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Modeling *versus* The Real World Of Hydraulic Fracturing

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Objectives

- Overview of potential migration pathways
- Identify and discuss key fate and transport (F&T) modeling parameters
- Review available data for key F&T parameters
- Identify data gaps and discuss implications for EPA study

Potential HF Related Migration Pathways

- Surface releases of HF and flowback fluids
  - Migration to groundwater
  - Migration to surface water
- Subsurface migration of HF additives (upward migration) to drinking water aquifers
  - Migration from the target zone

Sensitive F&T Model Parameters

- Key model “source” characterization information for surface release simulations
  - Spill volume
  - Spill area
  - Chemical constituents/concentrations in spilled fluid
- Source characterization considerations for migration from bedrock (upward migration)
  - Fraction of trapped HF fluid/ flowback (e.g., 9 to 35% in Marcellus shale, 68 to 82% in CBM)
  - Geochemistry of brine and HF additives in target formation

Sensitive F&T Model Parameters

- Surface Releases: Key parameters that typically control transport downgradient from source area
  - Hydraulic conductivity of soils and aquifers
  - Direction and magnitude of hydraulic gradient relative to drinking water well locations
  - Biodegradation of organic chemicals
  - Adsorption
- Upward Migration: Factors that control potential vertical migration of subsurface fluids
  - Direction and magnitude of natural head gradient
  - Bedrock stratigraphy and hydraulic properties
  - Distance between HF induced fractures and drinking water units
  - Strength of attenuation processes

Sensitive F&T Model Parameters (cont)

- Key sensitive F&T parameters can be grouped into four general categories:
  - Source chemical characterization
  - Surface release
  - Upward migration
  - Hydrogeological and attenuation processes

- Available data, gaps, and modeling challenges for each of these categories are discussed as follows

Source Chemical Characterization

- HF additives
  - Halliburton and other service companies have provided EPA-requested data
  - EPA should be able to use this information to assess F&T characteristics of HF fluids
- Flowback characterization
  - Data for Marcellus shale is being continually generated (e.g., Hayes, 2009; NYSDEC, 2009; The Palmerton Group, 2011), other formations are also being analyzed
- EPA should identify key marker HF-related compounds for F&T evaluation
  - HF additives vary by job and formation
  - Appropriate to identify group of marker compounds

Flowback Quality Variability

Sample	#1	#2	#3	#4	#5	#6	#7	#8	#9
Formation	Woodford Shale	Woodford Shale	Woodford Shale	Marcellus Shale	Marcellus Shale	Marcellus Shale	Marcellus Shale	Bakken Shale	Bakken Shale
Specific gravity	1.026	1.036	1.019	1.012	1.070	1.100	1.170	1.105	1.066
pH	7.92	7.51	7.91	6.61	6.72	6.68	6.05	7.11	7.04
Resistivity (ohms-cm)	20.42	14.87	36.46	54.93	8.363	6.342	4.776	5.585	8.057
Temperature (˚C)	23	23	23	23	23	23	23	23	23
Ionic Strength	0.59	0.881	0.319	0.199	1.919	2.794	4.96	2.874	1.754
Hydroxide (mpL)	0	0	0	0	0	0	0	0	0
Carbonate (mpL)	0	0	0	0	0	0	0	0	0
Bicarbonate (mpL)	1,010	717	1190	259	183	183	76	366	366
Chloride (mpL)	19,400	29,400	10,000	6,290	59,700	87,700	153,000	96,400	58,300
Sulfate (mpL)	34	0	88	67	0	0	0	670	749
Calcium (mpL)	630	1,058	294	476	7,283	10,210	20,100	4,131	2,573
Magnesium (mpL)	199	265	145	49.6	599	840	1,690	544	344.0
Barium (mpL)	49.4	94.8	6.42	6.24	278	213	657	1.06	5.1
Strontium (mpL)	107	179	44.7	74.3	2,087	2,353	5,049	178	112
Total Iron (mpL)	4.73	25.7	8.03	14	27.4	2.89	67.6	26.4	33.8
Aluminum (mpL)	0.17	0.21	0.91	0.38	0.18	0	0.1	0.17	0.78
Silica (mpL)	33.8	–	40.7	–	–	–	–	–	–
Baron (mpL)	28.2	27.1	26.7	8.82	45.1	73.1	80.4	94.5	65.7
Potassium (mpL)	192	273	78.7	85.8	977	1,559	2,273	2,232	1,439
Sodium (mpL)	10,960	16,450	5,985	3,261	26,780	39,990	61,400	54,690	32,600
TDS (mpL)	**33,300**	**49,300**	**18,200**	**10,800**	**98,600**	**144,000**	**252,000**	**160,000**	**97,700**
TSS (mpL)	57	246	50	30	10	12	32	120	13,762
TOC (mpL)	89	64	133	180	218	70	143	266	235

Surface Releases

- Understanding “actual” spill characteristics critical for evaluating release significance and F&T modeling
  - E.g., spill volume, area, location
- Spill databases maintained by various states (e.g., PA, CO, WV)
  - Data are difficult to extract (by public) to perform meaningful statistical analysis
  - If EPA has access, would be useful to characterize the size and frequency of spills associated with HF stimulations

Data Collected As Part of Spill Response Measures

	States Reporting Requirements			
Measurement Type	**CO**	**OH**	**PA**	**WV**
Nature of spill				
Volume or flow rate of spill				
Chemical analysis/identity/kind of spilled fluid				
Area and vertical extent of spill				
Distance to nearest surface water, water wells, groundwater				

Unclear, but may include this information

Spill volume is required for brine spills, but unclear for other spills

Required

Number of Oil and Gas Well Permits For Wells Drilled Directionally From Common Well Pads in Colorado
03-07-11

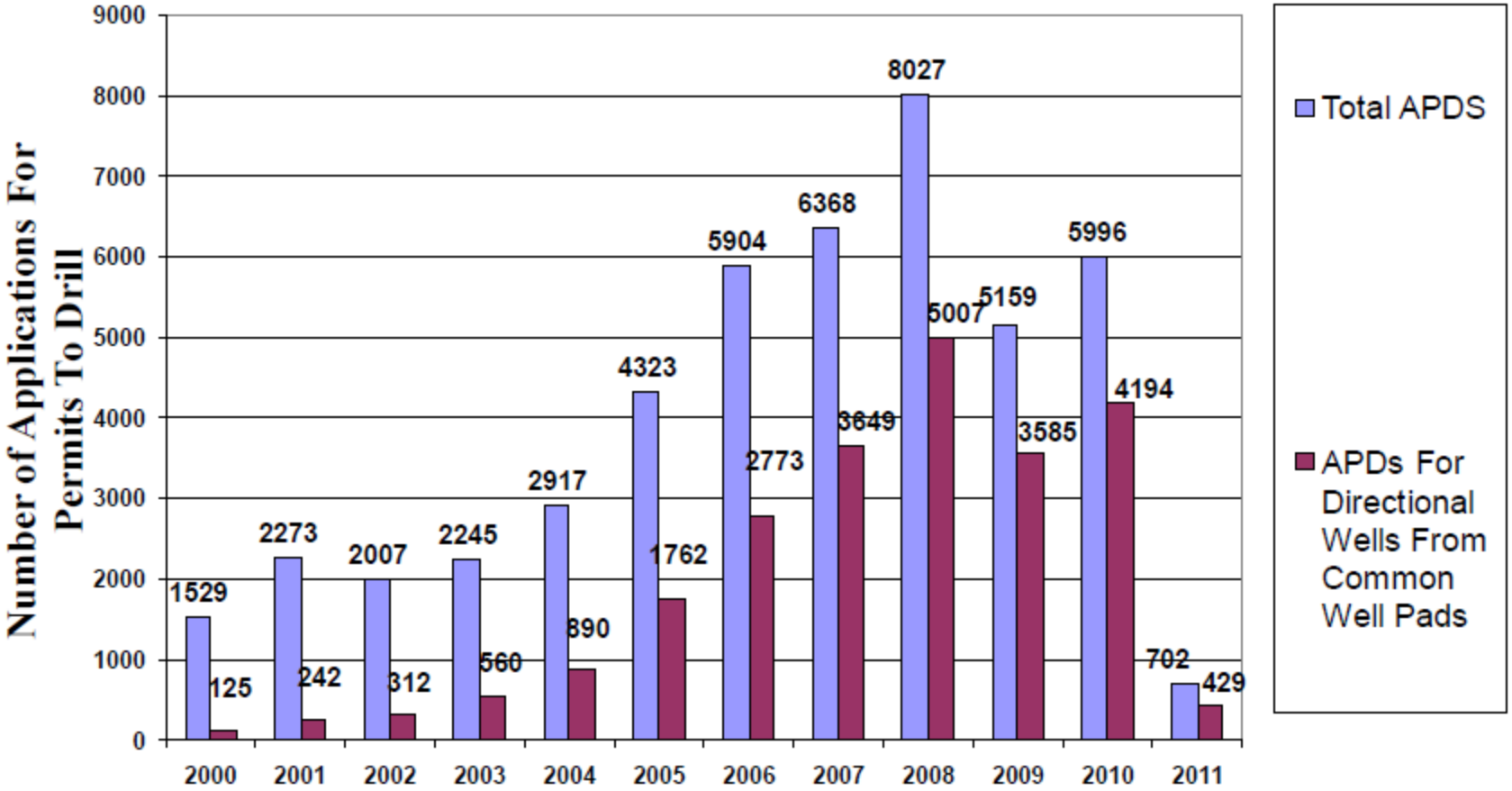
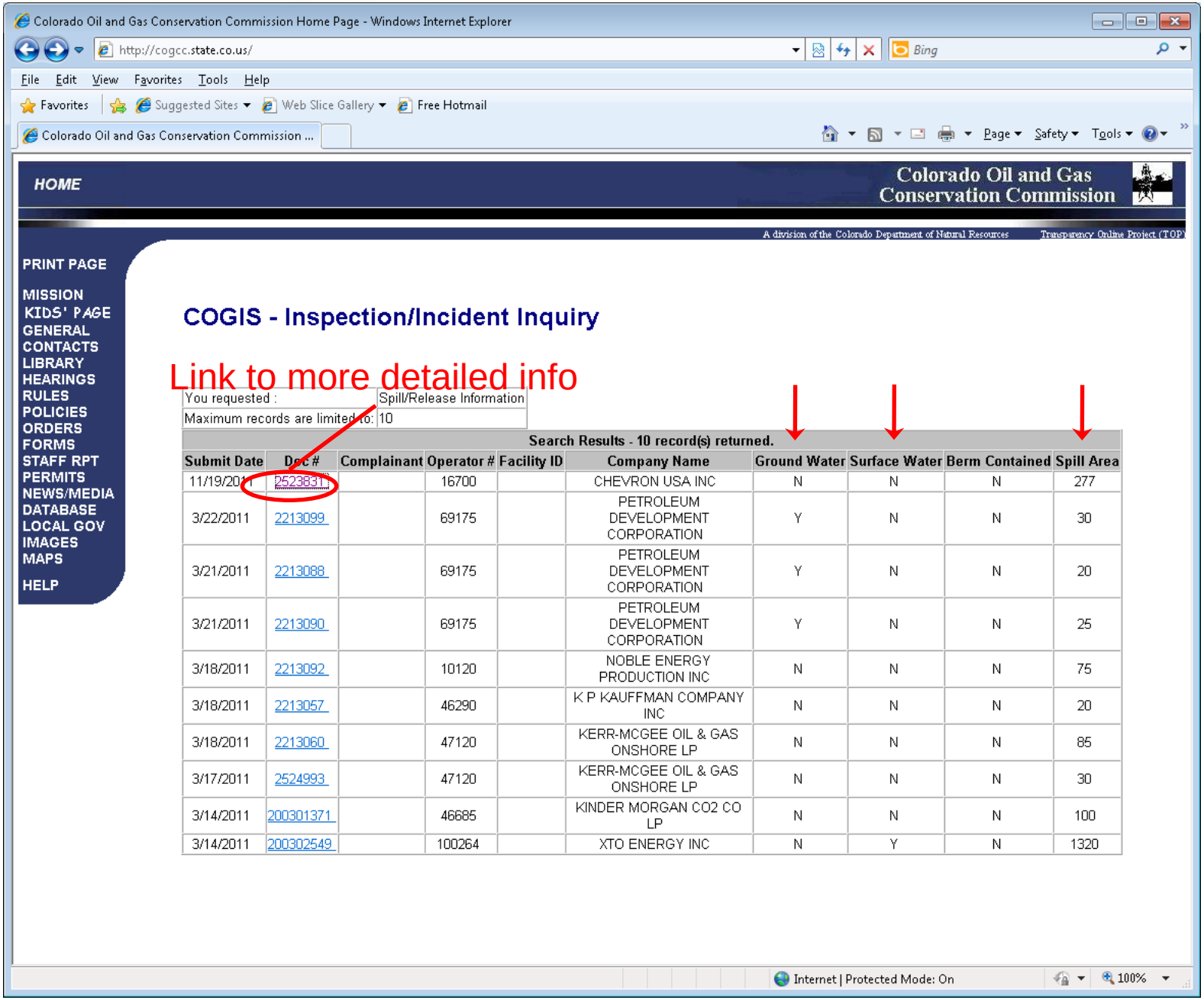
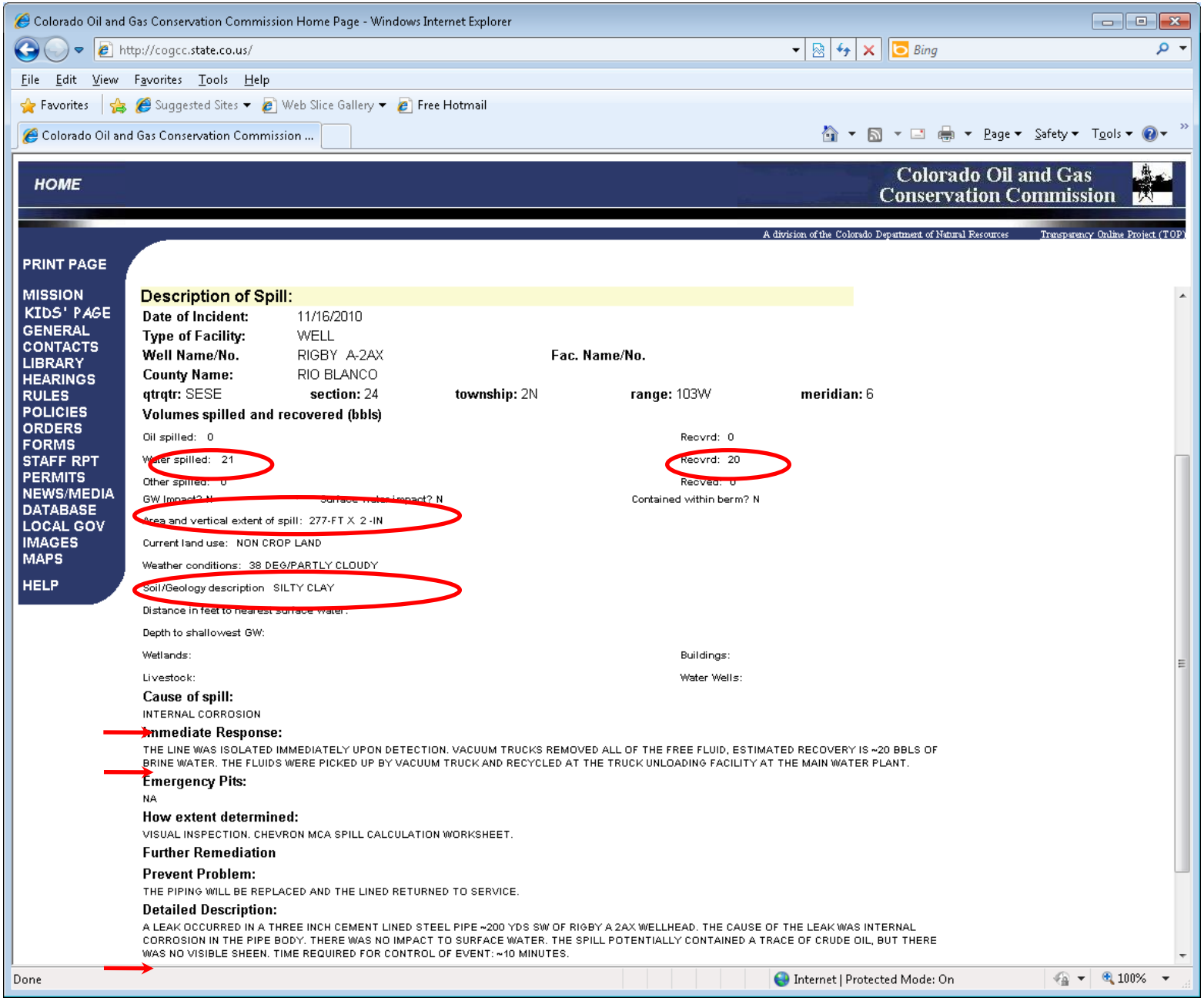


Figure from the COGCC website, Weekly & Monthly Oil & Gas Statistics





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Upward Migration

- Data collected at the time of well installation and stimulation
  - Could be used to perform screening level analysis to assess migration potential to drinking water aquifers
- Modeling of field conditions impracticable
  - Not aware of any standard models that can simulate transport processes
  - Data requirements to develop/calibrate a model make this unrealistic
- Migration of “stray gas” also common issue
  - Understanding F&T and modeling a challenge

Data Currently Reported During Well Installation and Stimulation

	States Reporting Requirements			
Measurement Type	**CO**	**OH**	**PA**	**WV**
Depth interval of stratigraphic units				
Depth interval of freshwater aquifers				
Depth interval of brines				
Depth of target formation				
Casing/wellbore size, type, and depth				
Electrical, radioactive or other geophysical logging				
Core/drill cutting analyses/logs				
Formation water chemical analysis				
Flowback chemical analysis				
Type and volume of fluid used to stimulate the well	a		b	

Only if collected during the course of business

Only if requested by the state

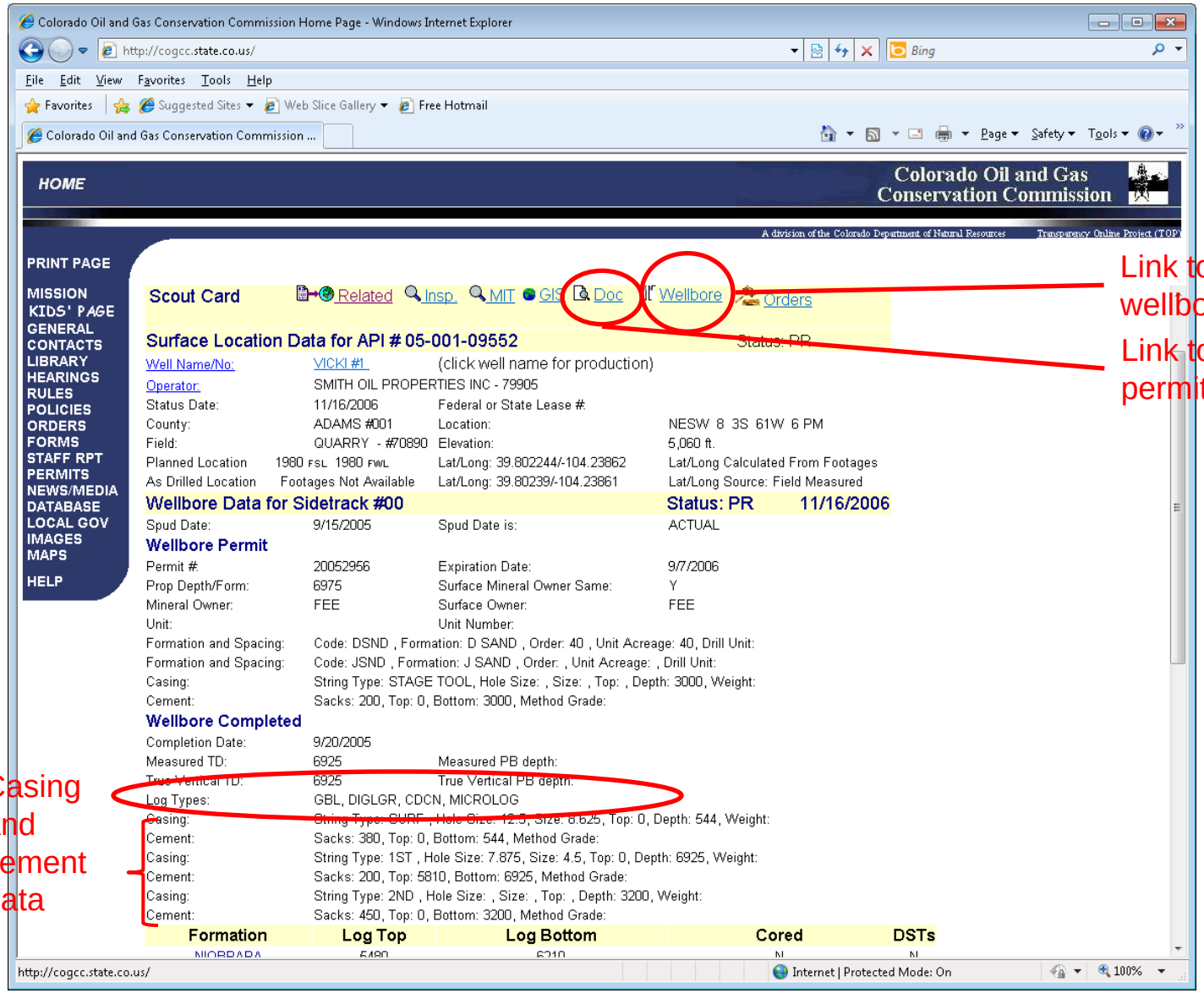
Only if collected during the course of business and requested by the state

Required

Notes:

a) Colorado requires chemical analysis of the injected fluid.

b) Pennsylvania requires operators to list the chemicals or additives used.



Link to diagram of wellbore

Link to reports and permit docs

Casing and cement data

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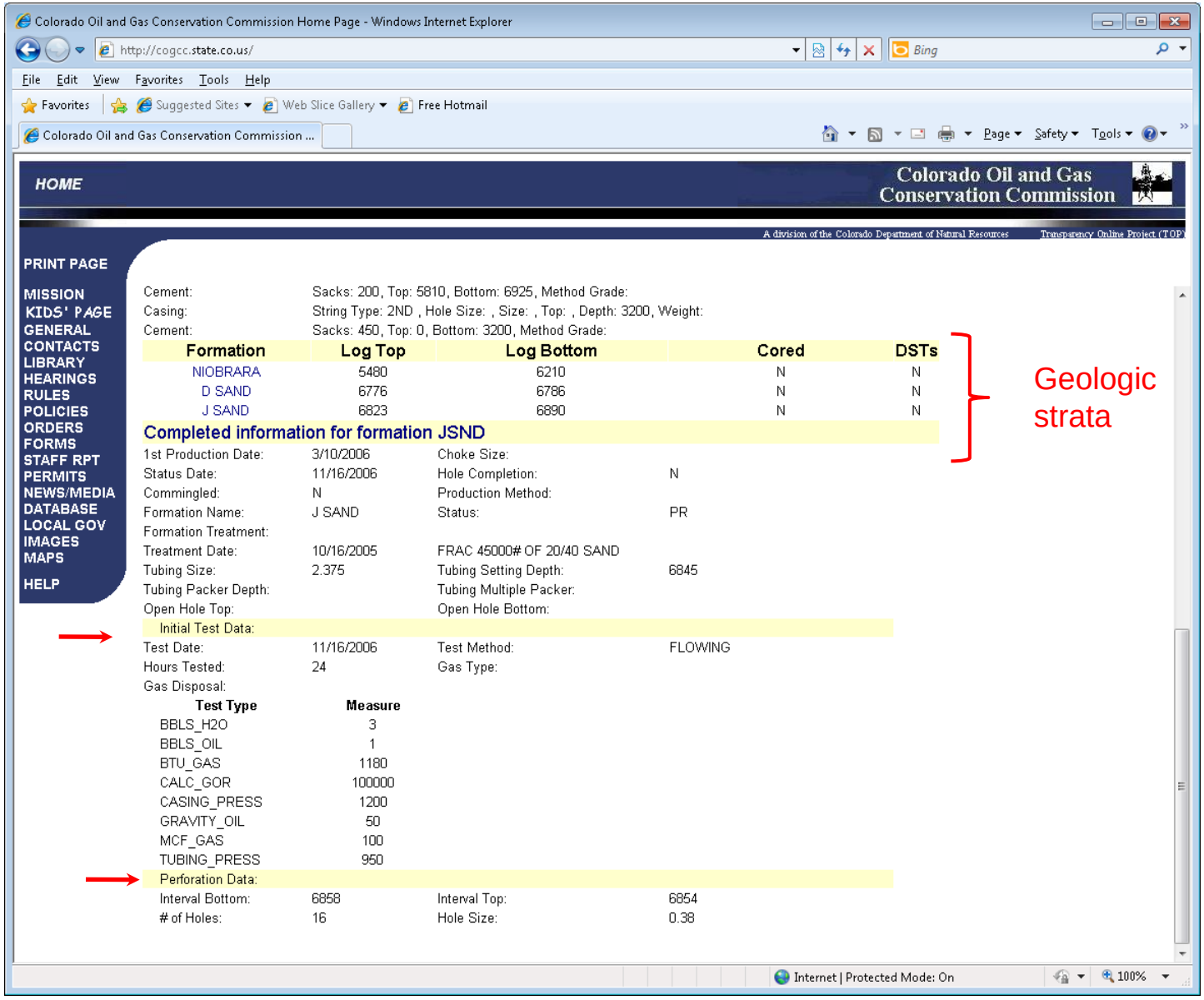

Geologic strata

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Induced Fracture Data

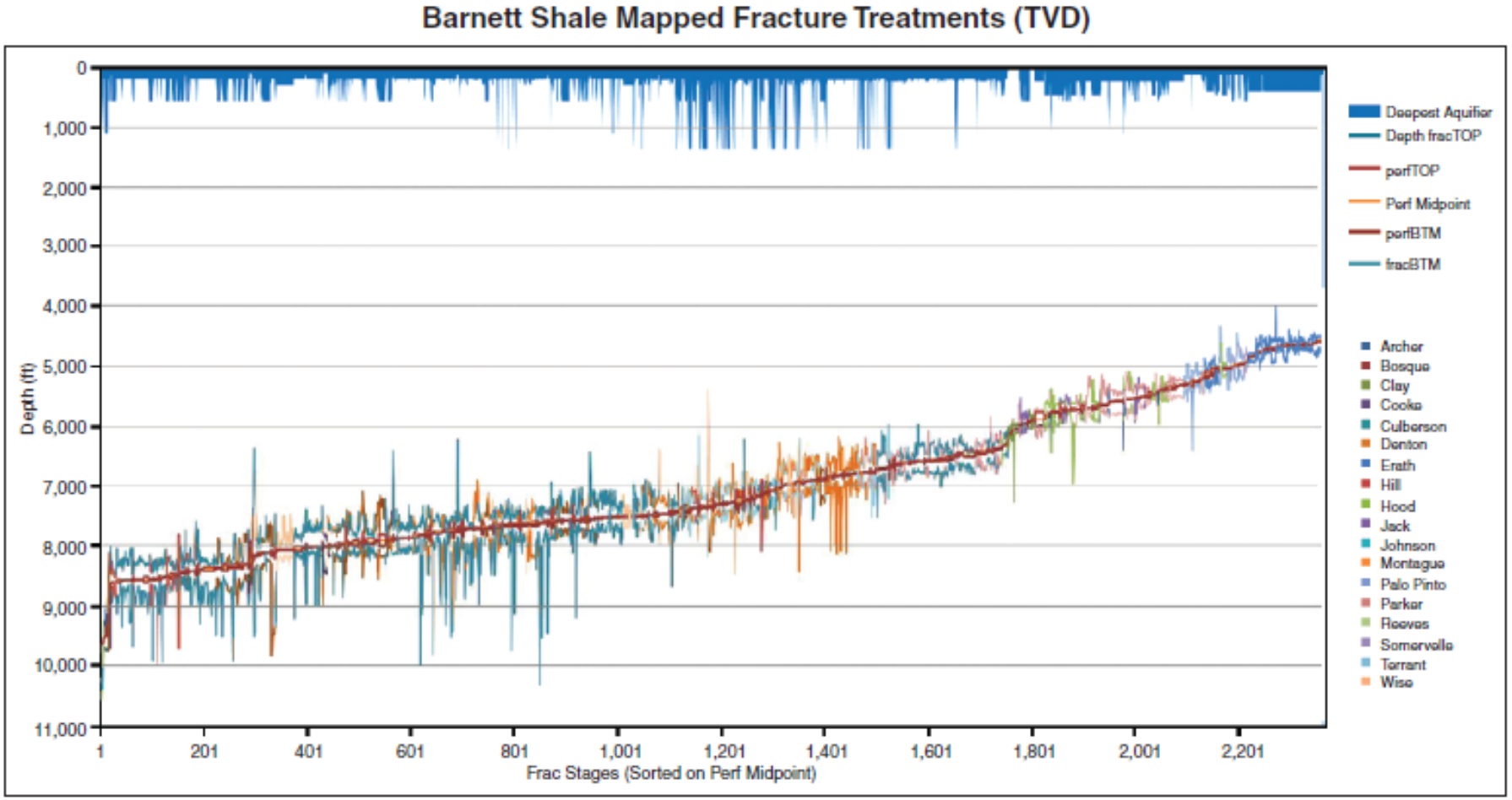

Figure from Fisher, K. 2010.

Induced Fracture Data

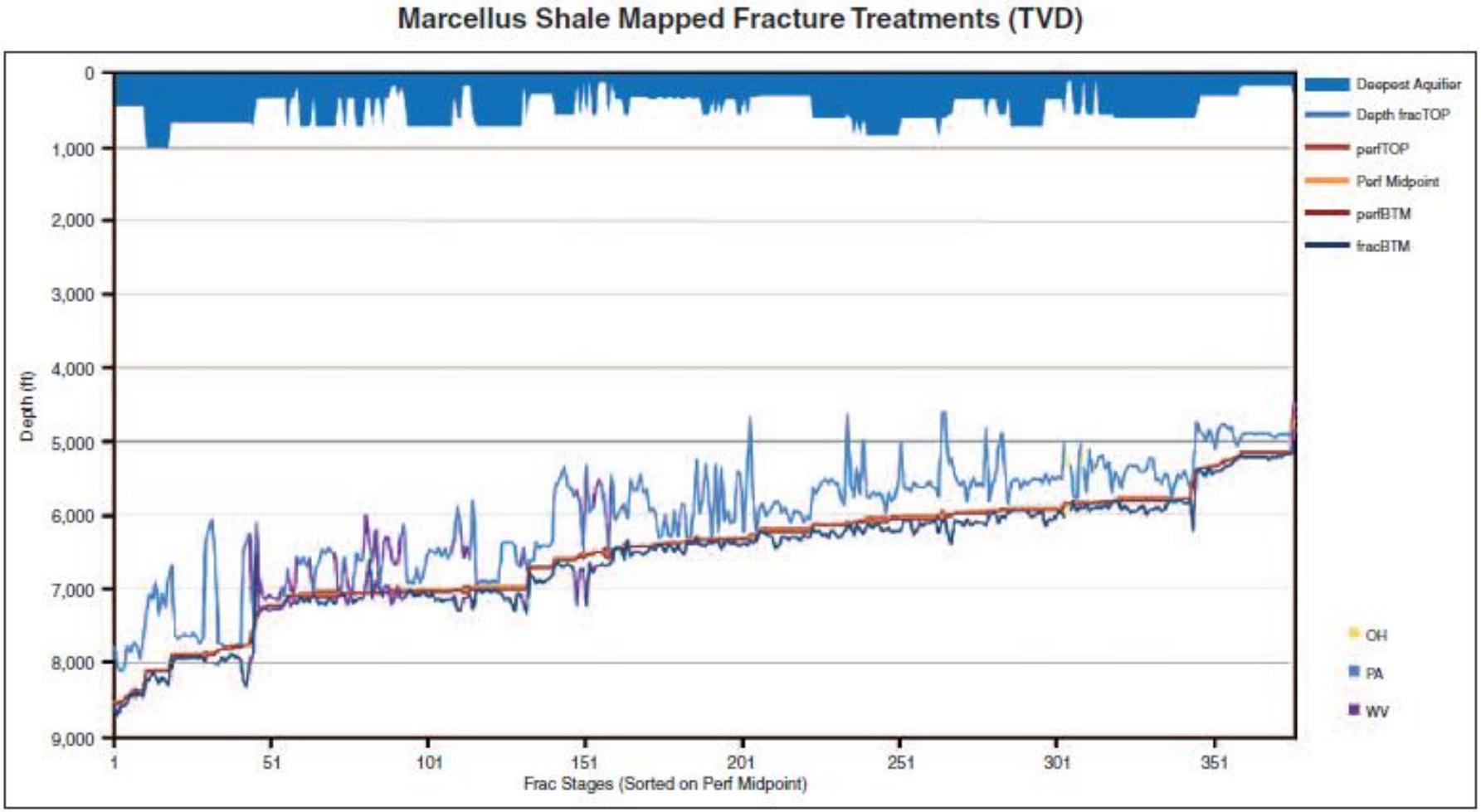

Figure from Fisher, K. 2010.

Stray Gas Migration

- Migration of natural stray methane to drinking water aquifers a common issue – no correlation with fracing
- Old improperly abandoned wells are typically the cause
  - Serve as preferential migration pathway
  - EPA's 2004 study found this to be a significant mechanism in investigated case studies
- Understanding communication of such wells to stray gas reservoirs and drinking water aquifers is difficult
  - No standard tests available for measuring such communication
  - Case-by-case analysis needed
- Credible modeling of such scenarios likely not possible
- Proper abandonment is the key to the solution

Hydrogeological & Attenuation Processes

- Hydrogeological and attenuation data (e.g., hydraulic gradient, conductivity) typically not collected as part of HF jobs
- However, extensive data available in the literature for F&T analyses, especially for surface releases
- Attenuation process expected to have a significant influence on HF additives F&T in shales
  - High organic carbon resulting in high retardation
  - Biodegradation expected to be significant due to long travel times
  - Nonetheless, modeling of such processes will be challenging

Overall Implications for EPA Study

- Key data required for F&T evaluations are available
  - E.g., spill databases, gas well construction details
  - Data will provide perspective on relatively low frequency and magnitude of spill incidents, distance to drinking water aquifers
  - Some gaps exist, but can be addressed by using literature values/ limited data collection
- HF fluid composition data and flowback characterization data are also available
  - Additive information provided by Halliburton and others
  - Flowback data are being continually generated
- EPA should utilize all data and assess human health risks associated with drinking water
  - EPA study draft places significant emphasis on case studies
  - Unclear how broad conclusions will be drawn on the basis of a few case studies
  - EPA should instead conduct a human health risk assessment that utilizes all available information including that from case studies

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