Geospatial analysis of the flint water crisis

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Overview

- In 2014, the City of Flint, Michigan, changed its water source from treated water sourced from Lake Huron to the Flint River
- Officials failed to apply corrosion inhibitors into the water source
- The water from Flint River irreversibly corroded the aging local pipe system causing unsafe levels of lead and copper to leach into the water supply
- Estimated cost to repair: $100M – $1.5B, full extent of damage unknown

Service lines

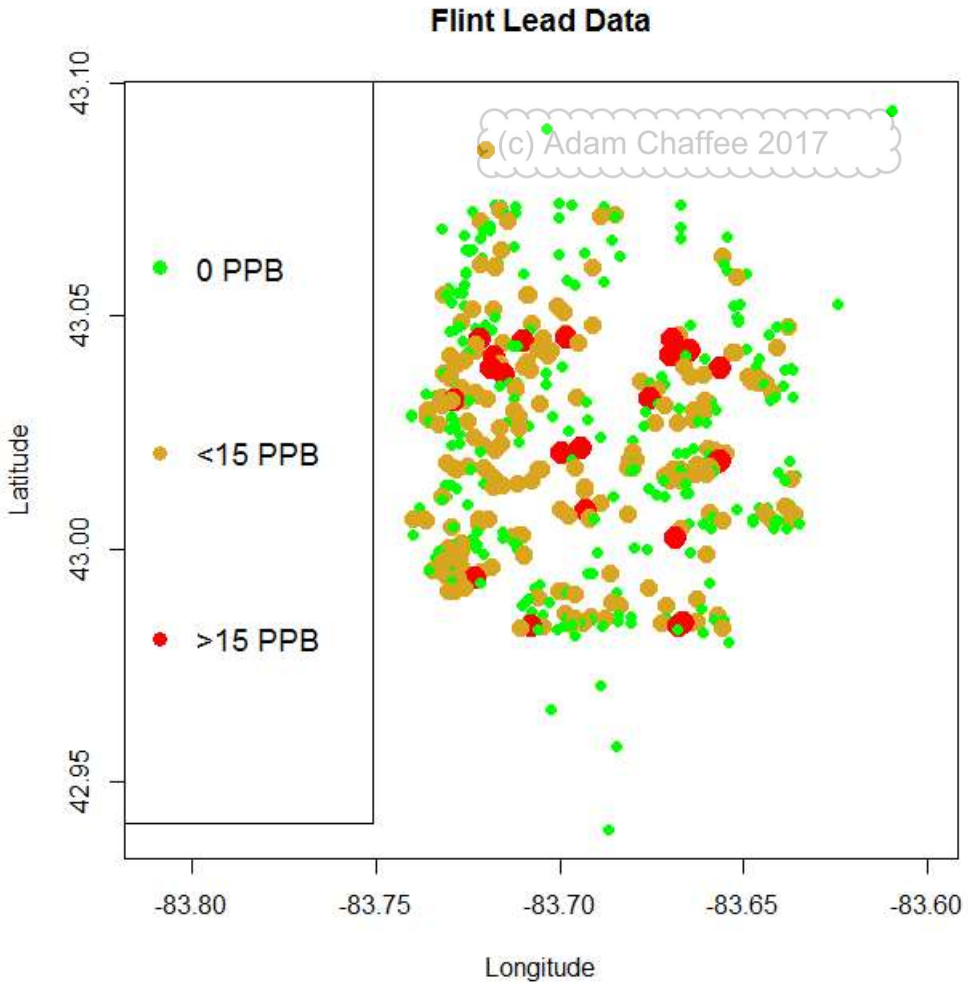
Goovaerts (20

Data Source

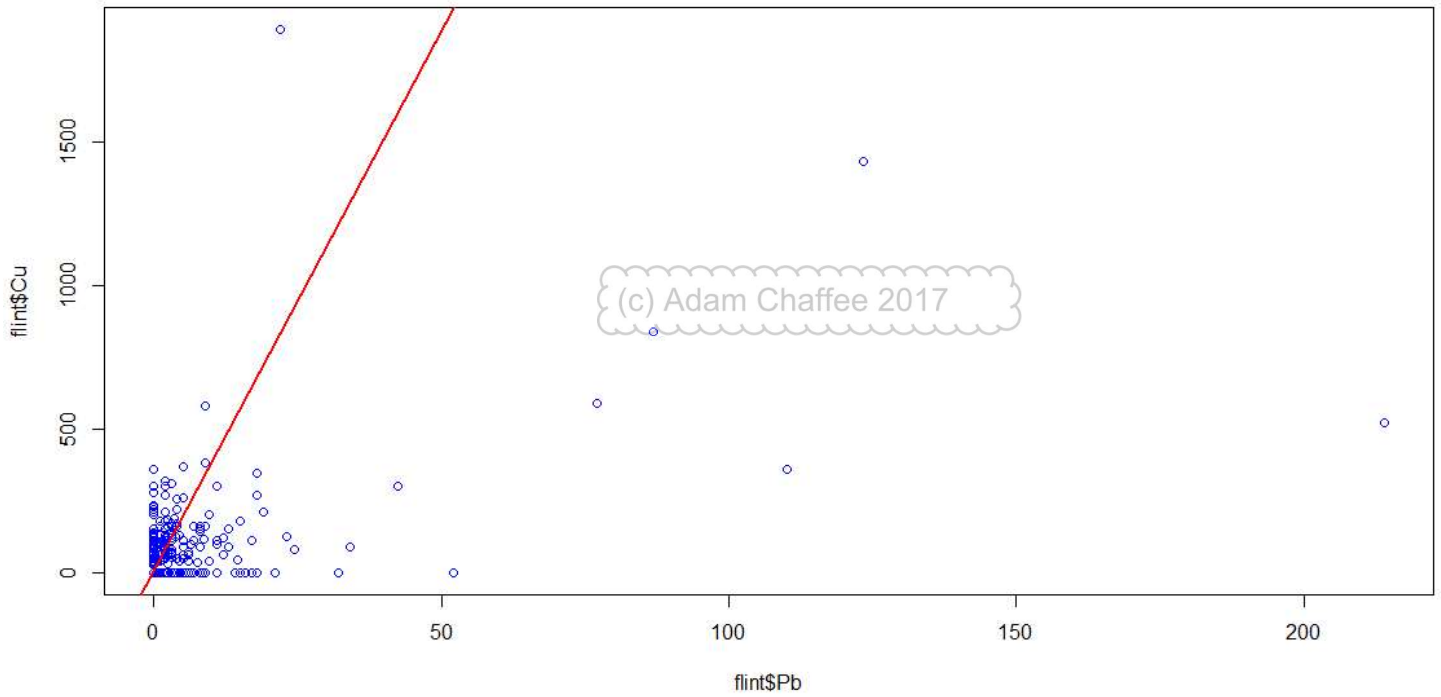
- Residents were supplied with testing kits and instructions to test the water in their own homes for lead and copper levels
- Obtained most recent residential testing results collected 1/1/17 – 3/2/17 (~550 observations after cleaning)
  - http://www.michigan.gov/flintwater/0,6092,7-345-76292_76294_76297---,00.html

Bubble Plot

EPA recommended level: 0 PPB
EPA mandatory action level: 15 PPB



Weak Correlation - Lead and Copper




```
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  37.6373     5.1107   7.364  6.7e-13 ***
flint$Pb      5.0081     0.3698  13.542  < 2e-16 ***
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 115.3 on 539 degrees of freedom
Multiple R-squared:  0.2539,    Adjusted R-squared:  0.2525
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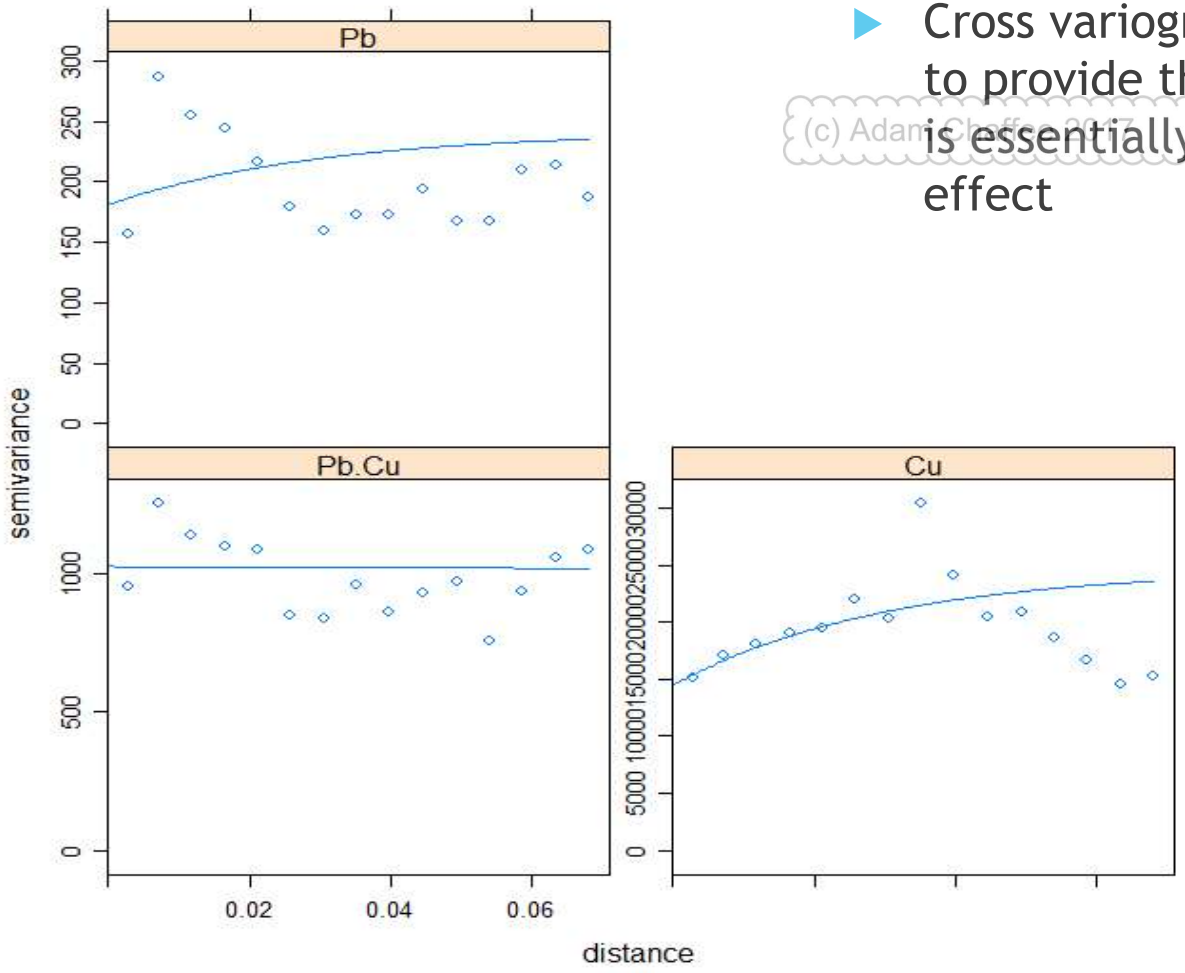
Fitted Variograms



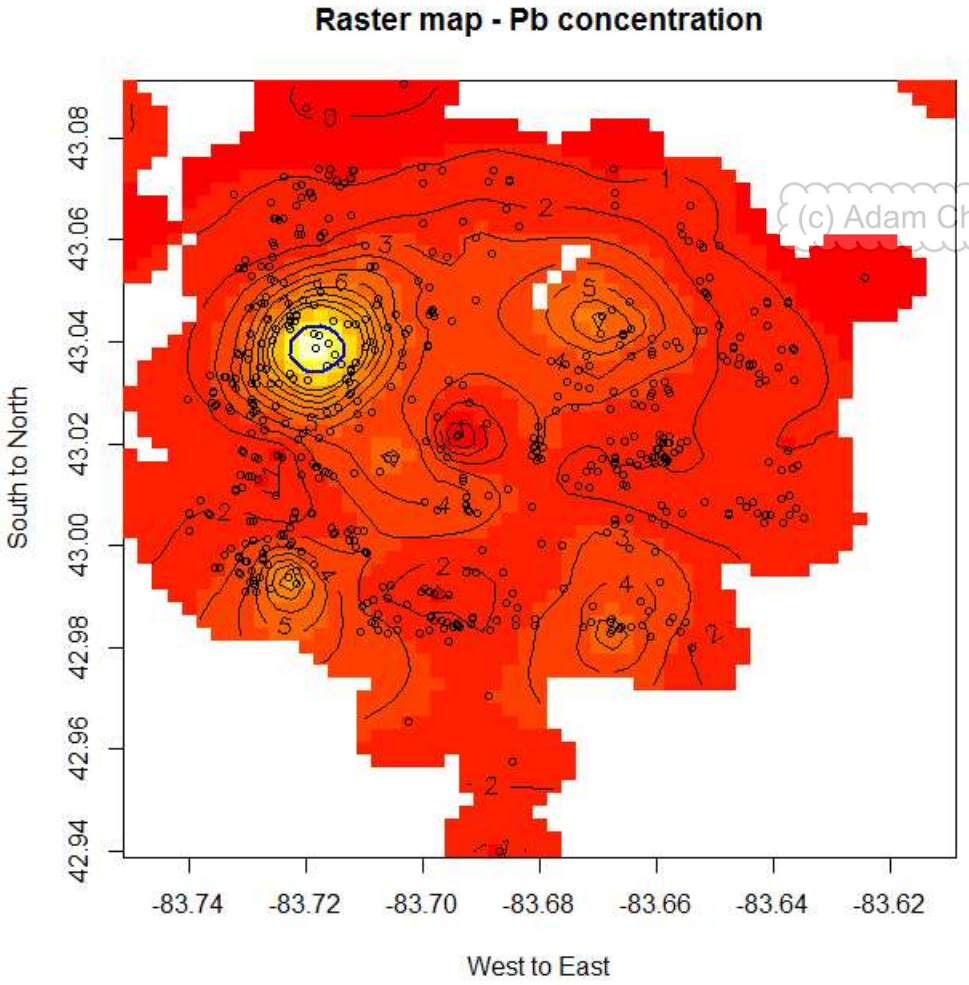
- Cross variogram appears to provide the best fit but is essentially pure nugget effect

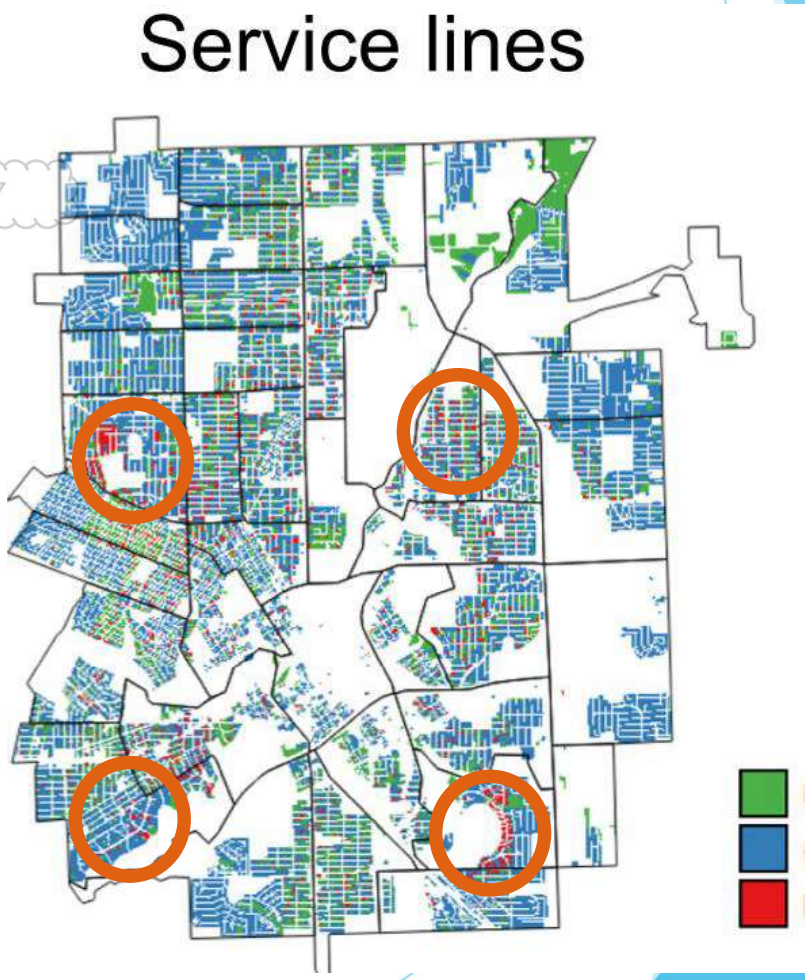
Comparing Kriging Methods

Improvement from co-kriging due to weak association with copper levels

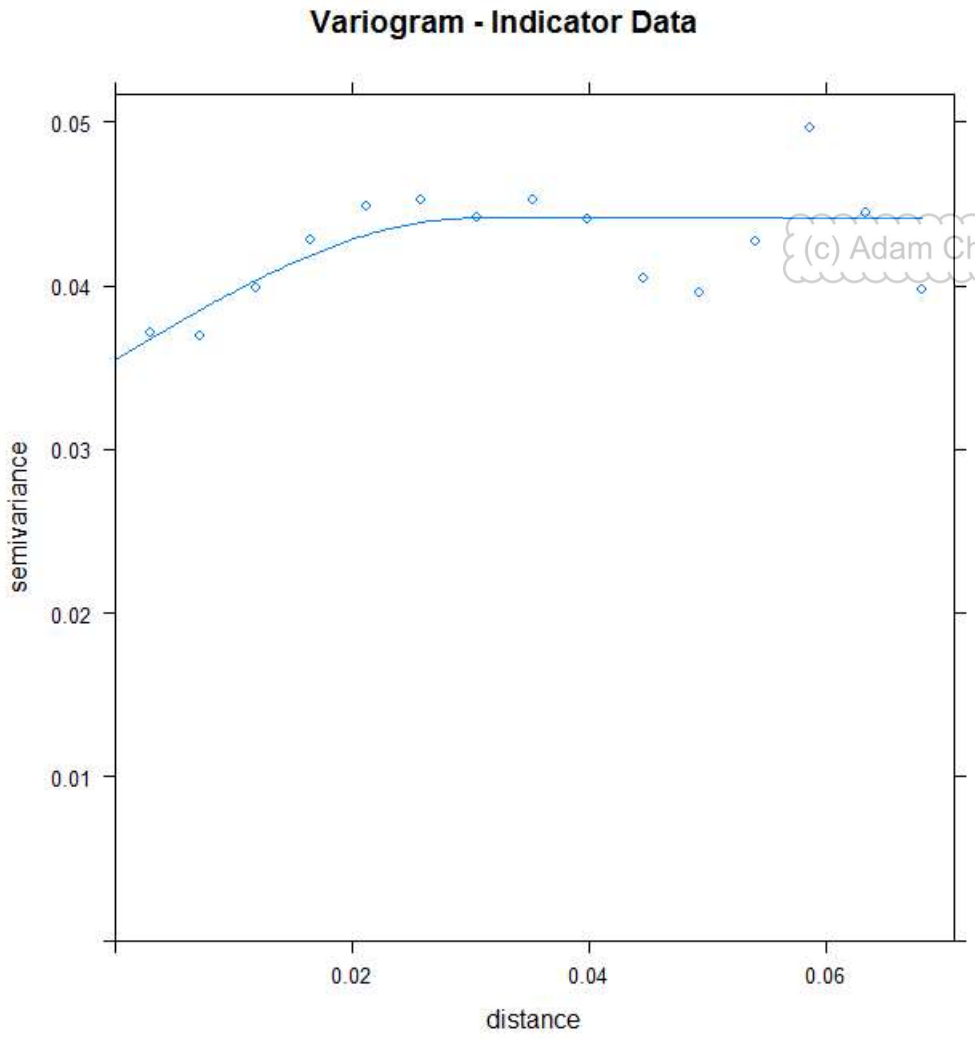
Method	Cross Validated PRESS
Co-Kriging with Cu	74,459.97
Simple Kriging	97,125.73
Ordinary Kriging	97,485.79
Universal Kriging	97,687.85

Raster Map Using Co-kriging





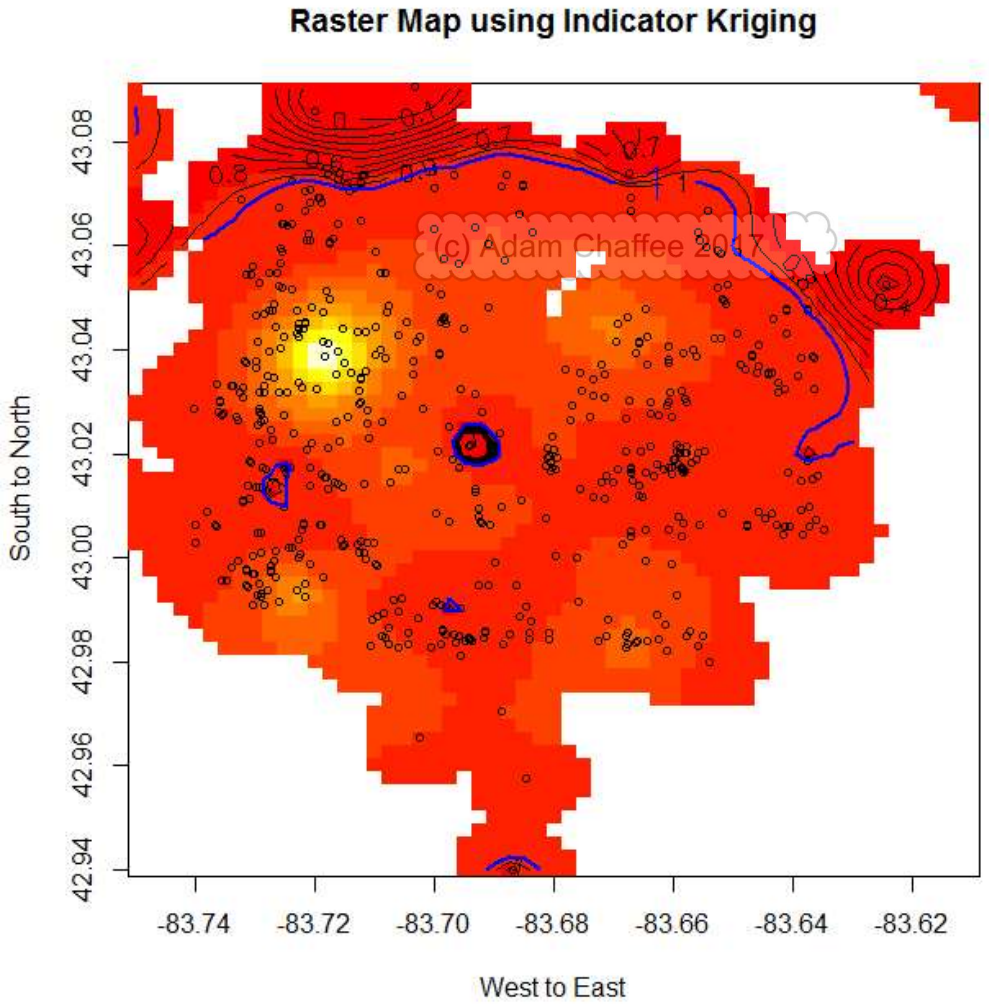
Indicator Kriging Results



Indicator Conversion:
1 assigned to lead level > 15 PPB
0 assigned to lead level < 15 PPB

Method	Cross Validated PRESS
Simple Kriging	21.07
Ordinary Kriging	21.08
Universal Kriging	21.09

Raster Map – Indicator Simple Kriging



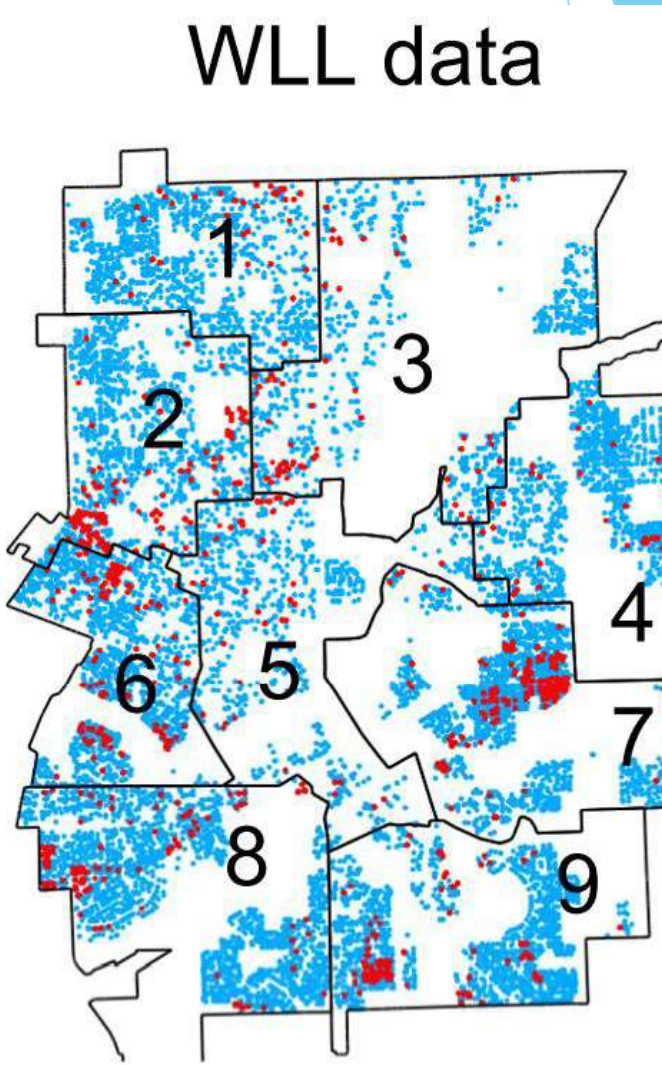
Voluntary vs. State Testing - Goovaerts (2016)

- Sentinel – state run testing
- Non-sentinel – any other testing, including voluntary

Table 5
Odds ratio for covariates of the GEE regression models fitted to five different WLL thresholds using all the data collected between 10/16/2015 and 9/15/2016.

Effects	WLL thresholds				
	1 µg/L	10 µg/L	15 µg/L	25 µg/L	50 µg/L
SL: lead vs others	2.929**	1.687**	1.582**	1.207	1.039
SL: unknown vs others	1.449**	1.148*	1.125	1.082	0.985
Built year: <1940 vs 1960–2016	3.143**	2.171**	2.106**	2.195**	2.232**
Built year: 1940–1959 vs 1960–2016	1.318**	1.426**	1.377**	1.348*	1.398*
Poverty: 25–50% vs < 25%	0.877**	0.968	1.021	1.040	1.056
Poverty: >50% vs < 25%	0.600**	0.760**	0.786*	0.817	0.835
Δt source switch (week)	1.001	1.001	1.002	1.006	1.011*
Sentinel site: No vs Yes	0.879*	1.331**	1.480**	1.712**	2.055**

* Significantly different from 1 at $\alpha = 0.05$.
** Significantly different from 1 at $\alpha = 0.01$.



Conclusions

- Co-kriging was the best estimator using the most recent data
  - Only showed nugget effect
  - Some clear hot spots which may serve as a guide for most troubled areas
- Indicator kriging with transformed data paints a different story – less targeted but overall more dangerous
- Controversial data source
  - Voluntary reporting differs from government reports
  - Possible non-random sampling from citizens, government, or both
- Uncertainty around method. Water pipes have lots of elbow joints and do not expand straight out in every direction.
  - Makes assumption of stationarity difficult due uncertain distances between points

Thank you!

- Sources:
  - Goovaerts, P. The drinking water contamination crisis in Flint: Modeling temporal trends of lead level since returning to Detroit water system. Sci Total Environ. 2017 Mar 1;581-582:66-79. doi: 10.1016/j.scitotenv.2016.09.207. Epub 2016 Oct 5.
  - Data from http://www.michigan.gov/flintwater/0,6092,7-345-76292_76294_76297--,00.html

- Special thanks to:
  - Dr. Nicolas Christou
  - Flint citizens who tested their water