Water-Related Impacts from Unconventional Oil and Gas Development (UOGD)

Nicole C. Deziel, PhD, MHS

Associate Professor

Department of Environmental Health Sciences, Yale School of Public Health

Yale School of the Environment

Yale School of Engineering & Applied Science

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Nicole.deziel@yale.edu

@Deziellab_yale

ISGlobal Barcelona Institute for Global Health

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UOGD is a Complex Process

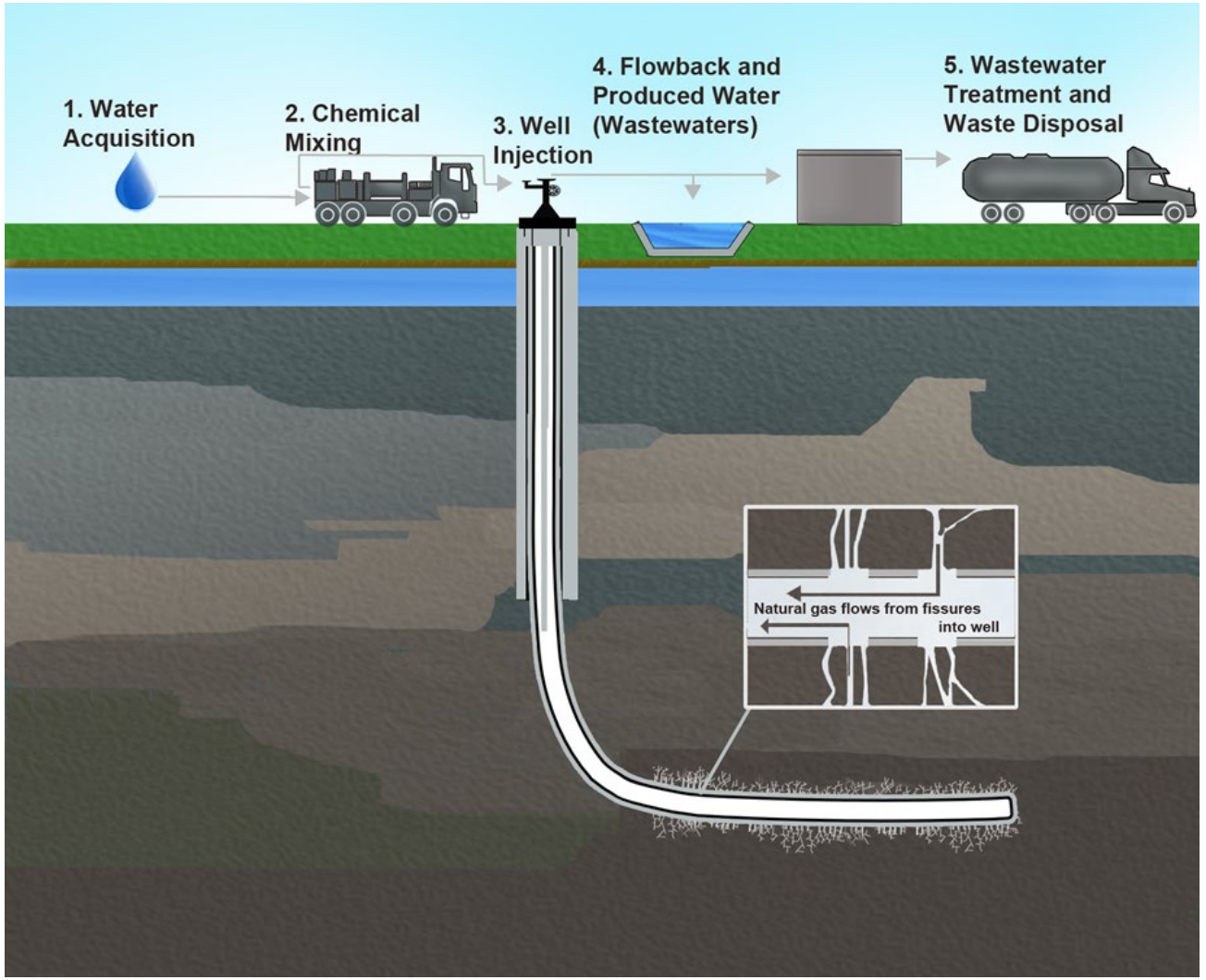
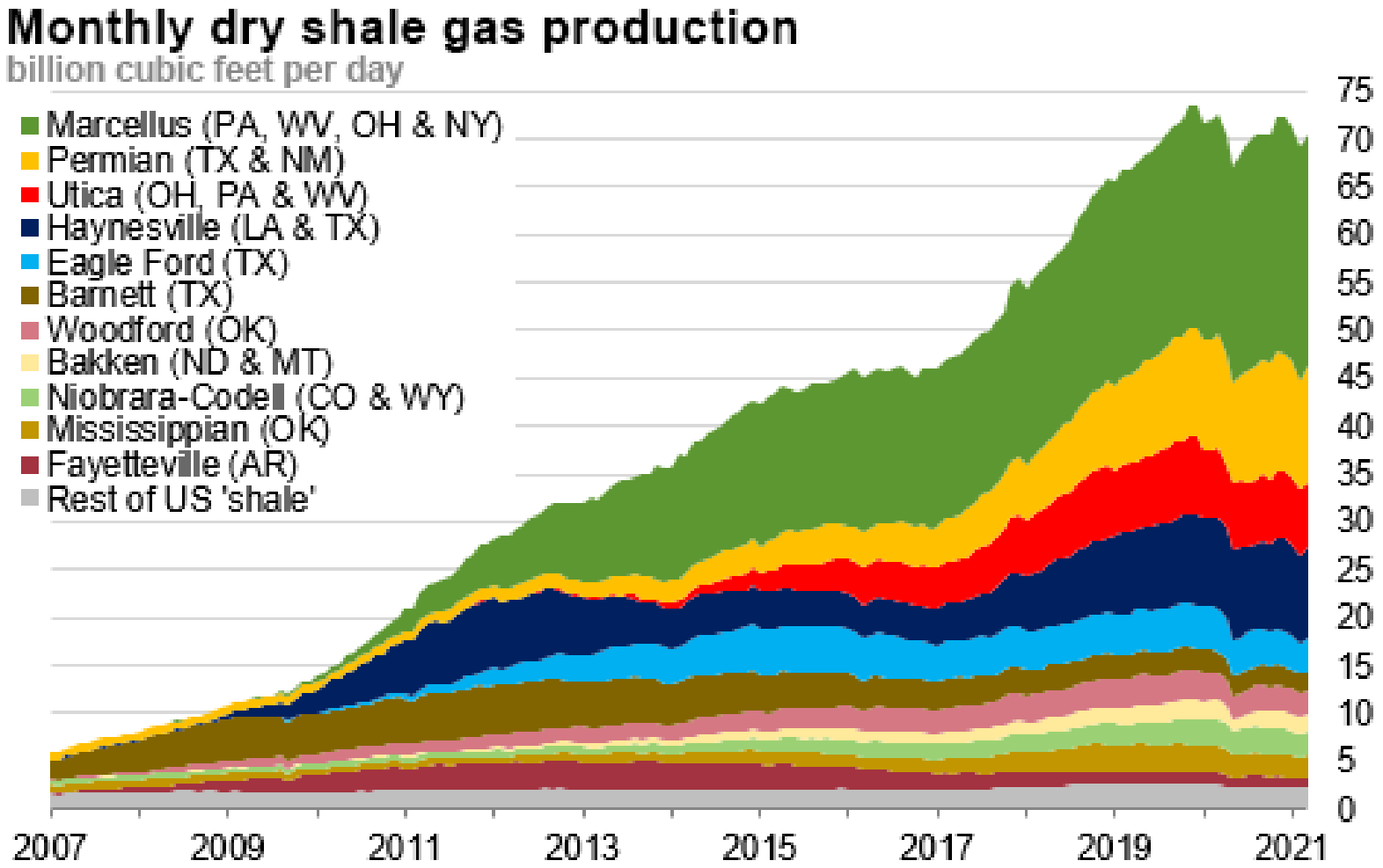


Image from USEPA

Rapid Expansion of UOGD in the US



https://www.eia.gov/naturalgas/weekly/

- ~4 million people live within 1600 m (1 mile) of a UOG well
- ~9 million people in the US have drinking water sources <1600 m of a UOG well
- Limited and varied regulatory oversight
- High community concern

EPA 2016; Czolowski et al. 2017 EHP; Clark et al. 2021 ERSS

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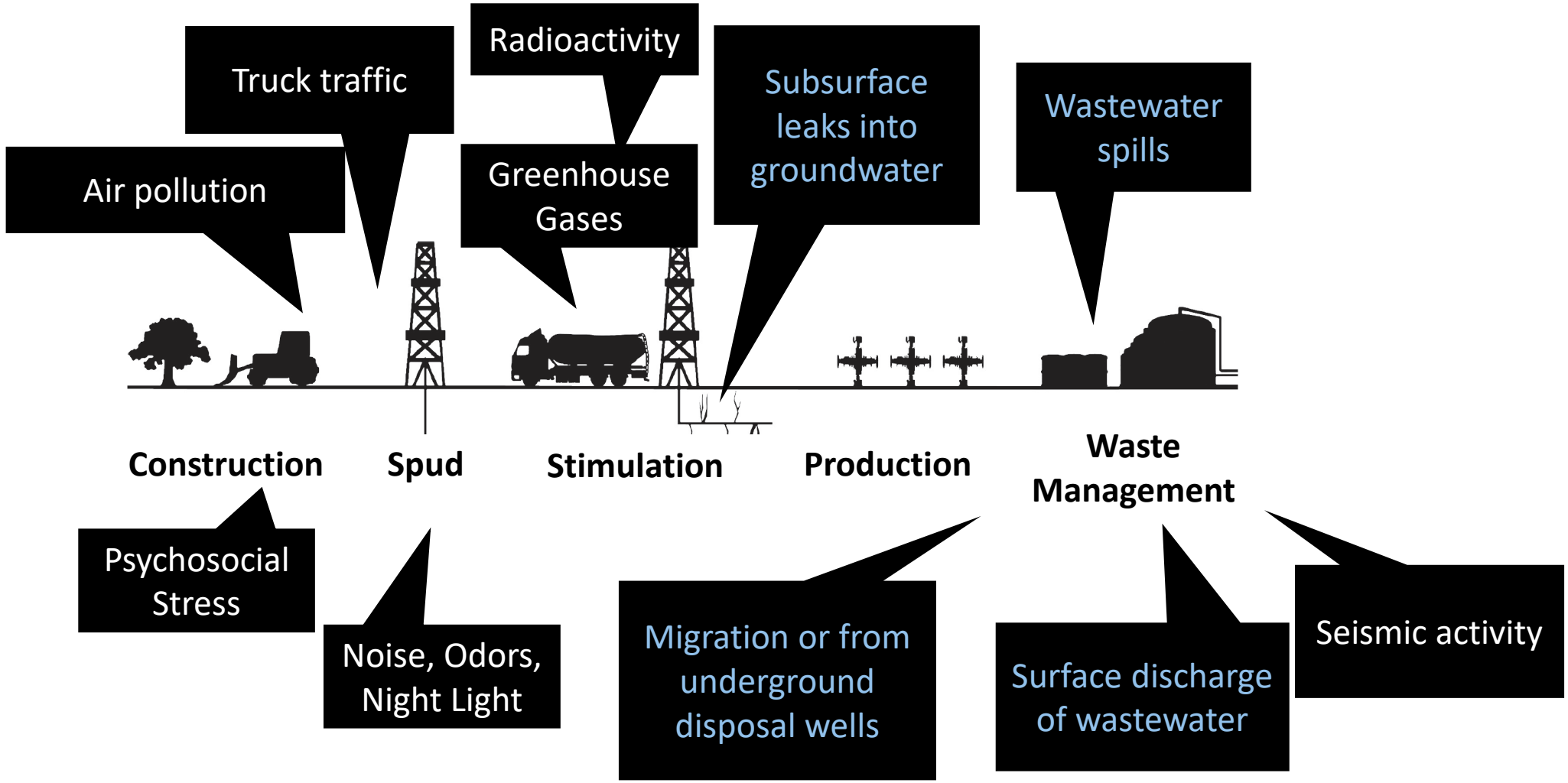
Potential Stressors of UOGD



Shonkoff et al. 2014 EHP; Adgate et al. 2014

Figure modified from Garcia-Gonzales , 2019

Residential proximity to UOGD has been associated with adverse health outcomes in >40 studies

Adverse perinatal outcomes (n = 21)

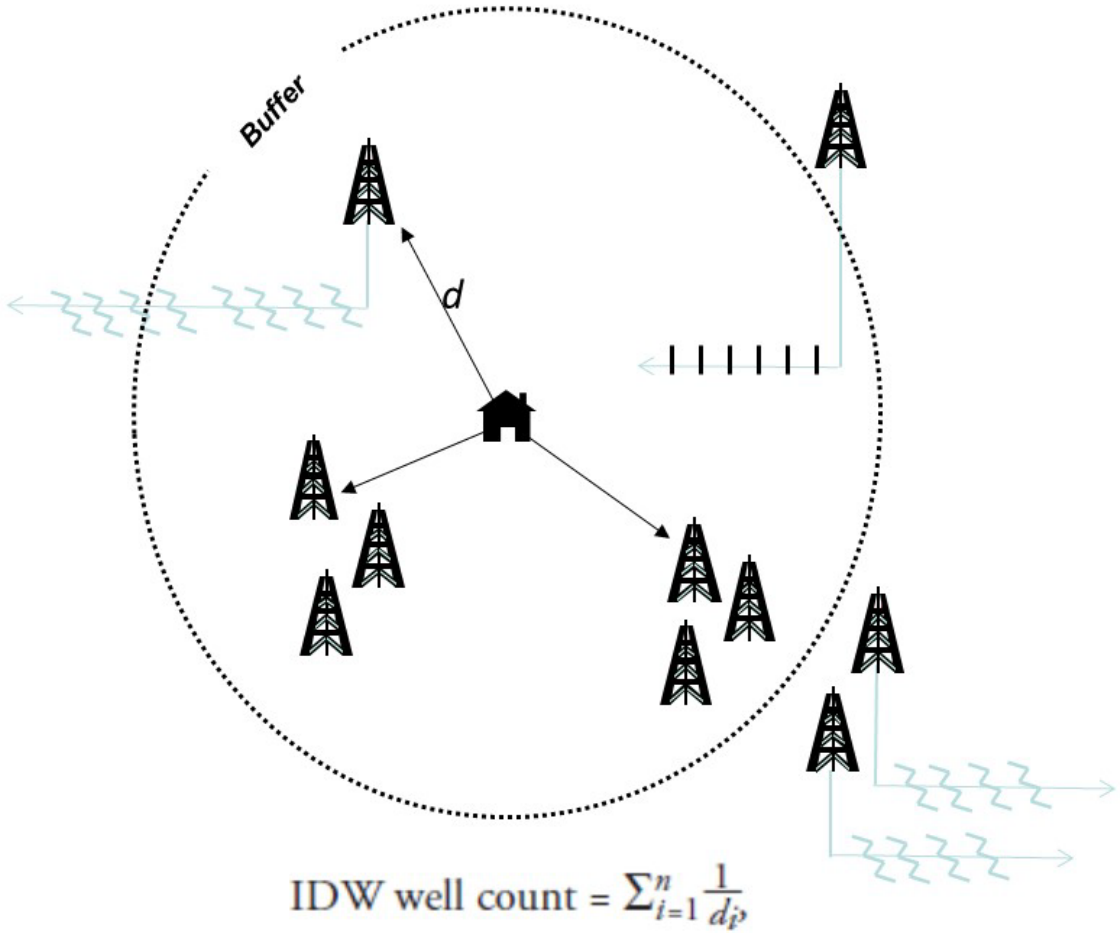
Cardiovascular disease, asthma, and hospitalizations (n = 12)

Other health outcomes (n = 6)

Cancer (n = 4)

Deziel et al. 2020 Env Res; Deziel et al. 2022 CEHR

Proximity Models



IDW well count = $\sum_{i=1}^{n} \frac{1}{d_i}$

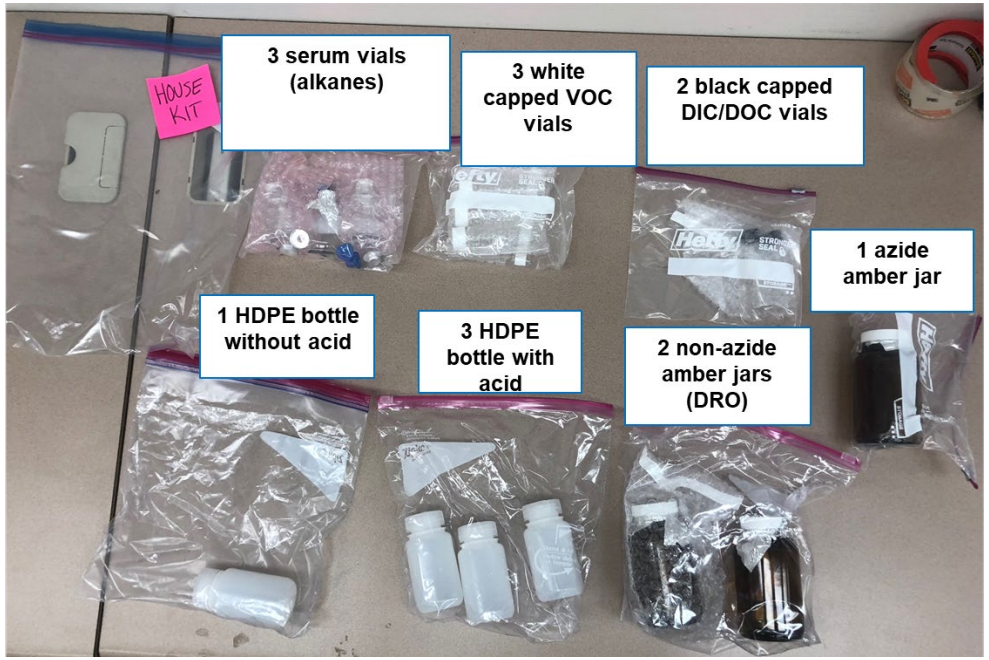
Strengths	Limitations
Provides aggregate metric of exposure when dominant hazard not known	Cannot distinguish etiologic agents or routes of exposure
Interpretable and relevant to policy (e.g., setbacks)	Assumes UOG exposure attenuates with distance in a predictable way

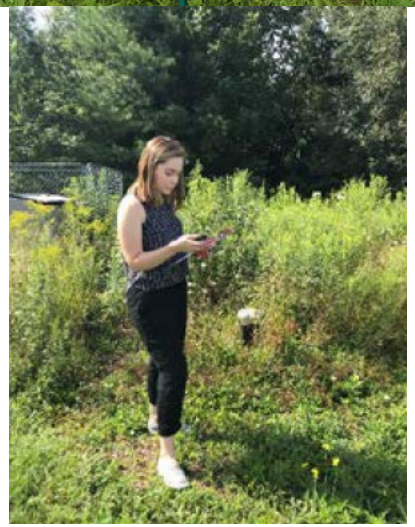
How do we assess exposure to UOG-related water contamination in population-based studies?

The challenges

1. Etiologic agents not necessarily known *(Elliott et al. 2017 JESEE, 2017 STOTEN)*
2. Limited groundwater well monitoring data *(Elliott 2018 Envr Res; Clark 2021 ES&T)*
3. Fate and transport modeling for drinking water may be computationally intensive *(Soriano 2021 ERL, Soriano 2022 ES&T)*
4. Contamination events stochastic/episodic and information on spills, leaks, violations not timely or readily publicly available

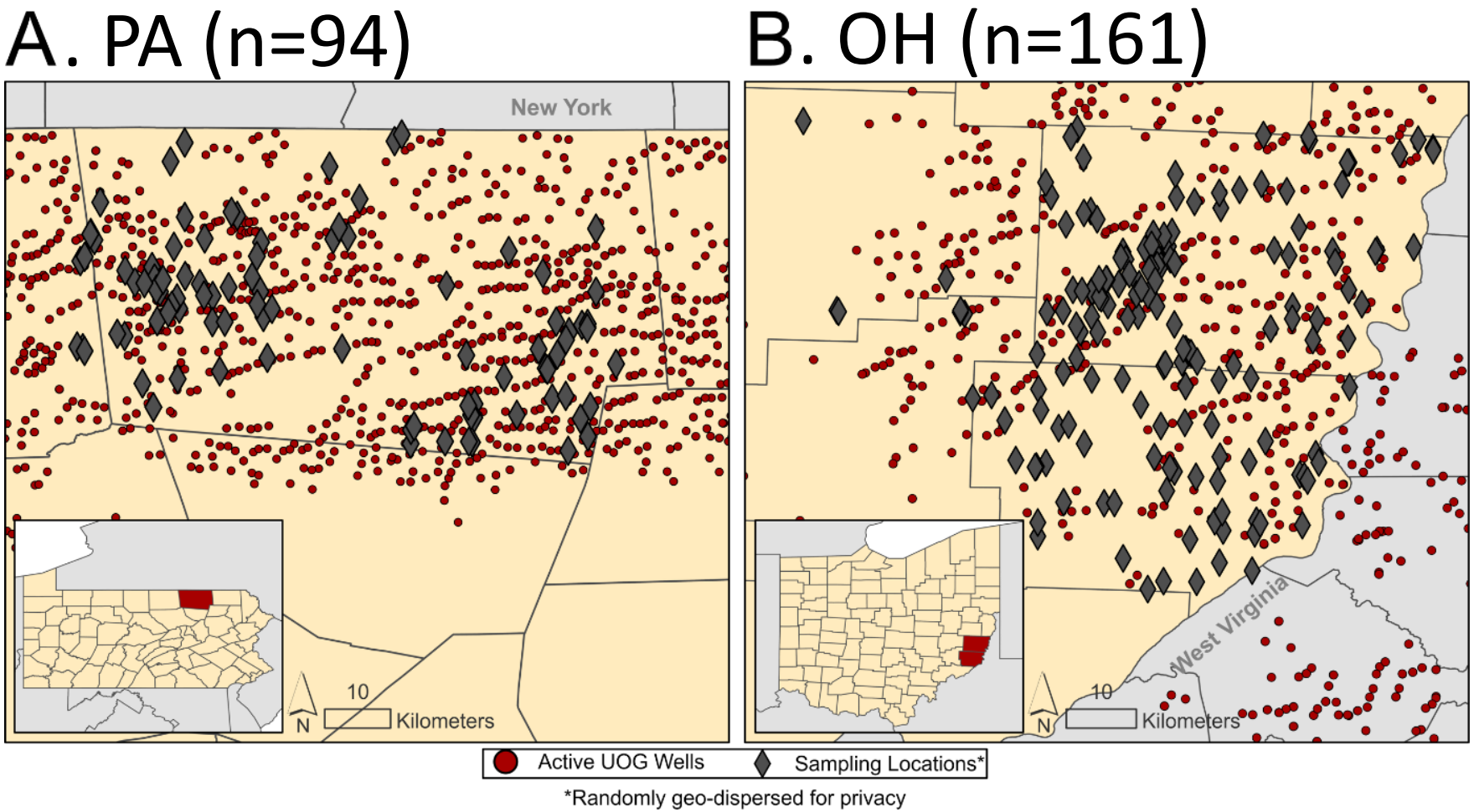
Collect new water measurements and compare to proximity models





- 255 homes in Pennsylvania & Ohio
- Samples analyzed for 64 organic and inorganic chemicals chosen for health relevance and association with UOGD
- GPS collection

Study area: Counties of Pennsylvania and Ohio



Grey diamonds represent sampling locations, red circles represent active UOG wells. Home locations randomly geo-dispersed (offset) by 0.1 km for privacy.

Clark 2021 ES&T

Analysis

- Compared **detection frequencies** of organics and **concentrations** of inorganics to several proximity metrics and a newly developed water-specific metric (varying buffer sizes)
- Aggregate proximity/density metric

  ID^2W = inverse-distance squared weighted well count
- New water metric *(Soriano et al. 2021 ERL; Soriano et al. ES&T 2022)*

  ID_{ups} = 1/u where u=the distance to nearest upgradient UOG well

Organic chemicals (PA n=89 homes, OH n=161)

	PA		OH		
Chemical	**>LOD (%)**	**Median (IQR) (μg/L)**	**>LOD (%)**	**Median (IQR) (μg/L)**	**USEPA MCL (μg/L)**
Bromochloromethane	97	0.52 (0.42, 0.63)	46	<LOD (<LOD, 0.08)	NS
Chloroform	76	0.09 (0.009, 0.19)	22	<LOD (<LOD, <LOD)	NS
1, 2-Dichloroethane & Benzene	75	0.02 (<LOD, 0.04)	24	<LOD (<LOD, <LOD)	5
Trichloroethene	75	0.04 (0.008, 0.06)	-	-	5
Toluene	64	0.01 (<LOD, 0.03)	20	<LOD (<LOD, <LOD)	1000
Bromomethane	58	0.02 (<LOD, 0.06)	67	0.012 (<LOD, 0.04)	NS
Dibromomethane	45	<LOD (<LOD, 0.12)	-	-	NS
1,1-Dichloroethene & trans-1,2-Dichloroethene	42	<LOD (<LOD, 0.02)	-	-	100
Vinyl chloride	26	<LOD (<LOD, 0.0004)	57	0.003 (<LOD, 0.023)	2
m-Xylene & p-Xylene	24	<LOD (<LOD, <LOD)	-	-	10000

IQR: inter-quartile range; LOD: Limit of detection; MCL: Maximum Contaminant Level; NS: No Standard.

Associations between detections of organic chemicals and metrics

Chemical	ID_{ups} 1 km* OR (95% CI)	ID_{ups} 2 km* OR (95% CI)	ID^2W 2 km* OR (95% CI)
PA			
Vinyl chloride	1.87 (0.71, 4.91)	1.87 (0.71, 4.91)	1.47 (0.56, 3.82)
Bromomethane	**2.55 (1.06, 6.13)**	1.72 (0.73, 4.07)	0.81 (0.34, 1.89)
1,2-Dichloroethene & Benzene	1.66 (0.66, 4.14)	**2.59 (1.01, 6.67)**	**3.29 (1.25, 8.66)**
Toluene	**2.63 (1.07, 6.45)**	1.74 (0.73, 4.19)	2.13 (0.88, 5.18)
Chloroform	2.63 (0.32, 2.28)	0.67 (0.25, 1.79)	0.86 (0.32, 2.28)
M-xylene & p-xylene	**3.36 (1.16, 9.72)**	1.50 (0.56, 4.02)	2.53 (0.91, 7.07)
1,1-Dichloroethene & trans-1,2-Dichloroethene	2.05 (0.75, 5.63)	2.05 (0.75, 5.63)	1.58 (0.58, 4.30)
Bromochloromethane	1.09 (0.49, 2.45)	1.09 (0.49, 2.45)	1.29 (0.57, 2.91)
Trichloroethene	0.76 (0.29, 2.00)	0.60 (0.23, 1.58)	0.60 (0.23, 1.58)
Dibromomethane	1.80 (0.78, 4.20)	1.25 (0.54, 2.88)	1.25 (0.54, 2.88)
OH			
Vinyl chloride	0.88 (0.44, 1.77)	0.67 (0.34, 1.33)	0.66 (0.34, 1.28)
Bromomethane	1.99 (0.89, 4.41)	1.48 (0.70, 3.11)	1.16 (0.57, 2.35)
1,2-Dichloroethene & Benzene	0.90 (0.40, 2.04)	0.91 (0.41, 2.03)	0.67 (0.30, 1.50)
Toluene	0.64 (0.26, 1.60)	0.44 (0.17, 1.15)	**0.30 (0.11, 0.82)**
Chloroform	0.71 (0.30, 1.71)	0.61 (0.26, 1.47)	0.92 (0.41, 2.05)
Bromochloromethane	0.89 (0.44, 1.78)	1.02 (0.52, 2.00)	1.45 (0.75, 2.81)

*Exposure is defined as a value above the median

Inorganic chemicals (PA n=94 homes, OH n=161)

	PA		OH		
Chemical	**>LOD (%)**	**Median (IQR) (μg/L)**	**>LOD (%)**	**OH Median (IQR) (μg/L)**	**USEPA MCL (μg/L)**
Arsenic	81	0.99 (0.36, 2.44)	8	<LOD (<LOD, <LOD)	10
Barium	100	166.03 (76.99, 399.46)	99	88.48 (50.74, 142.80)	2000
Bromide	34	<LOD (<LOD, 71.29)	53	27.00 (<LOD, 54.00)	NS
Calcium	99	34961 (20968, 42863)	100	72101 (51144, 101596)	NS
Chloride	100	5831 (3035, 16128)	99	6758 (3018, 19785)	250000[c]
Fluoride	80	82.37 (44.42, 114.2)	100	110.00 (82.00, 156.00)	4000
Iron	70	60.37 (<LOD, 139.02)	51	10.74 (<LOD, 32.70)	300[c]
Lead	96	1.27 (0.72, 2.05)	12	<LOD (<LOD, <LOD)	15
Lithium	100	23.33 (8.27, 51.95)	99	10.24 (6.79, 15.22)	NS
Magnesium	99	6767 (3526, 9845)	100	16116 (8870, 27149)	NS
Manganese	91	17.1 (0.94, 127.51)	58	1.84 (<LOD, 19.25)	50[c]
Nitrate	67	334.35 (<LOD, 1009.63)	99	560.00 (100.00, 1754.00)	10000
Potassium	100	1467.52 (1050.14, 1830.6)	100	1489.75 (1148.41, 2038.67)	NS
Sodium	100	16130 (7282, 46386)	100	23819 (16740, 52714)	NS
Strontium	100	472.04 (179.83, 1037.06)	100	526.48 (288.57, 967.63)	NS
Sulfate	100	10063 (6847, 15648)	96	30813 (20117, 50587)	250000[c]
Uranium	85	0.87 (0.24, 2.56)	16	<LOD (<LOD, <LOD)	30

IQR: inter-quartile range; LOD: Limit of detection; MCL: Maximum Contaminant Level; NS: No Standard.

Associations between concentrations of inorganic chemicals and metrics

- Most inorganic species not correlated or weakly correlated with metrics (Spearman ρ range: ±0.00-0.28)
- Direction of correlations mixed and inconsistent
- Concentrations of inorganics generally unrelated to UOGD exposure potential
  - Many inorganics have alternative natural and anthropogenic sources (e.g., arsenic is naturally occurring)
  - This analysis did not include source apportionment

Conclusions

- Organic chemicals detected infrequently and at low concentrations, though a few were positively associated with increasing UOGD exposure potential
- Several inorganic chemicals exceeded health-based standards, but were generally unrelated to UOGD exposure potential
- Limited correlations between measurements and metrics may be in part because:
  - Temporal factors
  - Contamination potential depends on many factors including occurrence of a spill, leak, violation

Application of Water-Specific Metric to Health Studies

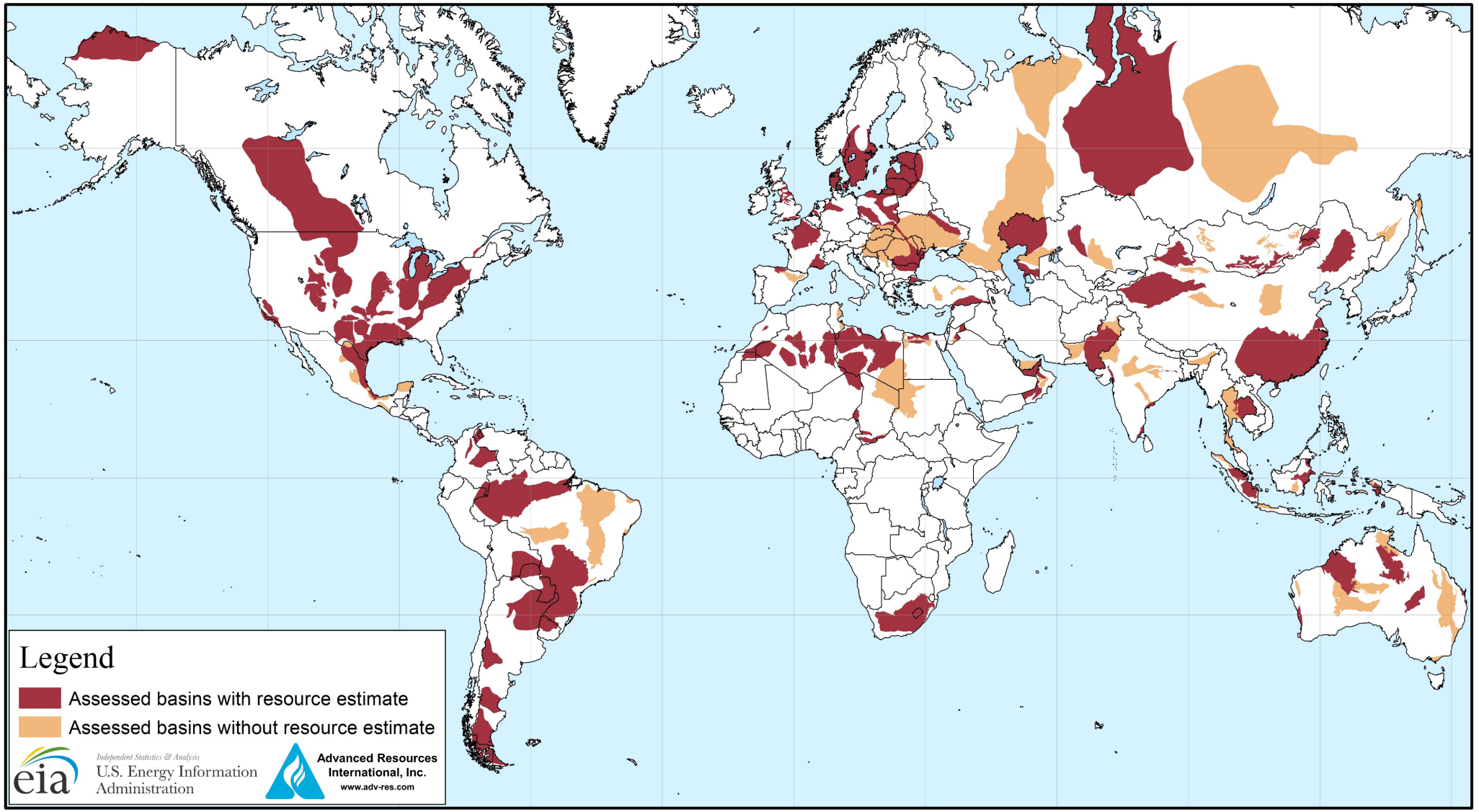
- We applied ID_{ups} in a recent case-control study of childhood acute lymphoblastic leukemia

	Odds Ratio (95% CI)*	
Buffer Around Maternal Residence at Birth	Presence of Any UOG Well	Presence of Upgradient UOG Well
3 mo pre-conception to 1 yr pre-diagnosis		
2 km	**1.98 (1.06, 3.69)**	1.94 (0.75, 4.99)
5 km	1.33 (0.88, 2.00)	1.45 (0.76, 2.77)
10 km	1.14 (0.84, 1.55)	1.26 (0.75, 2.14)
3 mo pre-conception to birth		
2 km	**2.80 (1.11, 7.05)**	3.10 (0.74, 13.01)
5 km	1.54 (0.90, 2.63)	1.48 (0.59, 3.68)
10 km	1.42 (0.99, 2.04)	1.60 (0.83, 3.08)

*Adjusted for birth year

Clark et al. 2022 EHP

Future Directions: World Shale Gas Basins



https://www.eia.gov/analysis/studies/worldshalegas/

Future directions: UOGD in the news

Ukraine war triggers push for more fracking in Pennsylvania March 27, 2022

ENERGY

Why Fracking Won't Solve the Global Oil and Gas Squeeze September 12, 2022

Biden Plans to Open More Public Land to Drilling

The president is under pressure to bring down gas prices, but any new drilling would be years away. The fees that companies pay would rise sharply. April 15, 2022

EUROPE

Earthquakes for Ukraine: Dutch gas drilling tests what countries will accept

September 1, 2022

Fracking ban in England lifted in bid to boost UK gas supply September 8, 2022

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Julie Plano

Livia Nock

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