The Society of Petroleum Evaluation Engineers

SPEE Denver Chapter announces its April Luncheon Meeting.

(Members and Guests are cordially invited to attend.)

Tuesday, April 17, 2018

Dr. Will Fleckenstein

Adjunct Professor, Colorado School of Mines and SPE Distinguished Lecturer 2017-18

Will be speaking on:

Shale Development – Does Cheap Energy Really Mean Flaming Tap Water and Burning Lungs?

LUNCHEON STARTS AT 11:30 A.M.

(A plated lunch will be served.)

PRESENTATION BEGINS AT NOON

The Denver Athletic Club

3rd Floor, Petroleum Room

1325 Glenarm Place (14th and Glenarm) Denver CO 80204

Parking flat rate $7.00 on space available basis

Cost: $25.00 per Person

(Credit Card, Cash or Check made out to 'SPEE Denver Chapter')

Sponsored in part by Entero Corporation, creators of Mosaic, a comprehensive software application for reserves management, petroleum economics, and decline analysis www.entero.com

Please RSVP by Noon Friday, April, 13, 2018

RSVP and simultaneously pay by credit card online at:

https://secure.spee.org/civicrm/event/info?reset=1&id=181

If the above link does not work, alternatively go to www.spee.org then select 'Local Chapters', then 'Denver', then 'Register Now'.

Abstract: Shale development has materially increased US oil and gas production, and driven prices down. Media reports and films such as "Gasland" have left the impression that shale development is widely polluting our fresh water aquifers and air. Estimates of aquifer contamination have been complicated by the presence of hydrocarbons at shallow depths in many parts of the world, and changing historical well construction standards. Consequently, there are a wide range of estimates of the probability of shallow aquifer contamination resulting from shale development. This leads to the question - does cheap energy really mean flaming tap water and burning lungs? This presentation answers that question by quantifying the risk of contamination of aquifers through wellbores, either by migration or hydraulic fracturing operations, and is based on a comprehensive study examining nearly 18,000 wells drilled in the Wattenberg Field in Colorado. In the midst of this oil field is heavy urban and agricultural development, resulting in the drilling of over 36,000 water wells, making this a natural laboratory to measure aquifer contamination. This study found no evidence of aquifer contamination through the subsurface and documented few hydrocarbon migration incidents. The probability of migration correlated to the well construction standards used on the wells, with modern wellbore designs having the lowest risks of contamination.

Speaker Bio.: **William (Will) W. Fleckenstein** was appointed in 2000 as an Adjunct Professor of Petroleum Engineering at the Colorado School of Mines, where he also served as Department Head 2012-2014, and currently is the College of Earth Resource Sciences & Engineering Director of Strategic Relationships and Enterprises. Will also serves as the managing partner in Fleckenstein, Eustes & Associates and holds BSc, ME, and PhD degrees in petroleum engineering from Mines. He has 30 years' experience in primarily drilling, completions and workovers, with direct experience on over 200 wells and was involved in drilling his first horizontal well in 1990. He was a Co-PI on a five-year project funded by the United States National Science Foundation focused on the sustainability of natural gas development.

About SPEE: http://www.spee.org SPEE was formed in 1962 as a professional, non-profit organization bringing together specialists in the evaluation of petroleum and natural gas properties. SPEE continues today to be strongly committed to providing educational and other services to its members and to the oil and gas industry, and to promoting the profession of petroleum evaluation engineering.

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Shale Development – Does Cheap Energy Really Mean Flaming Tap Water?

Dr. William W. Fleckenstein, PE (CA #1666)
Colorado School of Mines

Society of Petroleum Evaluation Engineers
April 17, 2018

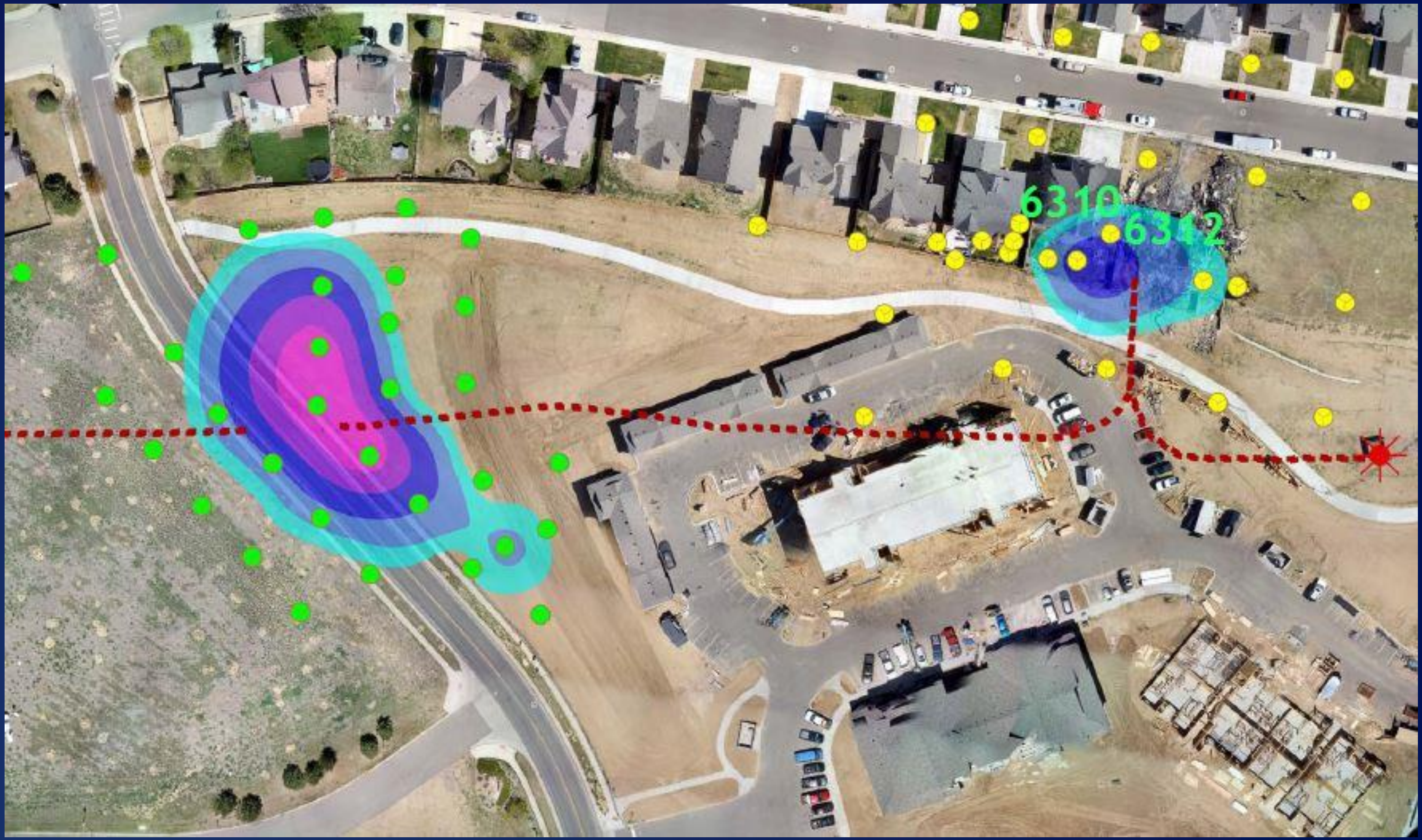
Society of Petroleum Engineers
Distinguished Lecturer

Presentation Outline

- Introduction
- Why is US shale development important?
- Aquifer protection
- Wattenberg study
- Summary
- Questions and answers

Longmont Panel Discussion Sept. 19, 2012

Firestone Tragedy



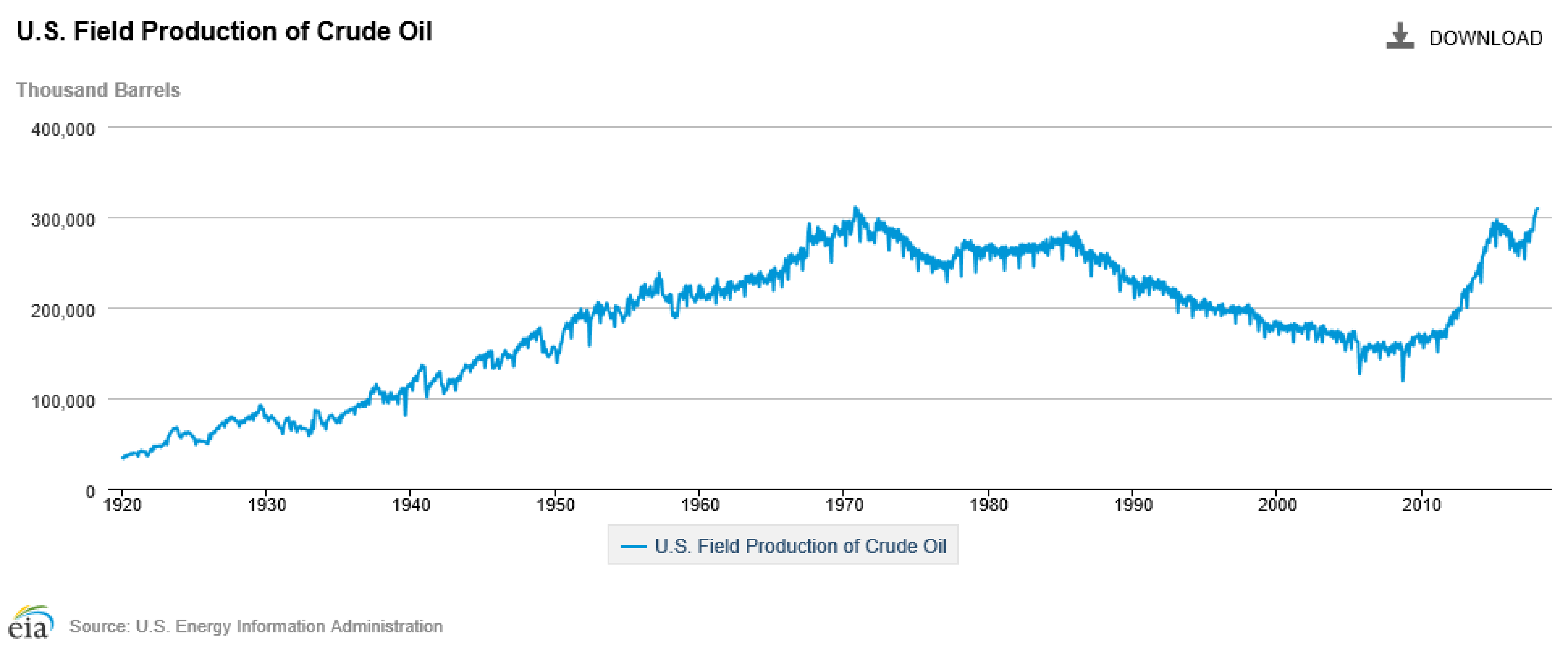
Introduction

- Shale development:
  - Controversial
  - Leakage estimates disputed

- This presentation provides a fact based estimate of leakage

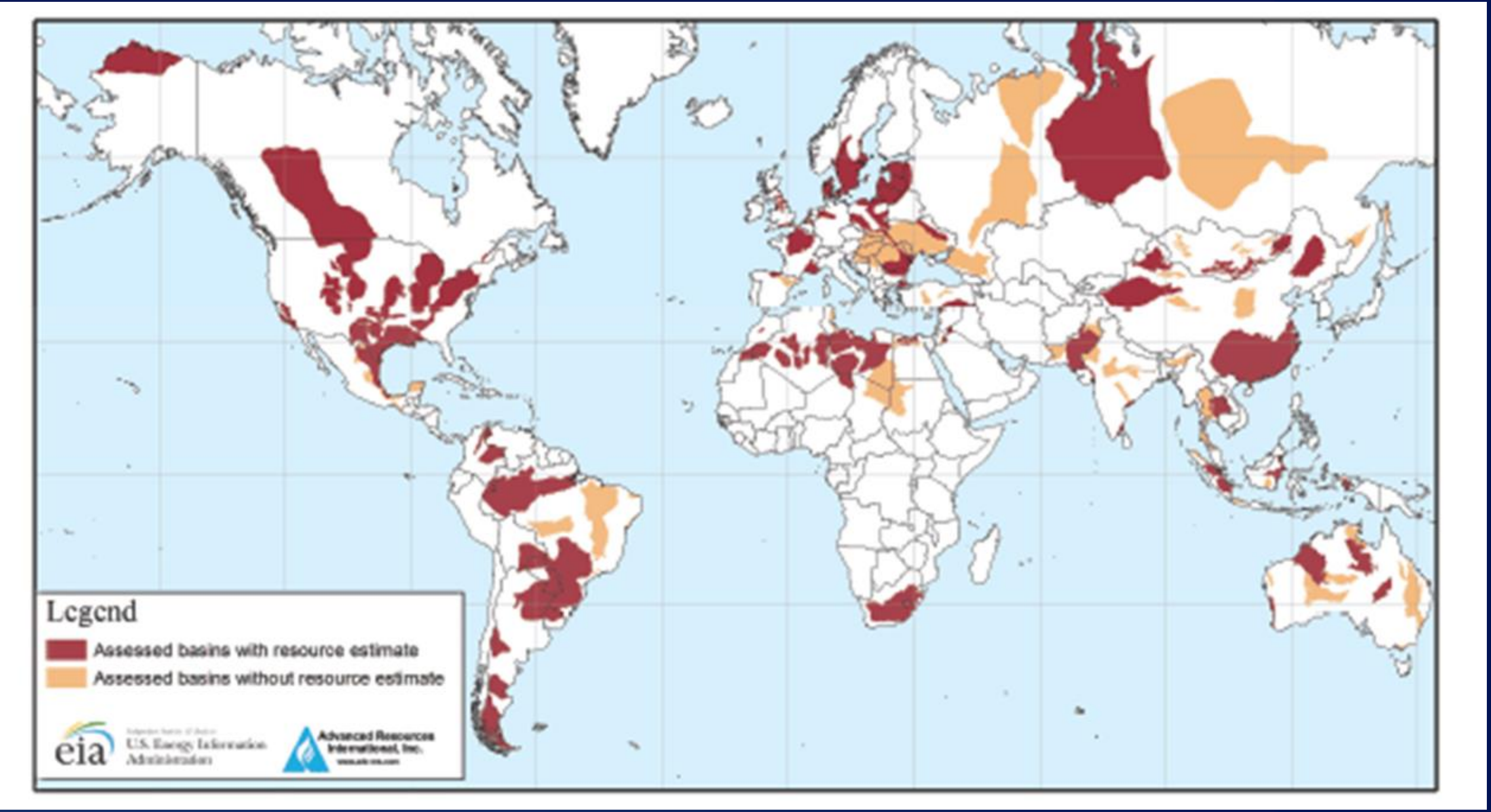
Images from “Gasland The Definitive Documentary on Fracking”

Why is US Shale Development Important?



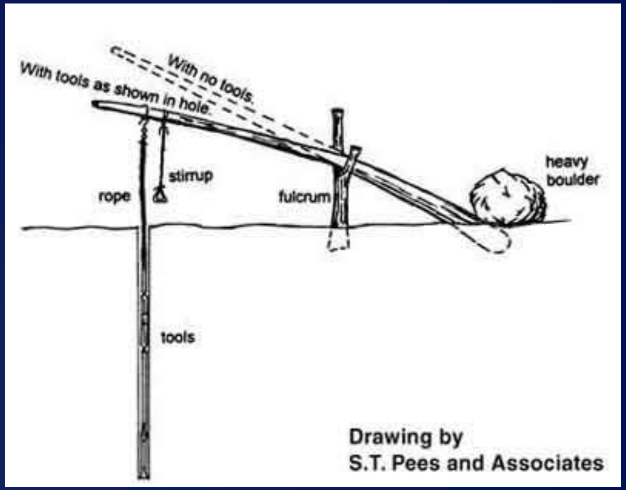
US EIA

Shale Plays Around the World



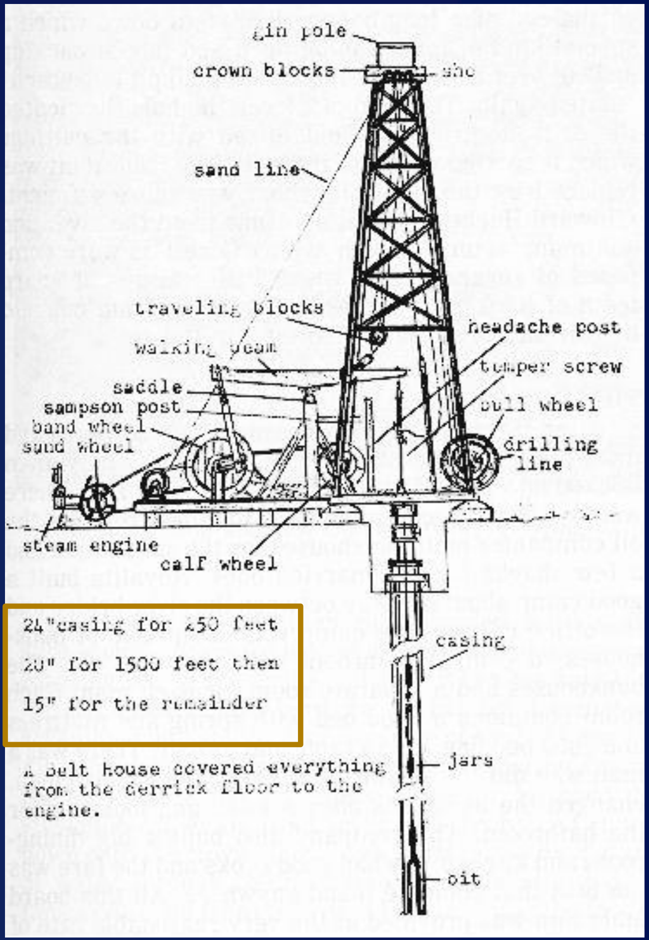
Historical Well Construction

- The first recorded salt well in China
  - 2,250 years ago
- Persian oil development
  - 8 centuries ago
- Baku hand-dug holes to 35 meters
  - 4 centuries ago



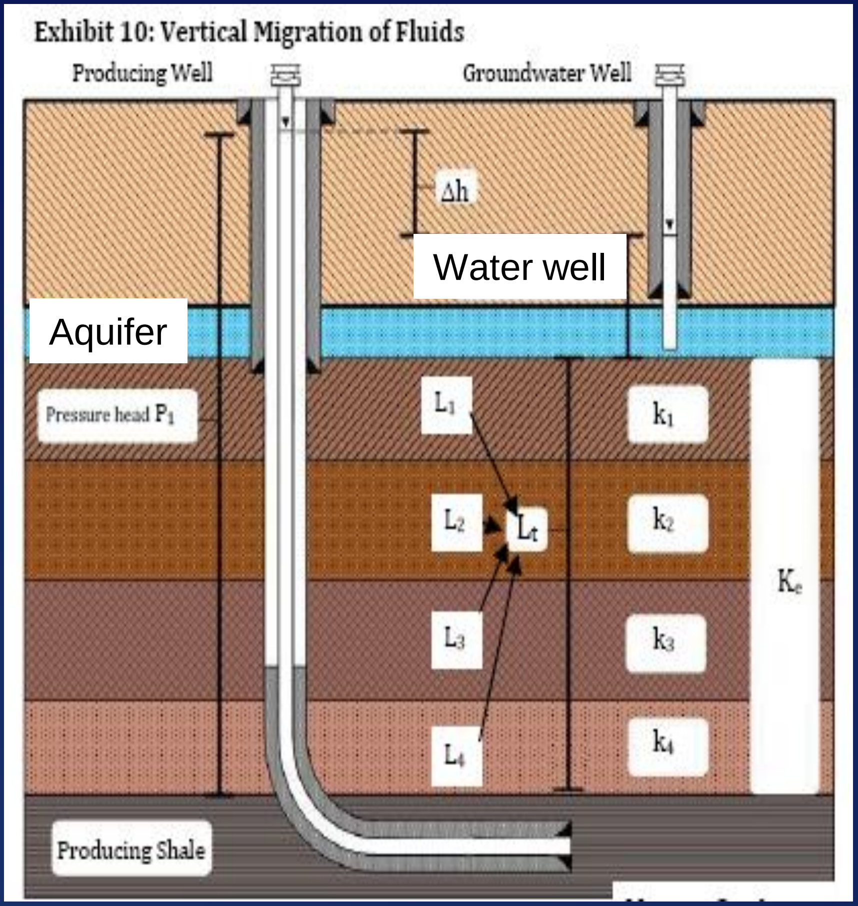
More "Modern" Drillers

- To access the subsurface you need a hole.
- To drill a hole, typically an aquifer is encountered.
- Early drillers recognized the need to case aquifers but:
  - How deep?
  - Good cement job?
  - Legacy wells?



http://drakewell.org

Aquifer Protection



R.A. Freeze and J.A. Cherry. 1979. *Groundwater*. Prentice Hall. 604pgs.

- Aquifer protection:
  - Drill through the aquifer to an impermeable formation
  - Run surface casing and cement

Simple?

Denver Basin Aquifers

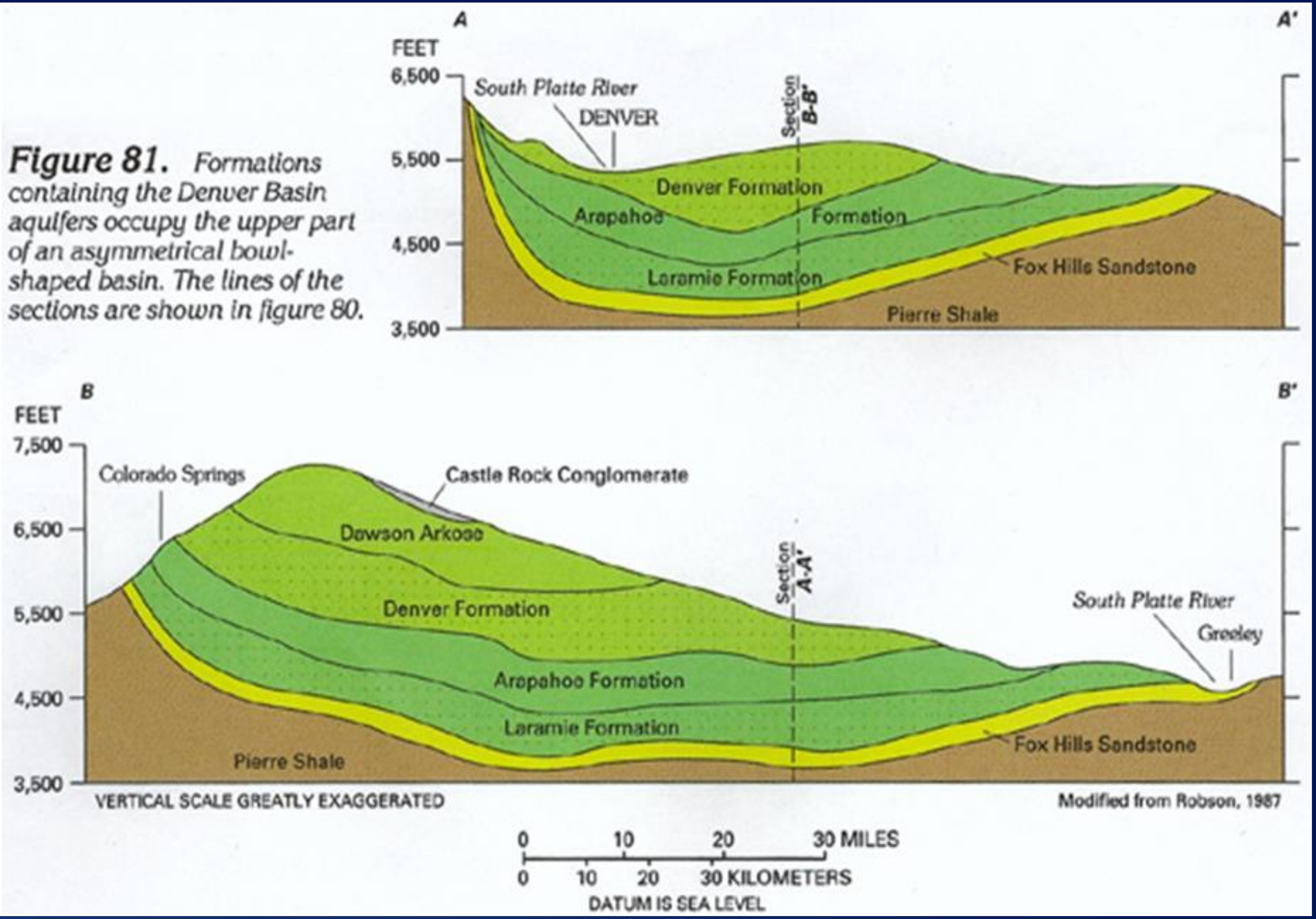
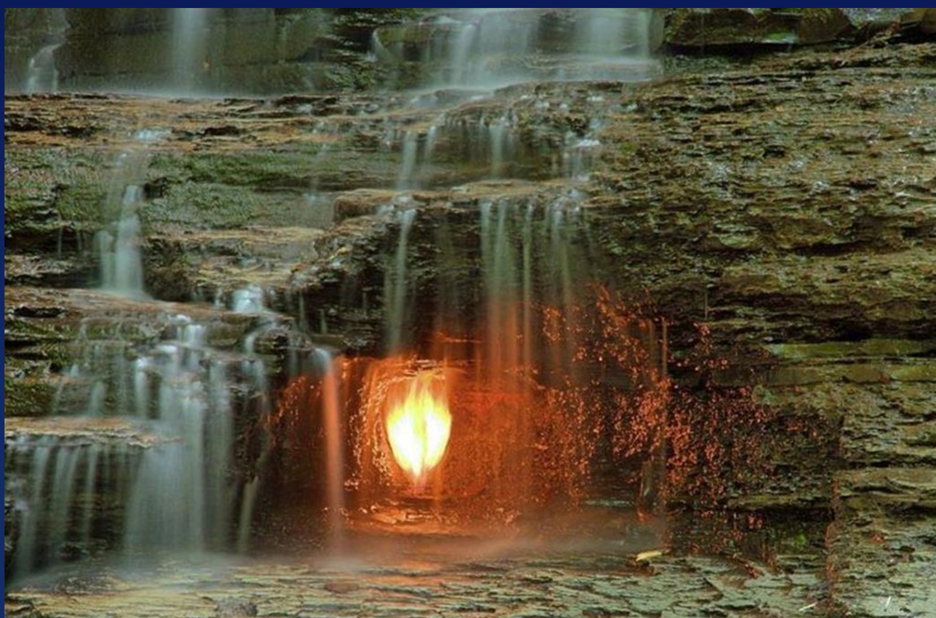


Figure 81. Formations containing the Denver Basin aquifers occupy the upper part of an asymmetrical bowl-shaped basin. The lines of the sections are shown in figure 80.

Cross section of the Denver Basin aquifer system (USGS 1995)

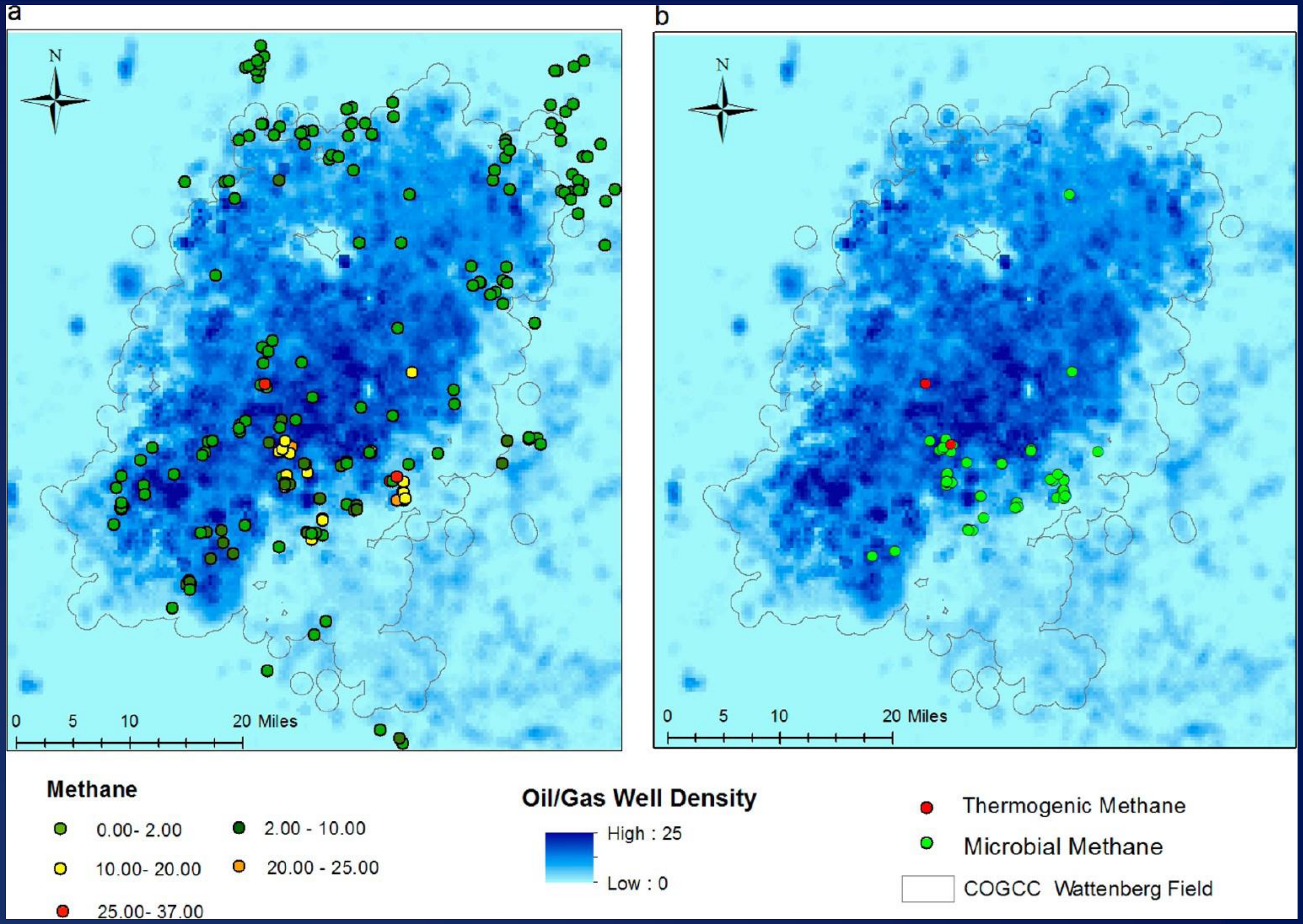
Does Methane Exist in Fresh Water Aquifers?



Biogenic gas, having a microbial origin, is naturally occurring in aquifers (think swamp gas).

Thermogenic gas is associated with deeper oil and gas maturation – may be from oil and gas development or the source may be natural seepage, as shown here.

Aquifer Methane

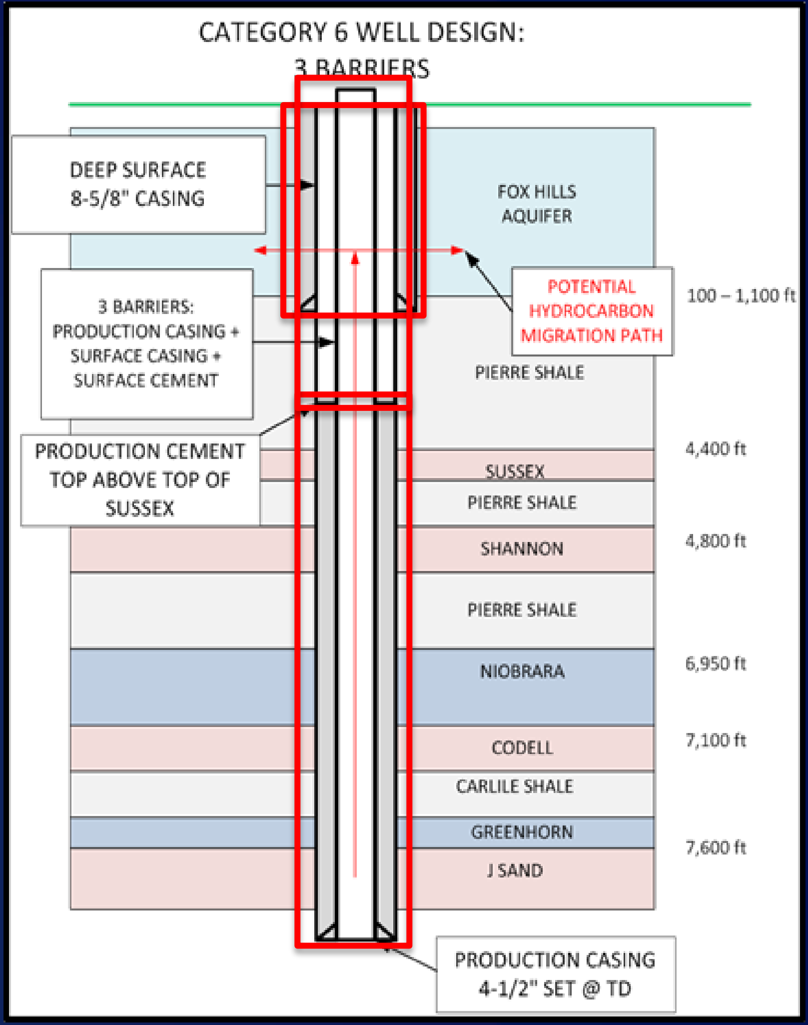


Distribution and Origin of Groundwater Methane in the Wattenberg Oil and Gas Field of Northern Colorado - Li and Carlson 2014

Aquifer Protection

Wellbores should have at least three barriers in place

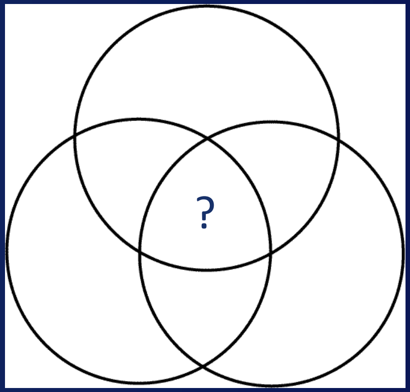
1. Cemented surface casing
2. Cemented prod. casing
3. Annular hydrostatic head



Contamination Probability Hypothesis

Multiplication rule for independent events can be used to estimate aquifer contamination.

$$P = \prod_{i=1}^{N} P(A_i)$$



What if a barrier failure probability is 5% or 1/20?

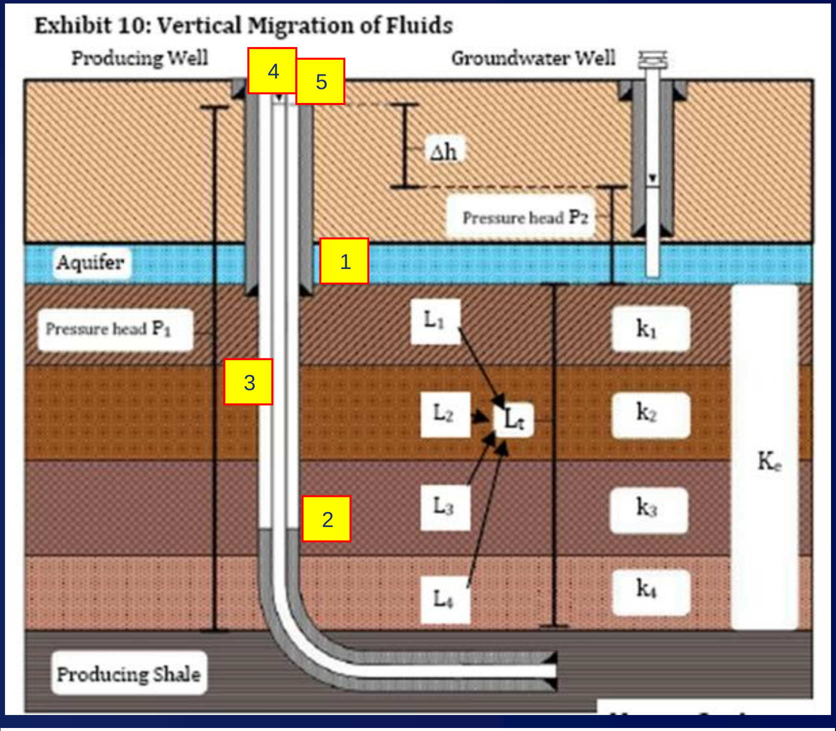
Hypothesis:
5% Individual Barrier Failure

During production:
three independent failures

1. Cemented surface casing
2. Cemented production casing
3. Annular hydrostatic head

During fracturing: two more:

4. Frac string pressure monitoring
5. Annular pressure monitoring



R.A. Freeze and J.A. Cherry. 1979. *Groundwater*. Prentice Hall. 604pgs.

Contamination Probability Hypothesis - Production

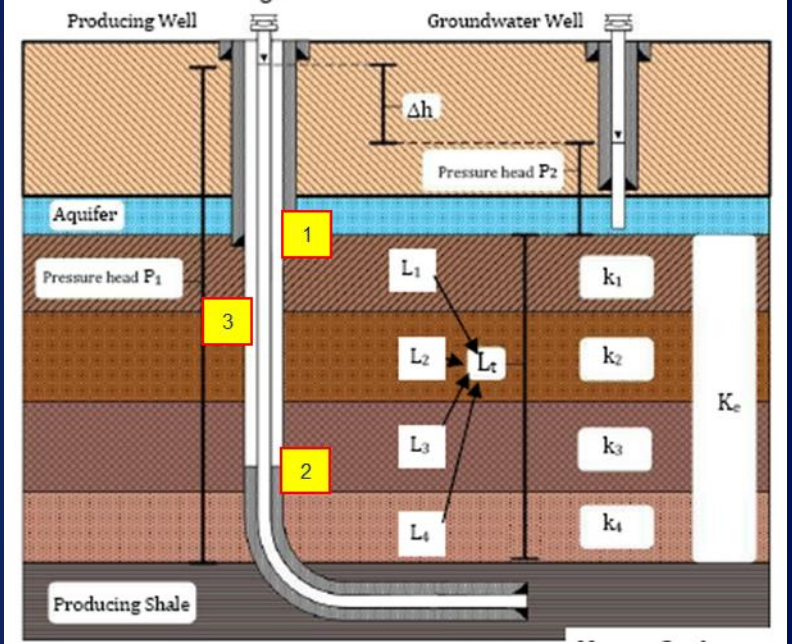
Probability of hydrocarbon migration:

$$P = \prod_{i=1}^{N} P(A_i)$$

$$P = 0.05^3$$

1 per 8,000 wells.

Exhibit 10: Vertical Migration of Fluids



R.A. Freeze and J.A. Cherry. 1979. *Groundwater*. Prentice Hall. 604pgs.

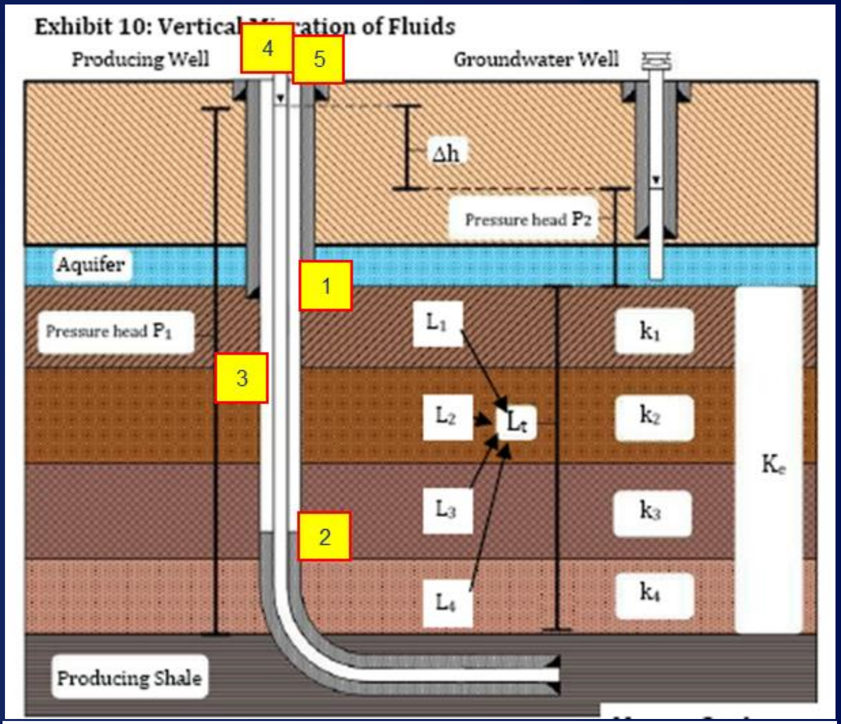
Contamination Probability Hypothesis - Fracturing

- Probability of frac fluid migration:

$$P = \prod_{i=1}^{N} P(A_i)$$

$$P = 0.05^5$$

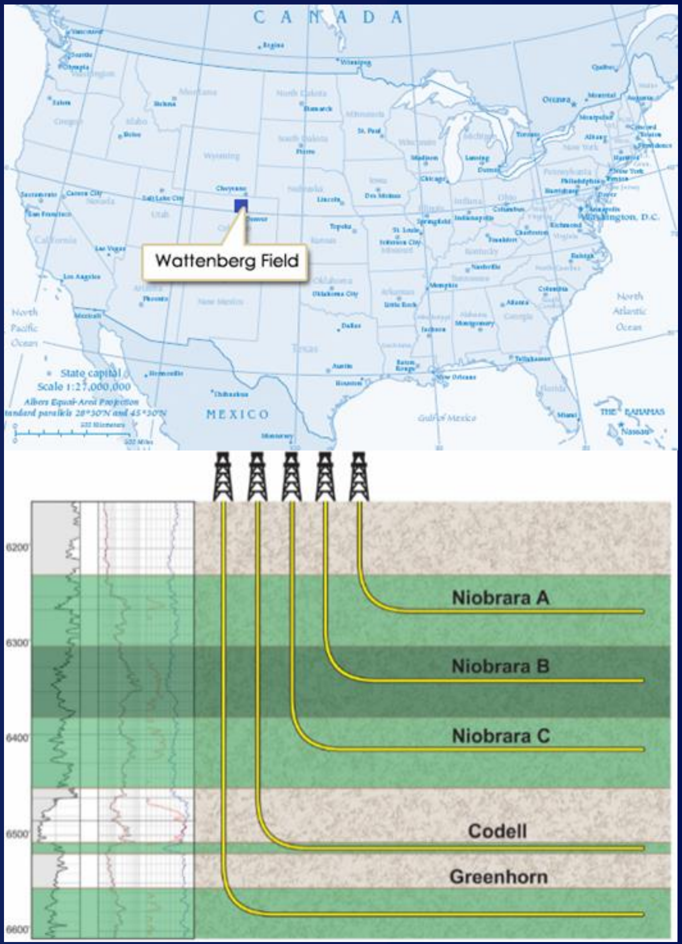
- 1 per 3,200,000 wells.



R.A. Freeze and J.A. Cherry. 1979. *Groundwater*. Prentice Hall. 604pgs.

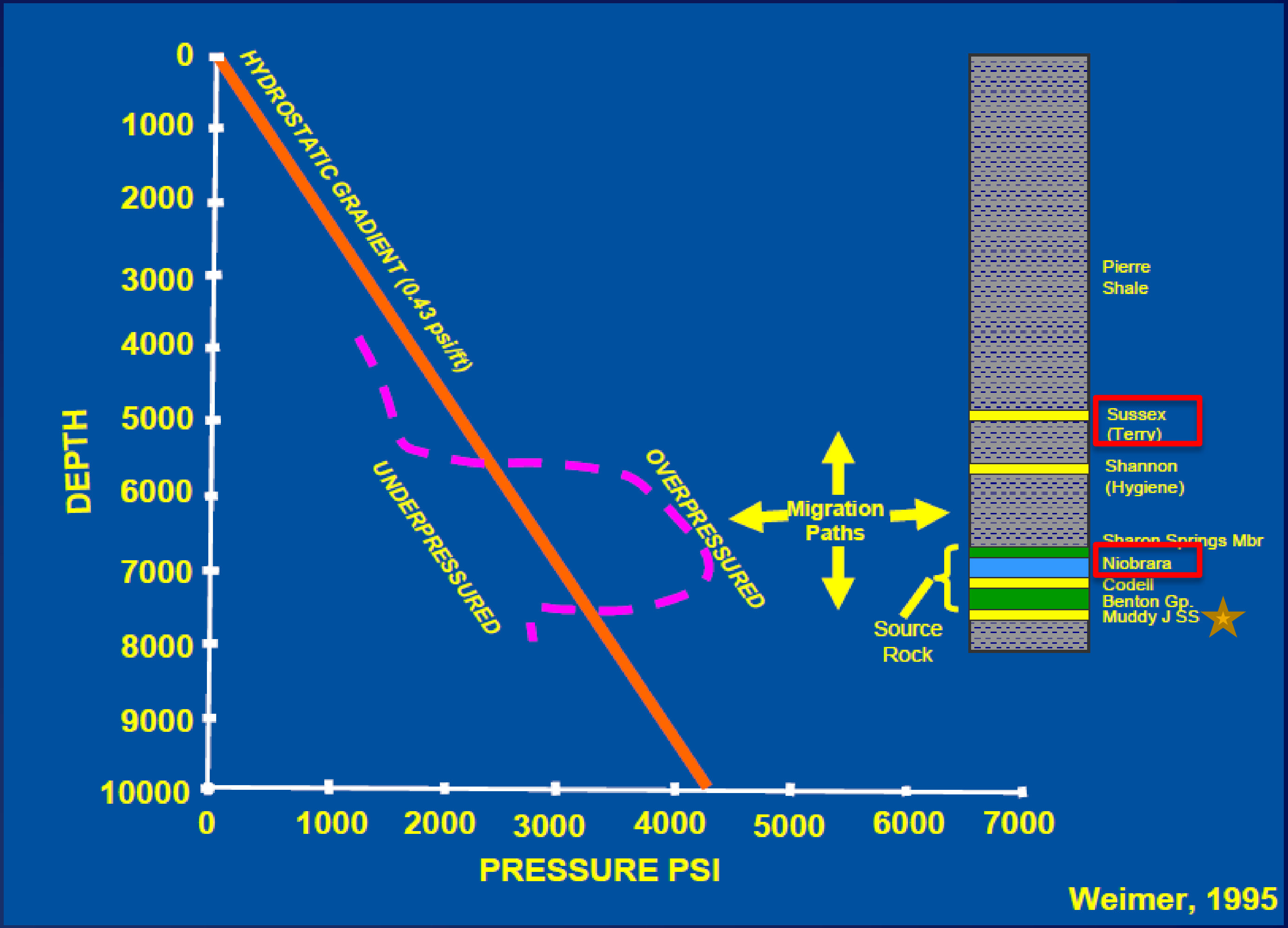
Aquifer Protection Case Study

- The Wattenberg Field near Denver, CO.
- Data from 17,948 oil wells (1970 – 2013).
- Wells were classified by construction types.
- **<u>Possible barrier failures</u>**:
  - Remedial cementing below the surface casing
  - Possible presence of Sustained Annular Pressure
- **<u>Catastrophic barrier failures</u>**:
  - Thermogenic gas detected in offset water wells combined with barrier failure in an adjacent well.



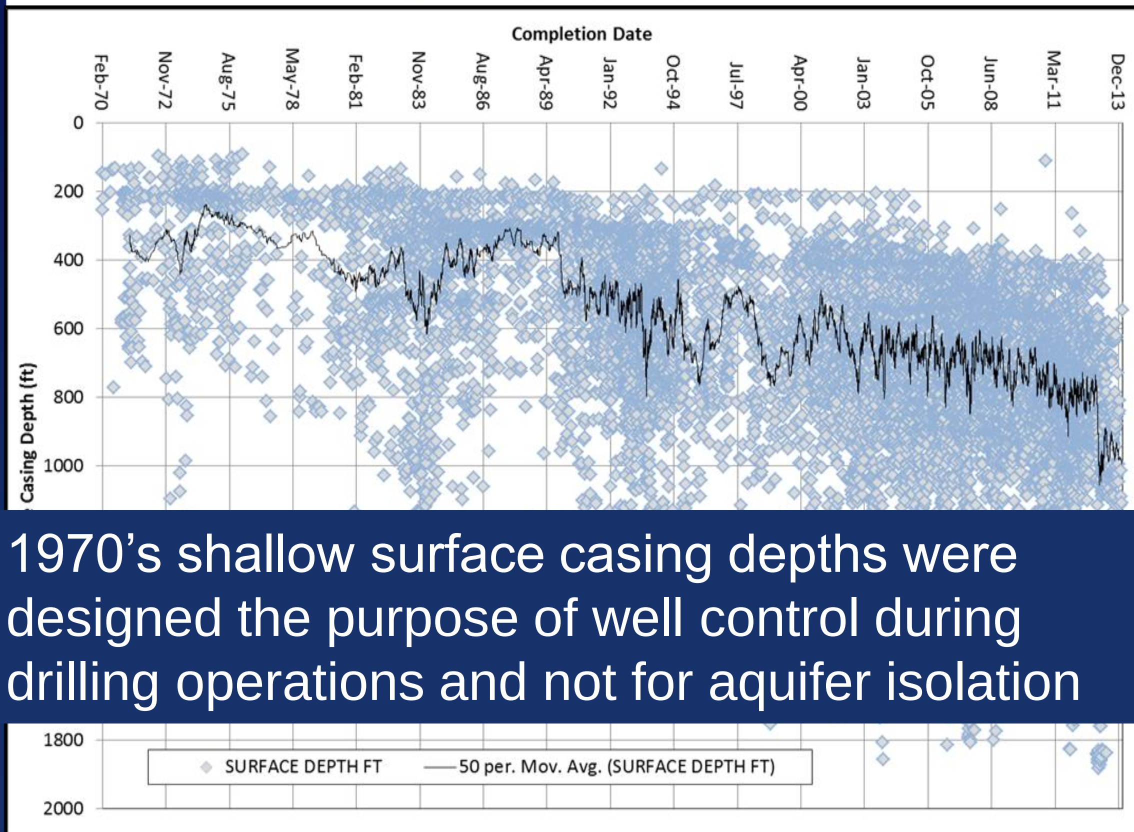
Bonanza Creek

Wattenberg Pressure Profile

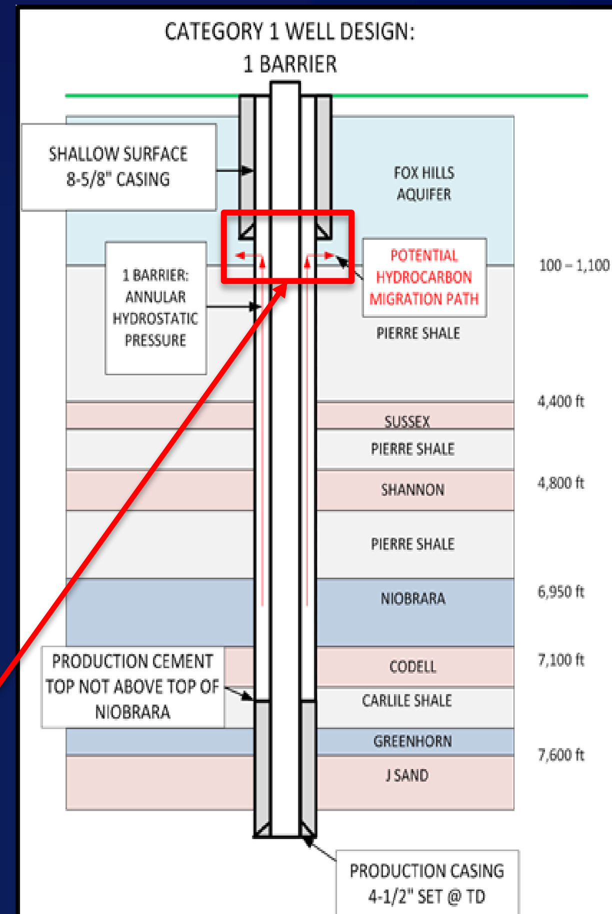


Surface Casing Setting Depths

Historical surface casing setting depths pre-cement remediation.



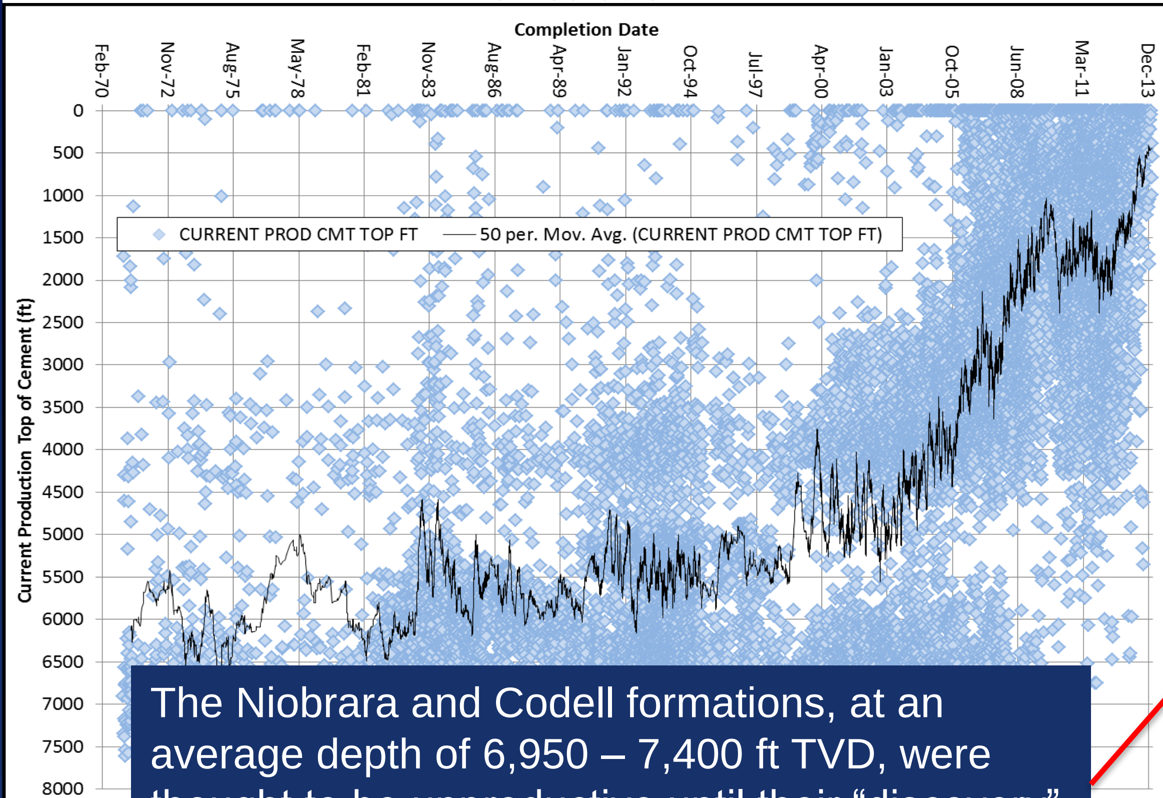
1970's shallow surface casing depths were designed the purpose of well control during drilling operations and not for aquifer isolation



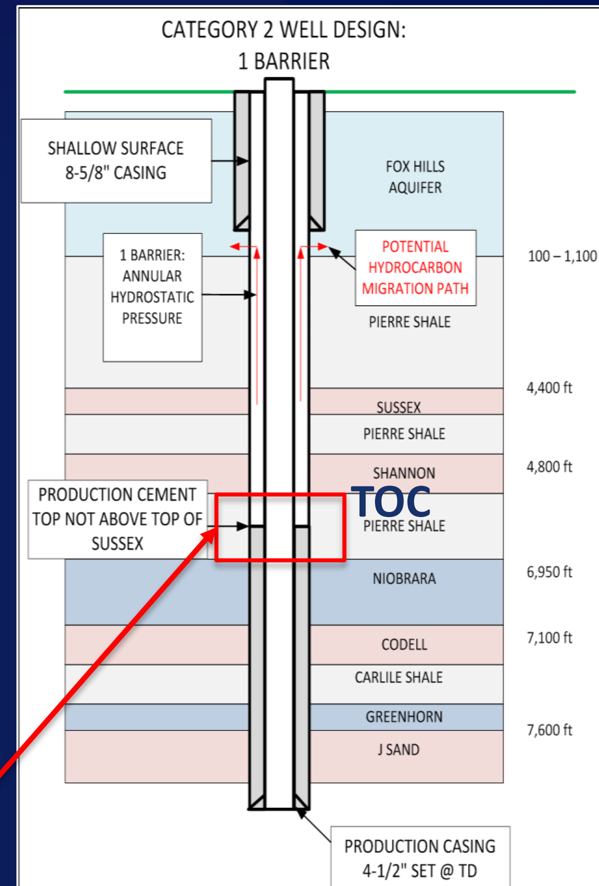
SPE-175401-MS • An Assessment of Risk of Migration to Fresh Water Aquifers: • Fleckenstein

Cementing Practices

Historical production top of cement (TOC) depths post-cement remediation.



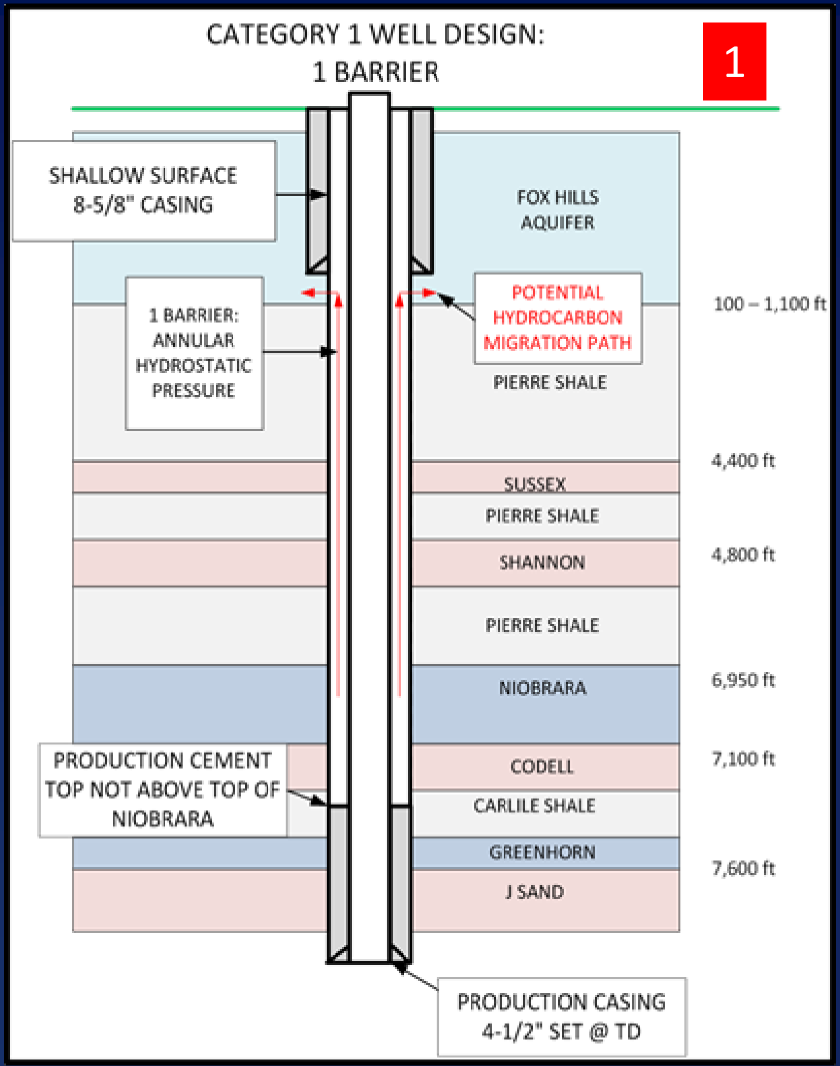
The Niobrara and Codell formations, at an average depth of 6,950 – 7,400 ft TVD, were thought to be unproductive until their “discovery” in the early 1980’s.

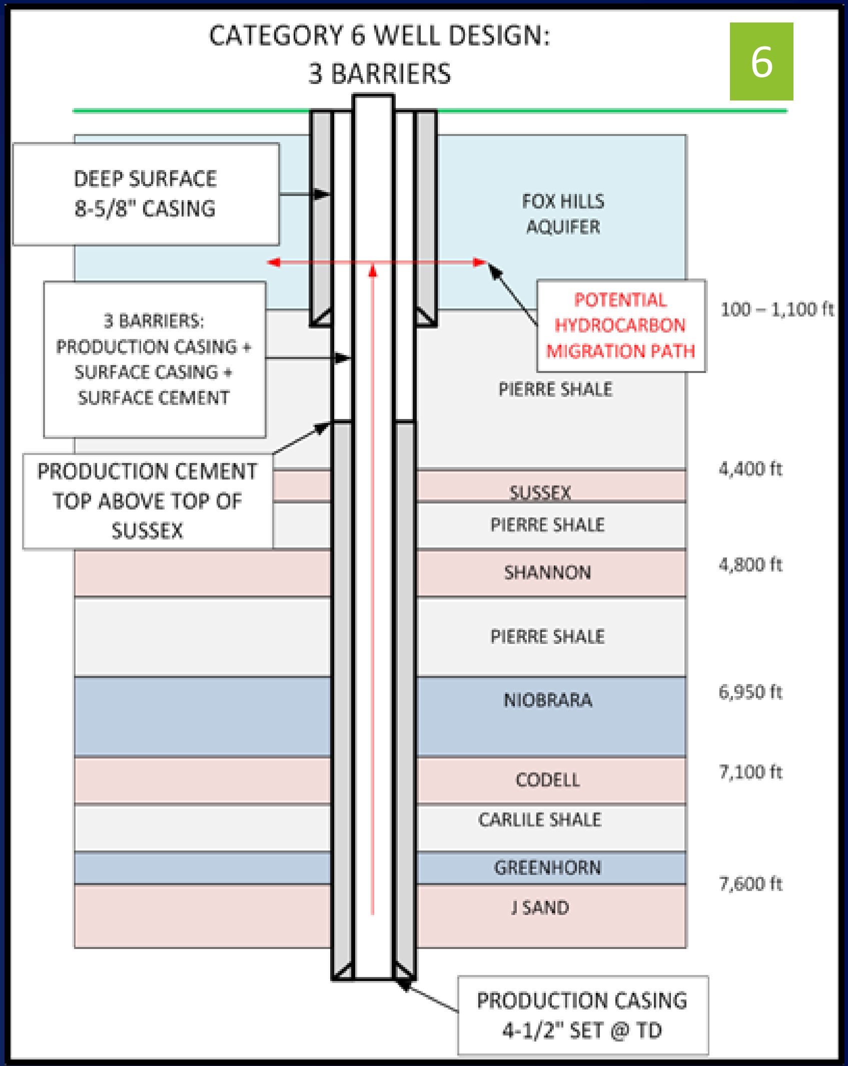


Well Design Risks

CATEGORY	DESCRIPTION
1	SHALLOW SURFACE CASING + TOP OF PRODUCTION CASING CEMENT BELOW OVER PRESSURED HYDROCARBON RESERVOIR
2	SHALLOW SURFACE CASING + TOP OF PRODUCTION CASING CEMENT BELOW UNDER PRESSURED HYDROCARBON RESERVOIR
3	SHALLOW SURFACE CASING + TOP OF PRODUCTION CASING CEMENT ABOVE TOP OF GAS
4	SHALLOW SURFACE CASING + TOP OF PRODUCTION CASING CEMENT ABOVE SURFACE CASING SHOE
5	DEEP SURFACE CASING + TOP OF PRODUCTION CASING CEMENT BELOW UNDER PRESSURED HYDROCARBON RESERVOIR
6	DEEP SURFACE CASING + TOP OF PRODUCTION CASING CEMENT ABOVE TOP OF GAS
7	DEEP SURFACE CASING + TOP OF PRODUCTION CASING CEMENT ABOVE SURFACE CASING SHOE

Wellbore Design Impacts





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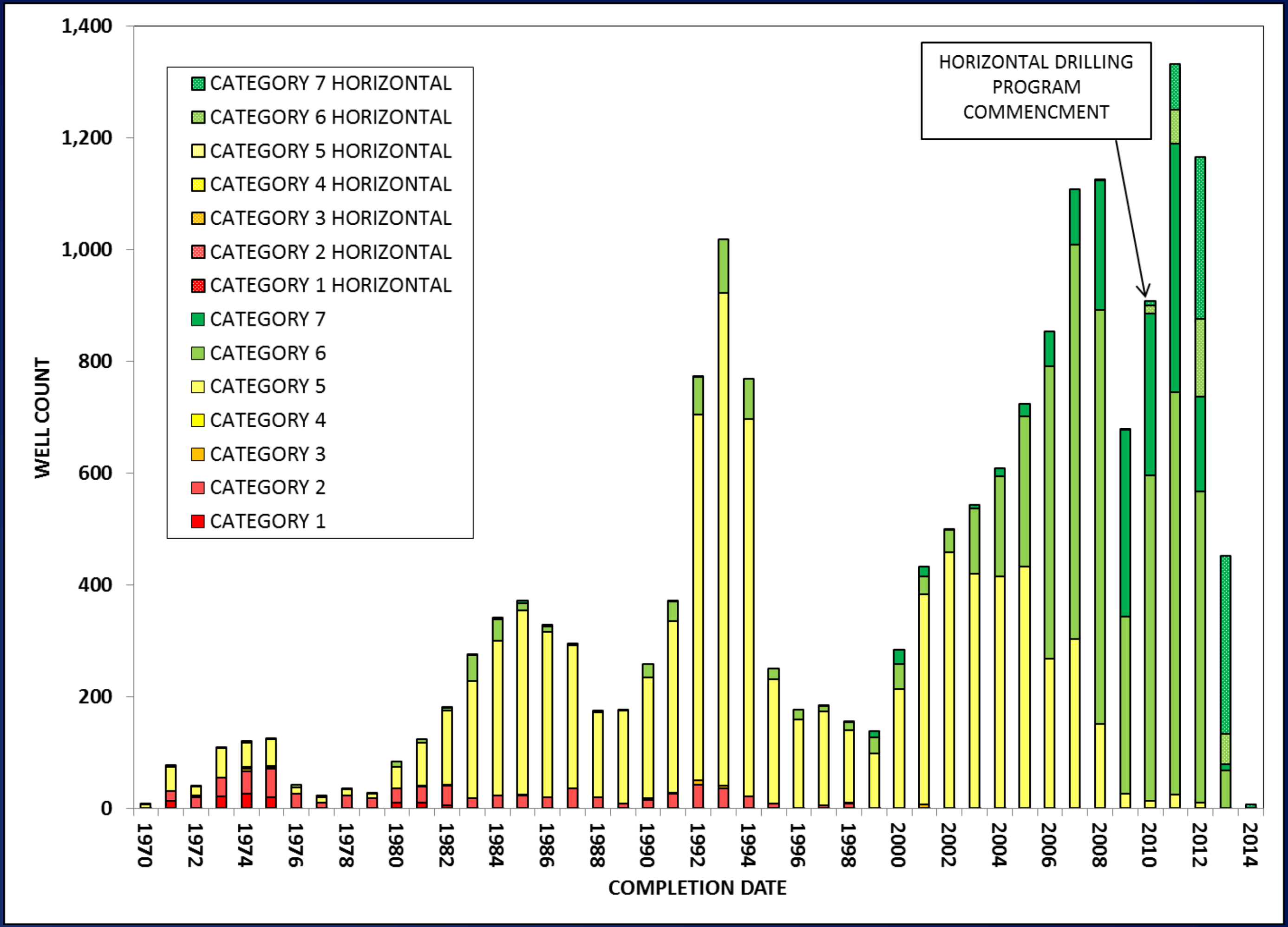
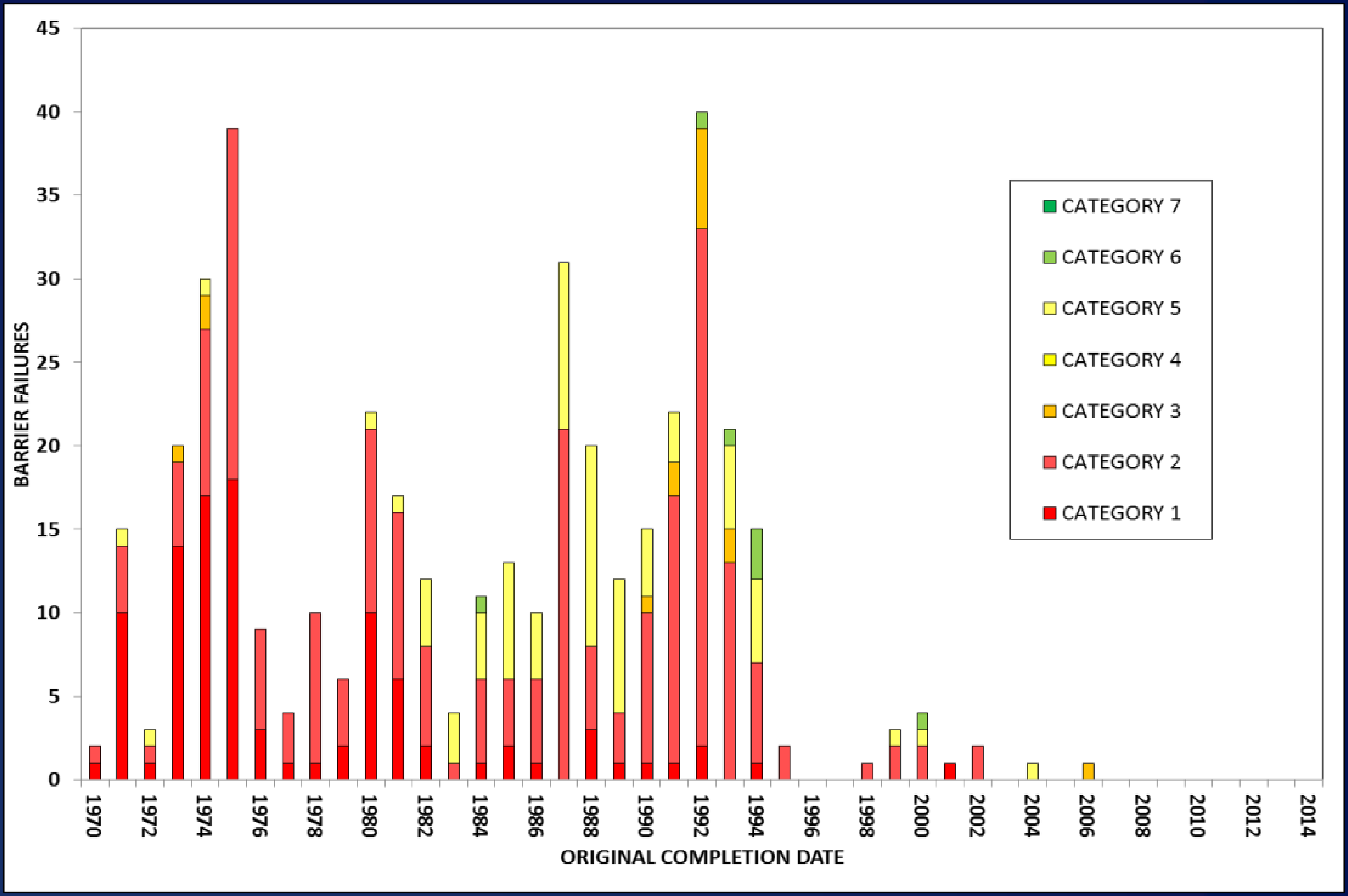
Well Designs in Use



Well Barrier Possible Failures



Potential and Catastrophic Barrier Failures

VERTICAL AND DEVIATED WELLS

	ORIGINAL WELL COUNT	POTENTIAL BARRIER FAILURES	POTENTIAL BARRIER FAILURE %	CATASTROPHIC BARRIER FAILURES	CATASTROPHIC BARRIER FAILURE %	AVG COMPLETION DATE	P&A WELL COUNT	CURRENT WELL COUNT	ORIGINAL AVG SURFACE CASING DEPTH (FT)	ORIGINAL AVG TOP OF PRODUCTION CEMENT (FT)
CATEGORY 1	166	100	60.24%	3	1.81%	1979	57	15	253	7,334
CATEGORY 2	621	219	35.27%	5	0.81%	1983	138	301	306	6,566
CATEGORY 3	46	16	34.78%	1	2.17%	1987	14	31	321	4,008
CATEGORY 4	7	0	0.00%	0	0.00%	1982	1	15	222	125
CATEGORY 5	8,789	77	0.88%	1	0.01%	1995	782	6,140	559	6,111
CATEGORY 6	5,433	6	0.11%	0	0.00%	2007	105	7,181	712	2,816
CATEGORY 7	1,766	0	0.00%	0	0.00%	2009	8	2,040	719	534
TOTAL	**16,828**	**418**	**2.48%**	**10**	**0.06%**		**1,105**	**15,723**		
D&A	**147**									

SPE-181696 • An Assessment of the Probability… • Fleckenstein

973 horizontal wells (Categories 6 and 7) have had neither potential or catastrophic barrier failures

Contamination Probability Hypothesis – Did it work?

Probability of hydrocarbon migration

$$P = 0.05^3 \qquad\qquad P_{act} = 0.024^3$$

1 per 8,000 wells – original hypothesis

10 per 17,950 wells (1 per 1,795)

– actual (4 times larger) – Why??

9 per 833 *poorly* constructed wells

1 per 15,995 *well* constructed wells

Summary

1. Aquifers can be protected against “fracking”.

2. Migration of natural gas in wellbores occurs, but infrequently.

3. The probability of potential and catastrophic failure of one or more barriers increases with poor well construction methods.

4. *Most* of the failures occur on wells with *shallow surface casing* set above the base of the aquifer.

5. Horizontal wells for shale development benefit from the historical improvement in well construction methods.

6. Wells cannot be identified as a generic well location for statistical studies. The well construction methods will dominate subsurface impacts.

Acknowledgments

- This research is supported in part by the AirWaterGas Sustainability Research Network funded by the National Science Foundation under Grant No. CBET-1240584. Any opinion, findings, and conclusions or recommendations expressed in this presentation are those of the author and does not necessarily reflect the views of the United States National Science Foundation.