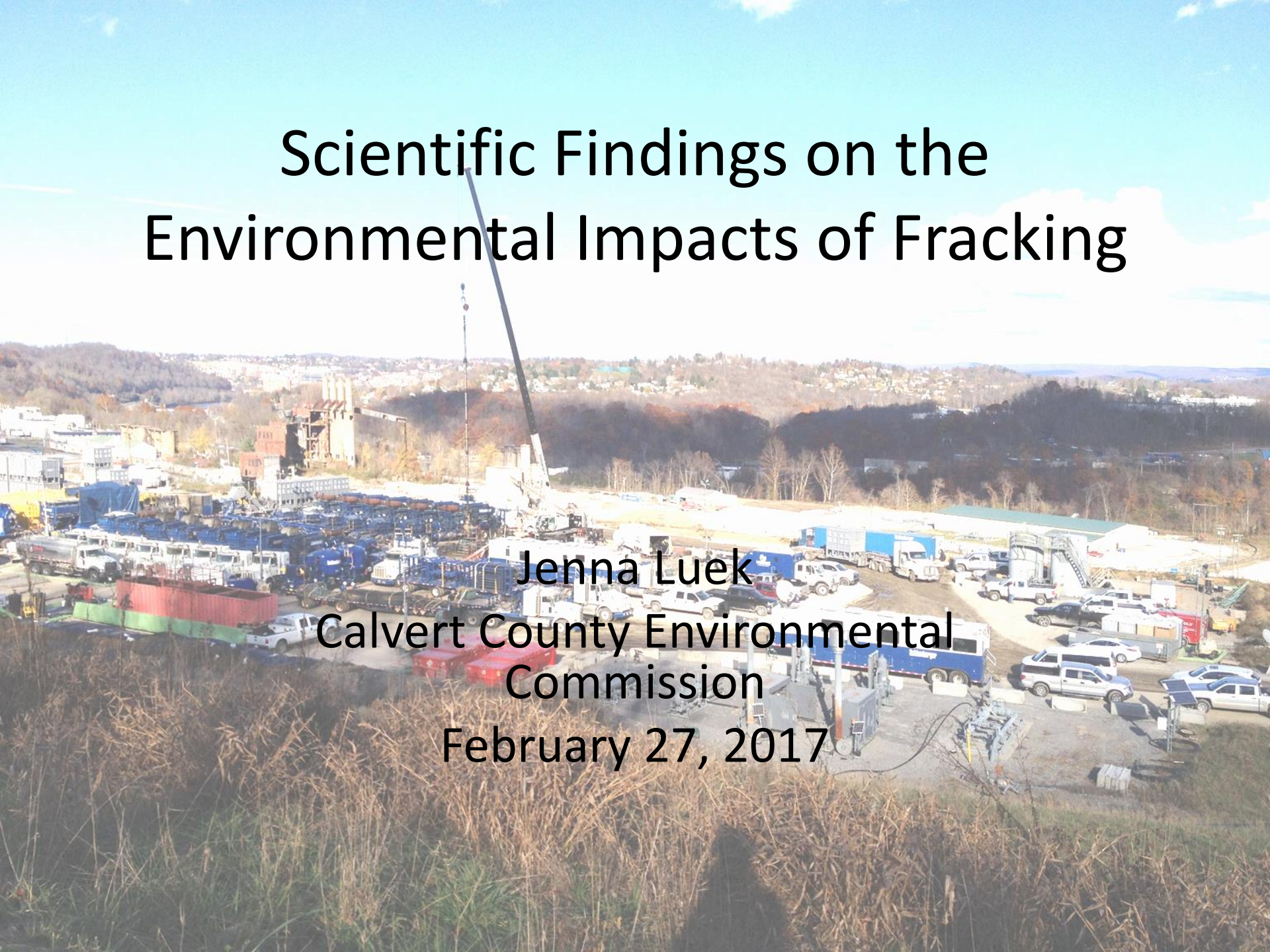
Scientific Findings on the Environmental Impacts of Fracking



Jenna Luek

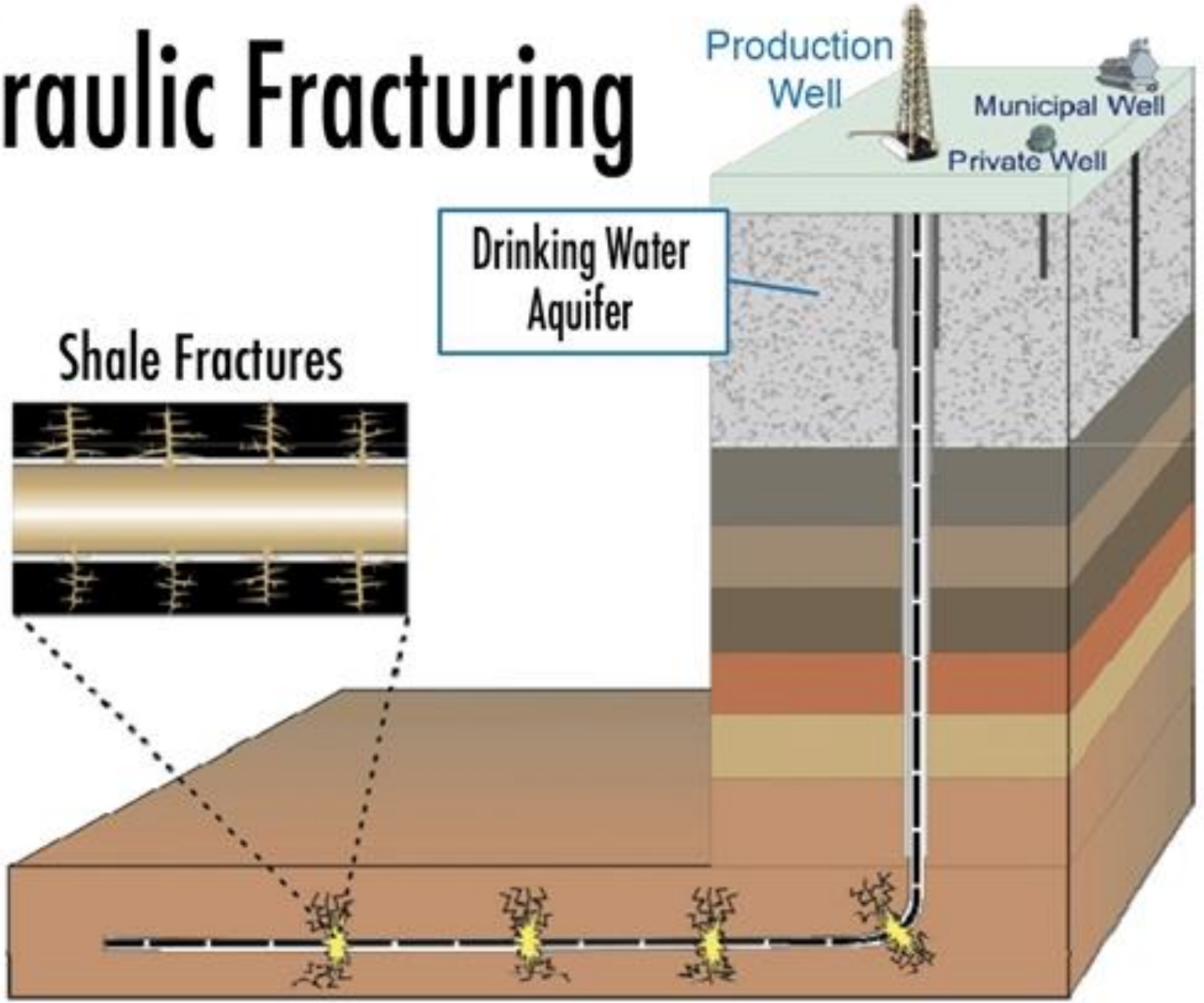
Calvert County Environmental Commission

February 27, 2017

Outline

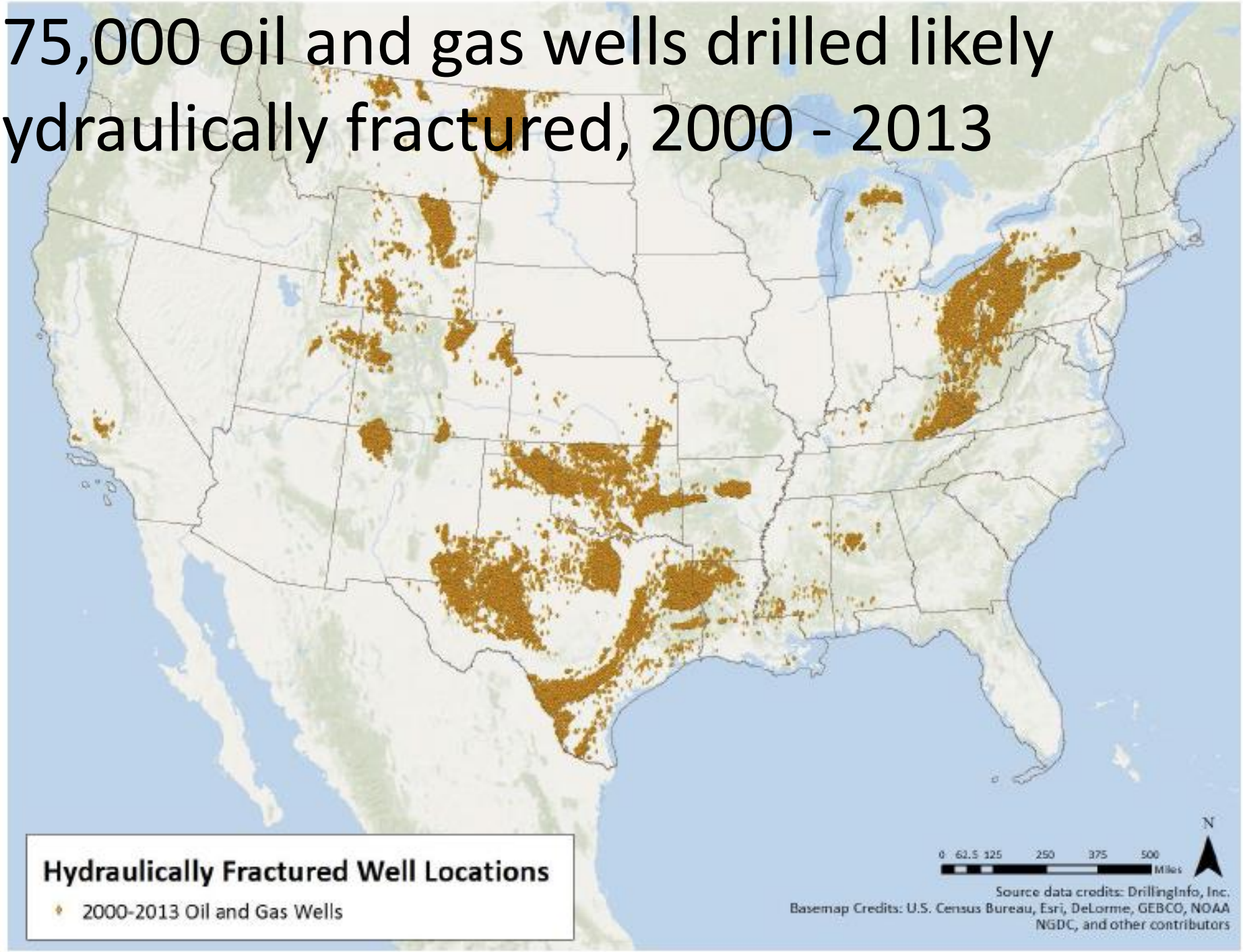
- Fracking in the US
- Water Impacts
  - EPA Hydraulic Fracturing Report (2016)
- Air Quality
- Health Impacts
- Socio-Economic Impacts
- Earthquakes

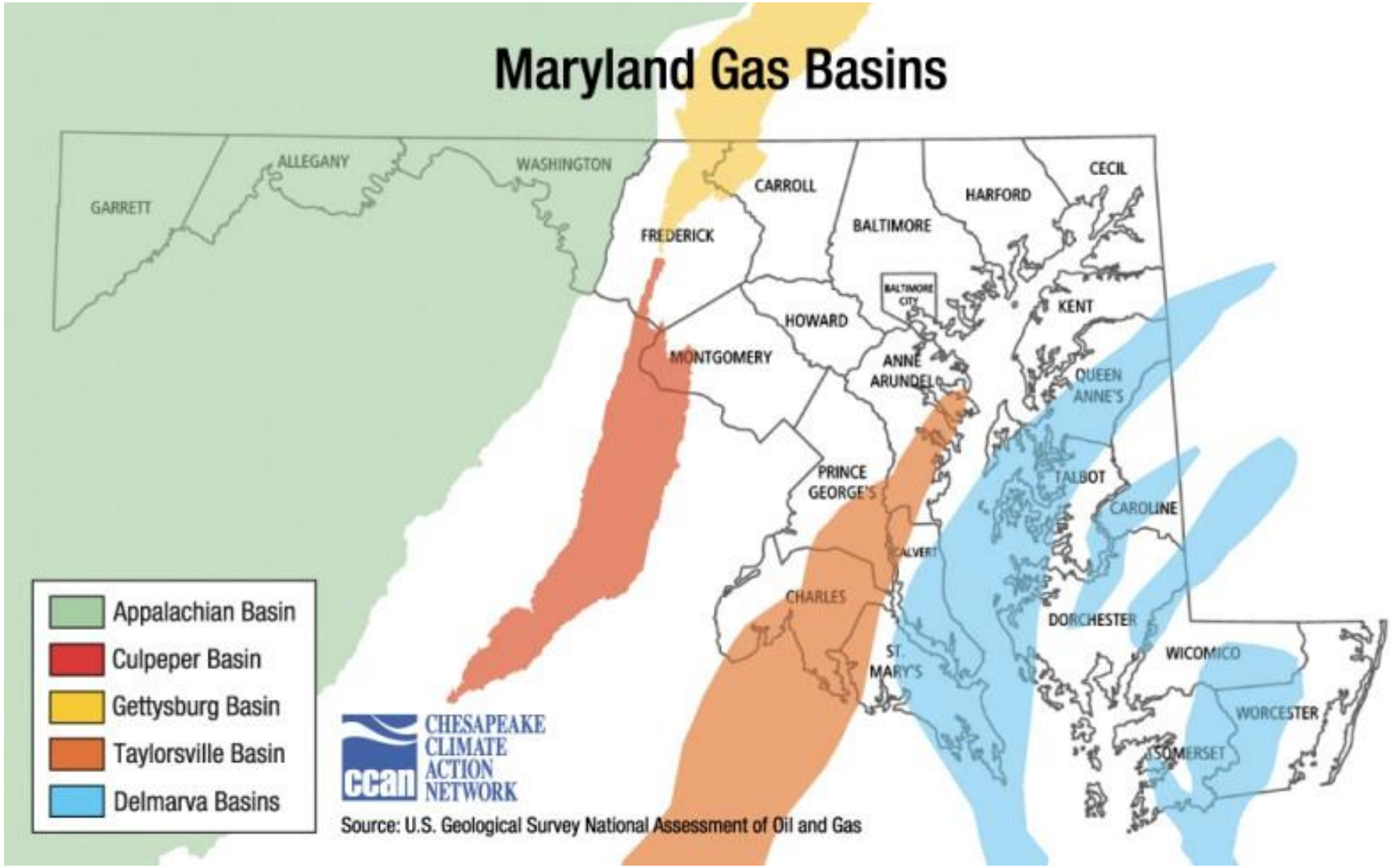
Hydraulic Fracturing

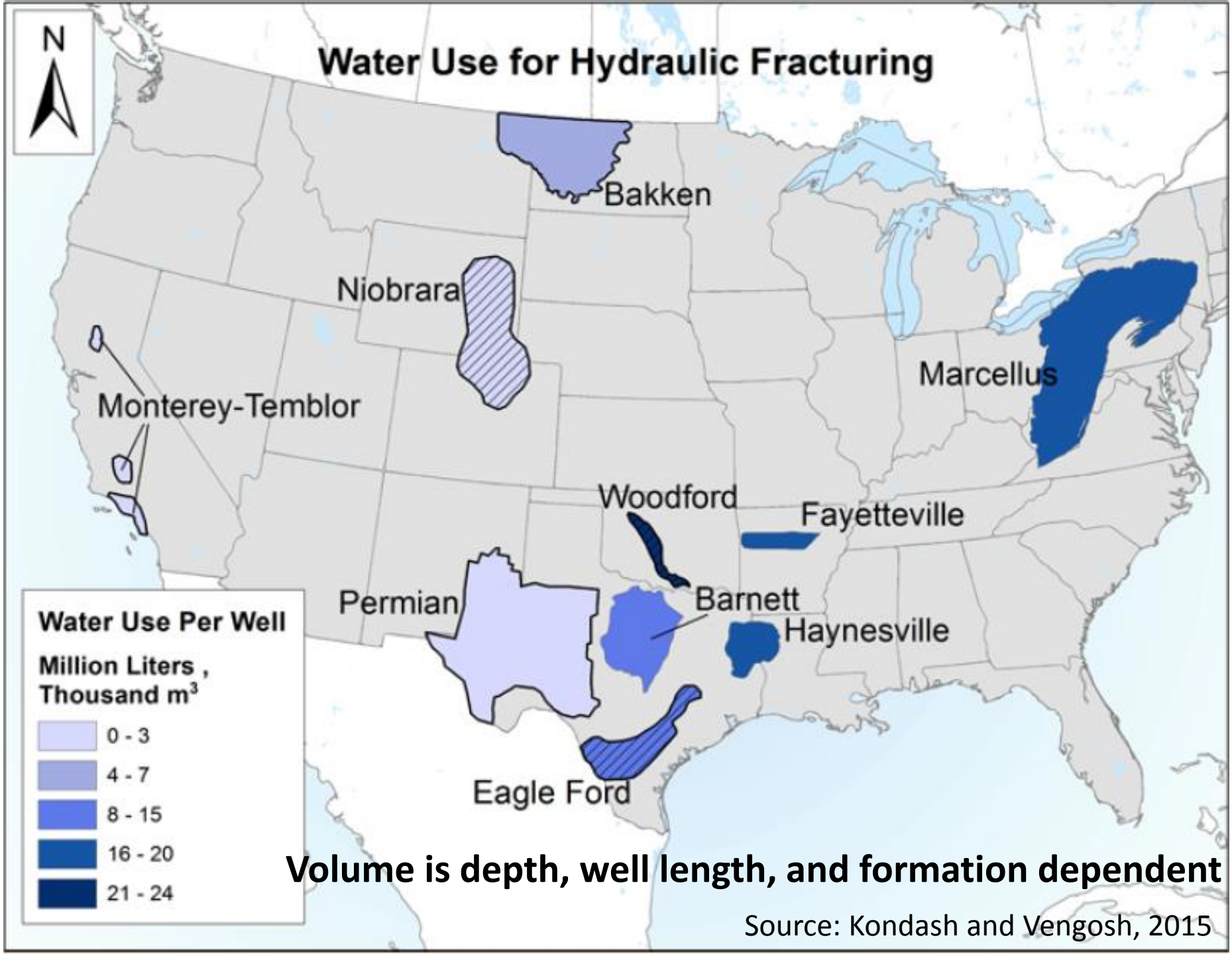


Source: EPA

275,000 oil and gas wells drilled likely hydraulically fractured, 2000 - 2013



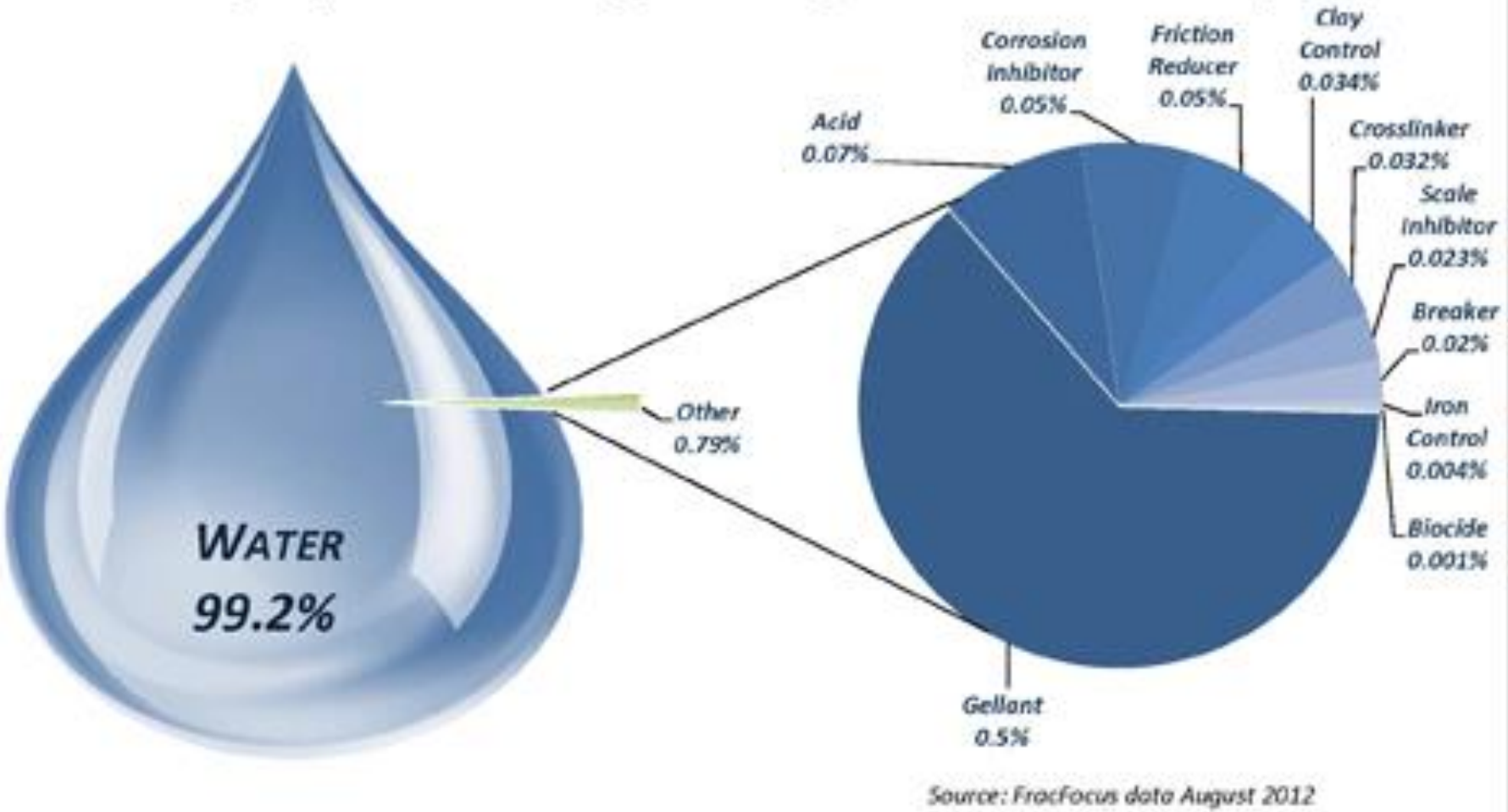

Maryland Gas Basins
GARRETT
ALLEGANY
WASHINGTON
FREDERICK
CARROLL
BALTIMORE
HARFORD
CECIL
BALTIMORE CITY
HOWARD
KENT
MONTGOMERY
ANNE ARUNDEL
QUEEN ANNE'S
PRINCE GEORGE'S
TALBOT
CAROLINE
CALVERT
CHARLES
DORCHESTER
ST. MARY'S
WICOMICO
WORCESTER
SOMERSET
Appalachian Basin
Culpeper Basin
Gettysburg Basin
Taylorsville Basin
Delmarva Basins
CHESAPEAKE CLIMATE ACTION NETWORK
ccan
Source: U.S. Geological Survey National Assessment of Oil and Gas



Volume is depth, well length, and formation dependent

Source: Kondash and Vengosh, 2015

Average Hydraulc Fracturing Fluid Composition for US Shale Plays



Source: FracFocus data August 2012

Table ES-2. Chemicals reported in 10% or more of disclosures in FracFocus 1.0. Disclosures provided information on chemicals used at individual well sites between January 1, 2011, and February 28, 2013.

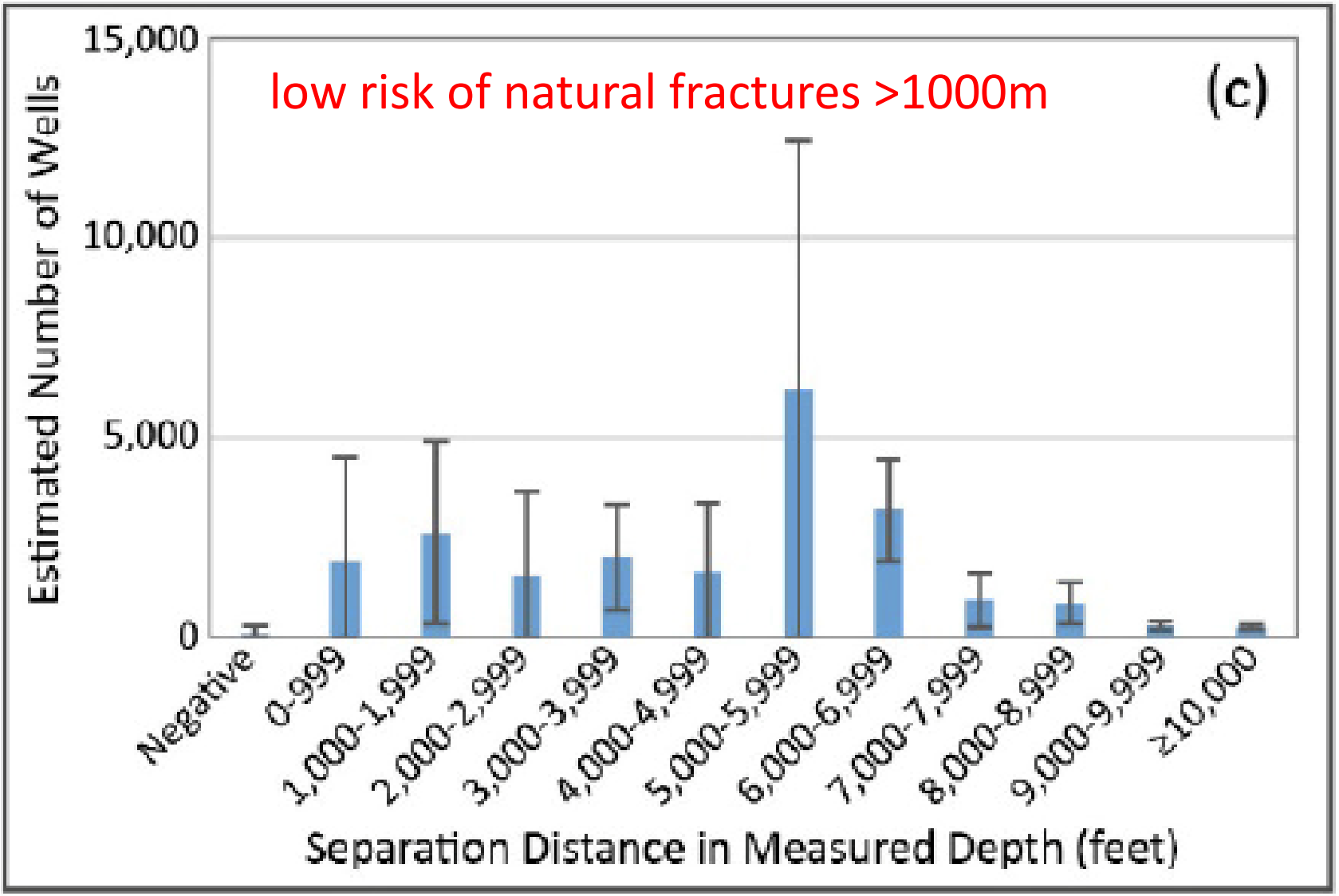
Chemical Name (CASRN)[a]	Percent of FracFocus 1.0 Disclosures[b]
Methanol (67-56-1)	72
Hydrotreated light petroleum distillates (64742-47-8)	65
Hydrochloric acid (7647-01-0)	65
Water (7732-18-5)[c]	48
Isopropanol (67-63-0)	47
Ethylene glycol (107-21-1)	46
Peroxydisulfuric acid, diammonium salt (7727-54-0)	44
Sodium hydroxide (1310-73-2)	39
Guar gum (9000-30-0)	37
Quartz (14808-60-7)[c]	36
Glutaraldehyde (111-30-8)	34
Propargyl alcohol (107-19-7)	33
Potassium hydroxide (1310-58-3)	29
Ethanol (64-17-5)	29
Acetic acid (64-19-7)	24
Citric acid (77-92-9)	24
2-Butoxyethanol (111-76-2)	21
Sodium chloride (7647-14-5)	21
Solvent naphtha, petroleum, heavy aromatic (64742-94-5)	21

Chemical Name (CASRN)[a]	Percent of FracFocus 1.0 Disclosures[b]
Naphthalene (91-20-3)	19
2,2-Dibromo-3-nitrilopropionamide (10222-01-2)	16
Phenolic resin (9003-35-4)	14
Choline chloride (67-48-1)	14
Methenamine (100-97-0)	14
Carbonic acid, dipotassium salt (584-08-7)	13
1,2,4-Trimethylbenzene (95-63-6)	13
Quaternary ammonium compounds, benzyl-C12-16-alkyldimethyl, chlorides (68424-85-1)	12
Poly(oxy-1,2-ethanediyl)-nonylphenyl-hydroxy (mixture) (127087-87-0)	12
Formic acid (64-18-6)	12
Sodium chlorite (7758-19-2)	11
Nonyl phenol ethoxylate (9016-45-9)	11
Tetrakis(hydroxymethyl)phosphonium sulfate (55566-30-8)	11
Polyethylene glycol (25322-68-3)	11
Ammonium chloride (12125-02-9)	10
Sodium persulfate (7775-27-1)	10

Sources of Drinking Water Contamination

- Direction migration through natural fractures to groundwater
  - unlikely in most regions due to depth of wells

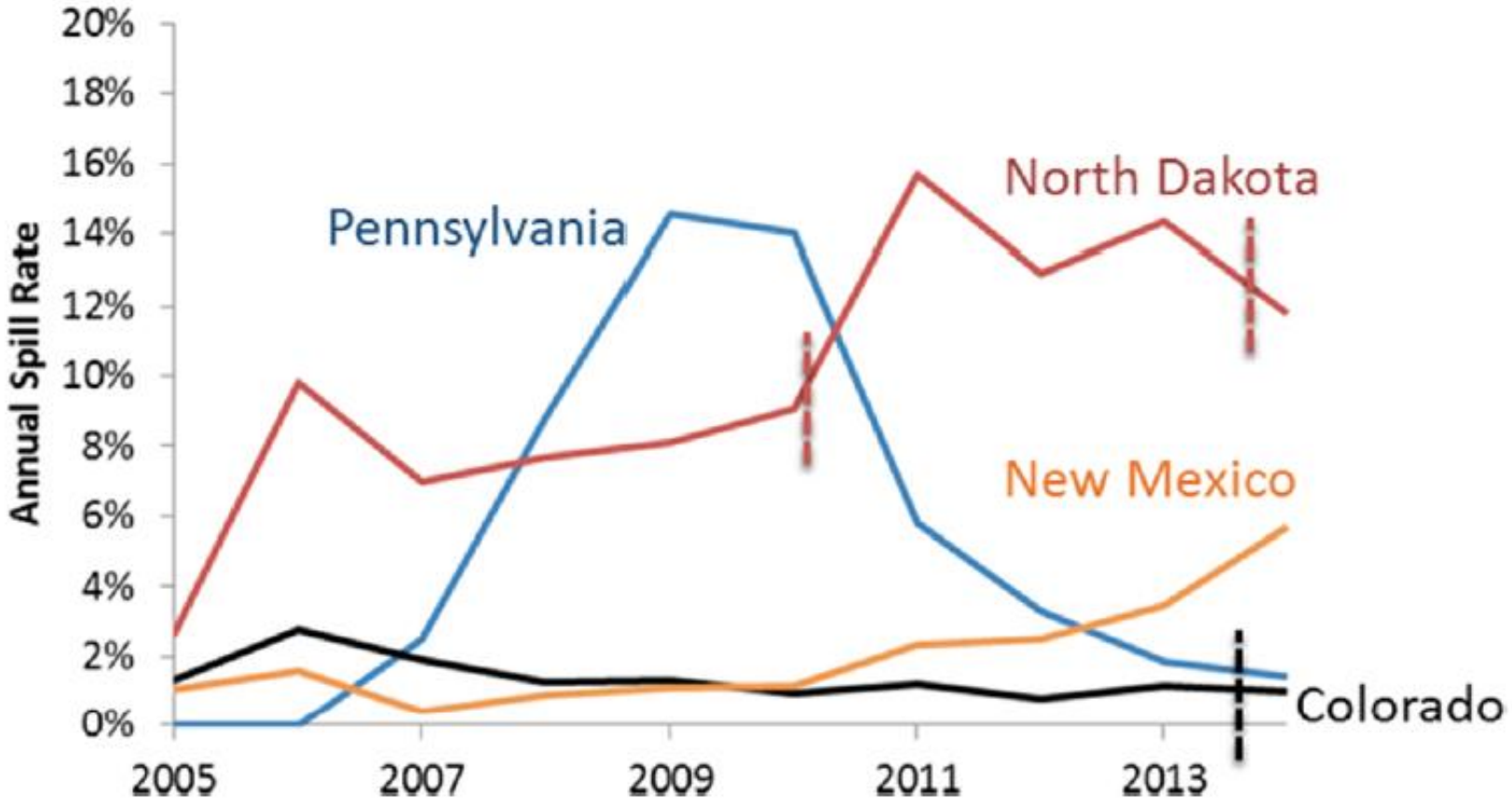
Separation Distance between HF Wells and Groundwater (Nationally)



Sources of Drinking Water Contamination

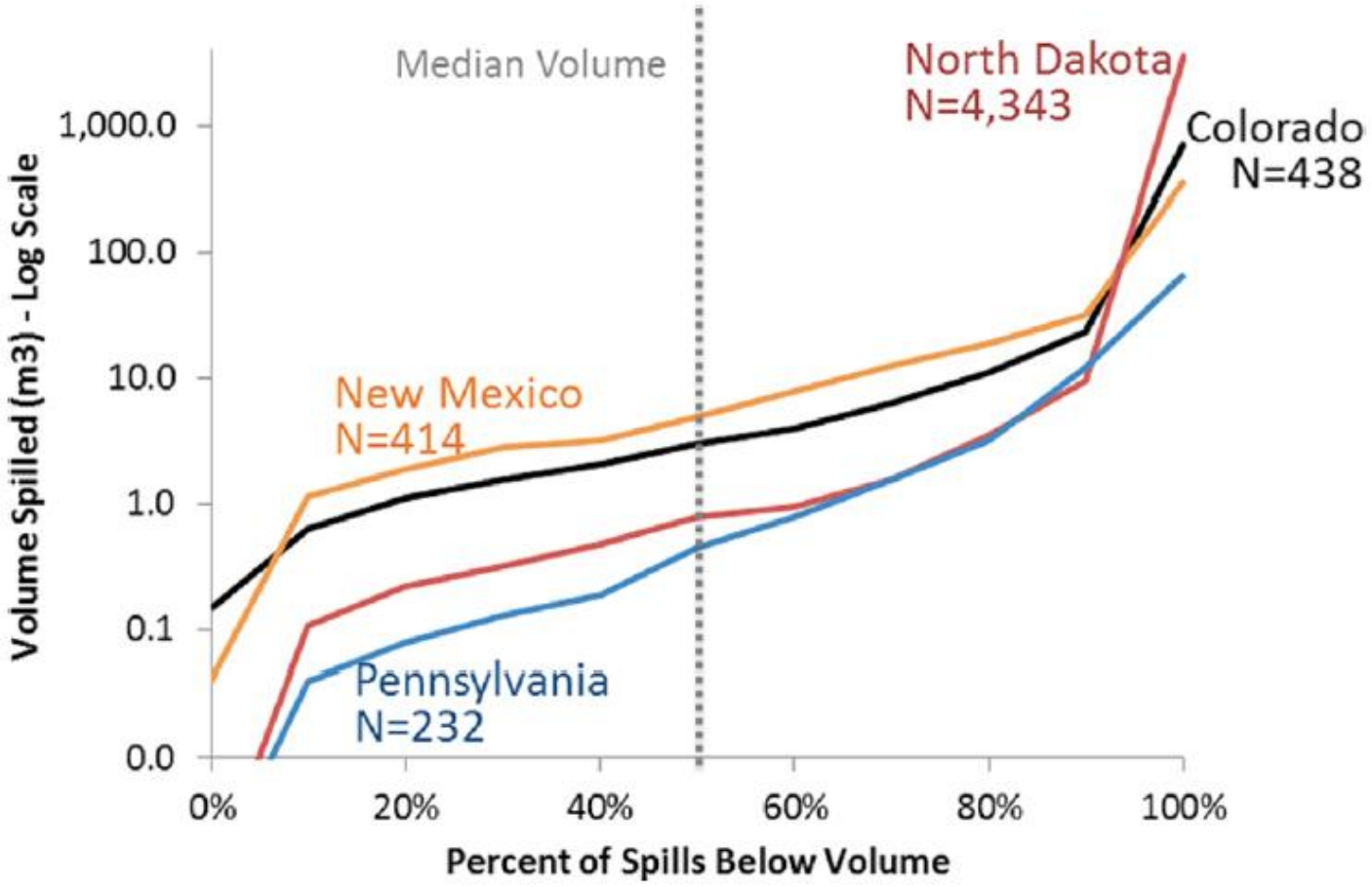
- Direction migration through natural fractures to groundwater
  - unlikely in most regions due to depth of wells
- Direction migration through man-made abandoned wells
- Poor well casing integrity allowing leaking fluids (3-6% failure rate in PA Marcellus)
- Surface spills to surface and groundwaters

Annual Spill Rate



Most spills from storing and moving fluids

Spill Volumes



Total volume of reported spills ranged from 377,000L in Pennsylvania to 769,000 L in Colorado.

EPA Study: Potential Impacts of Hydraulic Fracturing on Drinking Water Resources Report

- Started 2009, Released Dec. 2016
  - 50 page executive summary
  - 666 page main report, 572 pages of appendices
- Draft Database of HF Chemicals Physicochemical and Toxicological Information
- Also released 5 Retrospective Case Studies on Water Quality Impact (2015)

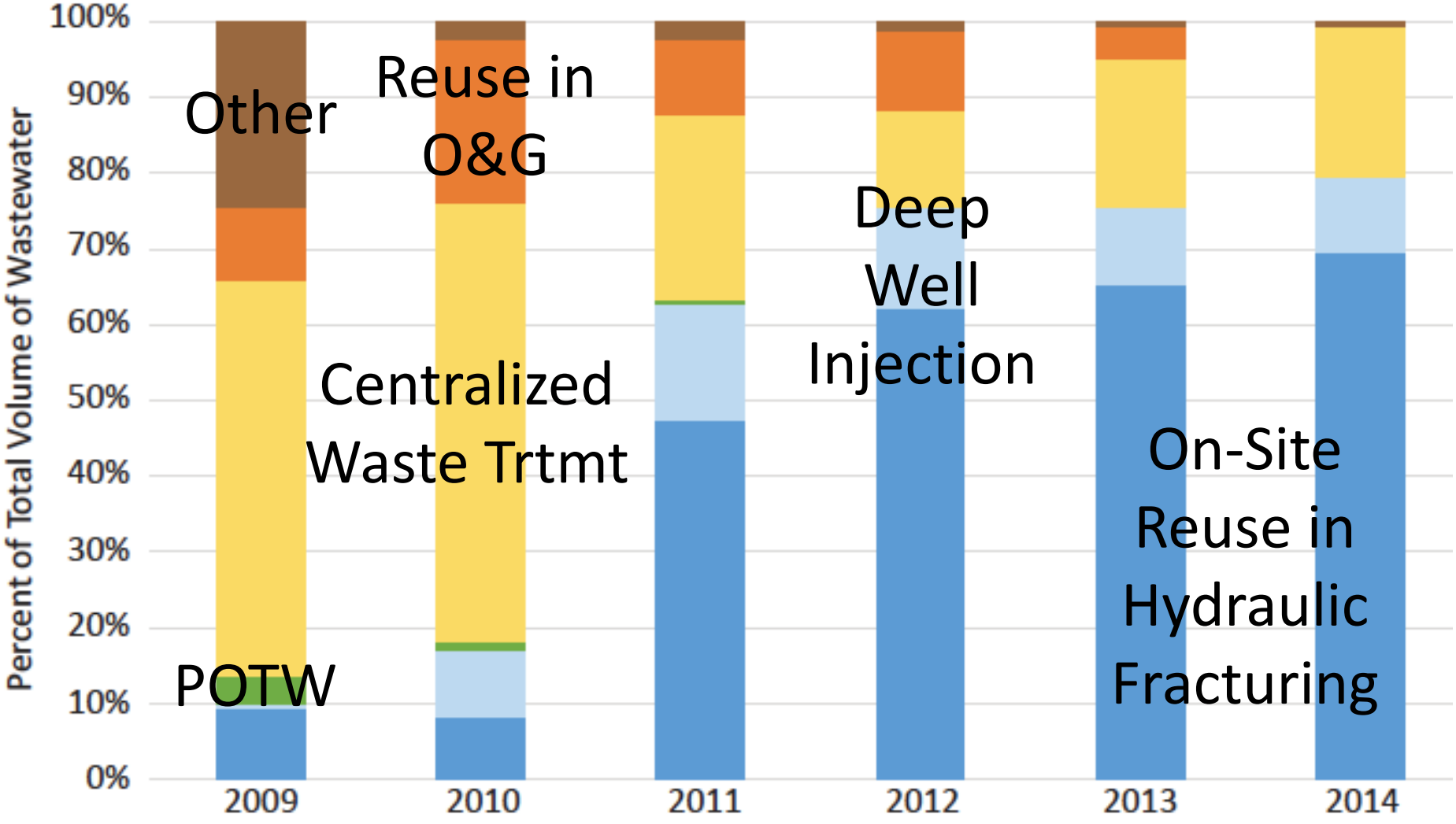
Areas of concern for drinking water resources: EPA Findings

- Water withdrawals for hydraulic fracturing in times or areas of low water availability, particularly in areas with limited or declining groundwater resources
- Spills during the management of hydraulic fracturing fluids and chemicals or produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources
- Injection of hydraulic fracturing fluids into wells with inadequate mechanical integrity, allowing gases or liquids to move to groundwater resources
- Injection of hydraulic fracturing fluids directly into groundwater resources
- Discharge of inadequately treated hydraulic fracturing wastewater to surface water resources
- Disposal or storage of hydraulic fracturing wastewater in unlined pits, resulting in contamination of groundwater resources

EPA Recommendations to reduce risk

- Spills during the management of hydraulic fracturing fluids and chemicals or produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources
  - Implementation of spill prevention and response measures
- Injection of hydraulic fracturing fluids into wells with inadequate mechanical integrity, allowing gases or liquids to move to groundwater resources
  - Design and placement of well casing and cement able to withstand the stresses imposed by hydraulic fracturing
  - Confirming mechanical integrity of O&G wells prior to, during, and after hydraulic fracturing, and correcting deficiencies if necessary
  - Identification of active or abandoned O&G wells nearby
- Discharge of inadequately treated hydraulic fracturing wastewater to surface water resources*
  - The use of treatment technologies to remove TDS, and other constituents, such as radium, when present prior to discharge

Wastewater Management Practices in the Marcellus Shale in PA



Data from the Pennsylvania Department of Environmental Protection (2015).

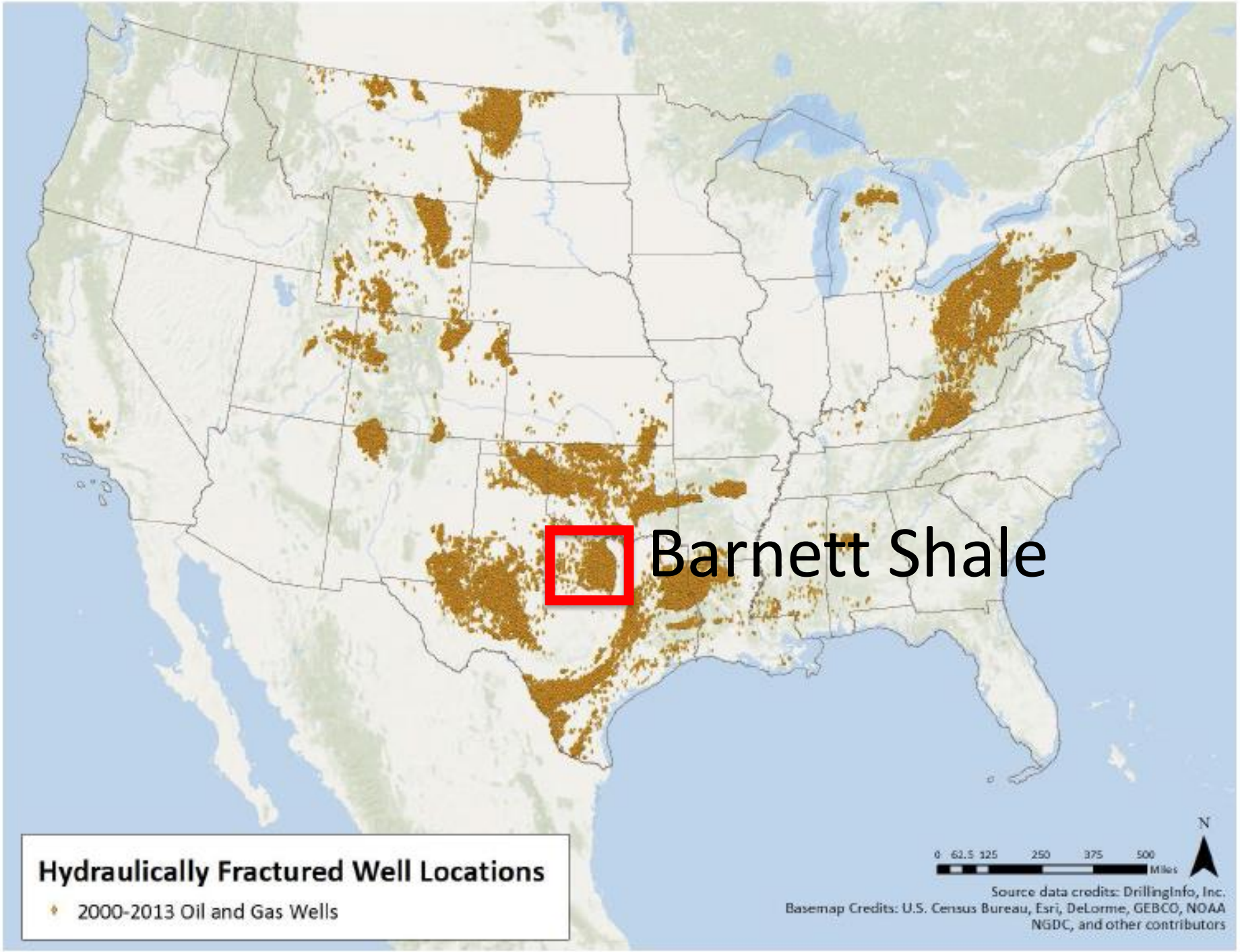
VOCs Identified in Well Site Atmospheric Emissions

- methane
- nonmethane hydrocarbons

<u>Toxics</u>

- hydrogen sulfide
- methanol
- higher molecular weight alkanes
- aromatics (benzene, toluene, ethylbenzene, xylene)
- methylene chloride

“Wet gas” (i.e, with oil) has more VOCs than “dry gas”


Barnett Shale
Hydraulically Fractured Well Locations
2000-2013 Oil and Gas Wells
N
0 62.5 125 250 375 500
Miles
Source data credits: DrillingInfo, Inc.
Basemap Credits: U.S. Census Bureau, Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

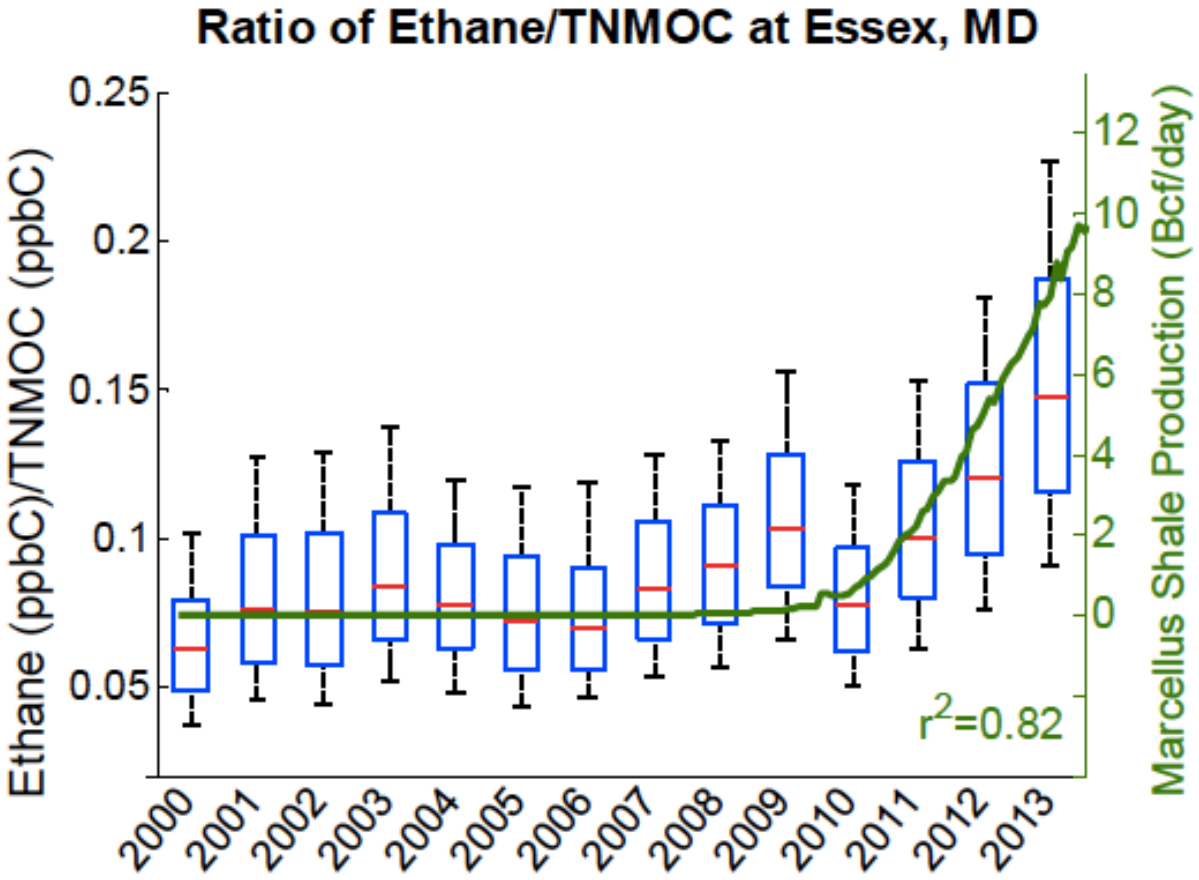
Total Volatile Organic Compound (VOC) Inventory Barnett Shale

- Major Sources (%, Tons per year)
  - Condensate Tank (58%, 11,550)
  - Fugitive Gases (21%, 4,260)
  - Water Tank (7%, 1,340)
  - Engine (6%, 1,240)

Total Barnett Shale Emissions:
19,835 tons per year

VOCs from cars: 0.5 – 5 g per km driven
Shanghai emission inventory: 39,400 tons per year

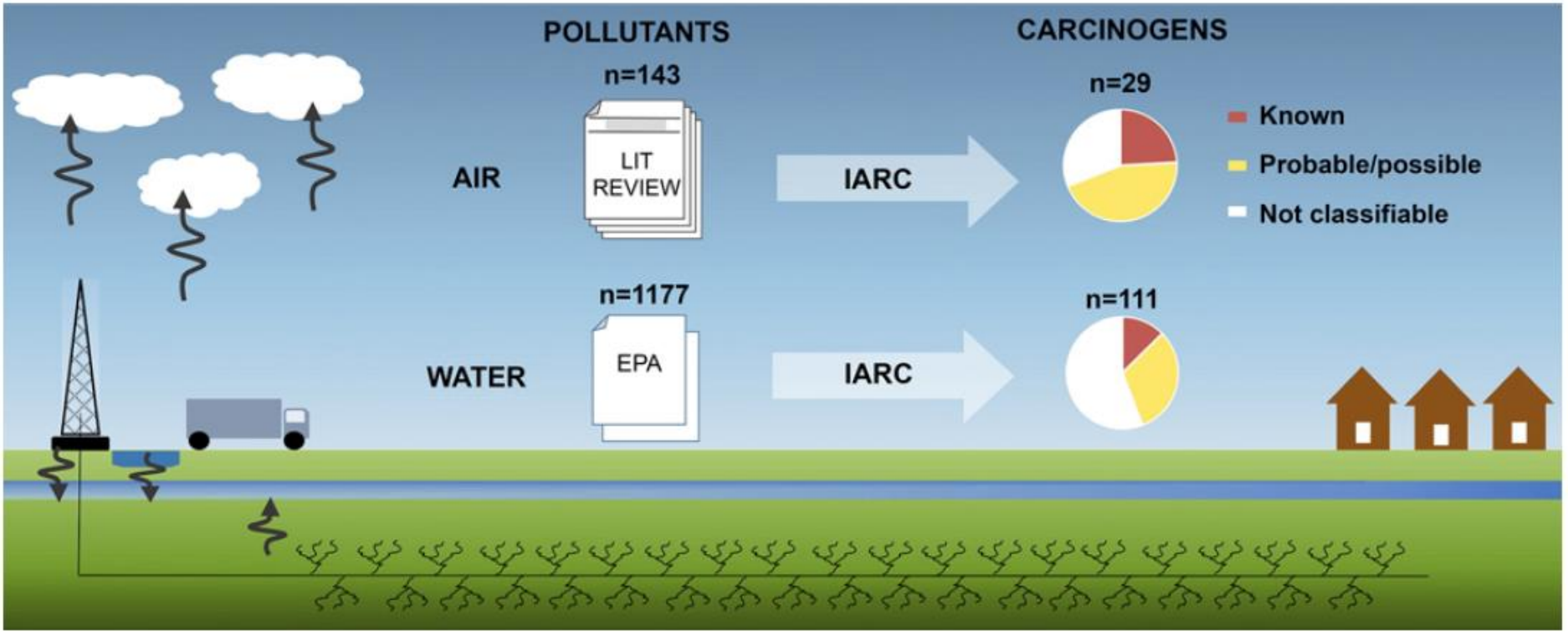
MD air quality already impacted by upwind fracking emissions



Ethane used as a tracer of fugitive methane emissions: increasing

Vinciquerra et al., 2015

Are pollutants carcinogenic?



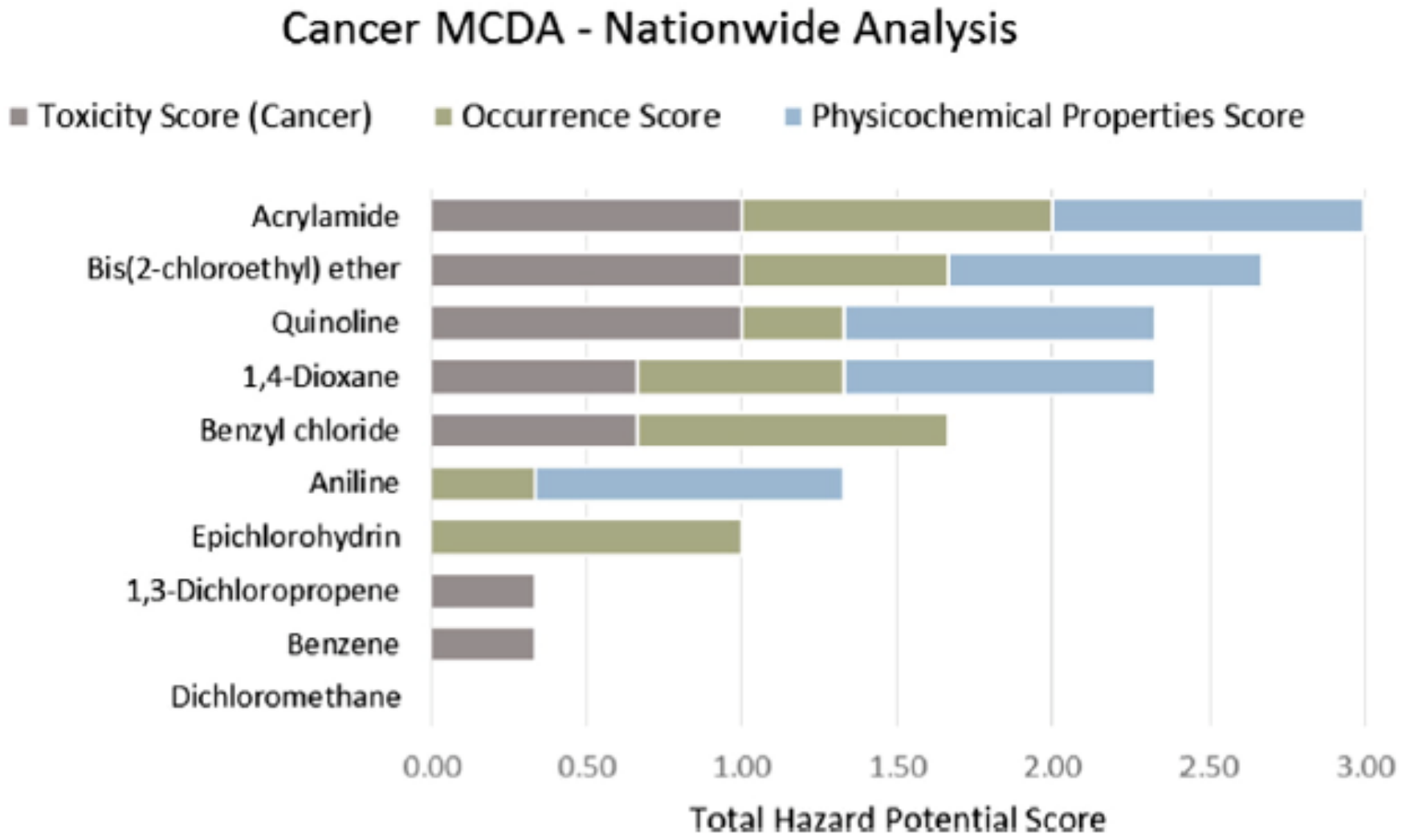
Health risks from air exposures

Within ½ mile of well, key atmospheric pollutants:

- Cumulative cancer risk: benzene and ethylbenzene
- Chronic non-cancer: trimethylbenzenes, aliphatic hydrocarbons, and xylenes
- Subchronic: trimethylbenzenes, aliphatic hydrocarbons, and xylene

- Chronic HIs were higher for residents <1/2 mile from wells (1 vs 0.4 for <1/2 mile vs. >1/2 mile)
- Cumulative cancer risks were higher for residents <1/2 mile from wells (10 in a million and 6 in a million)

Chemicals Cancer Risk



Health Impacts: Marcellus Shale Region

Most frequently self-reported health impacts:

- Dermal: rashes, sores
- Muscular: aches, weakness
- CNS: headaches, weakness
- Cardiac: shortness of breath
- Digestive: diarrhea, vomiting
- Psychological: stress, loss of sleep

Perceived stressors: odors, health concerns, being taken advantage of, feeling helpless, noise pollution, light pollution

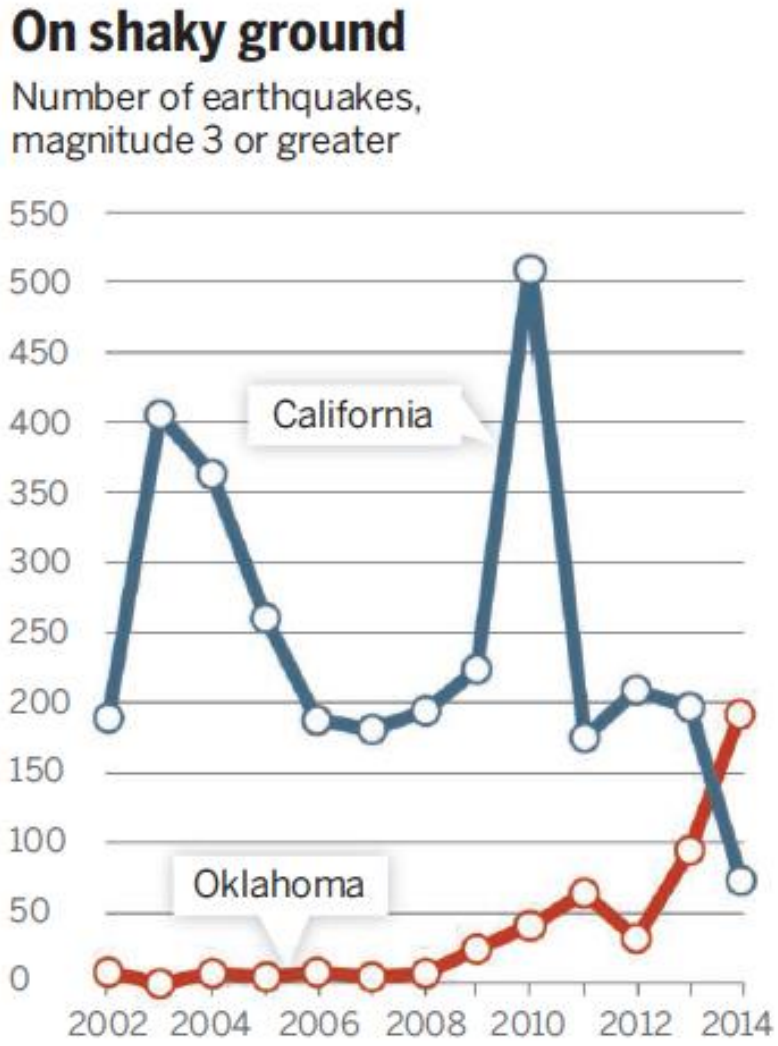
Health Impacts

- PA: Prenatal residential exposure to fracking
  - 4 year study, 9,384 mothers
  - Looked at distance, dates, duration, drilling, and production volume during pregnancy
  - associated with high risk pregnancy (1.4x more likely)
  - associated with pre-term weight (1.3x more likely)

Social Injustice

- In Southern TX: Wastewater disposal wells are disproportionately permitted in areas with higher proportions of people of color and residents living in poverty
- Denver CO:
  - Higher proportion of low value single family homes with 350-500 ft of wells
  - Higher proportion of low value housing built near existing wells

Induced Seismicity: Deep Well Injection of Fracking Wastewater



- Youngstown, OH: 109+ small earthquakes (M_w 0.4–3.9) were detected Jan. 2011 to Feb. 2012
- High-rate injection wells (>300,000 barrels per month) are much more likely to be associated with earthquakes than lower-rate wells

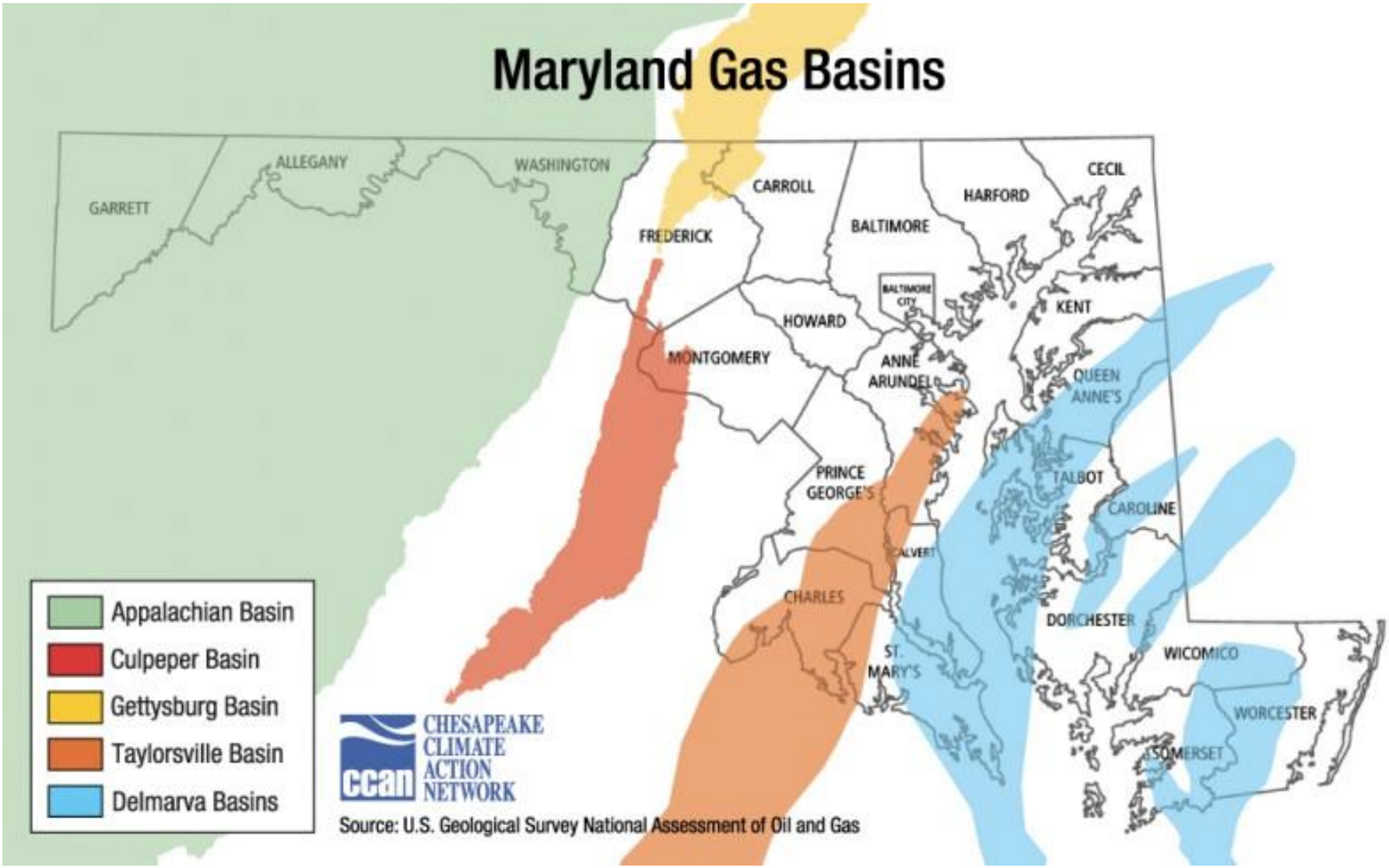
Induced Seismicity: Fracking

- Western Canada: Hydraulic fracturing activates faults in Western Canada ($M_w = 3.9$) during 2014 – 2015
- New “traffic-light protocol” in place now: immediate shutdown in hydraulic fracturing operations of $M_L > 4.0$ with 5km of well

Critical Areas to Reduce Pollution

- Well casing and cementing
- Handling wastewater
- Venting and flaring
- Equipment with air emissions
- Seismic events

Questions?


Maryland Gas Basins
GARRETT
ALLEGANY
WASHINGTON
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CARROLL
BALTIMORE
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CECIL
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KENT
HOWARD
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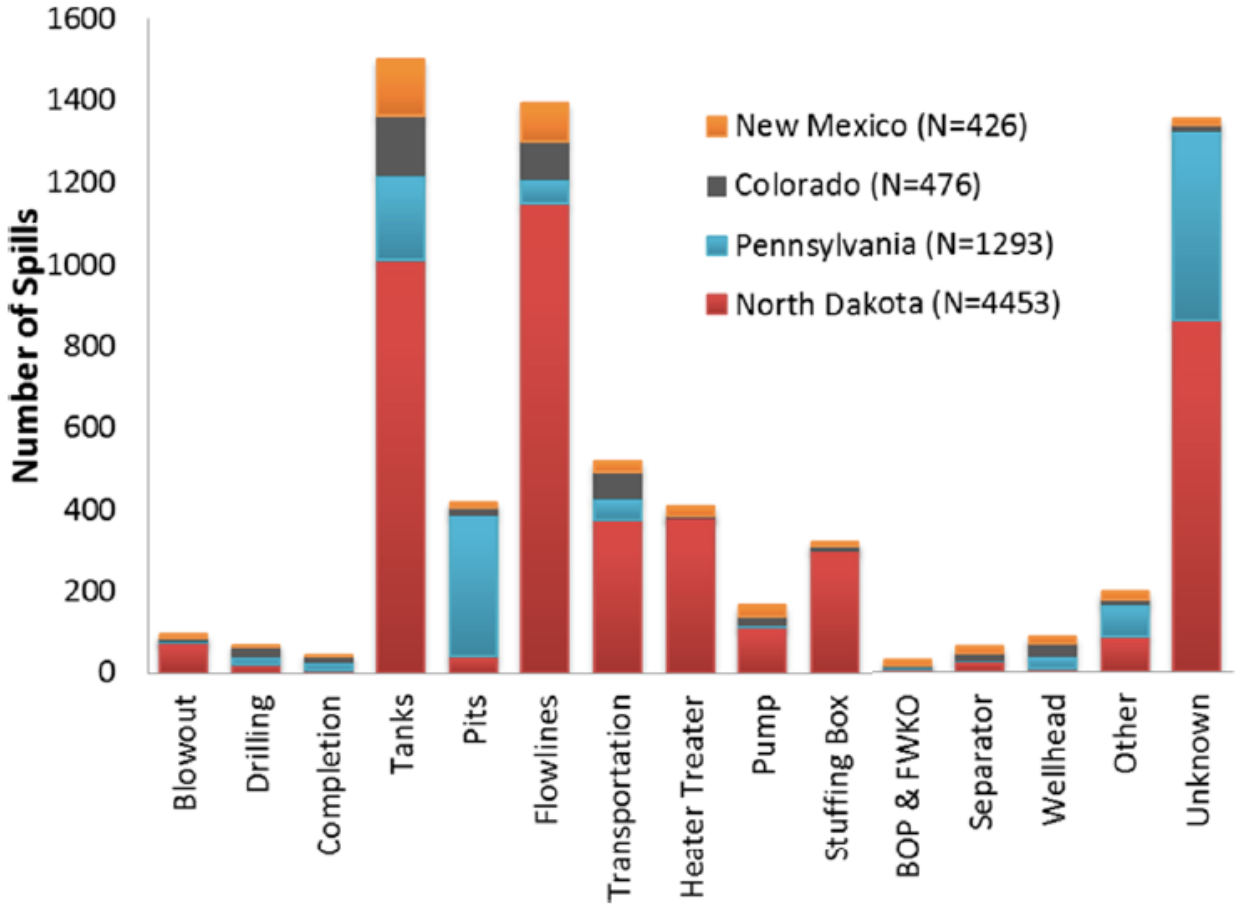
ANNE ARUNDEL
QUEEN ANNE'S
PRINCE GEORGE'S
TALBOT
CAROLINE
CALVERT
CHARLES
DORCHESTER
ST. MARY'S
WICOMICO
WORCESTER
SOMERSET
Appalachian Basin
Culpeper Basin
Gettysburg Basin
Taylorsville Basin
Delmarva Basins
CHESAPEAKE CLIMATE ACTION NETWORK
Source: U.S. Geological Survey National Assessment of Oil and Gas

Additional Information

Location of Spills



PA DEP Natural Gas Well Violations 2000 - 2014

Violation category	Number of violations
Waste discharge	1620
Surface spills	93
Erosion	2583
Encroachment	119
Gas migration into water supply	25
Gas venting	10
Cementing or casing failure	44
Site Restoration	535
Water supply restoration	53
Storage or transportation failure	434

Shale wells are more likely to have violations with potential to contaminate water

Small operators have higher odds of having a violation over large operators

Example Additives

Additive type	Example compounds	Purpose
Acid	Hydrochloric acid	Clean out the wellbore, dissolve minerals, and initiate cracks in rock
Friction reducer	Polyacrylamide, petroleum distillate	Minimize friction between the fluid and the pipe
Corrosion inhibitor	Isopropanol, acetaldehyde	Prevent corrosion of pipe by diluted acid
Iron control	Citric acid, thioglycolic acid	Prevent precipitation of metal oxides
Biocide	Glutaraldehyde, 2,2-dibromo-3-nitrilopropionamide (DBNPA)	Bacterial control
Gelling agent	Guar/xantham gum or hydroxyethyl cellulose	Thicken water to suspend the sand
Crosslinker	Borate salts	Maximize fluid viscosity at high temperatures

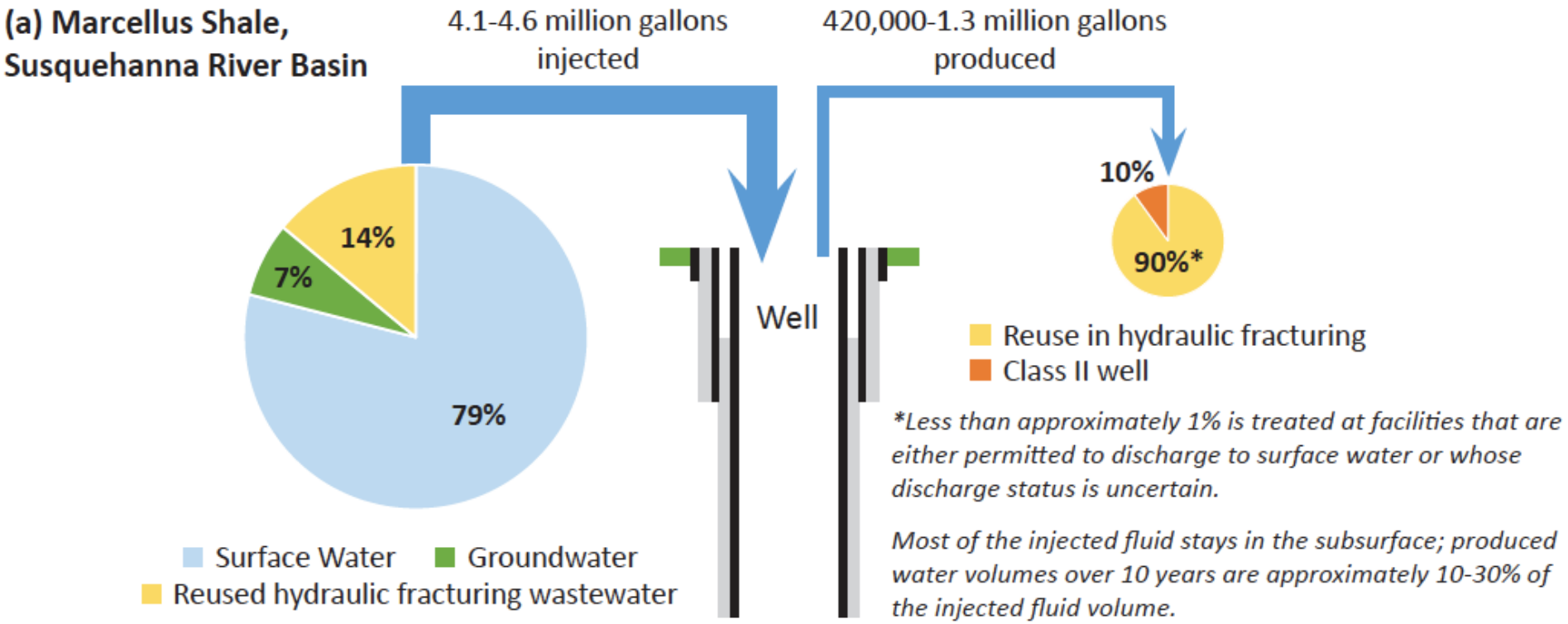
Source: Vidic et al., 2013

Example Additives

Additive type	Example compounds	Purpose
Crosslinker	Borate salts	Maximize fluid viscosity at high temperatures
Breaker	Ammonium persulfate, magnesium peroxide	Promote breakdown of gel polymers
Oxygen scavenger	Ammonium bisulfite	Remove oxygen from fluid to reduce pipe corrosion
pH adjustment	Potassium or sodium hydroxide or carbonate	Maintain effectiveness of other compounds (such as crosslinker)
Proppant	Silica quartz sand	Keep fractures open
Scale inhibitor	Ethylene glycol	Reduce deposition on pipes
Surfactant	Ethanol, isopropyl alcohol, 2-butoxyethanol	Decrease surface tension to allow water recovery

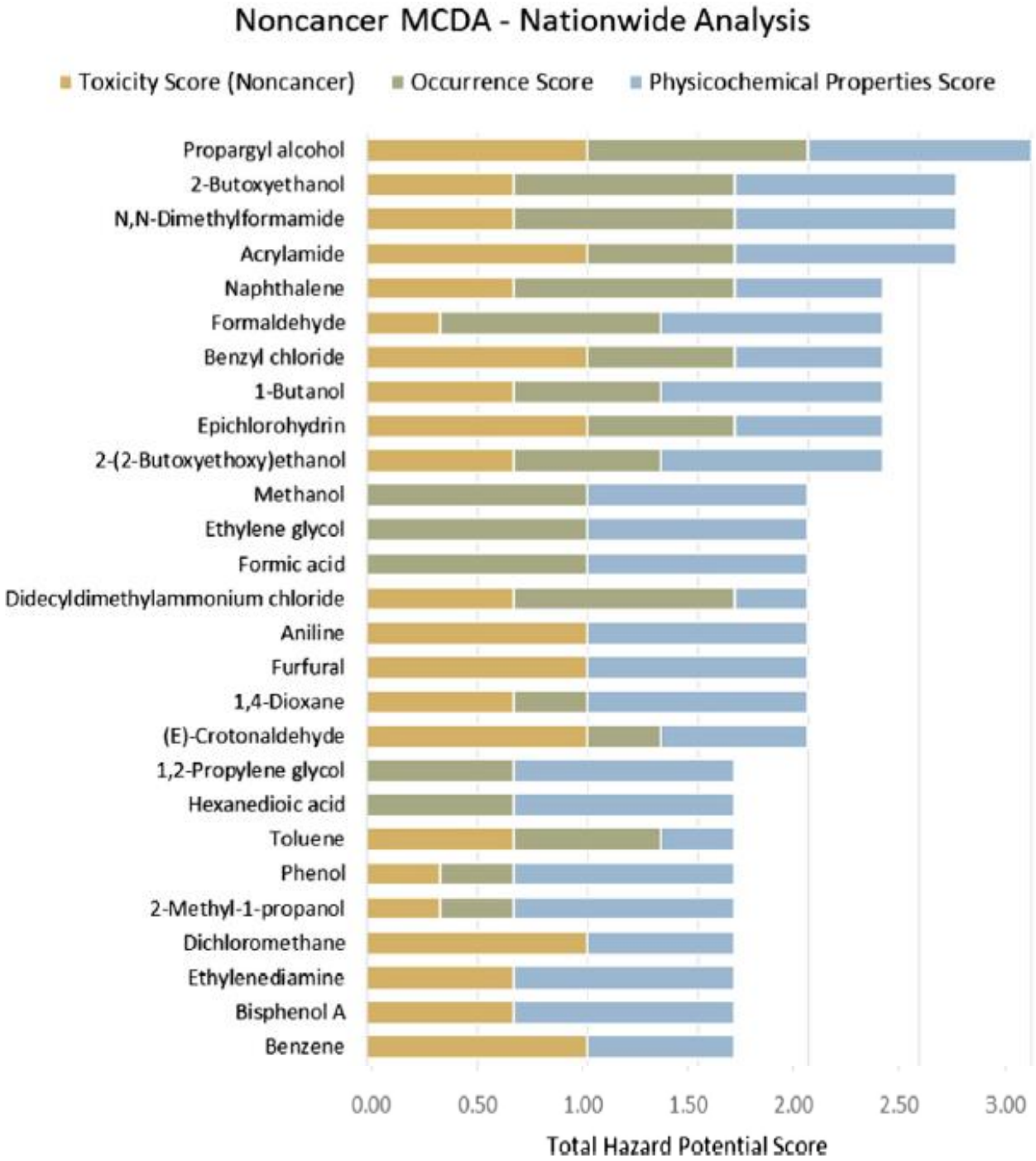
Source: Vidic et al., 2013

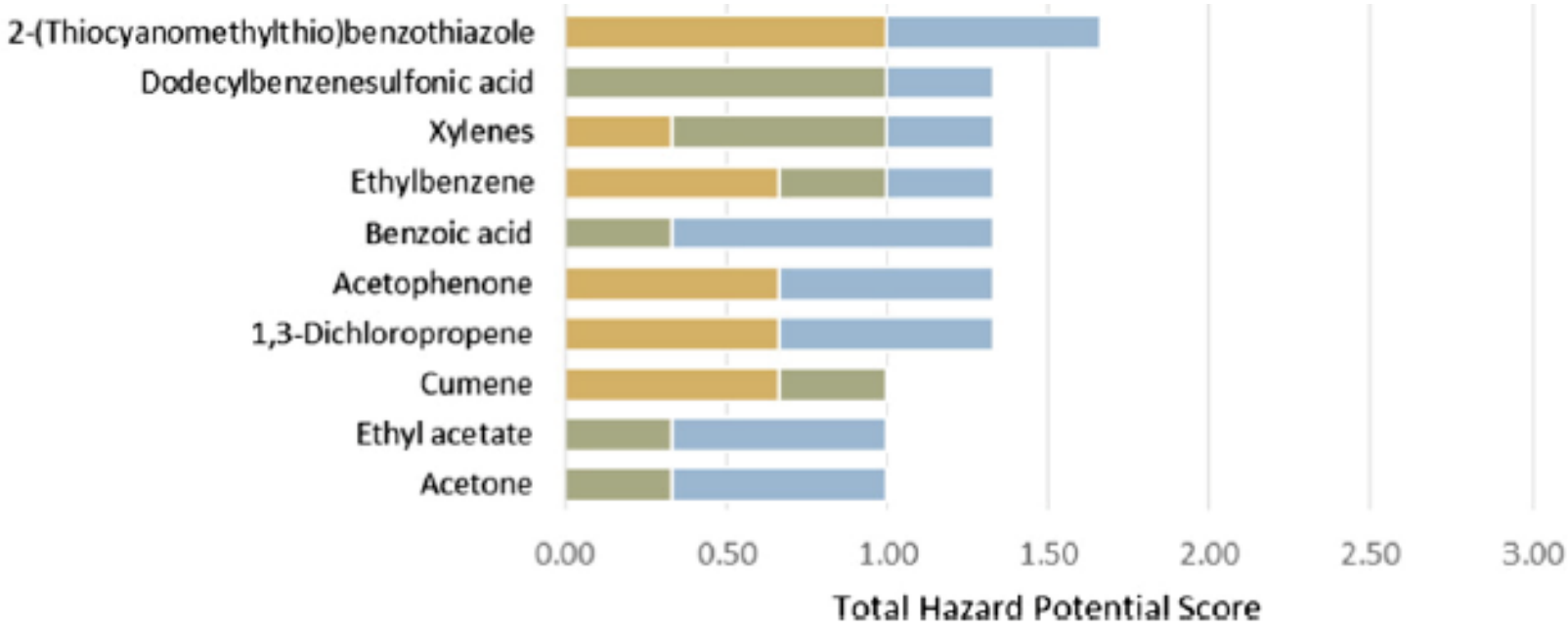
Where Does the Wastewater Go?



Air Quality: Emission Sources

- Sources of Pollution
  - Transport of materials on and off site
  - Diesel generators, trucks on site during drilling and fracking
  - Storage of fluids that contain VOCs and can “off gas”
  - Methane gas leaks
  - Flaring of natural gas when drilling for oil


Noncancer MCDA - Nationwide Analysis
Toxicity Score (Noncancer)
Occurrence Score
Physicochemical Properties Score
Propargyl alcohol
2-Butoxyethanol
N,N-Dimethylformamide
Acrylamide
Naphthalene
Formaldehyde
Benzyl chloride
1-Butanol
Epichlorohydrin
2-(2-Butoxyethoxy)ethanol
Methanol
Ethylene glycol
Formic acid
Didecyldimethylammonium chloride
Aniline
Furfural
1,4-Dioxane
(E)-Crotonaldehyde
1,2-Propylene glycol
Hexanedioic acid
Toluene
Phenol
2-Methyl-1-propanol
Dichloromethane
Ethylenediamine
Bisphenol A
Benzene
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Total Hazard Potential Score


2-(Thiocyanomethylthio)benzothiazole
Dodecylbenzenesulfonic acid
Xylenes
Ethylbenzene
Benzoic acid
Acetophenone
1,3-Dichloropropene
Cumene
Ethyl acetate
Acetone
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Total Hazard Potential Score

Toxicity of acidization fluids used in California oil exploration

Khadeeja Abdullah, Timothy Malloy, Michael K. Stenstrom & I. H. (Mel) Suffet

- To cite this article: Khadeeja Abdullah, Timothy Malloy, Michael K. Stenstrom & I. H. (Mel) Suffet (2017) Toxicity of acidization fluids used in California oil exploration, Toxicological & Environmental Chemistry, 99:1, 78-94, DOI: 10.1080/02772248.2016.1160285
- To link to this article: http://dx.doi.org/10.1080/02772248.2016.1160285

Effects on Biotransformation, Oxidative Stress, and EndocrineDisruption in Rainbow Trout (Oncorhynchus mykiss) Exposed to Hydraulic Fracturing Flowback and Produced Water

- Yuhe He,†,# Erik J. Folkerts,†,# Yifeng Zhang,‡ Jonathan W. Martin,‡ Daniel S. Alessi,§ and Greg G. Goss*,†
- DOI: 10.1021/acs.est.6b04695
- Environ. Sci. Technol. 2017, 51, 940−947
- The overall results suggested HF-FPW could cause significant adverse effects on fish, and the organic contents might play the major role in its toxicity.

Assessment and longitudinal analysis of health impacts and perceived stressors from Marcellus shale gas development

Table 2 Symptom counts are presented for session 1 (with all participants, $n=33$), session 1 with the subset whom also completed session 2 ($n=20$), and session 2 ($n=20$). Total percentages are given for each bodily system, as well as for each symptom. Count totals are presented in parentheses for each system and each symptom as well. For the symptoms, the count (x) represents the number of participants who referenced that symptom. For the system, the counts (y) are summations of all symptom counts

Systems affected and symptoms	Percentage of respondents reporting symptom and (symptom count total)					
	Session 1 ($n=33$)		Session 1 ($n=20$)		Session 2 ($n=20$)	
Immune response	24%	(8)	40%	(8)	35%	(7)
General illness	24%	(8)	40%	(8)	35%	(7)
Dermal system	39%	(26)	45%	(17)	55%	(34)
Rashes	27%	(9)	40%	(8)	55%	(11)
Sores	12%	(4)	15%	(3)	35%	(7)
Itching	9%	(3)	0%		15%	(3)
Blisters	6%	(2)	5%	(1)	10%	(2)
Redness and warmth	6%	(3)	10%	(2)	15%	(3)
Swelling	3%	(1)	5%	(1)	15%	(3)
Tooth loss	0%	(0)	0%	(0)	5%	(1)
Burning Eyes	12%	(4)	10%	(2)	20%	(4)
Skeletal system	15%	(5)	20%	(4)	30%	(6)
Pain or soreness	15%	(5)	20%	(4)	25%	(5)
Joint swelling	0%	(0)	0%	(0)	5%	(1)
Muscular system	21%	(11)	30%	(9)	25%	(9)
Muscle aches	15%	(5)	20%	(4)	20%	(4)
Weakness	18%	(6)	25%	(5)	25%	(5)

Systems affected and symptoms	Percentage of respondents reporting symptom and (symptom count total)					
	Session 1 (n=33)		Session 1 (n=20)		Session 2 (n=20)	
Endocrine system	9%	(5)	5%	(2)	10%	(2)
Hyperactivity	6%	(2)	5%	(1)	0%	(0)
Vitamin D deficiency	9%	(3)	5%	(1)	10%	(2)
Pulmonary system	21%	(9)	20%	(6)	25%	(8)
Cough	3%	(1)	0%	(0)	0%	(0)
Shortness of breath	21%	(7)	25%	(5)	25%	(5)
Productive cough	0%	(0)	0%	(0)	10%	(2)
Wheezing	3%	(1)	5%	(1)	5%	(1)
Reproductive system	0%	(0)	0%	(0)	5%	(1)
Irregular menstrual cycle	0%	(0)	0%	(0)	5%	(1)
Psychological symptoms	79%	(40)	80%	(24)	85%	(25)
Stress	76%	(25)	75%	(15)	80%	(16)
Loss of sleep	27%	(9)	30%	(6)	30%	(6)
Memory loss	18%	(6)	15%	(3)	15%	(3)
Excretory system	0%	(0)	0%	(0)	5%	(1)
Liver damage	0%	(0)	0%	(0)	5%	(1)
Digestive system	30%	(19)	40%	(14)	35%	(17)
Diarrhea	24%	(8)	30%	(6)	35%	(7)
Nausea	12%	(4)	15%	(3)	20%	(4)
Vomiting	9%	(3)	10%	(2)	15%	(3)
Stomach pain	9%	(3)	15%	(3)	10%	(2)
Constipation	3%	(1)	0%	(0)	0%	(0)
Primary biliary cirrhosis	0%	(0)	0%	(0)	5%	(1)

Table 3 Stressor counts are presented for session 1 (with all participants, $n=33$), session 1 with the subset whom also completed session 2 ($n=20$), and session 2 ($n=20$)

Perceived stressors			
	% of respondents reporting stressors		
Stressor	Session 1 ($n=33$)	Session 1 ($n=20$)	Session 2 ($n=20$)
Being taken advantage of	52%	50%	50%
Health concerns	82%	95%	100%
Concerns/complaints ignored	58%	70%	80%
Corruption	61%	50%	70%
Denied or provided with false information	79%	80%	65%
Desire to move/leave community	42%	35%	45%
Estrangement from community	39%	45%	65%
Financial damages	45%	45%	25%
Intimidation/fear of retribution	27%	25%	35%
Acid taste in air	0%	0%	5%
Odors	13%	50%	50%
Pet/livestock died/sickened/died	42%	45%	50%
Noise pollution	45%	55%	35%
Light pollution	9%	10%	5%

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