Understanding Water Quality in City Water Systems Using ArcGIS

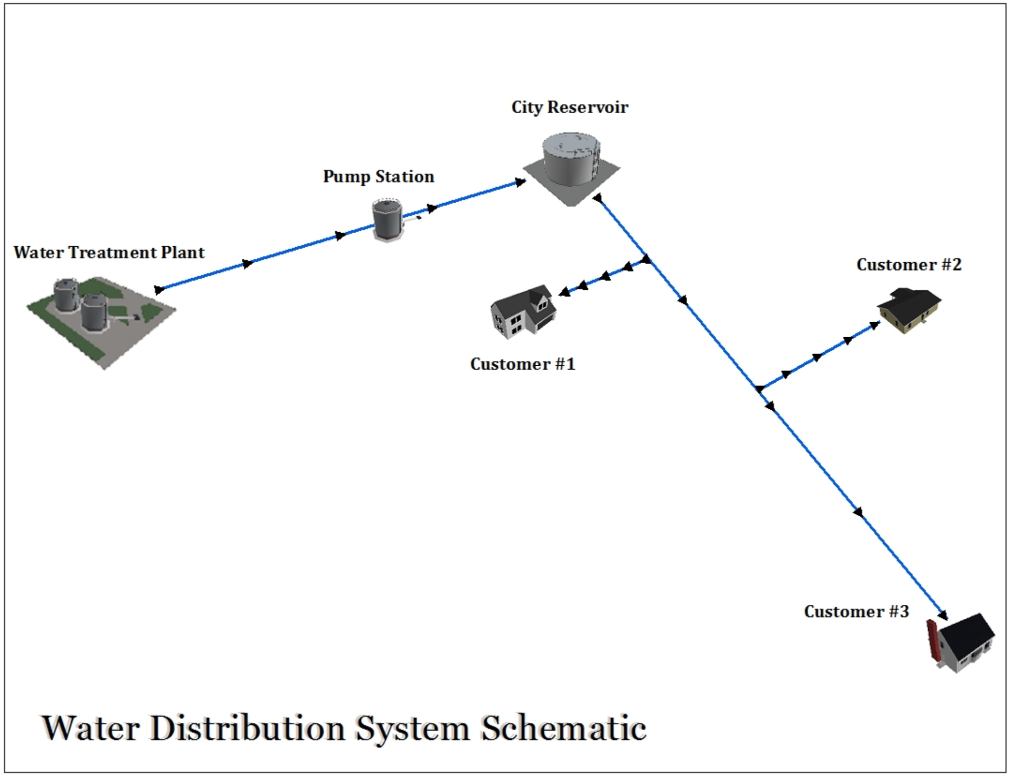
Jennifer Switzer
Geog 596A
Fall 2015 - Term 2

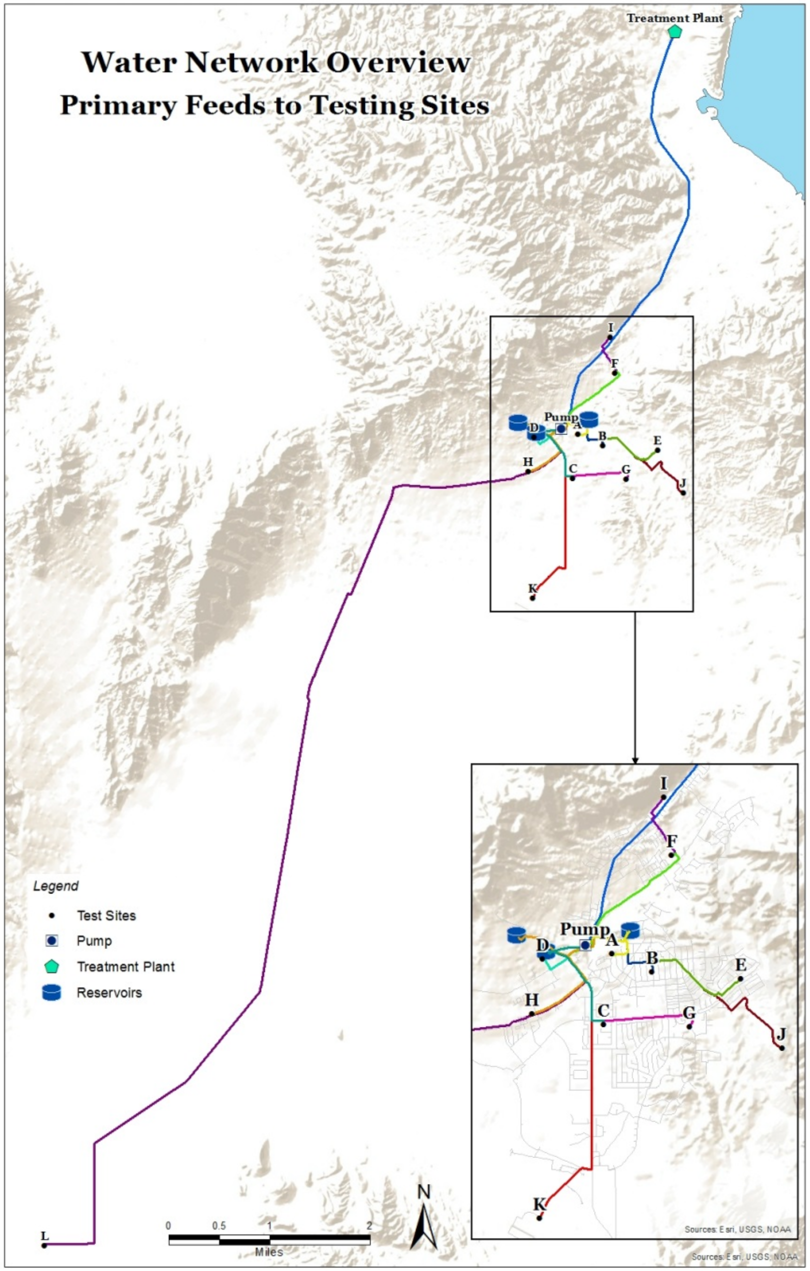
Advisor – Doug Miller, Ph.D.

Background

- Chlorine (Cl_2) is the most common drinking water disinfectant
- Residual Cl_2 travels through the distribution system
- Residual Cl_2 measures water's potability
- Minimum levels (>.5 mg/L) necessary to maintain water quality
- Water samples tested throughout the city

Distribution Systems





Background (cont)

- Water age – water's travel time from treatment plant to customer
- Water turnover & distance affect water age
- Water quality typically modeled using hydraulic modeling
- State-of-the-art hydraulic modeling software is expensive and time-consuming to use
- Most municipalities invest in GIS, but have limited resources to create models

Objectives

- Analyze factors that affect residual chlorine levels
  - Distance from source (pump station to test sites)
  - Pipe characteristics – material, diameter
  - Water usage
- Model the influence of each factor within the ArcGIS environment
  - Analyze the level of influence of each factor
  - Visualize chlorine decay
  - Predict residual chlorine values

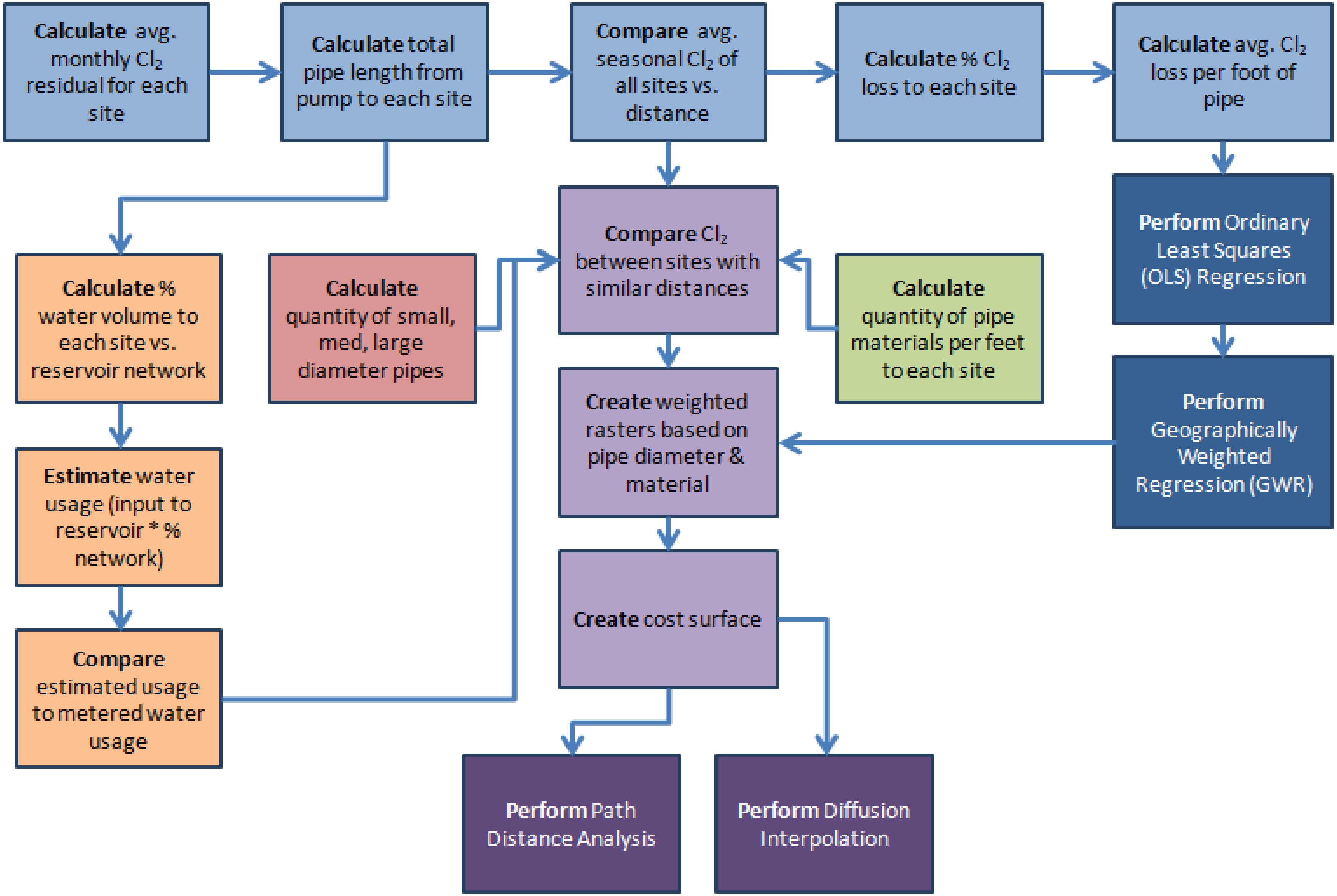
Data Sources

- Cl_2 test results from pump station and 12 city sites (April 2012- July 2015)
- GIS waterline data–length, diameter, pipe material
- Daily water input to city reservoirs from treatment plant
- Metered water usage

Methods

- Base Calculations
  - average monthly & seasonal residual chlorine levels
  - pipe length to each site
  - % chlorine loss
  - chlorine loss per foot
  - quantity of pipe material to each site
  - quantity of small, med, & large pipe diameters to each site
- Graphical trend analysis
- Water use estimations & comparisons
- Statistical Modeling
  - Regression – OLS and GWR
  - Path distance analysis
  - Diffusion interpolation

Workflow

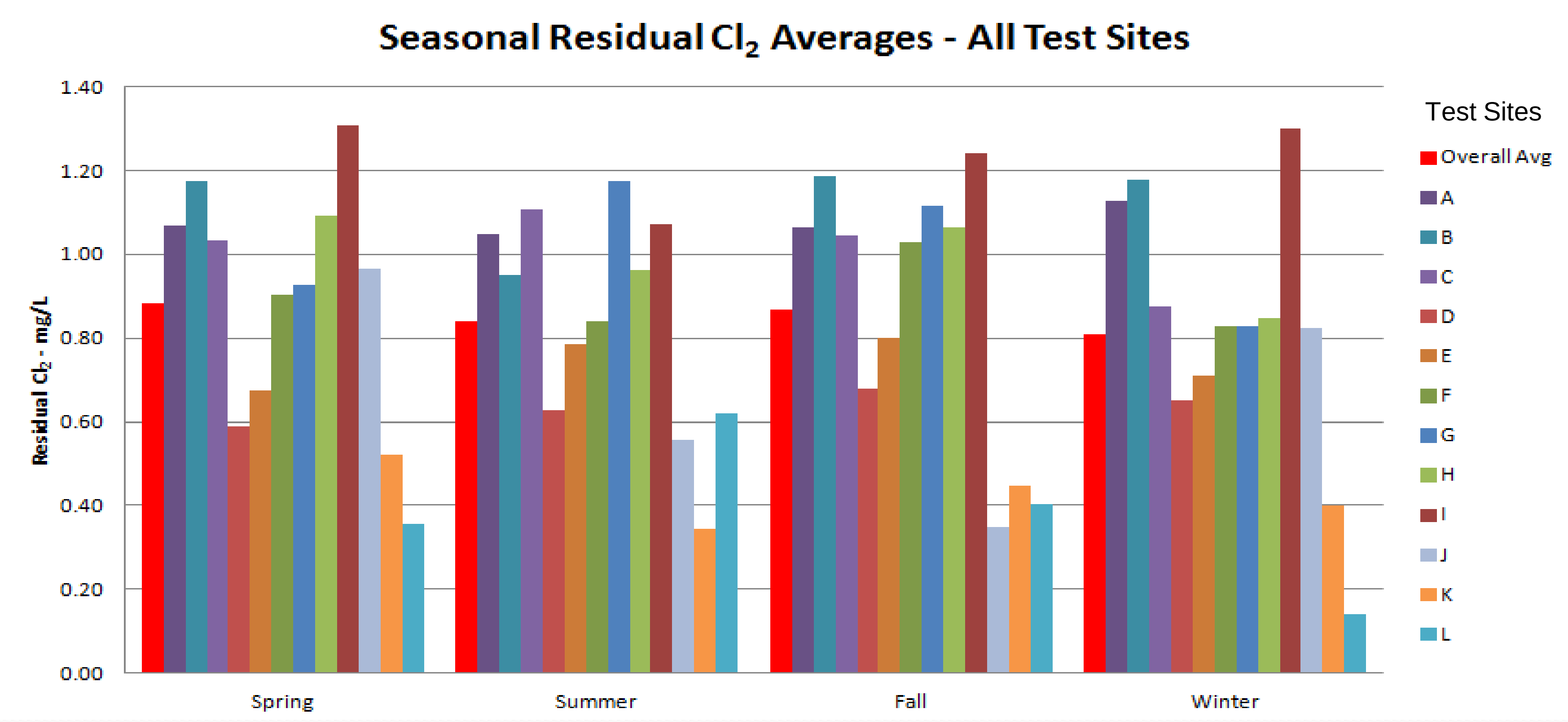


Calculate avg. monthly Cl_2 residual for each site
Calculate total pipe length from pump to each site
Compare avg. seasonal Cl_2 of all sites vs. distance
Calculate % Cl_2 loss to each site
Calculate avg. Cl_2 loss per foot of pipe
Calculate % water volume to each site vs. reservoir network
Calculate quantity of small, med, large diameter pipes
Compare Cl_2 between sites with similar distances
Calculate quantity of pipe materials per feet to each site
Perform Ordinary Least Squares (OLS) Regression
Estimate water usage (input to reservoir * % network)
Create weighted rasters based on pipe diameter & material
Perform Geographically Weighted Regression (GWR)
Compare estimated usage to metered water usage
Create cost surface
Perform Path Distance Analysis
Perform Diffusion Interpolation

Analyze Residual Cl_2 Testing Data

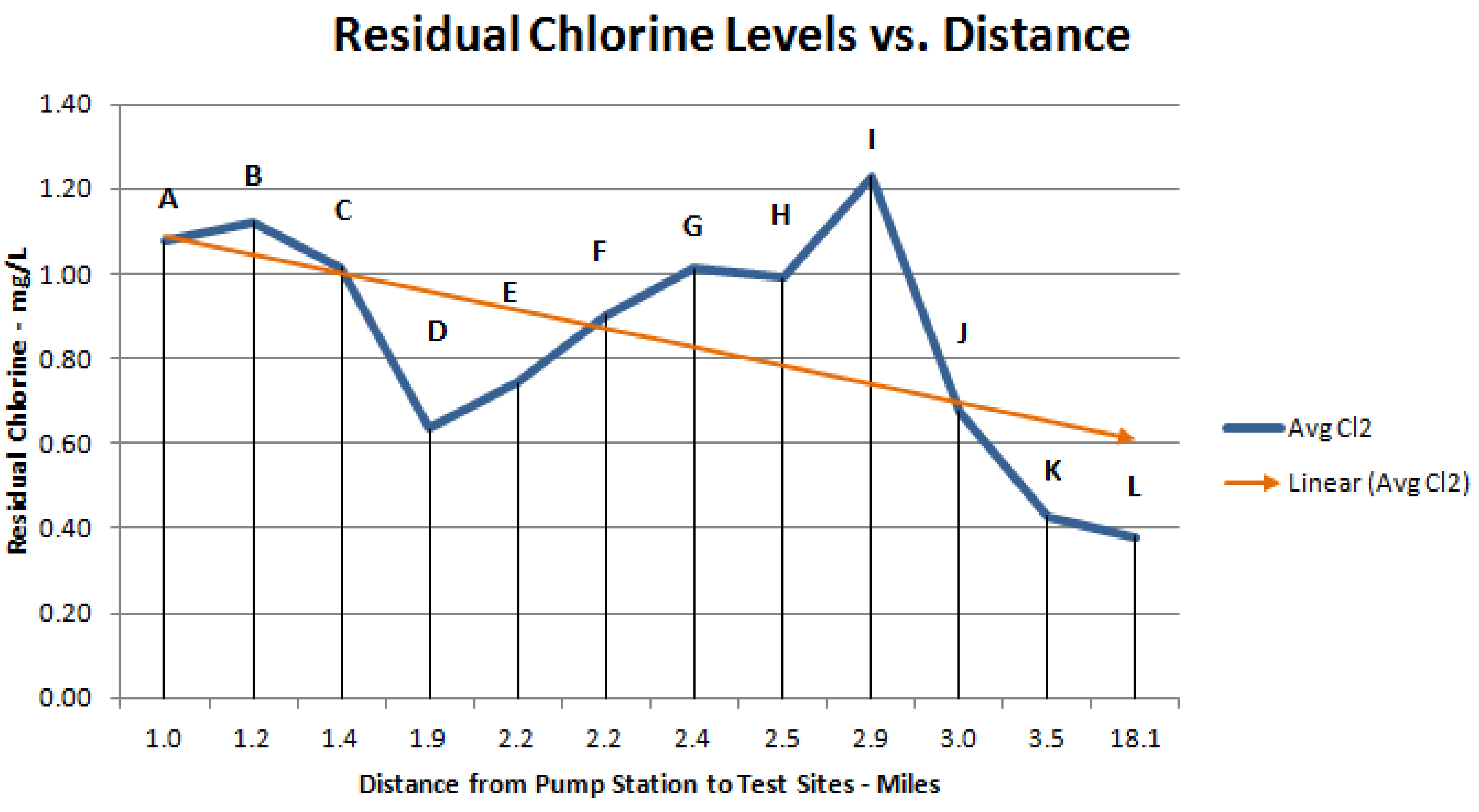
Base calculations:

- Average monthly Cl_2 levels at each site across all years
- Seasonal averages (spring, summer, fall, winter)



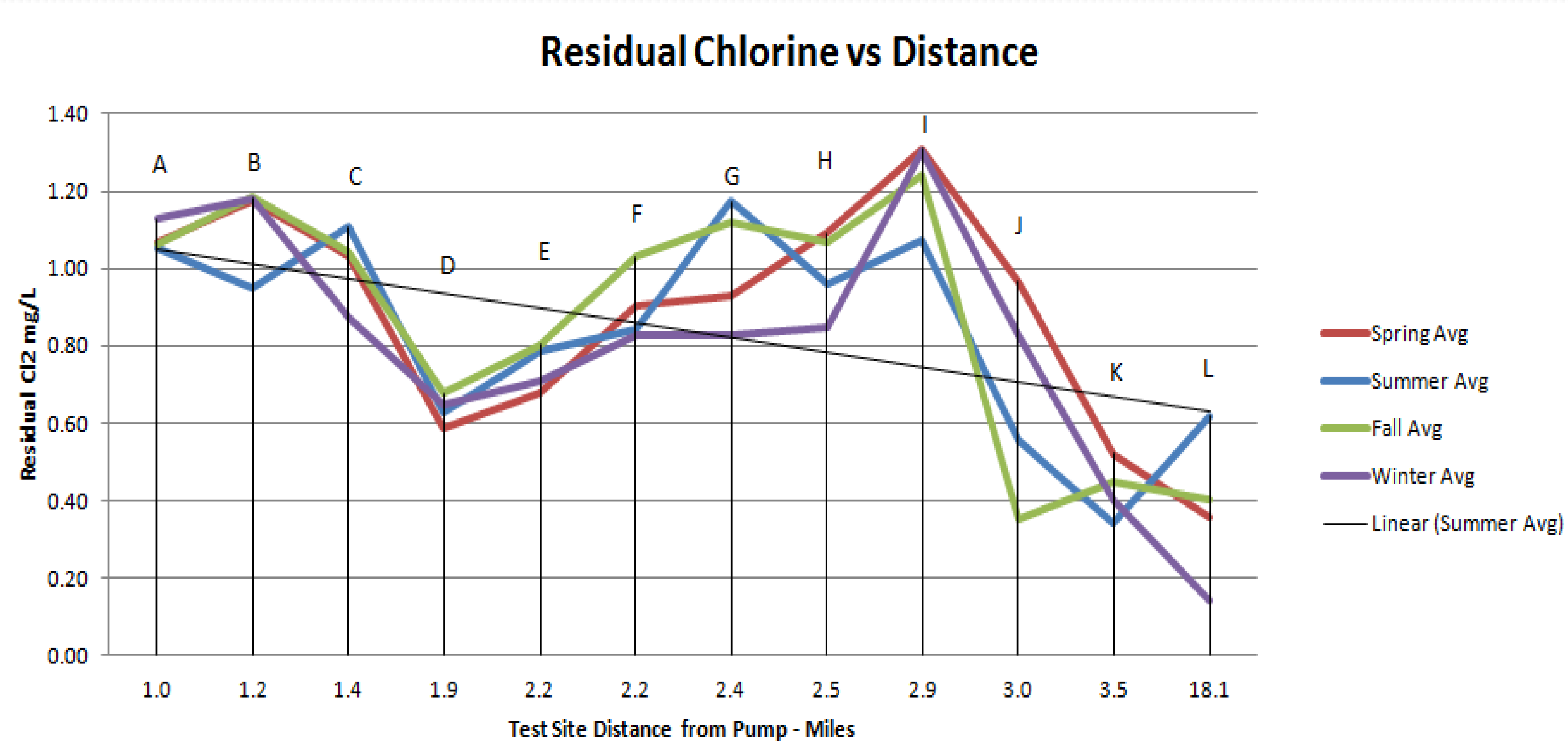
Distance

- Residual Cl_2 decreases as distance increases
- Longer time to react with organisms and pipe material



Seasonal Averages vs. Distance

- Subtle variation between seasonal averages
- Overall trend - decrease in Cl_2 with increased distance



Chlorine Decay Comparison

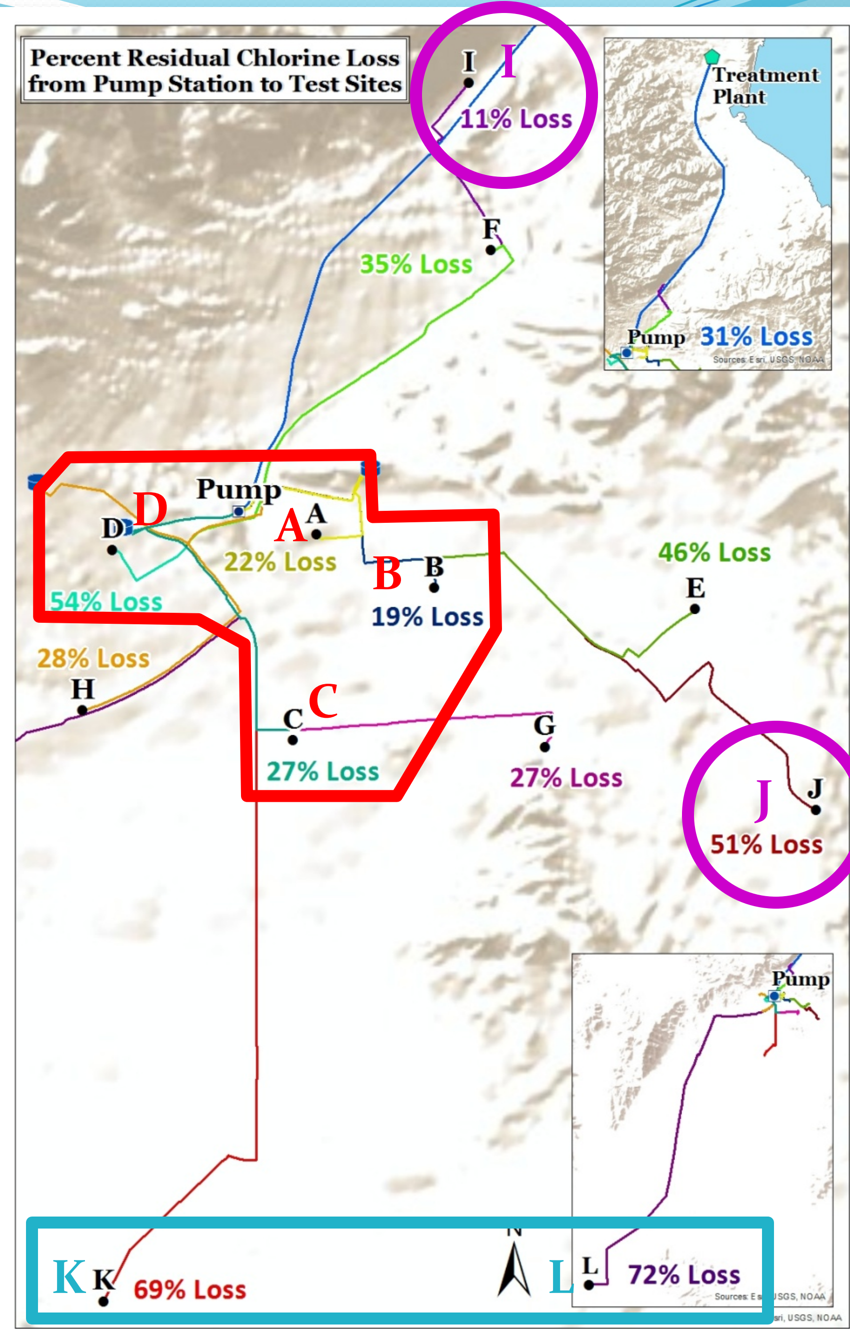
$\% \ Cl_2 \ loss = ((pump \ Cl_2 - site \ Cl_2)/pump \ Cl_2)*100$

Inconsistencies between sites within similar distances to pump station.

- Site D has significantly more chlorine loss (54%) than comparable sites like A, B, and C (19% -27% loss)

- Site L is 14.6 more miles from the pump than K, however there is only a 3% difference in residual chlorine loss between the sites

- Sites I and J have a distance difference of .1 miles from the pump, but site I has 11% chlorine loss while site J has 51% loss



Pipe Material

- Materials have different chemical reactions with Cl_2
- Reactive hierarchy

Iron > Steel > Cement > Plastic




% material = (Total ft of material/Total ft of pipeline)*100

Water Usage/Turnover

- Low water turnover lengthens water residence in the system
- Oversized distribution networks provide more supply than demand

EW = WV * PW

where EW = Estimated water used by site, WV = % Water volume to site, and PW = Amount of water pumped into reservoir

Statistical Modeling

- Ordinary Least Squares (OLS) Regression
  - Global model across the study region to predict Cl_2
- Geographically Weighted Regression (GWR)
  - Local model to provide linear relationships between variables
- Analysis Goals
  - Determine the amount of negative or positive influence factors have on Cl_2
  - Predict values at unsampled locations
  - Visual display of results

Statistical Modeling (cont)

- Path Distance Analysis
  - Determines the accumulative "cost" of travel from a source to each cell
  - Uses cost surface (weighted cell values for certain factors) and the surface distance (elevation layer)
- Diffusion Interpolation
  - Predicts unknown values using raster and feature barriers
  - Uses cost surface as input barrier

Anticipated Results

- Understand relationship between factors contributing to Cl_2 decay
- Visualize Cl_2 decay throughout system
- Predict residual Cl_2 levels at unsampled sites
- GIS-based workflow

Schedule

- **Dec 2015**– Finish analysis on pipe material, Cl_2 loss per foot, & diameter
- **Jan 2016** – Regression analysis; establish weights for cost surface
- **Feb 2016** – Path distance analysis and interpolation
- **April 2016** – Use model builder to create executable analysis process
- **June/July 2016** – Present at conference

Critical References

- Al-Jasser, A.O. "Chlorine decay in drinking-water transmission and distribution systems: Pipe service age effect." *Water Research*, 2007: 387-396.
- AWWA; Economic and Engineering Services. *Effects of Water Age on Distribution System Water Quality.* Issue Paper, Environmental Protection Agency, 2002.
- Centers for Disease Control and Prevention. *The Safe Water System; Free Chlorine Testing.* July 17, 2014. http://www.cdc.gov/safewater/chlorine-residual-testing.html (accessed October 21, 2015).
- Hallman, N.B., J.R. West, C.F. Forster, J.C. Powell, and I. Spencer. "The decay of chlorine associated with the pipe wall in water distribution systems." *Water Research*, 2002: 3479-3488.
- Masters, Sheldon, Hong Wang, Amy Pruden, and Marc A. Edwards. "Redox Gradients in Distribution Systems Influence Water Quality, Corrosion, and Microbial Ecology." *Water Research*, 2015: 140-149.
- Turgeon, Steve, Manuel Rodriguez, Marius Theriault, and Patrick Levallois. "Perceptions of drinking water in the Quebec City region (Canada): the influence of water quality and consumer location in the distribution system." *Journal of Environmental Management 70*, 2004: 363-373.
- Wang, Hong, et al. "Effect of Disinfectant, Water Age, and Pipe Material on Occurrence and Persistence of Legionella, mycobacteria, Pseudomonas aeruginosa, and Two Amoebas." *Environmental Science and Technology*, 2012: 11566-11574.
- Water Quality and Health Council. *Safe Water Delivered Safely.* http://www.waterandhealth.org/drinkingwater/safewater.html (accessed November 1, 2015).

Questions?