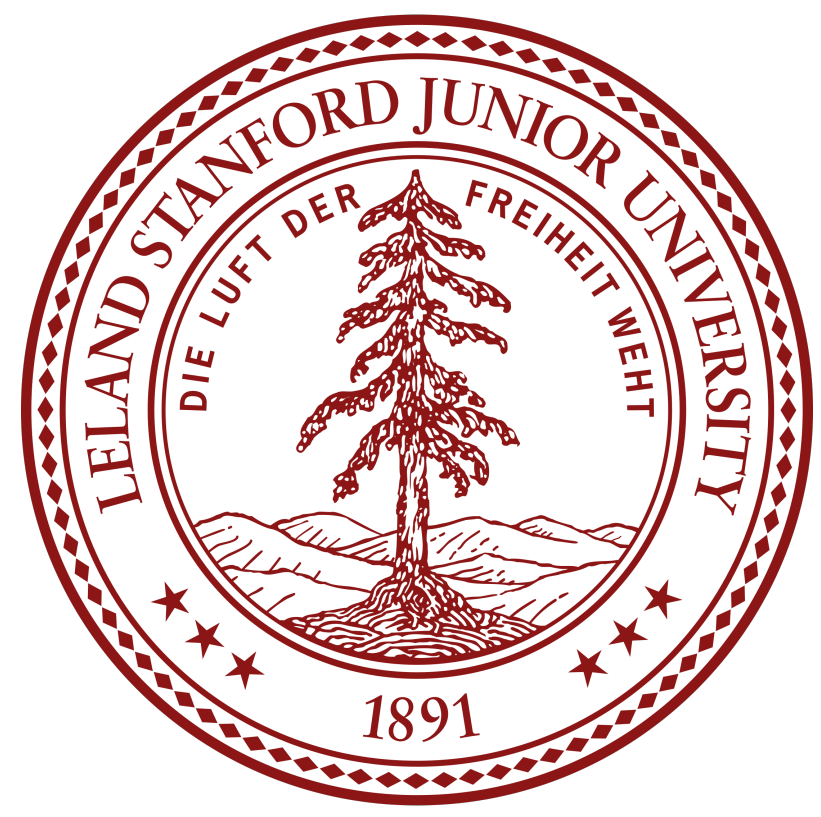




Deciphering the Role of Redox Conditions on Arsenic Contamination in the San Luis Valley, Colorado

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Sustainability

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Introduction

Arsenic is extremely hazardous to human health and a major threat to groundwater quality. It is a known carcinogen with an EPA contaminant limit of 10 µg/L. The San Luis Valley, Colorado, USA (SLV) is an arid agricultural region where many citizens rely on groundwater for personal drinking water. However, an estimated 30% of the population is exposed to drinking water above the EPA maximum. While naturally occurring in soil and sediments, the primary drivers behind arsenic release into groundwater can vary based on myriad environmental triggers.

Thus, this study sought to explore the relationship between arsenic levels in the SLV and redox conditions, a known potential trigger of arsenic release. This study utilized measurements from 496 well water samples provided by community members across the San Luis Valley.

Research Motivation

- ❑ In water with lower oxygen levels, arsenic tends to be reduced, becoming more mobile. Thus, I hypothesized that groundwater from deeper wells would have higher arsenic concentrations
- ❑ The high surface area of clay particles (and associated reactivity) make them a possibly potent source of mobile arsenic.

Lower oxygen levels

Higher clay content

Higher
arsenic
levels

Research Question

What amount of the variation in arsenic levels in groundwater can be explained by percent fines and well depth?

4. Depth and Fines in Tandem

Multiple models were used in order to determine if using both variables, percent fines and well depth, in tandem might improve the accuracy of arsenic predictions. For all models, log10 transformed arsenic was used as the dependent variable. Log10 transformed well depth and % fines (out of 100) were used as predictor variables.

Two - Way ANOVA

% Fines p – value = 2.95e-12

Well Depth p – value = 0.516

Multiple Linear Regression

% Fines p – value = 1.61e-07

Well Depth p – value = 0.0132

R² = 0.0710

RMSE = 7.0876 ppb

Random Forest Modeling

R² = 0.072

P – value = 0.007

Standard Error = 1.14 ppb

Variable Importance

% Fines = 57%

Well Depth = 43%

- ❑ Percent fines has a stronger relationship with arsenic than well depth, however both are significant

- ❑ Different models distribute weight between the two variables differently

Methods

Arsenic measurements (log transformed) were derived from 496 domestic water samples and measured by inductively coupled plasma mass spectrometry (ICP-MS).

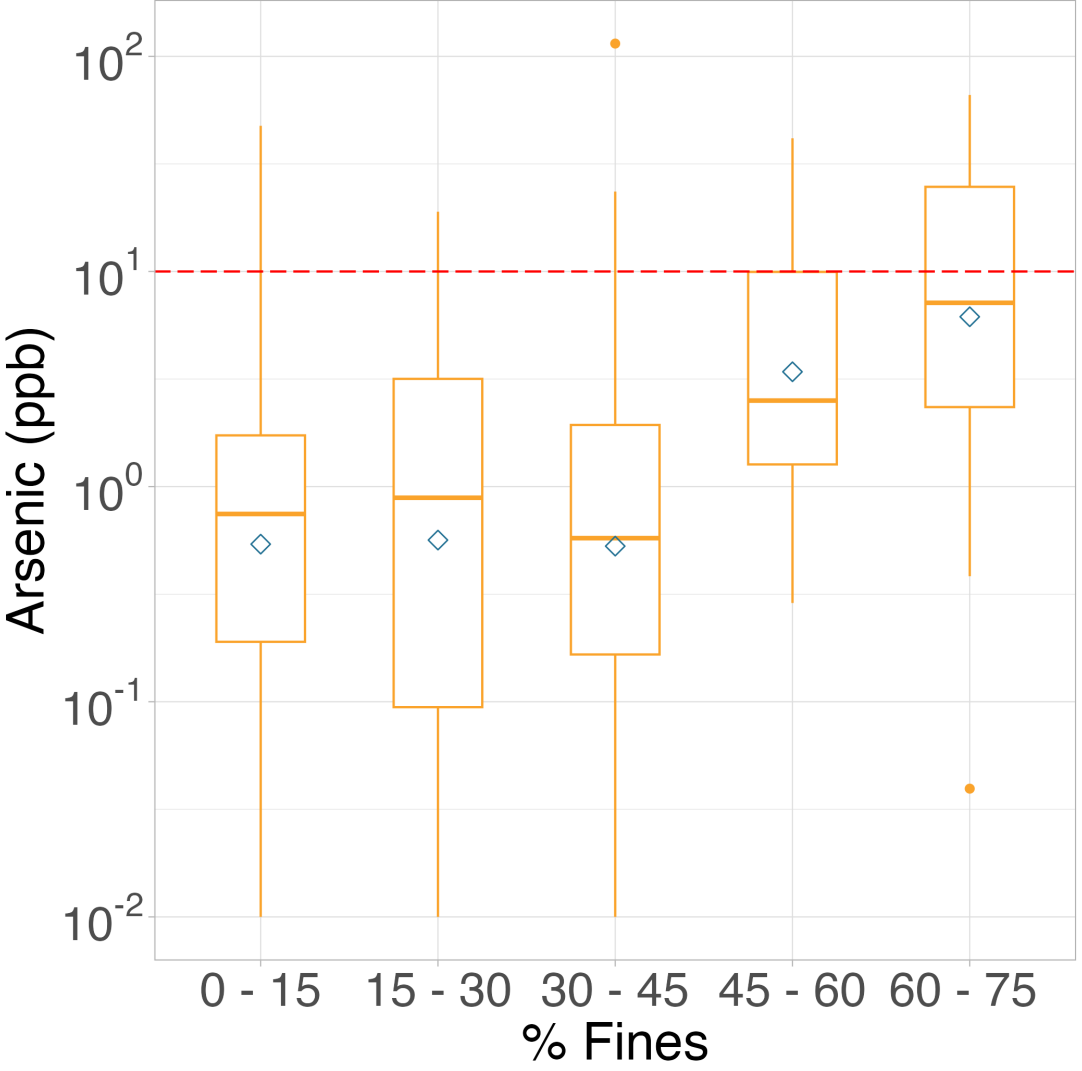
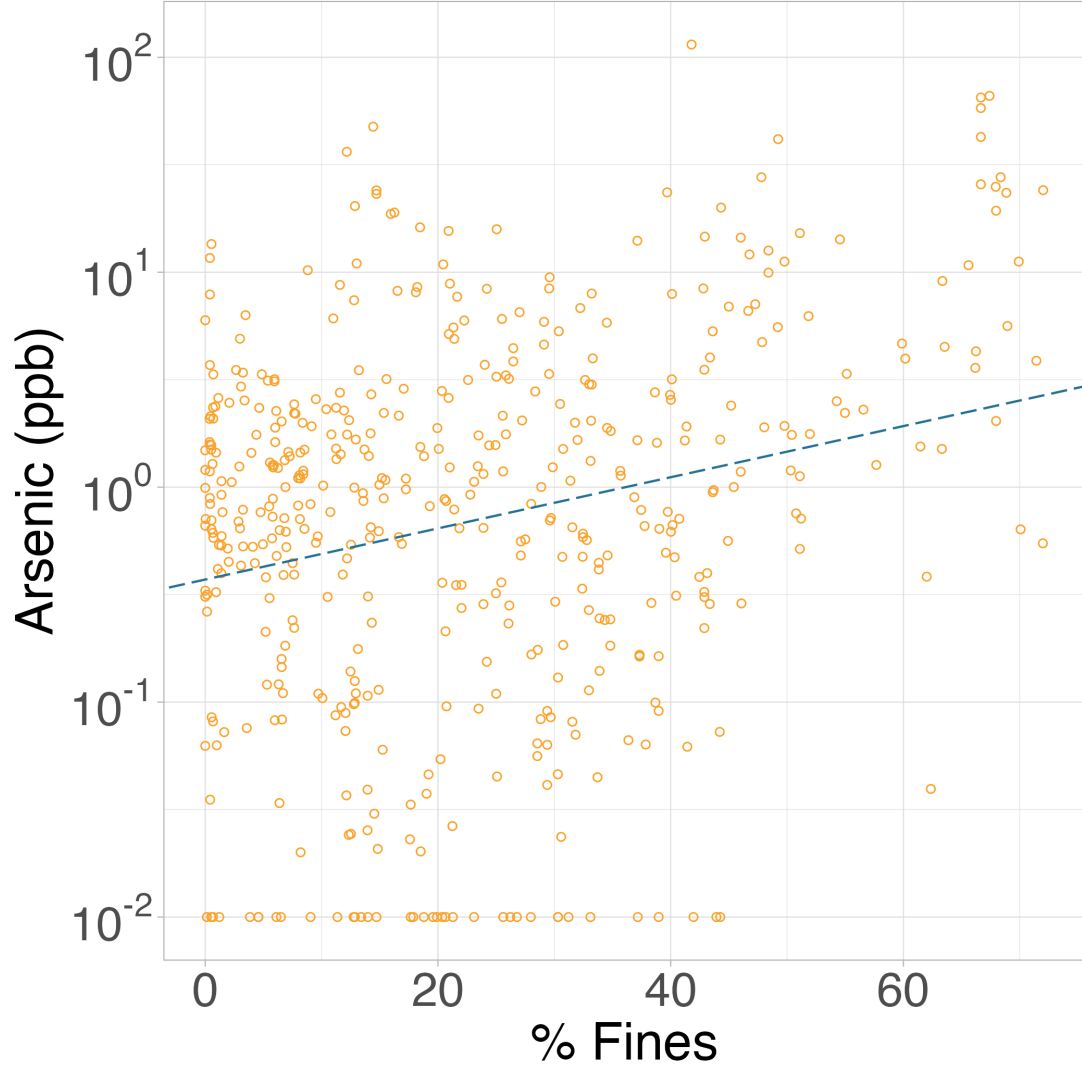
Clay occurrence was interpolated from a historical well log database from the region and matched to domestic water samples using geospatial kriging methods.

Percent fines (0-100 ft) is a measurement of the proportion of clay-sized particles relative to other sediments collected during well drilling. Spatial interpolation was done using kriging methods.

Well depth (log transformed) were acquired from well drilling records.

Statistical analysis was done using R, including one- and two- way ANOVA, linear regression, Kruskal-Wallis testing. Significant differences between particular groups were confirmed using Tukey HSD pairwise Wilcoxon testing. Maps and random forest models were generated in ArcGIS Pro.

1. Relationship Between Arsenic and Percent Fines



Linear Regression Modeling

RMSE: 7.160 ppb

R²: 0.0593

P-value: 3.938e-08

Threshold Modeling

P-value: 2.77e-12

One-way ANOVA shows significant difference between groups, particularly between the 30-45 and 45-60 % ranges

- ❑ P-values show a positive linear trend between percent fines and arsenic levels
- ❑ The relationship is weak, fines explain ~ 6% of the variation in arsenic
- ❑ The model is correct within ~ 7 ppb, which is notably high as the EPA limit is 10 ppb

2. Relationship Between Arsenic and Well Depth

Linear Regression Modeling:

RMSE: 7.475 ppb

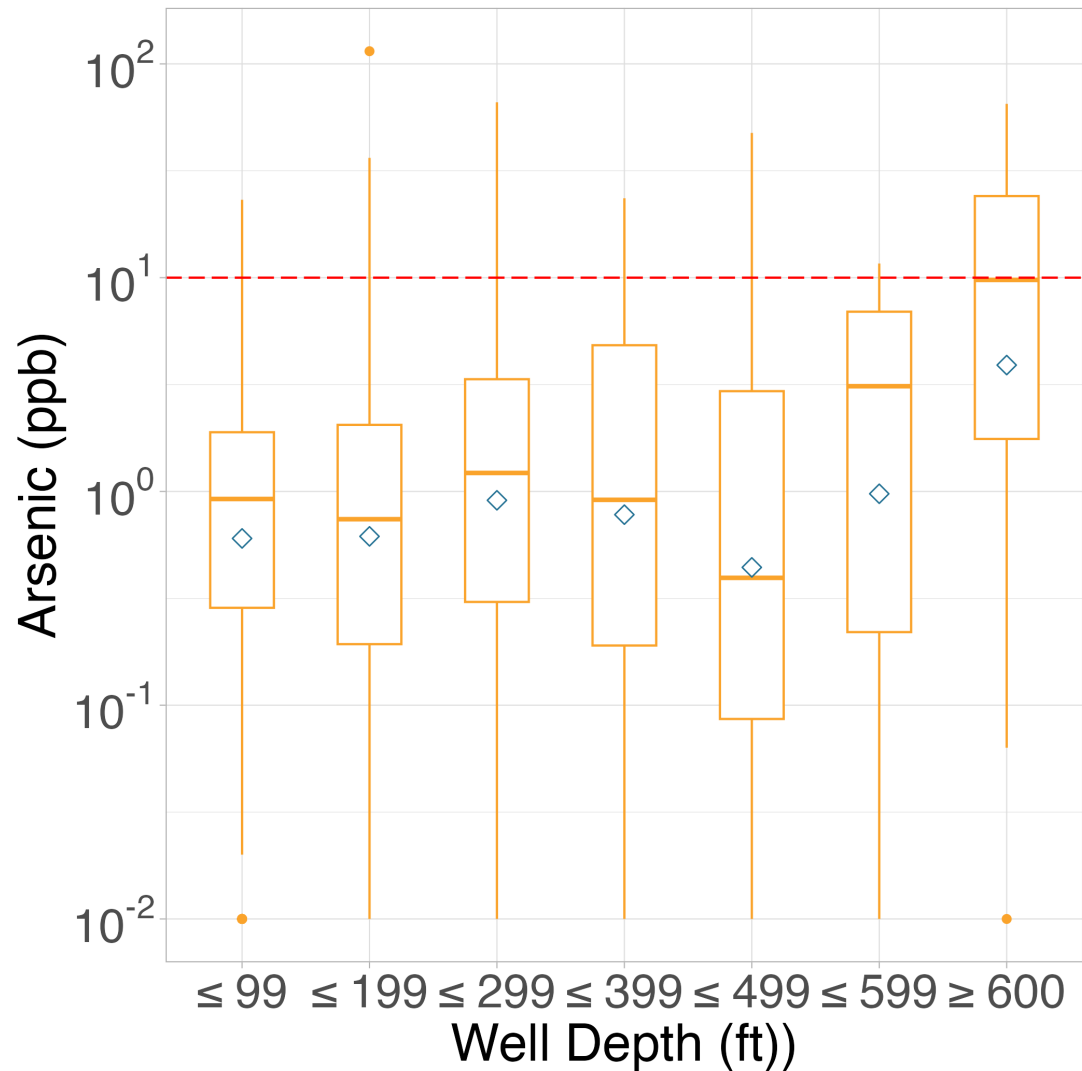
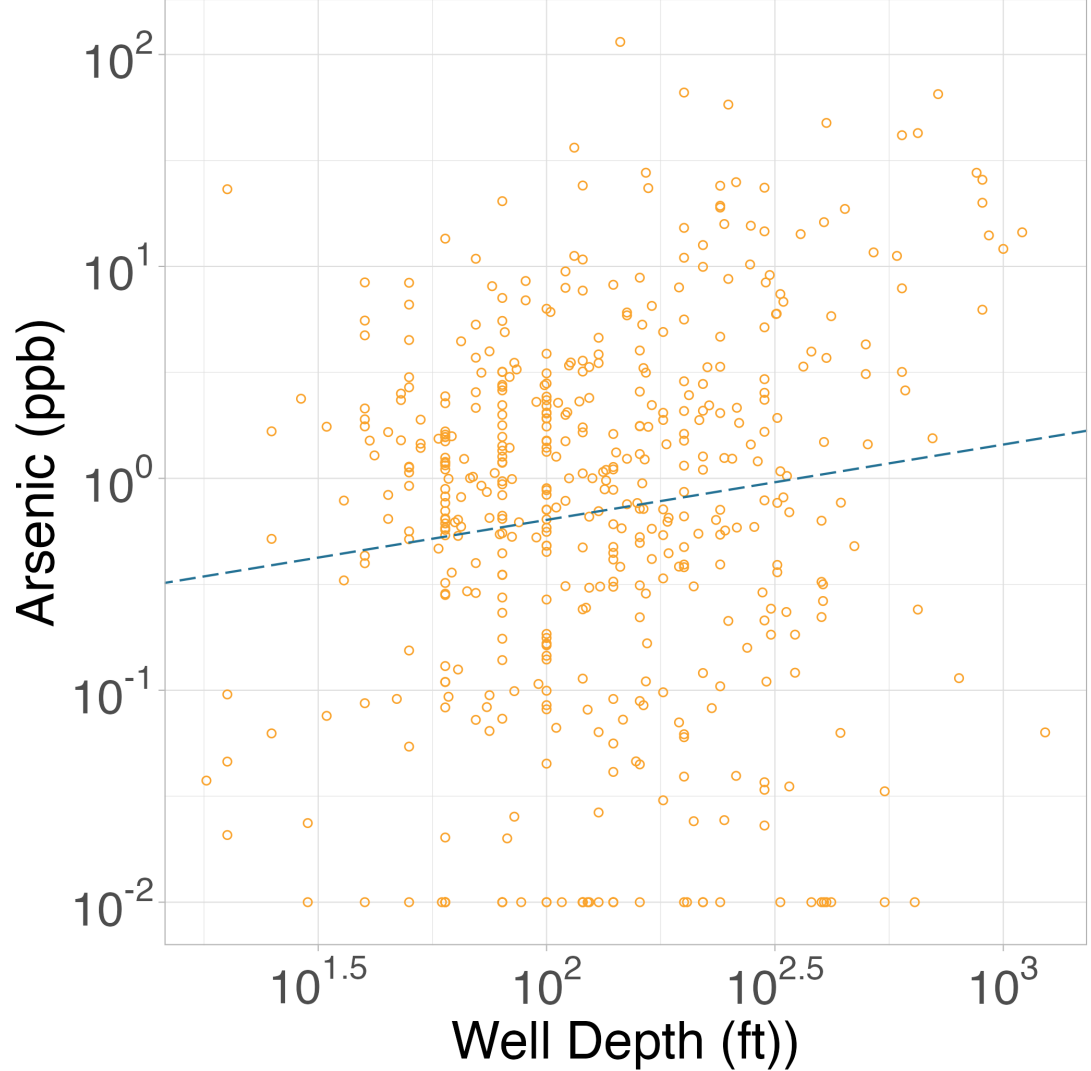
R²: 0.0177

P-value: 0.00297

Threshold Modeling

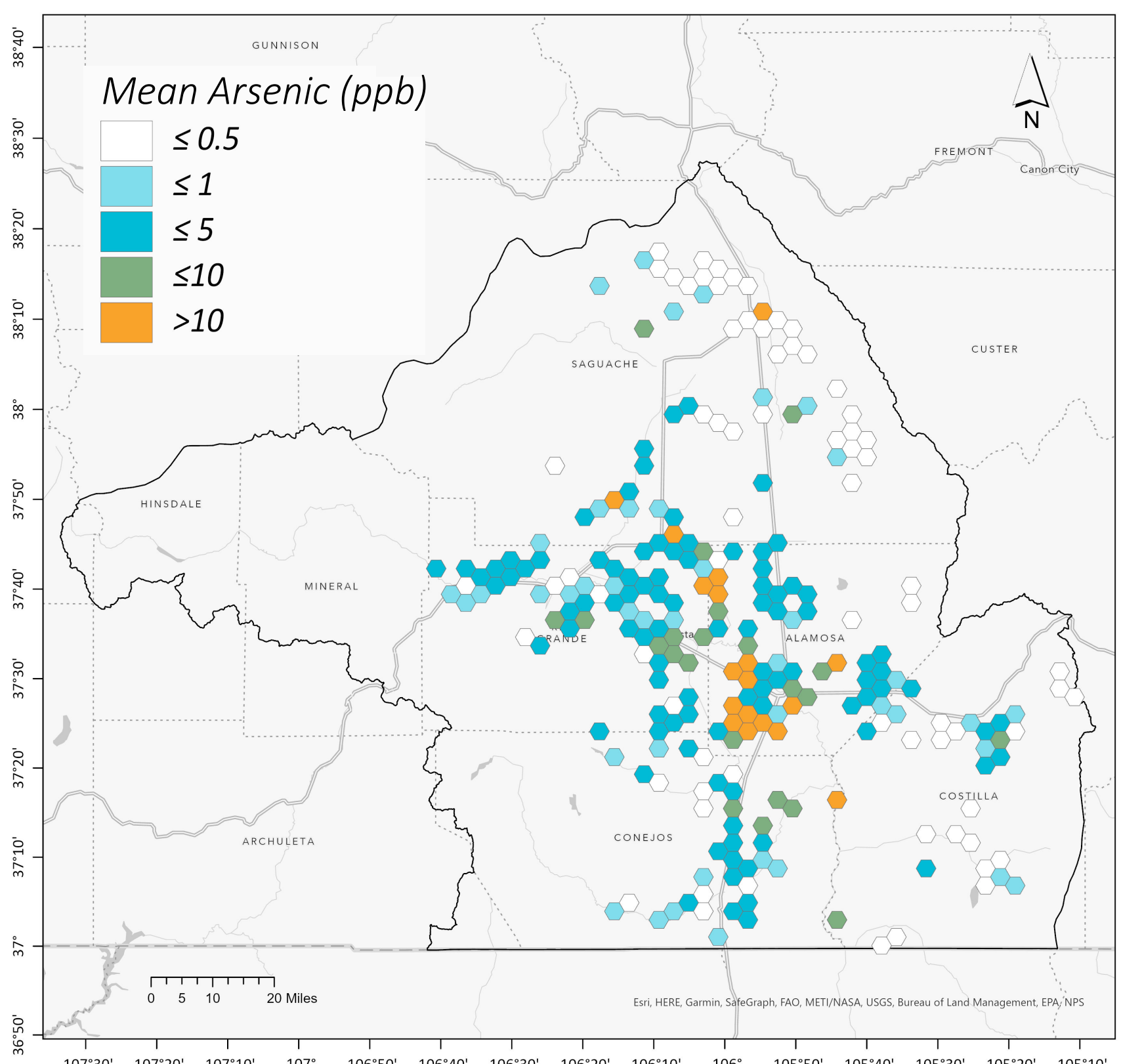
P-value: 0.00907

One-way ANOVA shows significant difference between groups



- ❑ P-values show a positive linear trend between well depth and arsenic levels
- ❑ This trend is fairly weak, well depth explains ~ 2% of the variation in arsenic levels
- ❑ The model is correct within ~ 7 ppb, which is notably high as the EPA limit is 10 ppb

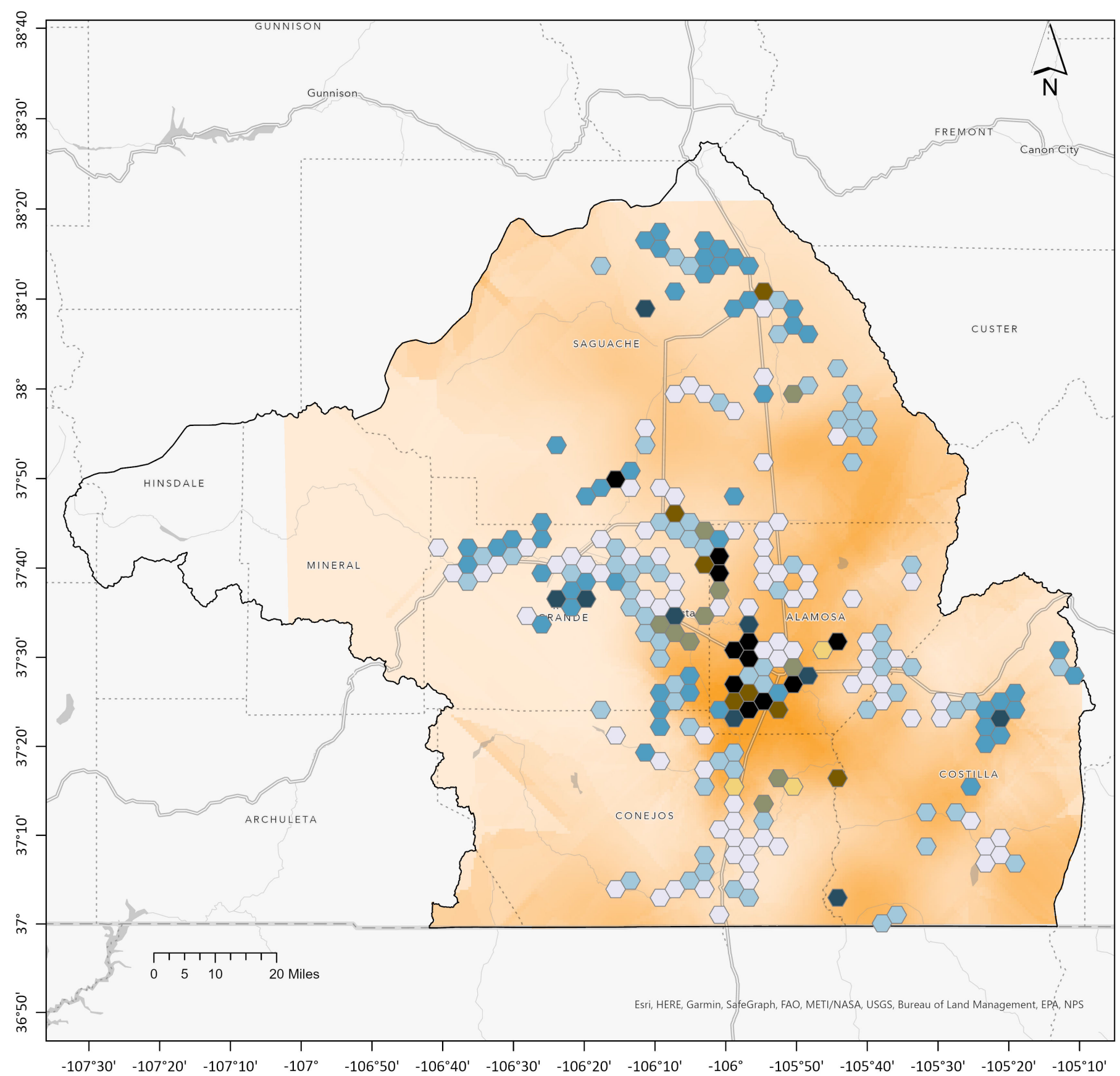
3. Spatial Relationships Between Variables



Mapping of the arsenic levels of all the wells in our data reveal a spatial trend for arsenic concentration in the San Luis Valley.

- ❑ A notable arsenic hotspot is present around the center of the valley
- ❑ Lower arsenic levels are present around the edges of the valley

5 10 >10 Mean Arsenic (ppb)
100 200 >200 Well Depth (ft)



Adding percent fines and well depth to the arsenic map shows a strong spatial relationship between the three variables.

- ❑ The area with the highest percentage of clay fines also contains a number of wells with both deeper wells and higher arsenic levels.

* sample hexagons are anonymized within an area of 10 square miles

Conclusions and Implications

Through this project, we now better understand the role of redox conditions on arsenic mobility in the San Luis Valley. The two variables explored, percent fines and well depth, are measurements of environmental conditions in which arsenic reduction is favored. Thus, the positive relationships between these variables and arsenic level in the valley indicates that higher arsenic concentrations are partly driven by reducing conditions.

- ❑ While the relationships are weak, both percent fines and well depth explain some amount of the variation in arsenic levels in the San Luis Valley.
- ❑ The percentage of clay fines in well soil explain a greater amount of variation than well depth
- ❑ For fines, a threshold seems to exist around 45% where arsenic levels increase greatly. A similar threshold for well depth is not apparent
- ❑ Multivariate methods like random forest modeling further illuminate predictive capacity of both well depth and % fines
- ❑ In the San Luis Valley, a hot spot is apparent around the center of the valley where measurements for arsenic, percent fines, and well depth are all relatively high indicating a spatial relationship between the three variables

Next Steps

- ❑ Predictive models should be explored more in depth and with more influential variables
- ❑ Current percent fines data only takes into account the first 100 feet of each well. Analysis of percent fines deeper in the valley may help sharpen trends
- ❑ In order to further explore redox conditions, oxygen levels in water samples should be measured and analyzed.

Acknowledgements

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