# Salinization of streamwater in exurban and suburban watersheds of southeastern Pennsylvania, 1999-2019

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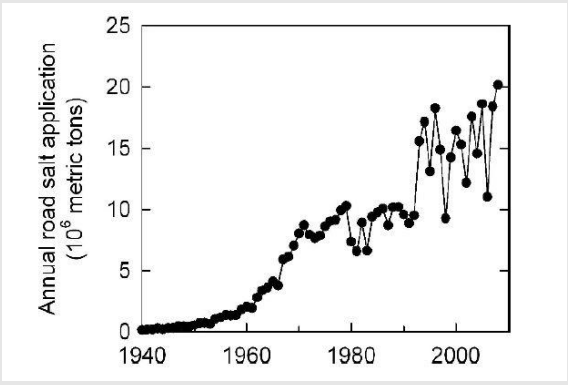
## Cumulative Application of Road Salt





Kelly et al., 2012; *Environsci. Eng. Geosci.*

- Approximately twentyfold increase since 1940's in the United States

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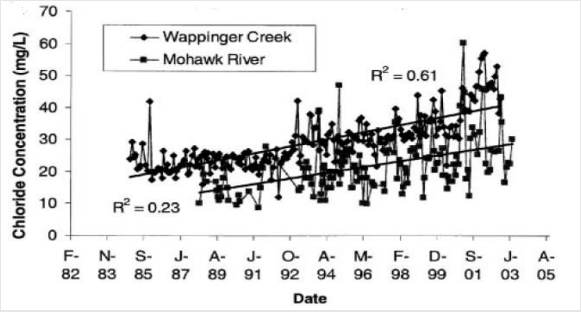
# Increasing $Cl^-$ Concentrations in Streamwater

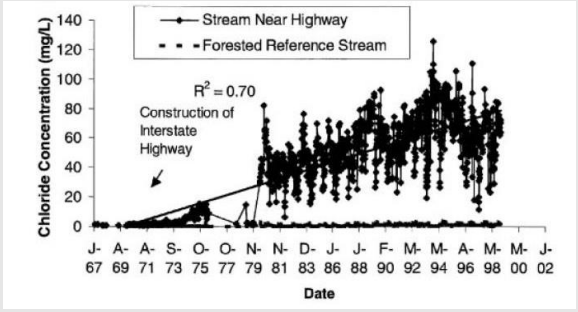
Hudson River Valley, NY




Kaushal et al., 2005; *PNS USA*

- Increasing concentrations of chloride in surface water over time

Hubbard Brook Valley (White Mountains, NH)




Kaushal et al., 2005; *PNS USA*

- Increasing concentrations of chloride in stream near highway

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# How does road salt end up in our streams?

## 1. Stormwater runoff

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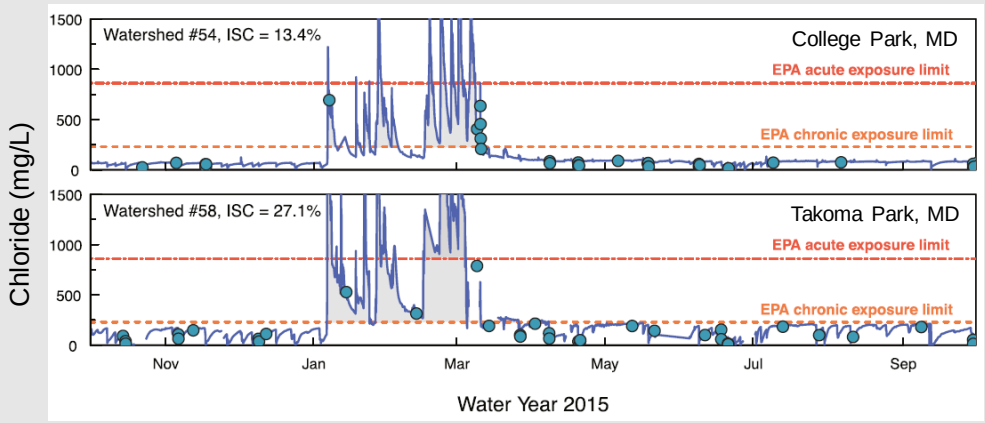
# Winter Chloride Spikes

Mid-Atlantic Watersheds




Moore et al., 2020; *Environ. Sci. Technol.*

- Winter discrete $Cl^-$ concentrations greater than USEPA chronic exposure limit

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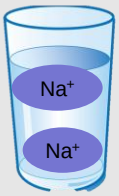
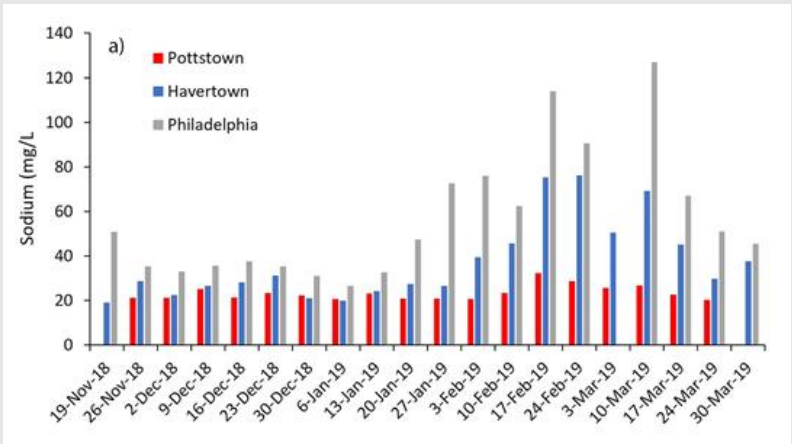
# Sodium Spikes in Drinking Water

- Winter 2018-2019
  - Late season spike in $Na^+$ concentrations at all 3 locations
  - Coincide with peak snow melt period
  - All samples exceeded 20 mg/L




Cruz et al. (2022); *GeoHealth*

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# Relationship with Hypertension

- Percent recommended daily sodium consumed through drinking water
- Normal vs. low salt diet

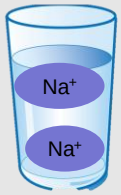


**Table 3**
*Percent Contribution of Water Ingested Sodium Toward Recommended Sodium Ingestion Guidelines*

| | Tolerable upper limit (TUL)[a] | | Low sodium[b] | |
|---|---|---|---|---|
| | Women (%) | Men (%) | Women (%) | Men (%) |
| Philadelphia | | | | |
| Average | 6.1 | 8.3 | 10.1 | 13.9 |
| High range | 13.7 | 18.8 | 22.9 | 31.3 |
| Havertown | | | | |
| Average | 4.0 | 5.5 | 6.7 | 9.2 |
| High range | 8.2 | 11.3 | 13.7 | 18.8 |
| Pottstown | | | | |
| Average | 2.5 | 3.4 | 4.2 | 5.7 |
| High range | 3.5 | 4.8 | 5.8 | 7.9 |

[a]U.S. Institute of Medicine's tolerable upper limit (TUL) of 2,500 mg day$^{-1}$ (Institute of Medicine, 2005). [b]U.S. National Institute of Health-National Heart blood and Lung Institute's Dietary Approaches to Stop Hypertension diet recommendation of no more than 1.5 g per day for populations at risk of hypertension (NIH, 2006).

Cruz et al. (2022); *GeoHealth*

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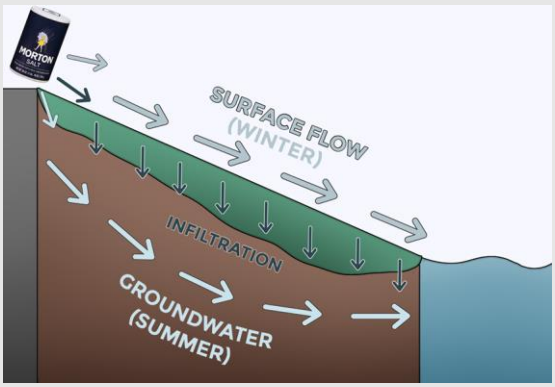
# How does road salt end up in our streams?

2. Soil infiltration → shallow groundwater → streams (baseflow)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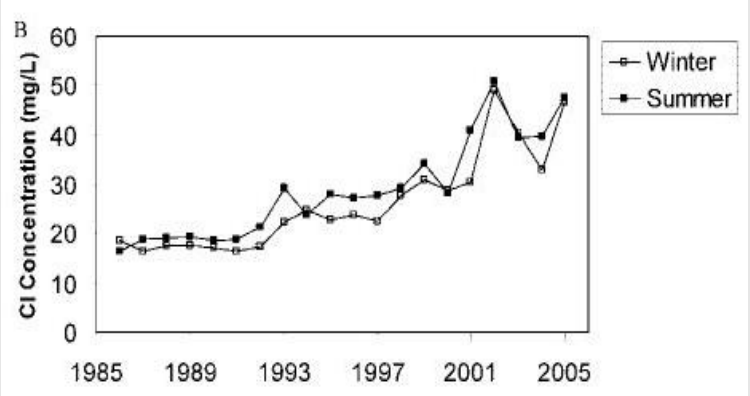
# Legacy Impact of Road Salt

- Increasing $Cl^-$ concentrations observed in both winter and summer months

Wappinger Creek (Millbrook, NY)




Kelly et al., 2008; *Environ. Sci. Technol.*

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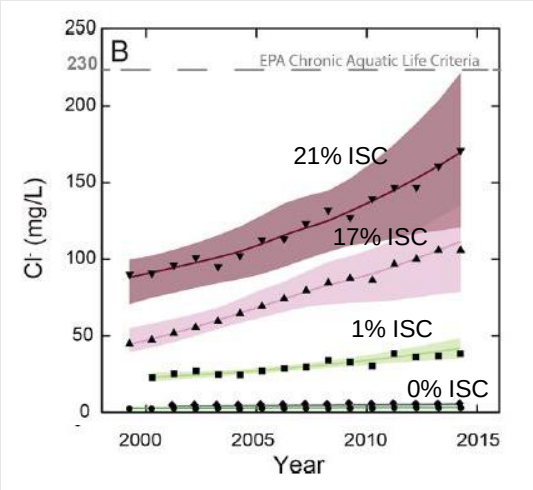
# Links with Impervious Surface Cover

Piedmont (Baltimore, MD)




Bird et al., 2018; *Environ. Sci. Technol.*

- Concentrations lowest in forested watersheds
- Concentrations elevated in watersheds with greater than 1% ISC
- Concentrations increased with increasing ISC

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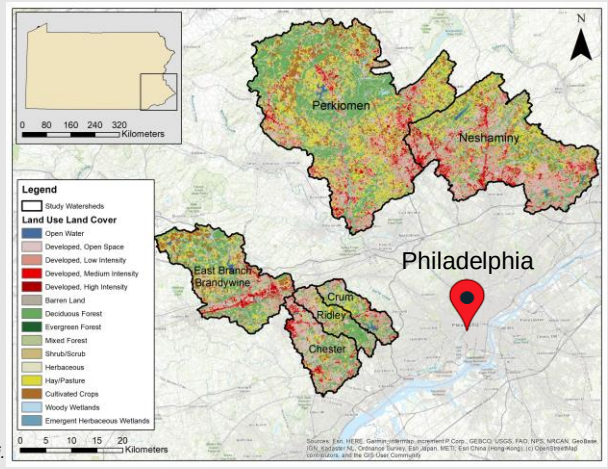
# Study Context

- Study Objectives:
  - Evaluate $Cl^-$ concentrations in multiple watersheds with changing land cover over time in the same geographic region
  - Provide data points for exurban/suburban watersheds




Rossi et al., 2022; *Sci. Total Environ.*
Rossi et al., 2023; *Front. Environ. Sci.*

**Question: What is the relationship between impervious surface cover change, long-term ion concentrations, and road salt application for six exurban/suburban watersheds in southeastern Pennsylvania?**

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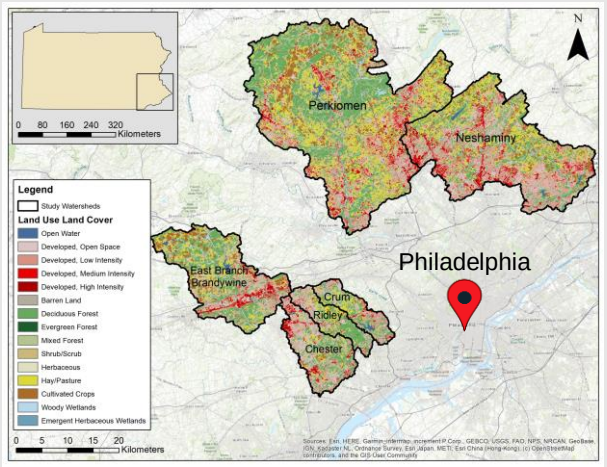
# Study Context


**Developed Land**

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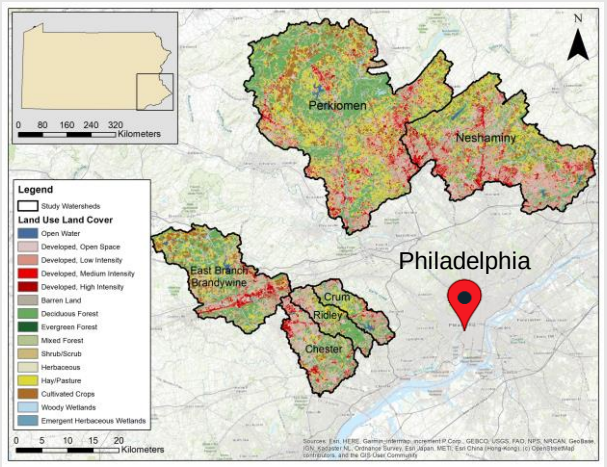
# Study Context


**Forested Land**

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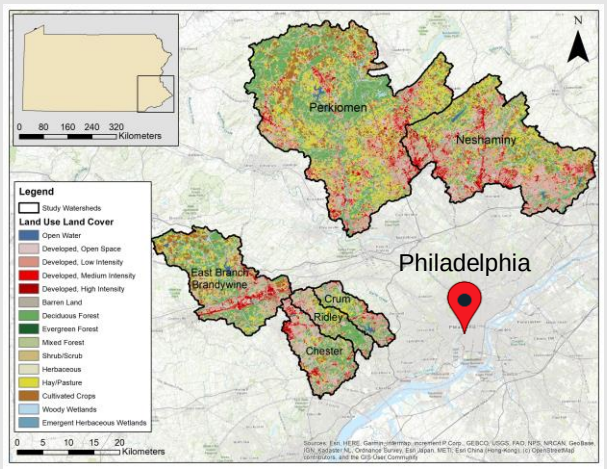
# Study Context


**Cultivated Crops and Pasture**

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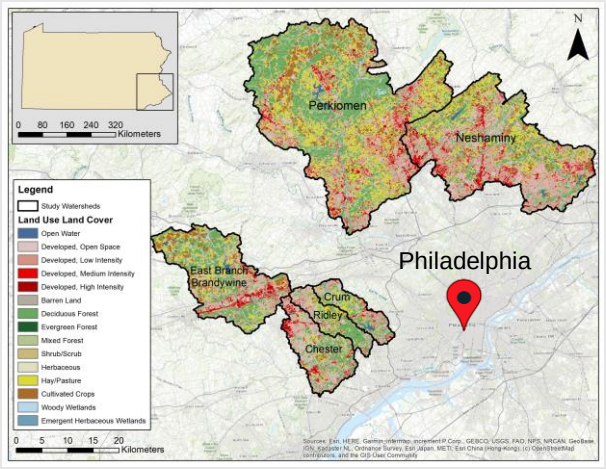
# Study Context



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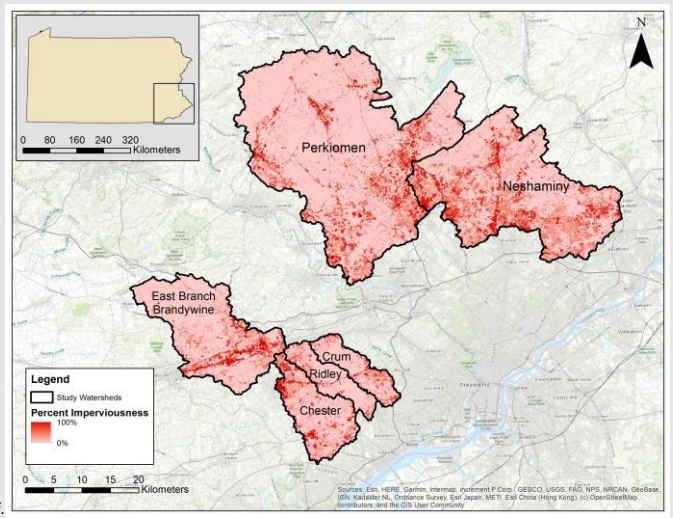
# Impervious Surface Cover Analysis

- Impervious Surface Cover
  - National Landcover Database
  - 30 m resolution data (2001, 2004, 2006, 2008, 2011, 2013, 2016, 2019)




Rossi et al., 2022; *Sci. Total Environ.*
Rossi et al., 2023; *Front. Environ. Sci.*

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# Streamwater Chemistry Analysis

- Water Chemistry
  - Long-term water utility sourced dataset for 6 suburban/exurban watersheds in Philadelphia metro region
  - Monthly measurements of ions from 1999-2019
- Stream Discharge
  - U.S. Geological Survey: National Water Information System
  - Daily mean discharge data

https://en.wikipedia.org/wiki/East_Branch_Brandywine_Creek#/media/File:East_Branch_Brandywine_Creek_north_of_Downingtown.jpeg

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# Streamwater Chemistry Analysis

- Flow-normalized ion concentrations
- WRTDS (Hirsch & De Cicco, 2015)
  - Weighted Regressions on Time, Discharge, and Season
  - Removes impact of yearly discharge variation
- EGRET package
  - Exploration and Graphics for RivEr Trends
- All statistical analyses conducted in R

https://bicyclecoalition.org/chester-creek-trail-opening-ceremony/

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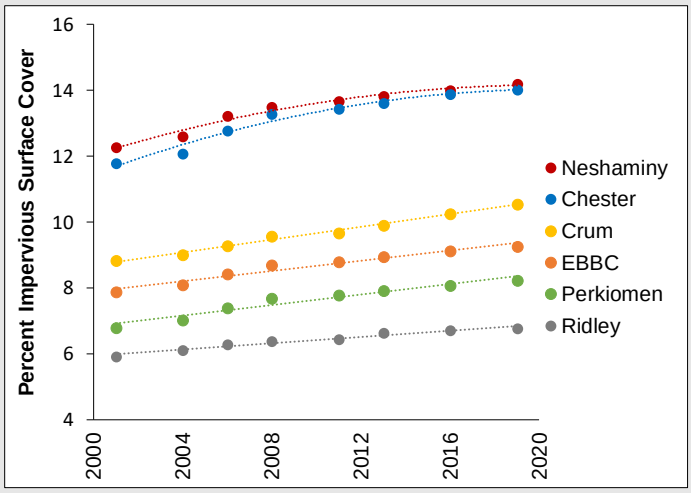
# Results: Impervious Surface Cover Change




| Watershed | Starting Value | Ending Value | % Change |
|---|---|---|---|
| Neshaminy | 12.3 | 14.2 | 1.92 |
| Chester | 11.8 | 14.0 | 2.25 |
| Crum | 8.84 | 10.6 | 1.71 |
| EBBC | 7.88 | 9.26 | 1.38 |
| Perkiomen | 6.79 | 8.23 | 1.44 |
| Ridley | 5.92 | 6.77 | 0.84 |

Rossi et al., 2022;
*Sci. Total Environ.*

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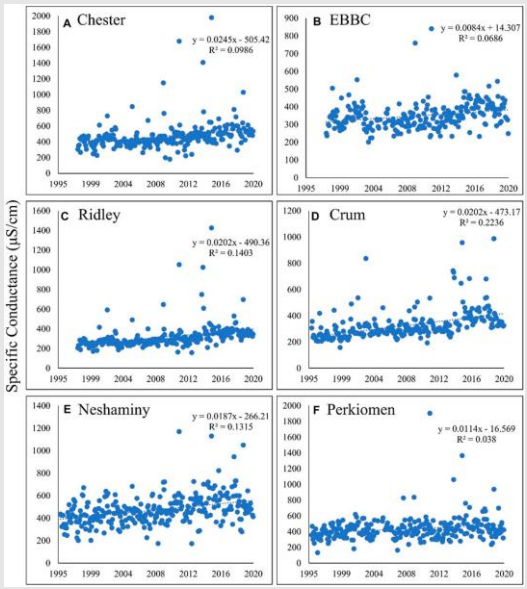
# Results: Increasing Salinity




- Specific Conductance
  - Measure of salinity
  - Calculated using PHREEQC and the reported ion concentrations
  - Increasing ~0.8 to 2.5% per year

Rossi et al., 2023;
*Front. Environ. Sci.*

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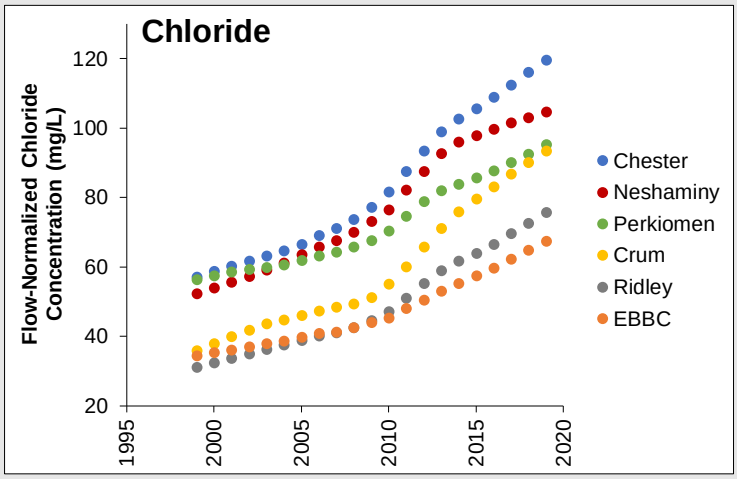
# Results: Flow-Normalized $Cl^-$ Concentrations




| Watershed | $R^2$ | Change (mg/L) |
|---|---|---|
| Chester | 0.97 | 62.6 |
| Neshaminy | 0.98 | 52.3 |
| Perkiomen | 0.95 | 38.9 |
| Crum | 0.94 | 57.5 |
| Ridley | 0.96 | 44.5 |
| EBBC | 0.96 | 33.1 |

Rossi et al., 2022;
*Sci. Total Environ.*

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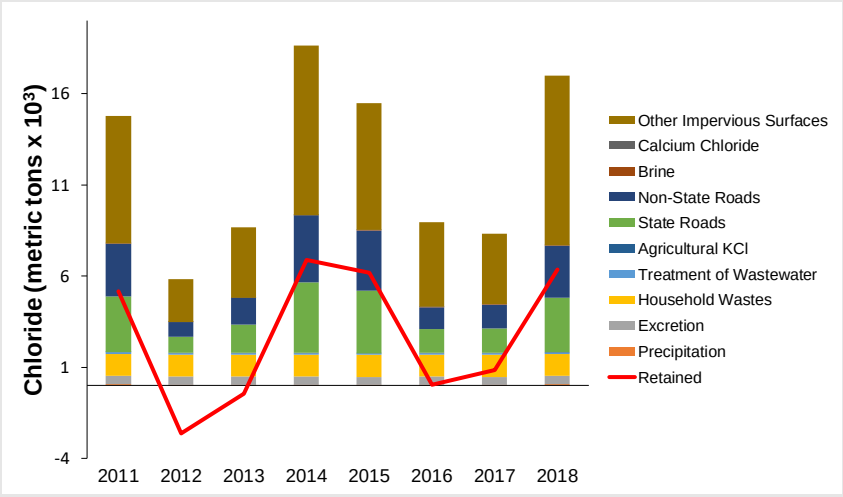
# Where Does All This $Cl^-$ Come From?




Chester Watershed

- Road salt accounts for majority of $Cl^-$ inputs
  - Roads & other impervious surfaces
- On average, ~30% of annual inputs are retained in shallow groundwater

Rossi et al., 2022;
*Sci. Total Environ.*

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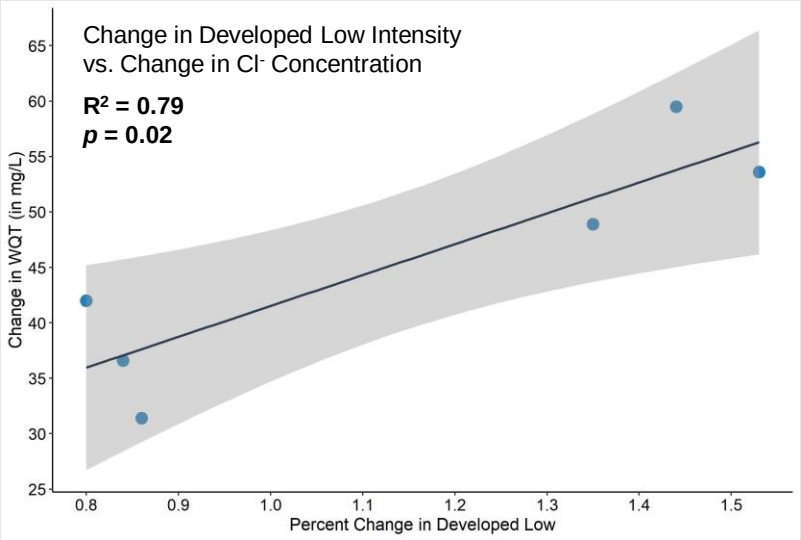
# Relationship Between $Cl^-$ and ISC




- Watersheds with greatest changes in low-intensity development:
  - Greatest changes in flow-normalized $Cl^-$ concentrations
- Watersheds with limited ISC can impact water quality
  - Impacts of exurban/suburban growth

Rossi et al., 2022; *Sci. Total Environ.*

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# Implications: Impacts to Freshwater Organisms

- Based on current trends:
  - Five of the six watersheds will exceed USEPA chronic threshold value (230 mg/L) by the end of the century
  - Winter concentrations exceeding earlier
- Impacts to benthic macroinvertebrates, amphibians, and fish

| Watershed | Annual | Winter |
|---|---|---|
| Chester | 2053 | 2037 |
| Neshaminy | 2063 | 2047 |
| Perkiomen | 2090 | 2058 |
| Crum | 2070 | 2052 |
| Ridley | 2088 | 2068 |
| East Branch Brandywine | 2120 | 2109 |

Rossi et al., 2022; *Sci. Total Environ.*

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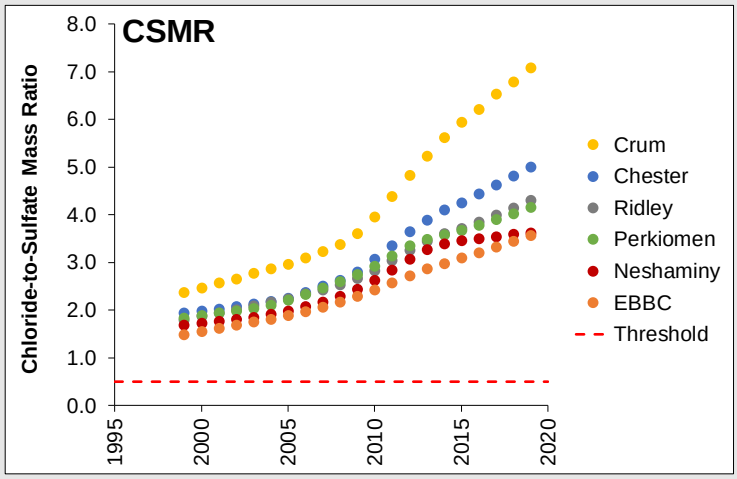
# Implications: Increased Corrosion Potential




- Chloride-to-Sulfate Mass Ratio (CSMR)

  $[Cl^-]/[SO_4^{2-}]$

- Increasing CSMR → increased corrosivity potential of pipes
- Threshold found to cause corrosion in pipes: 0.5

Rossi et al., 2023;
*Front. Environ. Sci.*

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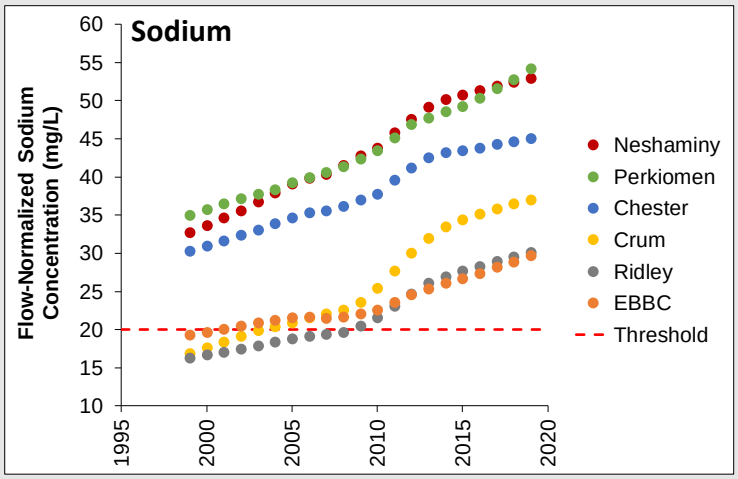
# Results: Flow-Normalized $Na^+$ Concentrations




- 20 mg/L = EPA recommended threshold for those following a low-sodium diet
- All streams exceeded threshold in 2019
- Concentrations likely increase during treatment process

Rossi et al., 2023;
*Front. Environ. Sci.*

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## Acknowledgements


- Aqua, Inc.
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## Questions?


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