Understanding Water Quality in City Water Systems Using ArcGIS

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Background

- Chlorine (Cl₂) is the most common drinking water disinfectant
- Residual Cl₂ travels through the distribution system
- Residual Cl₂ measures water’s potability
- Minimum levels (> .5 mg/L) necessary to maintain water quality
- Water samples tested throughout the city
Distribution Systems

Water Distribution System Schematic

Water Network Overview
Primary Feeds to Testing Sites

Legend:
- Test Sites
- Pump
- Treatment Plant
- Reservoirs
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

- Cl₂ 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

1. Calculate avg. monthly Cl₂ residual for each site
2. Calculate total pipe length from pump to each site
3. Compare avg. seasonal Cl₂ of all sites vs. distance
4. Calculate % Cl₂ loss to each site
5. Calculate avg. Cl₂ loss per foot of pipe
6. Calculate % water volume to each site vs. reservoir network
7. Calculate quantity of small, med, large diameter pipes
8. Compare Cl₂ between sites with similar distances
9. Calculate quantity of pipe materials per feet to each site
10. Perform Ordinary Least Squares (OLS) Regression
11. Perform Geographically Weighted Regression (GWR)
12. Estimate water usage (input to reservoir * % network)
13. Create weighted rasters based on pipe diameter & material
14. Create cost surface
15. Perform Path Distance Analysis
16. Perform Diffusion Interpolation
17. Compare estimated usage to metered water usage
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\textsubscript{2} with increased distance
Chlorine Decay Comparison

\[
\% \text{ Cl}_2 \text{ loss} = \frac{(\text{pump Cl}_2 - \text{site Cl}_2)/\text{pump Cl}_2}{} \times 100
\]

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 = \( \frac{\text{Total ft of material}}{\text{Total ft of pipeline}} \times 100 \)
Water Usage/Turnover

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

\[ EW = WV \times PW \]

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 Cl₂ decay
- Visualize Cl₂ decay throughout system
- Predict residual Cl₂ 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


Questions?