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HALLIBURTON

Modeling *versus* The Real World Of Hydraulic Fracturing

Denise A. Tuck, P.E.
Global Manager, Chemical Compliance

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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

Measurement Type	States Reporting Requirements			
	CO	OH	PA	WV
Nature of spill	Required	Required	Required	Required
Volume or flow rate of spill	Required	Required	Spill volume is required for brine spills, but unclear for other spills	Required
Chemical analysis/identity/kind of spilled fluid	Required	Required	Unclear, but may include this information	Required
Area and vertical extent of spill	Required	Required	Required	Unclear, but may include this information
Distance to nearest surface water, water wells, groundwater	Required	Required	Required	Required

	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

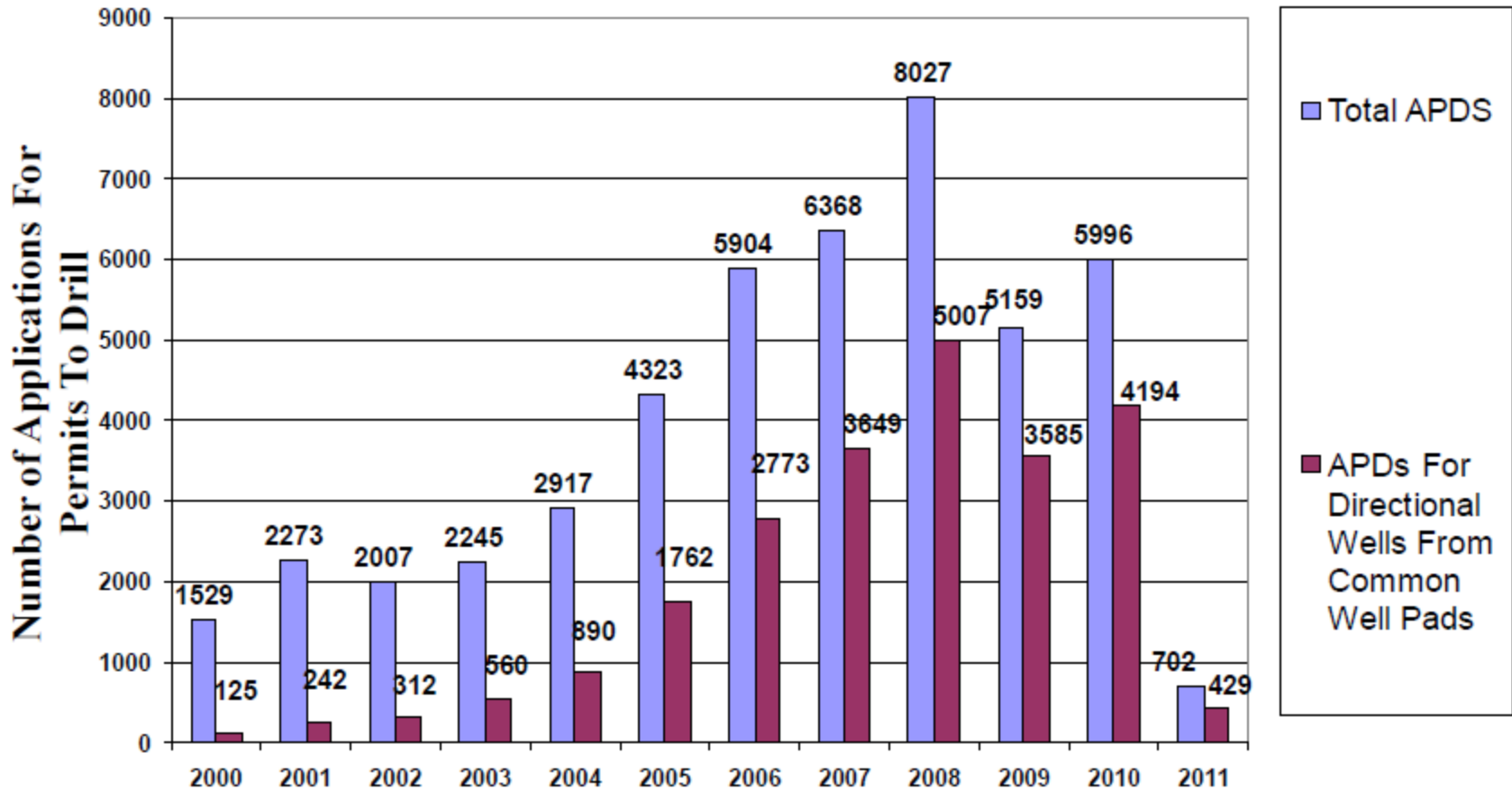


Figure from the COGCC website, Weekly & Monthly Oil & Gas Statistics

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COGIS - Inspection/Incident Inquiry

Link to more detailed info

You requested :
 Maximum records are limited to:

Search Results - 10 record(s) returned.

Submit Date	Doc #	Complainant	Operator #	Facility ID	Company Name	Ground Water	Surface Water	Berm Contained	Spill Area
11/19/2011	2523831		16700		CHEVRON USA INC	N	N	N	277
3/22/2011	2213099		69175		PETROLEUM DEVELOPMENT CORPORATION	Y	N	N	30
3/21/2011	2213088		69175		PETROLEUM DEVELOPMENT CORPORATION	Y	N	N	20
3/21/2011	2213090		69175		PETROLEUM DEVELOPMENT CORPORATION	Y	N	N	25
3/18/2011	2213092		10120		NOBLE ENERGY PRODUCTION INC	N	N	N	75
3/18/2011	2213057		46290		K P KAUFFMAN COMPANY INC	N	N	N	20
3/18/2011	2213060		47120		KERR-MCGEE OIL & GAS ONSHORE LP	N	N	N	85
3/17/2011	2524993		47120		KERR-MCGEE OIL & GAS ONSHORE LP	N	N	N	30
3/14/2011	200301371		46685		KINDER MORGAN CO2 CO LP	N	N	N	100
3/14/2011	200302549		100264		XTO ENERGY INC	N	Y	N	1320

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Description of Spill:

Date of Incident: 11/16/2010
Type of Facility: WELL
Well Name/No.: RIGBY A-2AX **Fac. Name/No.**
County Name: RIO BLANCO
qtqrt: SESE **section:** 24 **township:** 2N **range:** 103W **meridian:** 6

Volumes spilled and recovered (bbls)

Oil spilled: 0	Recvrd: 0
Water spilled: 21	Recvrd: 20
Other spilled: 0	Recvrd: 0
GW Impact? N	Surface Water Impact? N
Contained within berm? N	

Area and vertical extent of spill: 277-FT X 2 -IN

Current land use: NON CROP LAND

Weather conditions: 38 DEG/PARTLY CLOUDY

Soil/Geology description: SILTY CLAY

Distance in feet to nearest surface water:

Depth to shallowest GW:

Wetlands: **Buildings:**

Livestock: **Water Wells:**

Cause of spill:
INTERNAL CORROSION

Immediate Response:
THE LINE WAS ISOLATED IMMEDIATELY UPON DETECTION. VACUUM TRUCKS REMOVED ALL OF THE FREE FLUID, ESTIMATED RECOVERY IS ~20 BBLs OF BRINE WATER. THE FLUIDS WERE PICKED UP BY VACUUM TRUCK AND RECYCLED AT THE TRUCK UNLOADING FACILITY AT THE MAIN WATER PLANT.

Emergency Pits:
NA

How extent determined:
VISUAL INSPECTION. CHEVRON MCA SPILL CALCULATION WORKSHEET.

Further Remediation

Prevent Problem:
THE PIPING WILL BE REPLACED AND THE LINED RETURNED TO SERVICE.

Detailed Description:
A LEAK OCCURRED IN A THREE INCH CEMENT LINED STEEL PIPE ~200 YDS SW OF RIGBY A 2AX WELLHEAD. THE CAUSE OF THE LEAK WAS INTERNAL CORROSION IN THE PIPE BODY. THERE WAS NO IMPACT TO SURFACE WATER. THE SPILL POTENTIALLY CONTAINED A TRACE OF CRUDE OIL, BUT THERE WAS NO VISIBLE SHEEN. TIME REQUIRED FOR CONTROL OF EVENT: ~10 MINUTES.





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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

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

	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.

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Surface Location Data for API # 05-001-09552 Status: PR

Well Name/No. [VICKI #1](#) (click well name for production)

Operator SMITH OIL PROPERTIES INC - 79905

Status Date: 11/16/2006 Federal or State Lease #

County: ADAMS #001 Location: NESW 8 3S 61W 6 PM

Field: QUARRY - #70890 Elevation: 5,060 ft.

Planned Location 1980 FSL 1980 FWL Lat/Long: 39.802244/-104.23862 Lat/Long Calculated From Footages

As Drilled Location Footages Not Available Lat/Long: 39.80239/-104.23861 Lat/Long Source: Field Measured

Wellbore Data for Sidetrack #00 Status: PR 11/16/2006

Spud Date: 9/15/2005 Spud Date is: ACTUAL

Wellbore Permit

Permit #: 20052956 Expiration Date: 9/7/2006

Prop Depth/Form: 6975 Surface Mineral Owner Same: Y

Mineral Owner: FEE Surface Owner: FEE

Unit: Unit Number:

Formation and Spacing: Code: DSND , Formation: D SAND , Order: 40 , Unit Acreage: 40 , Drill Unit:

Formation and Spacing: Code: JSND , Formation: J SAND , Order: , Unit Acreage: , Drill Unit:

Casing: String Type: STAGE TOOL, Hole Size: , Size: , Top: , Depth: 3000, Weight:

Cement: Sacks: 200, Top: 0, Bottom: 3000, Method Grade:

Wellbore Completed

Completion Date: 9/20/2005

Measured TD: 6925 Measured PB depth:

True Vertical TD: 6925 True Vertical PB depth:

Log Types: GBL, DIGLGR, CDCN, MICROLOG

Casing: String Type: CURF , Hole Size: 12.3, Size: 8.625, Top: 0, Depth: 544, Weight:

Cement: Sacks: 360, Top: 0, Bottom: 544, Method Grade:

Casing: String Type: 1ST , Hole Size: 7.875, Size: 4.5, Top: 0, Depth: 6925, Weight:

Cement: Sacks: 200, Top: 5810, Bottom: 6925, Method Grade:

Casing: String Type: 2ND , Hole Size: , Size: , Top: , Depth: 3200, Weight:

Cement: Sacks: 450, Top: 0, Bottom: 3200, Method Grade:

Formation	Log Top	Log Bottom	Cored	DSTs
NIOBADA	6480	6310	N	N

http://cogcc.state.co.us/ Internet | Protected Mode: On 100%

Link to diagram of wellbore

Link to reports and permit docs

Casing and cement data

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Cement: Sacks: 200, Top: 5810, Bottom: 6925, Method Grade:

Casing: String Type: 2ND, Hole Size: , Size: , Top: , Depth: 3200, Weight:

Cement: Sacks: 450, Top: 0, Bottom: 3200, Method Grade:

Formation	Log Top	Log Bottom	Cored	DSTs
NIOBRARA	5480	6210	N	N
D SAND	6776	6786	N	N
J SAND	6823	6890	N	N

Completed information for formation JSND

1st Production Date: 3/10/2006 Choke Size:

Status Date: 11/16/2006 Hole Completion: N

Commingled: N Production Method:

Formation Name: J SAND Status: PR

Formation Treatment:

Treatment Date: 10/16/2005 FRAC 45000# OF 20/40 SAND

Tubing Size: 2.375 Tubing Setting Depth: 6845

Tubing Packer Depth: Tubing Multiple Packer:

Open Hole Top: Open Hole Bottom:

Initial Test Data:

Test Date: 11/16/2006 Test Method: FLOWING

Hours Tested: 24 Gas Type:

Gas Disposal:

Test Type	Measure
BBLS_H2O	3
BBLS_OIL	1
BTU_GAS	1180
CALC_GOR	100000
CASING_PRESS	1200
GRAVITY_OIL	50
MCF_GAS	100
TUBING_PRESS	950

Perforation Data:

Interval Bottom: 6858 Interval Top: 6854

of Holes: 16 Hole Size: 0.38

Geologic strata

Induced Fracture Data

Barnett Shale Mapped Fracture Treatments (TVD)

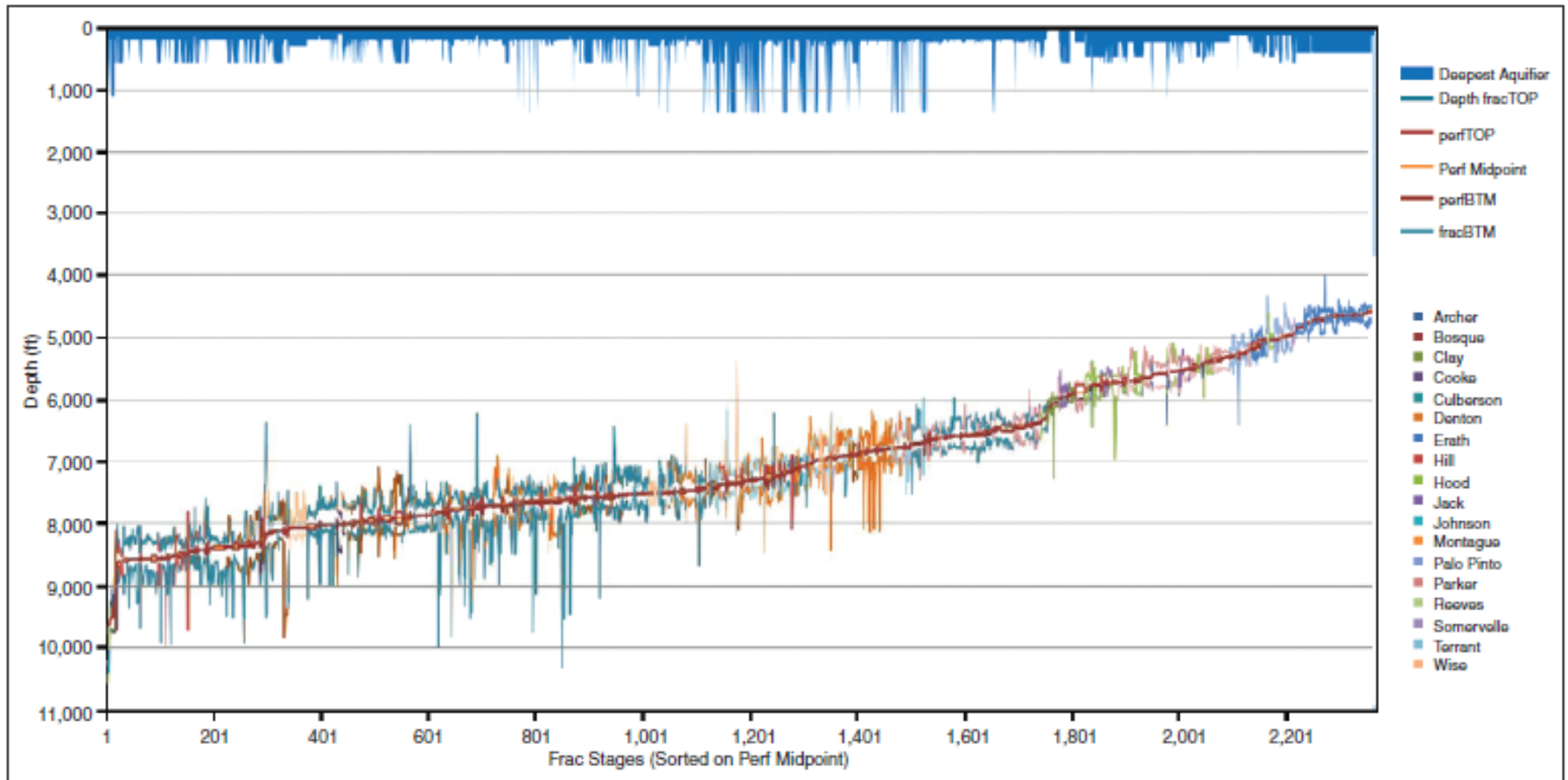


Figure from Fisher, K. 2010.

Induced Fracture Data

Marcellus Shale Mapped Fracture Treatments (TVD)

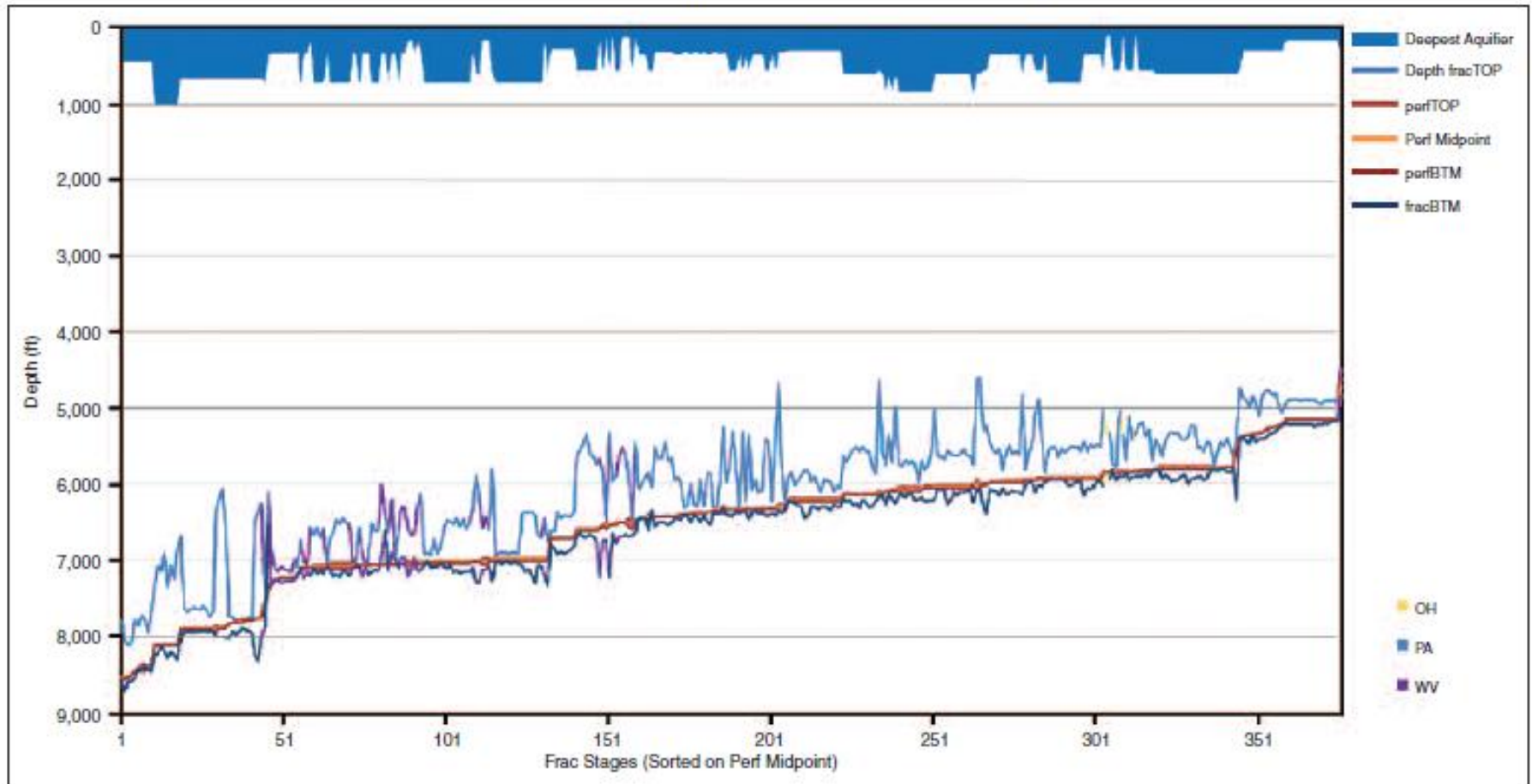


Figure from Fisher, K. 2010.

Stray Gas Migration

- Migration of natural stray methane to drinking water aquifers a common issue – no correlation with fracking
- 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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