A photograph of a shallow stream with a wooden bowl in the center, surrounded by fallen leaves and rocks. The water is clear, and the leaves are in various shades of brown and orange. The bowl is made of wood and is filled with water. The background is a mix of rocks and leaves.

CEC Workshop

# Methane Emissions from Abandoned Oil and Gas Wells

Mary Kang, Stanford University

November 10, 2015

# Outline

- Background
- Field measurements in Pennsylvania
  - What is the methane emission rate?
- Oil and gas wells in California

# Methane Emissions and Oil & Gas Industry

- Methane emissions estimates are uncertain
  - Gap in “bottom-up” and “top-down” estimates (e.g., Miller et al., PNAS, 2013)
  - Missing sources (e.g., Natural gas systems - Brandt et al., Science, 2014)
- Methane emissions from the oil & gas industry
  - U.S. Environmental Protection Agency proposed new regulations (August, 2015)
  - Numerous on-going measurement studies

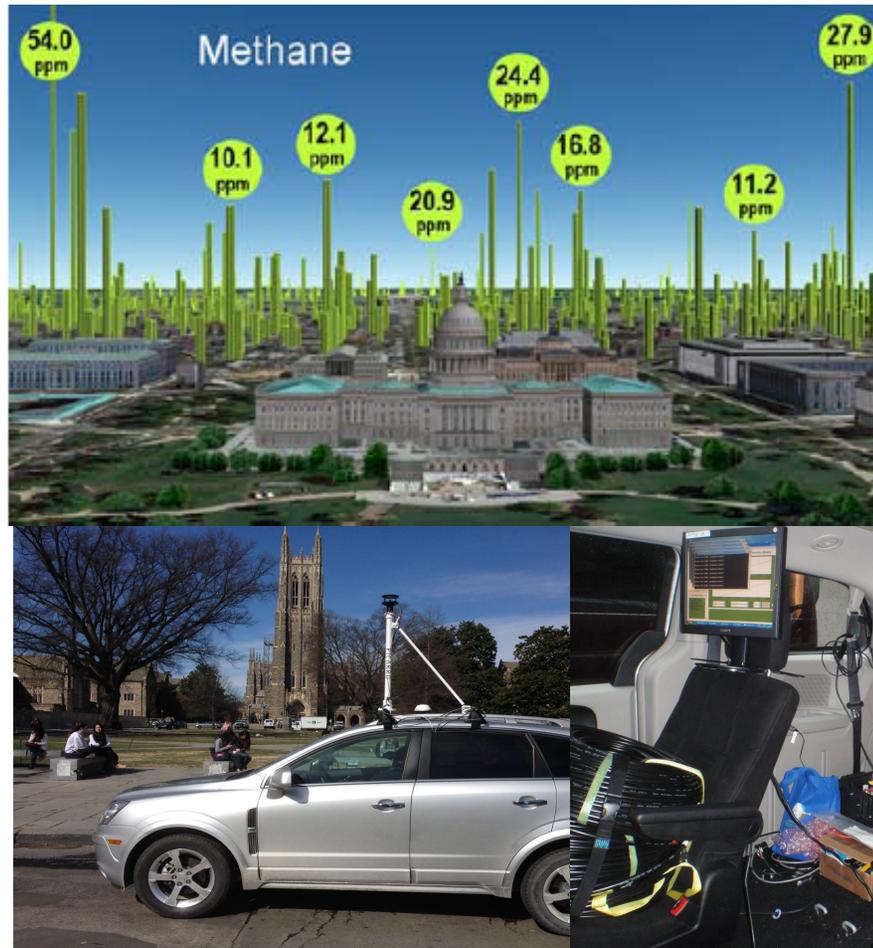
# Methane Emissions from Natural Gas Systems: Measurement Studies

## Natural Gas Production



Helicopter and airplane flights across 6 regions (in collaboration with EDF), including the Bakken.

## Natural Gas Distribution

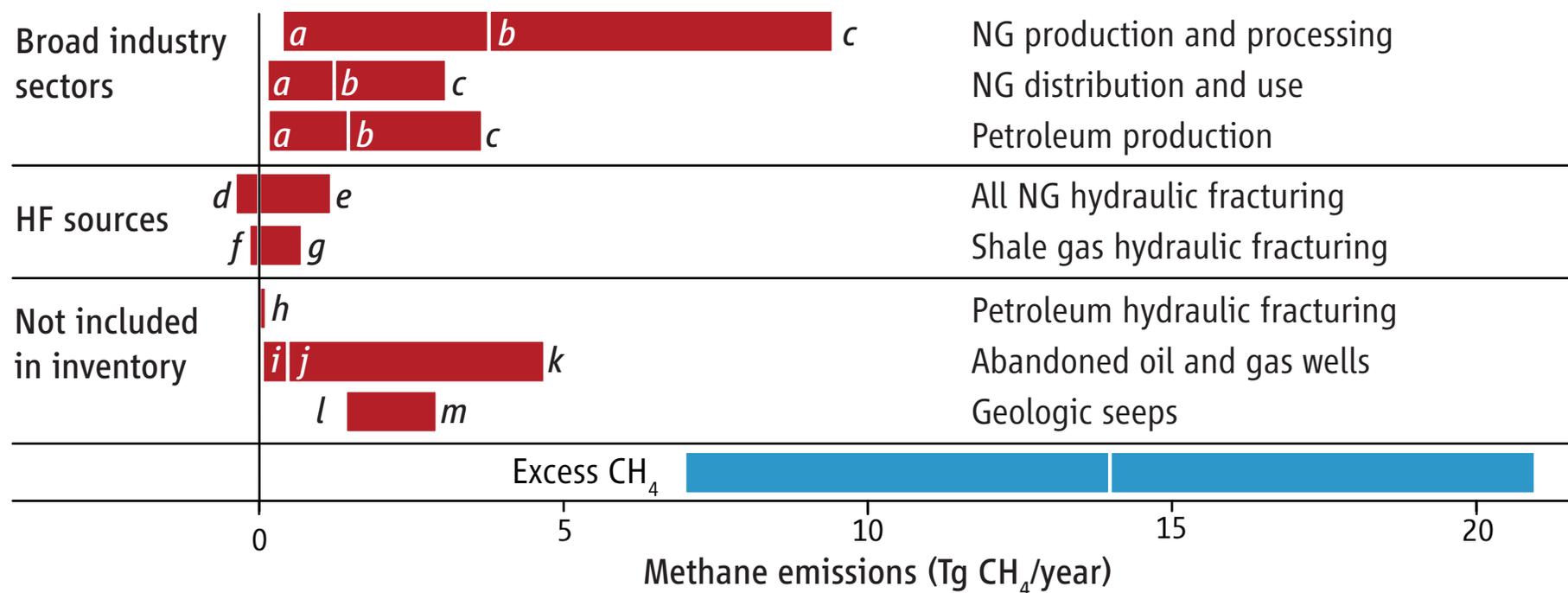


Pipeline leaks in Washington, DC, Boston, MA, Manhattan, NY, Cincinnati, OH, Durham, NC.

Jackson *et al.*, 2014; McKain *et al.*, 2015; Gallagher *et al.*, 2015

# Potential Contributions to Total U.S. CH<sub>4</sub> Emissions Above EPA Estimates From Natural Gas Systems

(Brandt *et al.*, *Science*, 2014)



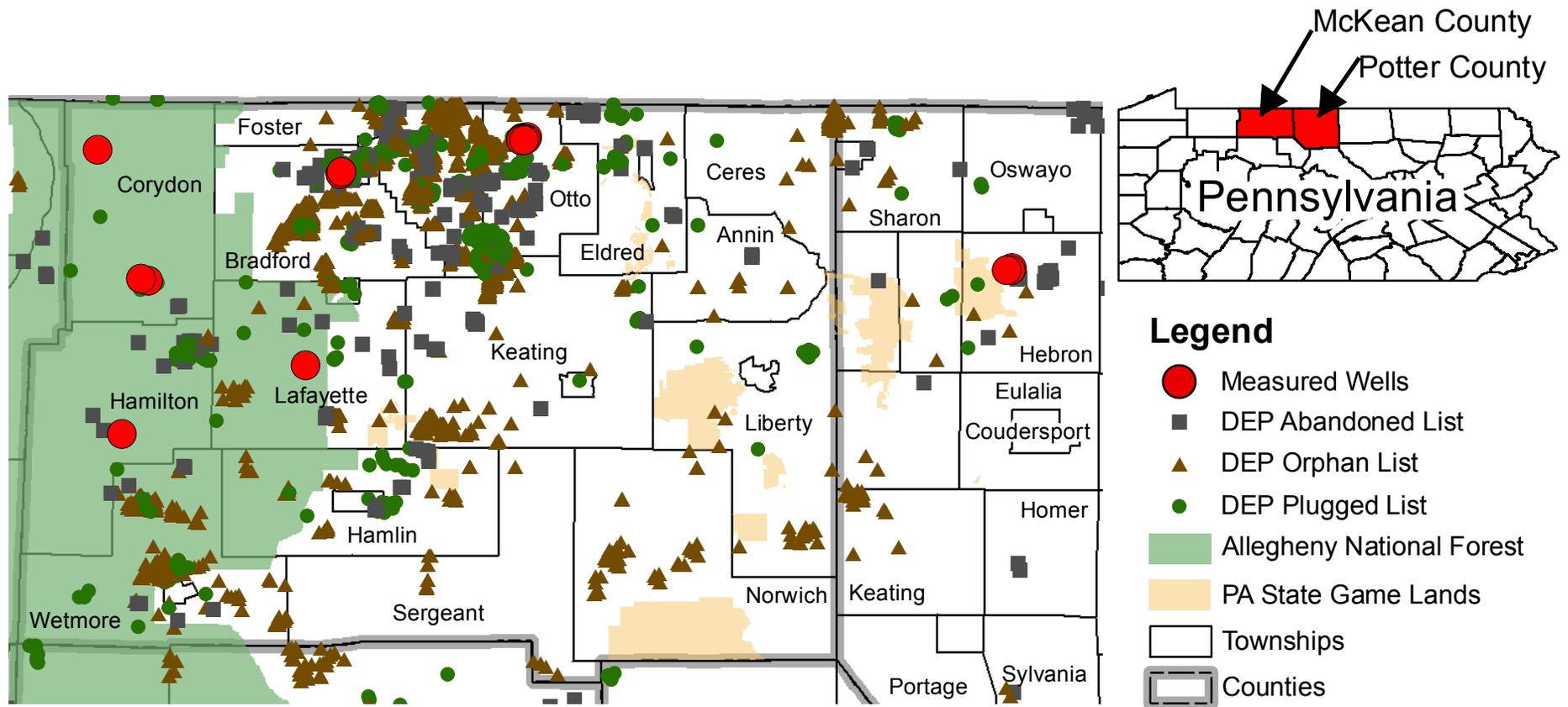
# Methane Emissions from Abandoned Oil and Gas Wells

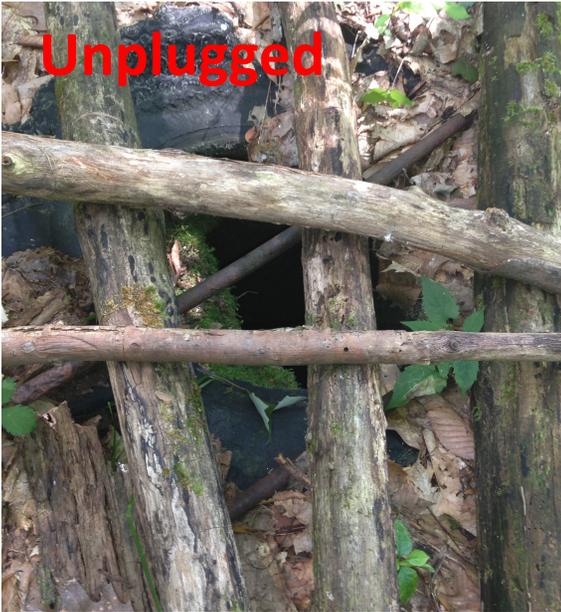
- 4 million abandoned wells in the U.S. alone (Brandt *et al.*, Science, 2014)
- Abandoned wells are pathways for fluid migration to overlying aquifers and gas emissions to the atmosphere
- Not included in any GHG emissions inventory



What is the emission rate?

# Field Sites in Pennsylvania





**Unplugged**



**Unplugged**



**Plugged**



**Plugged**

# Abandoned Wells in Pennsylvania



**Unplugged**

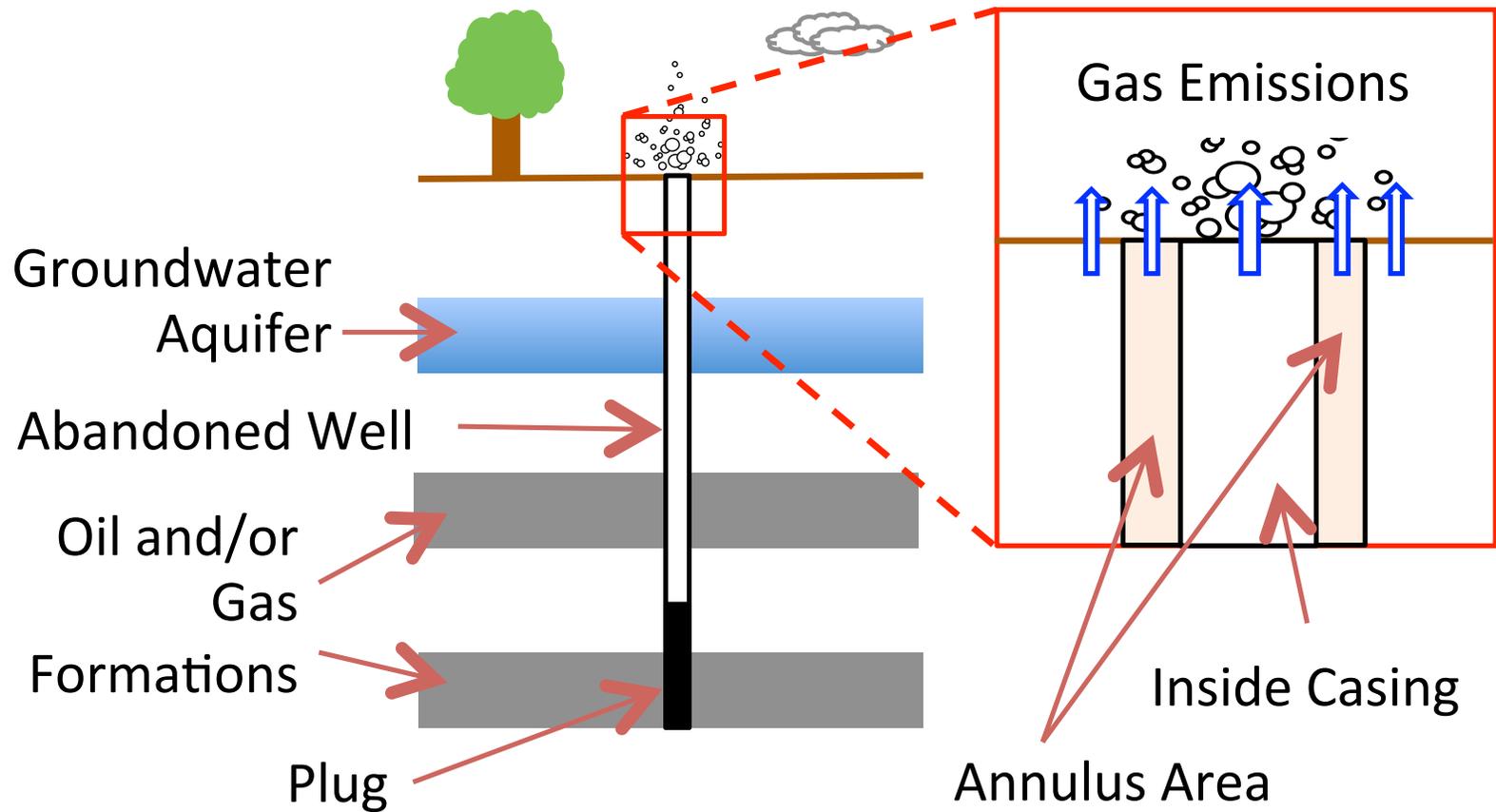


**Unplugged**



**Unplugged**

# Focusing on emissions at the surface



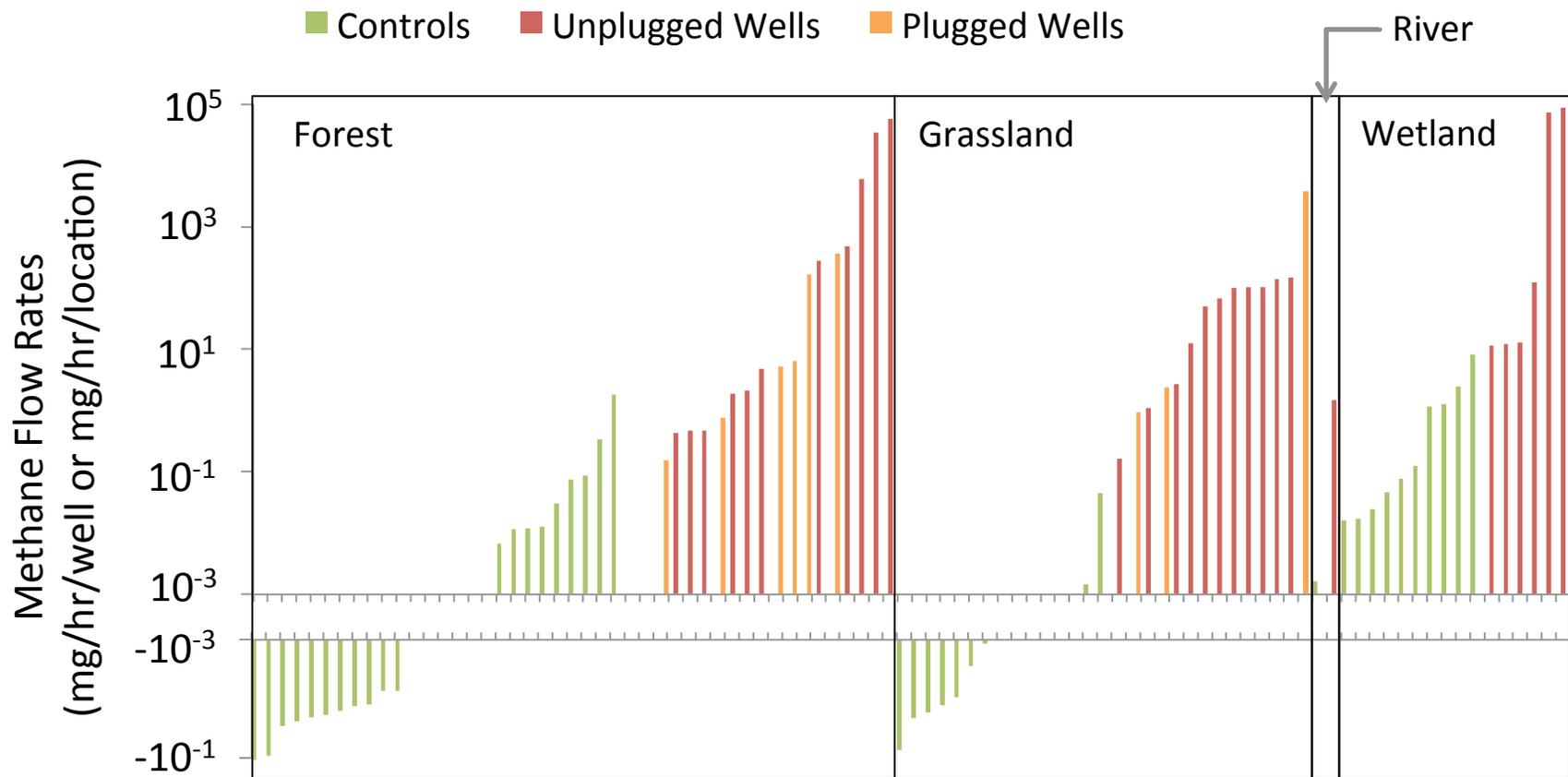
# Measurement / Analysis

- Air samples from flux chambers analyzed for:
  - Flame ionization gas chromatography:  $\text{CH}_4$ ,  $\text{C}_2\text{H}_6$ ,  $\text{C}_3\text{H}_8$ , n- $\text{C}_4\text{H}_{10}$
  - Continuous wave-cavity ring-down spectrometer:  $\delta^{13}\text{C}-\text{CH}_4$
- Mass flow rates of methane determined by:

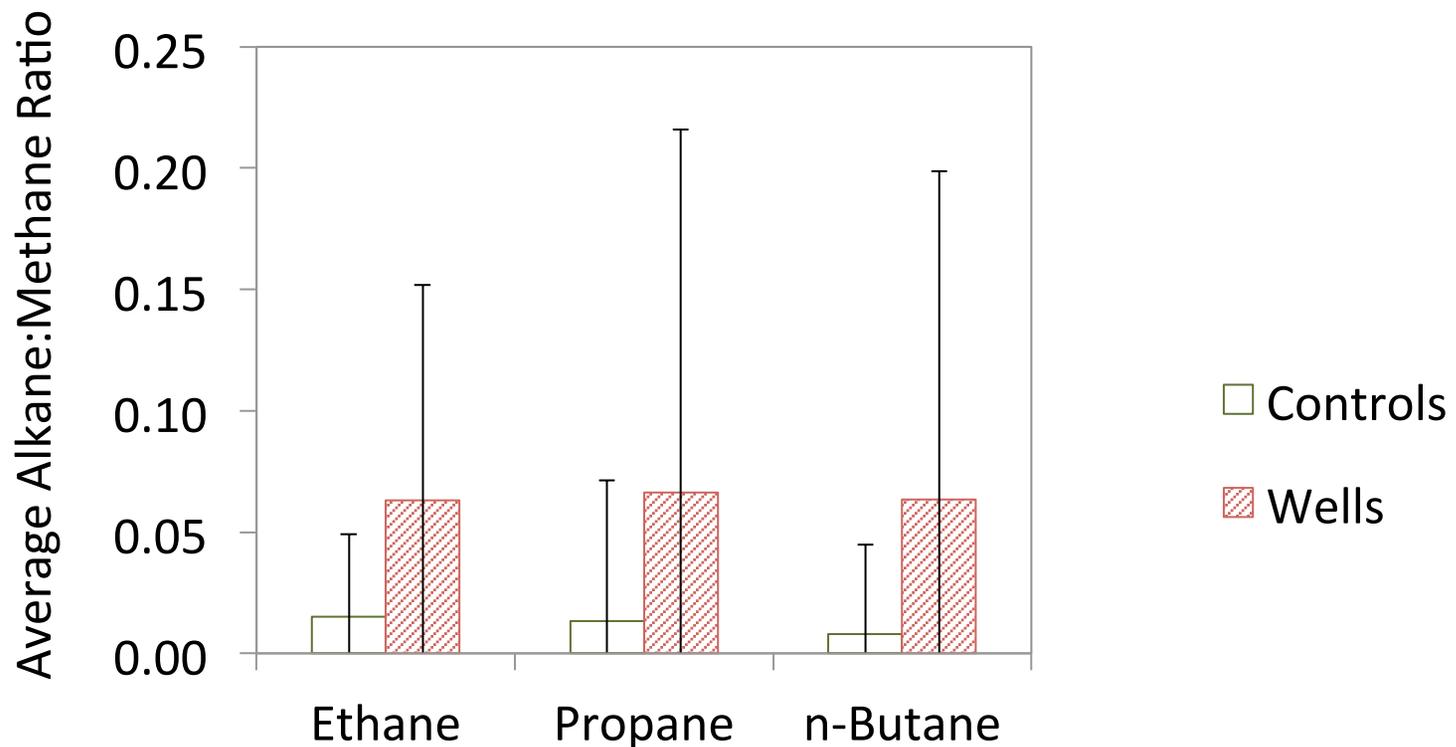
$$\dot{m} = \frac{dC}{dt} V$$



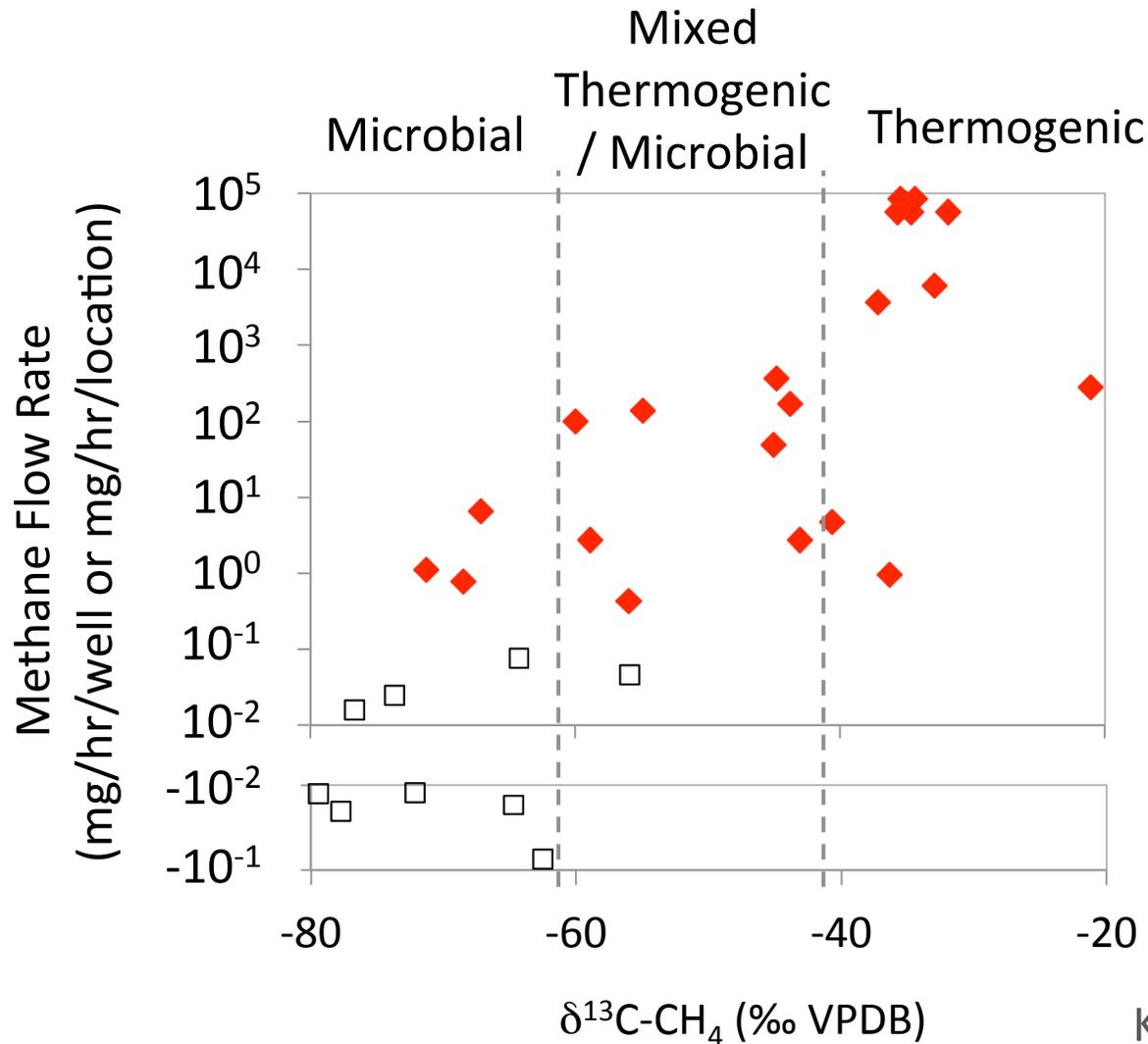
More methane is emitted at abandoned wells (even if plugged) than in the surrounding natural environment.



# More of the heavier hydrocarbons ( $C_{2+}$ ) emitted at abandoned wells than controls



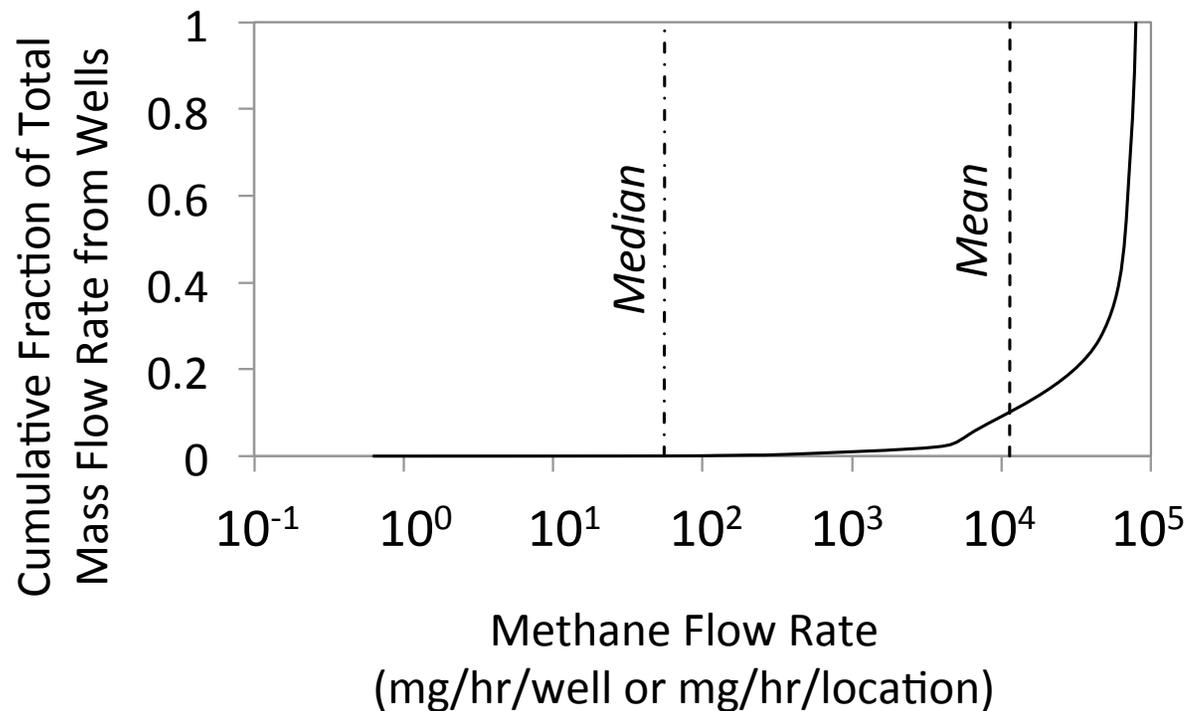
# Methane emitted from wells more likely to be of deeper, thermogenic origin



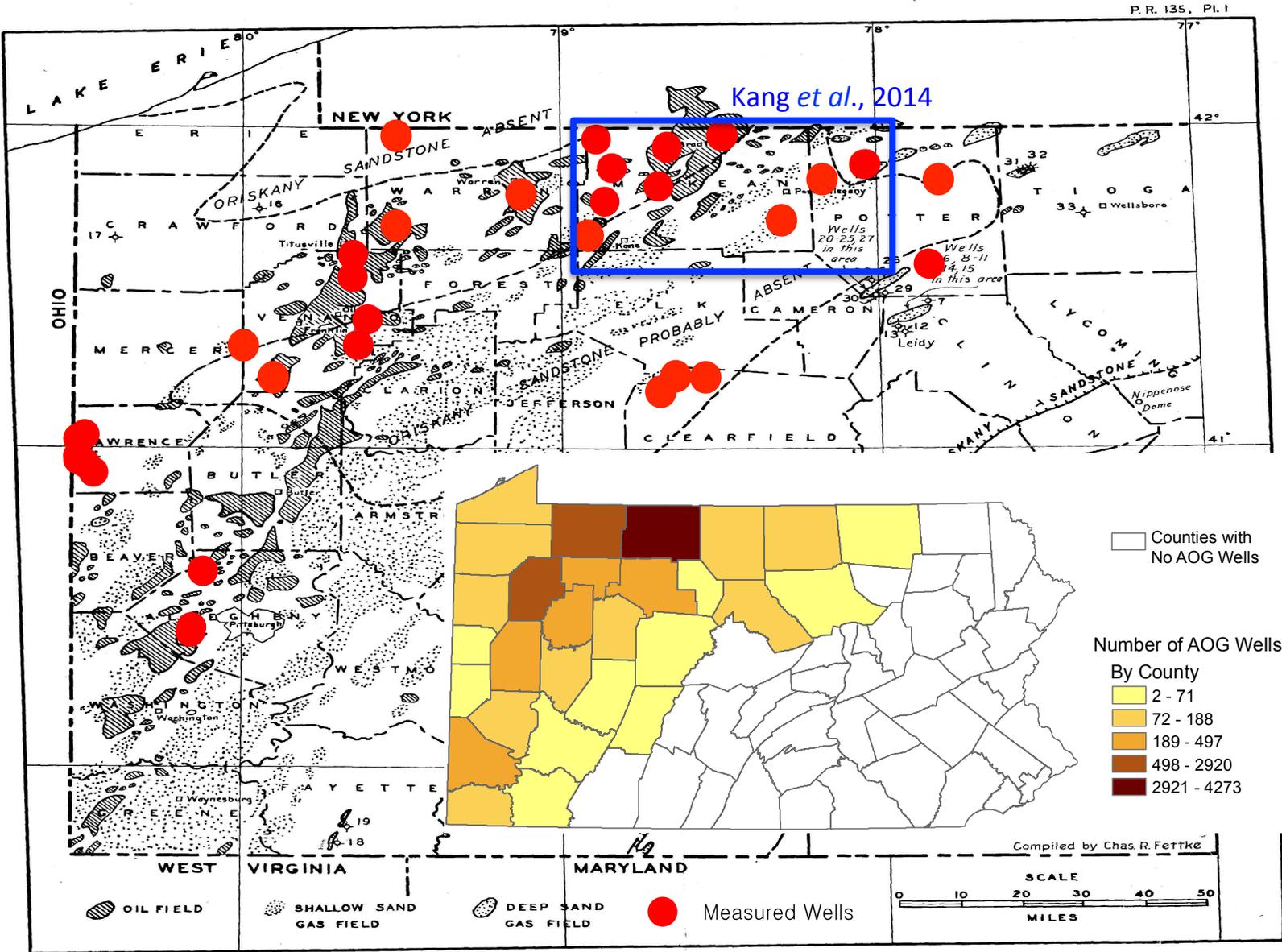
Kang *et al.*, PNAS, 2014

# Scaling up methane emissions

- Abandoned wells may represent 4 to 7% of total statewide annual anthropogenic methane emissions in Pennsylvania
- High emitters govern the cumulative emissions rate

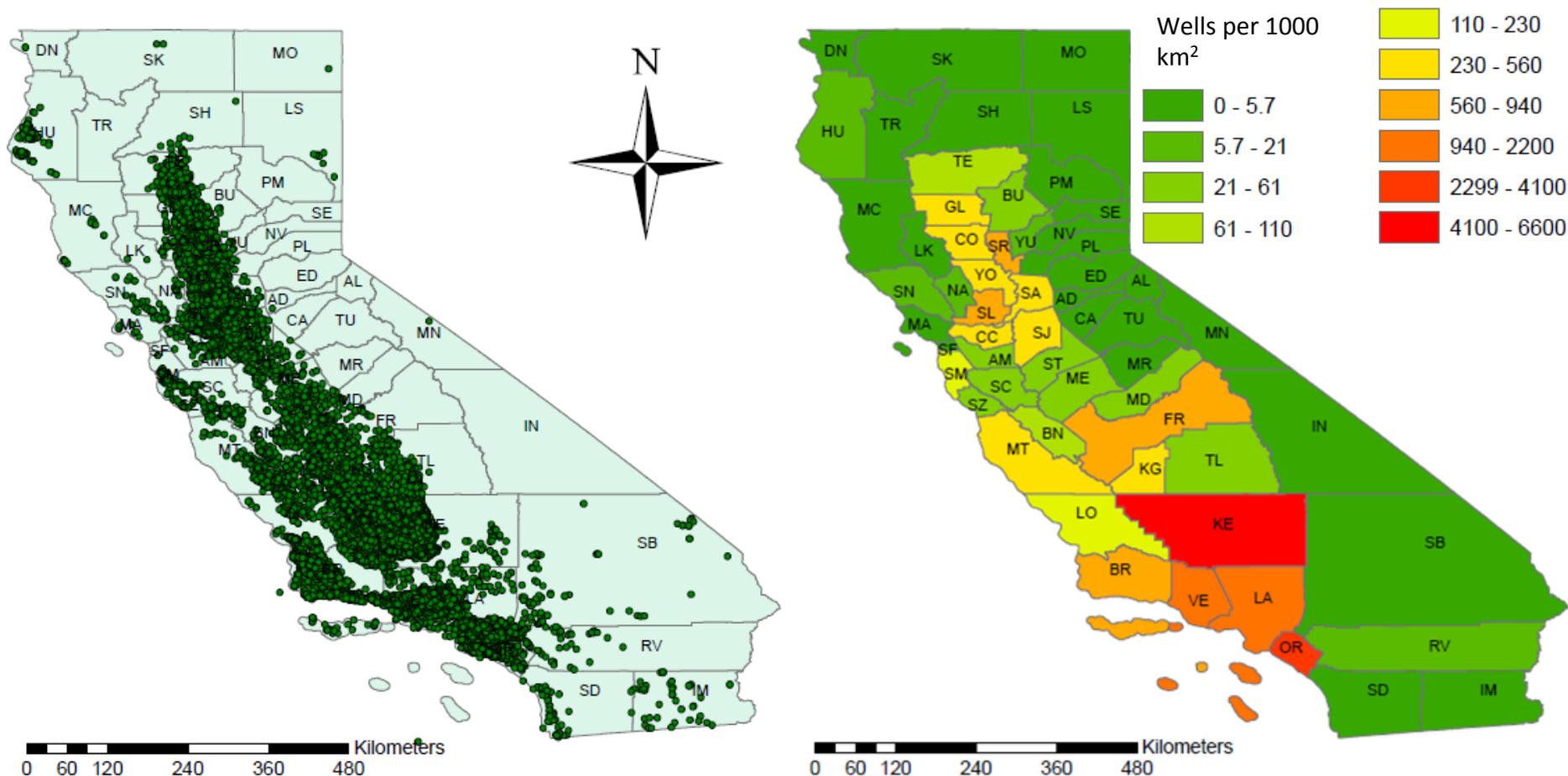


# Follow-Up Measurements in Pennsylvania



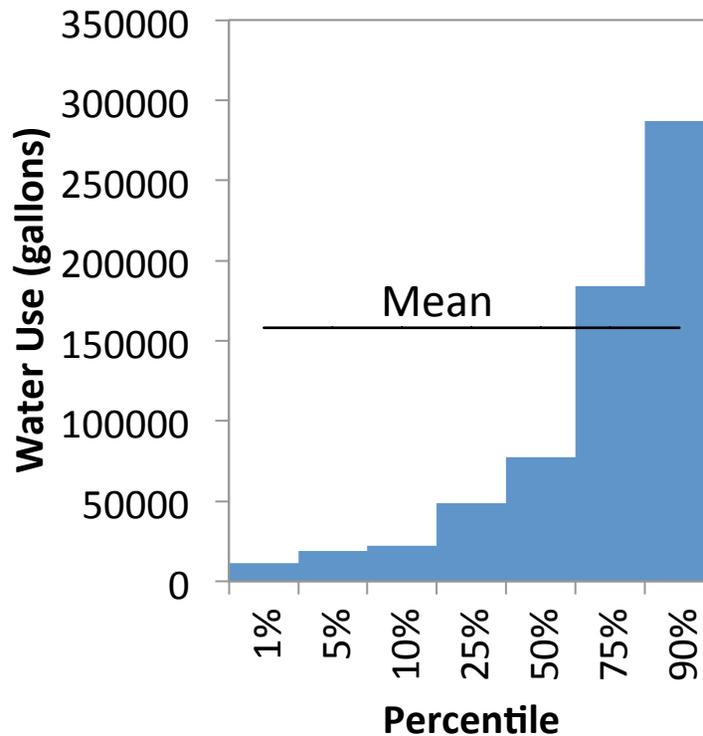
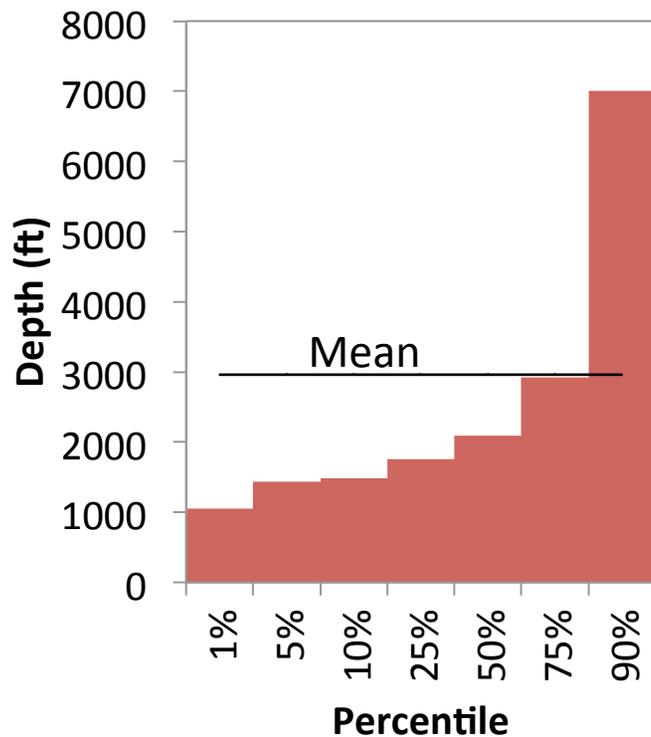
# Oil and Gas Wells in California

- ~223,000 oil and gas wells on the DOGGR database
- 45% (~130,000) are “Plugged & Abandoned”



# Hydraulic Fracturing in California

- Depths are shallow (relative to U.S.-wide)
  - 918 wells, of which 804 (88%) are < 1 mile deep
- Water use is low (relative to U.S.-wide)



# Thank you!



*Abandoned oil well in California*

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