Evaluating Drinking-Water Vulnerability to Contamination from Oil and Gas Extraction

Mario Soriano, Jr.
Yale School of the Environment
High Meadows Environmental Institute, Princeton University

Nicole Deziel
Yale School of Public Health

James Saiers
Yale School of the Environment

Study Objective and Rationale

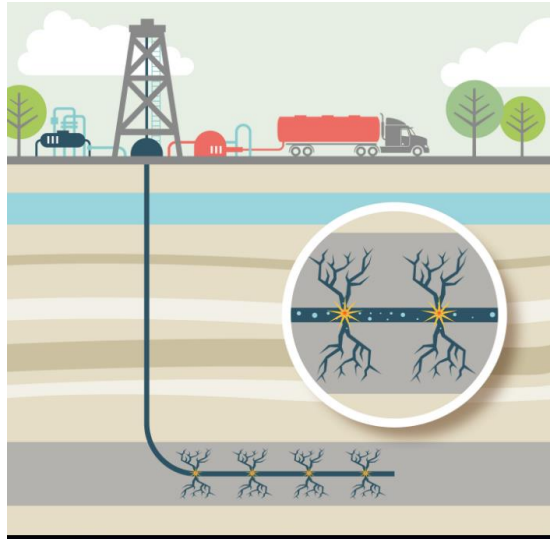
- **Objective:** Advance and apply *hydrologic-based* approaches for assessing *vulnerability* of household drinking-water wells to contamination by unconventional oil and gas development (UOGD).

- **Rationale:** Estimates of water-well *vulnerability* that draw on hydrologic principles to simulate groundwater flow rates and patterns can improve exposure assignments in human-health studies focusing on the drinking-water pathway.

- **Broader Applications:** Vulnerability approach may be useful for exposure assessments involving other sources of contamination, in addition to UOGD.

UOGD and Drinking-Water Contamination

- UOGD has enabled the recovery of oil and gas from low-permeability formations
  - directional drilling
  - hydraulic fracturing (fracking)



- UOGD generates large volumes of wastewater
  - drilling fluids
  - frack fluids
  - flowback and produced water

- UOGD activities have contaminated groundwaters and streamwaters
  - Leaking gas/oil wells
  - Wastewater spills and other releases

Fracked Oil and Gas Wells in the Appalachian Basin of

USA

- 15,000 fracked gas and oil wells
- Heavy reliance on household water wells

Ohio

Pennsylvania

West Virginia

Year Drilled

- 2018 to 2019 (2,004 wells)
- 2016 to 2017 (2,206 wells)
- 2014 to 2015 (3,628 wells)
- 2012 to 2013 (3,945 wells)
- 2010 to 2011 (4,212 wells)
- 2008 to 2009 (1,832 wells)
- 2006 to 2007 (887 wells)
- 2004 to 2005 (115 wells)
- Extent of Utica, Marcellus, and Upper Devonian shales

PennState | MCOR
Marcellus Center for Outreach and Research

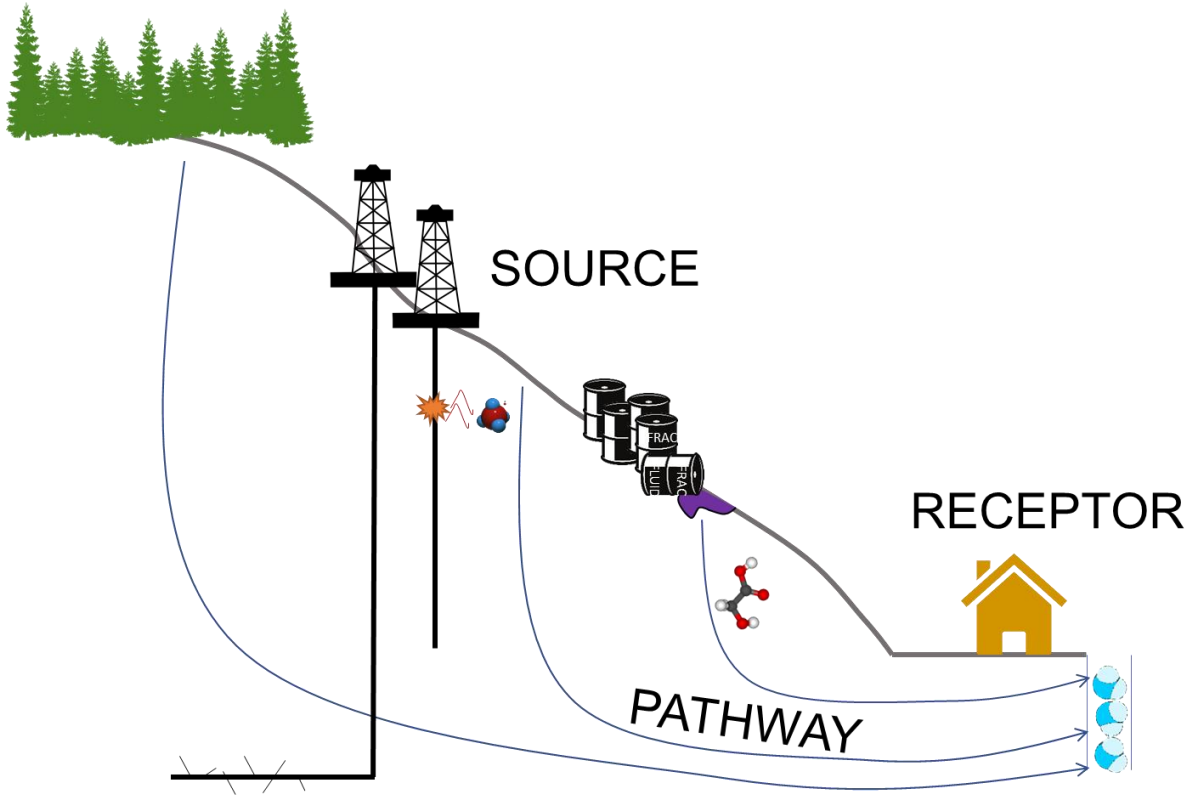
Drinking-Water Vulnerability Analysis

- Vulnerability
  - likelihood of drinking-water impairment at a receptor in the event of contaminant release from a source

- Receptor
  - residential water well

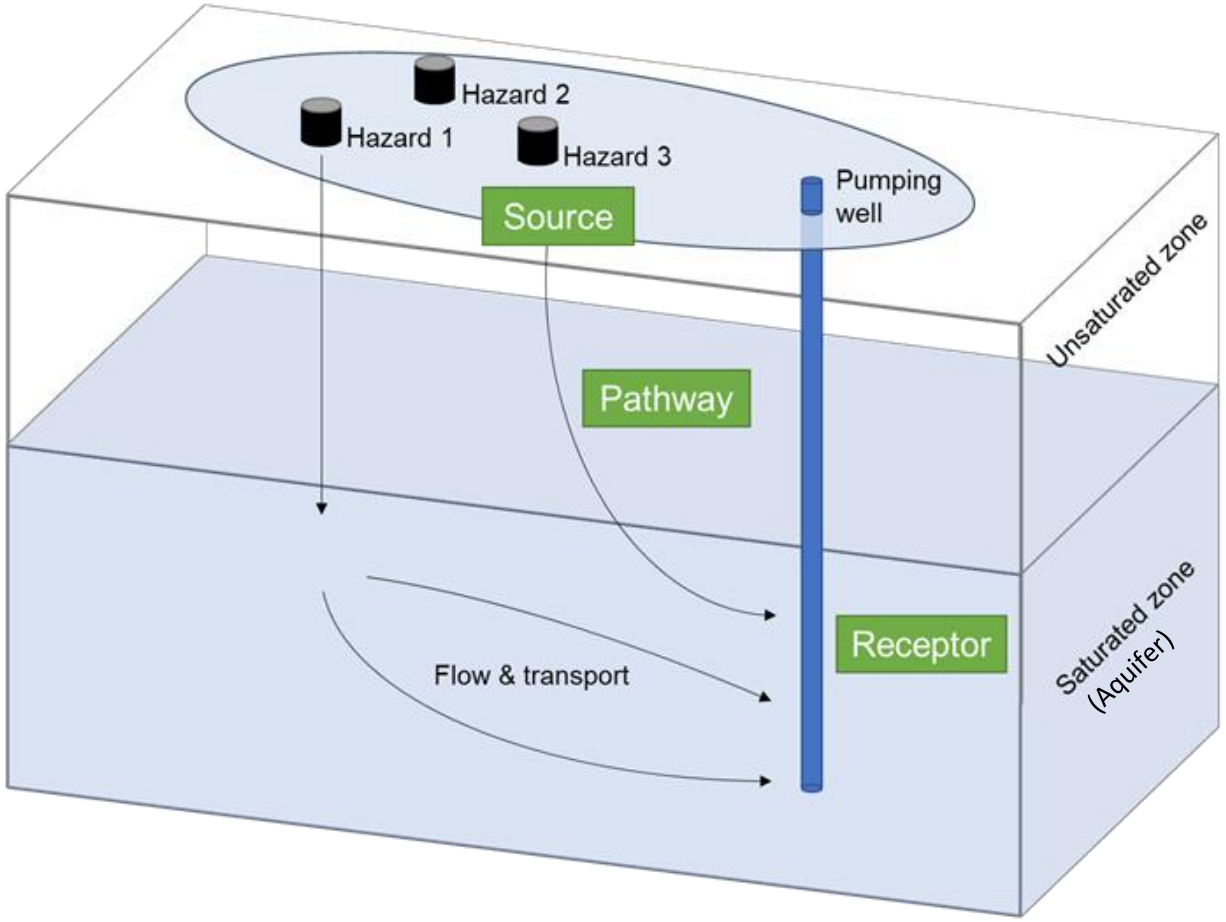
- Contaminant sources
  - surface spills
  - gas/oil well drilling and fracking
  - compromised well integrity
  - numerous non-UOG sources

- Vulnerability reflects
  - source & receptor locations
  - groundwater flow patterns

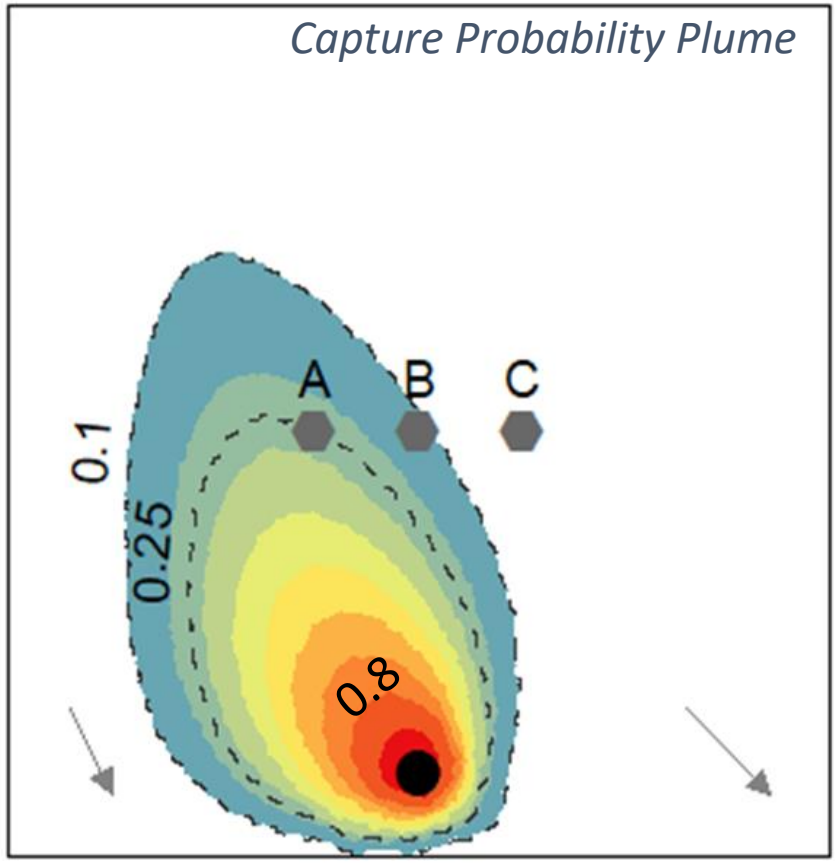


Capture-Zone Framework for Vulnerability

- A *capture zone* is the portion of the aquifer from which a drinking-water well draws its water
- Delineate capture zones by hydrologic modeling
- Do potential contaminant sources lie inside or outside of capture zones?
- To account for uncertainty, the simulated results are represented by plumes of *capture probability*.



Vulnerability and the Capture Probability Plume



Legend

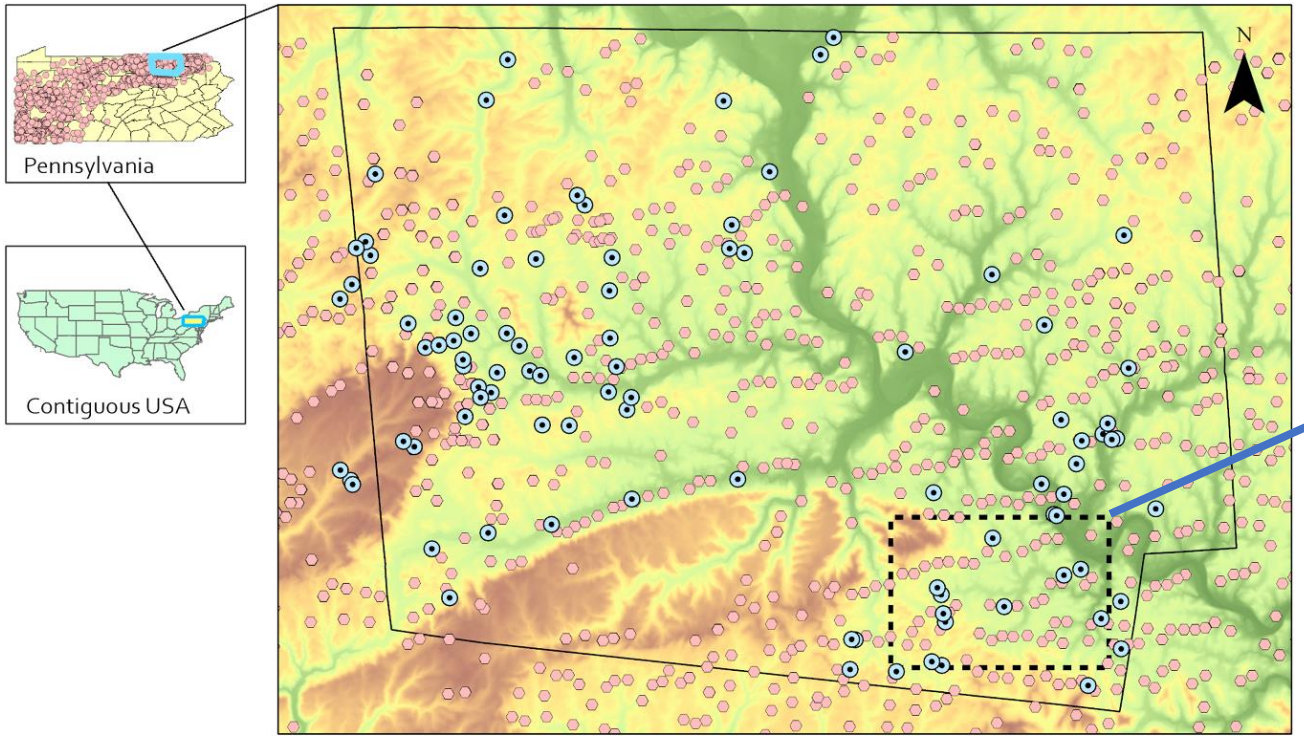
- Drinking water well
- UOG well pad
- Ambient groundwater flow direction

- The shape/extent of the capture probability plume depends on
  - (i) time
  - (ii) water-well pumping rate
  - (iii) ambient groundwater flow direction
  - (iv) aquifer properties

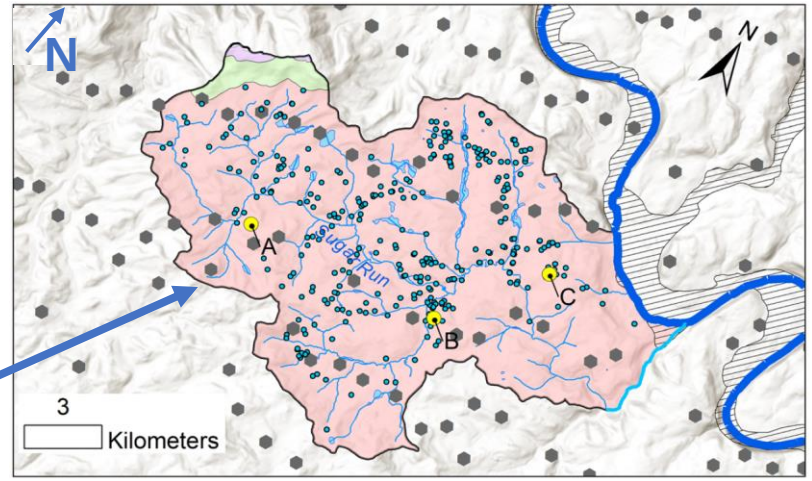
- The calculation of vulnerability (*V*)
  - (i) ranges from 0 to 1
  - (ii) depends on location & number of UOG well pads within capture zone
  - (iii) is equal to 0.33 in the illustration.

Application of Vulnerability Model

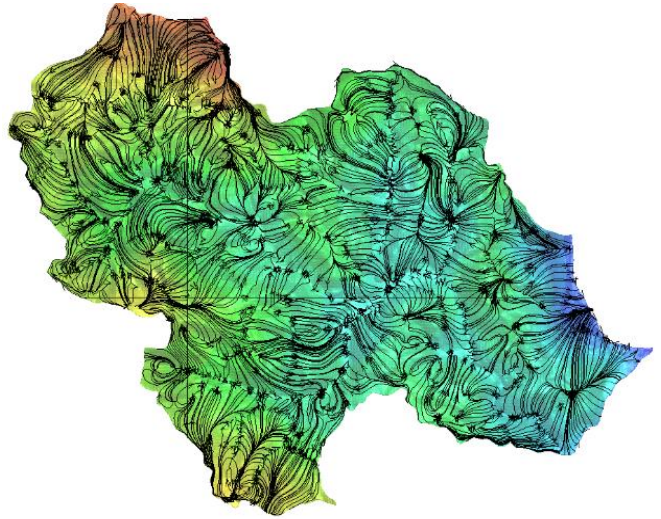
Bradford County, Pennsylvania



Domain of Vulnerability Model

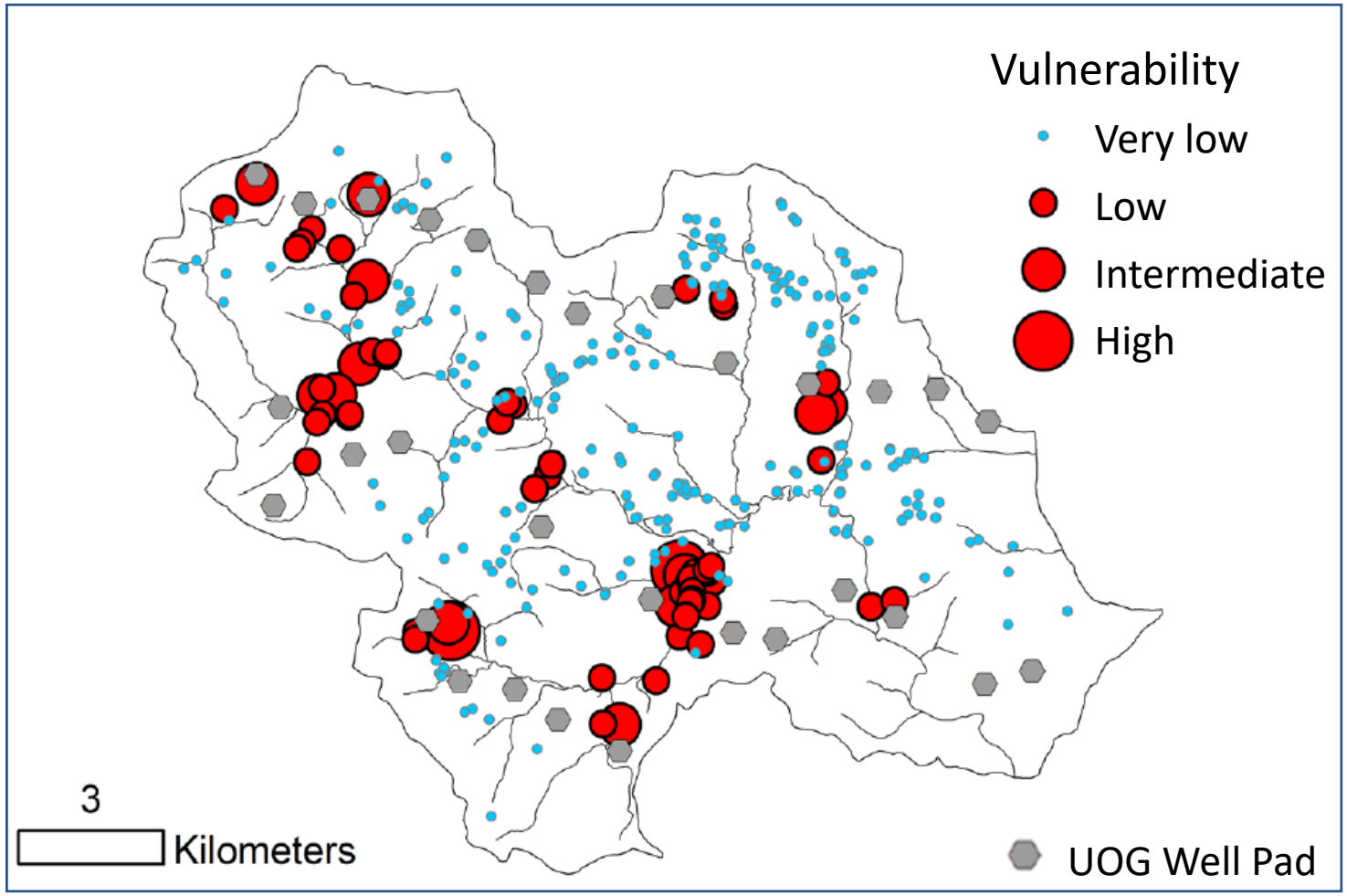


Groundwater flow patterns



Soriano et al. 2020

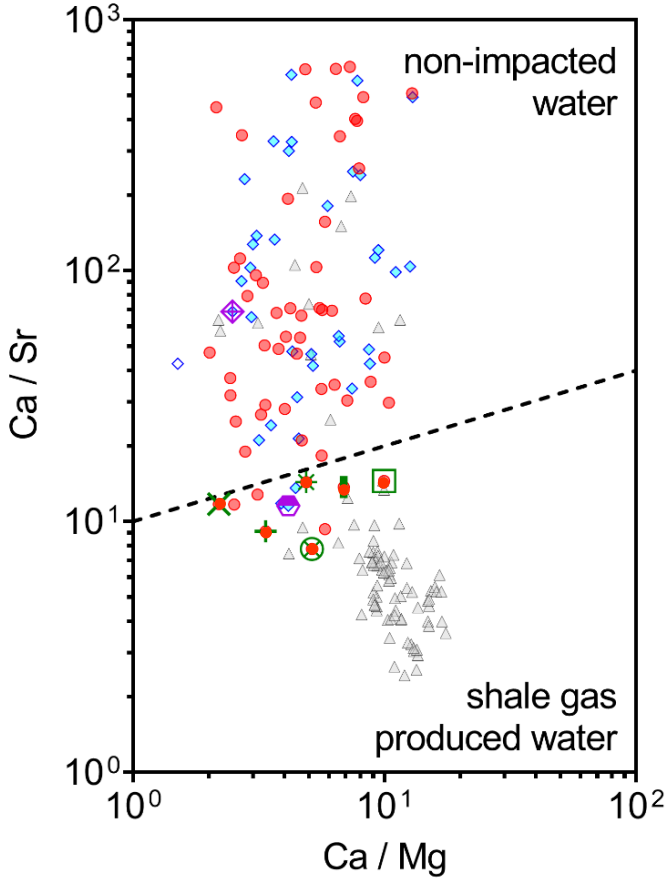
Drinking-Water Vulnerability Estimates

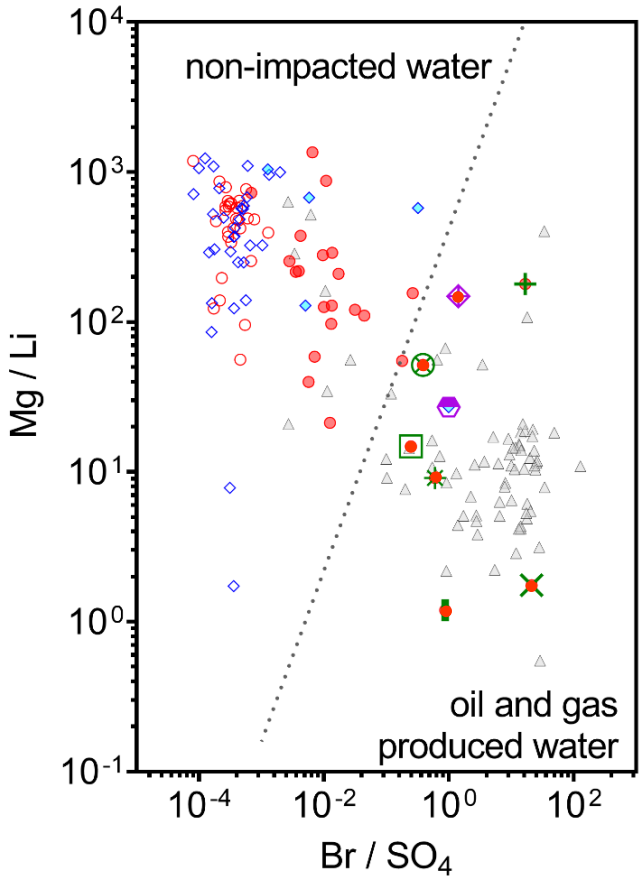


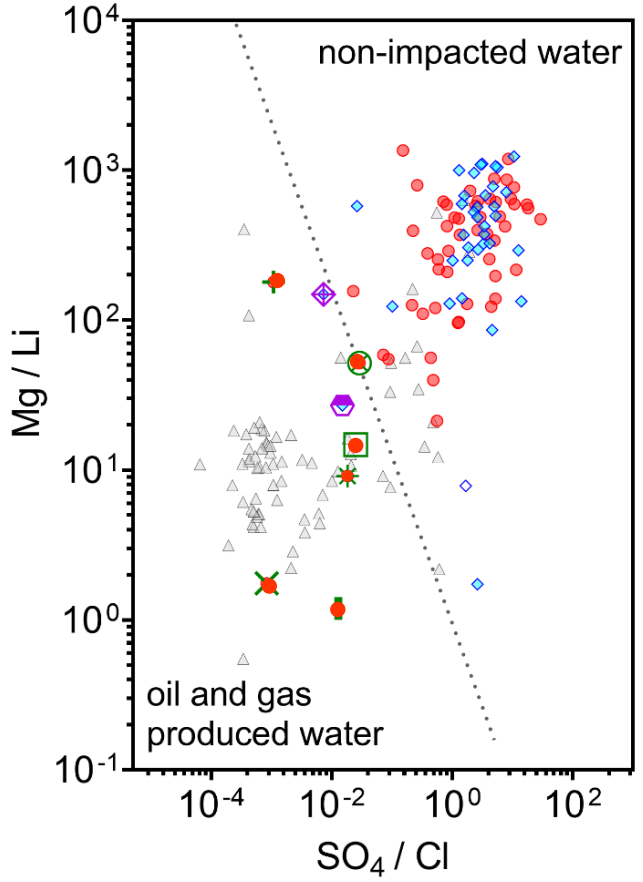
Vulnerability Class	Percentage of 316 water wells
Very low ($V < 0.001$)	78%
Low ($0.001 \leq V < 0.01$)	18%
Intermediate ($0.01 \leq V < 0.1$)	4%
High ($V > 0.1$)	0.6%

Soriano et al. 2020

Disproportionate Occurrence of Produced-Water Signatures in Samples from Vulnerable Drinking-Water Wells







Categories:

- Class V
- Class NV
- Shale gas produced water

Individual sample IDs:

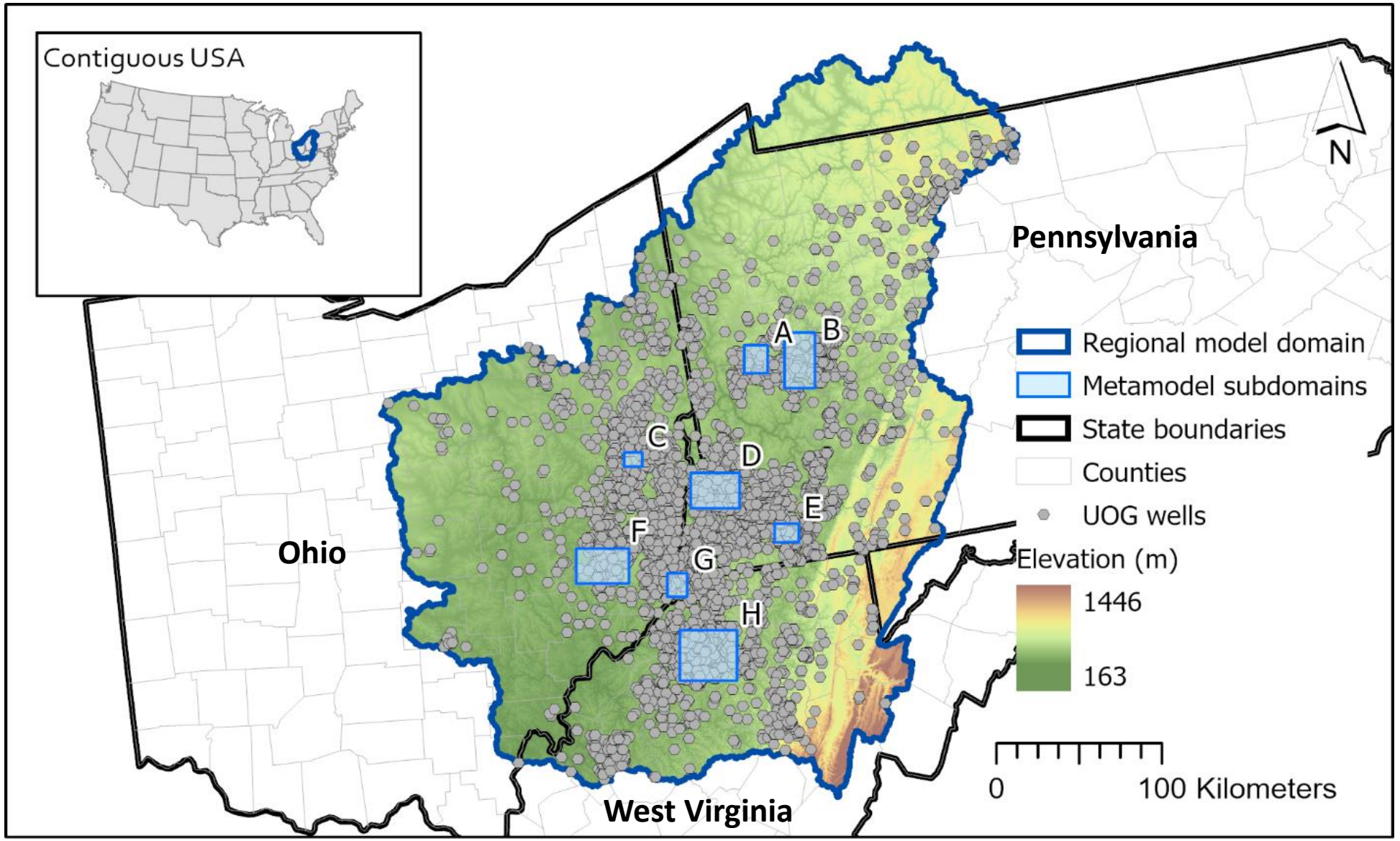
032 046 054 076
036 052 063 092

Soriano et al. (2021)

Fracking-Site Spills and Other Violations Near Brine-Affected Water Wells

Sample ID	Class	Number of violations within 2 km	Keywords extracted from violation reports indicating potential for release
032	Vulnerable	0	
036	Vulnerable	15	large drill mud oil base spill, oily substance leaking out, discharge of polluting material, cement returns and litter on ground, failure to minimize erosion and stabilize earth disturbance, inadequate diking, insufficient pit and tank capacity
046	Vulnerable	21	oil spill, release of production or frac water, industrial waste discharged, pit/tank leak, unlined pit, inadequate freeboard, residual waste on site, failure to minimize erosion and stabilize site
052	Vulnerable	2	defective casing, combustible gas coming off
054	Vulnerable	7	polluting substances allowed to discharge, elevated conductivity, dead/stressed vegetation between production tanks and edge of pad, failure to minimize erosion and stabilize site, residual waste on ground
063	Vulnerable	51	frac fluid discharge on ground and waters, small brine spill, 28% HCl spill, pit leak, defective casing, inadequate freeboard, failure to minimize erosion and stabilize site, drill cuttings/ residual waste on ground, stimulation/ flowback fluids not contained
076	Non-Vulnerable	0	
092	Non-Vulnerable	0	

Vulnerability of Residential Drinking-Water Wells in Pennsylvania, Ohio, and West Virginia



Soriano et al. (2022)

Vulnerability of Residential Drinking-Water Wells in Pennsylvania, Ohio, and West Virginia

Population served by domestic groundwater within regional domain	1.5×10^6
Vulnerable population within regional domain	29,990
Vulnerable population as % of total *Soriano et al. (2022)*	2.0%

- Our estimate of the vulnerable population is several fold lower than those based solely on household proximity to UOG

Utility of the Hydrologically Based Vulnerability Approach

- Vulnerability can serve as an exposure metric in epidemiological studies.
- It can readily be applied to quantify drinking-water vulnerability to other potential sources of contamination.
- The vulnerability approach can predict the likelihood of future exposures, enabling households of greatest risk to be targeted for monitoring and preventative actions.
- Vulnerability analysis can inform regulatory decision-making, such as in the establishment of science-based set-back distances

Acknowledgements

US Department of Environmental Protection Agency, Assistance Agreement CR839249

Yale Institute of Biospheric Studies

Geological Society of America

Yale Analytical and Stable Isotope Laboratory