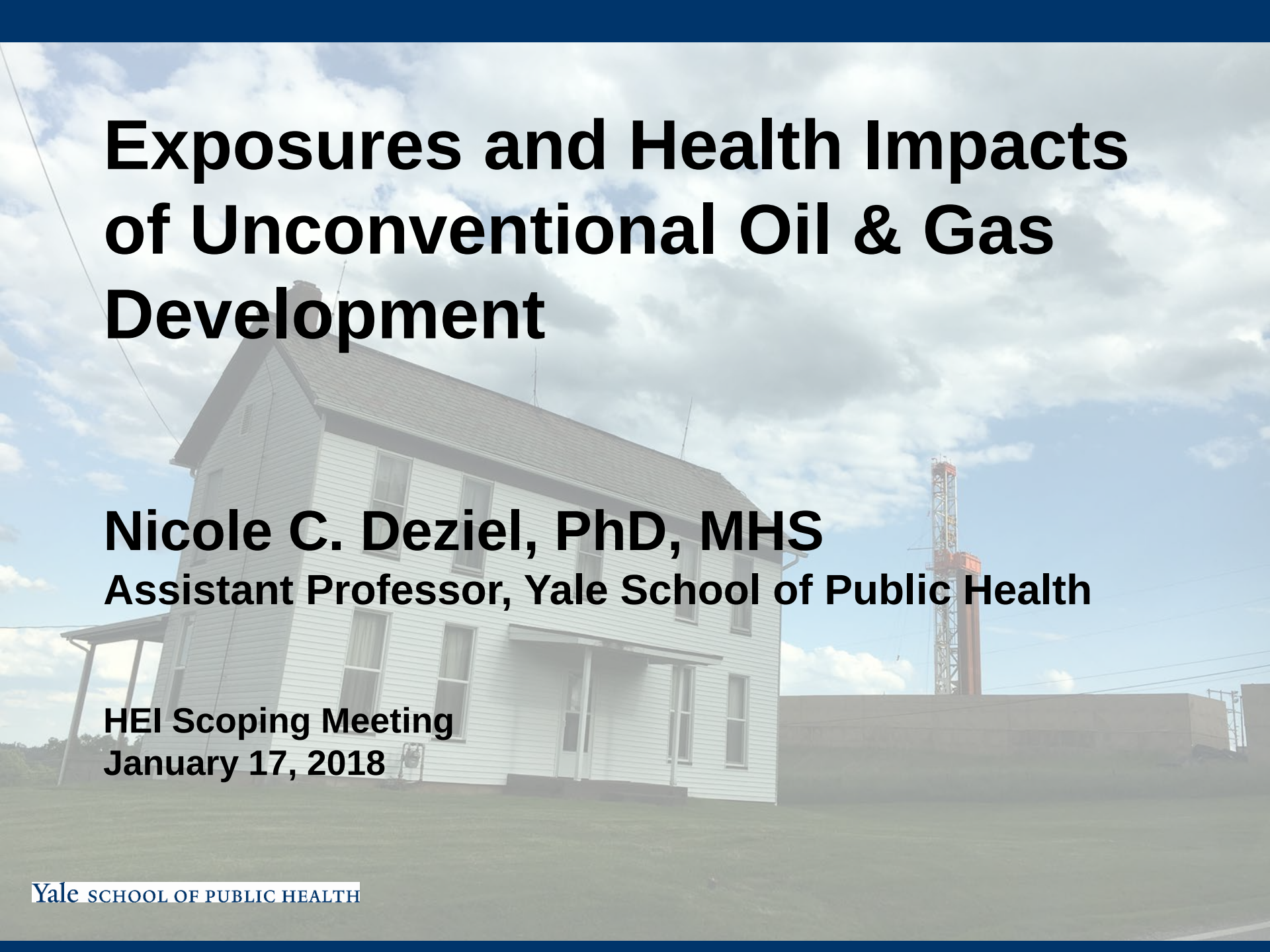
Exposures and Health Impacts of Unconventional Oil & Gas Development



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Problem Scope

- 25-30,000 wells hydraulically fractured (HF) annually in the US (EPA 2016)
- ~4 million people live within 1 mile of a HF well (Czolowski 2017)
- Drinking water sources for 9 million people within a mile of an HF well (EPA 2016)
- UOG waste water contains toxic and radioactive compounds (Shih 2015, Elliott 2016)
- HF-related activities have affected drinking water resources (e.g., Jackson 2013, Llewellyn 2015)
- UOG sites release air pollutants (e.g., carcinogens) (Elliott 2017, McKenzie 2012)
- Water and air quality monitoring and human health data are insufficient

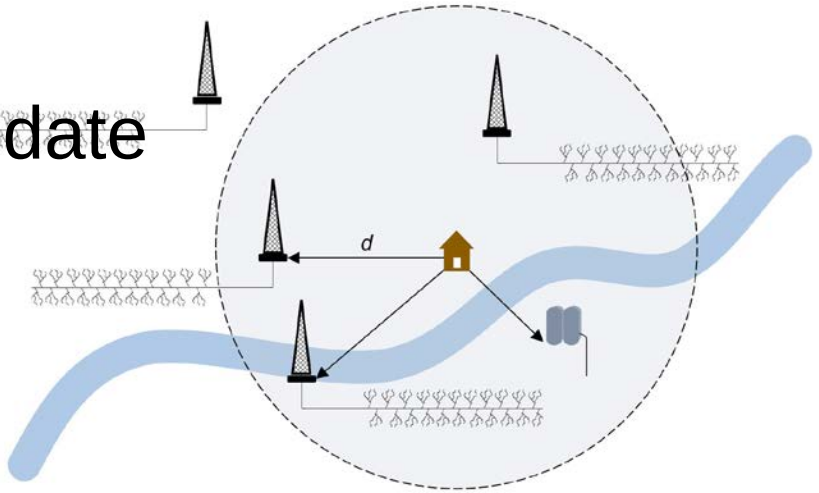
Multiple Potential Exposures/Stressors

Limited but Growing Epi Literature

- Perinatal outcomes (McKenzie 2014, Stacy 2015, Casey 2015, Whitworth 2017, Currie 2017)
- Childhood leukemia (McKenzie 2017, Fryzek 2013)
- Respiratory symptoms (Rabinowitz 2014, Rasmussen 2016, Tustin 2016)
- Self-reported dermal irritation (Rabinowitz 2014)
- Migraine, fatigue symptoms (Tustin 2016)
- Hospitalizations (Jemielita 2015)
- Risk Assessments (McKenzie 2012, Regli 2015)

Challenges in Exposure Assessment in Epidemiologic Context

- Proximity/density metrics and models better suited for air emissions
- Models don’t identify underlying etiologic agents
- Limited feasibility to conduct detailed monitoring on large-scale populations
- Only single-state studies to date
- Registry and records-based



Increasing Detail in Exposure/Activity Modeling

Physically-based hydrogeological models

Activity model (incorporates proximity, density, well attributes, literature-based emission weights)

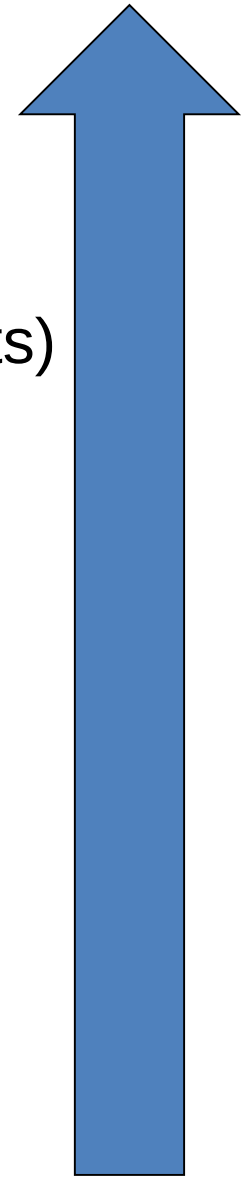
Inverse distance-weighted well count

Distance to Nearest Well

Zip code # UO&G wells

County-level # UO&G wells

Increasing precision



Limited but Growing Water Literature*

Author Year	State	# Samples	Primary Analytes	Geospatial Analysis
Elliott submitted	OH	66	VOCs, GRO, DRO linked to reprotox/carcinogenicity	Inverse distance well count, distance to nearest well
Drollette 2015	PA	64	GRO, DRO	distance to nearest well, distance to nearest violation
Jackson 2013	PA	141	methane, ethane	distance to nearest well
Osborn 2011	PA	68	methane	distance to nearest well
Alawattegama 2015	PA	33	methane, major ions	drilling activity over time
Fontenot 2013	TX	100	major ions	distance to nearest well
Hildenbrand 2015	TX	550	metals/ions, alcohols	distance to nearest well
Hildenbrand 2017	TX	77	ions/bromides/chlorides	distance to nearest well

*partial list

Challenges & Opportunities for Water Exposure Studies

- Shift emphasis from methane to contaminants of greater public health concern
- Use hydrologic-based inferences to:
  - Reduce uncertainty in contaminant source attribution
  - Strengthen proximity-based metrics of exposure
- Leverage new analytical techniques to identify chemicals in frac fluids and UOG wastewater

Limited but Growing Air Quality Studies*

Author Year	State	Example Compounds
Ahmadi & John 2015	TX	ozone
Brantley 2015	CO	VOCs, HAPs
Brown 2014	PA	PM2.5, VOCs
Bunch 2014	TX	VOCs
Eapi 2014	TX	methane, hydrogen sulfide
Elliott submitted	OH	VOCs
Goetz 2015	PA	methane, VOCs, NOx
Halliday	CO	benzene
Karion 2015	TX	methane
Lavoie 2015	TX	methane
Macey 2014	AK, CO, OH, PA, WY	VOCs
Walters 2015	WI	PM

*partial list

Challenges & Opportunities of Air Exposure Studies

- Differences in:
  - Modeling vs measurements
  - Reported UO&G proximity information
  - Sampling location
  - Sampling methods
  - Sampling duration
  - Target analytes

Study Quality

- Peer review
- Existing standards
  - STROBE (2007)
  - Journal guidelines
  - Navigation Guide (Woodruff 2014)

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