW is basically defined in 40 C.F.R. 144.3 as an aquifer that currently or could supply drinking water, contains less than 10,000 mg/L total dissolved solids, and is not an exempted aquifer.

**But**

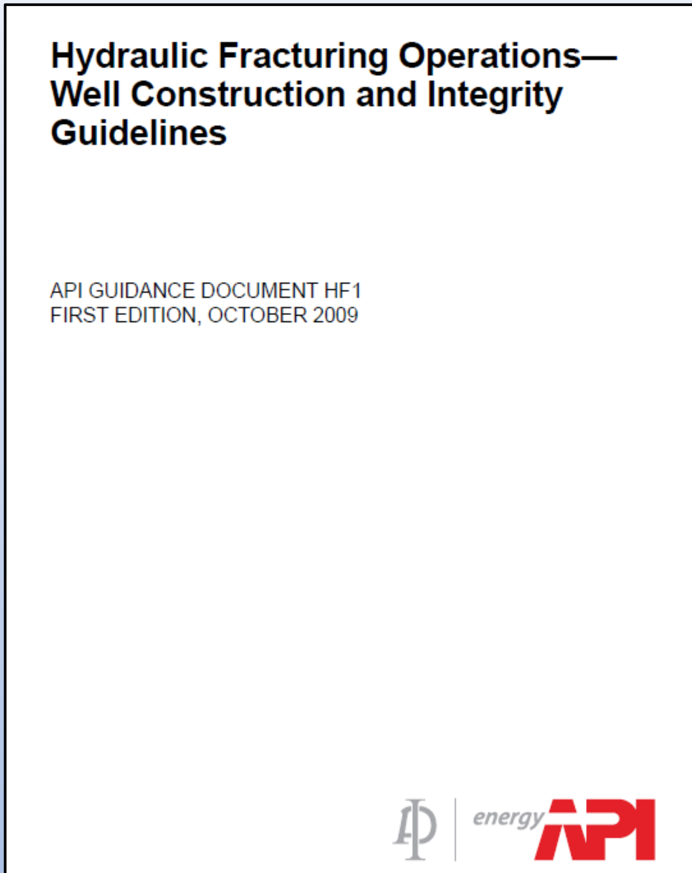
The Energy Policy Act (EPAct) of 2005 stated that "*underground injection of fluids or propping agents (other than diesel fuel) pursuant to hydraulic fracturing operations*" was not underground injection in the SDWA.

**Question**

Did the EPAct just remove Class II requirements for hydraulic fracturing or in effect legalize degradation of groundwater resources by allowing hydraulic fracturing in USDWs?

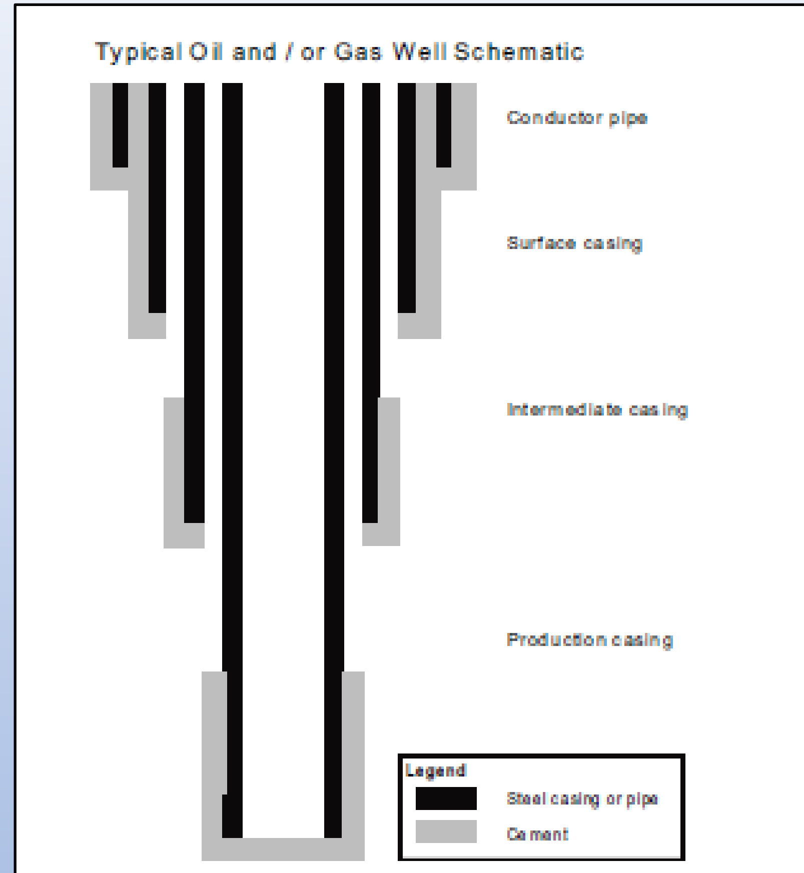
PSE

# The Definition of Protected Groundwater Used by States Should be Equivalent to an USDW



**Hydraulic Fracturing Operations—Well Construction and Integrity Guidelines**

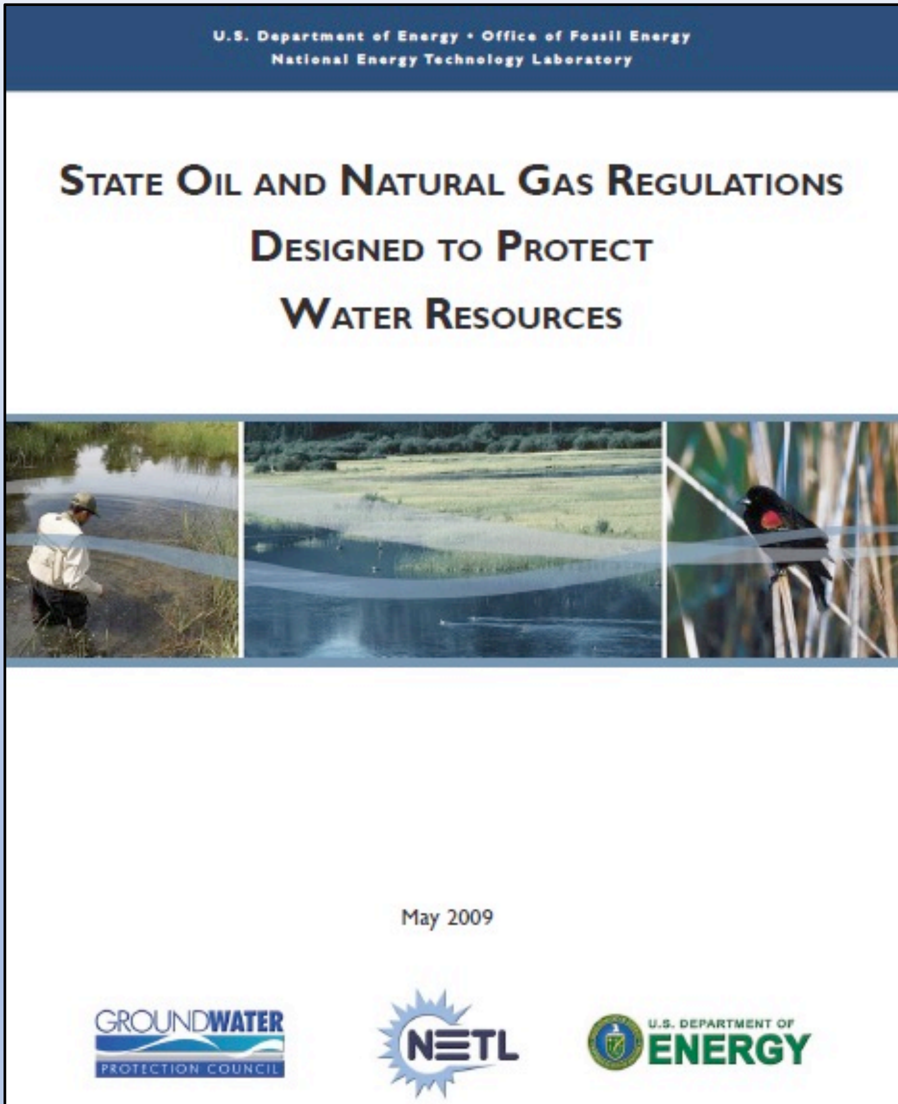
API GUIDANCE DOCUMENT HF1
FIRST EDITION, OCTOBER 2009




*"At a minimum, it is recommend that surface casing be set at least 100 ft below the deepest USDW encountered while drilling the well…If intermediate casing is not cemented to the surface, at a minimum the cement should extend above any exposed USDW or any hydrocarbon bearing zone."* (p. 11, 12) (API 2009)

PSE

# The Definition of Protected Groundwater Used by States Should be Equivalent to an USDW


U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory

STATE OIL AND NATURAL GAS REGULATIONS DESIGNED TO PROTECT WATER RESOURCES

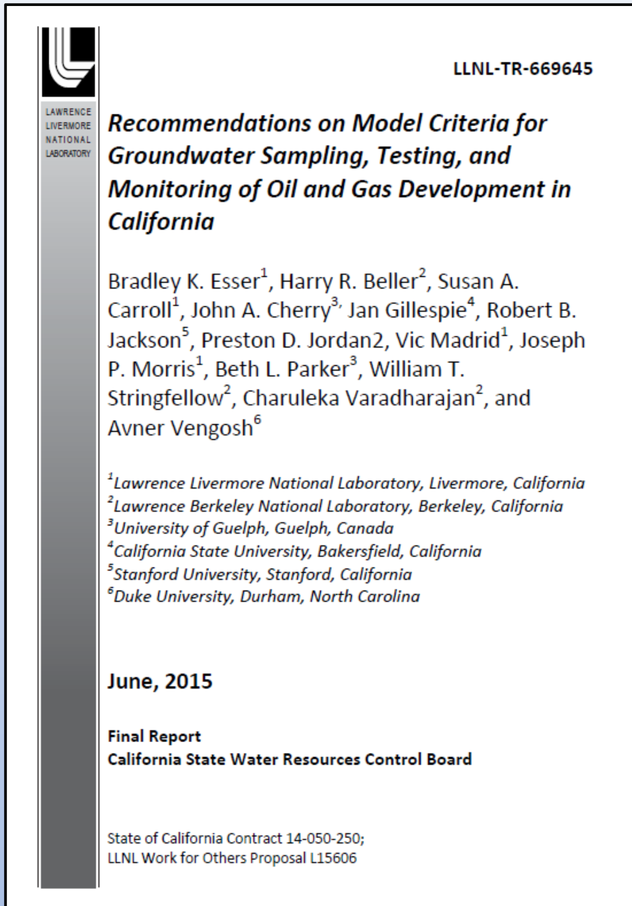
May 2009

GROUNDWATER PROTECTION COUNCIL
NETL
U.S. DEPARTMENT OF ENERGY

*"Hydraulic fracturing in oil or gas bearing zones that occur in non-exempt USDW's should either be stopped, or restricted to the use of materials that do not pose a risk of endangering ground water and do not have the potential to cause human health effects"(p 40) (GWPC 2009)*

PSE

# The Definition of Protected Groundwater Used by States Should be Equivalent to an USDW



LAWRENCE LIVERMORE NATIONAL LABORATORY

LLNL-TR-669645

***Recommendations on Model Criteria for Groundwater Sampling, Testing, and Monitoring of Oil and Gas Development in California***

Bradley K. Esser[1], Harry R. Beller[2], Susan A. Carroll[1], John A. Cherry[3], Jan Gillespie[4], Robert B. Jackson[5], Preston D. Jordan2, Vic Madrid[1], Joseph P. Morris[1], Beth L. Parker[3], William T. Stringfellow[2], Charuleka Varadharajan[2], and Avner Vengosh[6]

*[1]Lawrence Livermore National Laboratory, Livermore, California*
*[2]Lawrence Berkeley National Laboratory, Berkeley, California*
*[3]University of Guelph, Guelph, Canada*
*[4]California State University, Bakersfield, California*
*[5]Stanford University, Stanford, California*
*[6]Duke University, Durham, North Carolina*

**June, 2015**

**Final Report**
**California State Water Resources Control Board**

State of California Contract 14-050-250;
LLNL Work for Others Proposal L15606

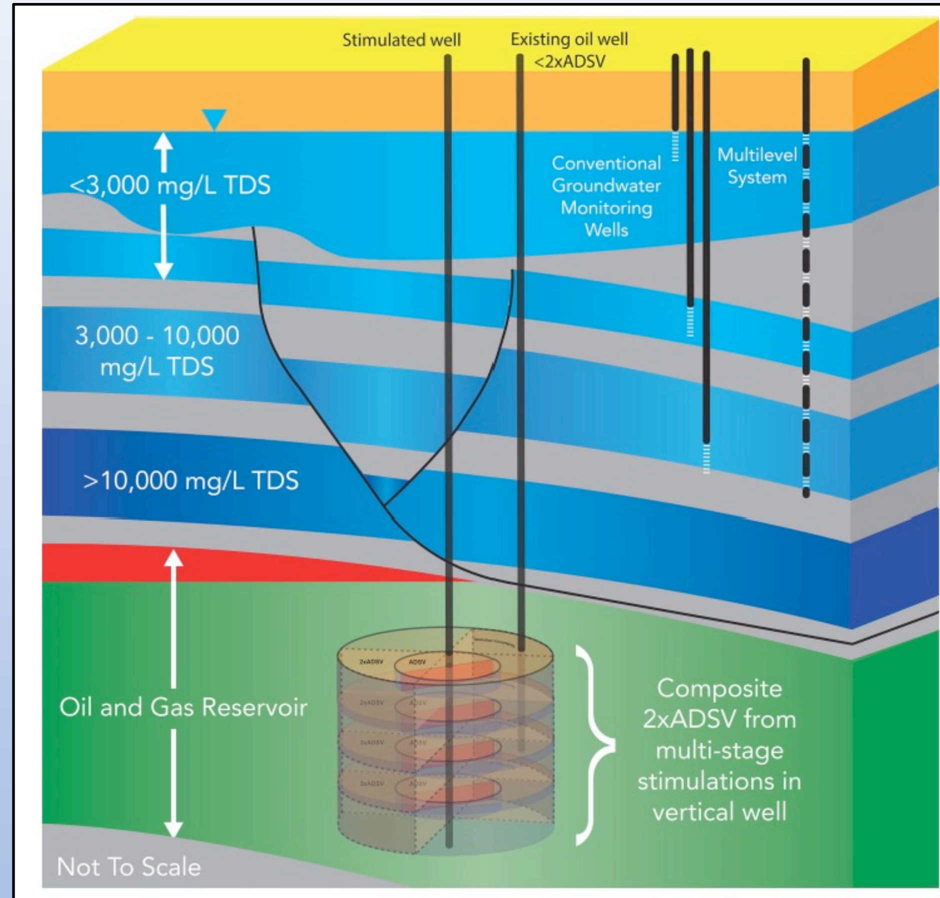



**Figure from Esser et al. (2015)**

The panel stated monitoring at 10,000 mg/L TDS is appropriate because it aligns with EPA's UIC program and is "technically and economically feasible to desalinate" water at this level of salinity.

PSE

# The Definition of Protected Groundwater Used by States Should be Equivalent to an USDW

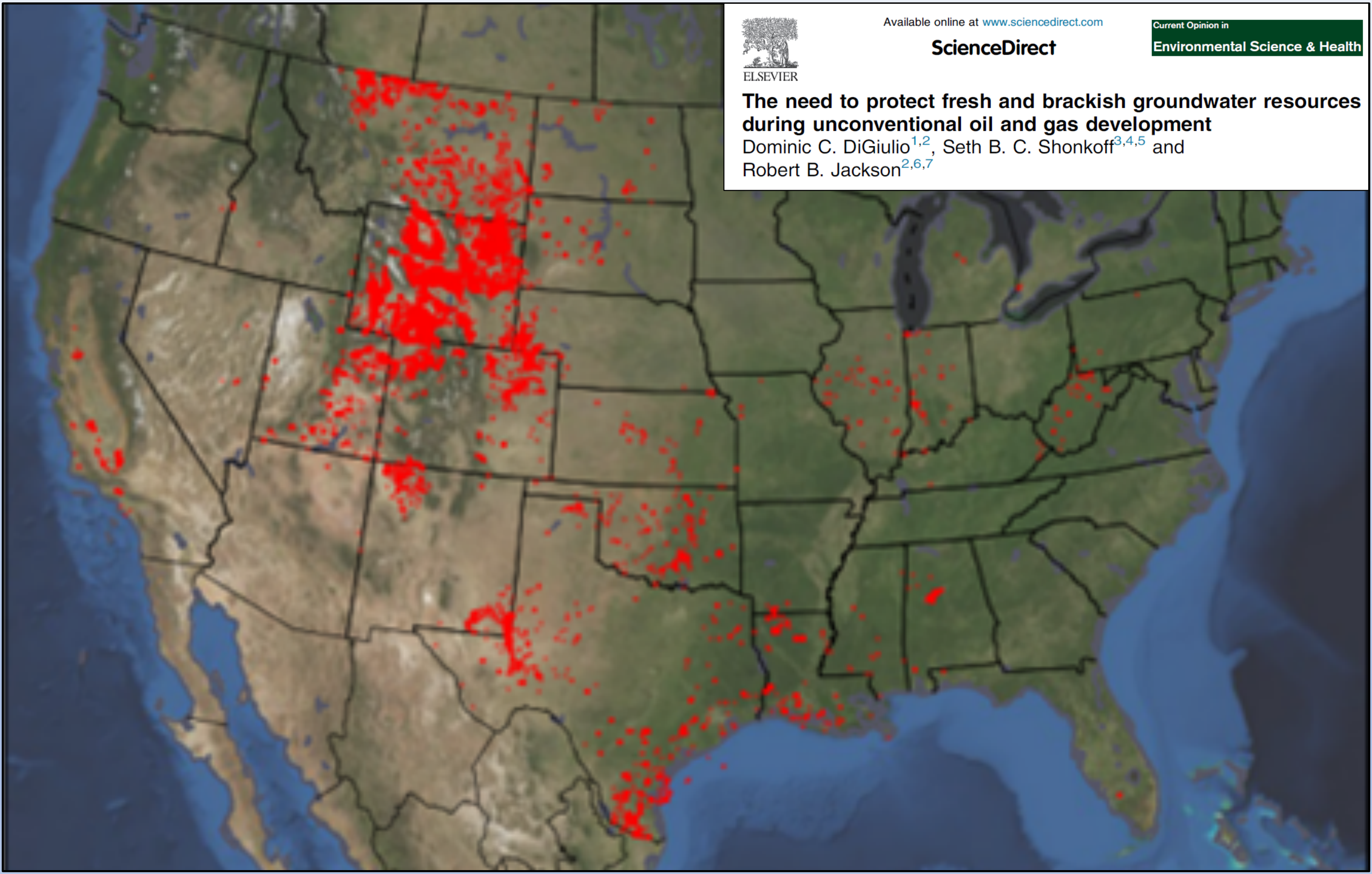
In the BLM Rule on hydraulic fracturing, for federal and tribal mineral rights, the BLM recommended protecting water at 10,000 mg/L stating that, *"Given the increasing water scarcity and technological improvements in water treatment equipment, it is not unreasonable to assume aquifers with TDS levels above 5000 ppm are usable or will be usable in the future…It is foreseeable that a TDS threshold higher than 10,000 ppm may be established under applicable law in the future for aquifers supplying agricultural, industrial, or ecosystem needs."* But…

**But**

The BLM Rule was repealed the rule on 7/25/2017 (BLM 2017) *"to reduce the burden of Federal regulations that hinder economic growth and energy development."*

PSE

# Oil and gas development in USDWs in 17 states and concentrated in the Rocky Mountain Region

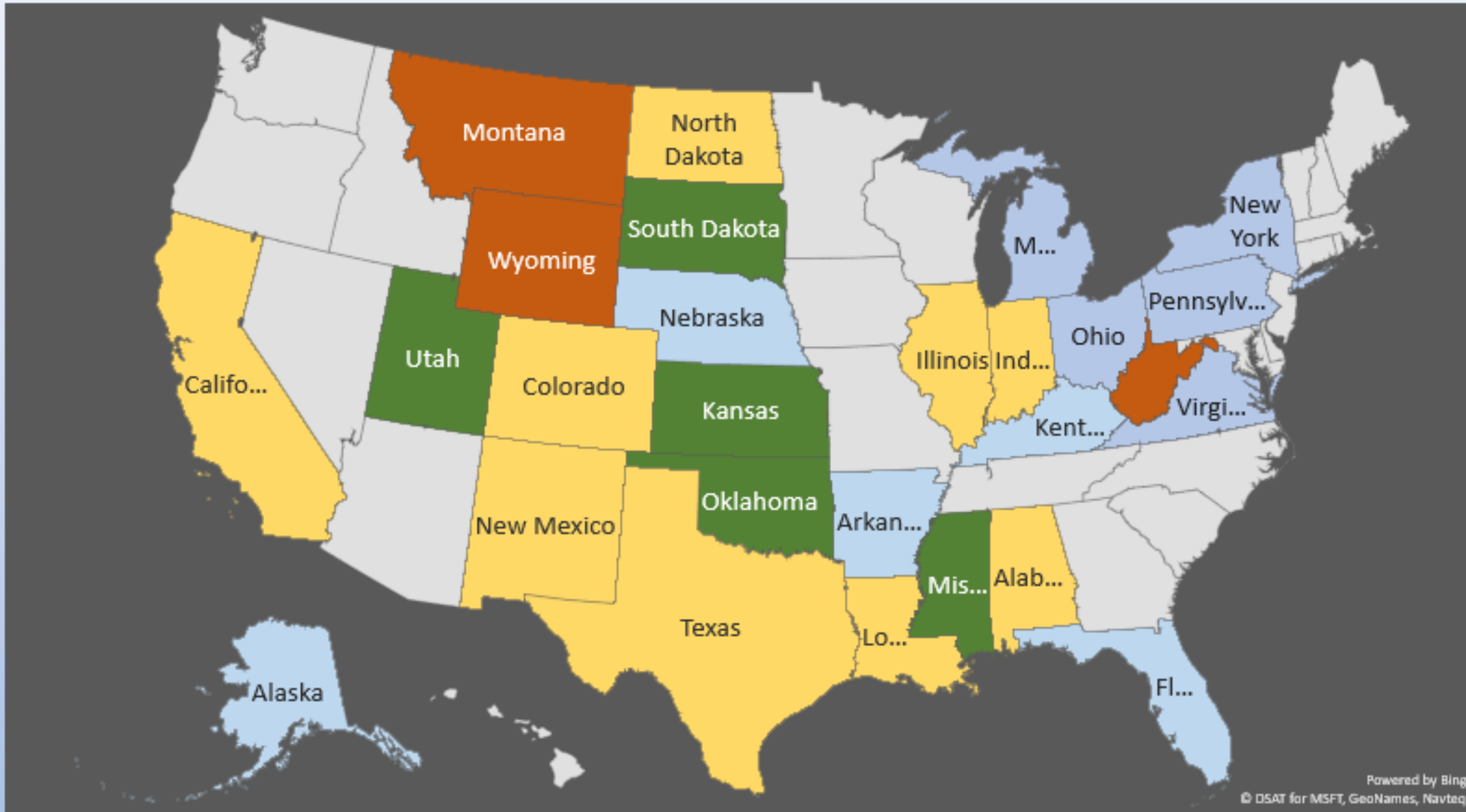



Produced water concentrations < 10,000 mg/L TDS (n = 18,762 of 165,961 ~11%). Data from the USGS National Produced Waters Geochemical Database

**Figure from DiGiulio et al. 2018**

PSE

# Definitions of protected groundwater are not equivalent to USDWs in most oil and gas producing states.




West Virginia, Montana, and Wyoming have language in regulations which explicitly removes groundwater protection during oil and gas development.

**Figure created from information in DiGiulio et al. 2018**

ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Current Opinion in
Environmental Science & Health

**The need to protect fresh and brackish groundwater resources during unconventional oil and gas development**

Dominic C. DiGiulio[1,2], Seth B. C. Shonkoff[3,4,5] and Robert B. Jackson[2,6,7]

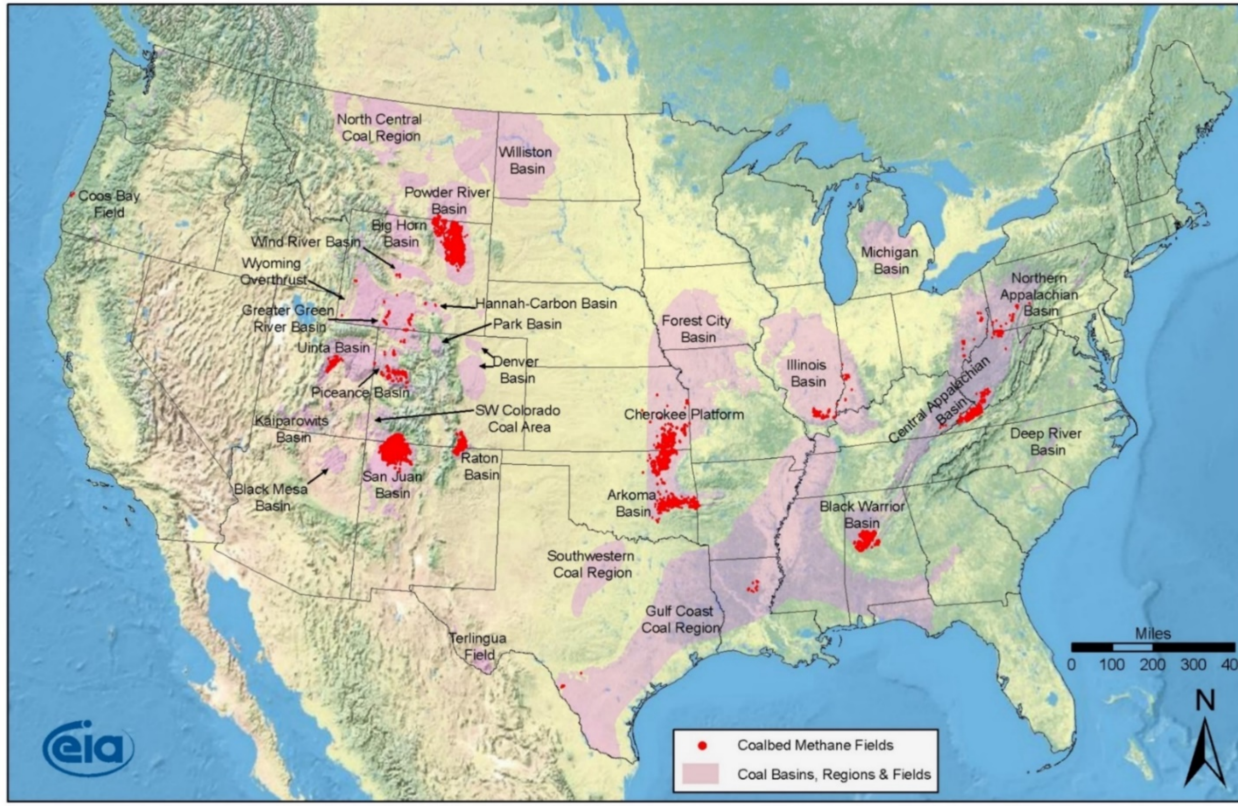
PSE

# Why do we care about this? Hydraulic fracturing is occurring in formations containing USDWs

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

| 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

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

# Hydraulic fracturing in coal seems occurs very close to fresh and brackish groundwater resources.

You can contaminate groundwater without impacting domestic water wells (non-disclosure agreements).

Hydraulic fracturing is contaminating groundwater.

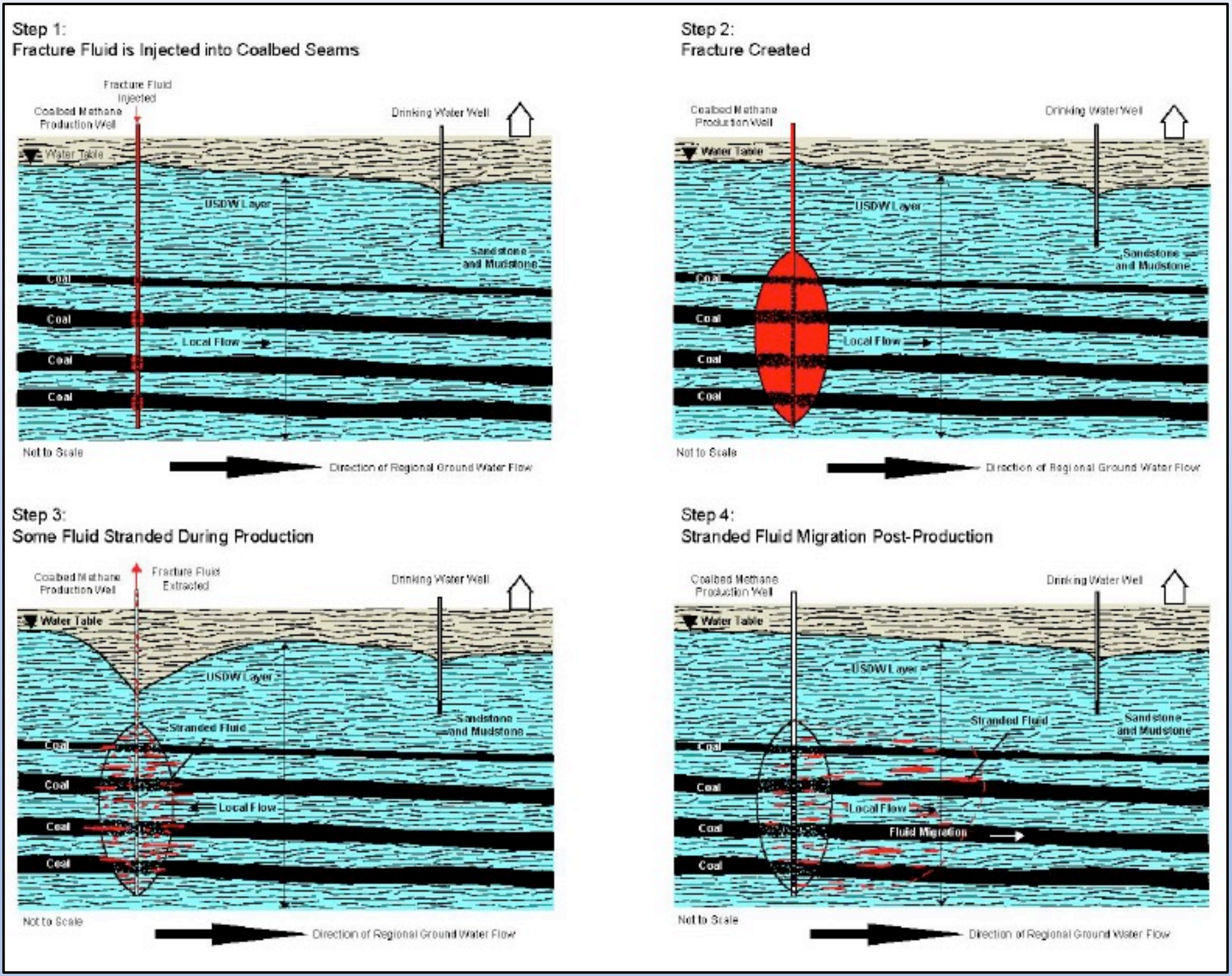



Figure from EPA (2004)

United States Environmental Protection Agency

# Permitting Guidance for Oil and Gas Hydraulic Fracturing Activities Using Diesel Fuels:

## Underground Injection Control Program Guidance #84

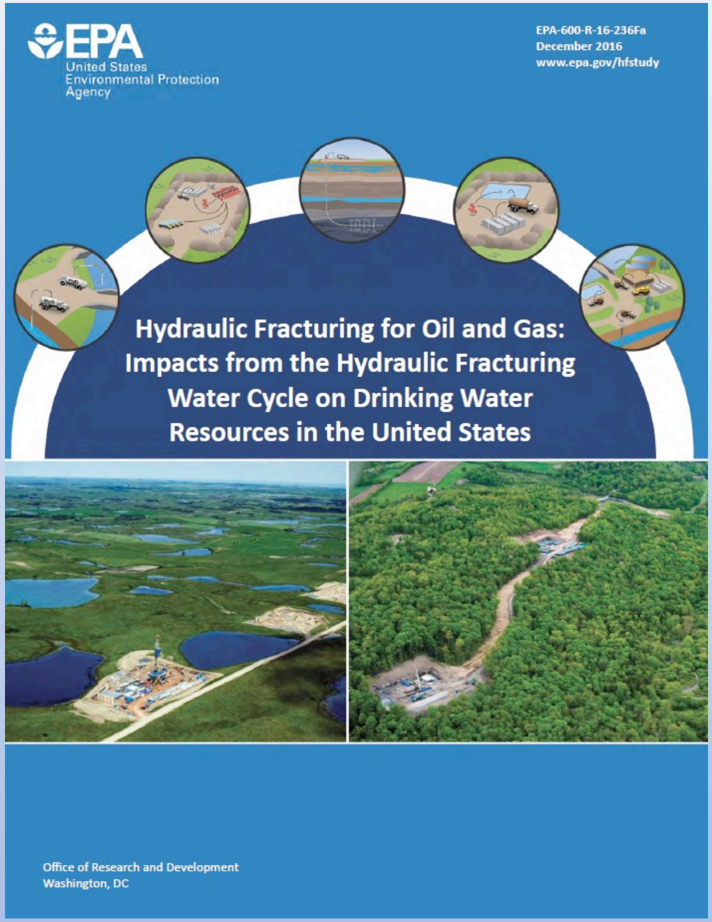
Office of Water (4605M) EPA 816-R-14-001 February 2014

"Direct injection of fluids into or above a USDW…presents an immediate risk to public health because it can directly degrade groundwater, especially if the injected fluids do not benefit from any natural attenuation" EPA (2014)

PSE

# Frequency of Hydraulic Fracturing in USDWs

- EPA looked at USGS produced water database to evaluate hydraulic fracturing into USDWs.
- EPA narrowed search to produced water samples from tight gas, tight oil, shale gas, and coalbed methane.
- This resulted in 1650 produced water samples from 5 states (AL, CO, ND, UT, WY).
- 1200 samples had TDS concentrations < 10,000 mg/L (~73%).
- **Conclusion:** *"The overall frequency of this occurrence is relatively low, but is concentrated in particular areas of the country" (p 6-50).*




**Alternative Conclusion**: Hydraulic fracturing into USDWs is concentrated in certain areas of the country. The frequency is relatively high in CBM and unknown in tight gas deposits. Hence, the overall frequency is unknown.

PSE

# Hydraulic Fracturing into Formations Containing USDWs and Impact to USDWs: Pavillion, WY Field Case Study

Photograph overlooking Pavillion Field

PSE

# Geologic Basins in the Rocky Mountain Region (Formation during Laramide orogeny - Late Cretaceous through early Eocene)

Pavillion, WY Field

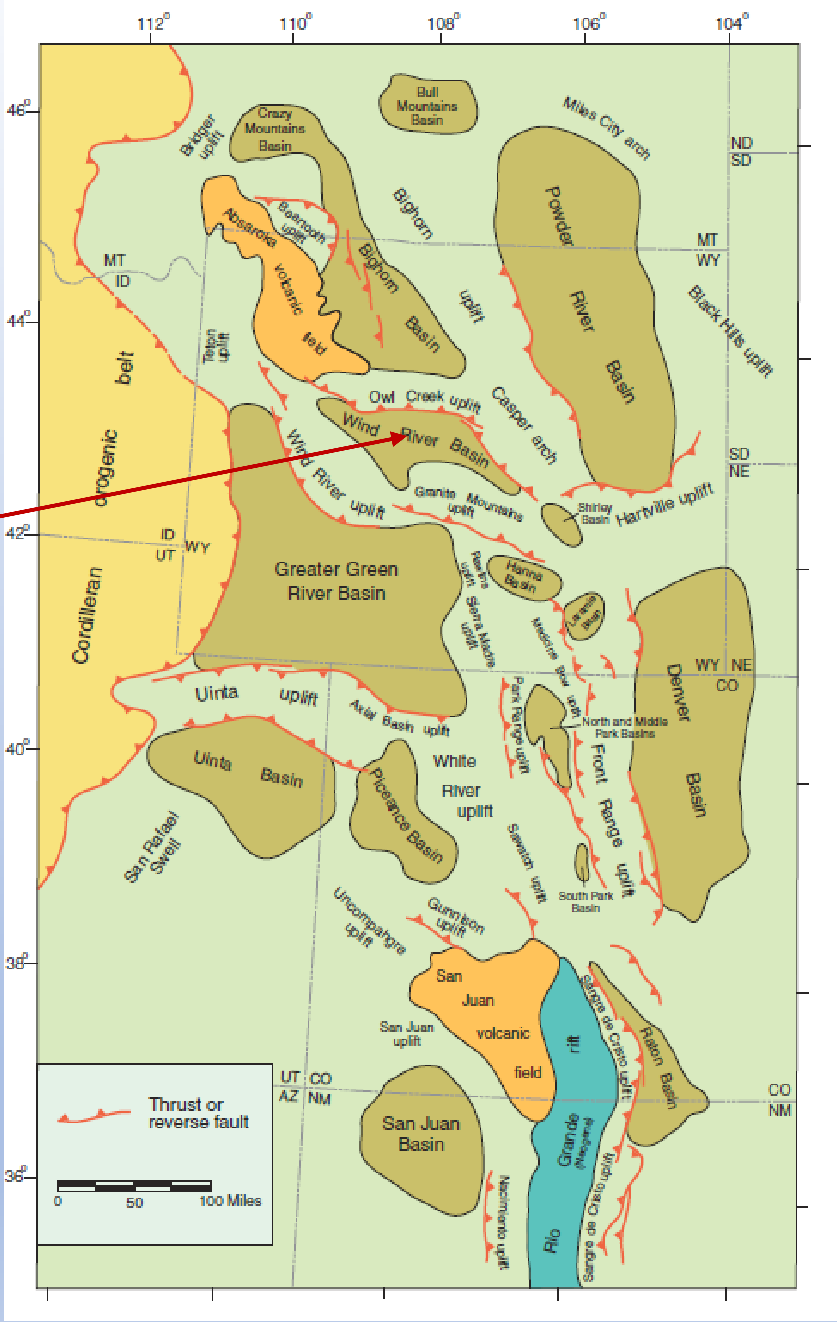
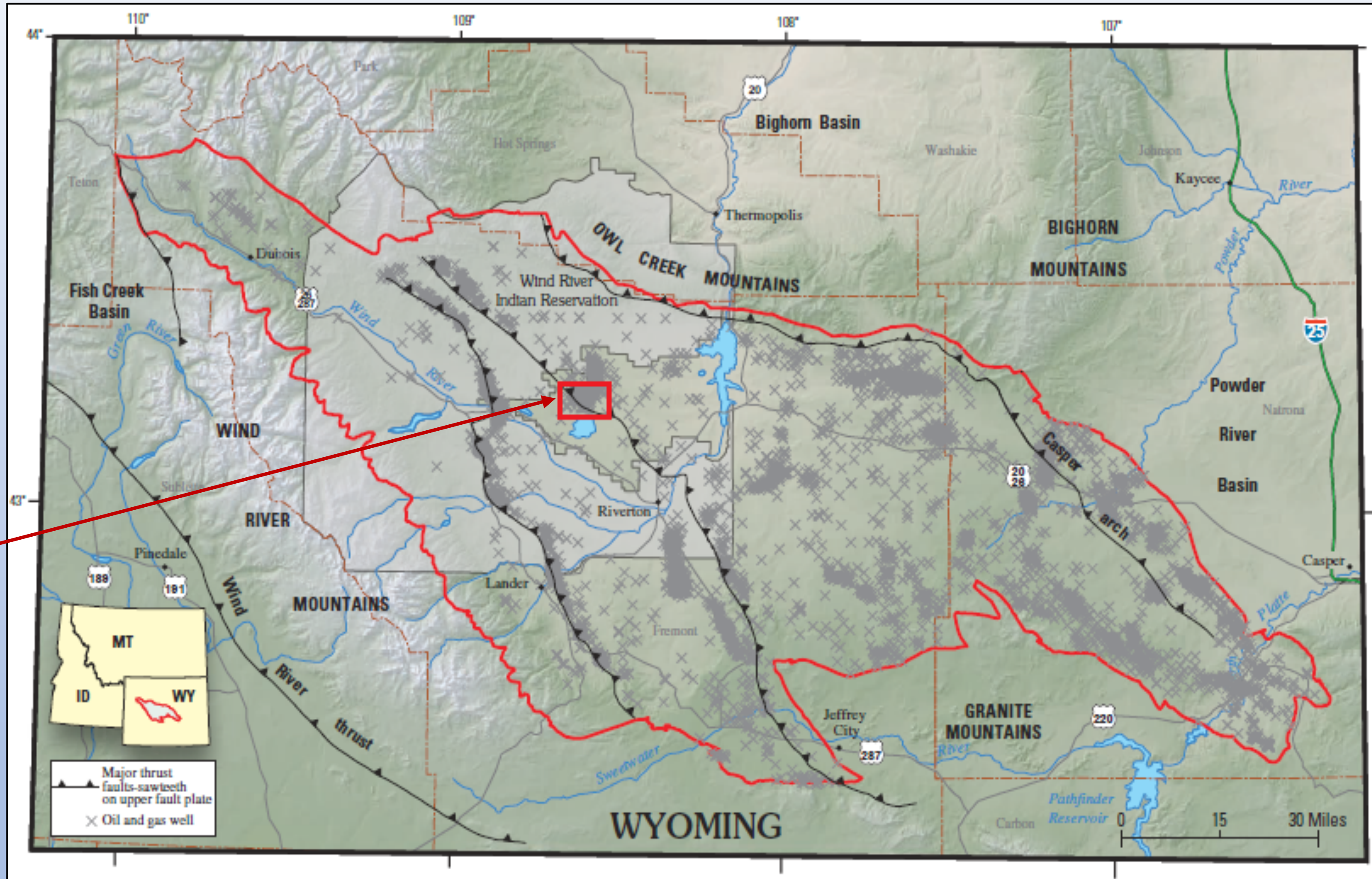



Figure modified by Finn (2005)

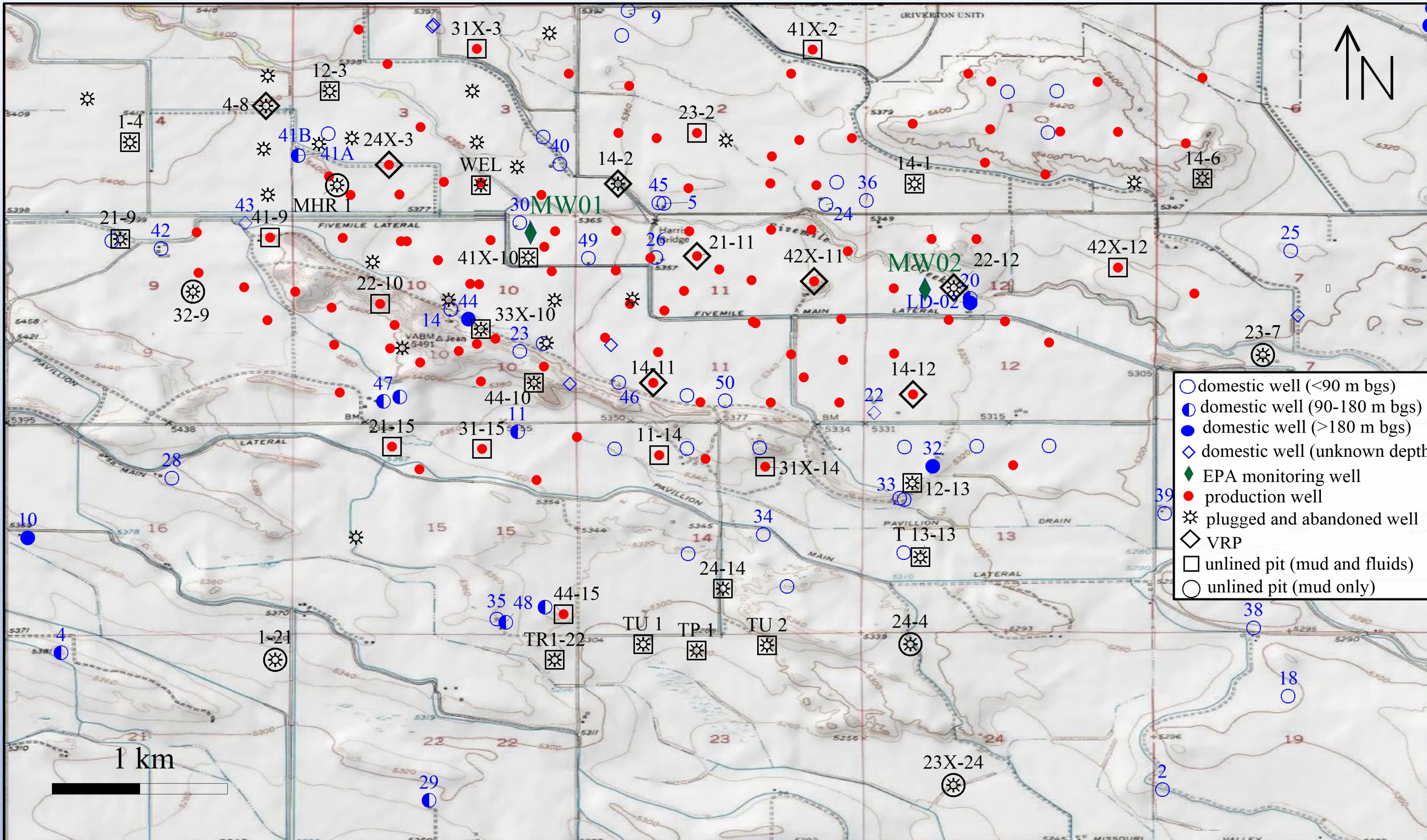
# Pavillion, WY Field

Pavillion,
WY Field




Nelson and Kibler 2007

# Center Portion of the Pavillion, WY Field




Shallow to unknown depth groundwater contamination due to disposal of diesel fuel based drilling mud and production fluids disposed in 44 unlined pits

Deeper groundwater (700 – 1000 ft) contamination from stimulation fluids.

# Geology and Hydrocarbon Production in the Pavillion Field

Conventional development and hydraulic fracturing in Lower Tertiary Wind River and Fort Union Formations

Mostly gas, some oil migration via fault and fractured media

Primary source rocks

Pavillion Field

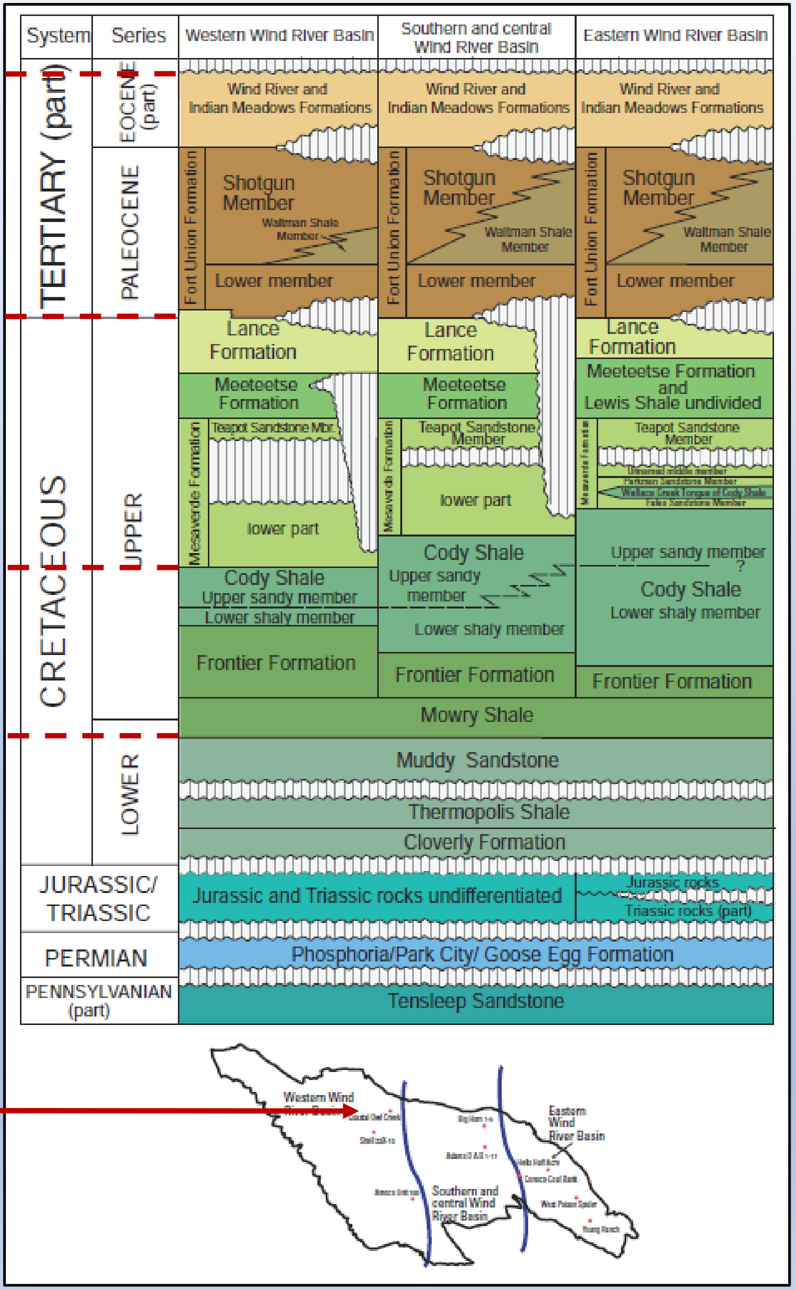



Figure modified from Roberts et al. (2007)

# Principal Aquifers in the Mid-Continent

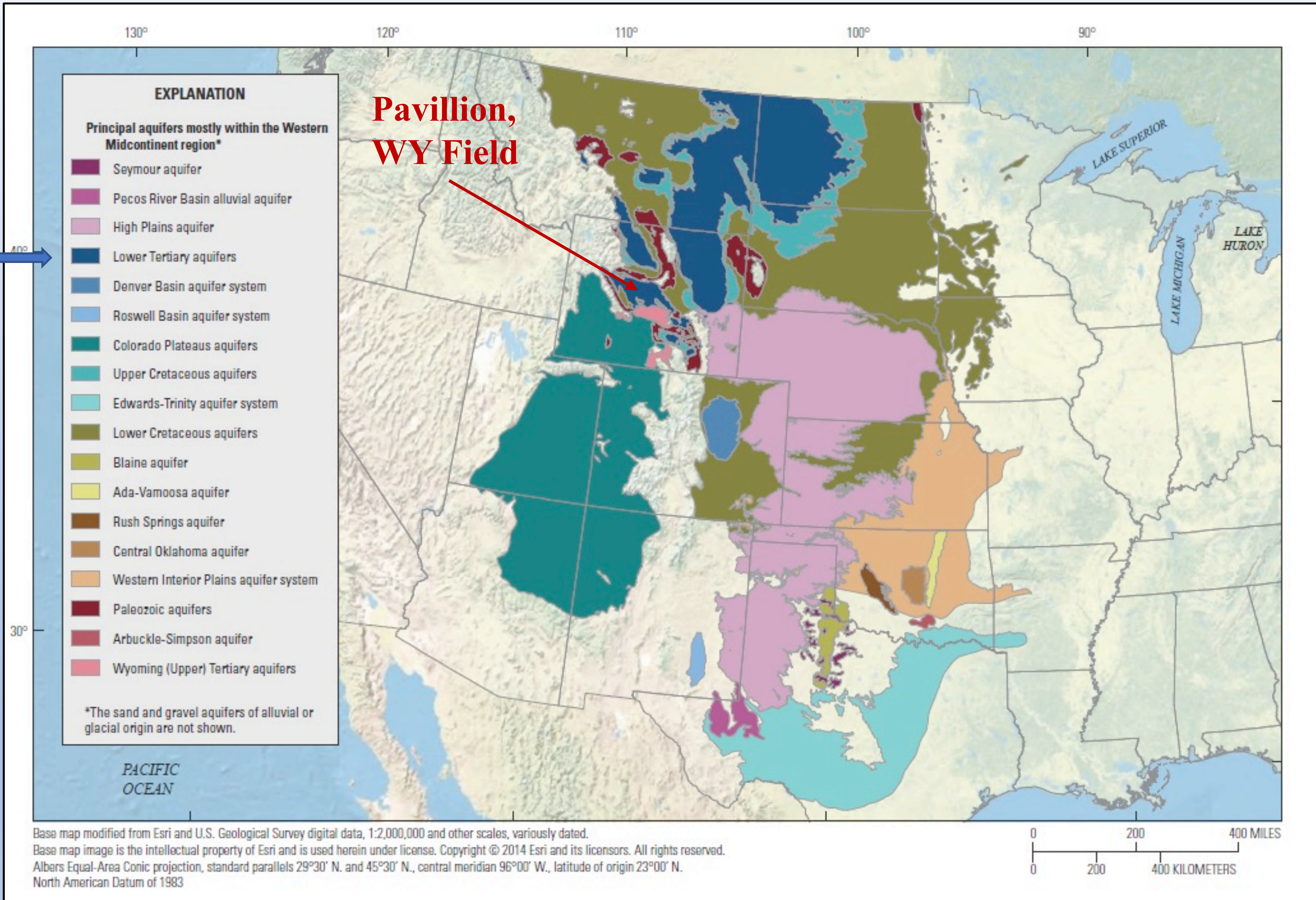
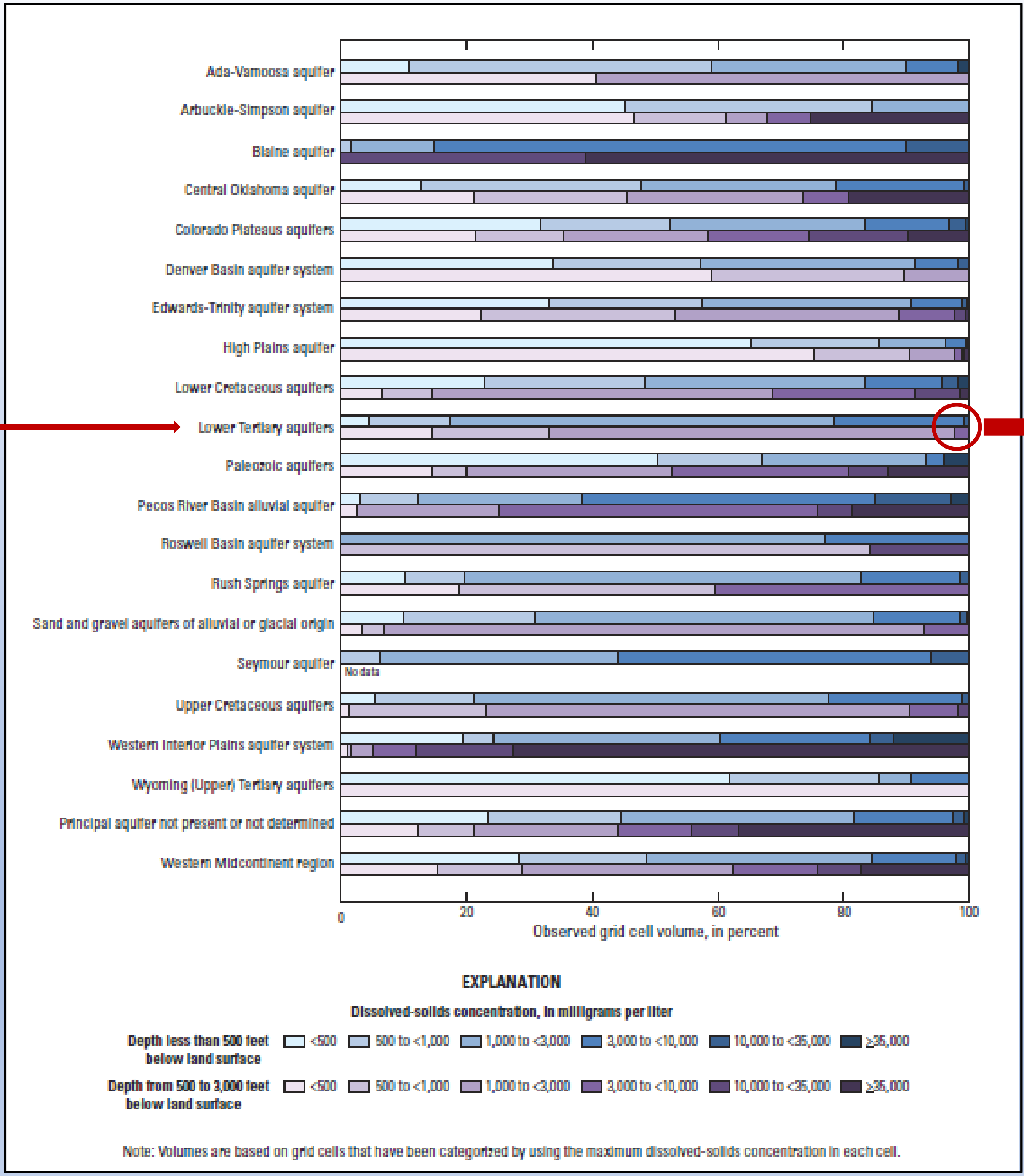



**Figure from Stanton et al. (2017)**

# Deep brackish groundwater resources exist in the Rocky Mountain Region

Lower Tertiary Aquifers




**100% of cell volume from 500 – 3000 ft have TDS < 10,000 mg/L.**

**> 95% cell volume from 500 – 3000 ft have TDS < 3,000 mg/L.**

Cell size: 10 km x 10 km

**From Stanton et al. (2017)**

PSE

# 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) |

**Table from DiGiulio and Jackson (2016)**

Major ion chemistry in domestic wells in Pavillion Field is typical of the Wind River Formation (elevated TDS and $SO_4$)

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

PSE

# Current Use of Wind River Formation, Potential Use of Fort Union Formation

## Wind River Formation

- Primary 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).
- 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)

## Fort Union Formation

- 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).
- Total dissolved solids range from about 1,000 to 5,000 ppm (McGreevy et al. 1969).

# Is Groundwater at Depths of Stimulation in the Pavillion Field USDWs or not?

## No, because of Wyoming's Groundwater Classification System

Wyoming Department of Environmental Quality Chapter 8 Quality Standards for Wyoming Groundwaters (WDEQ 2015)

- Class I – domestic use (TDS < 500 mg/L)
- Class II – agricultural use (TDS < 2,000 mg/L)
- Class III – livestock use (TDS < 5,000 mg/L)
- Class IV (A) – industry use
  - Class IV (A) (TDS < 10,000 mg/L)
  - Class IV (B) (TDS > 10,000 mg/L)
- Class V [no TDS criterion]
  - Class V (hydrocarbon commercial)
  - Class V (mineral commercial)
  - Class V (geothermal)
- Class VI – unsuitable for use
  - *"excessive"* TDS [undefined]
  - *"so contaminated that it would be economically or technologically impractical to make the water usable"*
  - *"located in such as way, including depth below the surface, so as the make use economically and technologically impractical."*

## Yes, because:

- EPA explicitly stated that USDWs exist in the Pavillion Field: DiGiulio et al. (2011), EPA (2013), EPA (2016).
- TDS levels and groundwater yield clearly meet the definition of USDWs.
- The definition of an USDW is not dependent on a state groundwater classification system
- The presence of natural gas does not invalidate the definition of an USDW (an aquifer exemption is required for this purpose).
- Class V does not have a TDS criterion meaning that Class V groundwater can also meet Class I, II, or III water criteria as was the case at Pavillion.
- For Class VI water, there is no definition of excessive TDS.
- For Class VI, groundwater would not have been contaminated without oil and gas development.
- For Class VI, groundwater is not too deep for use (in some cases, domestic use at same depths of stimulation at Pavillion)

PSE

# Production Well Stimulation Occurred at Depths of Deepest Groundwater Use in the Pavillion, WY Field

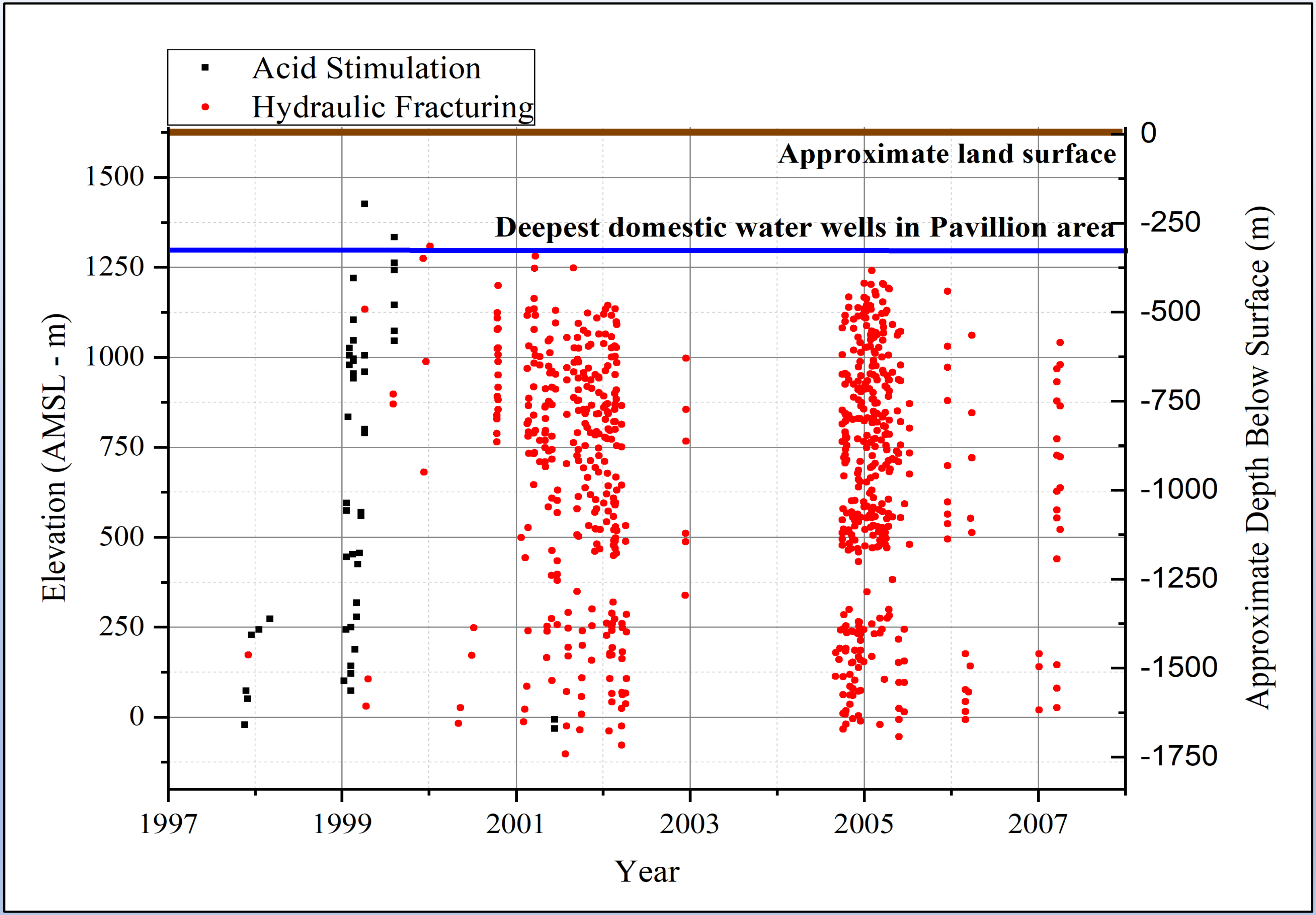



**Figure from DiGiulio and Jackson (2016)**

PSE

# Factors Indicating Impact to USDWs in the Pavillion, WY Field

Environmental Science & Technology

Article

pubs.acs.org/est

**Impact to Underground Sources of Drinking Water and Domestic Wells from Production Well Stimulation and Completion Practices in the Pavillion, Wyoming, Field**

Dominic C. DiGiulio[*,†] and Robert B. Jackson[†,‡,§]

[†]Department of Earth System Science, [‡]Woods Institute for the Environment, and [§]Precourt Institute for Energy, Stanford University, Stanford, California 94305, United States

At least 41.5 million liters (or ~11 million gallons) of stimulation fluids was injected into formations containing USDWs in the Pavillion Field. The cumulative volume of well stimulation in closely spaced vertical wells in the Pavillion Field is characteristic of high volume hydraulic fracturing in shale units.

- Injection of stimulation fluids directly into water-bearing sandstone units.
- Fracture propagation and leakoff of stimulation fluids into water-bearing sandstone units (distance to water-bearing units meters or tens of meters)
- Pressure build-up during stimulation far in excess of drawdown during production.
- Loss of zonal isolation in production wells during hydraulic fracturing.
- Detection of organic compounds associated with well stimulation in EPA monitoring wells.

More detail on impact to USDWs in supplemental slides

PSE

# Conclusions

- Conventional and unconventional oil and gas development threaten fresh and brackish groundwater resources.
- Provisions in the Safe Drinking Water Act (SDWA) protected groundwater resources during oil and gas development but were stripped in 2005 by the EPAct.
- States need to use criteria established for an Underground Source of Drinking Water (USDW) under SDWA to define protected groundwater to fully protect present and future groundwater resources.

**Because**

- Criteria for protected groundwater in states are ambiguous and in many cases do not protect brackish groundwater to the standard of an USDW.
- As demonstrated by the 2004 report on CBM and data from the Pavillion, WY Field, hydraulic fracturing into USDWs is occurring.
- As demonstrated by data from the Pavillion, WY Field, impact to USDWs is occurring.

PSE

Bringing science to energy policy


Dominic DiGiulio, Ph.D.

domdigiulio@psehealthyenergy.org


Facebook.com/PSEHealthyEnergy

@PhySciEng

# Supplemental Slides

# The Wind River and Fort Union Formations exhibit extremely physical heterogeneity formed under fluvial depositional environments

- Contains connected, poorly connected, and unconnected water bearing sandstone units (McGreevy 1969).
- Sandstone units may be connected by fracture systems (Morris et al. 1959)
- Sandstone units surrounded by discontinuous mudstone, and shale units.
- No extensive areal confining units.

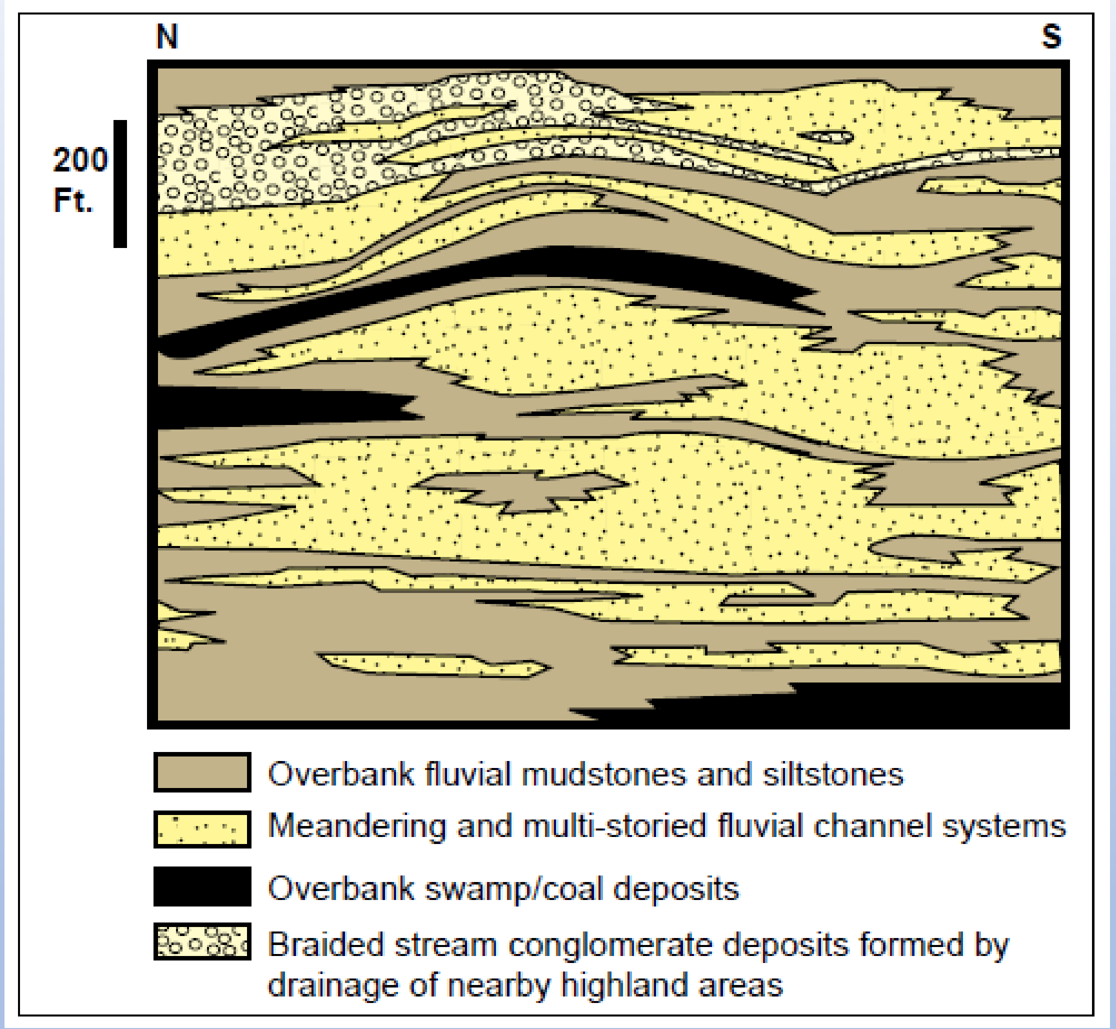



**Figure from Flores and Keighin (1993)**

# The Eocene (34-55 mya) Wind River flowed through the Pavillion Field

Pavillion Field

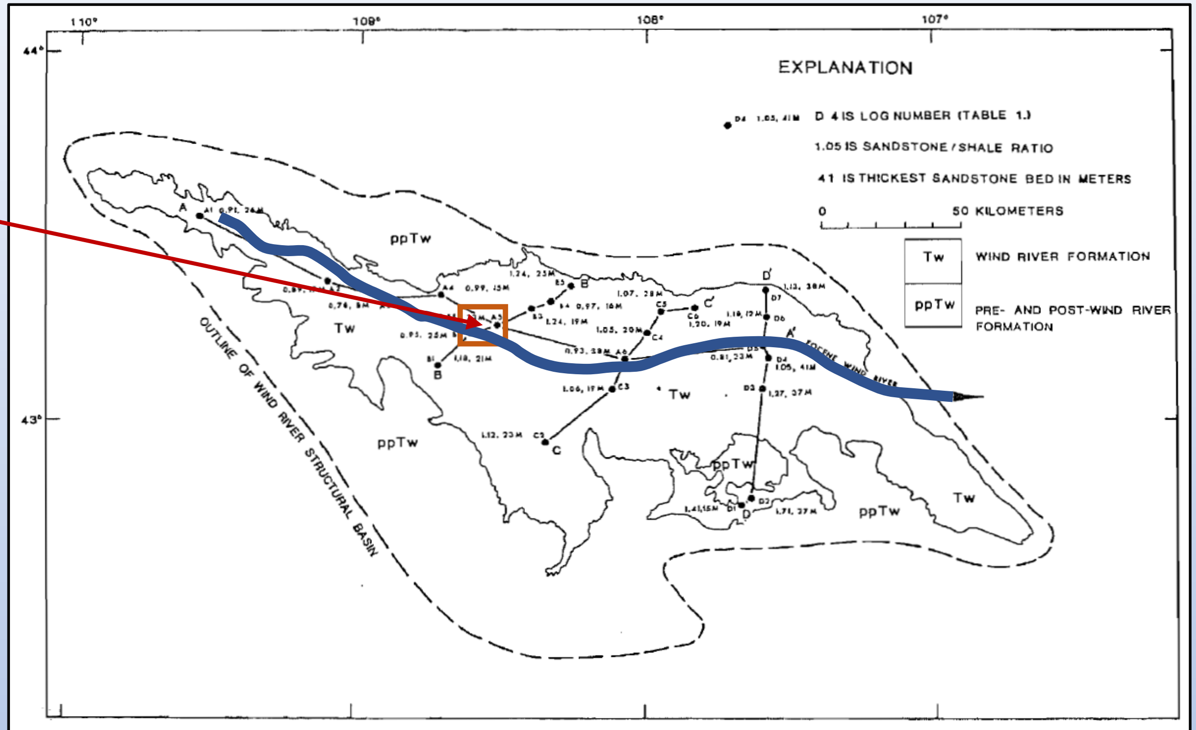



**Figure modified from Seeland (1978)**

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

**Photograph from DiGiulio et al. (2011)**

PSE

# The Wind River and Fort Union Formations are Variably Water Saturated in the Pavillion Field

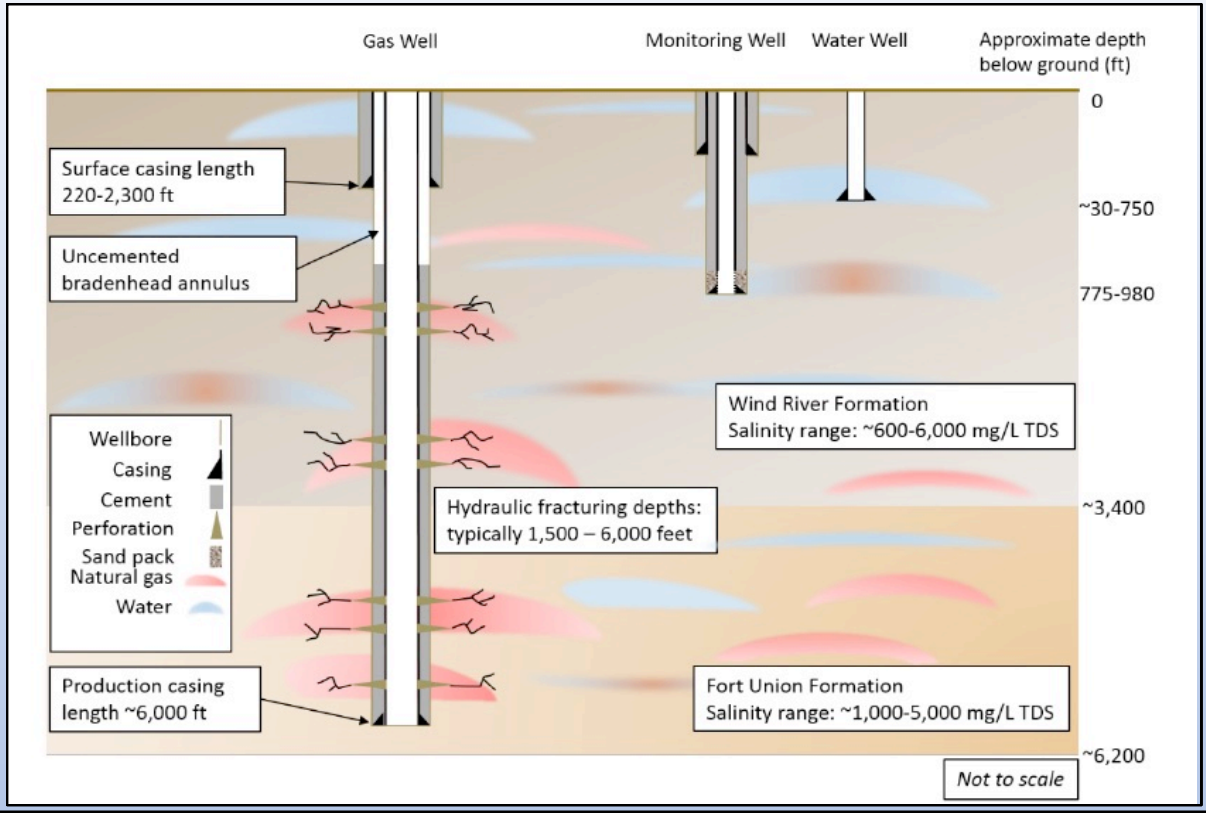



**Figure from EPA (2016)**

- Gas saturation in sandstone units increases with depth.
- Volumetric calculations indicate that gas saturation can be spatially extensive with low water to gas recovery rates in many production wells. **But**
- Significant groundwater resources exist within both formations at depth (noted in drilling logs or production wells shut in because of water production).
- Impact to USDWs then depends on advective-dispersive transport to water saturated sandstone units. Transport distance?

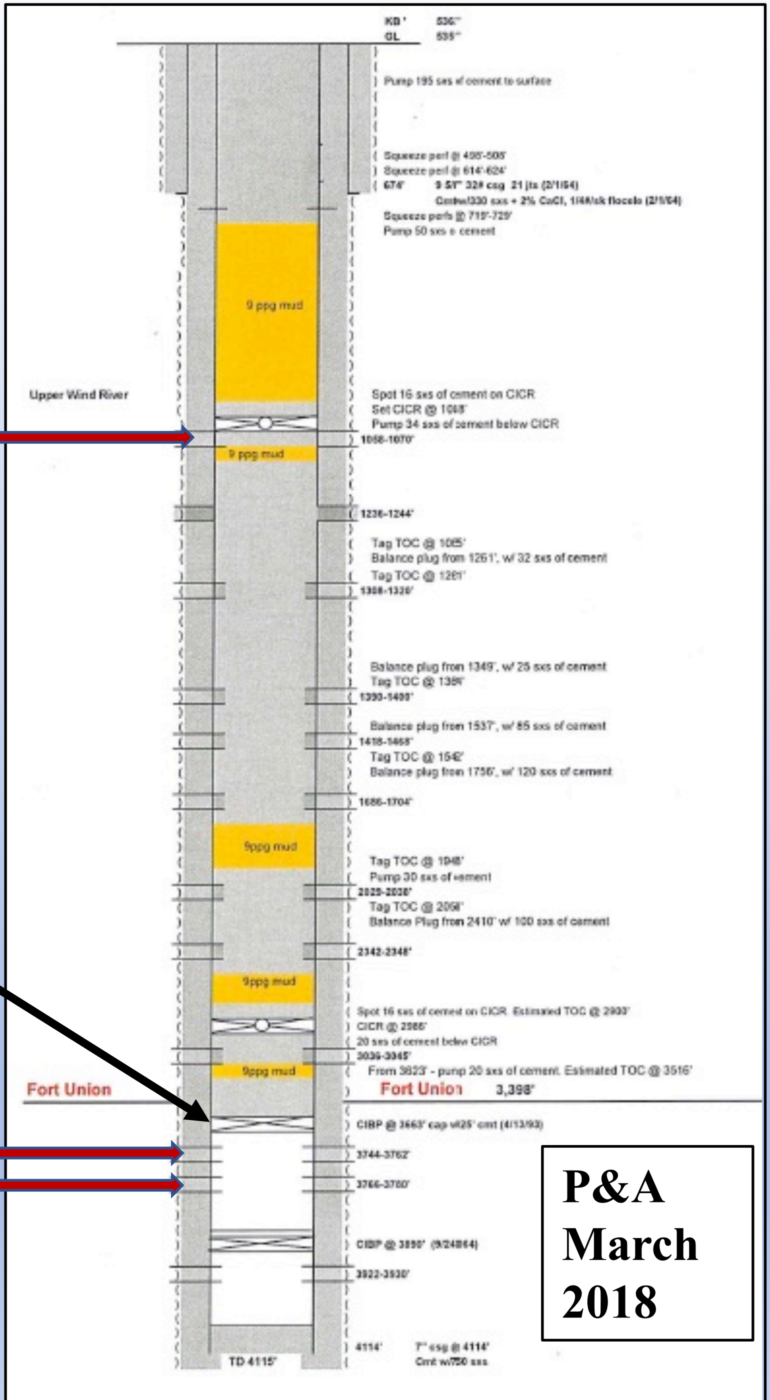
PSE

# Impact to USDWs in the Pavillion Field: Injection of Stimulation Fluids into Water-Bearing Zones

3. On 10/16/1964, hydraulic fracturing at 1058 ft with CO2 foam and 4,360 gallons of methanol.

2. On 3/25/1993, *"plug back water bearing perforation in the Fort Union at 3744-3780 with a 7" CIBP"*

1. On 10/16/1964, hydraulic fracturing with 12,000 gallons of #2 diesel at 3744-3780 ft




Information from well completion and sundry notices available from [http://wogcc.state.wy.us/legacywogcce.cfm](http://wogcc.state.wy.us/legacywogcce.cfm)

**Tribal Pavillion 14-01**

# Impact to USDWs in the Pavillion Field: Fracture Propagation and Leakoff into Water-Bearing Zones

- Distances to water-bearing sandstone units in the Pavillion Field (on the order of meters to tens of meters).
- Leakoff increases in complex fracture networks as a result of lithologic variation over short distances and contact with permeable strata (Adachi et al 2007, Fisher and Warpinski 2011, Valkó and Economides 1999, Yarushina et al 2013) typical of the Wind River and Fort Union Formations.
- Leakoff can remove much or most of the fracturing fluid even for moderate sized induced fractures (Adachi et al 2007, Fisher and Warpinski 2011).

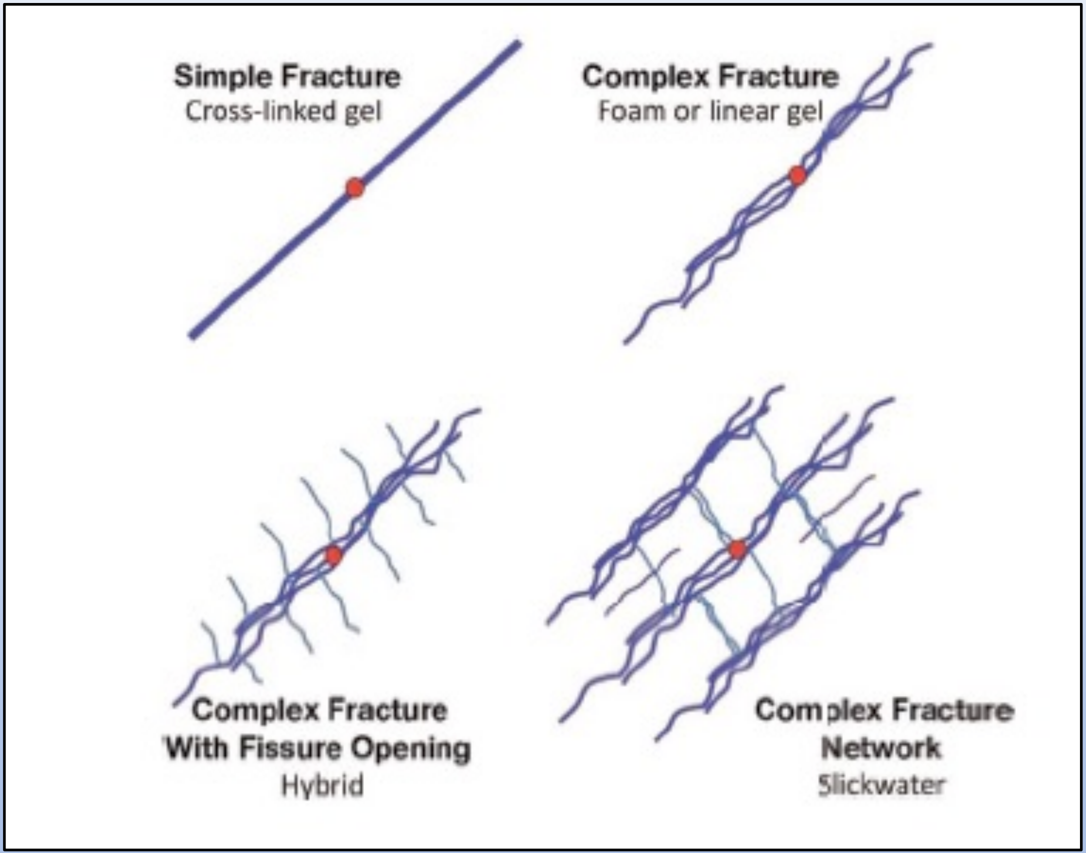



**Figure from CCST (2015) modified from Warpinski (2009)**

# Impact to USDWs in the Pavillion Field: Instantaneous Shut-In Pressures indicate strong hydraulic gradients

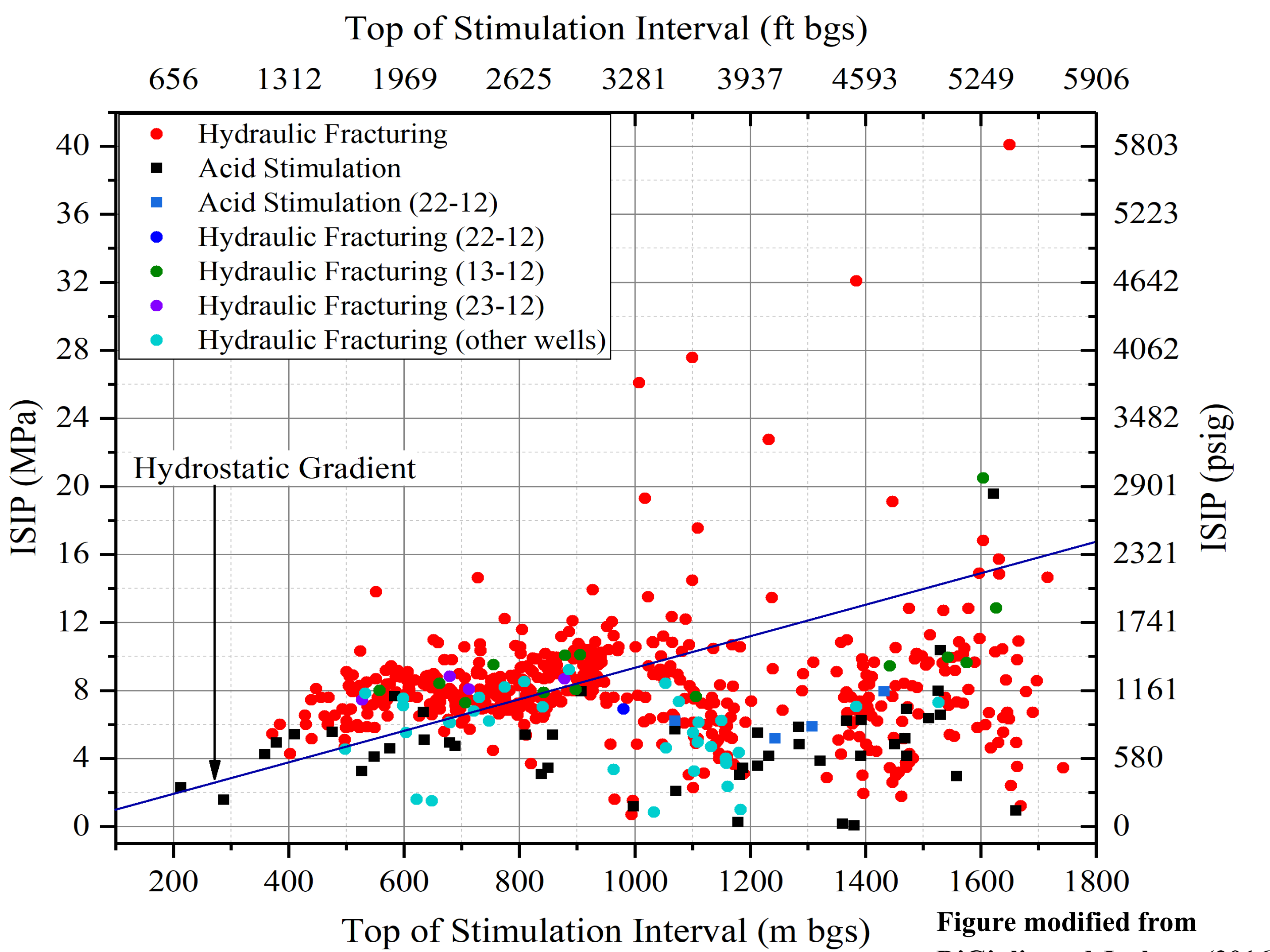
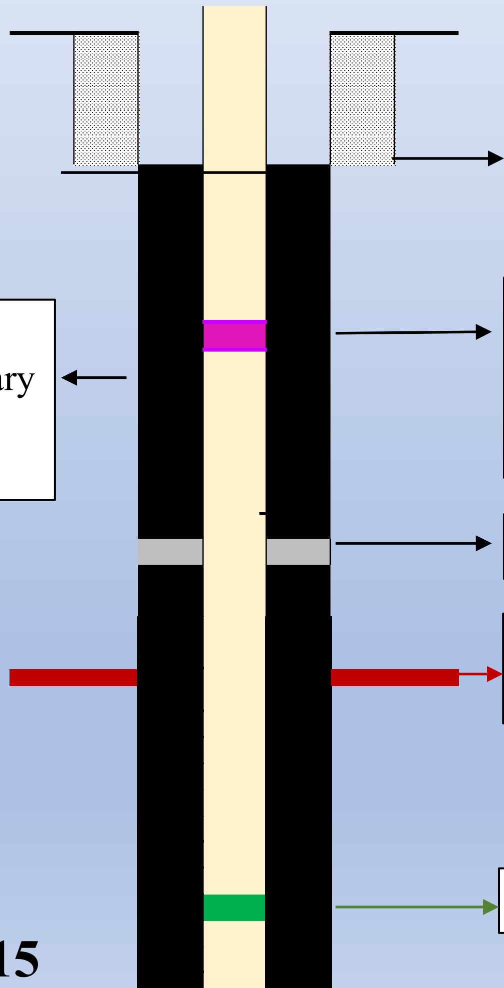



**Figure modified from DiGiulio and Jackson (2016)**

High pressure gradients in excess of hydrostatic pressure (up to 40.1 MPa or 4100 m of hydraulic head. Pressure buildup far in excess of drawdown during fluid recovery.

# Impact to USDWs in the Pavillion Field: Potential Loss of Zonal Isolation

Casing failure occurred at 5 production wells.



Letter on 8/14/2012 from WDEQ to BLM requesting information on potential release to shallow aquifer.

Surface casing at 619’

Invert mud – depth to primary cement unknown

Sundry Notice on 3/7/2012 indicated “failed casing” between **735’ – 1105’** during mechanical integrity testing.

Cement squeeze at 1550’ October 1982

1. Acid stimulation (1000 gallons) at 2622’ September 1982

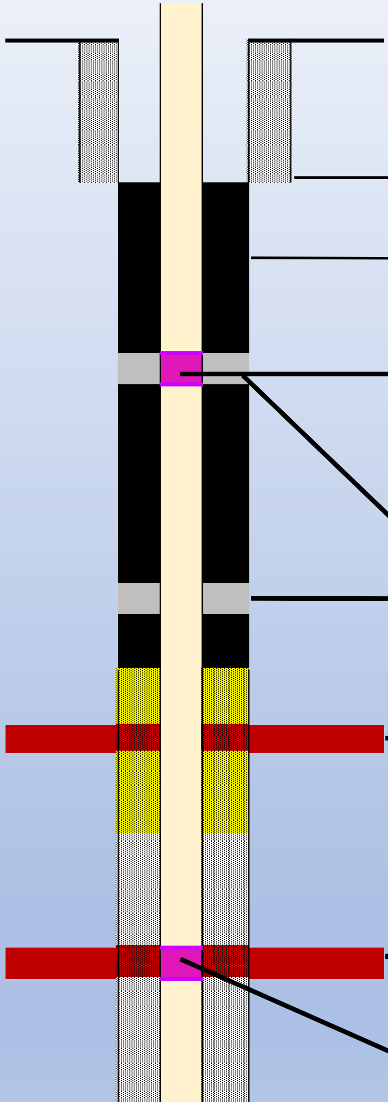
Packer at 3294’

**Information from well completion and sundry notices available from [http://wogcc.state.wy.us/legacywogcce.cfm](http://wogcc.state.wy.us/legacywogcce.cfm)**

**Tribal 21-15**

PSE

# Impact to USDWs in the Pavillion Field: Potential Loss of Zonal Isolation and Hydraulic Fracturing Directly Below Intervals Containing Poor Cement



Surface casing at 444’

Invert mud (up to 78% diesel oil) from 444’ – 1850’

1. On 1/11/2005, a cement bond-variable density log conducted at 400 psig indicated top of cement at 1850’ with high amplitude to 2050’.

2. On 1/21/2005, a “*hole*” in casing at 1025’-1062’ was reported. No cement outside casing - potential gas or fluid migration.

3. On 1/25/2005, cement squeezes at 1062’ and 1775’.

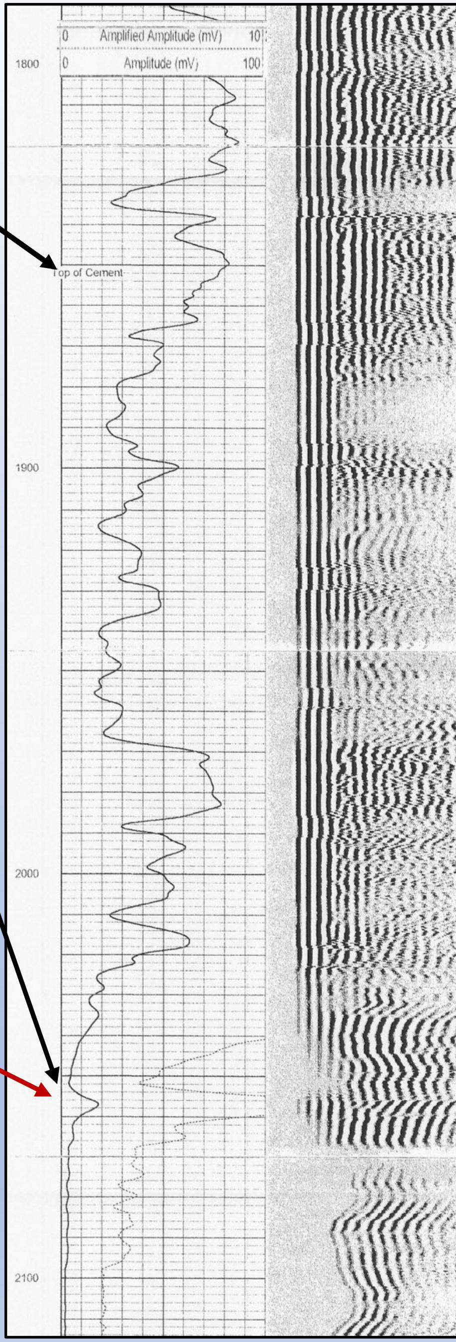
**P&A March 2018**

5. On 2/12/2005, slickwater frac at 2070’ at 5711 psig . At most, 20’ of good bonding above frac.

(burst pressure ~ 5350 psig).

4. On 2/8/2005, slickwater frac with $CO_2$ assist at 2671’ at 5546 psig on 2/8/2005

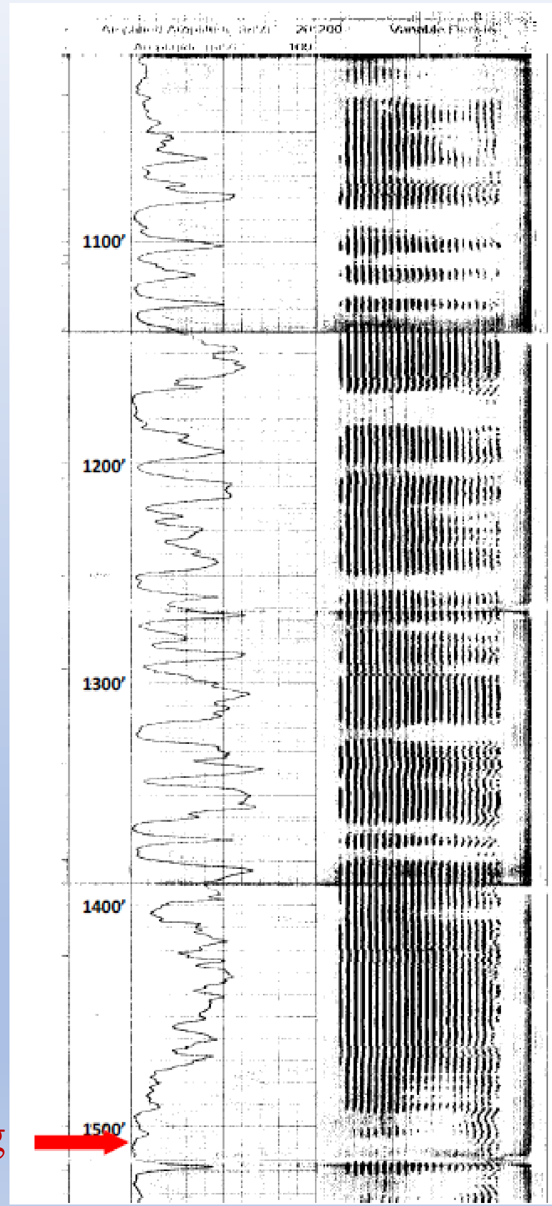
6. In a wellbore diagram dated 10/5/2011, casing was parted at 2593 and 2597 (12/21/2006)’.

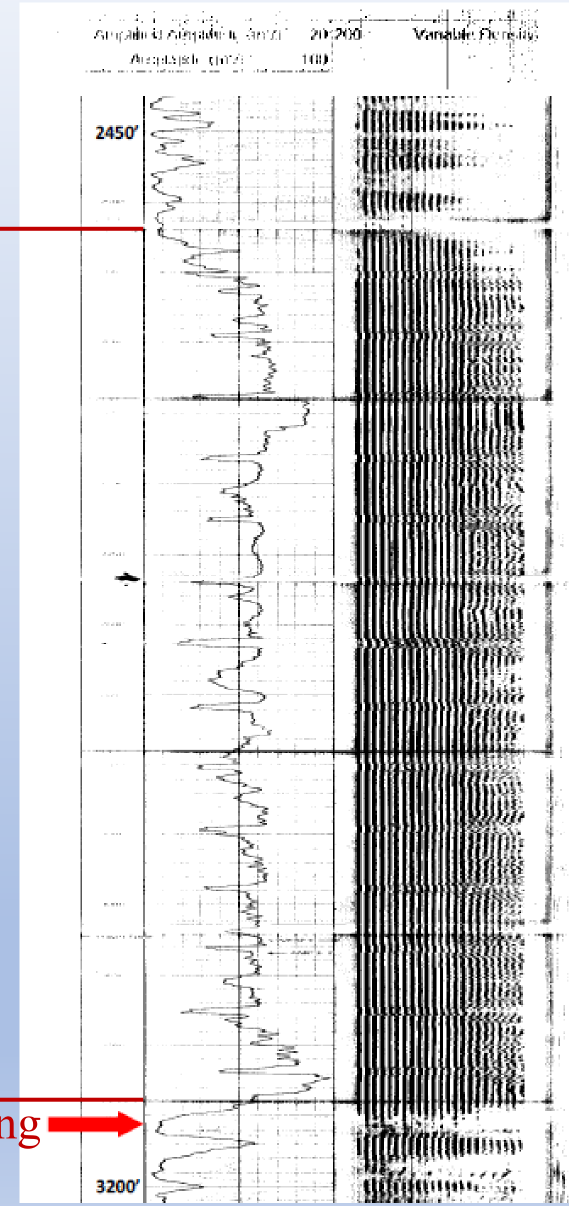



**Blankenship 4-8**

**Information from well completion and sundry notices available from [http://wogcc.state.wy.us/legacywogcce.cfm](http://wogcc.state.wy.us/legacywogcce.cfm)**

# Impact to USDWs in the Pavillion Field: Potential Loss of Zonal Isolation - Hydraulic Fracturing Directly Below Intervals Containing Poor Cement




*"void @ 2550-3150"*

**Tribal Pavillion 11-11B**

Hydraulic fracturing @ 1516' in 2005

Hydraulic fracturing @ 3165' in 2005

**Information from well completion and sundry notices available from http://wogcc.state.wy.us/legacywogcce.cfm**

# EPA Monitoring Wells

**Figure from DiGiulio et al. 2011**

# EPA Monitoring Wells

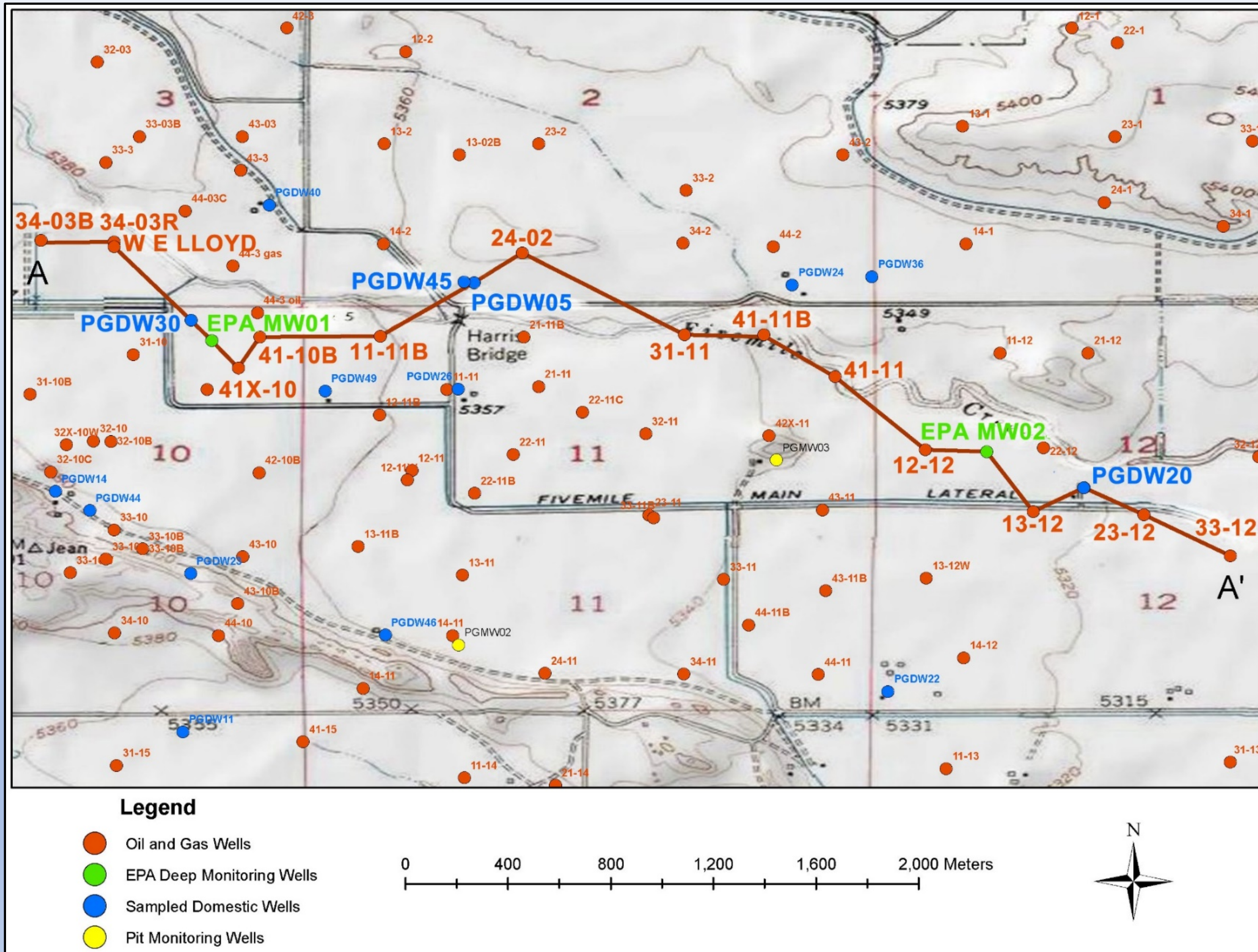



Figure from DiGiulio et al. 2011

# EPA Monitoring Wells

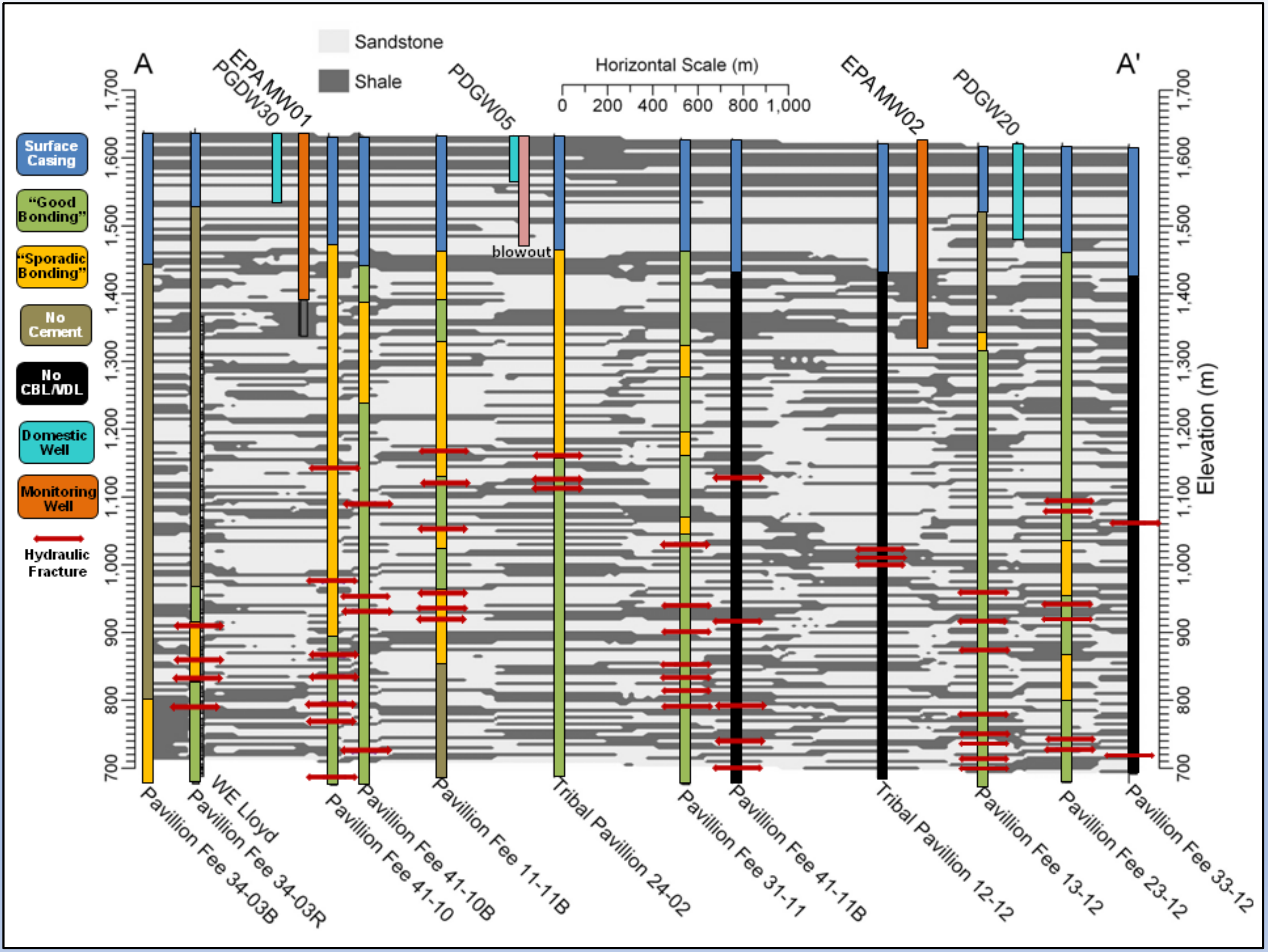
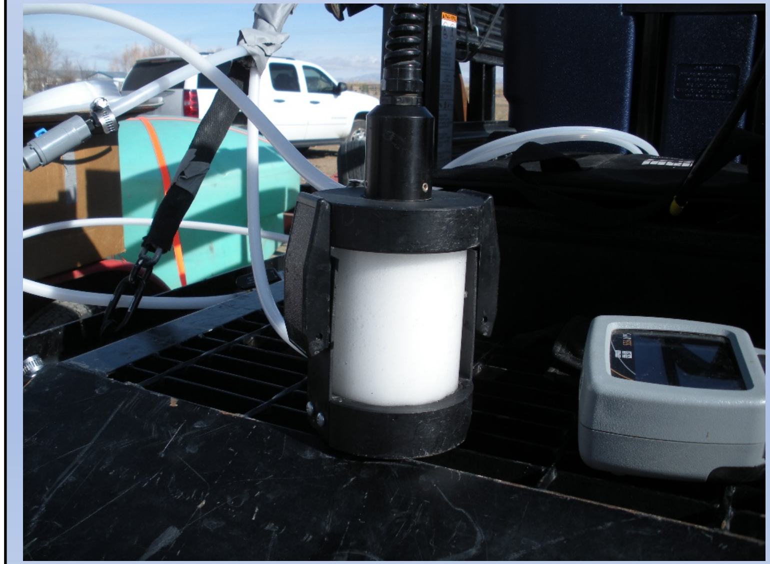



Figure from DiGiulio et al. 2011

# Organic Compounds Detected in EPA Monitoring Wells

- Methanol, isopropanol, and 2-butoxyethanol were used in high concentrations. Detection is likely due to hydraulic fracturing.
- Detection of nonylphenol and octylphenol (endocrine disrupters) are likely due to biodegradation of products (e.g., surfactants) used for hydraulic fracturing.
- Detection of low molecular weight organic acids, and ketones are likely due to biodegradation of compounds used for hydraulic fracturing.
- Detection of benzene, toluene, ethylbenzenes, xylenes, napthalenes, alkylbenzenes and high levels of gasoline range organics and diesel range organics could be due to hydraulic fracturing or be of geogenic origin.
- Detection of glycols could be due to hydraulic fracturing or potentially from well construction materials.



**Figures from DiGiulio et al. 2011**

PSE

# References


Adachi, J; Siebrits, E.; Peirce, A; Desroches, J. Computer simulation of hydraulic fractures. *International Journal of Rock Mechanics & Mining Science* 2007, 44, 739-757.

American Petroleum Institute. *API Guidance Document HF1, Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines*, First Edition, October 2009.

California Council on Science and Technology. *Advanced Well Stimulation Technologies in California,* Lawrence Berkeley National Laboratory, Pacific Institute, 2015

Daddow, R.L. *Water resources of the Wind River Indian Reservation*, Wyoming. U.S. Geological Survey Water-Resources Investigation Report 95-4223, 1996

DiGiulio, D.C.; Wilkin, R.T., Miller, C.; Oberley, G. *Investigation of Ground Water Contamination near Pavillion, Wyoming* – Draft Report. U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Ada, OK and Region 8, Denver, CO, December 2011.

DiGiulio, D.C.; Jackson, R.B. Impact to Underground Sources of Drinking Water and domestic wells from production well stimulation and completion practices in the Pavillion, Wyoming Field. *Environmental Science & Technology* 2016 50, 4524-4536.

DiGiulio, D.C.; Shonkoff, S.B.C. Is reuse of produced water safe? First, let's find out what's in it. EM, Air & Waste Management Association, August 2017

DiGiulio, D.C.; Shonkoff, S.B.C.; Jackson, R.B. The Need to Protect Fresh and Brackish Groundwater Resources During Unconventional Oil and Gas Development. *Current Opinion in Environmental Science & Health* 2018, 3,1-7.

Esser, B.K.; Beller, H.R.; Carroll, S.A.; Cherry, J.A.; Gillespie, J.; Jackson, R.B.; Jordon, P.D.; Madrid, V.; Morris, J.P.; Parker, B.L.; Stringfellow, W.T.; Varadharajan, C.; Vengosh, A. *Recommendations on Model Criteria for Groundwater Sampling, Testing, and Monitoring of Oil and Gas Development in California*. Lawrence Livermore National Laboratory, LLNL-TR-669645, Final Report, California State Water Resources Control Board, June 2015.

Federal Register, Vol. 80, No. 58, March 26, 2015, Part III, Department of the Interior, Bureau of Land Management, 43 CFR Part 3160, *Oil and Gas; Hydraulic Fracturing on Federal and Indian Lands; Final Rule.*

Finn, T.M. (2007a) Source Rock Potential of Upper Cretaceous Marine Shale in the Wind River Basin, Wyoming in USGS Wind River Province Assessment Team, Petroleum systems and geologic assessment of oil and gas in the Wind River Basin Province, Wyoming: U.S. Geological Survey Digital Data Series DDS-69J, ch 8, 24p. 2007.

# References


Fisher, K.; Warpinski, N. Hydraulic fracture – height growth: Real data. *SPE* 145949, 2011

Flores, R.M.; Keighin, C.W. (1993). Reservoir Anisotropy and Facies Stratigraphic Framework in the Paleocene Front Union Formation, Western Wind River Basin, Wyoming, in W.R. Keefer, W.J. Metzger and L.H. Godwin, eds., Oil and Gas and Other Resources of the Wind River Basin, Wyoming: Wyoming Geological Association Special Symposium, 1993, 121–141.

Gores and Associates. Pavillion Area Water Supply I Study, Final Report for the Wyoming Water Development Commission, October 2011

Groundwater Protection Council. State Oil and Natural Gas Regulations Designed to Protect Water Resources, 2009.

Jackson, R.E.; Lowry, E.R.; Pickle, A.; Kang, M.; DiGiulio, D.C; Zhao, K. The Depths of Hydraulic Fracturing and Accompanying Water Use Across the United States. Environmental Science & Technology 2015, 49 (15), 8969–8976.

Maupin, M.A.; Kenny, J.F.; Hutson, S.S.; Lovelace, J.K.; Barber, N.L.; Linsey, K.S. *Estimated Use of Water in the United States in 2010*. U.S. Geological Survey, Circular 1405, 2014.

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

Morris, D.A.; Hackett, O.M.; Vanlier, K.E.; Moulder, E.A.; Durum, W.H. Ground-Water Resources of Riverton Irrigation Project Area, Wyoming, Geological Survey Water-Supply Paper 1375, 1959.

Nelson, P.H.; Kibler, J.E. Distribution of Fluids and Pressures in the Wind River Basin, Wyoming, In USGS Wind River Province Assessment Team, Petroleum systems and geologic assessment of oil and gas in the Wind River Basin Province, Wyoming: U.S. Geological Survey Digital Data Series DDS-69J, Chapter 7, 2007.

Plafcan, M., Eddy-Miller, C.A., Ritz, G.F., and Holland, J.P.R. Water Resources of Fremont County, Wyoming. U.S. Geological Survey, Water-Resources Investigations Report 95-4095, 1995

Roberts, L.N.R., Finn, T.M., Lewan, M.D. Kirschbaum, M.A. Burial History, thermal Maturity, and Oil and Gas Generation History of Petroleum Systems in the Wind River Basin Province, Central Wyoming, in USGS Wind River Province Assessment Team, Petroleum systems and geologic assessment of oil and gas in the Wind River Basin Province, Wyoming: U.S. Geological Survey Digital Data Series DDS-69J, Chapter 6, 2007.

Roy, S.B.; Chen, L.; Girvetz, E.H.; Maurer, E.P.; Mill, W.B.; Grieb, T.M. Projecting water withdrawal and supply for future decades in the U.S. under climate change scenarios. *Environmental Science & Technology* 2012, 46(5), 2545-2556.

# References


Seeland, D. Sedimentology and Stratigraphy of the Lower Eocene Wind River Formation, Central Wyoming. Thirtieth Annual Field Conference, Wyoming Geological Association Guidebook, 1978, 181-198.

Stanton, J.S., Anning, D.W., Brown, C.J., Moore, R.B., McGuire, V.L., Qi, S.L., Harris, A.C., Dennehy, K.F., McMahon, P.B., Degnan, J.R., and Böhlke, J.K., 2017, *Brackish groundwater in the United States*: U.S. Geological Survey Professional Paper 1833, 185 p., https://doi.org/10.3133/pp1833.

U.S. Department of Interior, Bureau of Land Management, Letter from Robert V. Abbey, Director to Edward J. Markey, Natural Resources Committee, House of Representatives, November 7, 2011.

U.S. Department of Interior, Bureau of Land Management. BLM Proposed to Rescind Rule on Hydraulic Fracturing, accessed on 8/21/2017

U.S. Environmental Protection Agency. *Evaluation of Impacts to Underground Source 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.

U.S. Environmental Protection Agency. Region 8, Denver, CO. *Pavillion Gas Well Integrity Evaluation*, July 25, 2013

U.S. Environmental Protection Agency. *Permitting Guidance for Oil and Gas Hydraulic Fracturing Activities Using Diesel Fuels: Underground Injection Control Program Guidance #84*, Office of Water, EPA 816-R-14-001, February 2014

U.S. Environmental Protection Agency. *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States* (Final Report). Washington, DC, EPA/600/R-16/236F, 2016.

Valkó, P.P.; Economides, M.J. Fluid-leakoff delineation in high permeability fracturing. SPE Prod. & Facilities 1999, 14(2), 117-130.

Wyoming Department of Environmental Quality. *Chapter 8: Quality Standards for Wyoming Groundwaters*, Effective Date 09/15/2015.

Yarushina, V.M.; Bercovici, D.; Oristaglio, M.L. Rock deformation models and fluid leak-off in hydraulic fracturing. *Geophys J Int* 2013, 194, 1514-152