Influence of Lead in Water on Lead in Children's Blood

A Bayesian Network Risk Model

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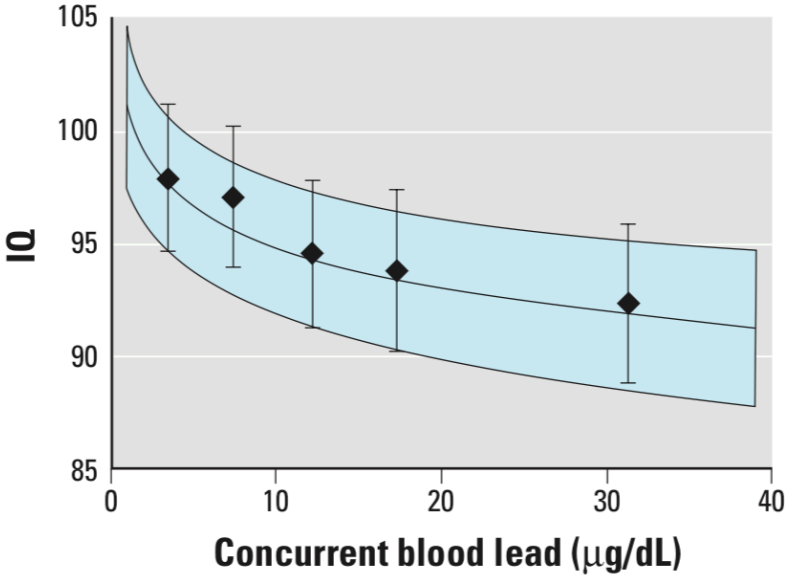
Lead (Pb) Is a Potent Neurotoxin, Especially Damaging for Children

Linked to

- **Decreased IQ**
- **Poor performance in school**
- **Increased risk of juvenile delinquency**



IQ loss occurs even at low Pb exposure levels.

SOURCE: Lanphear et al., 2005.

Many Environmental Pb Sources in U.S. Are Now Controlled

1973: Pb phase-out in gasoline begins

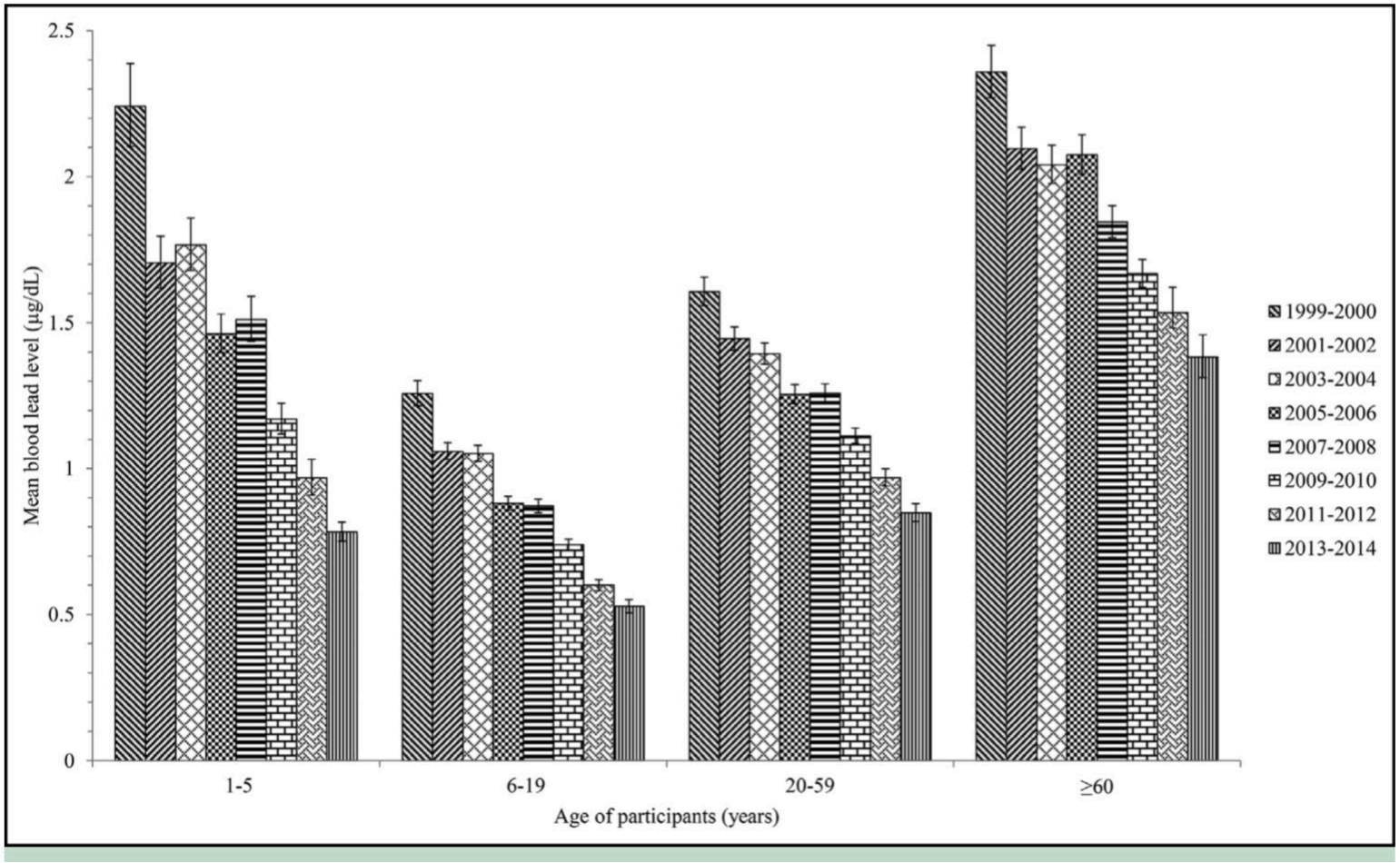
1978: Pb banned in paint

1995: Pb banned in solder in canned goods

1996: Full ban on sale of leaded gas

1997: Public water supplies required to implement corrosion control

Nationwide, Blood Pb Has Declined as a Result of Regulations



Blood Pb has declined in all age groups (1999-2014).

SOURCE: Tsoi et al., 2016.

Recent Water Crises Have Drawn Attention to Water as a Pb Source

- Under bankruptcy, Flint changed its water source and failed to adequately control corrosivity of the new water.
- Lead and other metals dissolved from water pipes.

IMAGE SOURCE: https://file.ejatlas.org/img/Conflict/water-crisis-in-flint-michigan/bknation_flint.png

Nonetheless, Most People with Municipal Water Are Protected from Pb

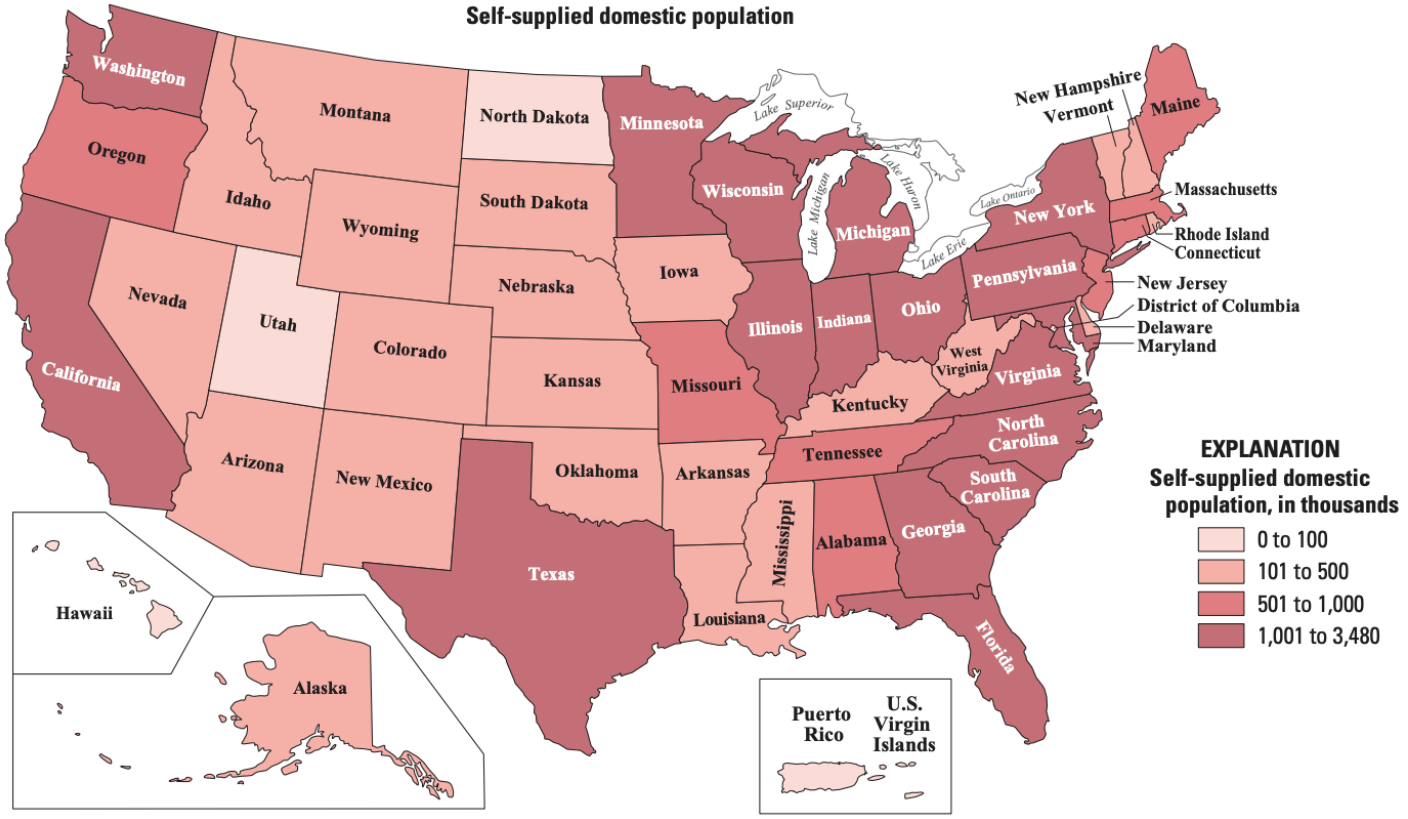
Proper corrosion control forms protective scale.

SOURCE: City of Austin, Texas: http://www.austintexas.gov/sites/default/files/files/Water/_MG_0050-001.JPG

Flint's corrosion control failed, dissolving scale.

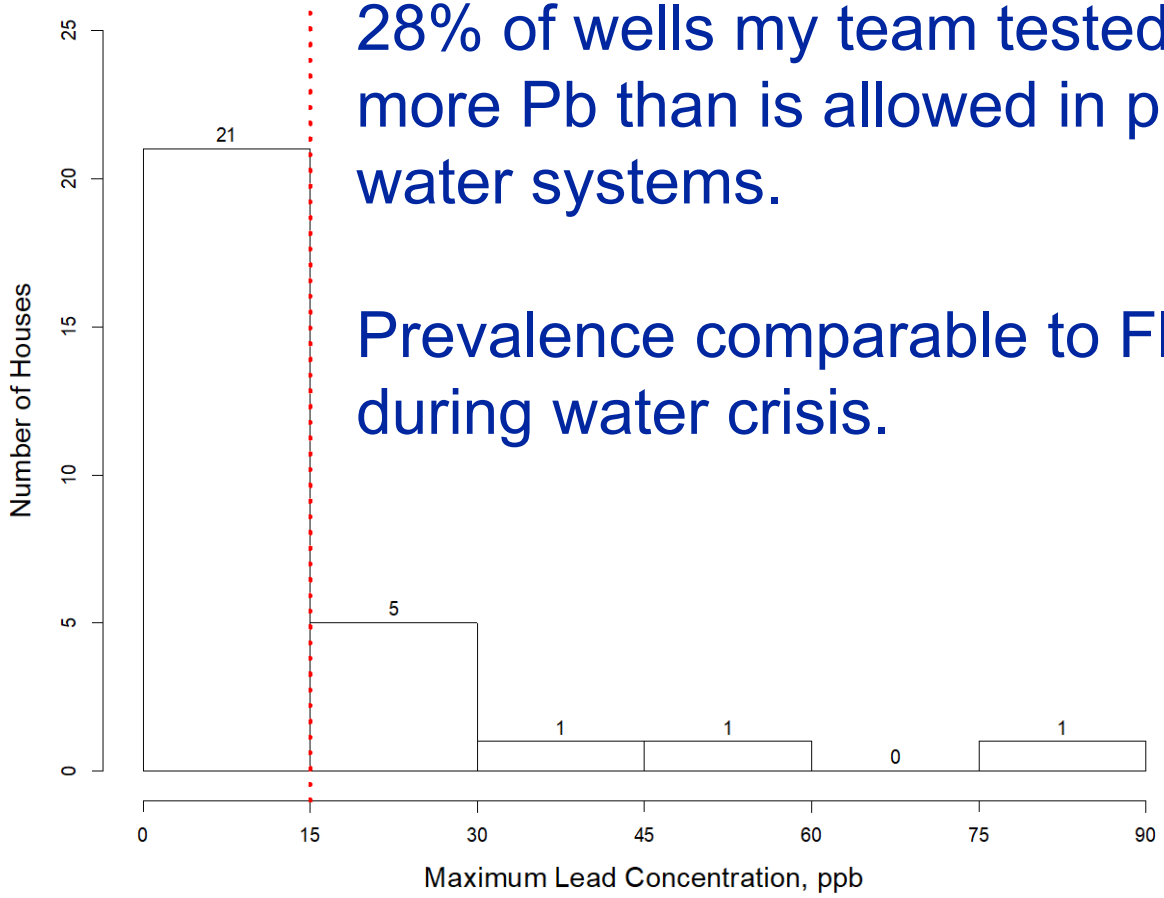
SOURCE: Min Tang and Kelsey Pieper, published in Smithsonian: https://thumbs-prod.si-cdn.com/Z5QDzvtGaIks2u59-dlOgAk9fwc=/800x600/filters:no_upscale()/https://public-media.si-cdn.com/filer/9e/58/9e58491b-76b2-483e-b3fb-e1afbaeae4c2/inside-flint-pipes-min-tang-and-kelsey-pieper_2.jpg

42.5 Million Americans Relying on Private Wells Are Not Protected from Pb



SOURCE: USGS, https://pubs.usgs.gov/circ/1441/circ1441.pdf

Evidence Suggests Pb Risk from Private Wells Can Be High



28% of wells my team tested had more Pb than is allowed in public water systems.

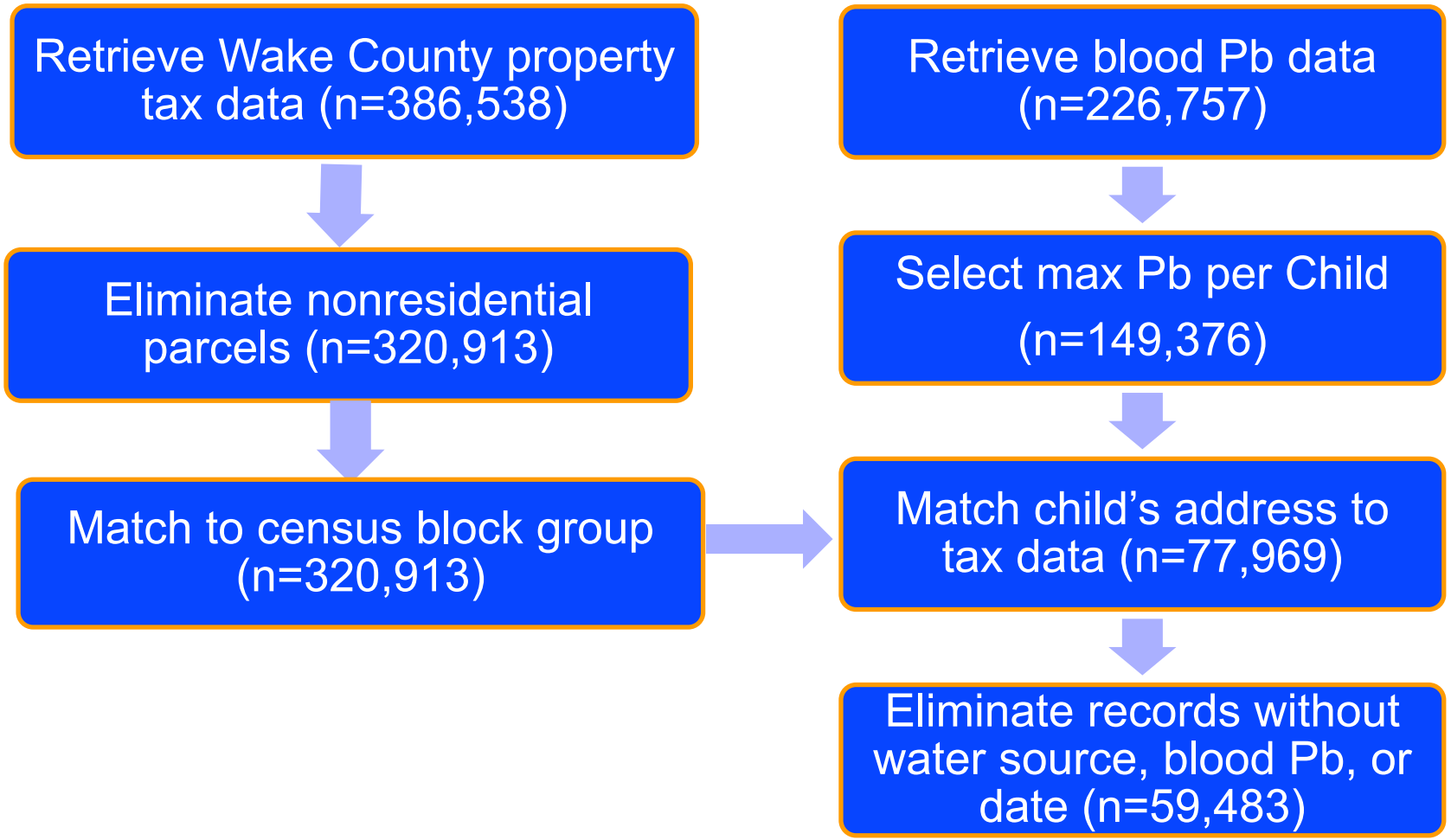
Prevalence comparable to Flint during water crisis.

Research Questions

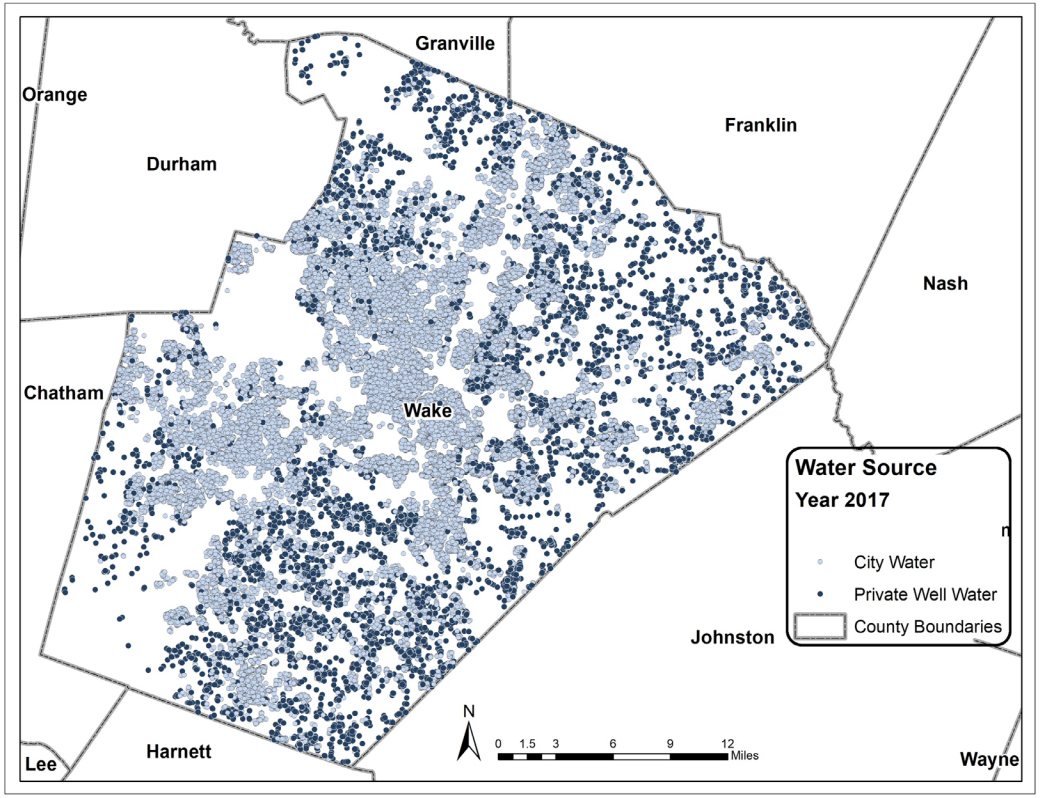
- Are children in homes with private wells at higher risk of Pb in blood?
- If so, can we predict which houses are most at risk?
- How accurately can a Bayesian network model predict risks, compared to a statistical regression model?

Methods

We Built a Curated Data Set, Merging Data from Multiple Sources



Example: Children's Addresses and Water Sources for 2017



For each child:

- Blood Pb
- Water source
- Age, gender
- Age, value, size of house
- Census block racial composition
- Census block median income
- Location in "extraterritorial jurisdiction"

Regression and Bayesian Network Models Were Fitted to the Data

Objective: Predict probability of elevated blood Pb

- Defined by U.S. Centers for Disease Control and Prevention as ≥ 5 µg/dL

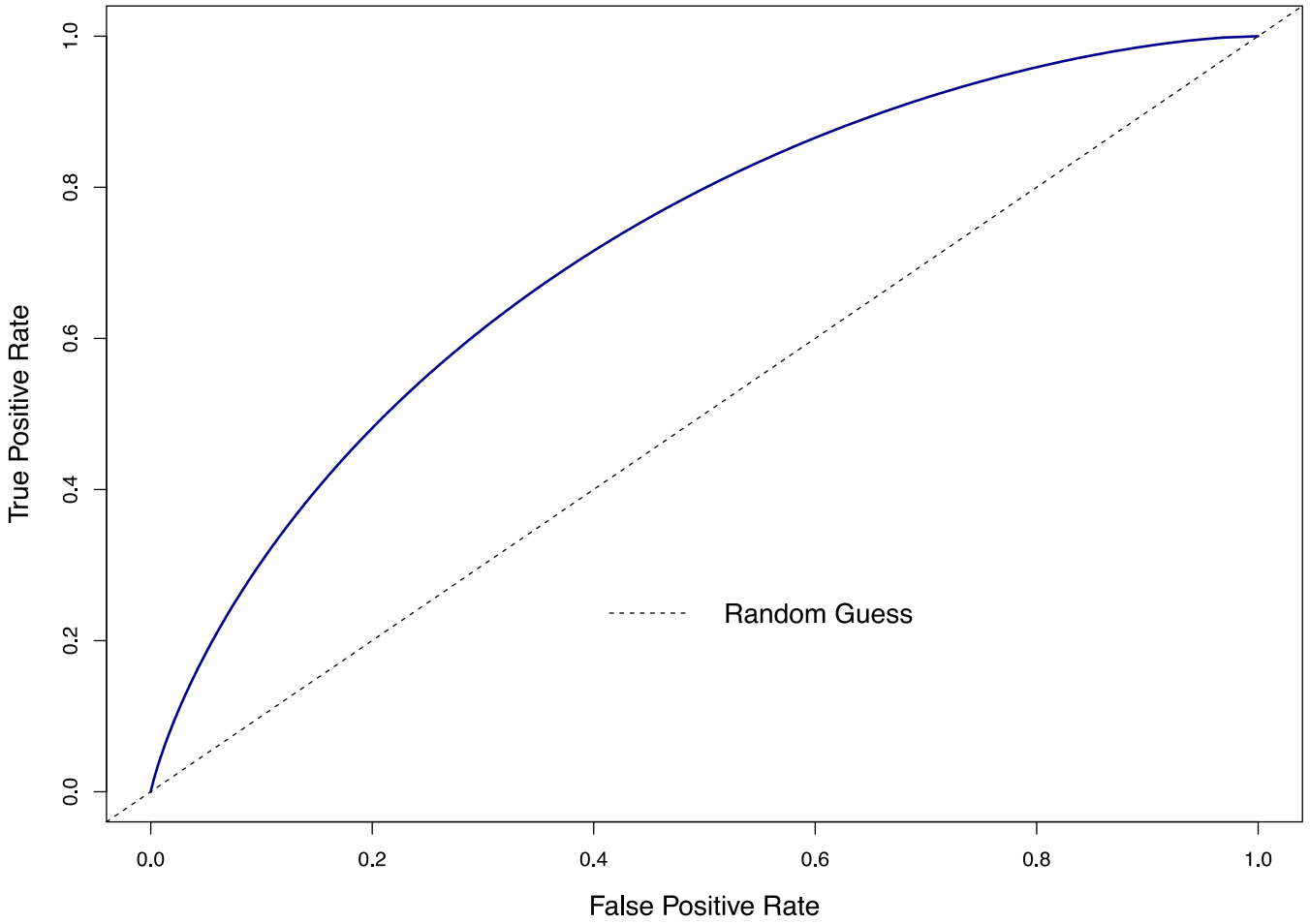
Logistic regression models were fitted using Stata:

- $log(odds) = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots$
- Errors account for clustering of children within households and households within census block groups

Bayesian network model:

- Augmented naïve Bayes
- Eliminate variables if mutual information with blood Pb is not significant at *p*=5%

Area Under the ROC Curve Was Used as Measure of Accuracy



Diagnostic accuracy = area under curve (1=perfect)

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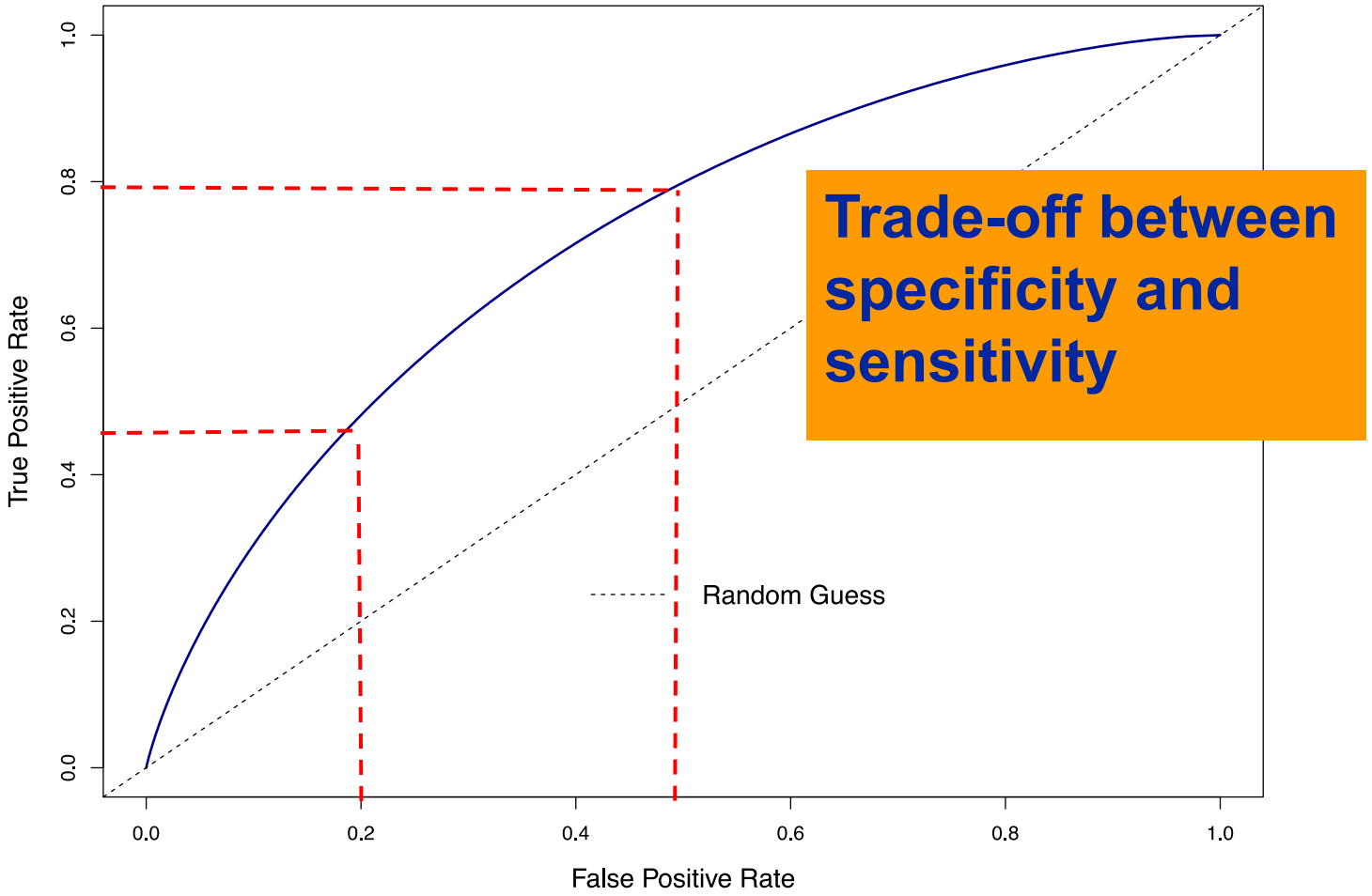
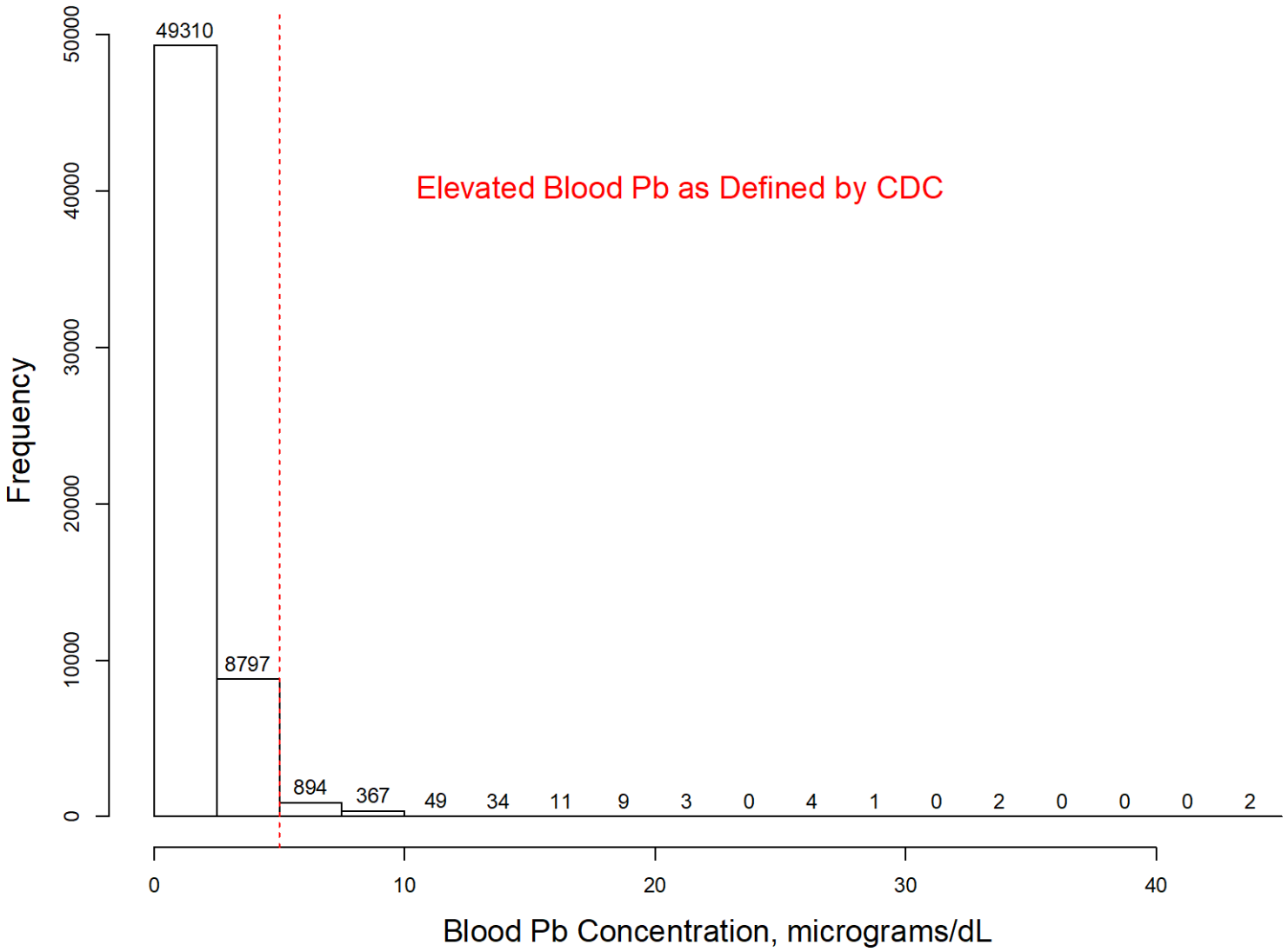


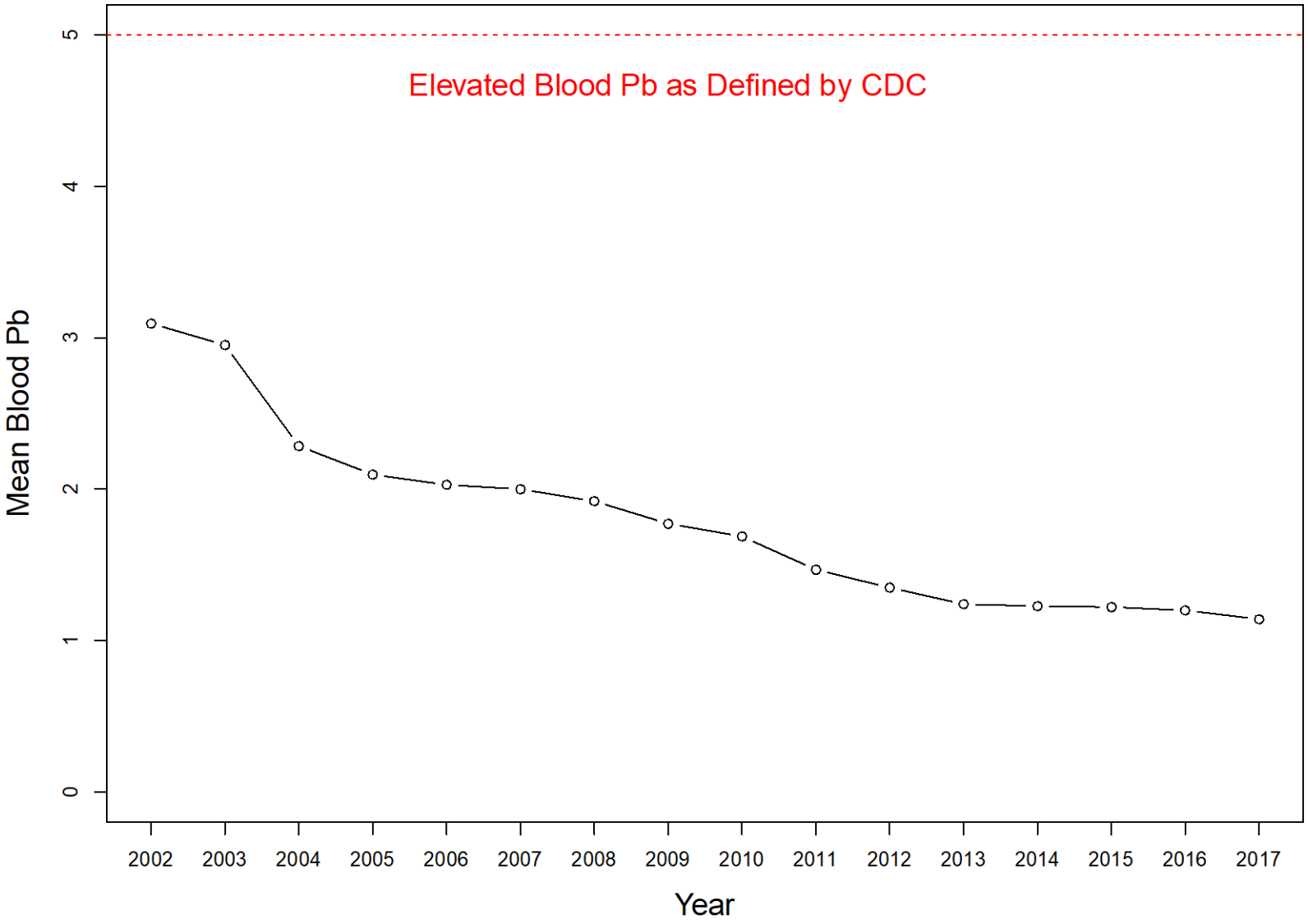
Diagnostic accuracy = area under curve (1=perfect)

RESULTS

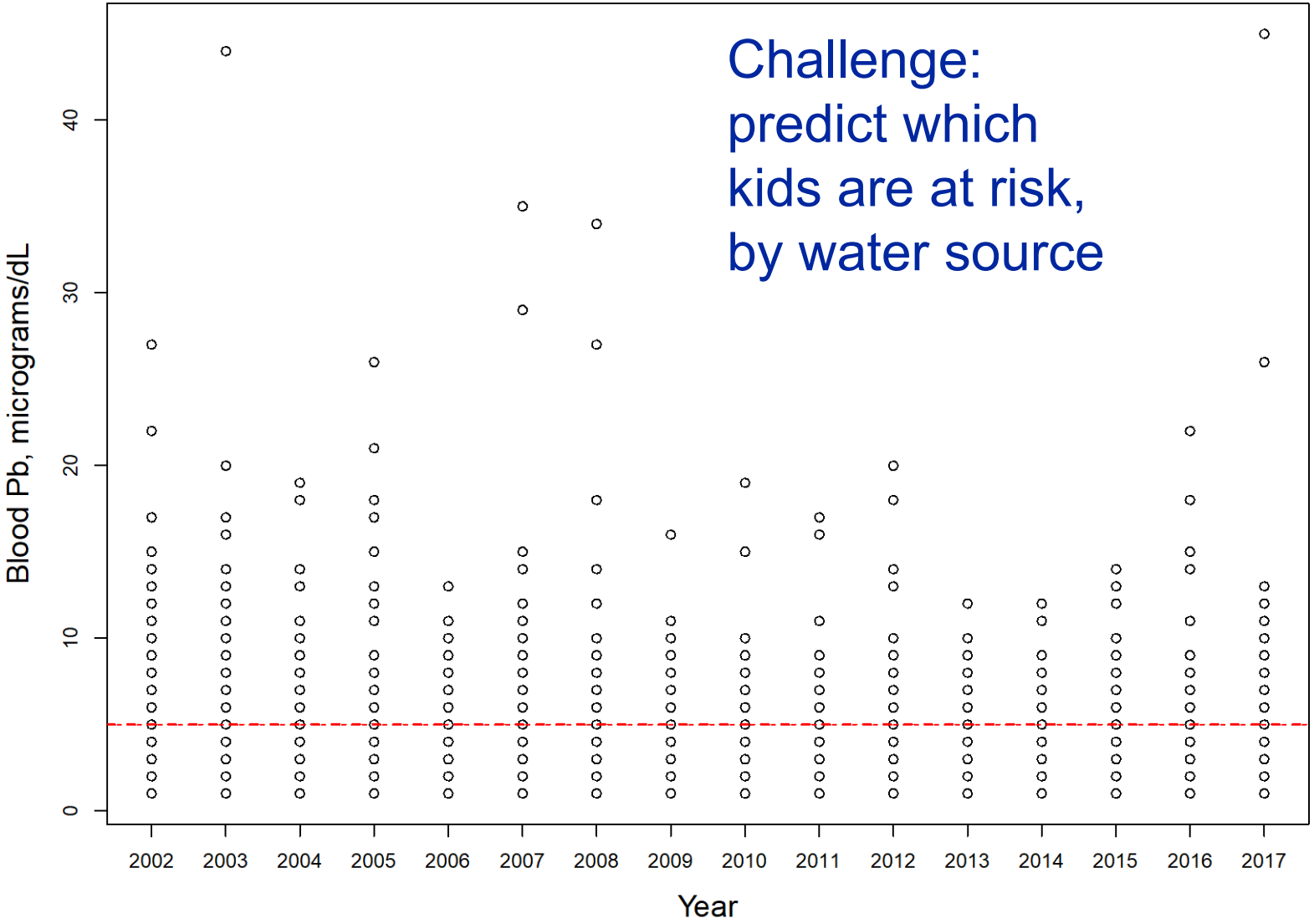
4.2% of Children Had High Blood Pb



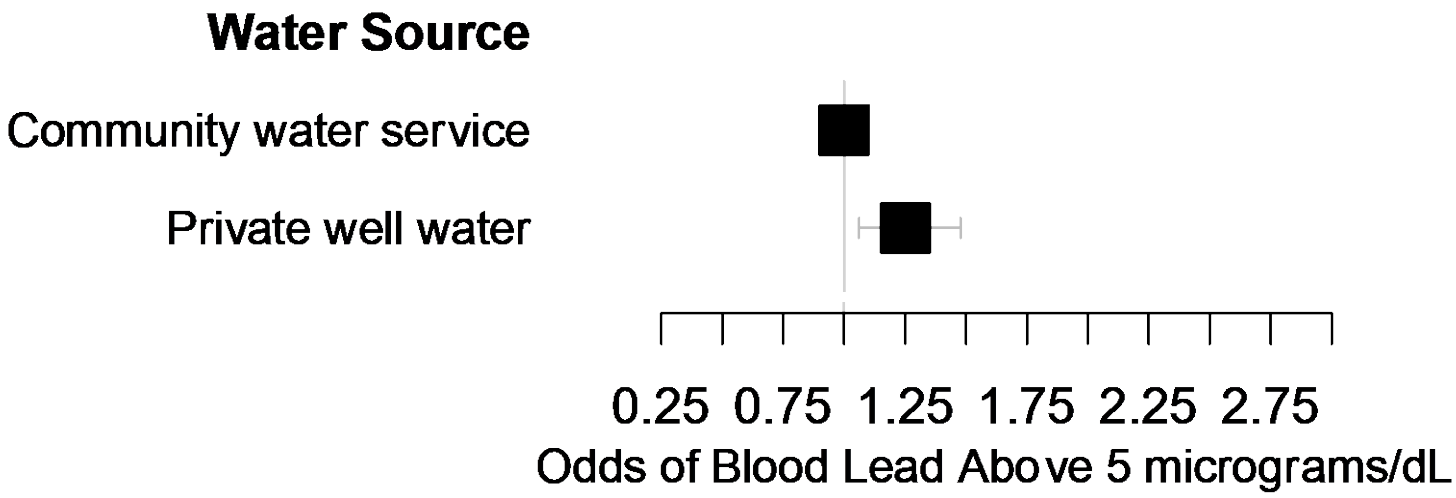
Average Blood Pb Has Declined Over Time



But Some Kids Remain at Risk



Regression Showed Kids with Wells at Higher Risk of Elevated Blood Pb



Kids with private well water have 25% increased odds of elevated blood lead, according to logistic regression.

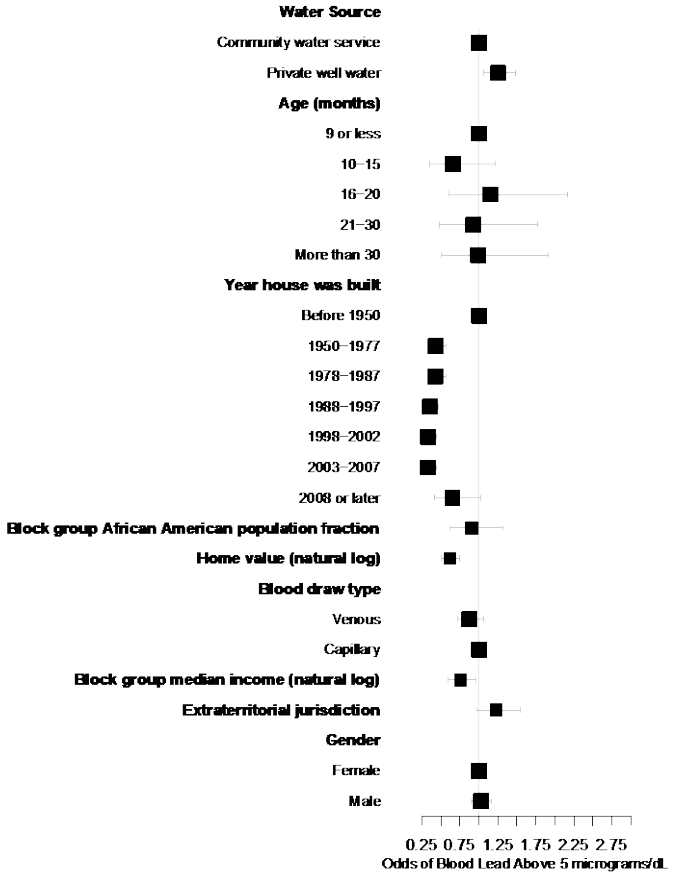
Regression Model Assumes Log-Linear Relationships, No Interactions

$$Log(Odds\ of\ high\ Pb) =$$

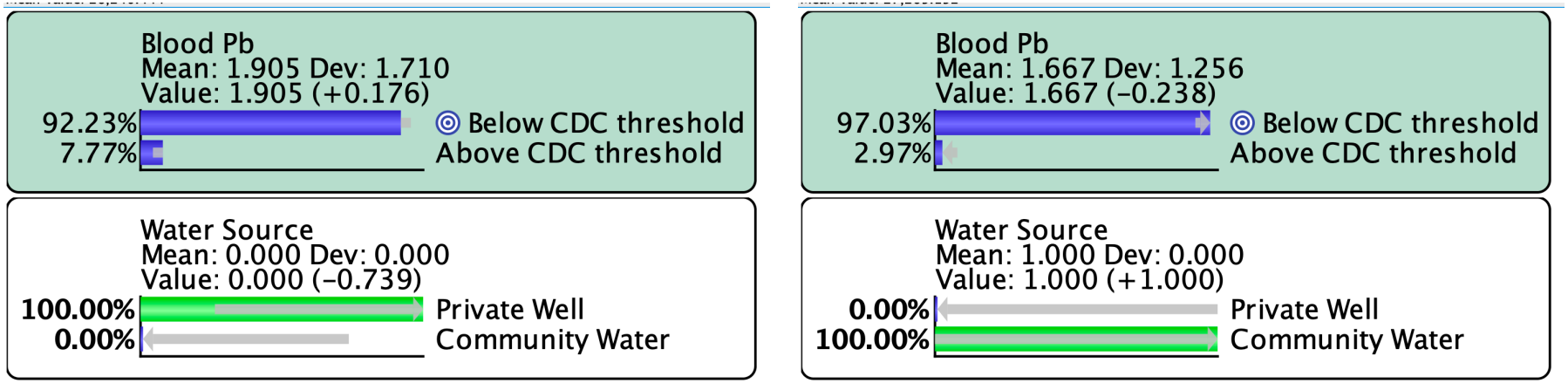
$$0.22 \times private\ well - 0.42$$

$$\times (age\ 10{-}15\ months)\ + 0.14$$

$$\times (age\ 16{-}20\ months)\ldots$$

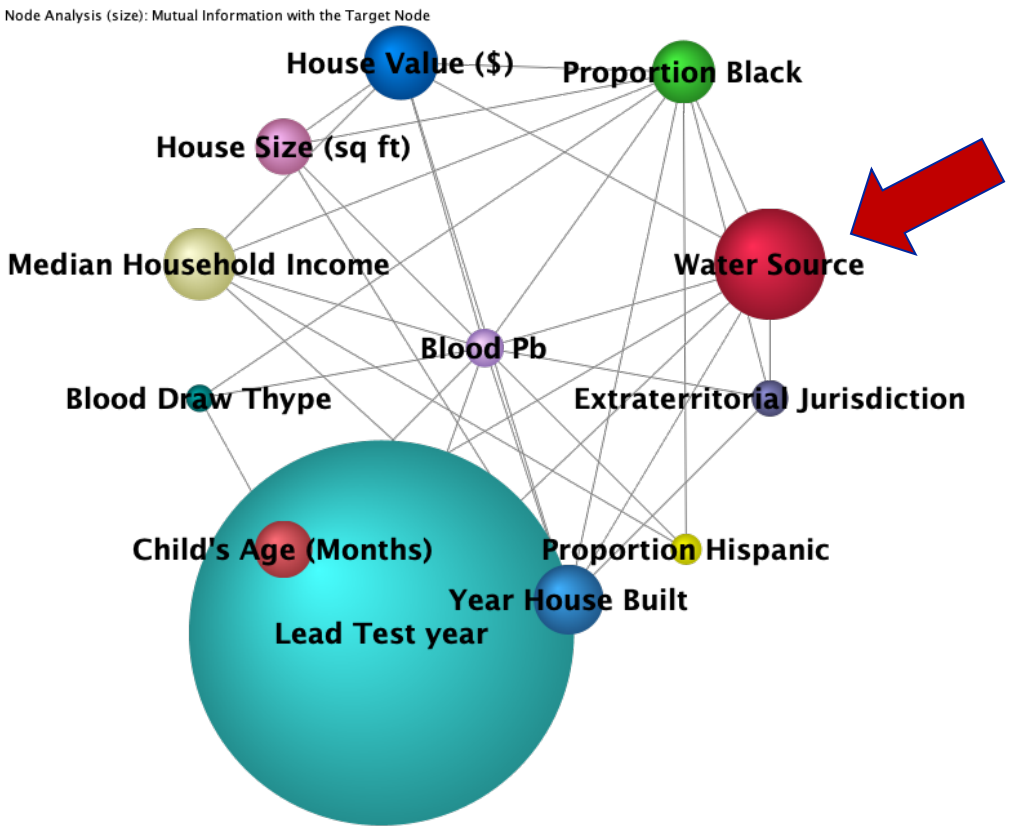


Bayesian Network Also Showed Kids with Wells at Higher Risk of Elevated Pb



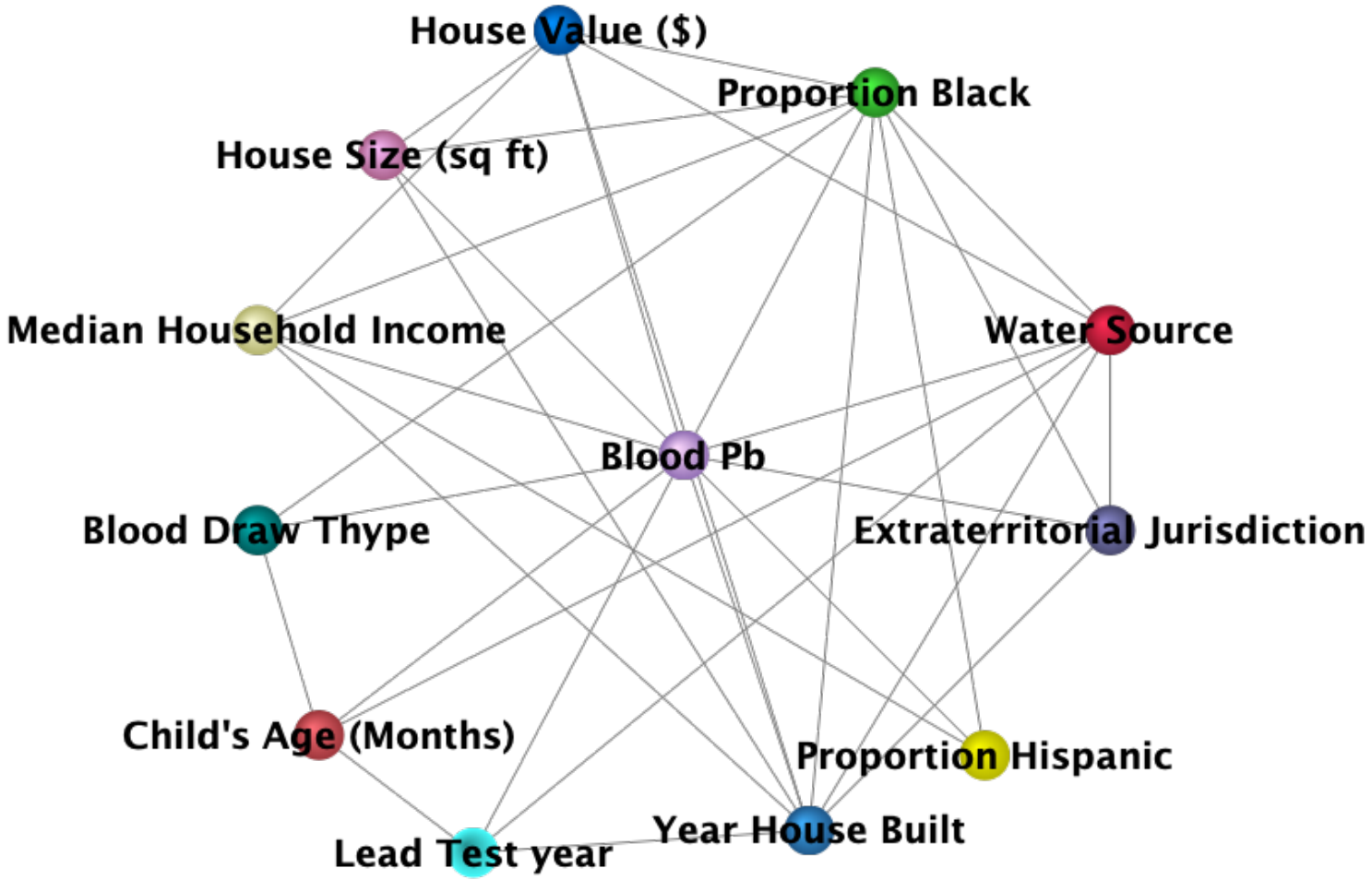
- **Network predicts odd of elevated blood lead in kids with wells are 2.7 times higher than for kids with community water (odds ratio=2.7).**
- **Result suggests logistic regression does not capture key interactions and may underestimate risks.**

After Year of Test, Water Source Is One of Most Important Predictors



Water source has more information about blood Pb than any variable other than year.

Network Allows Us to See How Variables Interact

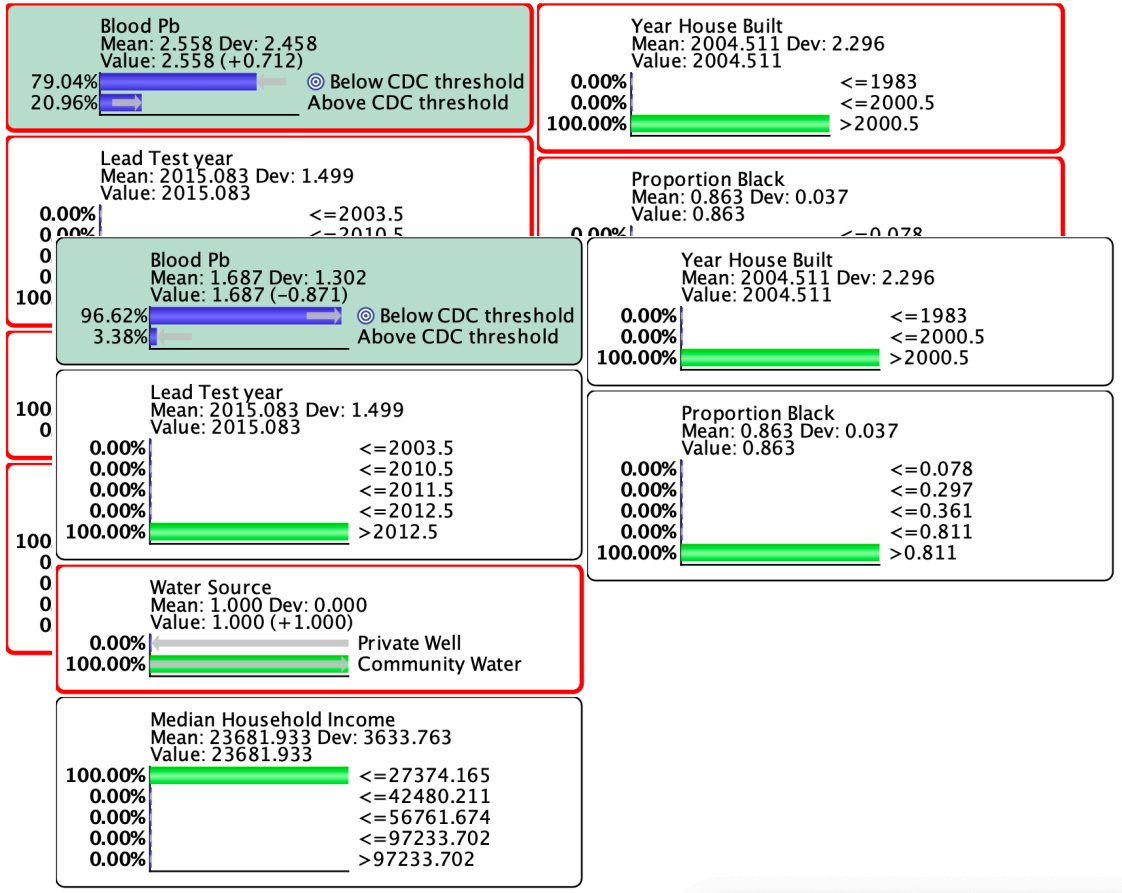


Example: Using Network to Prioritize Houses for Outreach

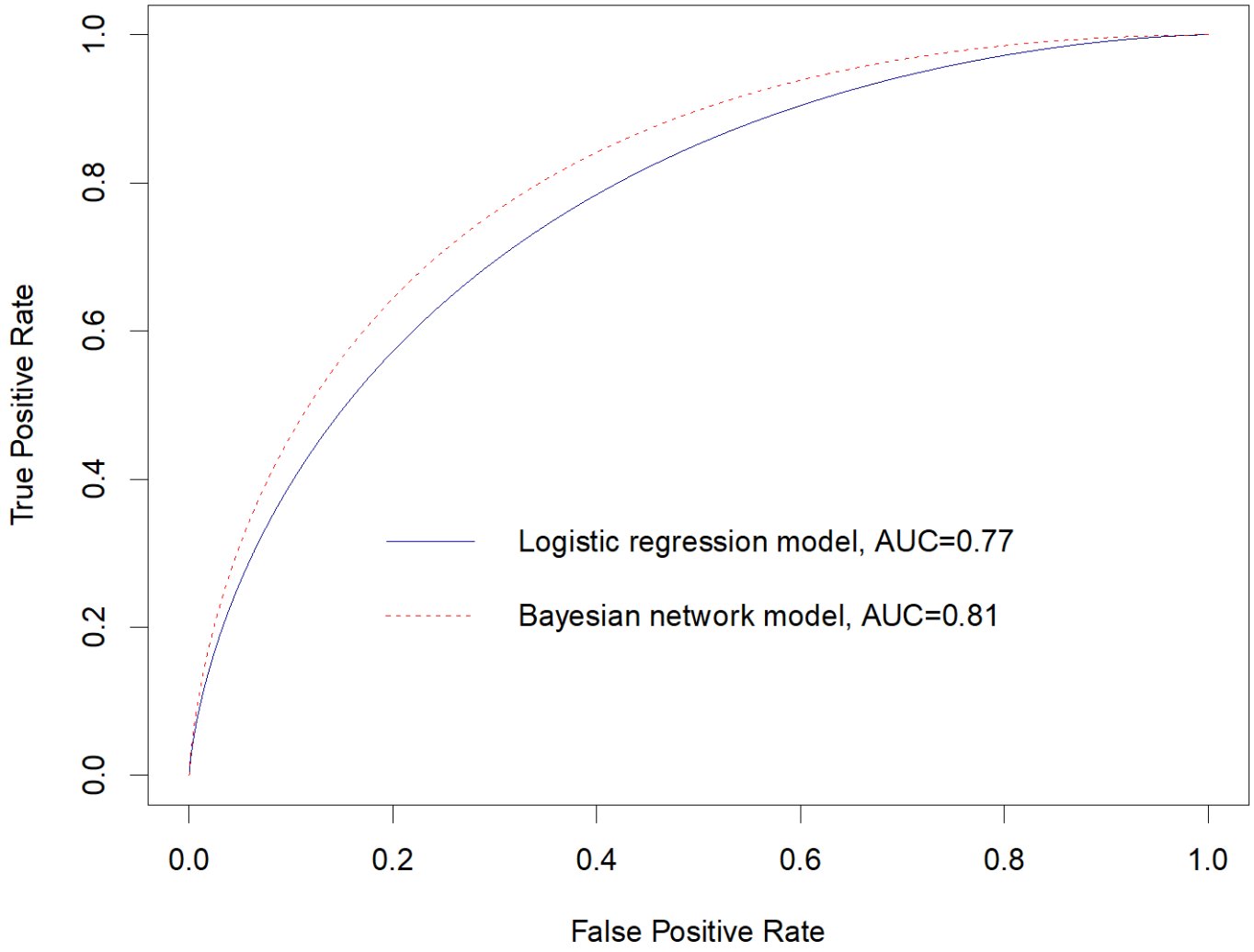
21% chance of elevated blood lead in kids tested recently (since 2012) for children

- **With private wells**
- **In houses built after 2000**
- **In census blocks with household incomes below 27,400 and more than 81% African American**

Probability decreases to 3.4% for kids with community water.



Bayesian Network Had Higher Predictive Ability than Regression



CONCLUSIONS

Summary

- **Kids in houses with private well water had higher risks of elevated blood Pb.**
- **Bayesian network had reasonably strong predictive accuracy.**
  - **Uncovered potentially important interactions (e.g., between age of house and reliance on private well)**
- **Could be used to prioritize private well households for outreach.**
  - **Encourage water testing.**
  - **Install filters when elevated Pb is detected.**

Next Steps

- **Account for additional variability sources**
  - **Differences among community water system types**
    - **Smaller systems more at risk**
    - **Systems violating Lead and Copper Rule more risky**
  - **Add additional potential Pb sources (e.g., proximity to roadways, industrial sources)**
- **Develop mapping interface for use by local health departments**

Acknowledgments

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