

Occurrence of per- and polyfluoroalkyl substances in stormwater management pond sediment and relationship to land use.

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Maryland Department of the Environment: Leonard Schugam



UMBC

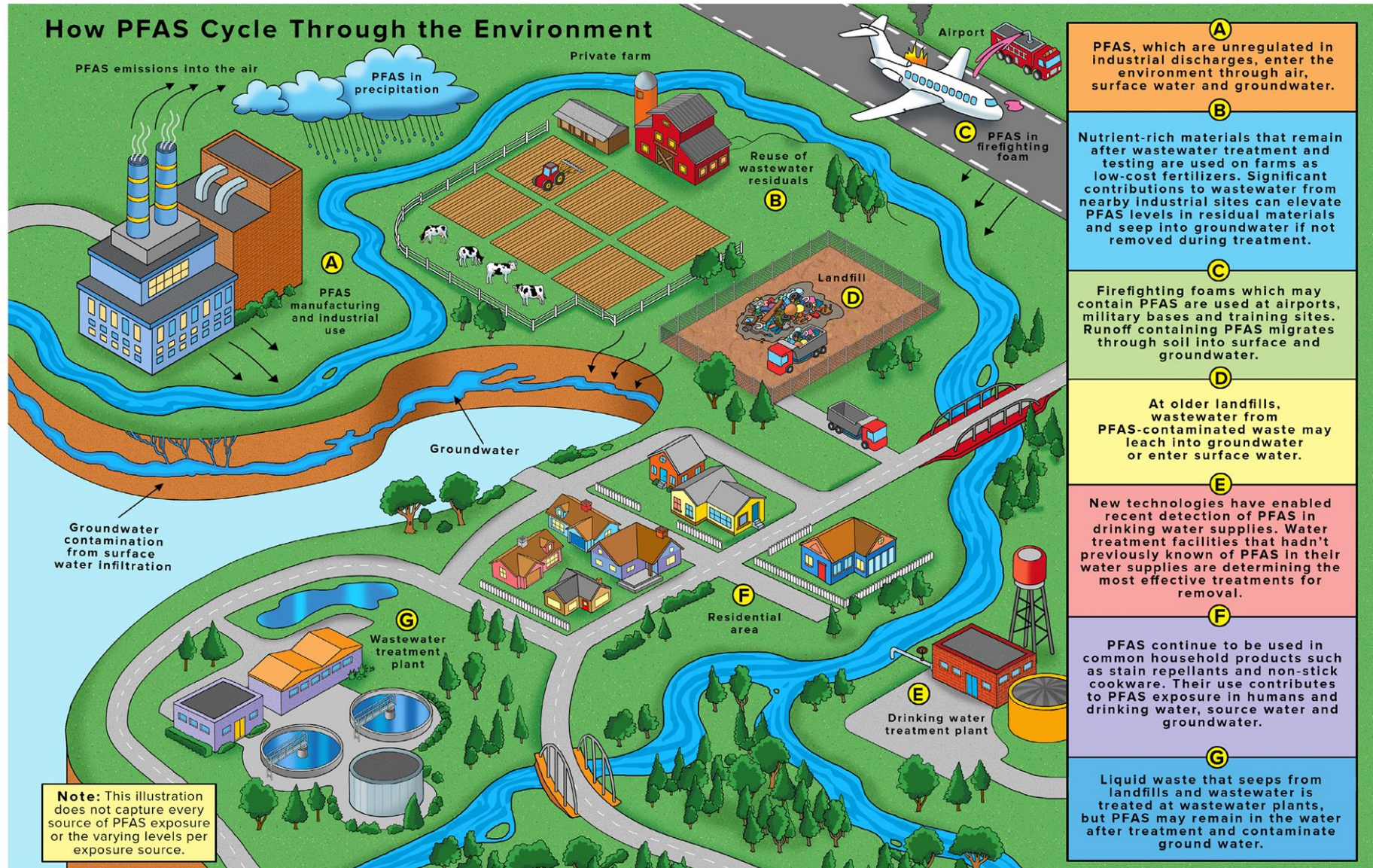


Maryland
Department of
the Environment

Where do you expect to find PFAS across the landscape?

What are the sources?

How PFAS Cycle Through the Environment



Note: This illustration does not capture every source of PFAS exposure or the varying levels per exposure source.

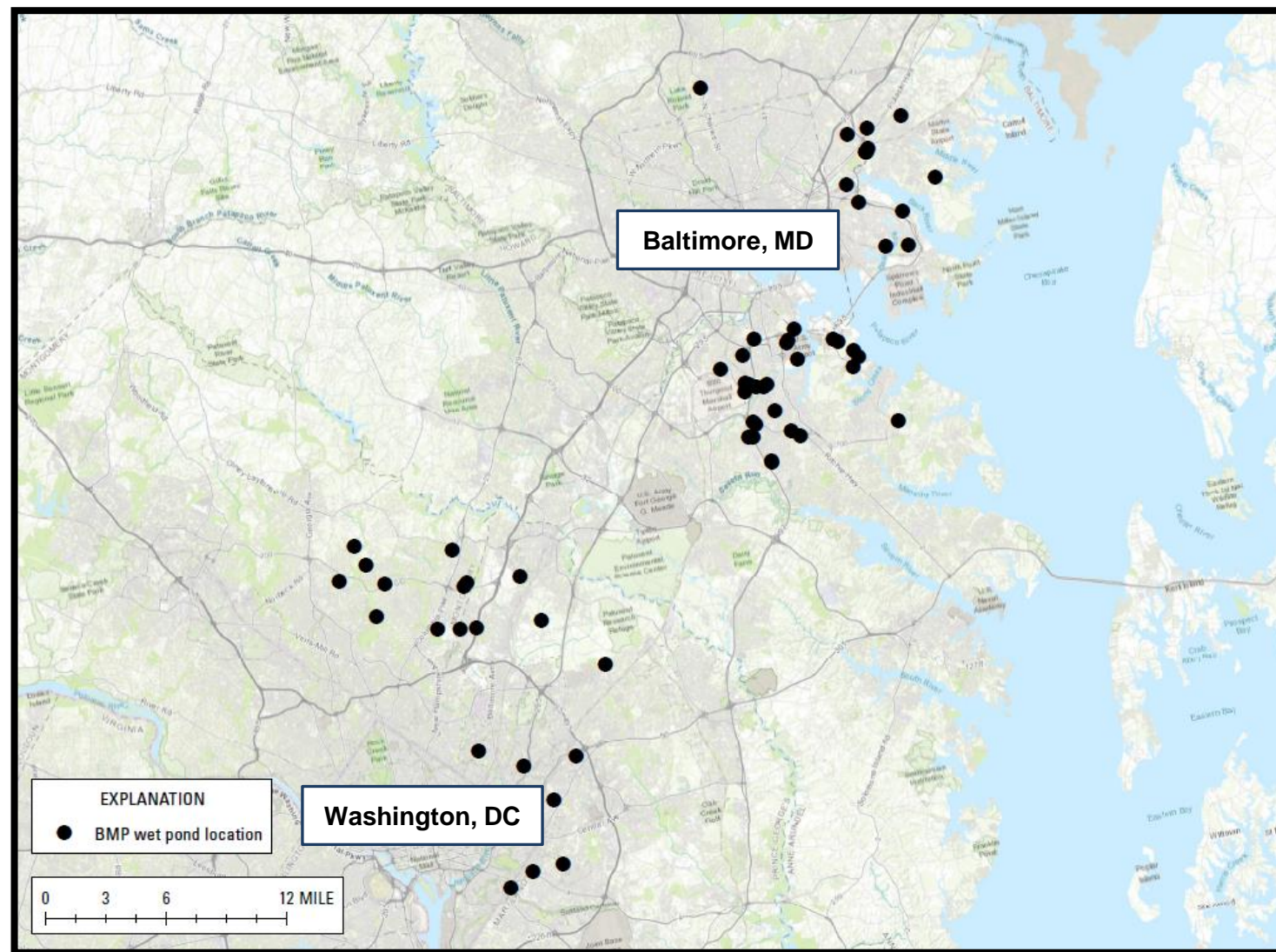
Wet Ponds

- Wet ponds are part of stormwater infrastructure best management practices (BMPs) to reduce inputs to receiving waterbodies
- Typically designed to reduce one or more impairments to water quality such as: sediment, nutrients, volume of stormwater, etc.
- Drainage areas for these ponds are relatively small (1-100 acres) with distinct land use within the drainage area.
- Functions like a sediment trap for studying mobilized contaminants in stormwater within the defined drainage
- Interest in potential co-benefits for contaminant capture
- Study selected wet ponds from three land use types: 22 residential sites, 17 commercial sites, and 24 industrial sites

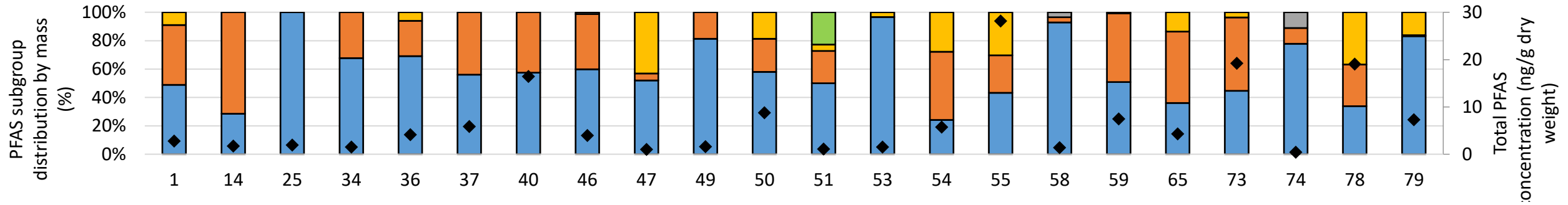


Study Area

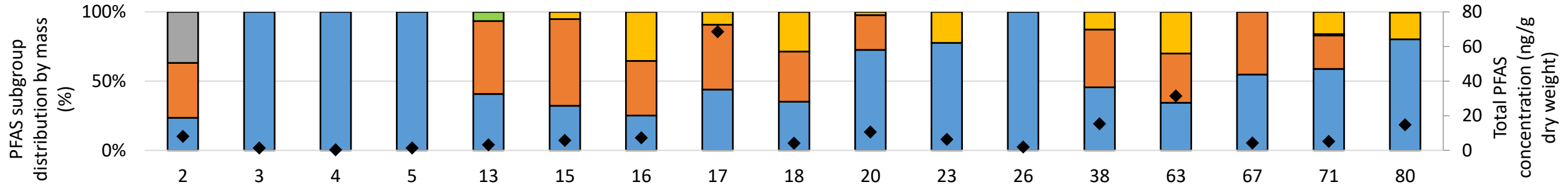
- Baltimore-Washington metropolitan area within the Chesapeake Bay Watershed
- The Patapsco River and Anacostia River are 2 sub watersheds with Federal Urban Water designation
- 63 sampling locations located in residential, commercial, and industrial land-uses



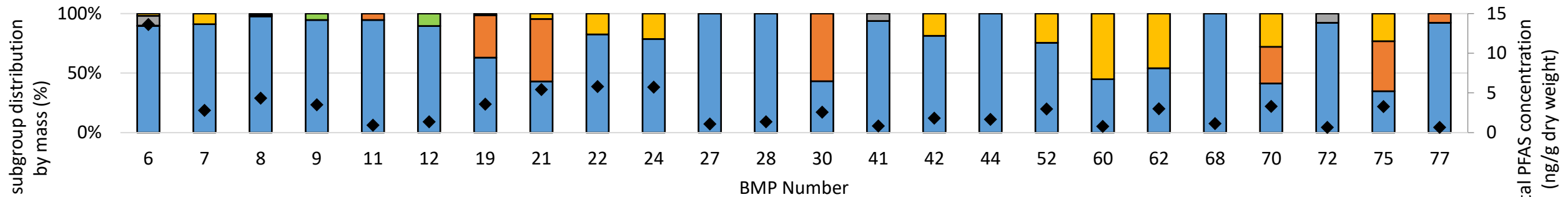
PFAS: Land use- Residential (by PFAS subgroups)



PFAS: Land use- Commercial (by PFAS subgroups)



PFAS: Land use- Industrial (by PFAS subgroups)



■ Total PFCAs
 ■ Total PFSAAs
 ■ Total FTSAAs
 ■ Total FASAAs
 ■ Total PFE
 ◆ Total PFAS

Preliminary Data-Not for Citation

Statistics for Select PFAS

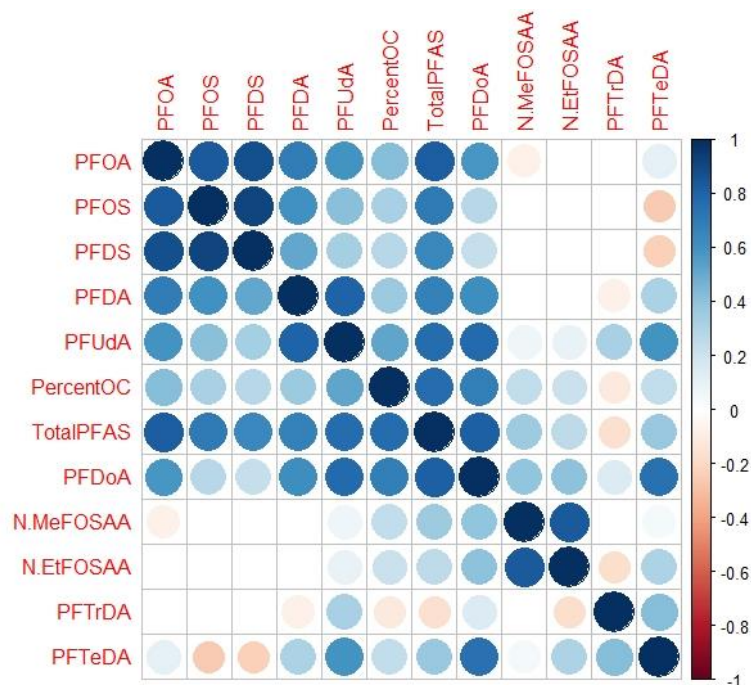
Name		Group	Structure	C Chain Length	Average	Stdev	Median	Max	Min	Number of Detects
Perfluoro-n-dodecanoic acid	PFDoA	PFCAs	LC	12	1.13	1.06	0.89	5.82	0.05	63
Perfluoro-n-tetradecanoic acid	PFTeDA	PFCAs	LC	14	0.51	0.63	0.25	2.99	0	56
Perfluoro-n-undecanoic acid	PFUdA	PFCAs	LC	11	0.58	0.78	0.25	4.03	0	49
Perfluoro-n-decanoic acid	PFDA	PFCAs	LC	10	0.44	0.75	0.05	3.88	0	48
N-ethyl perfluorooctanesulfonamidooacetic acid	N-EtFOSA A	FASAAS	LC	8	0.66	1.35	0	7.03	0	31
Perfluoro-1-octanesulfonate	PFOS	PFSAAs	LC	8	1.2	3.86	0	28.03	0	29
Perfluoro-n-tridecanoic acid	PFTrDA	PFCAs	LC	13	0.42	0.75	0	3.66	0	29
N-methyl perfluorooctanesulfonamidooacetic acid	N-MeFOSA A	FASAAs	LC	8	0.25	0.72	0	4.46	0	23

Frequency of detection was > 33% for wet ponds

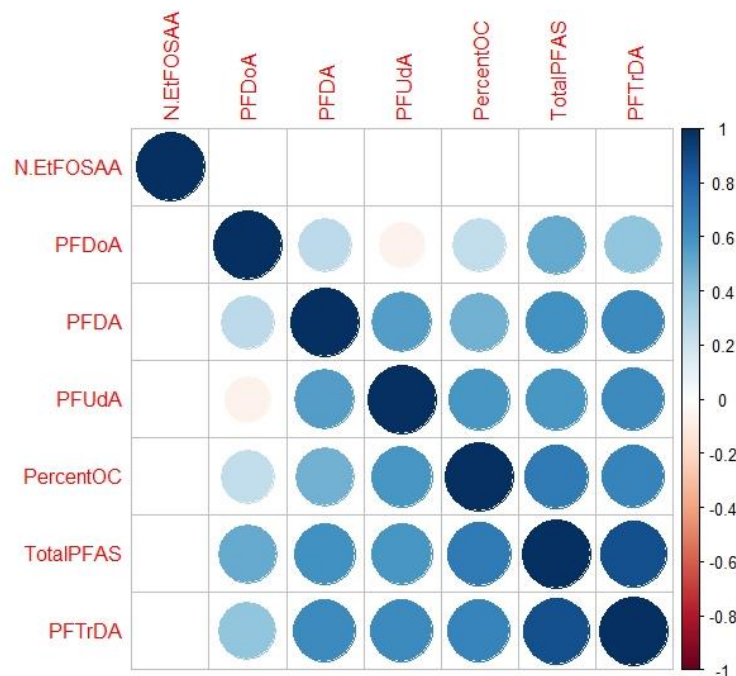
Preliminary Data-Not for Citation

Spearman correlation with hierarchical clustering

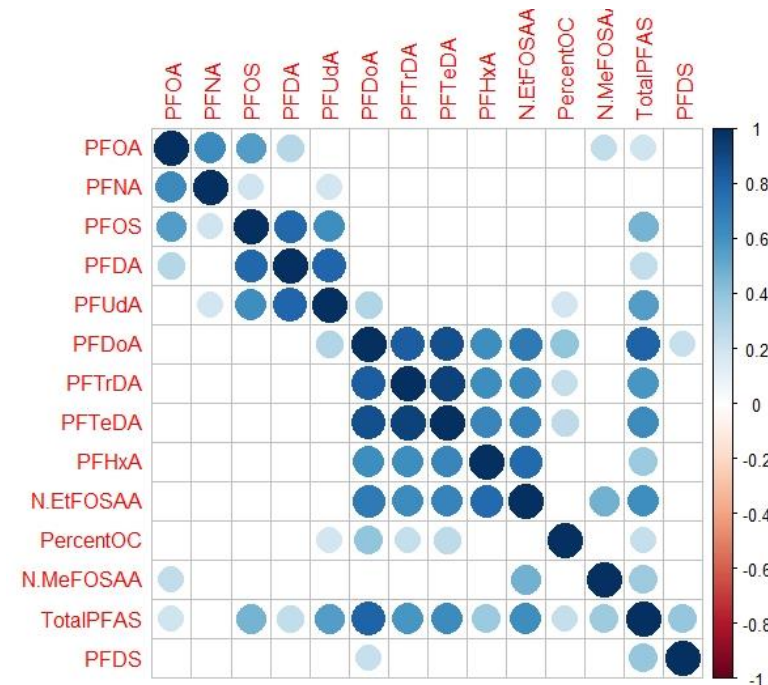
Commercial Land Use



Industrial Land Use



Residential Land Use

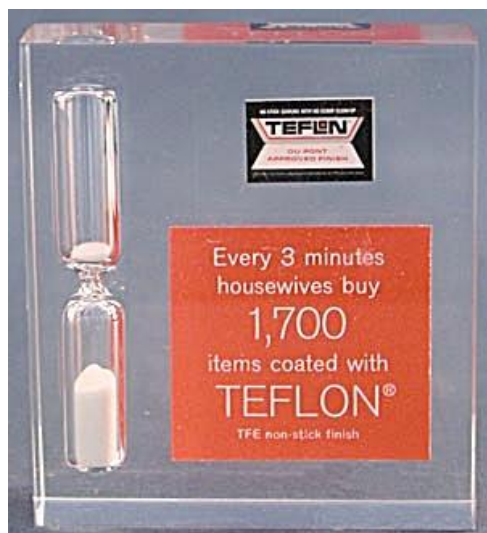


- Excluded non-statistical correlation ($p > 0.05$)
- Applied hierarchical clustering to find patterns using different sub-groupings

PFAS correlations with land use

- All Ponds had correlations between Total PFAS, % OC, PFTrDA, PFDoA, PFUdA, and PFDA.
- Commercial and Residential Ponds had additional correlations for PFOS, PFOA, PFDS, PFTeDA, and N-EtFOSAA.
- Commercial ponds had additional correlations for N-MeFOSAA and PFPeS.
- Suggests different source materials in commercial and residential land use.
- Organic carbon (%OC) was a significant factor in all ponds
- Long chain, more hydrophobic PFAS compounds more common and correlated better with % OC
- Dominant PFAS differ by land use

What are the sources?



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the super-scorch-resistance that keeps this cover new-looking for years and years! And check these other super features: super-sized, to fit over the largest ironing boards; super-smooth fit, thanks to its drawstring closure; super-porous for quick moisture evaporation; and super-stain-resistance that wipes clean with a damp cloth! Make your ironing chore easier with a guaranteed MAGLA ironing board cover coated with TEFLON!

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*Registered trademark for DUPONT fluorocarbon resins



<https://www.tias.com/vintage-teflon-acrylic-advertising-with-egg-timer-390281.html> (tias.com),

Accessed on 9/14/2022

https://en.wikipedia.org/wiki/Firefighting_foam

https://www.scotchgard.com/3M/en_US/scotchgard/

<https://www.fishersci.com/shop/products/economy-certified-glass-voa-vials-0-125in-septa/12100107>

<https://ecofriendlylink.com/blog/toxic-fast-food-packaging/>

<https://www.northcountrypublicradio.org/news/story/32092/20160623/new-york-searches-statewide-for-industrial-chemical-in-water>

industrial-chemical-in-water

Current and Future Tools

- Replicate this approach to better develop predictions for PFAS occurrence and stormwater sediment load
- As part of this study we found ponds built before 1980 were 2.25 times ($p < 0.001$) more likely to contain sediment concentrations above the TMDL goal for PCBs

Research and Management Priorities

- Need to expand the matrixes we are sampling to better understand how PFAS is moving in stormwater
 - Most work is focused on water
 - Additional transport occurring with sediment and possibly foam
- Standardization of methods and a consolidated repository of results
 - Adopting a model like the Delaware River Basin Commission for PBCs

Project Collaborators and Laboratories

- Maryland Department of the Environment (MDE)
 - Selected wet ponds, did land use analysis
 - Collected initial sediment composite and provided access
 - PCB analysis, % Organic Carbon, % Fines
- University of Maryland Baltimore County
 - Dr. Lee Blaney and Dr. Ke He, PFAS analysis and investigators
- USGS
 - Dr. Denise Akob, Microbial Analysis (Reston Microbiology Lab) and investigator
 - Inorganic analysis (Denver, CO)

Discussion and Questions

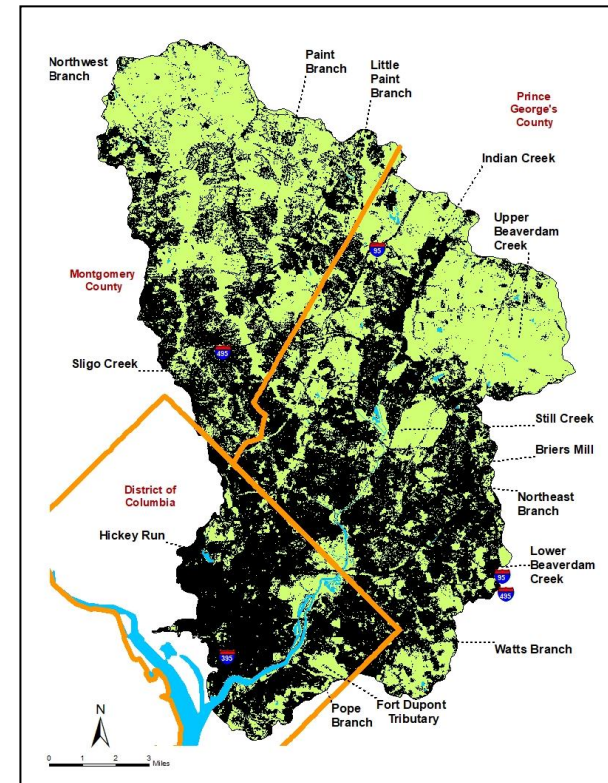
tneedham@usgs.gov

Anacostia Watershed Plastic Pollution



The Anacostia Watershed

- 176 Square Miles
- Prince George's County (48%)
- Montgomery County (35%)
- District of Columbia (17%)
- Highly urbanized
- 2010 Trash TMDL
- Count and Pick Monitoring Surveys



COG TRASH ITEMS/CATEGORIES

1. Plastic Bags: Typical “carryout” items include plastic grocery bags and shopping bags. Typical “other” items include garbage bags, newspaper sleeves, sheet stretch wrap, mulch bags and the shreds or parts of torn bags.

2. Plastic Bottles: Typical items include plastic containers of any size, used to store liquids. Exceptions include auto products containers such as oil quart, antifreeze, car wax containers, etc. They are recorded in a separate category.

3. Food Wrappers: Typical food items that comes packaged such as potato chip bags, candy wrappers, juice pouches, etc. Recent biodegradable “take-out” containers are included.

4. Aluminum Cans: Typical items include aluminum containers of any size, typically used to store liquids.

5. Polystyrene foam: (Extruded and expanded polystyrene cups, packaging, etc.): Extruded polystyrene foam (other) are typically thermal insulation sheets and expanded polystyrene foam are typically coffee cups, coolers, or cushioning material in packaging made expanded polystyrene beads.

6. Paper: Typical items include newspaper, napkins, receipts, coated paper cups and plates, etc.

7. Cardboard: Typical items include corrugated thick sheets of paper.

8. Textile/Clothing/Carpeting: Typical items include shirts, pants, socks, hats, shoes, purses, backpacks, wallets, umbrellas and carpet and pads. Recent “wet-wipe” towelettes are included in this category.

9. Glass Bottles: Typical items include glass containers of any size, typically used to store liquids.

10. Auto: Products Containers- Typical items include bottles, cans, tubes, and other containers that held products used in the care and maintenance of an automobile. Items include oil and antifreeze containers, engine fluid bottles, washer fluid bottles, car wax or polish containers, etc. Vehicle body parts - Anything that was once part of an automobile separated out to large (items greater than 1 square foot) and small (items less than 1 square foot).

11. Automotive/Car batteries: Items include small 6 volt to more typical 12 to 24 volt batteries.

12. Automotive/Car: Items include various sized vehicle tires.

13. Construction Debris: Typical items that were used in the construction or deconstruction of something and include bricks, lumber, concrete, drywall, vinyl tile, siding, or roofing material, and tools.

14. Appliances: Typical items include bicycles, strollers, scooters, lawnmowers, furniture, and appliances such as washing machines, refrigerators, radiators, etc.

15. Wooden Pallets: Typical item include whole or part of wooden pallets.

16. Metal (drums, cans, pipes and foil): Typical items include small and large non-aluminum food or drink containers. It also includes aluminum foil and metal drums, posts and pipes.

17. Shopping Carts: Typical item include various metal and plastic shopping carts.

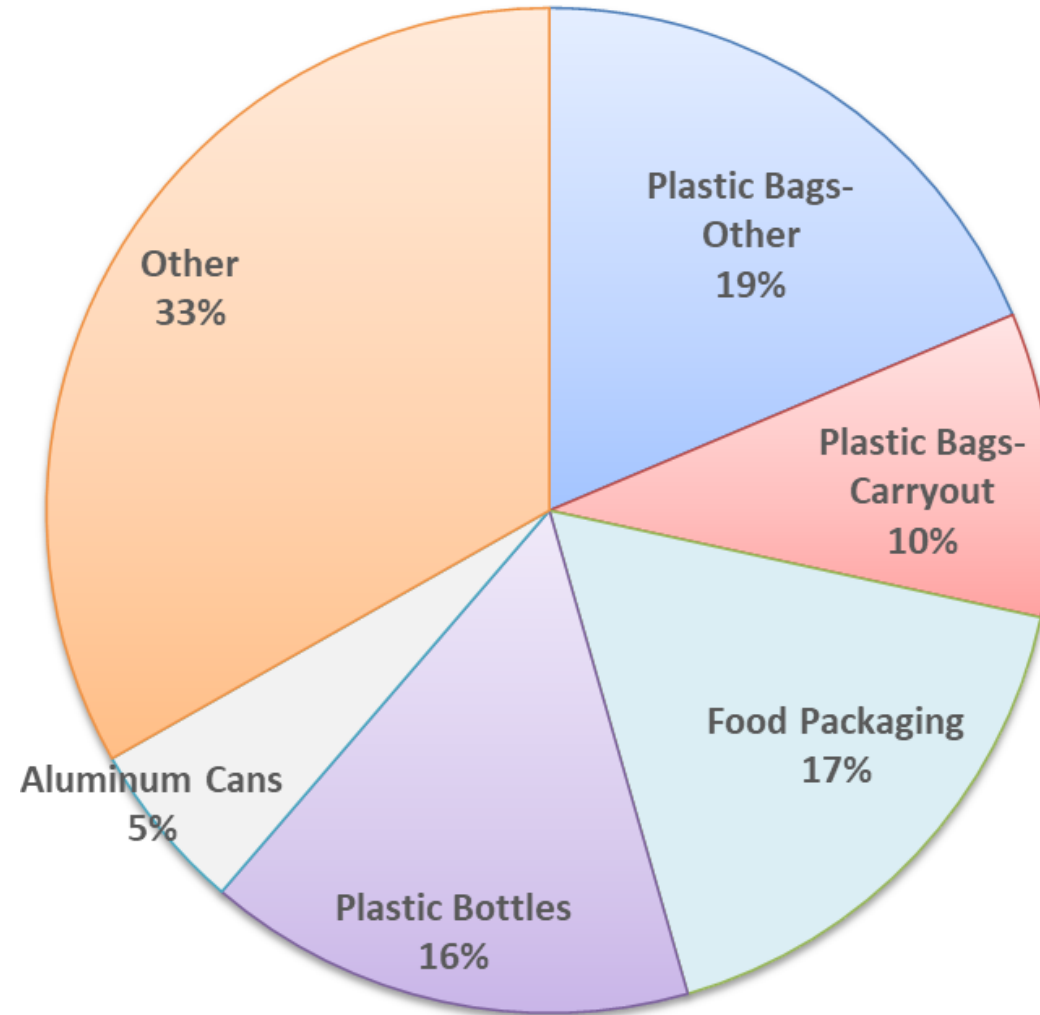
18. Toiletries/Drug Containers: Typical items include personal care products and their packaging and prescription and over-the-counter drug container and packaging and hypodermic syringes.

19. Sport Equipment/Toys: Typical items include all types and sizes of recreational balls and any toy or discernible part of a toy larger than 1 inch.

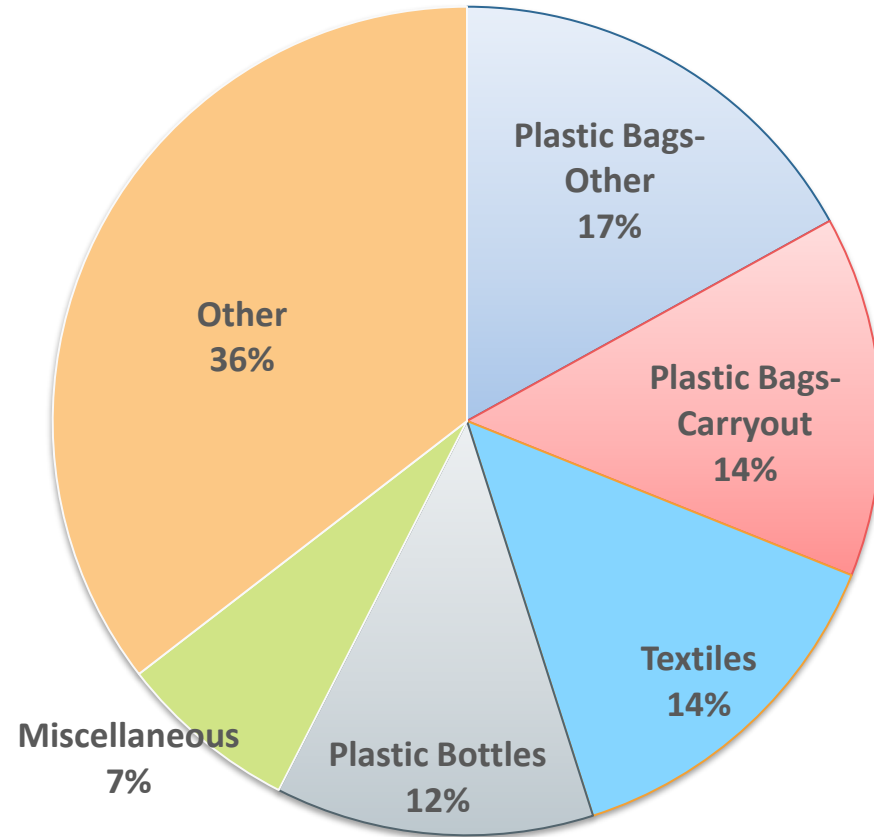
20. Miscellaneous: Items that do not fit in any other category or are not identifiable.



Top Trash Items by Count



Top Trash Items by Weight





Plastics



Metropolitan Washington
Council of Governments

Expanded Polystyrene Foam



What is Microplastic?

- **Small plastic fragments, film, fibers, pellets, granules, beads, etc.**
- **Size - upper limit ~ 5 millimeter (mm) down to 1 micrometer (μm)**



Photo of sample collected by Yonkos et al. (2014)

- **Primary Microplastics** – manufactured products used in:
 - -Facial cleansers and cosmetics (microbeads)
 - -As air-blasting media for removing rust (often contaminated with heavy metals, e.g., cadmium, chromium, lead)
 - -Virgin plastic production pellets –Pellets are convenient to ship and are eventually melted down and molded into manufactured products
- **Secondary Microplastics** – pieces that have broken off larger plastic objects pieces that have broken off larger plastic objects through physical, biological, or chemical processes



Microplastics in the Chesapeake Bay

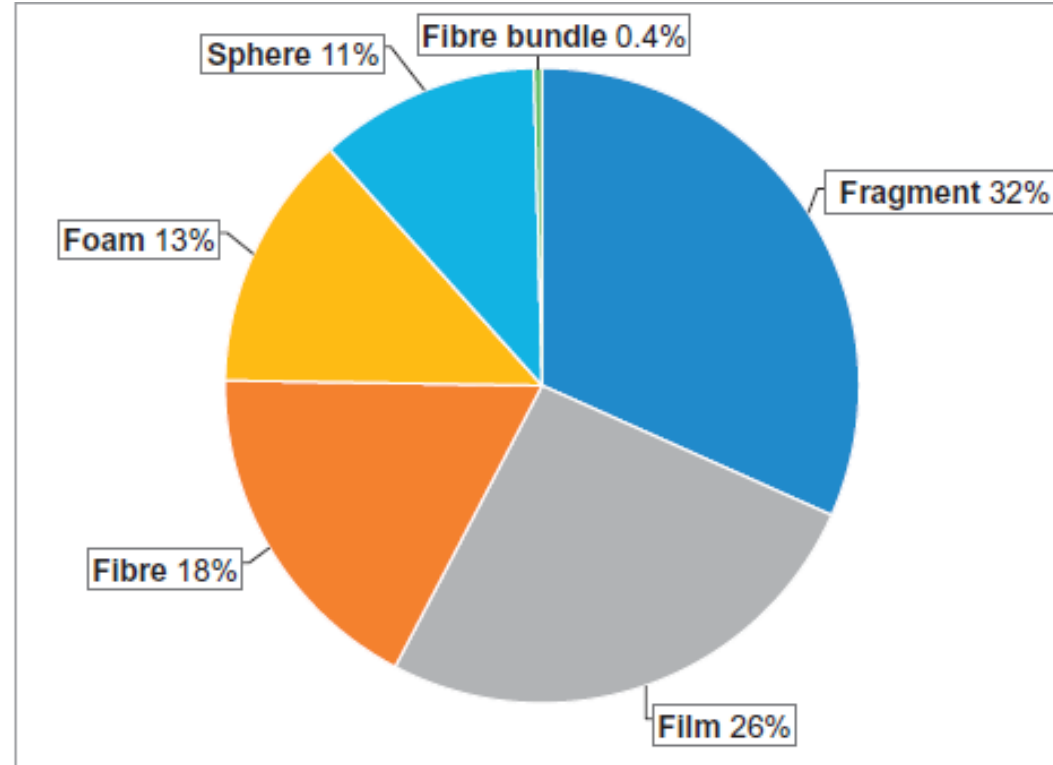
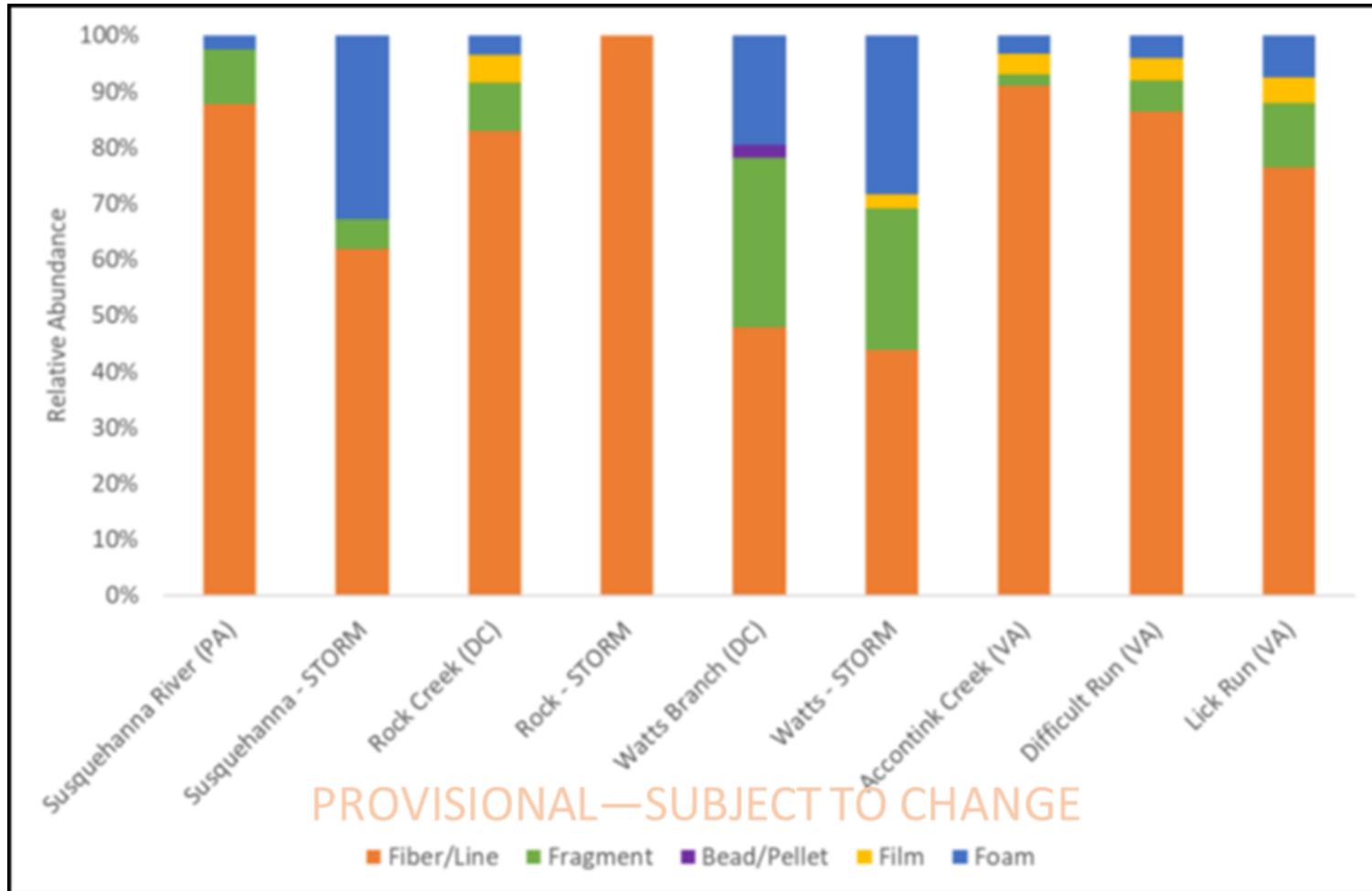


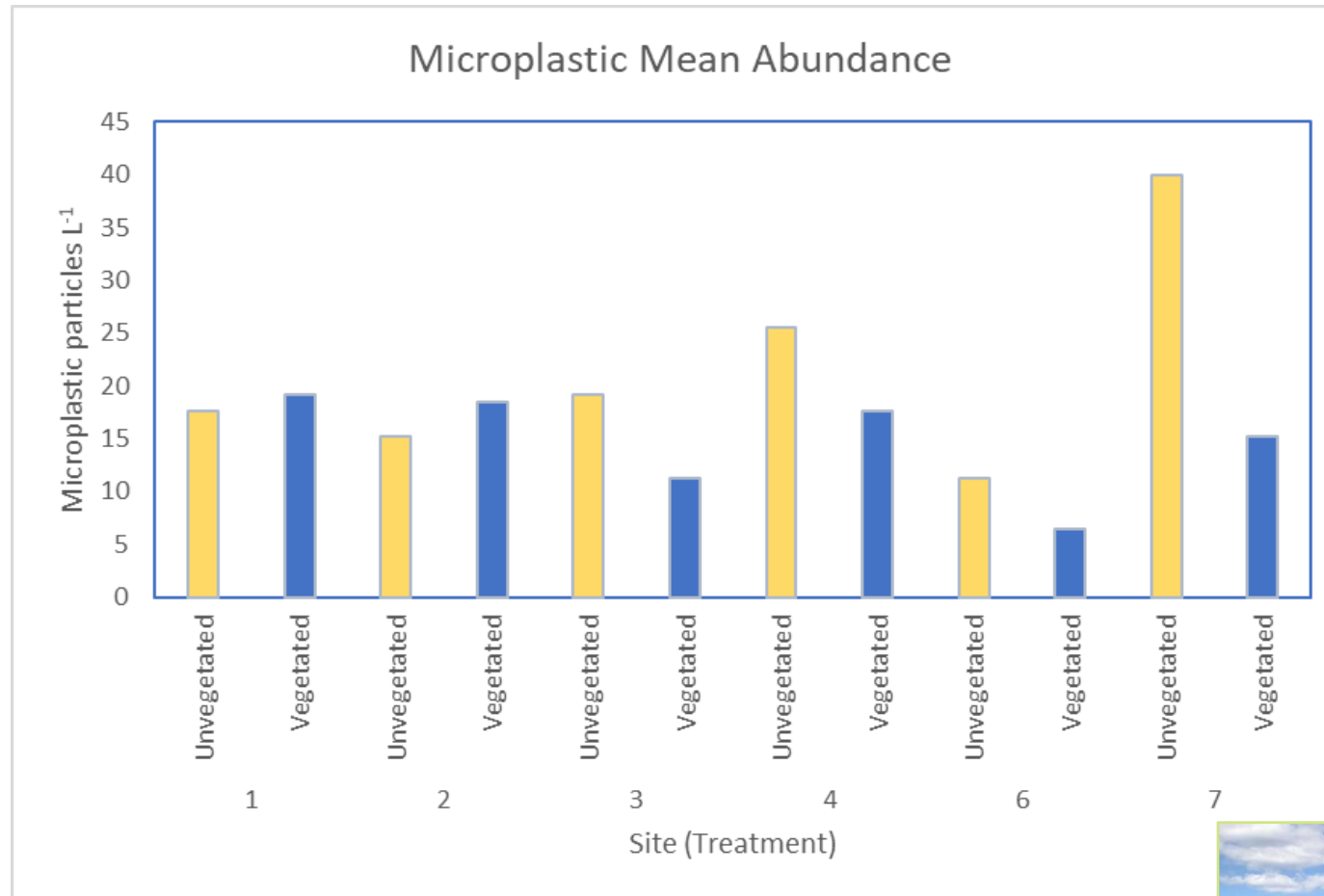
Fig. 3. Morphology of particles from thirty surface water samples (after blank correction) in the Chesapeake Bay.

Bikker, Lawson, Wilson and Rochman, 2020



Relative abundance of different types of microplastic particles found by USGS from 2017 - 2018 at five nontidal sites in the Chesapeake Bay watershed (USGS 2019)

Anacostia 2019 SAV Areas



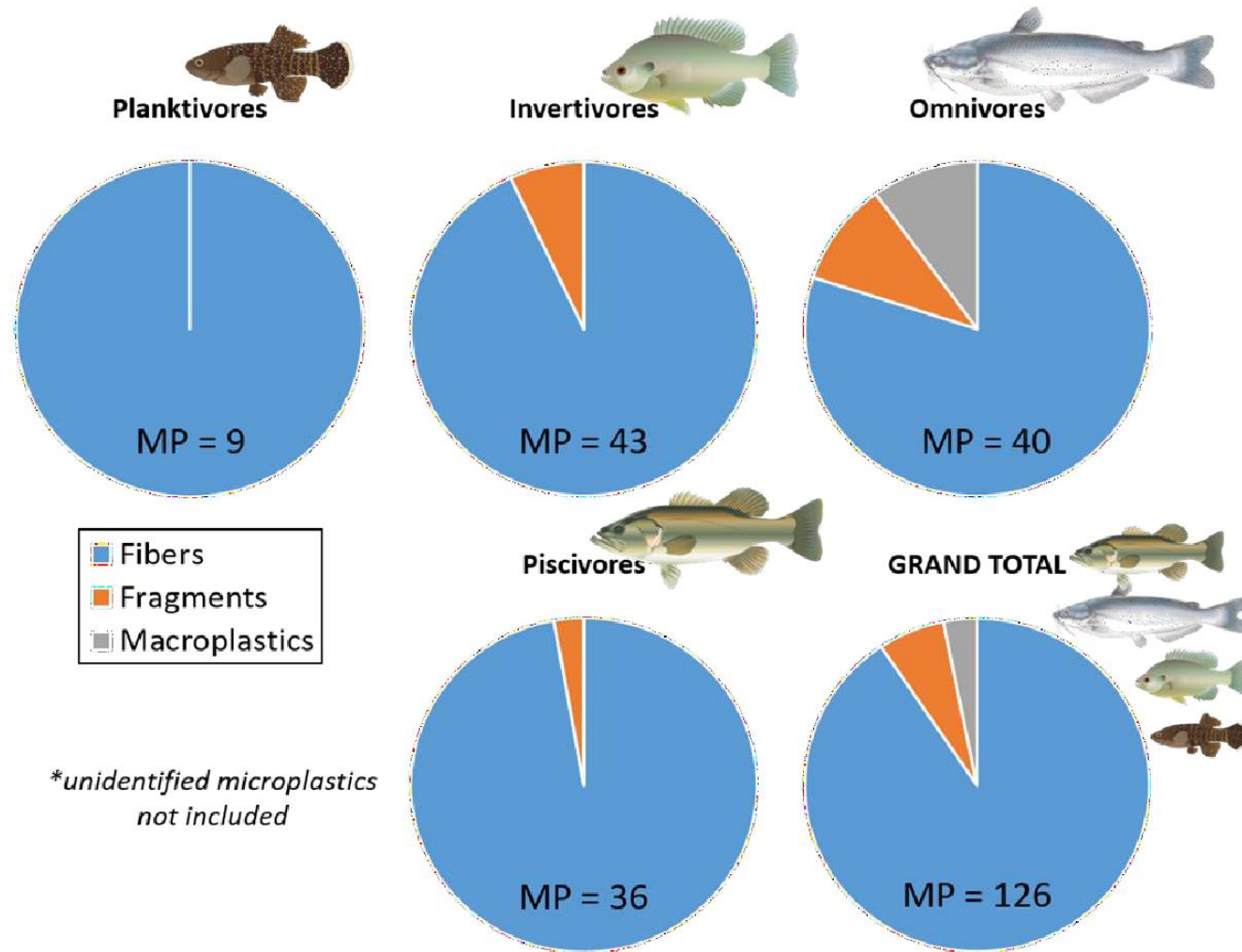
Microplastic abundance Anacostia River SAV areas (Tetra Tech, 2019)



Metropolitan Washington
Council of Governments



Microplastic Across Trophic Levels: Fish



Microplastic In Potomac and Anacostia River Fish (Tetra Tech, 2022)

Plastic Pollution Action Team (PPAT) Tasks

01

Develop an ecological risk assessment (ERA) conceptual model looking at the effects of microplastics on various ecological endpoints in the Potomac River.

02

Compile the best available science to develop a preliminary ERA using the EPA framework. A gap analysis will be conducted to identify needs for future study.

03

Develop uniform size classification and concentration unit terminology that can be adopted for future microplastic research in the Potomac River, and possibly elsewhere in the Mid-Atlantic Region.



Beyond Nutrients: Chloride & deicing salts



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2023 Bay-wide Stormwater Partners Retreat

Apr 13, 2023

Funding



Maryland Water Resources
Research Center

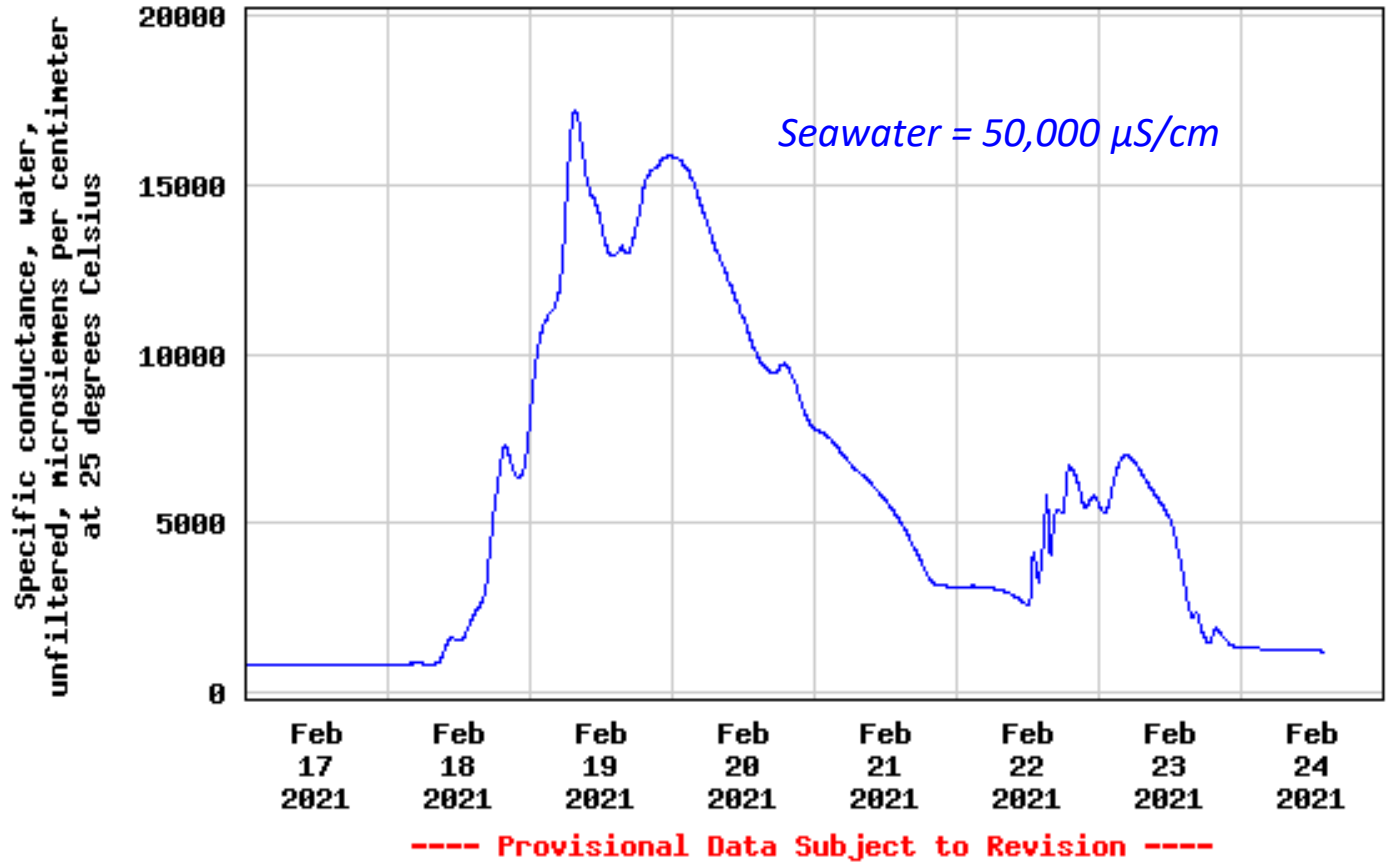
MD-DE-DC Water Science Center



Urban Critical Zone Cluster
2012313



USGS 01589290 SCOTTS LEVEL BRANCH AT ROCKDALE, MD



Definitions

- Why deice? Public safety
- Question is how to adjust practices & approaches to mitigate negatives for drinking water, infrastructure, & ecology
- Deicing salts: **NaCl** (most common), CaCl_2 , MgCl_2
 - Tradeoffs of cost and terrestrial versus aquatic
 - Once applied, virtually no way to remove from watersheds except via streamflow



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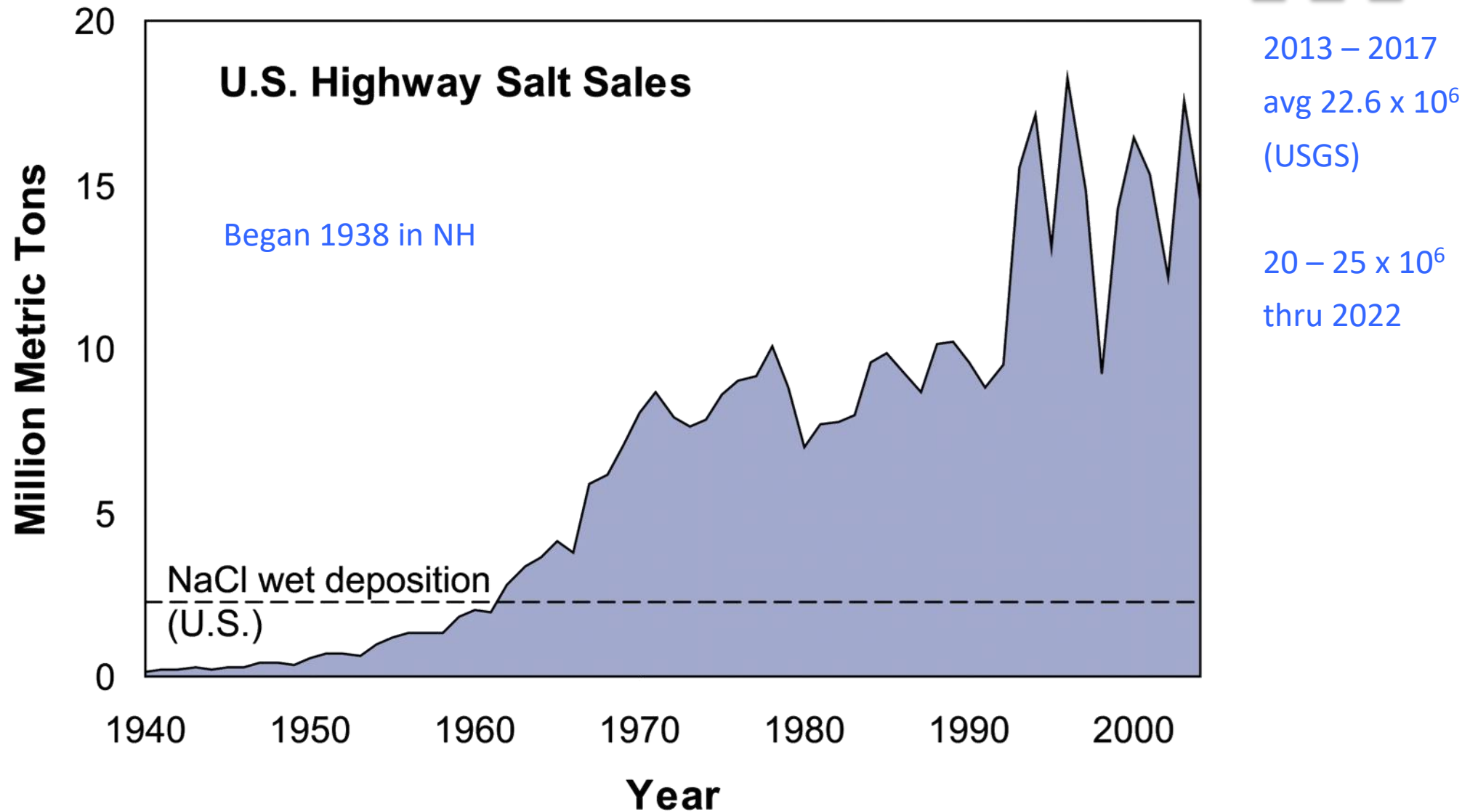


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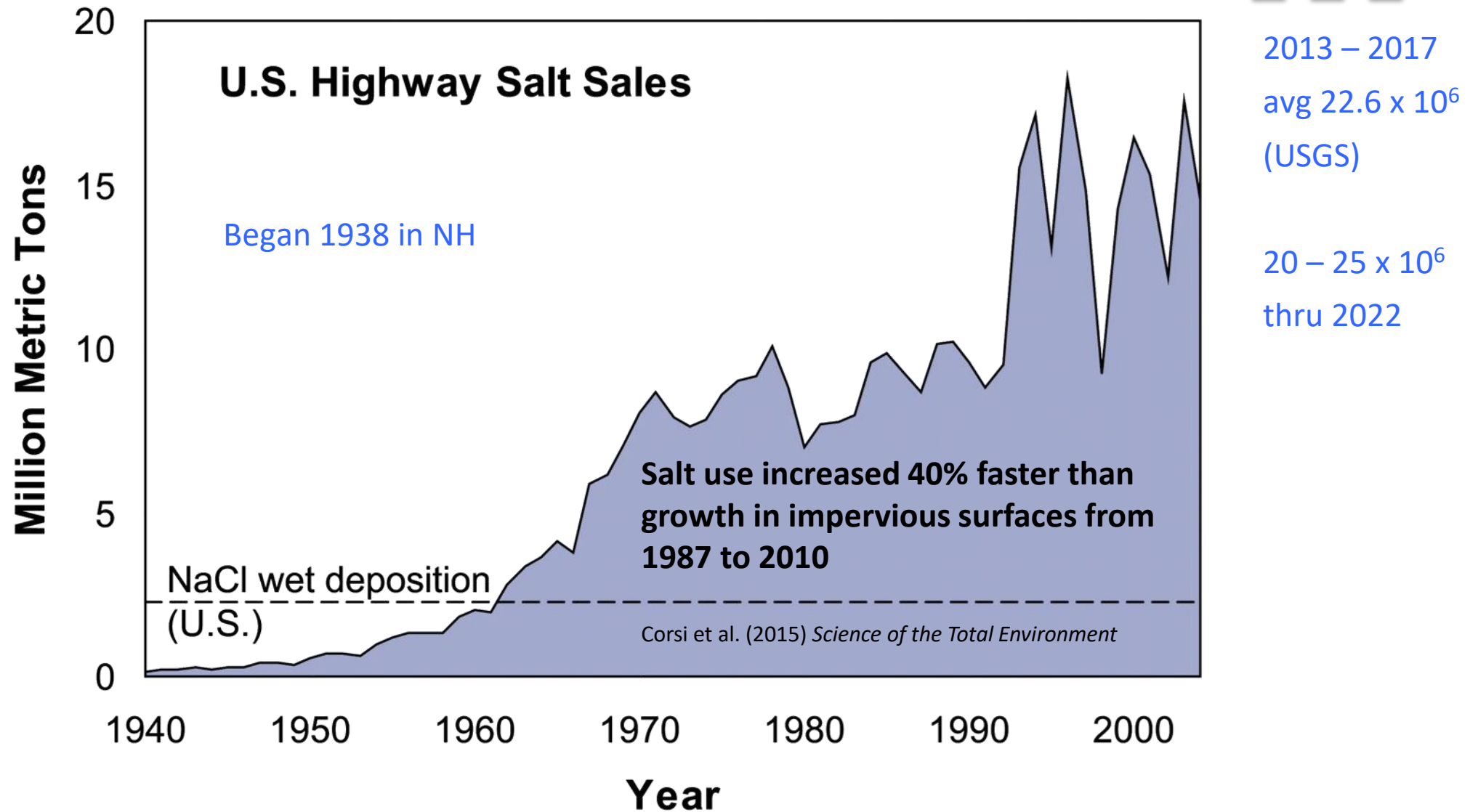
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- Relevant guidelines / regulations
 - US EPA (1988): *chronic (4 days)* **230 mg/L** *acute (1 hour)* **860 mg/L**
 - Canada (2011): *chronic*: 120 mg/L *acute*: 640 mg/L



The problem: Deicing salt use continues to increase



The problem: Deicing salt use continues to increase (more practices than roads)



Deicing salt use negatively affects water quality: **Aquatic life**

Direct: Cl toxicity

Indirect: elevated SpC (likely osmotic stress)



Effects are greater in watersheds with naturally low SpC (common in MD & across Chesapeake)

- MD has identified Cl as contributing to impairment of 27 watersheds

Some species like mayflies particularly vulnerable



Deicing salt use negatively affects water quality: **Drinking water**

Pipes & other infrastructure:
Increased corrosivity with
higher Cl (e.g., Flint,
Michigan)



Deicing salt use negatively affects water quality: **Drinking water**

Pipes & other infrastructure:
Increased corrosivity with
higher Cl (e.g., Flint,
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Human health:

Elevated Na

*Increased formation of
disinfection by-products*



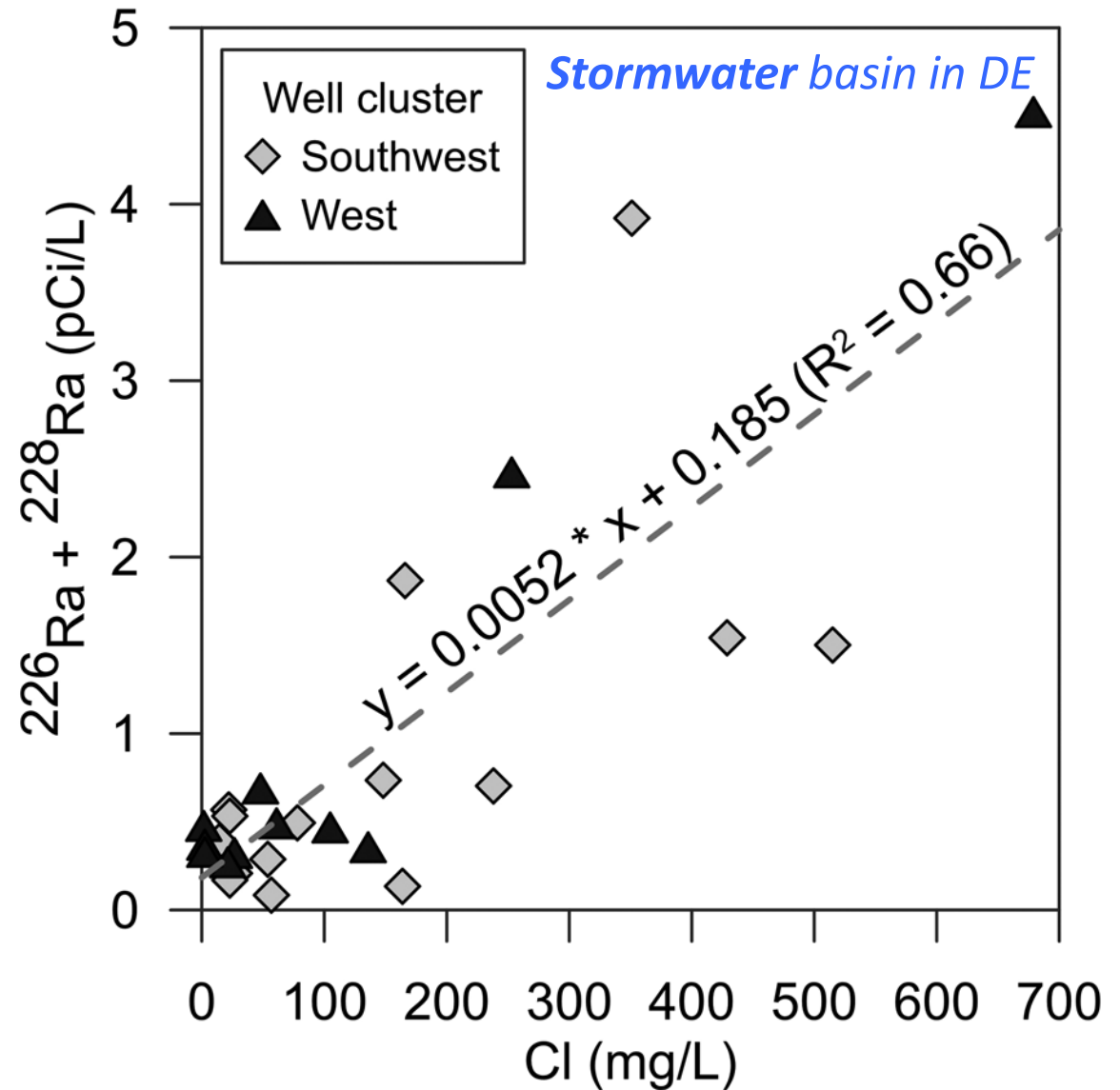
Deicing salt use negatively affects water quality: **Nutrients & metals**

Evidence that nitrogen & organic matter are mobilized from sediments and **stormwater** basins, e.g., Kaushal group

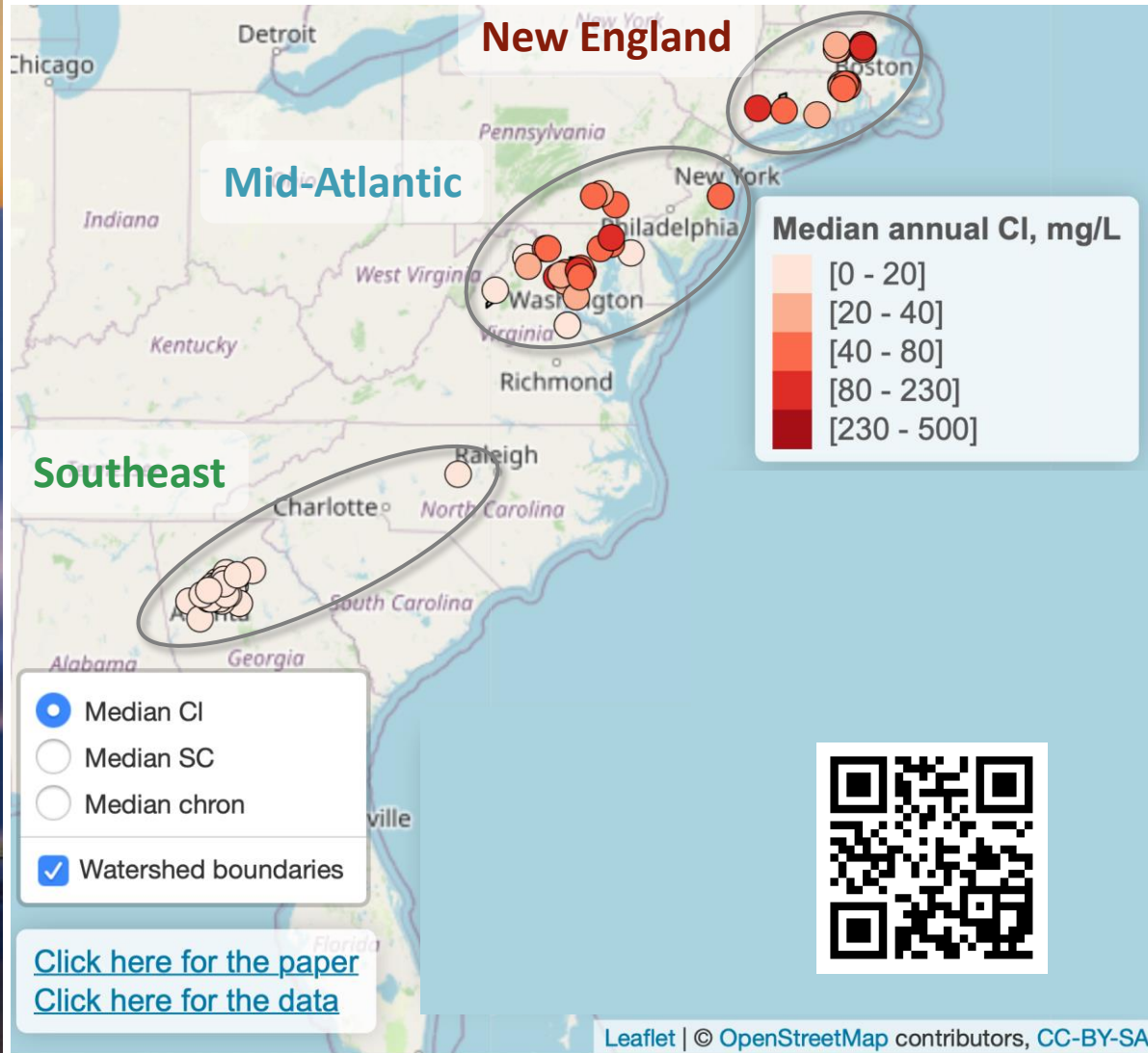
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Metals, including radionuclides are mobilized

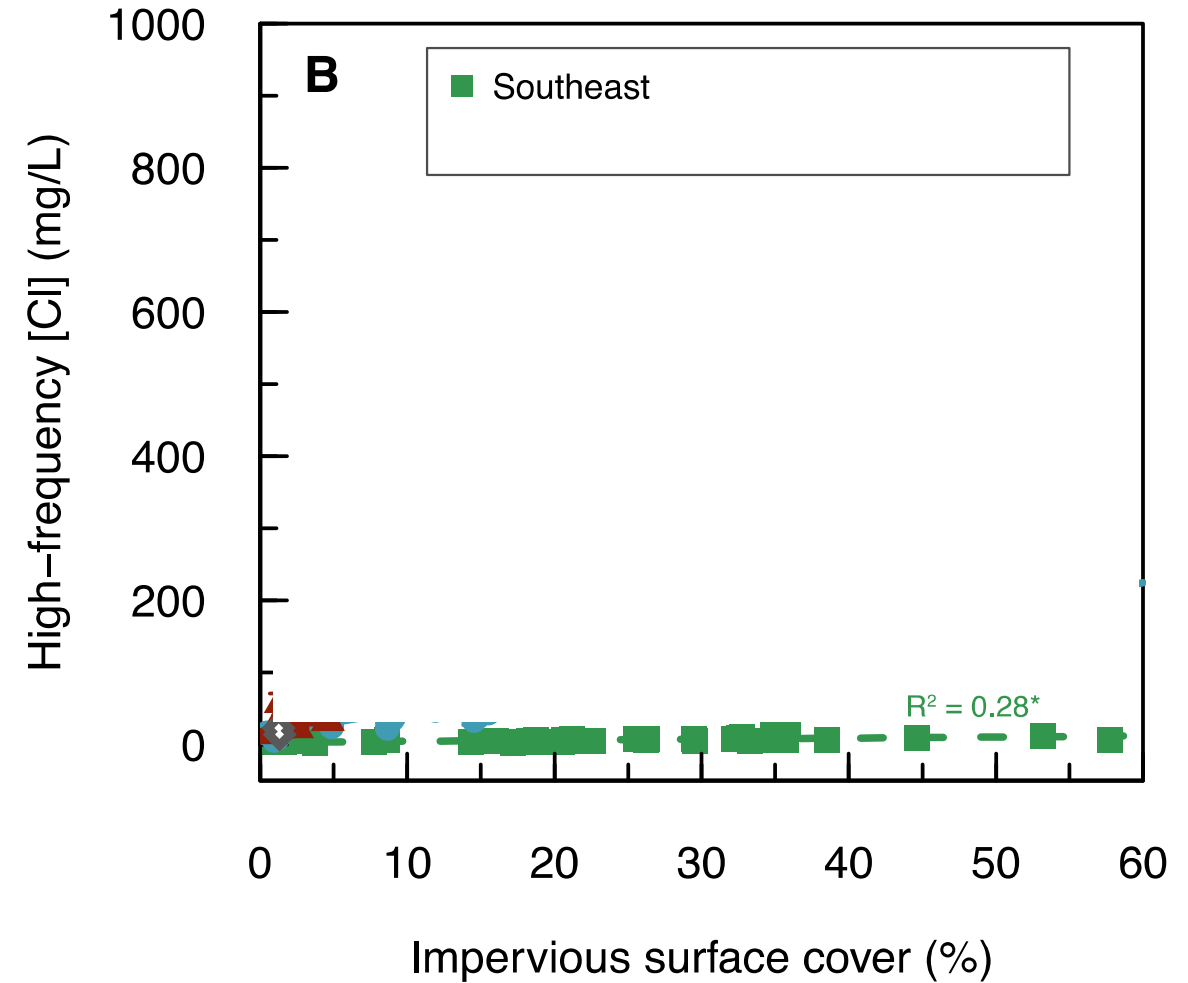
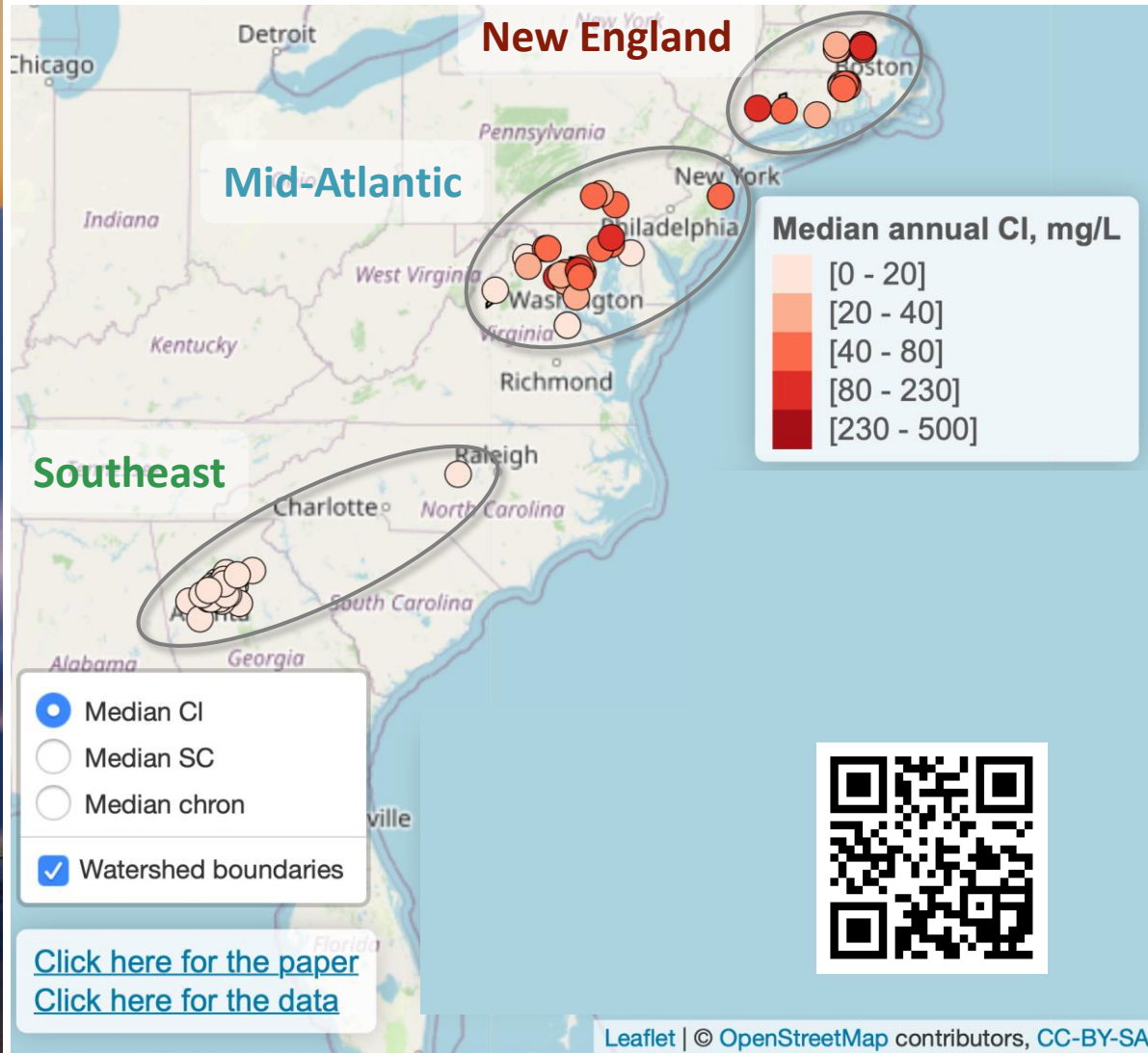


Chloride increases from south to north



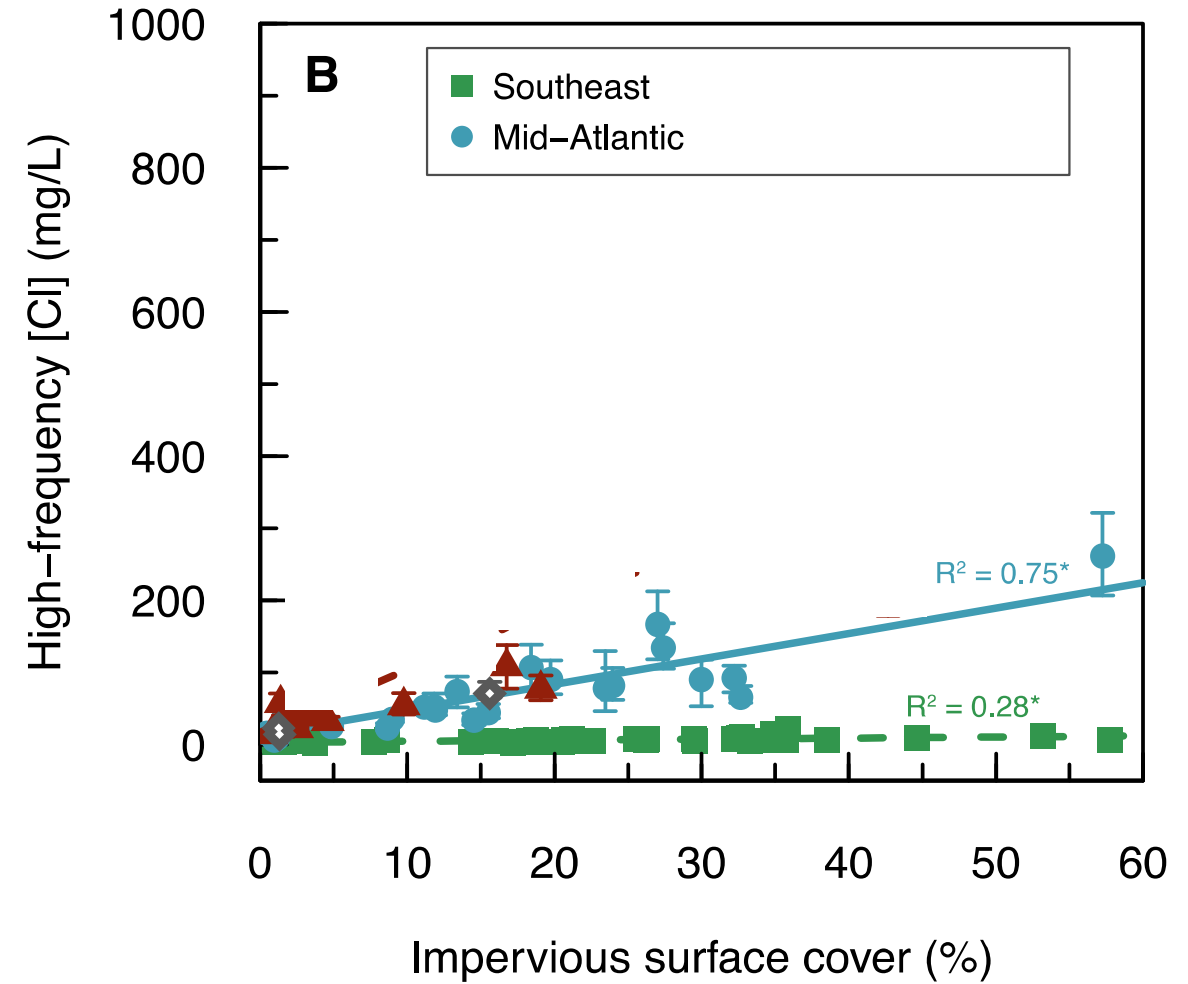
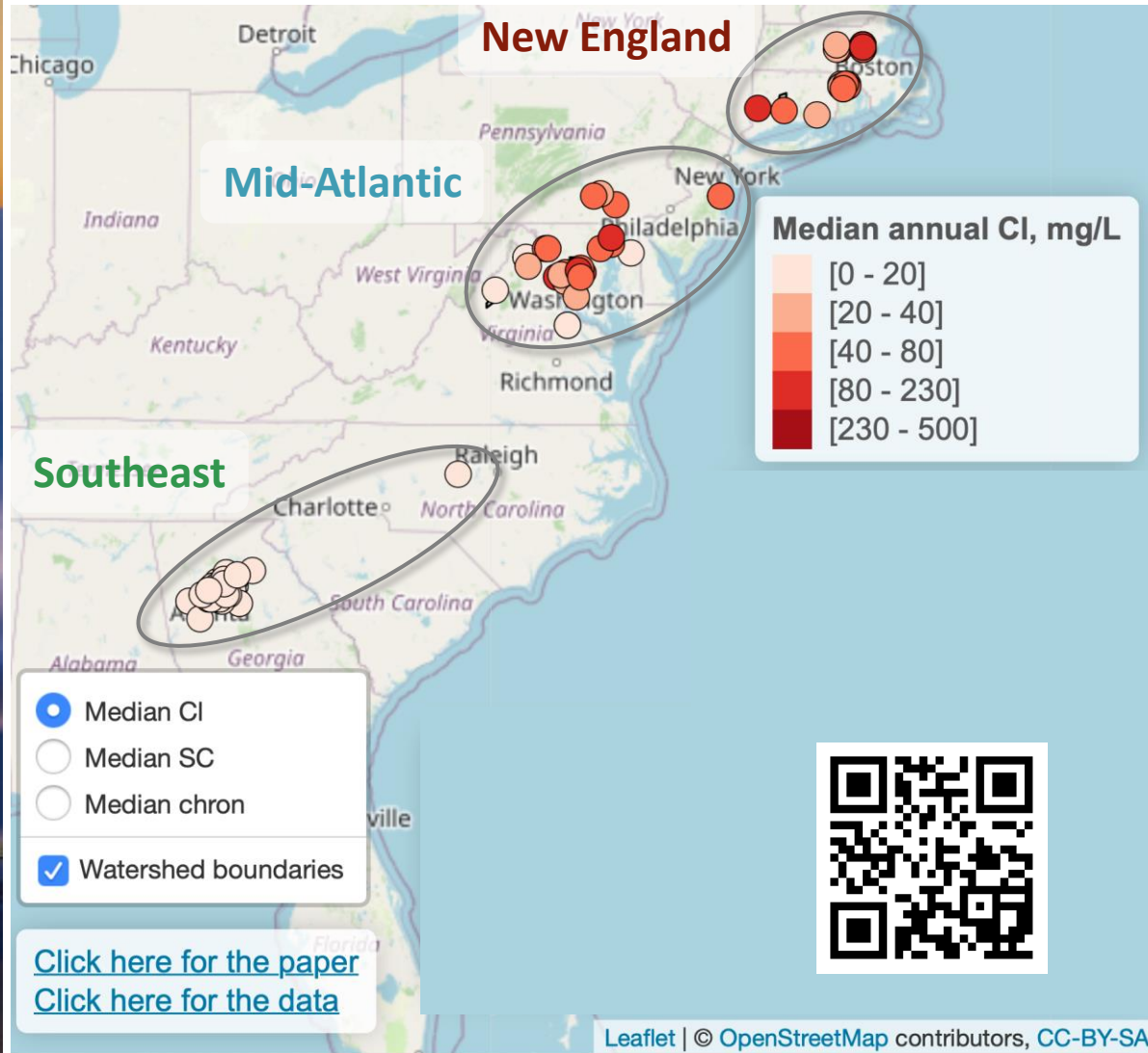
https://tigerweb.towson.edu/moore/chloride_map_12062019.html

Chloride increases from south to north & with impervious within region



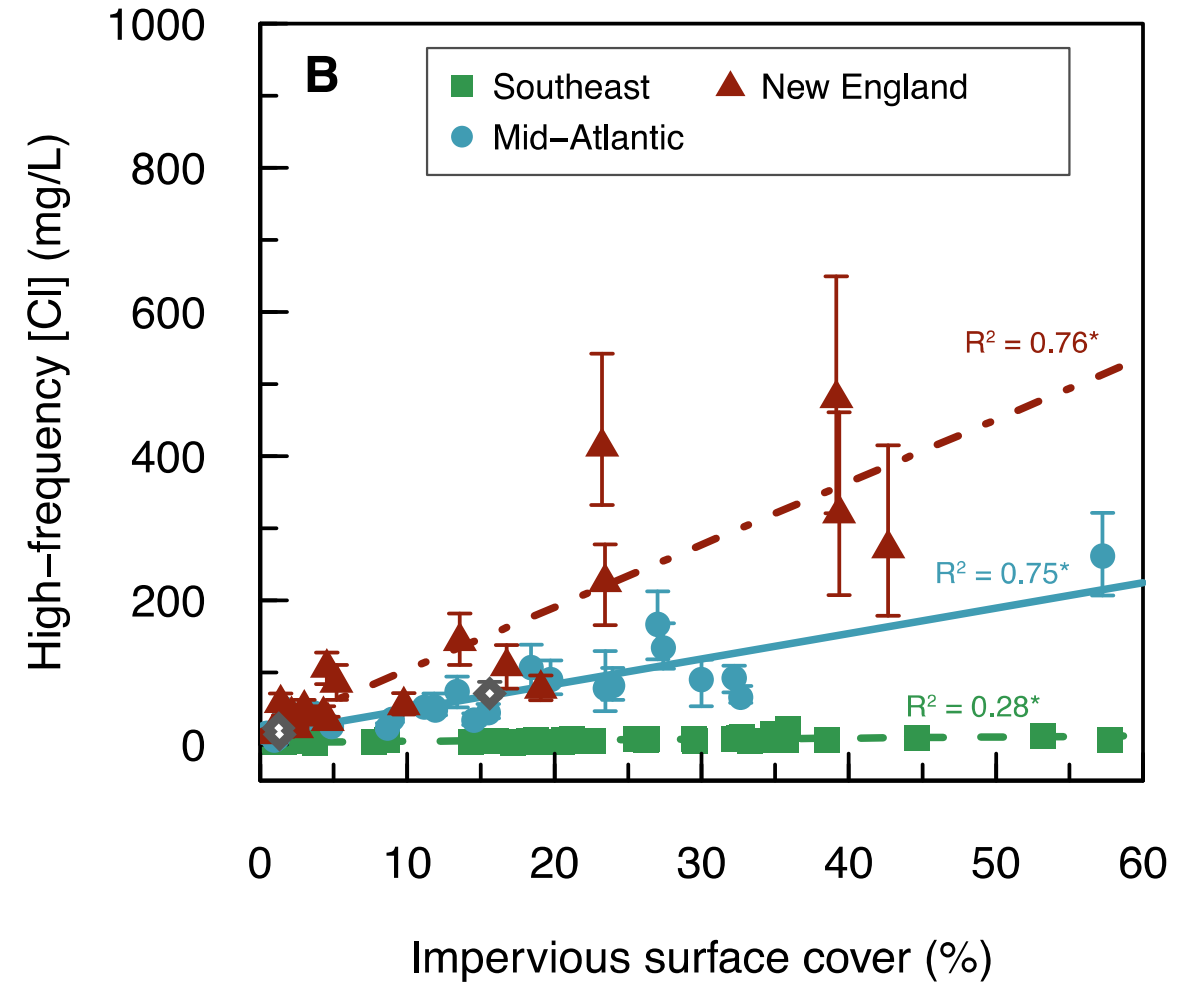
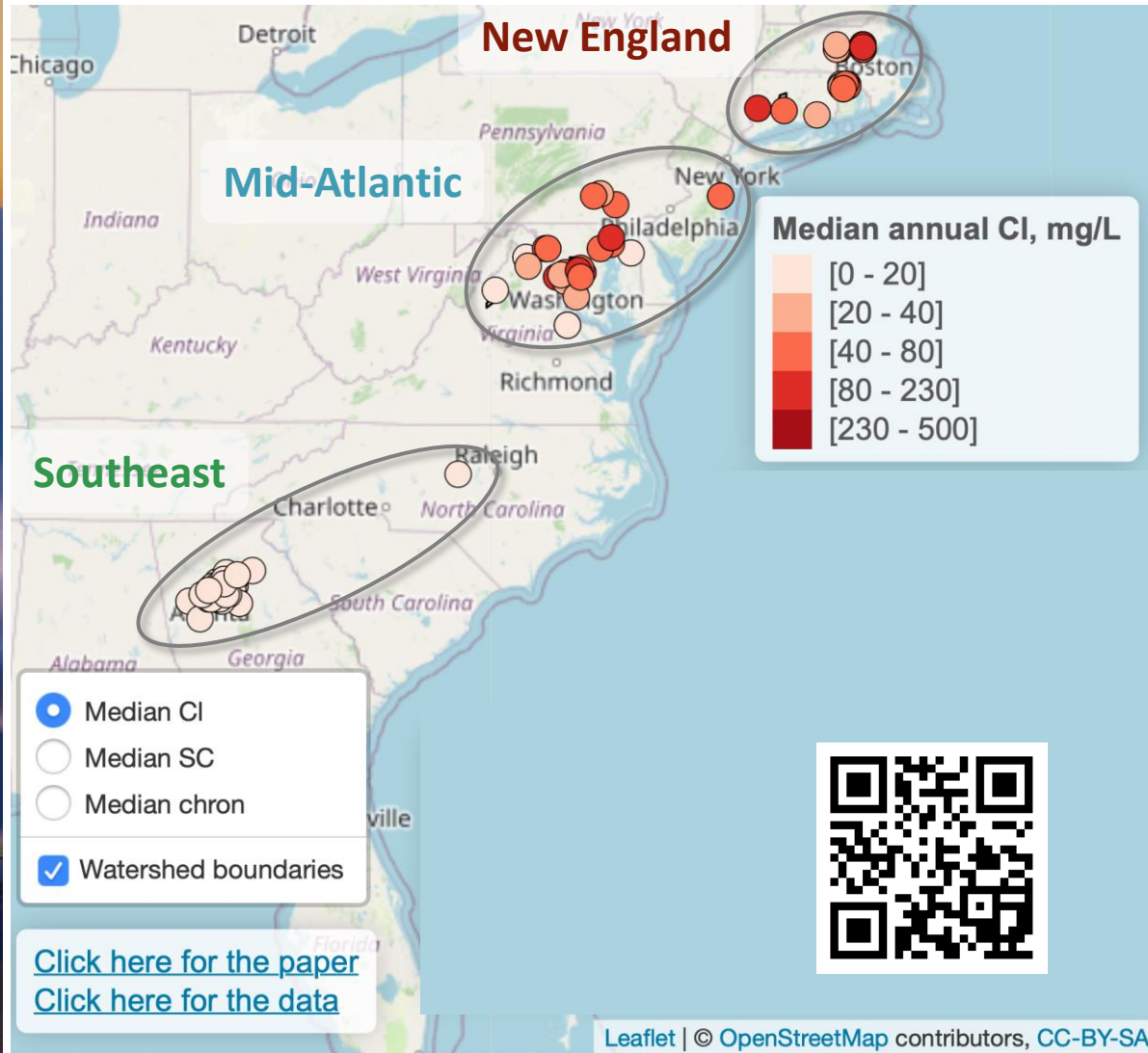
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Long-term increases in chloride: Example from Baltimore region

Beaver Dam Run, Cockeysville



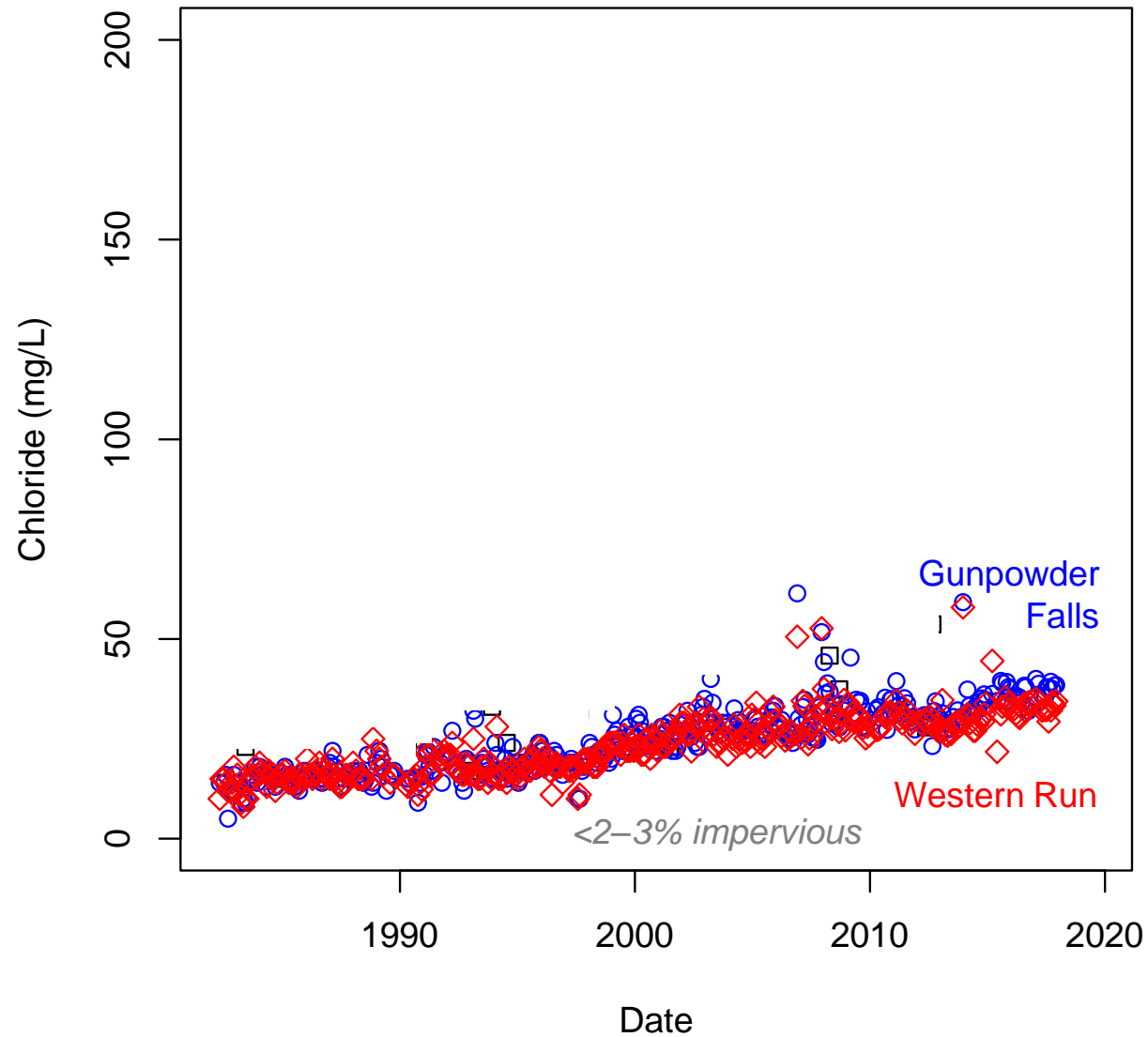
1) Cl (& Na) concentrations have doubled to tripled since 1980s even with most tributary watersheds having less than 2–3 % impervious surface cover

Gunpowder Falls, Hoffmanville (upstream of Prettyboy)

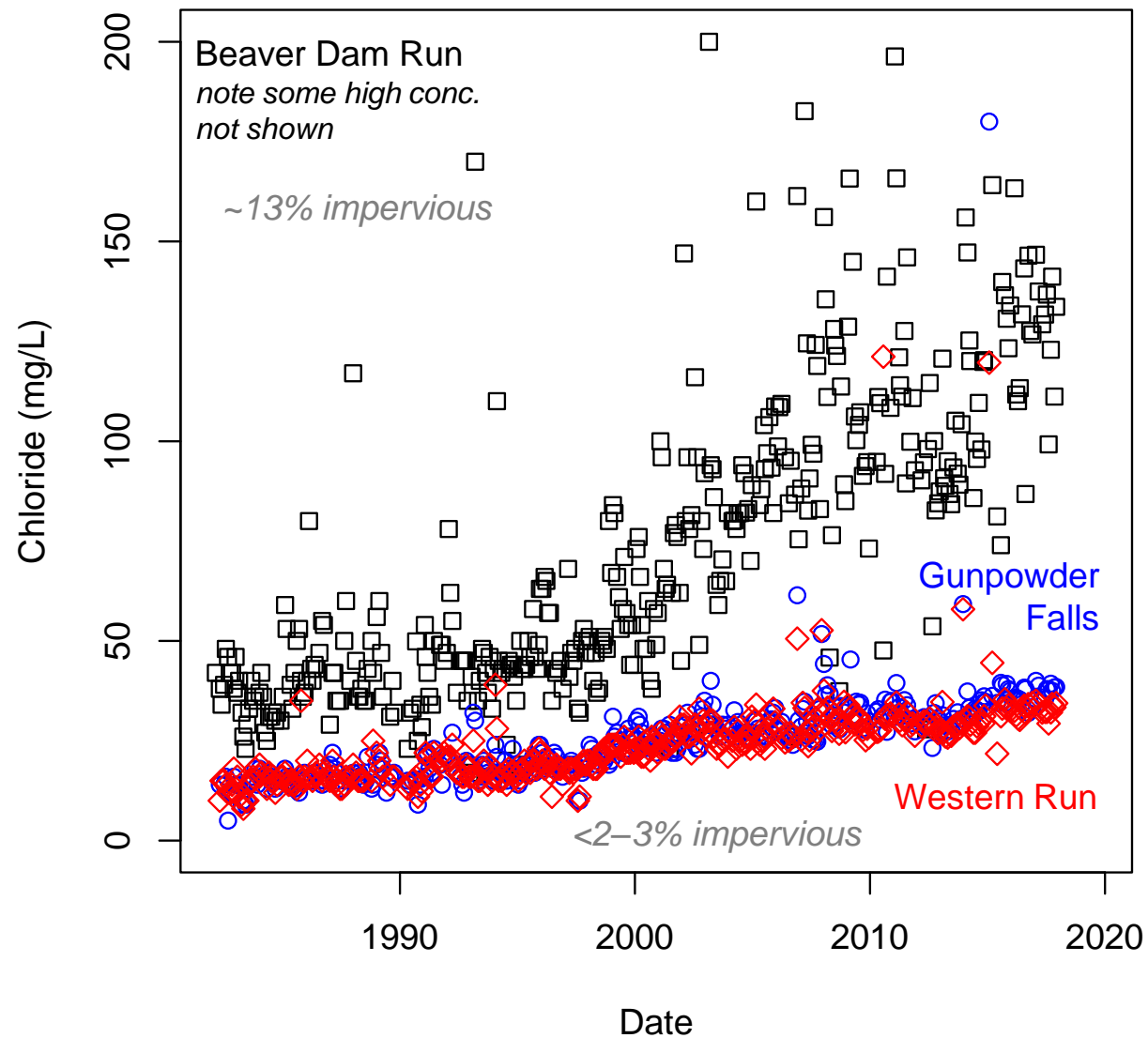


2) Concentrations have increased even faster in more urban tributaries

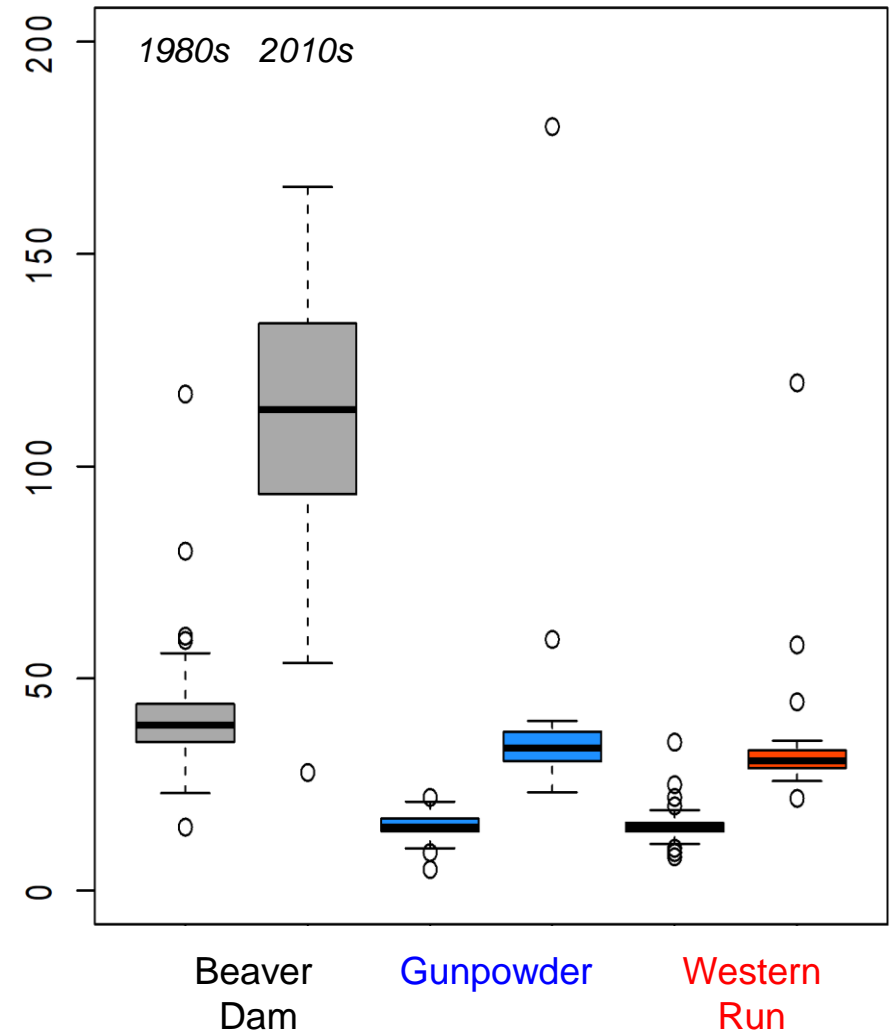
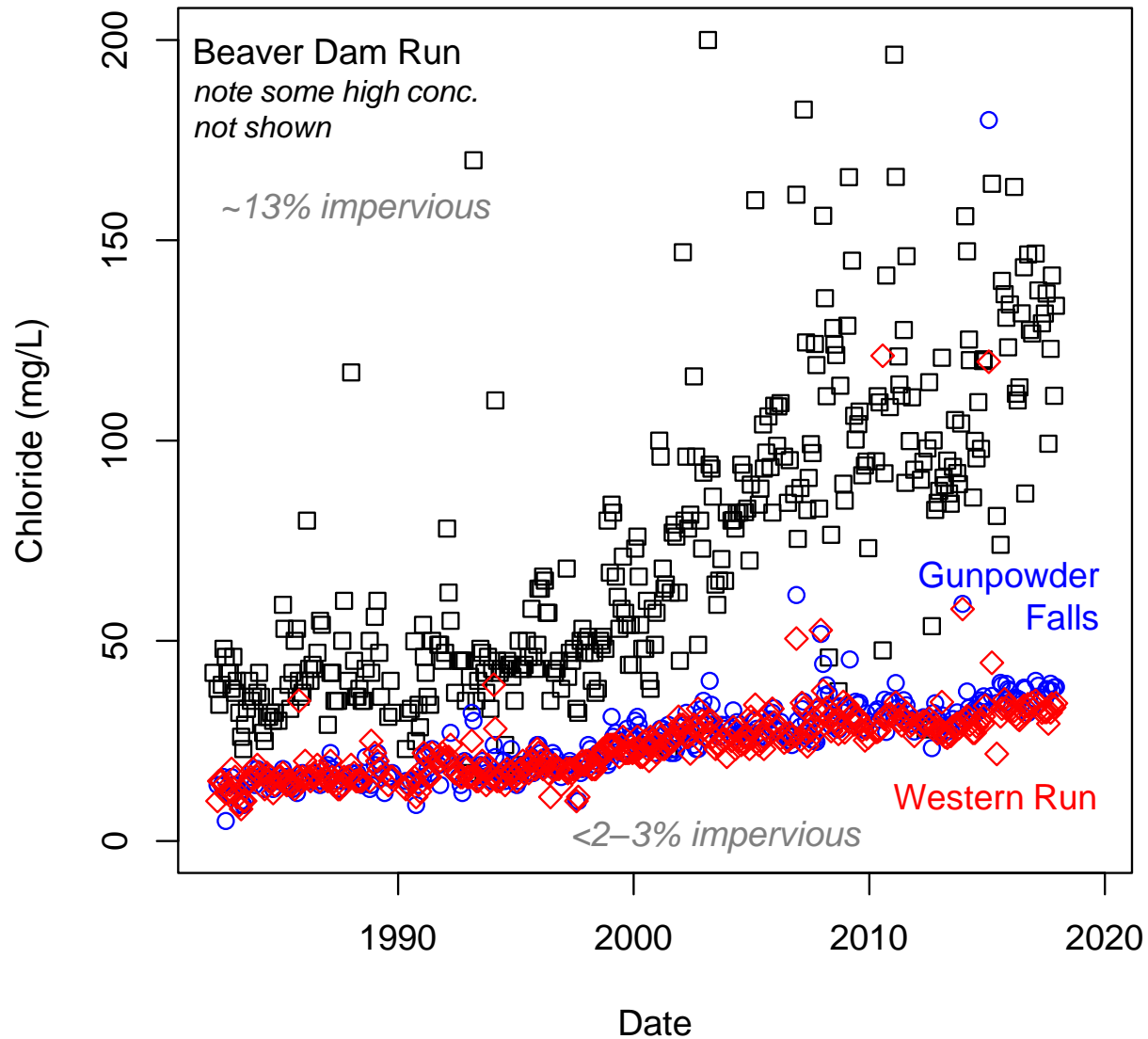
Long-term Cl increases: Example from Baltimore water supply



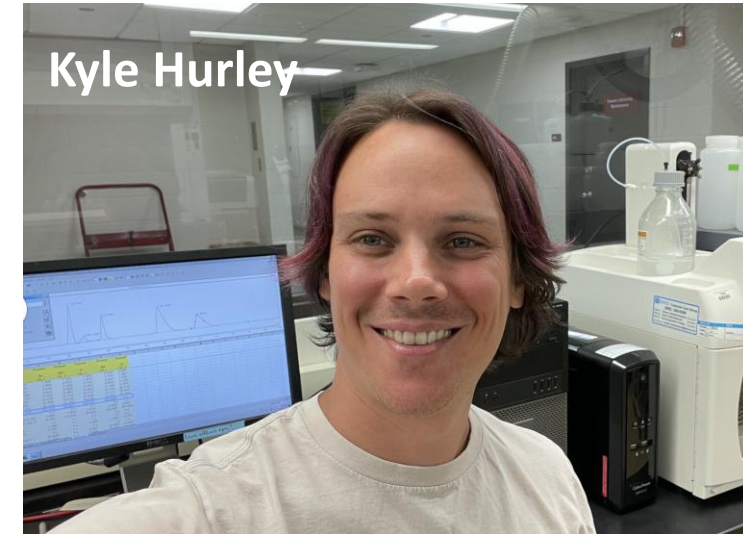
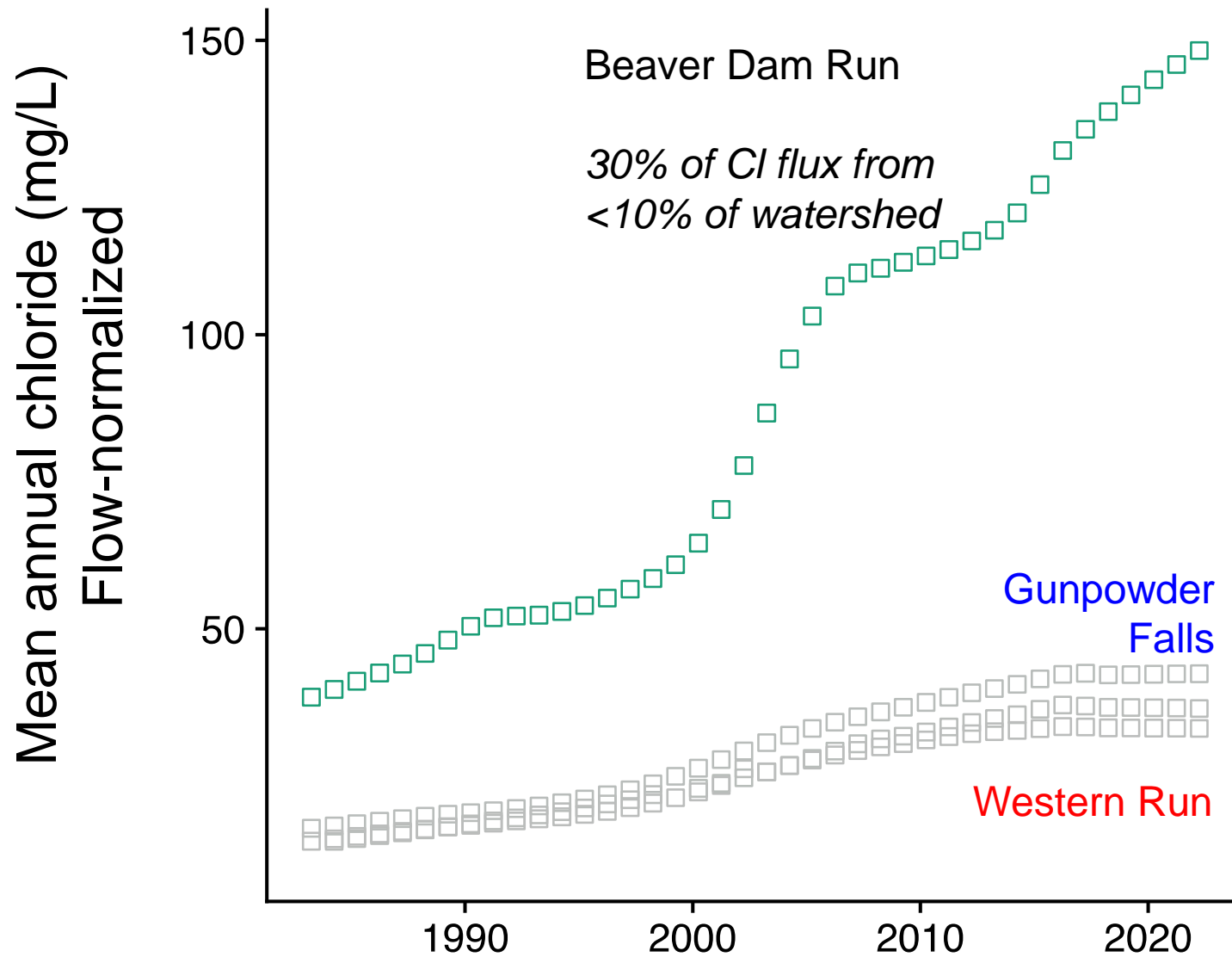
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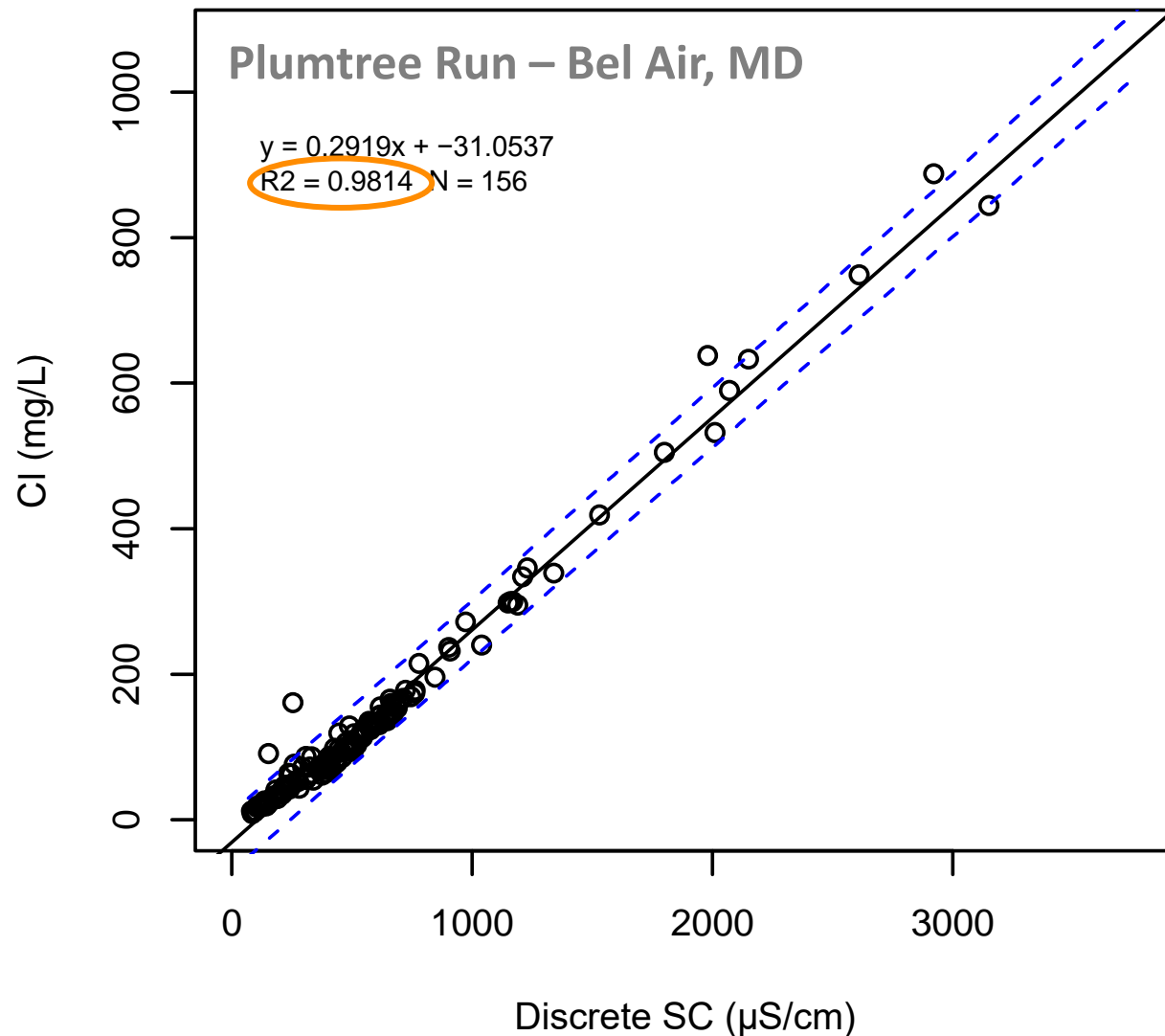
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Short-term: Correlation of Cl & SpC allows for cheap in-stream sensors

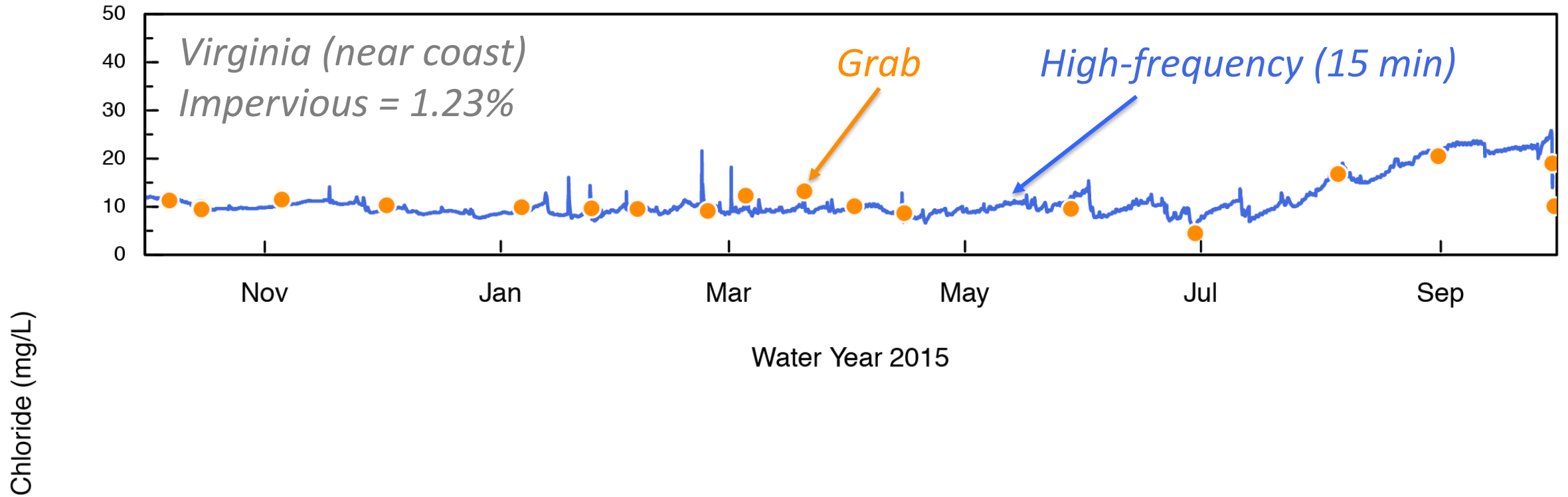


High correlation means that high-frequency SpC can be used to calculate Cl

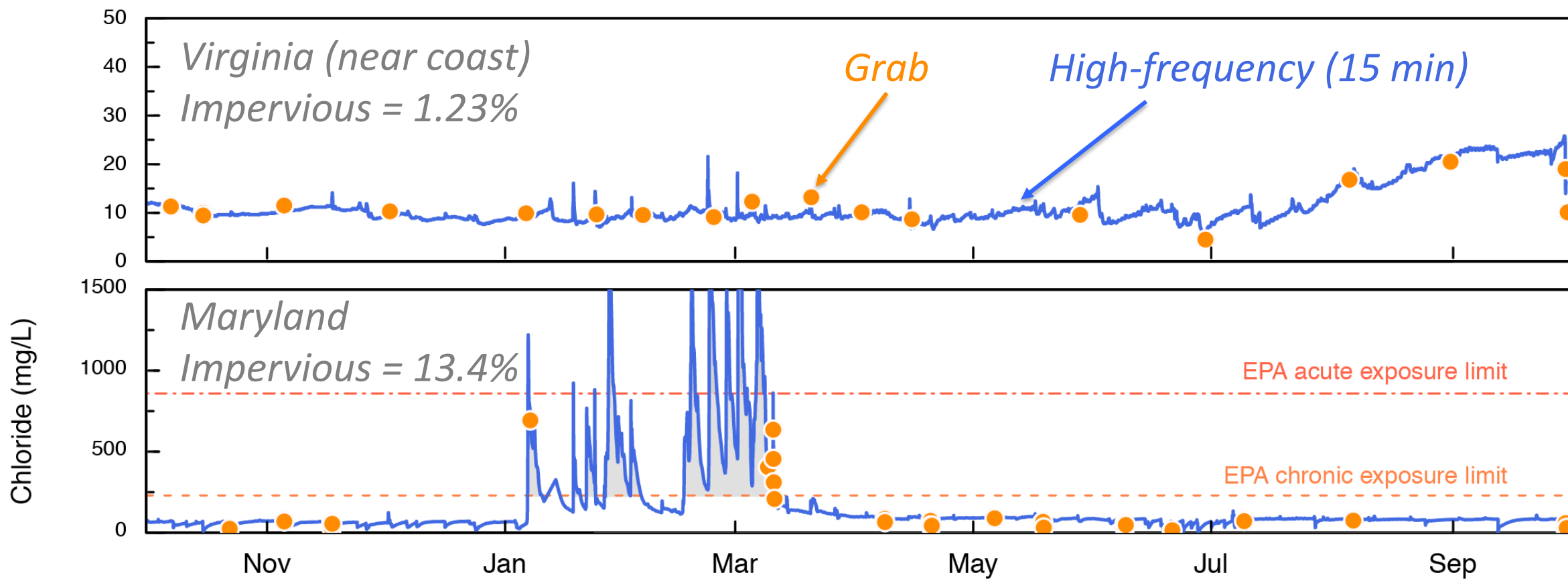
Regional relationships can work well

Weaker correlation when Cl is low and/or other ions dominate
Carbonate: limestone, marble

Short-term: High-frequency essential, especially urban or highway



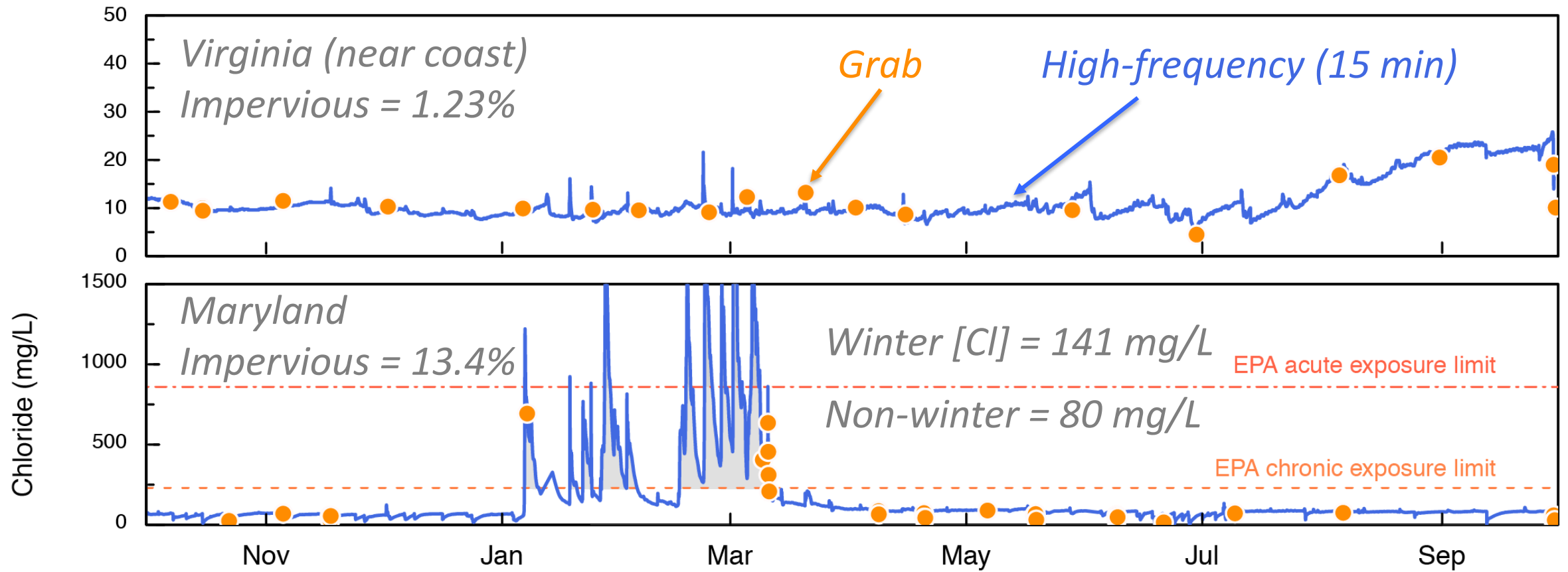
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In winter, increases in SpC & chloride

In non-winter, typically dilution

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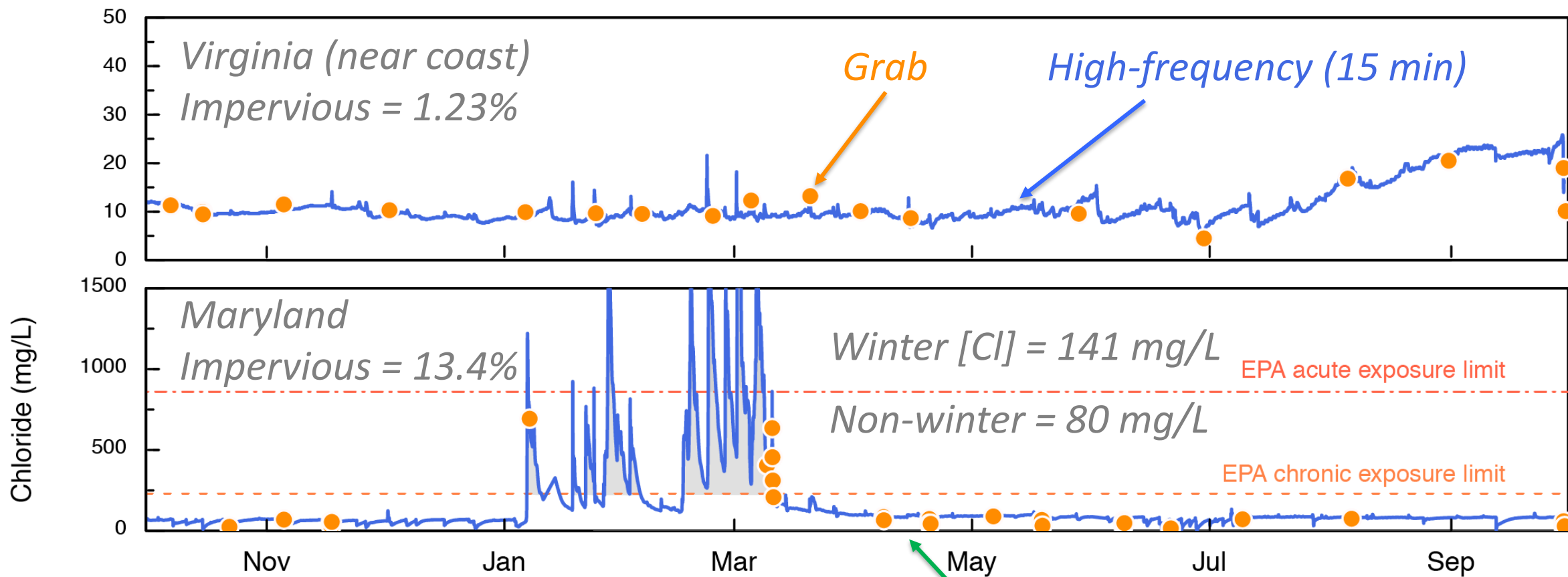


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Water Year 2015

In non-winter, typically dilution

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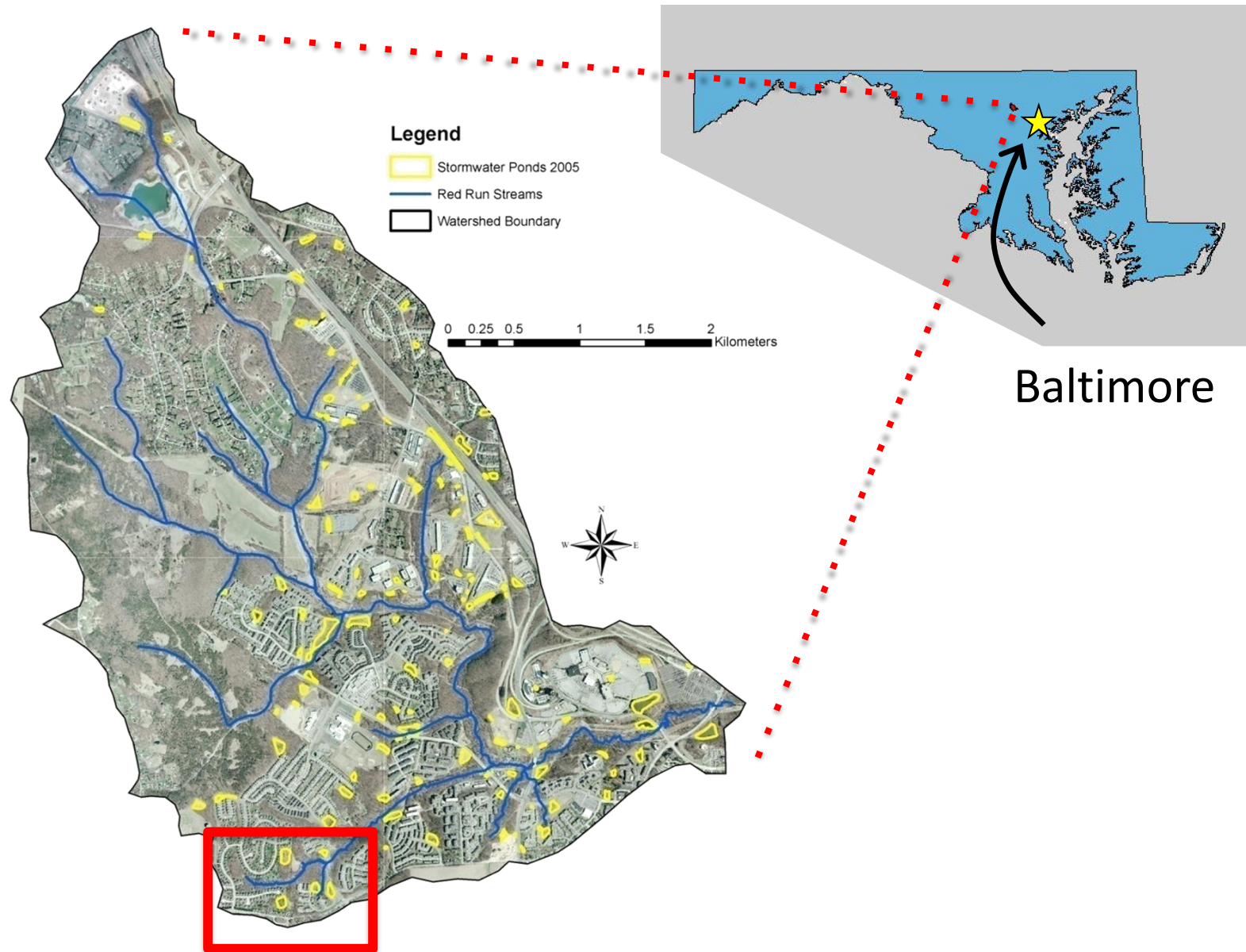


In winter, increases in SpC & chloride

In non-winter, typically dilution

Think about timing of sample collection. Baseflow is good for Cl

Stormwater basin buildout in suburban Baltimore, MD



Stormwater basin study site map

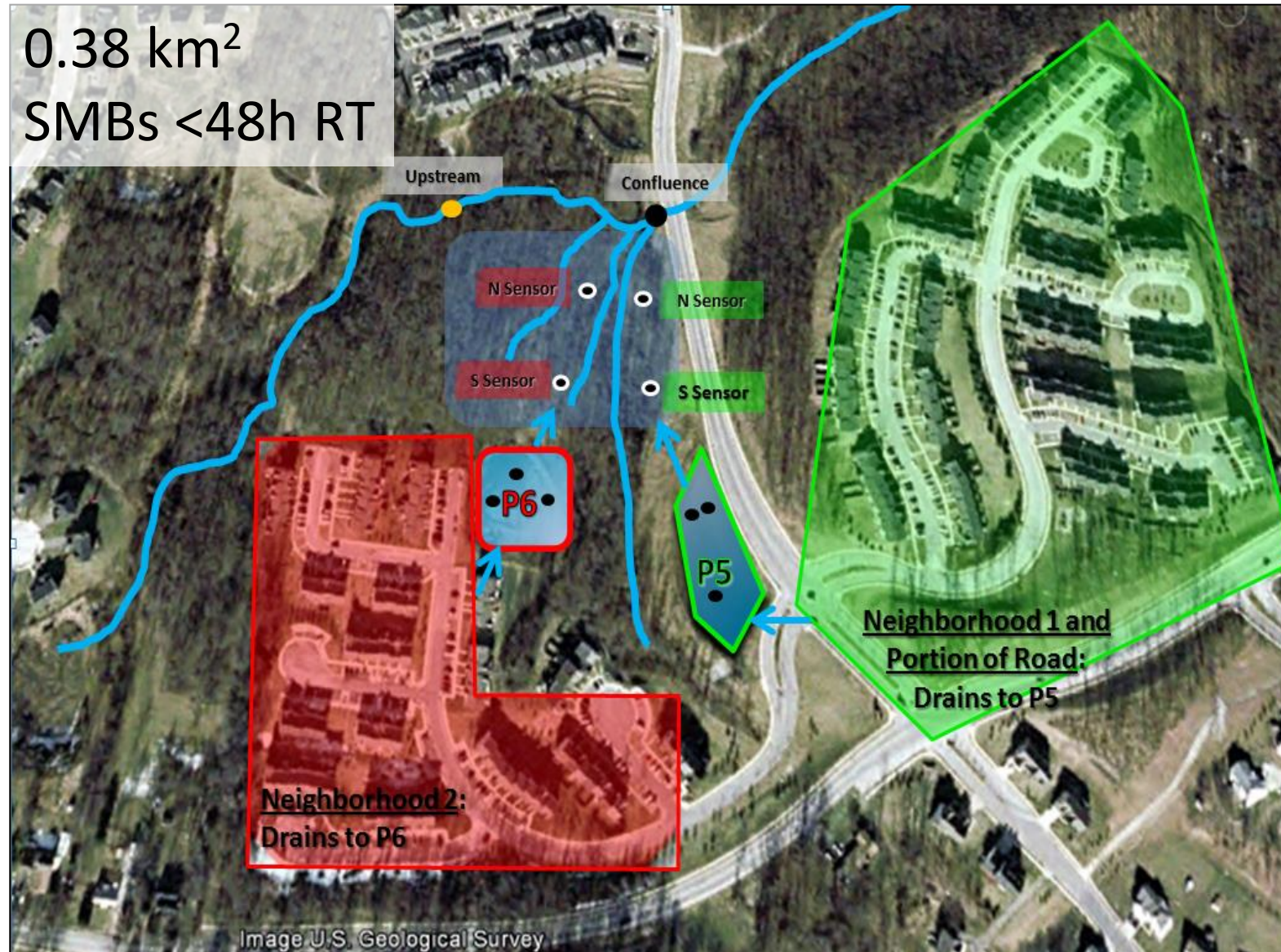
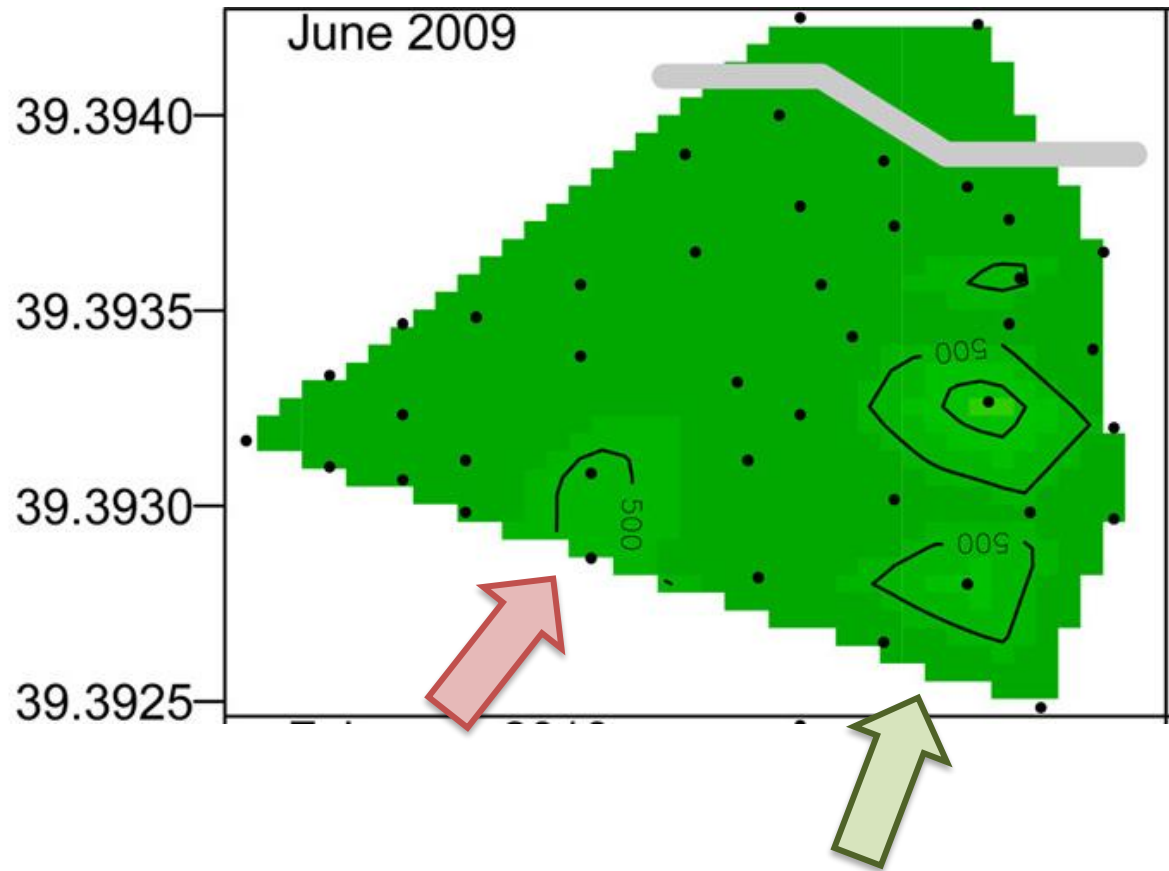
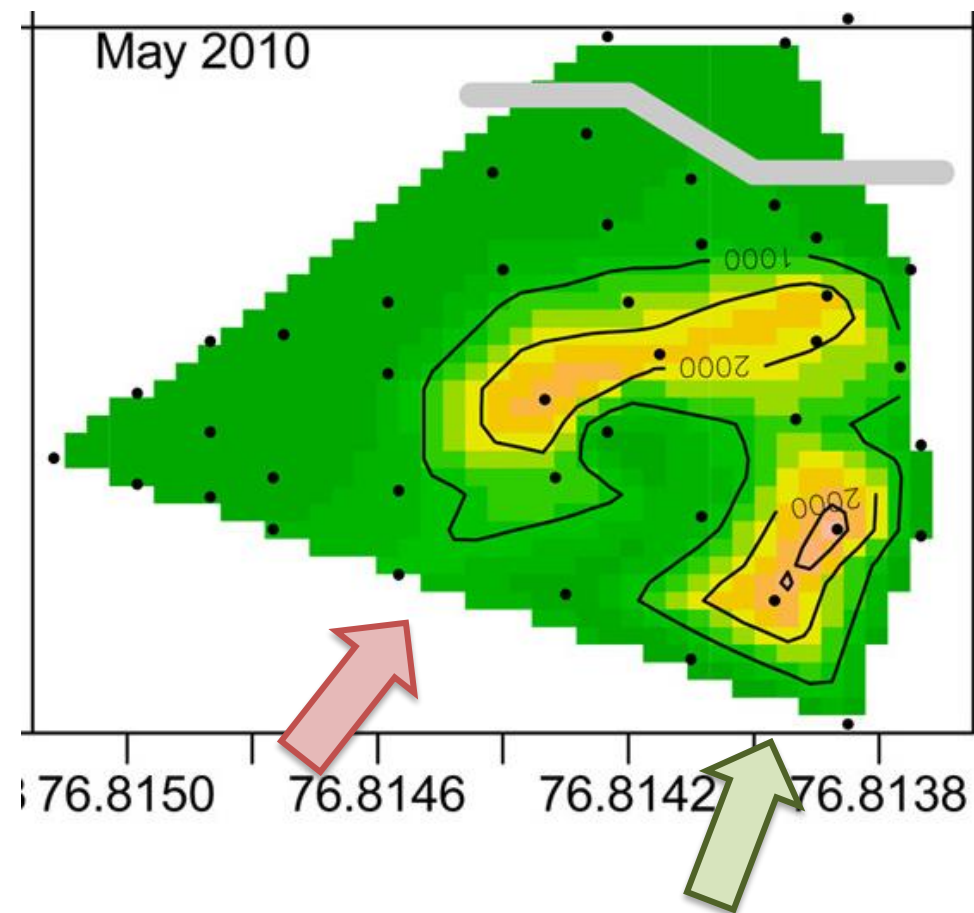
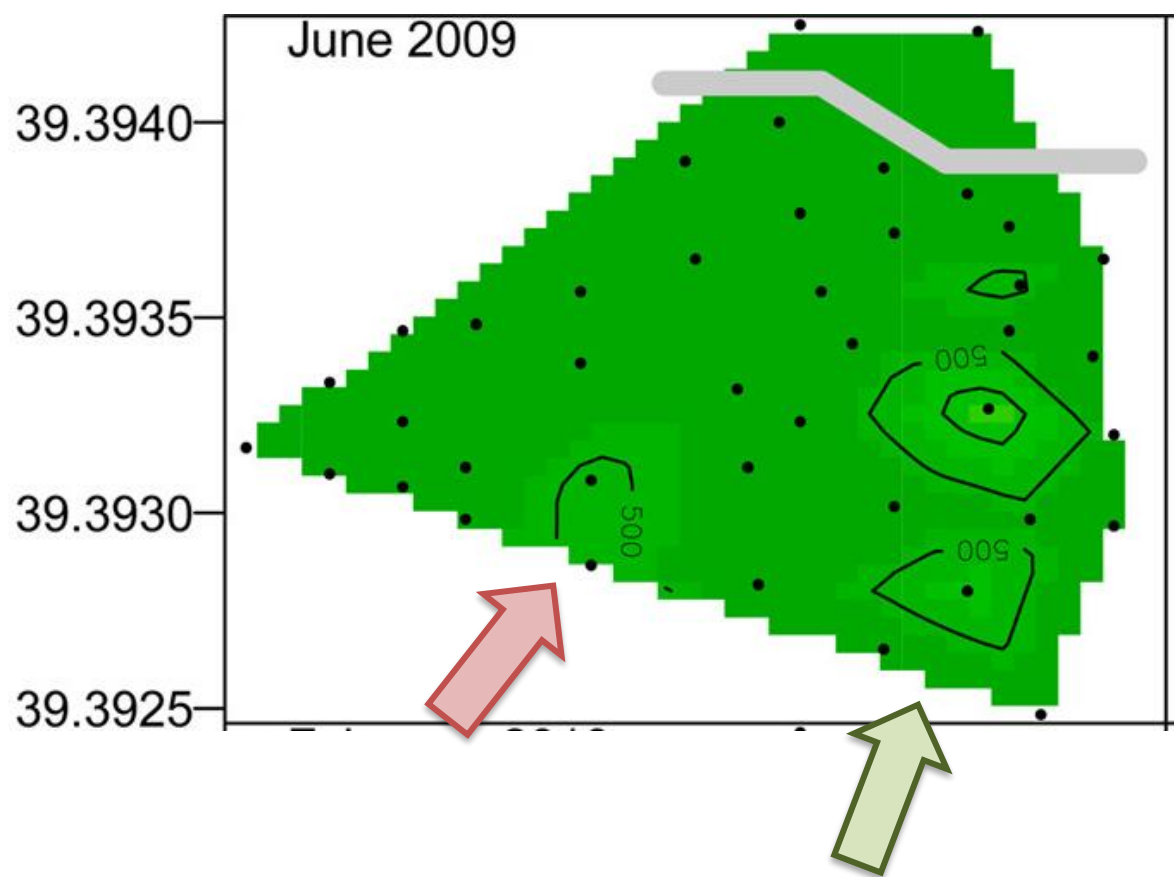


Figure by Brandon Sandosky

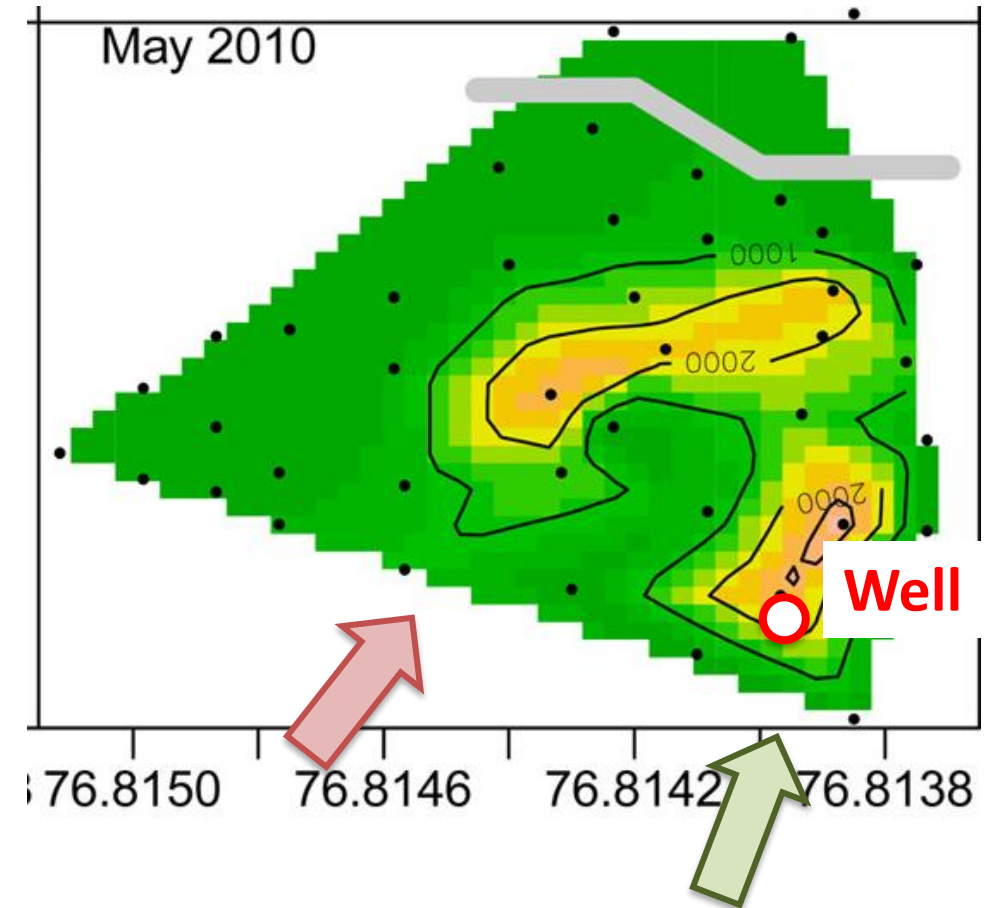
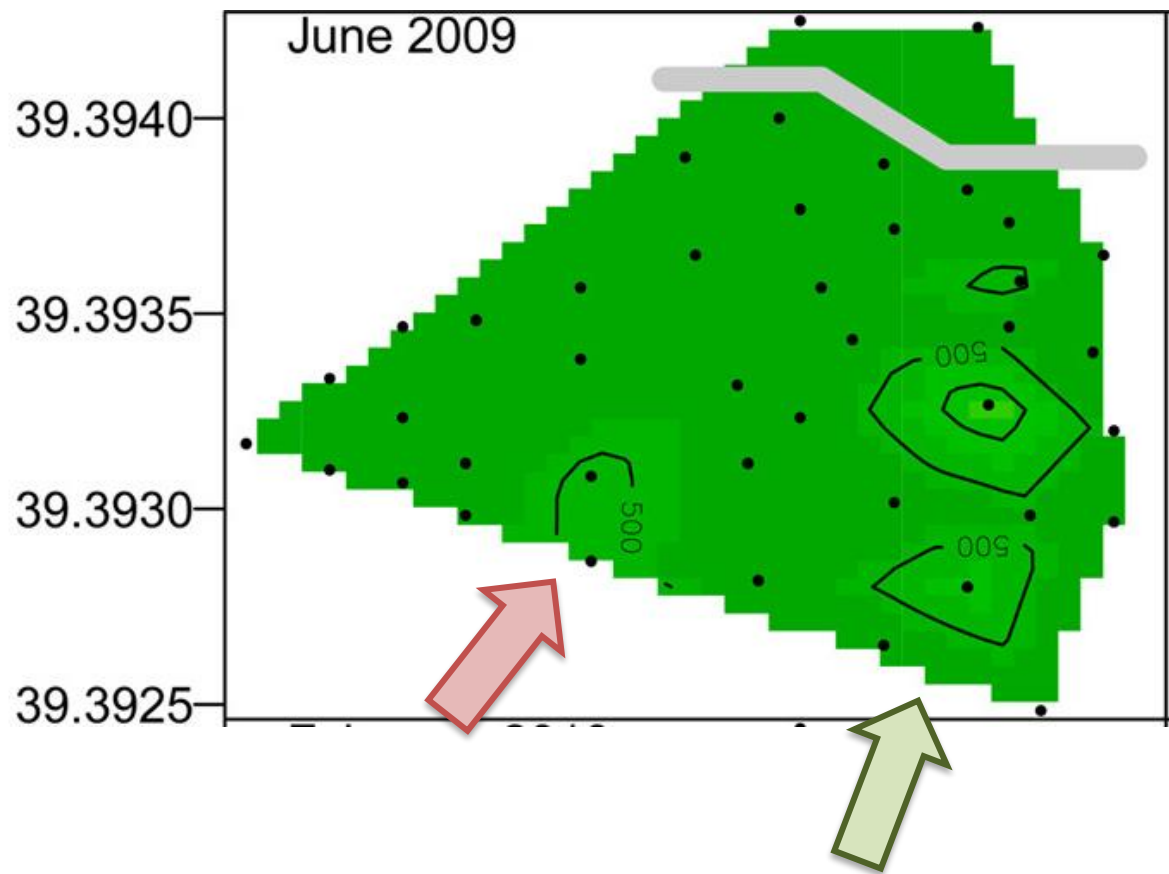
Persistent chloride plumes downgradient of stormwater basins



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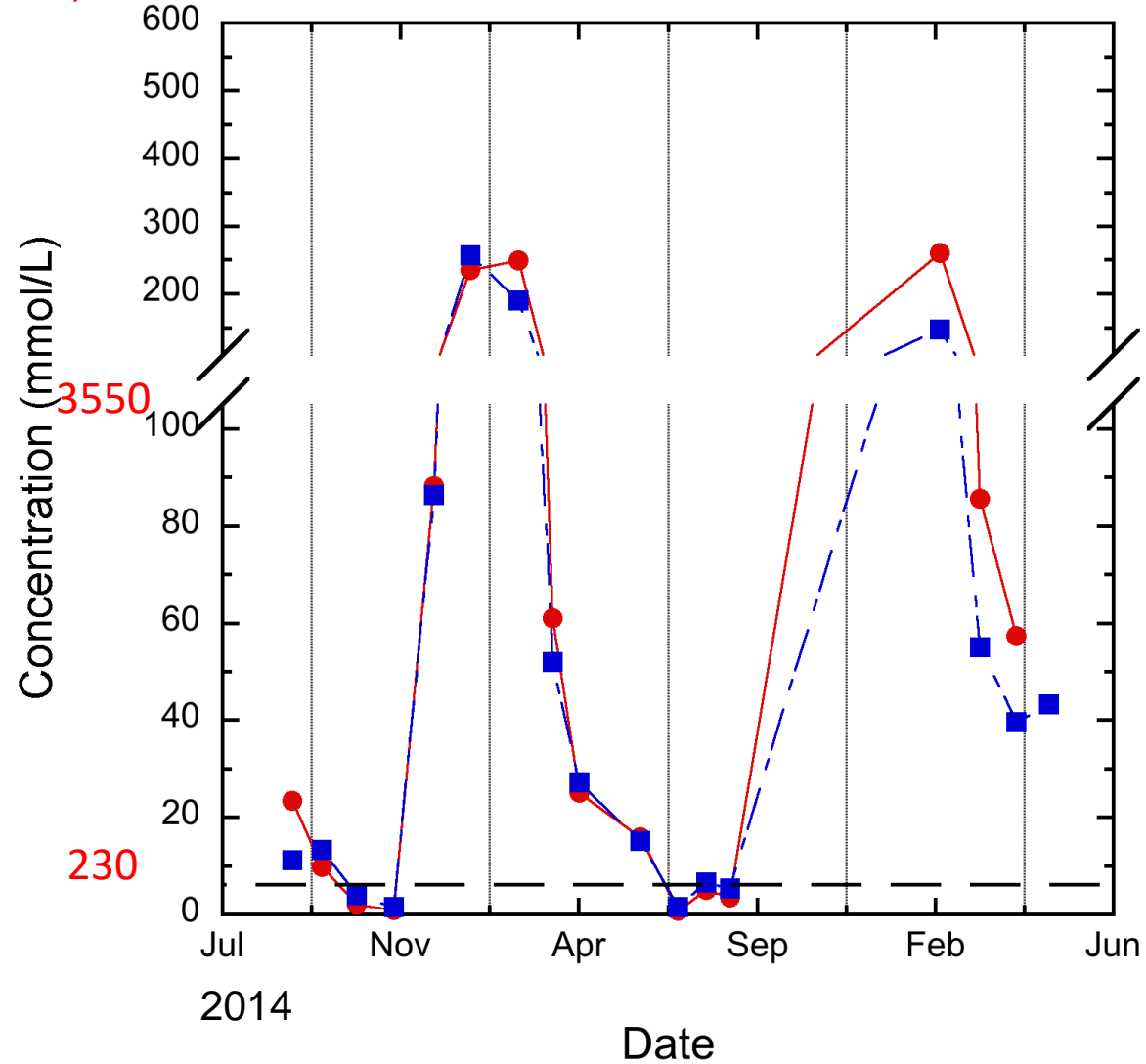
Persistent chloride plumes downgradient of stormwater basins



Groundwater chloride concentrations

Cl (mg/L)

21,300



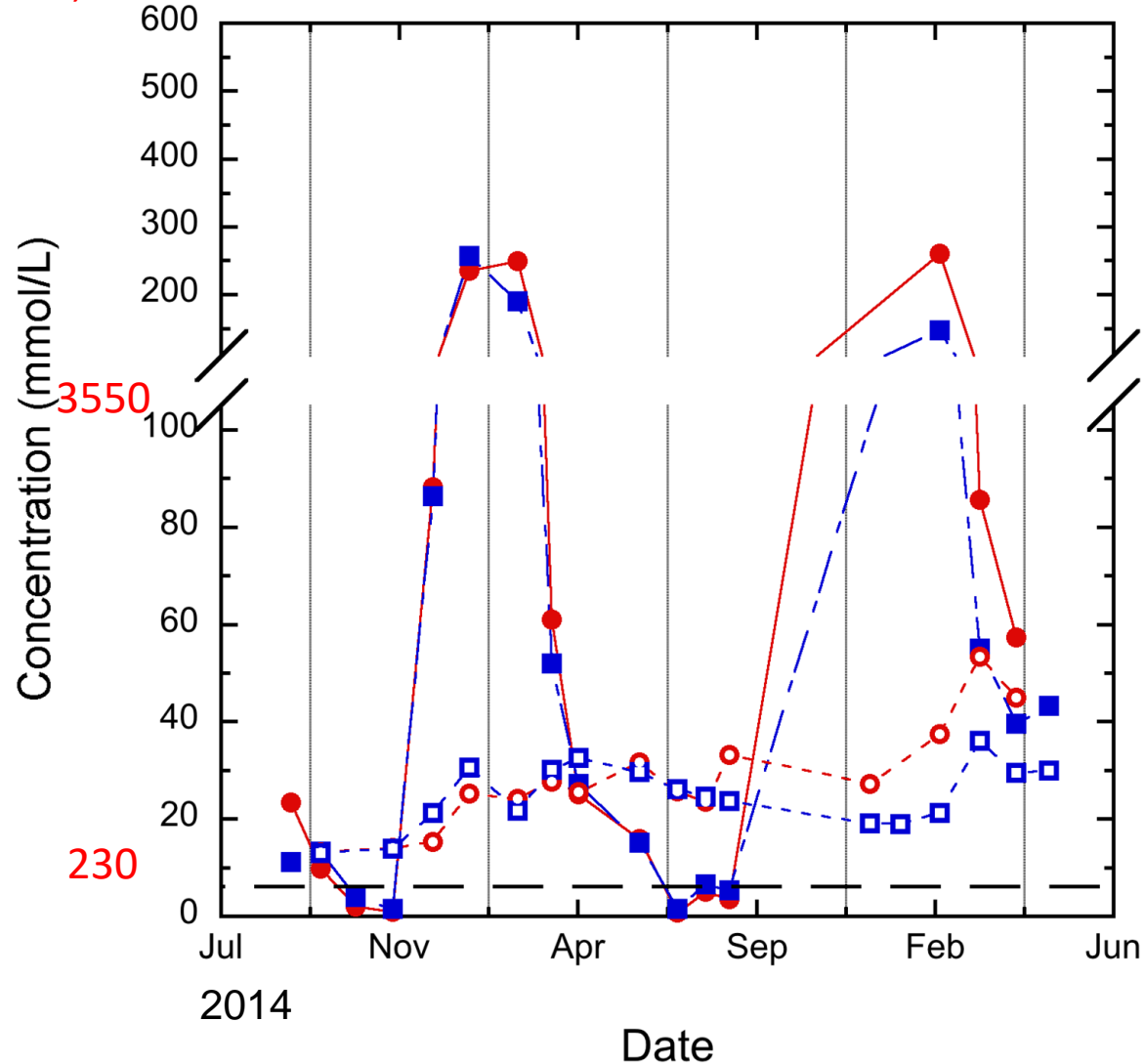
Shallow
below surface

3 ft

Groundwater chloride concentrations

Cl (mg/L)

21,300



Shallow 3 ft
below surface

Deep 8 ft
below surface

High Cl groundwater means
elevated Cl year-round at baseflow

Beginning to address issue

1 teaspoon can contaminate a 5 gallon bucket

50 lb bag can contaminate >10,000 gallons of water

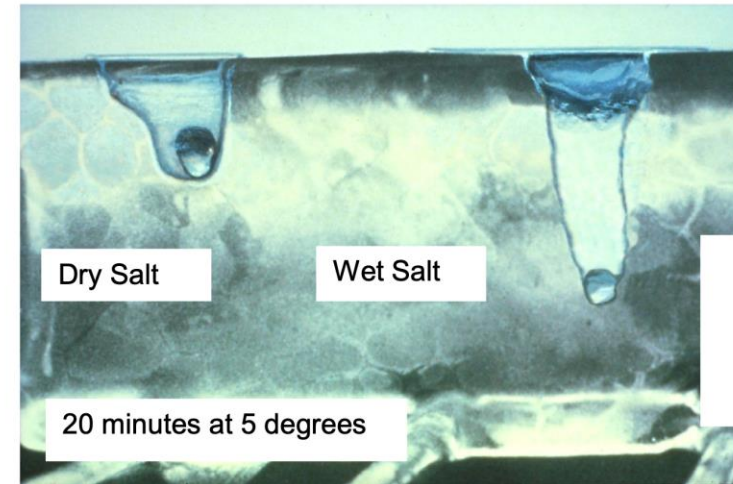


Photo courtesy
of Wisconsin
DOT
transportation
bulletin #22

Figure 19: Dry salt vs. wet salt



<https://www.pca.state.mn.us/sites/default/files/p-tr1-10.pdf>; Haake & Knouft (2019) *Environmental Science & Technology*;

<http://archive.boston.com/business/gallery/brinesolution/>

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Only solution is to put down less salt

Lots of ways to achieve that while maintaining the same or similar levels of service,
MD SHA has reduced its salt use by 30–50% over last several years

Prewetting / pretreating: Can use ~1/3 less salt

Liquid/Brining: Can use 45–50% less salt
& often save on overtime (Haake & Knouft, 2019)

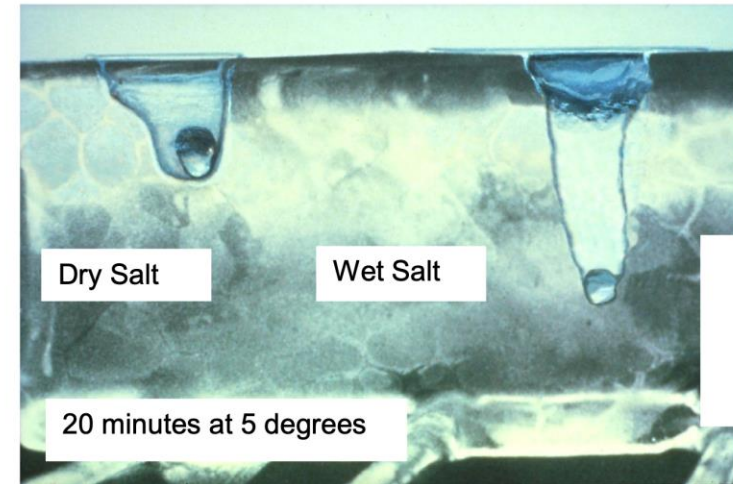


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Maryland: permit-driven via MS4 permits

Virginia: regulatory (TMDL) & voluntary

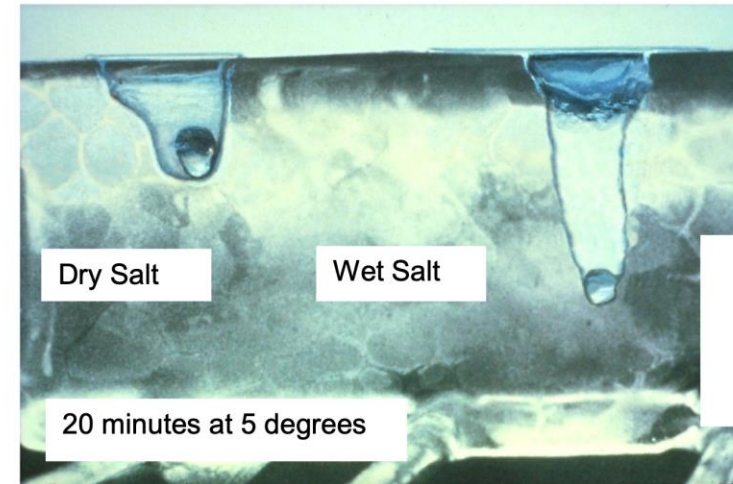


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<https://www.northcountrypublicradio.org/news/story/40493/20200201/the-flavors-of-road-safety-pickles-beets-and-cheese>;

Thank you!

What questions do you have??

**Headwater stream into drinking water reservoir system
Gunpowder Falls, Hoffmanville** (upstream of Prettyboy)

**Urban stream into drinking water reservoir
Beaver Dam Run, Cockeysville**

Knowledge & research gaps

- 1) How much are private entities applying? And how encourage & implement best practices?
 - Often apply at higher rates
- 2) How long does Cl take to flush from watersheds & what role can stormwater management play?
- 3) How do freshwater *communities* respond and change to stress from chloride (and chloride from different sources, e.g., NaCl versus MgCl₂).



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- 4) How can existing data be used and extrapolated to non-monitored (or less frequently monitored) streams?
- 5) What are long-term effects on nutrient fluxes?
- 6) Effects on drinking water & disinfection by-products



Resources: Smarter use

Virginia (northern) Salt Management Strategy (SaMS) Development

<https://www.novaregion.org/1399/Northern-Virginia-Salt-Management-Strate>

Montgomery County: <https://montgomerycountymd.gov/water/education/winter-salt-management.html>

<https://montgomerycountymd.gov/water/education/winter-salt-other-agencies.html>

WSSC (formerly Washington Suburban Sanitary Commission): <https://www.wsscwater.com/saltwise>

Minnesota Winter Parking Lot and Sidewalk Maintenance Manual

<https://www.pca.state.mn.us/sites/default/files/p-tr1-10.pdf>

Minnesota Pollution Control Agency

<https://www.pca.state.mn.us/water/salt-applicators>

Minnesota Smart Salting for Property Management Manual: <https://www.pca.state.mn.us/sites/default/files/p-tr1-11.pdf>

Wisconsin Salt Wise: <https://www.wisaltwise.com>

New Hampshire training, including limited liability for applicators if trained

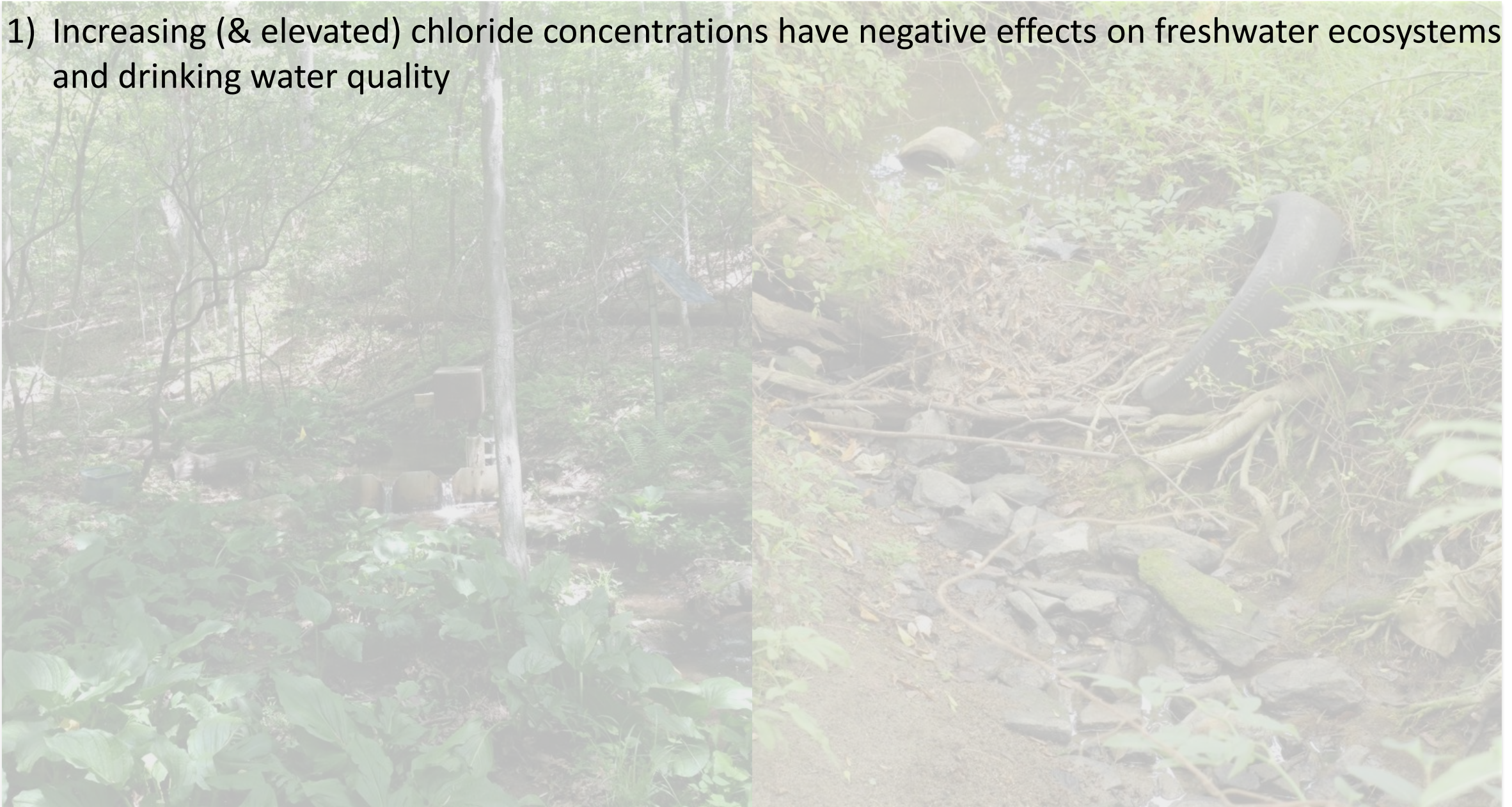
<https://www.des.nh.gov/land/roads/road-salt-reduction/green-snowpro-certification>

<https://www.des.nh.gov/land/roads/road-salt-reduction>

Cary Institute: <https://www.caryinstitute.org/news-insights/guide/road-salt-tips-municipalities-highway-departments-and-winter-maintenance-staff>

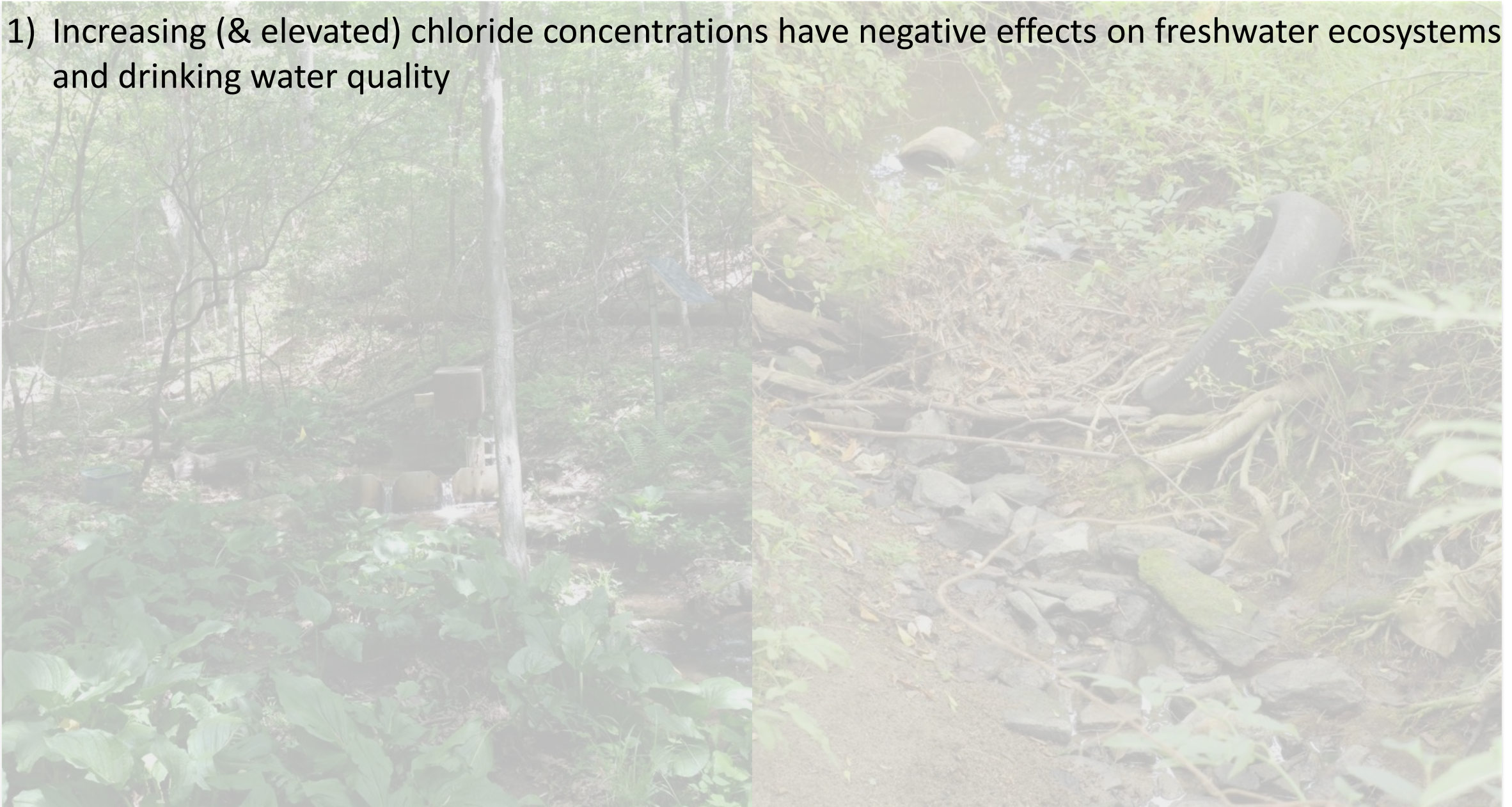
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- 1) Increasing (& elevated) chloride concentrations have negative effects on freshwater ecosystems and drinking water quality



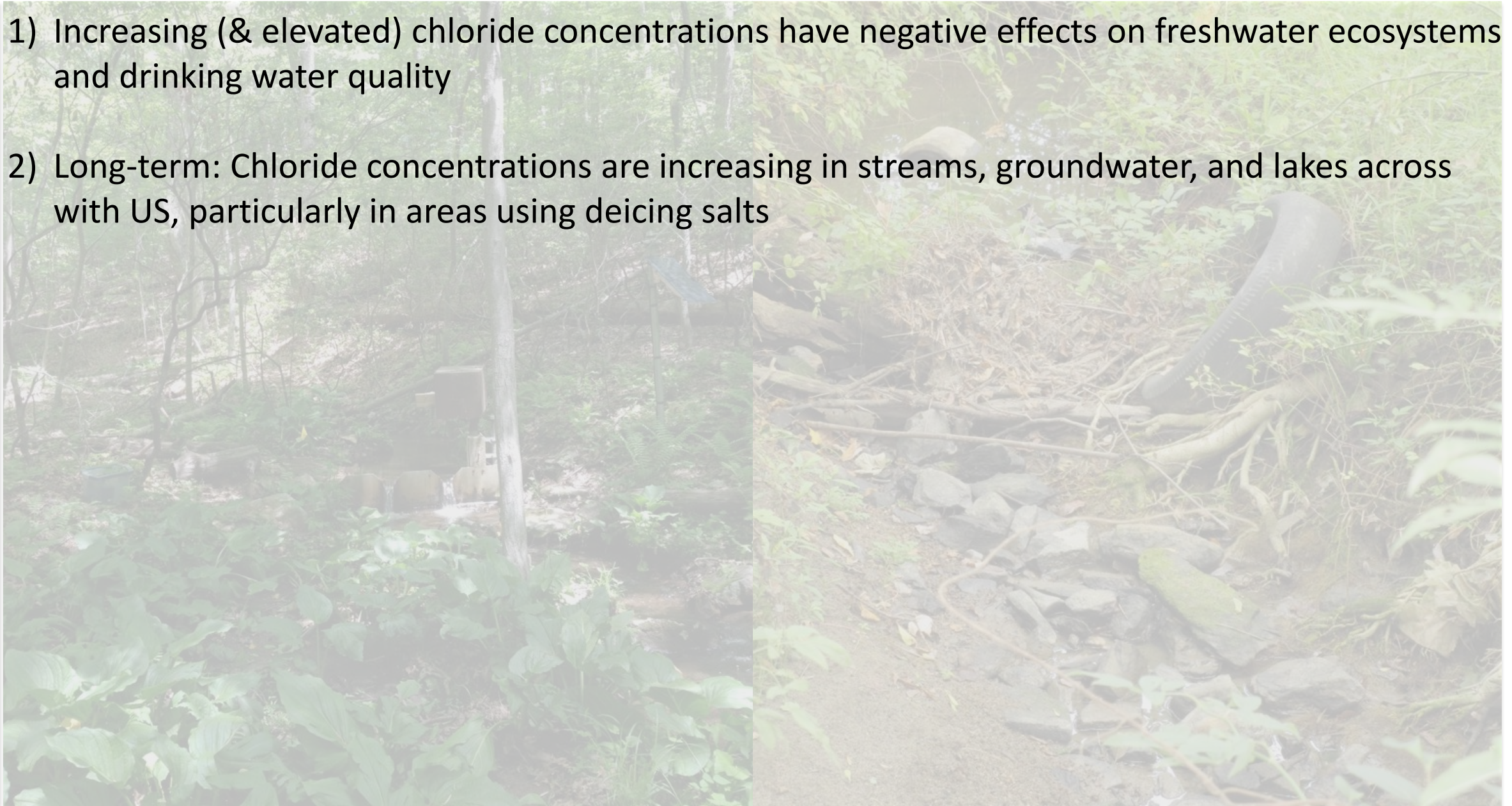
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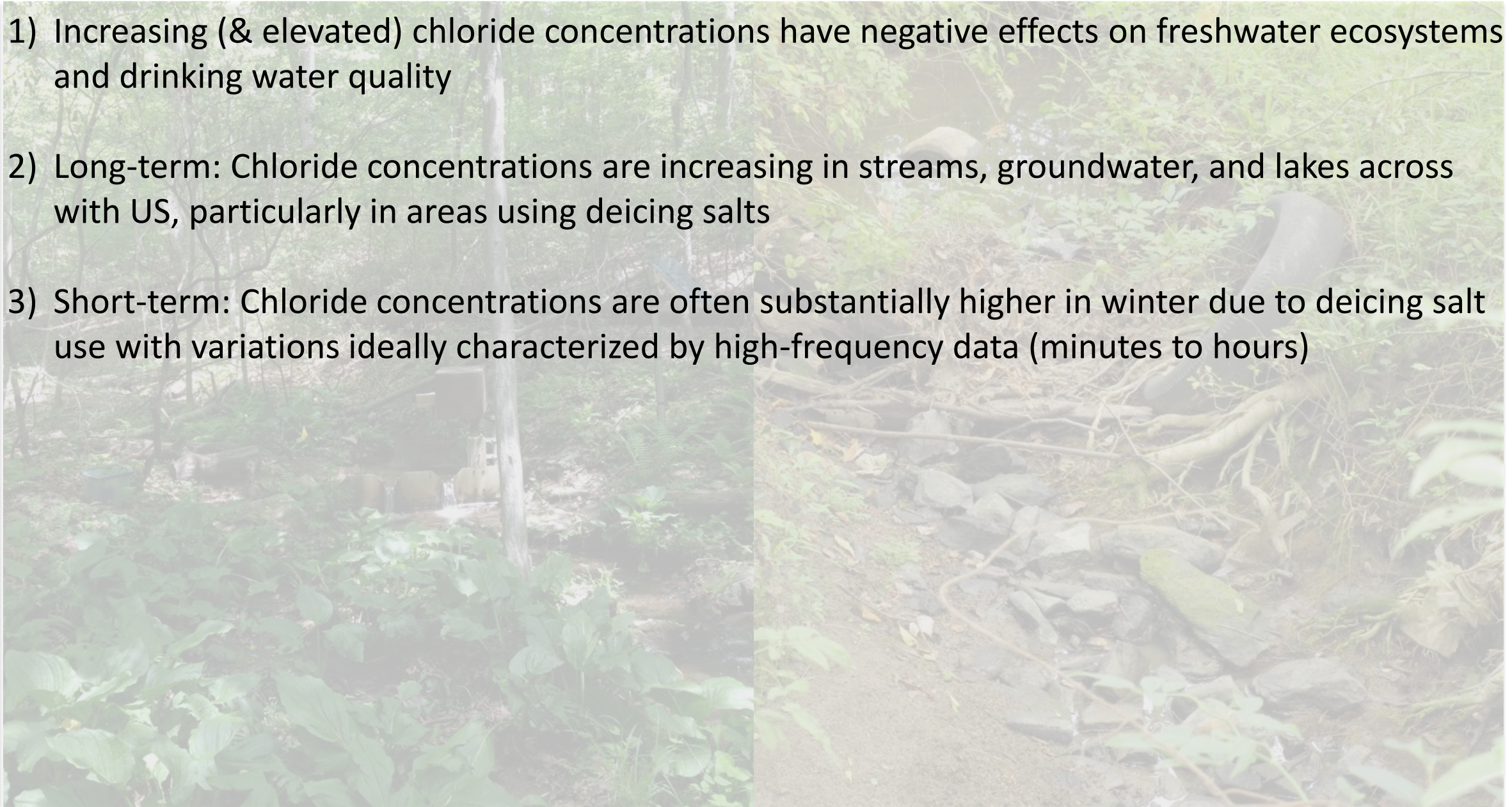
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- 6) Problem is increasingly on people's radar and things are beginning to move in right direction

Resources: My publications on chloride (& other ions)

Snodgrass J. W. et al. (2017) Influence of modern stormwater management practices on transport of road salt to surface waters. *Environmental Science & Technology*. 51: 4165–4172.

<http://dx.doi.org/10.1021/acs.est.6b03107>

Moore J. et al. (2017) Nonpoint source contributions drive elevated major ion and dissolved inorganic carbon concentrations in urban watersheds. *Environmental Science & Technology Letters*. 4: 198–204.

<http://dx.doi.org/10.1021/acs.estlett.7b00096>

Bird D. L. et al. (2018) Steady-state land cover but non-steady-state major ion chemistry in urban streams. *Environmental Science & Technology*. 52: 13015–13026.

<http://dx.doi.org/10.1021/acs.est.8b03587>

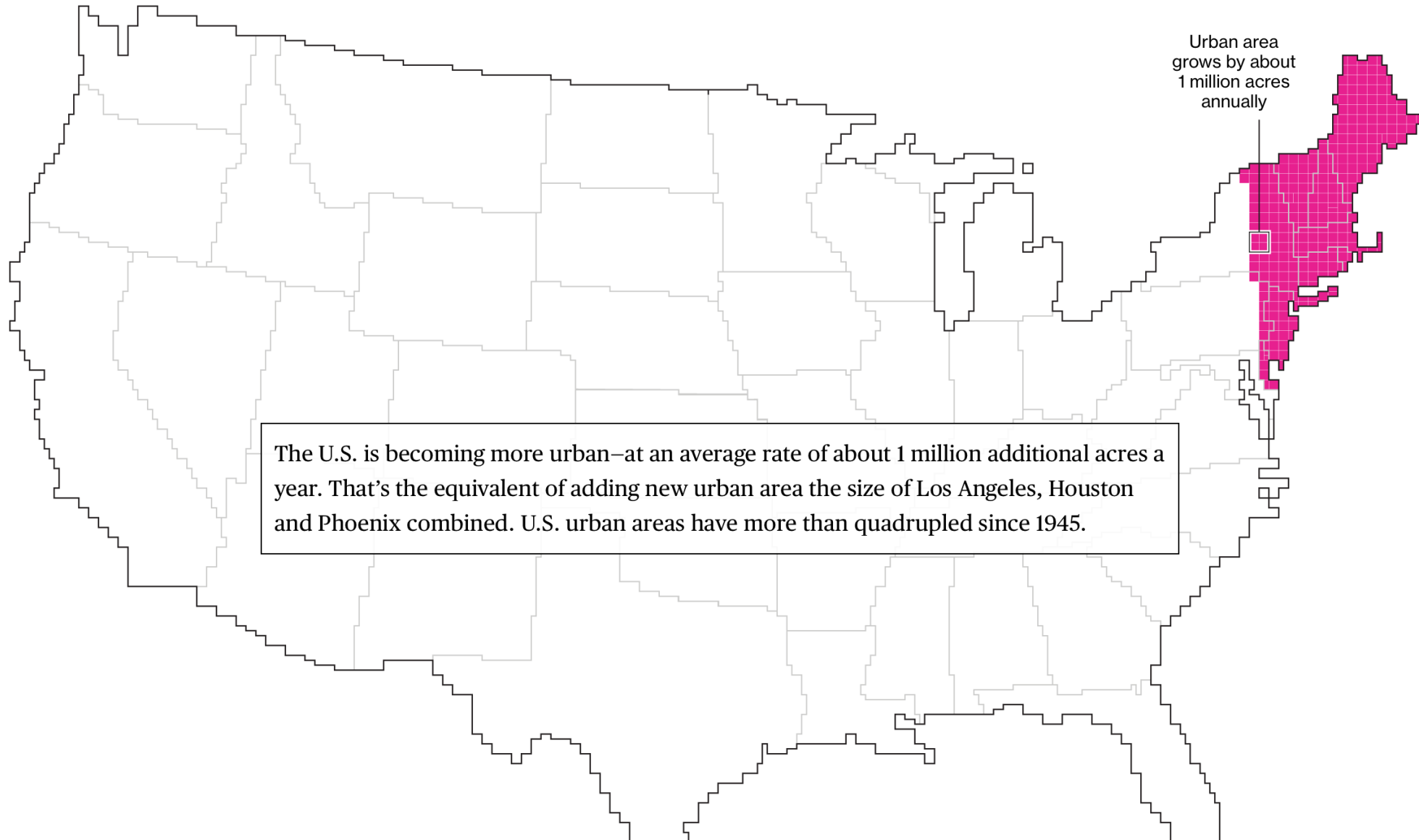
Moore J. et al. (2020) High-frequency data reveal deicing salts drive elevated specific conductance and chloride along with pervasive and frequent exceedances of the U.S. Environmental Protection Agency aquatic life criteria for chloride in urban streams. *Environmental Science & Technology*. 54: 778–789.

<https://doi.org/10.1021/acs.est.9b04316> (open access / free)

Welty et al. (2023) Spatial heterogeneity and temporal stability of baseflow stream chemistry in an urban watershed. *Water Resources Research*. 59: e2021WR031804.

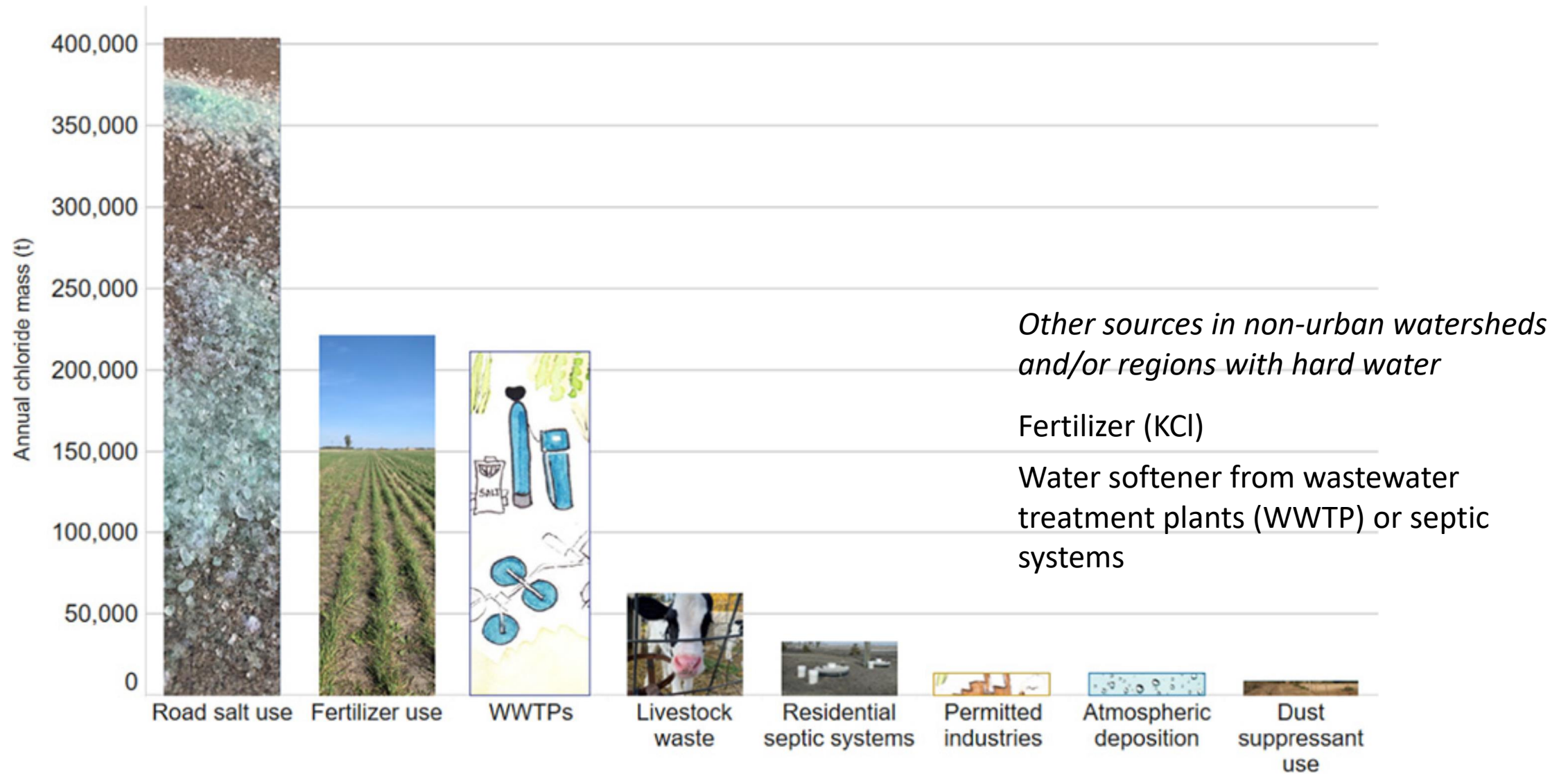
<https://doi.org/10.1029/2021WR031804>

Rapid growth of urban population & land use

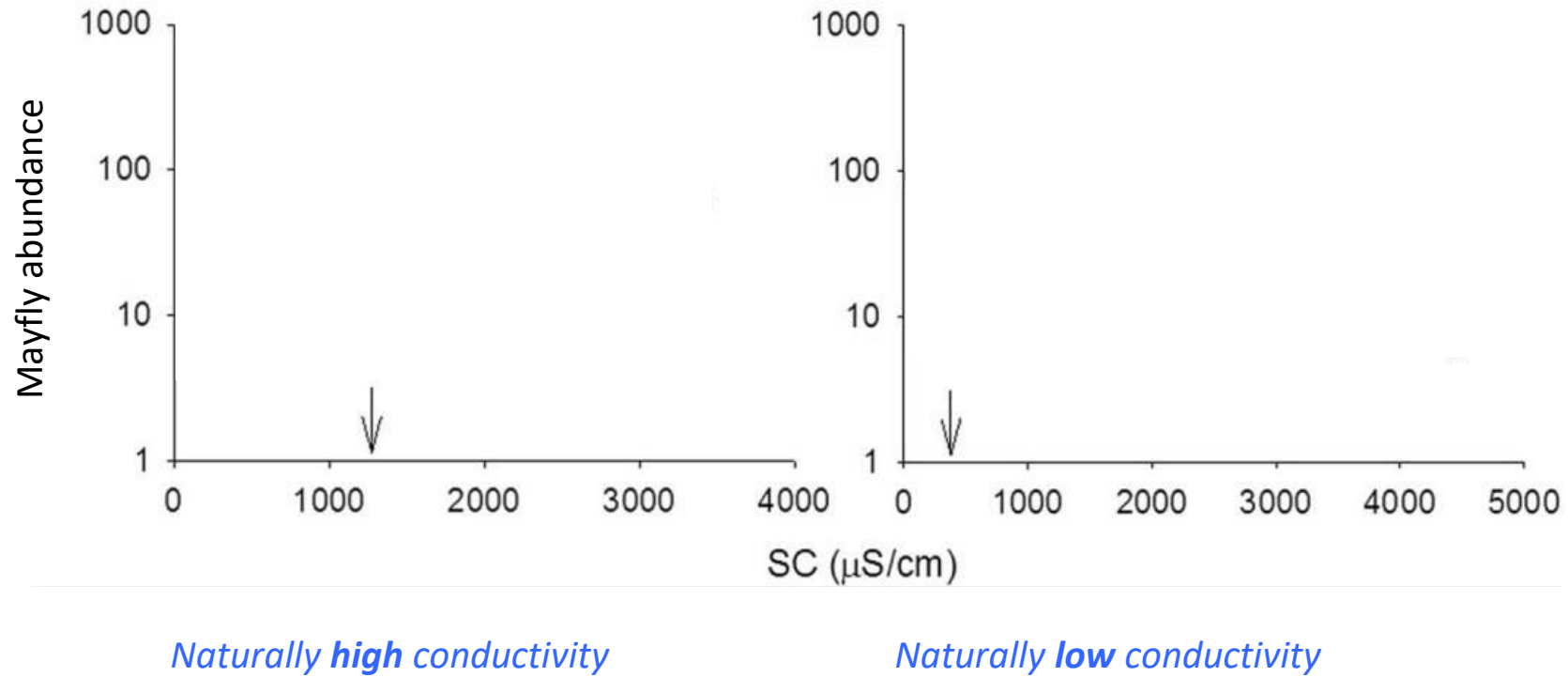


In some regions or watersheds: more than just deicers (but think rate)

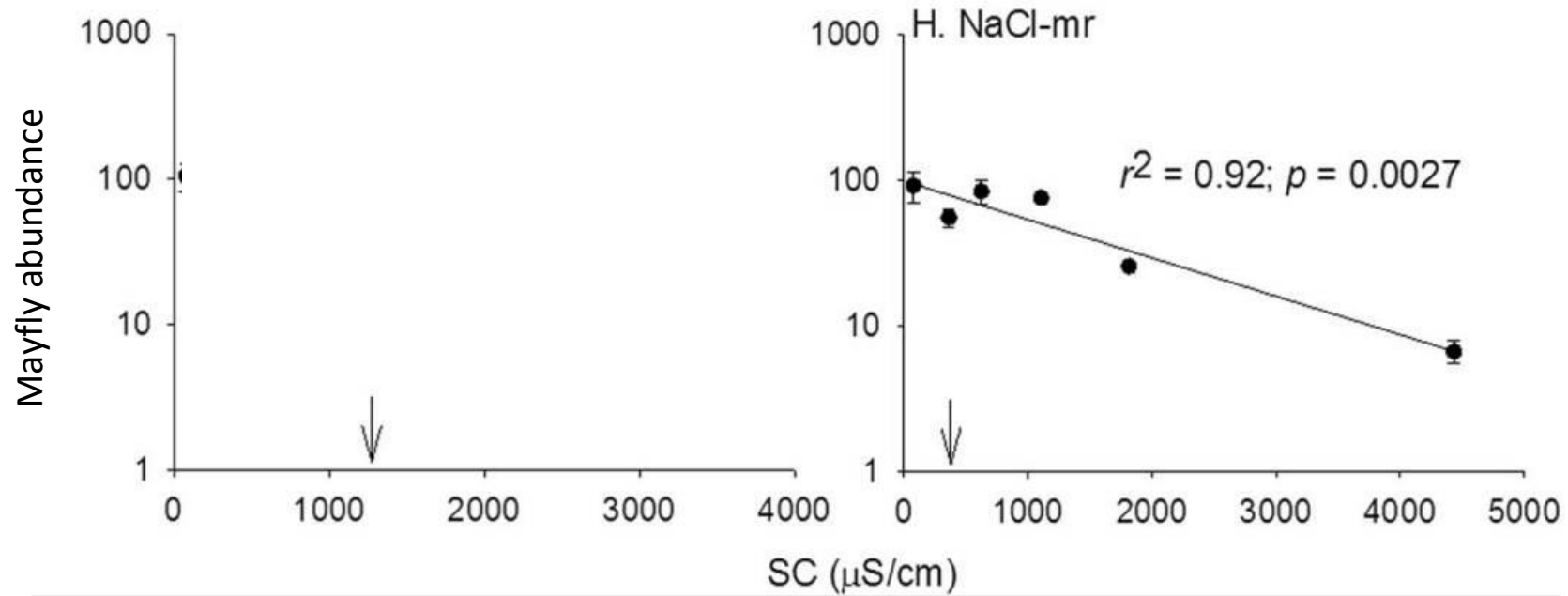
Annual chloride use in Minnesota



Aquatic life: Mayfly abundance vs specific conductance



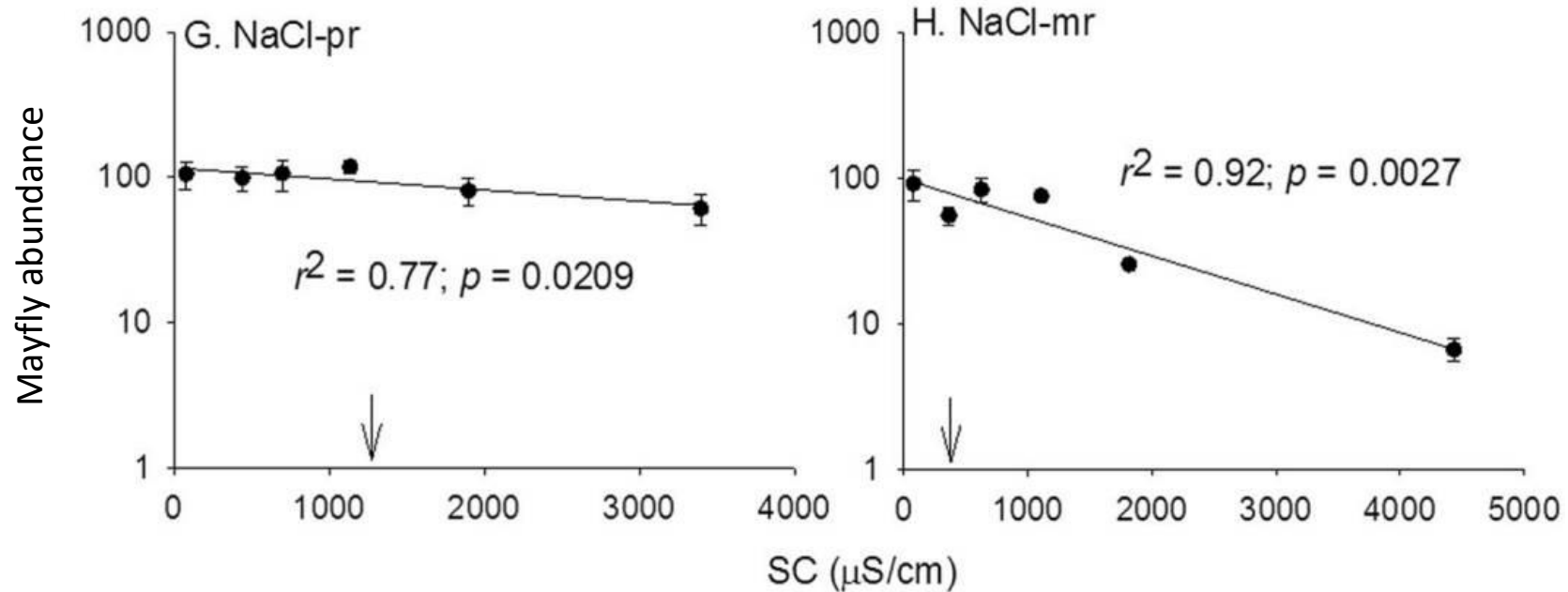
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Naturally **high** conductivity

Naturally **low** conductivity

Aquatic life: Mayfly abundance vs specific conductance



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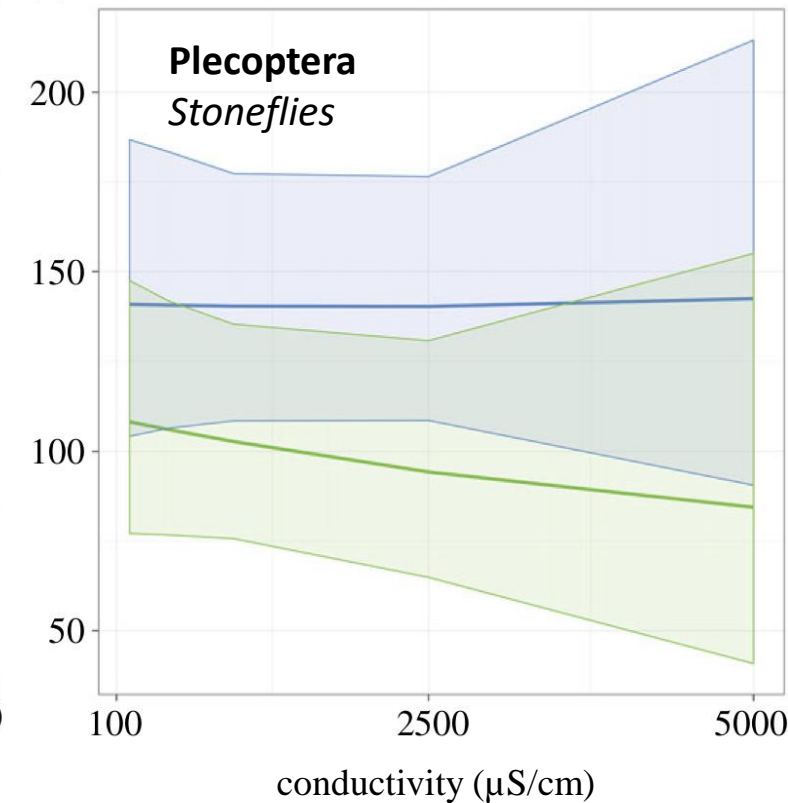
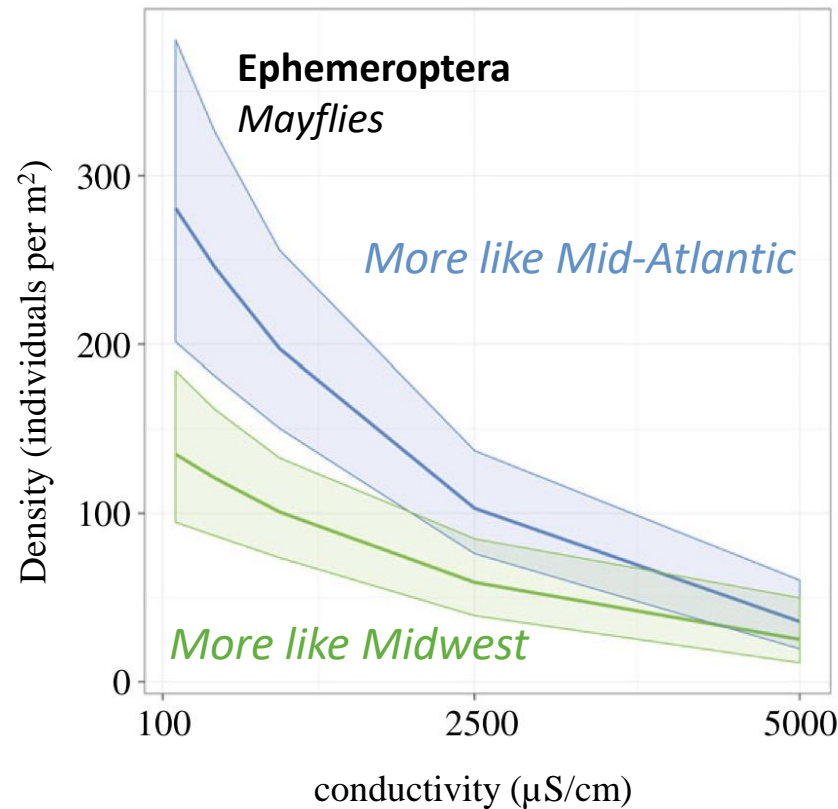
Naturally **low** conductivity

Deicing salt use negatively affects water quality (1)

Aquatic life

Direct: chloride toxicity

Indirect: elevated specific conductance (likely osmotic stress)



treatment

— salt-sensitive communities

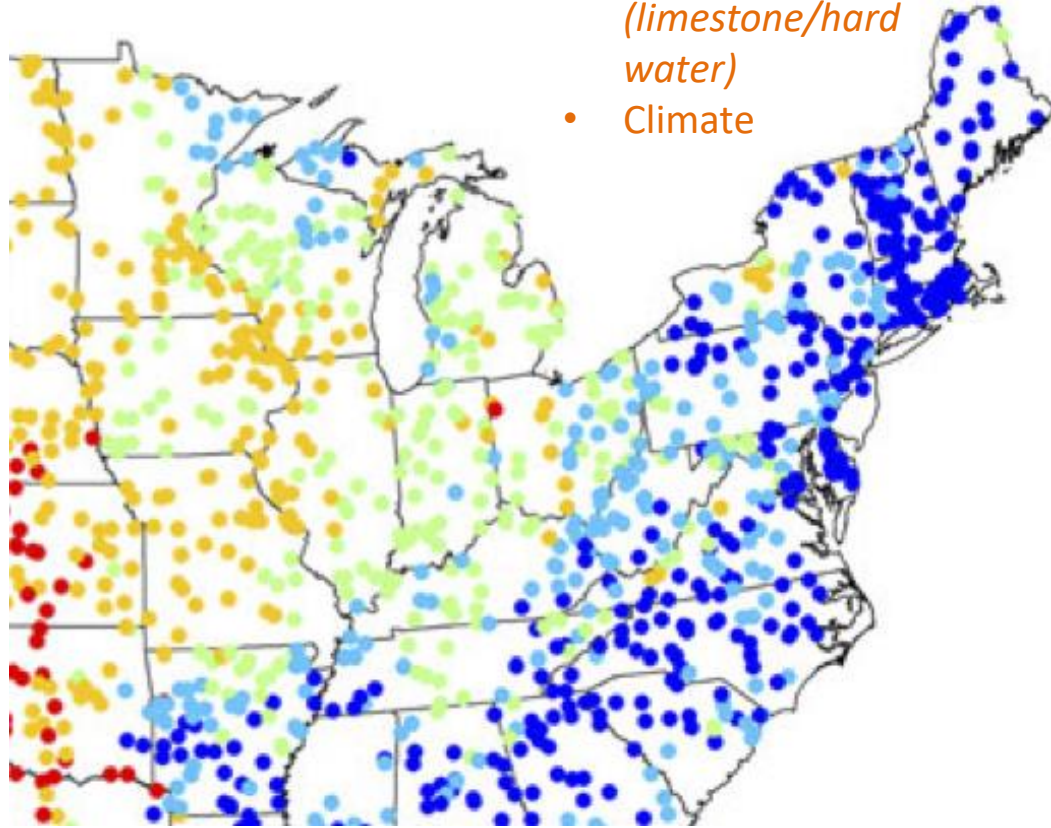
— salt-tolerant and sensitive communities

Conductivity across Midwest & US (commonly correlated with chloride)

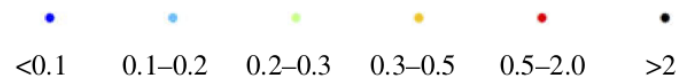
Predicted: background

Biggest Factors

- Bedrock & soil
(limestone/hard water)
- Climate



predicted natural background EC at NRSA sites (mS cm^{-1})

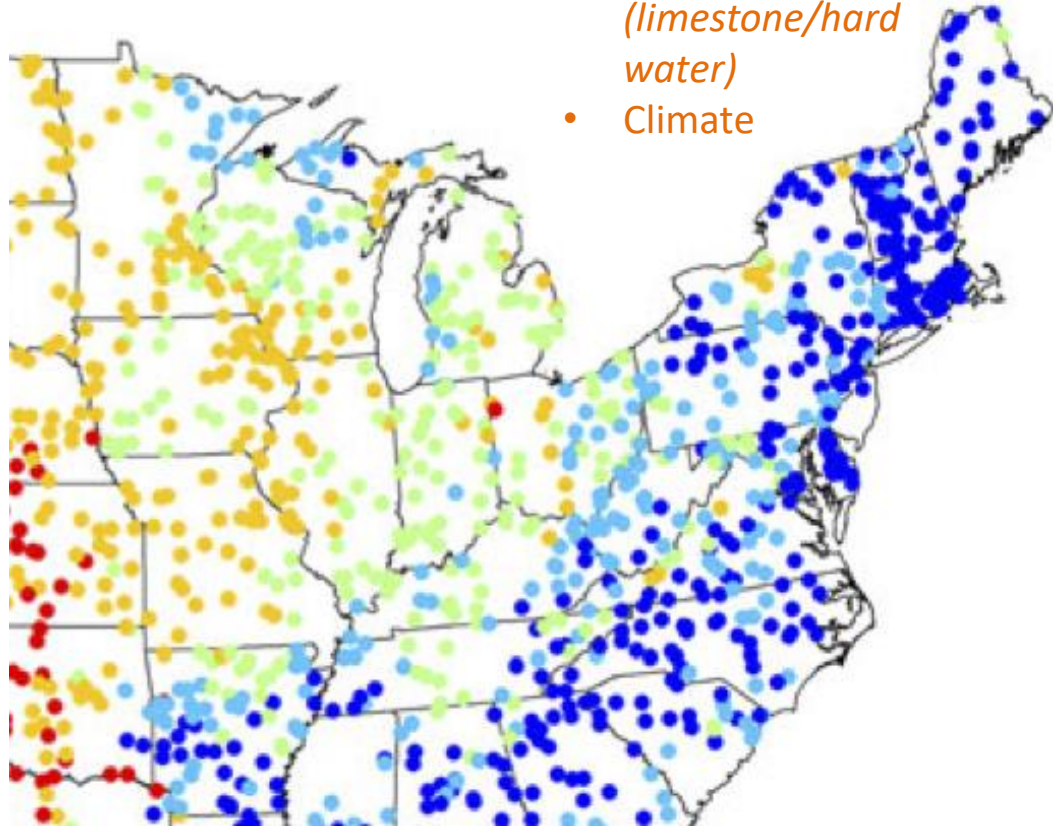


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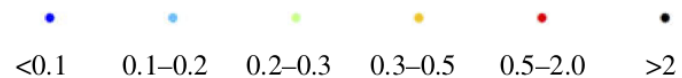
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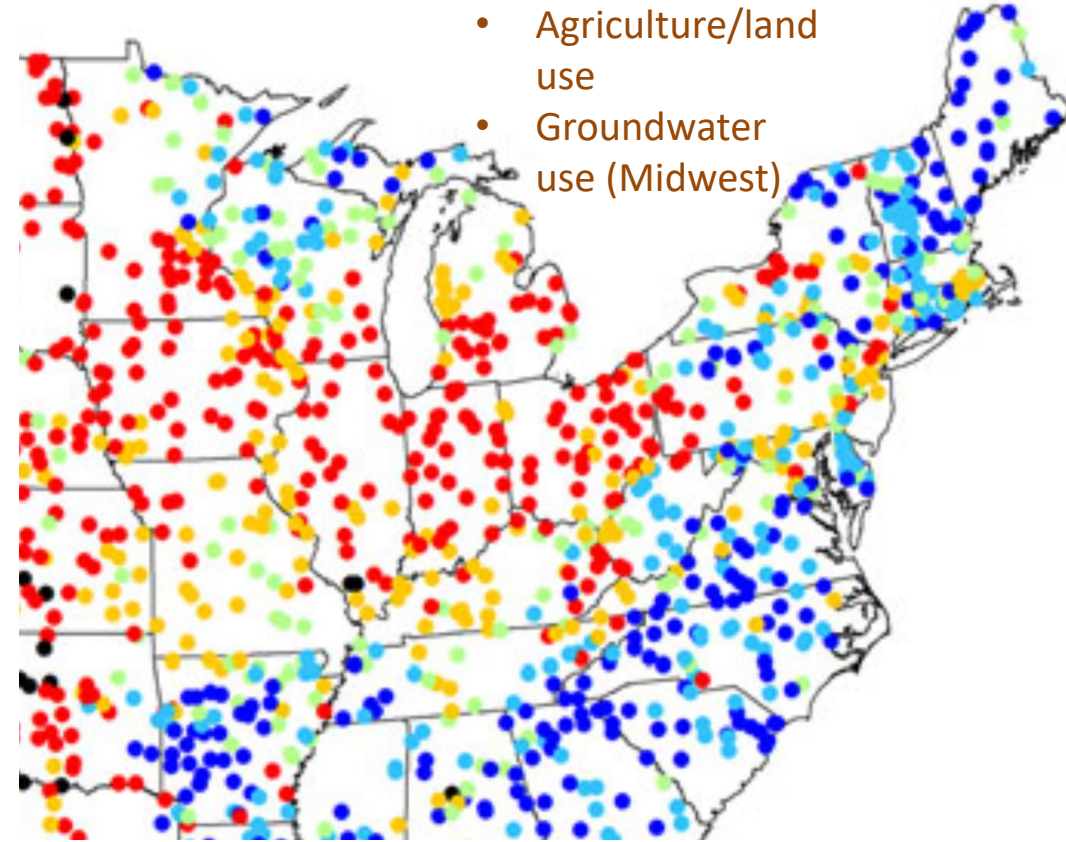


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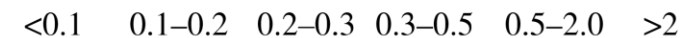


Reasons for change

- Deicing salts
- Agriculture/land use
- Groundwater use (Midwest)



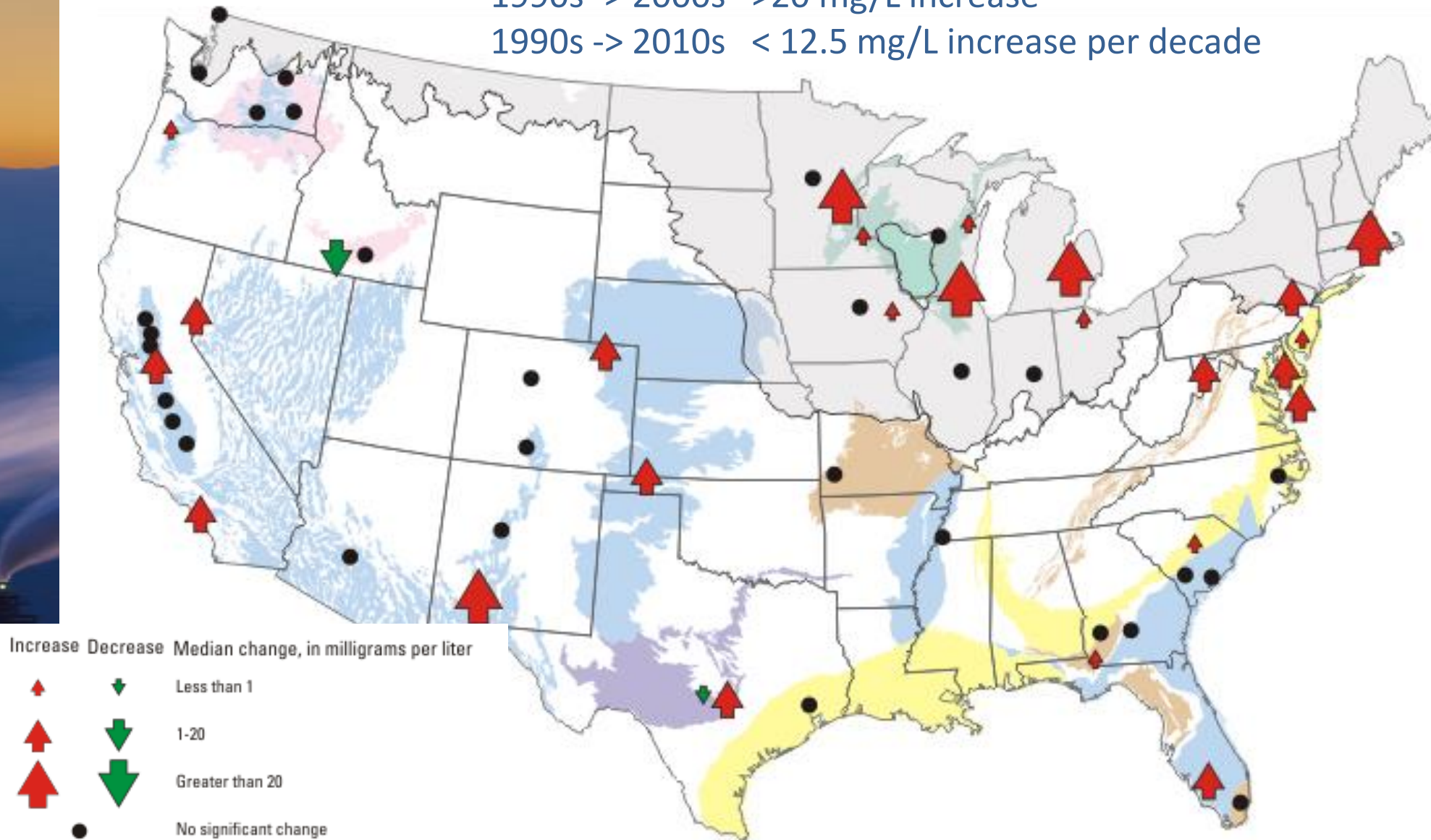
observed EC at NRSA sites (mS cm^{-1})



Of course chloride in groundwater is increasing too

1990s -> 2000s >20 mg/L increase

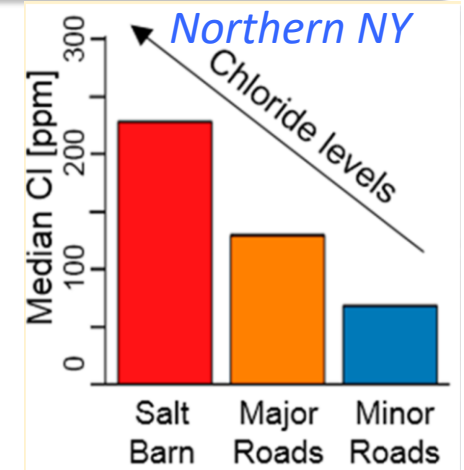
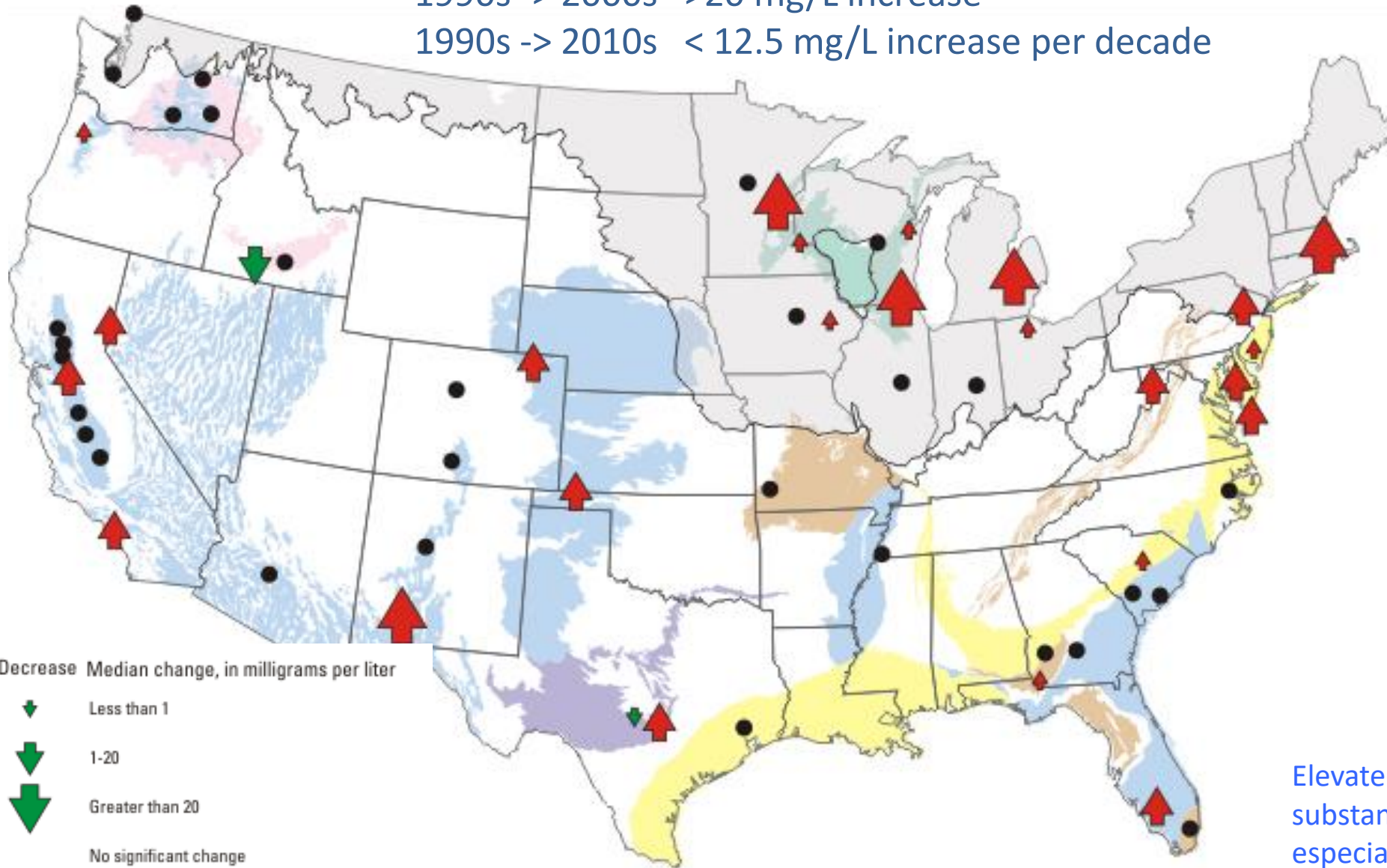
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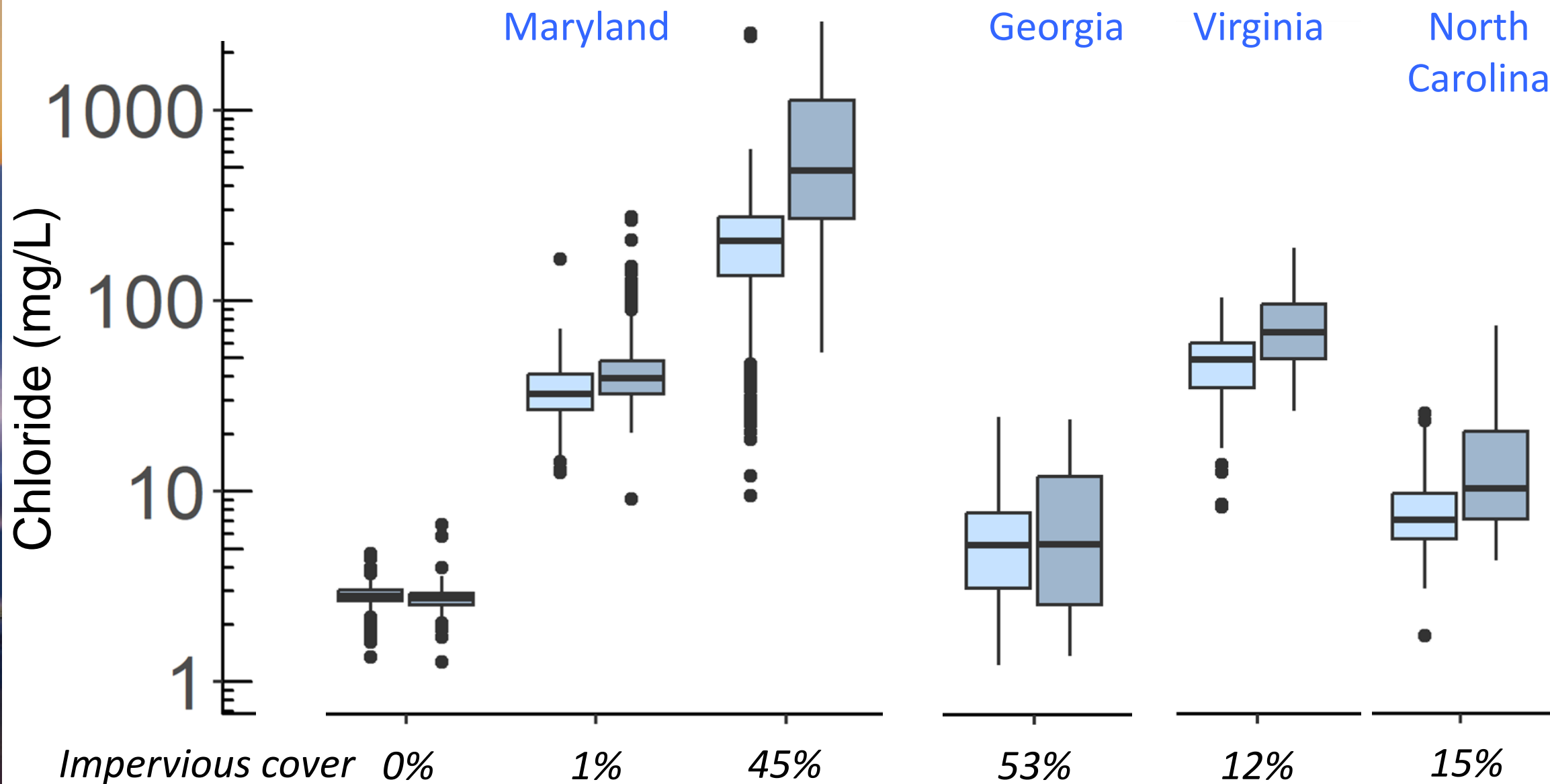
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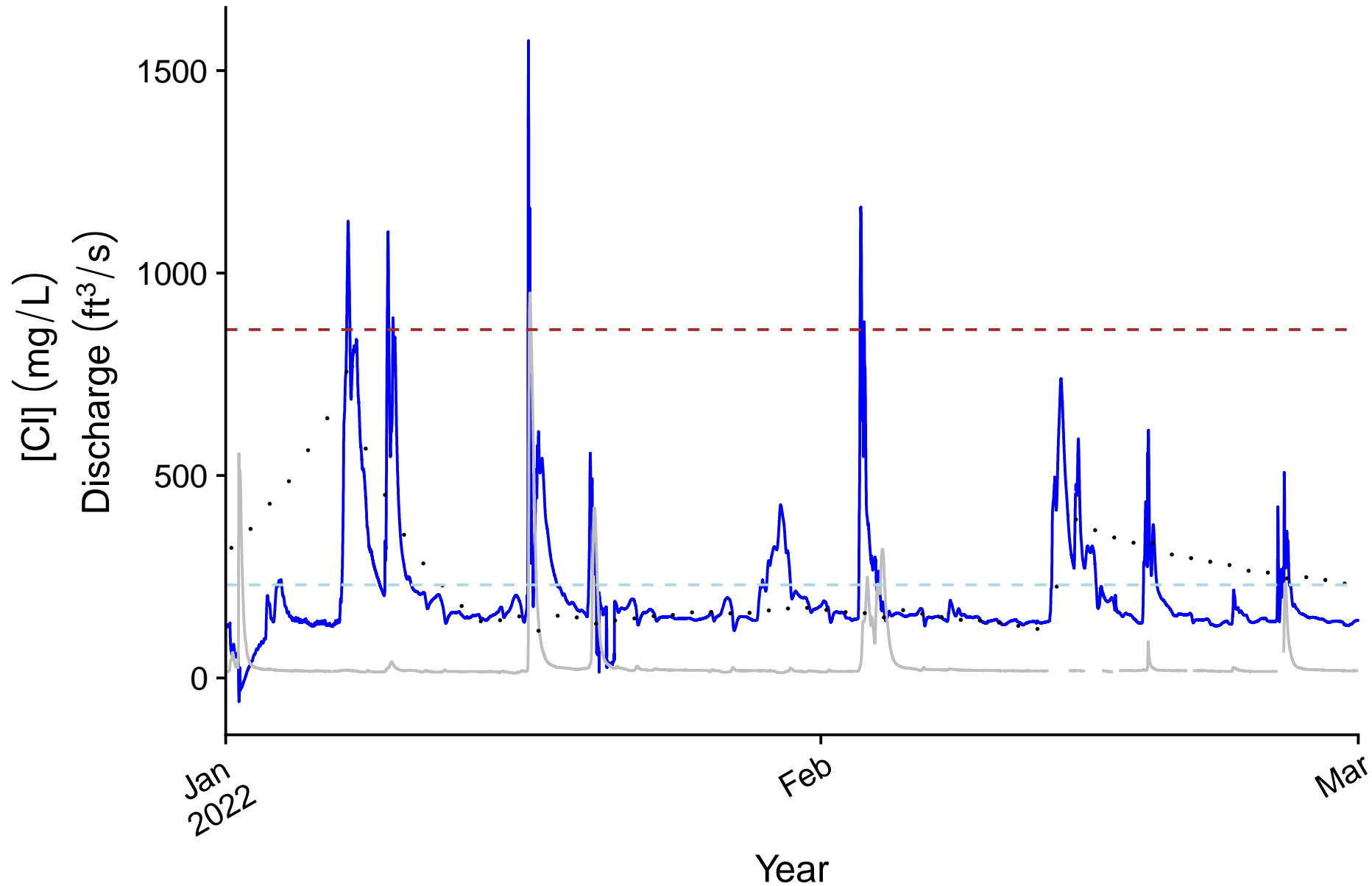


Elevated/increasing chloride causes substantial corrosivity increases especially in soft water

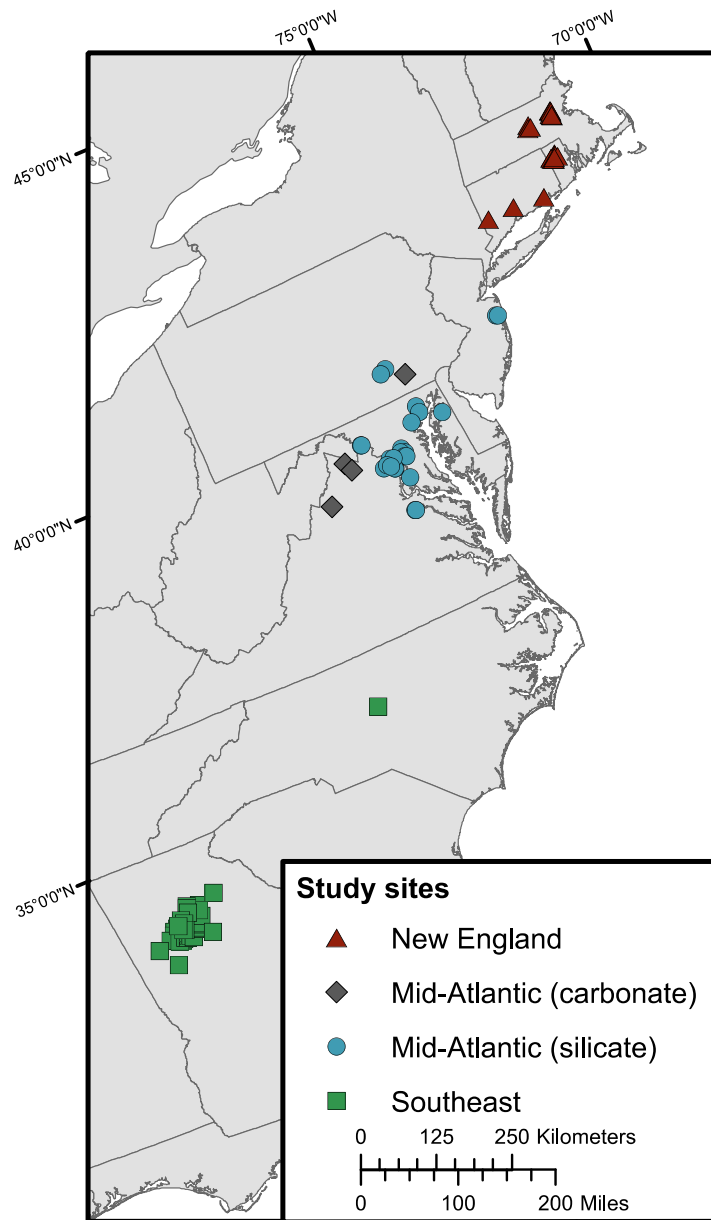
Seasonal differences between north & south



Sensor versus discrete: Beaver Dam Run, Cockeysville



Study #1: Chloride & conductivity along East Coast (2008 – 18)

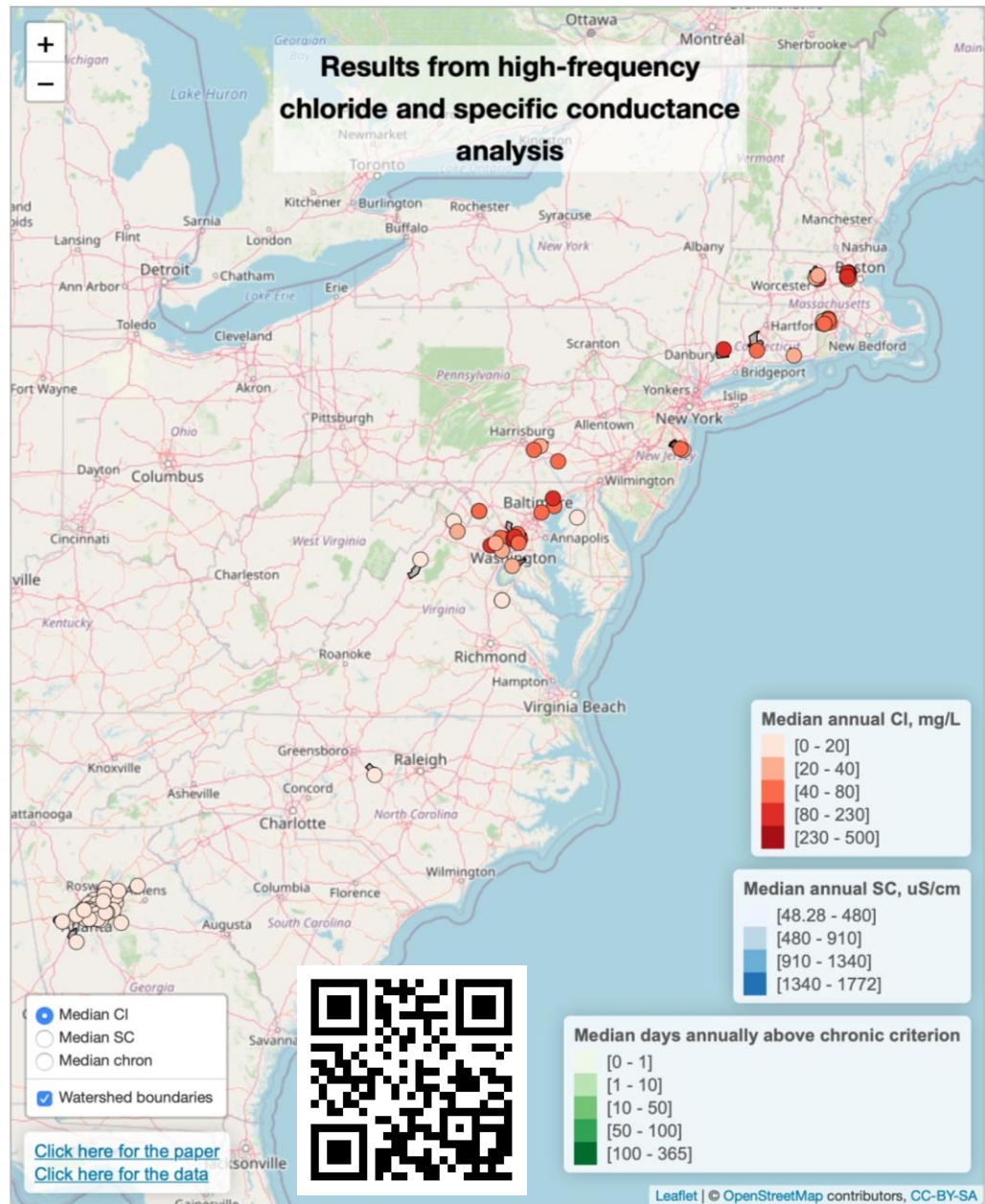


93 sites with 3–11 years of high-frequency data
- 2-min to 15-min

56 sites with ≥ 20 discrete chloride (Cl) & specific conductivity (SC) data

Nearly **30 million** observations

Study #1: Key takeaway points for this group



1) Elevated Cl & SC correlate with impervious surface cover within each region a

- Southeast
- Mid-Atlantic
- New England

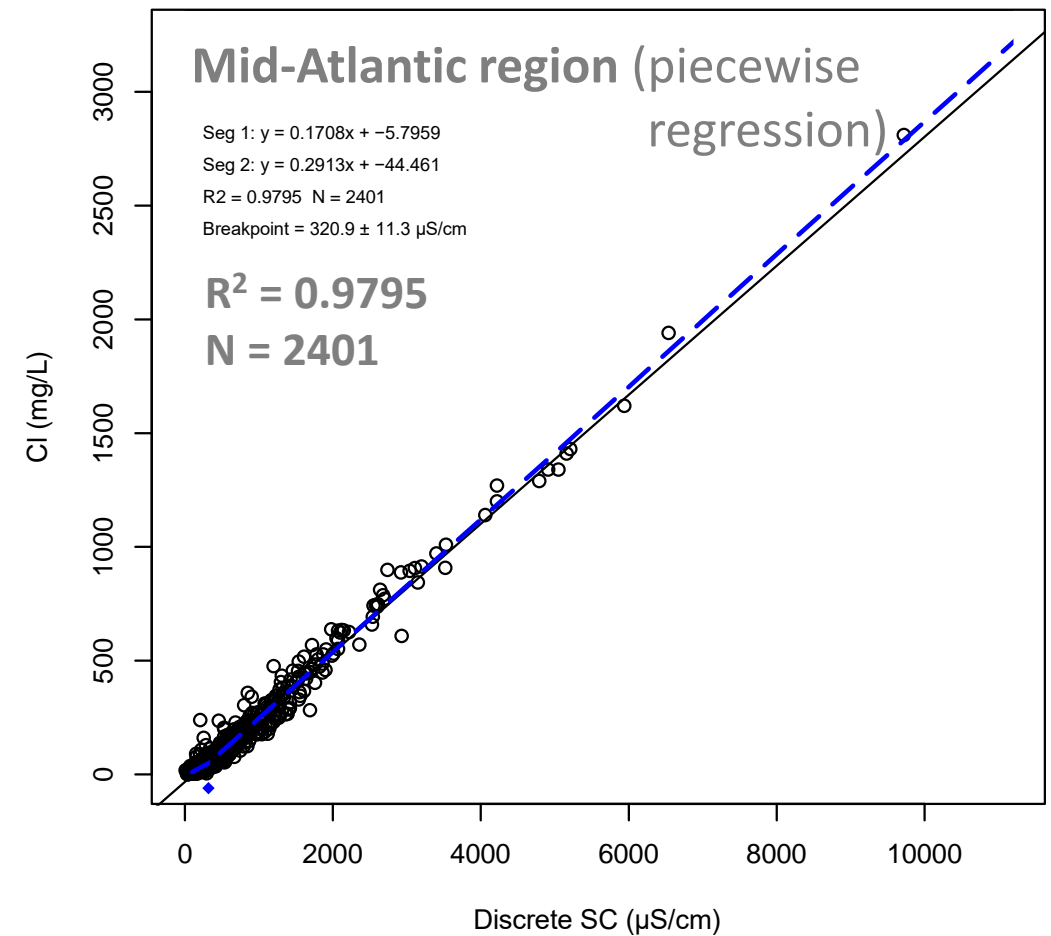
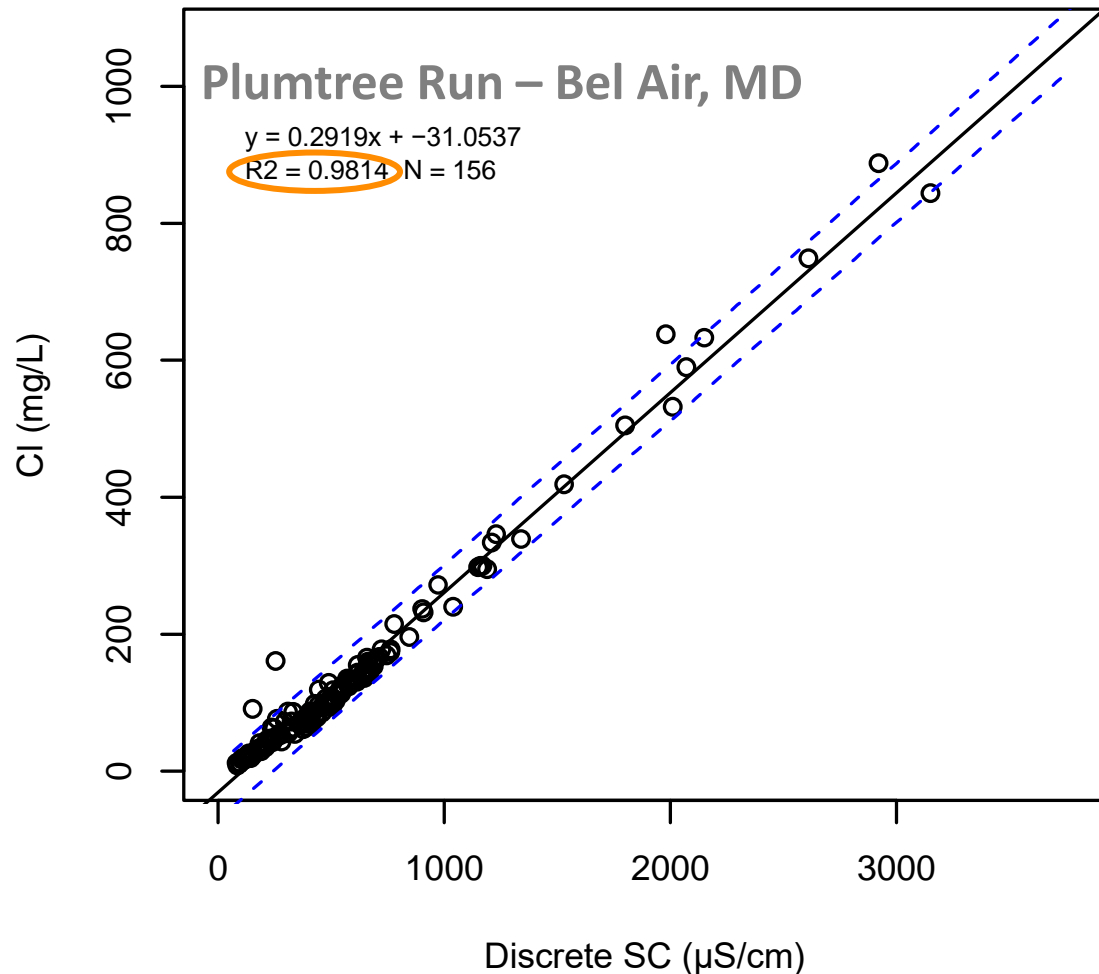
and increase from south to north

2) High Cl periods, *e.g.*, exceedance of US EPA Cl chronic criteria for aquatic life*, correlate with impervious surface cover and median Cl concentrations

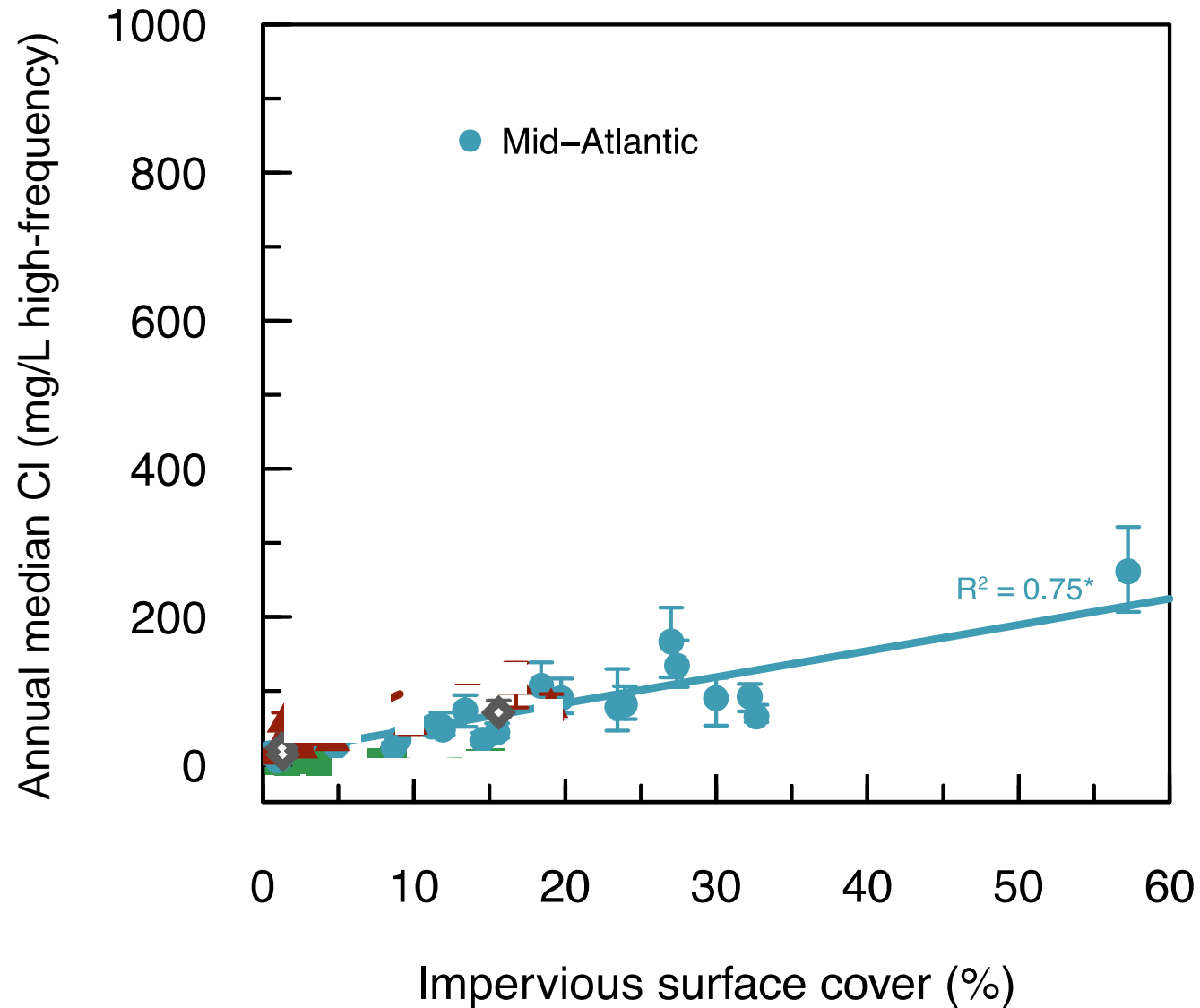
* *Chronic*: 4-day period with average Cl concentration higher than 230 mg/L, not to be exceeded more than 1x in 3 years

Chloride & specific conductance (SC) highly correlated for sites & regions

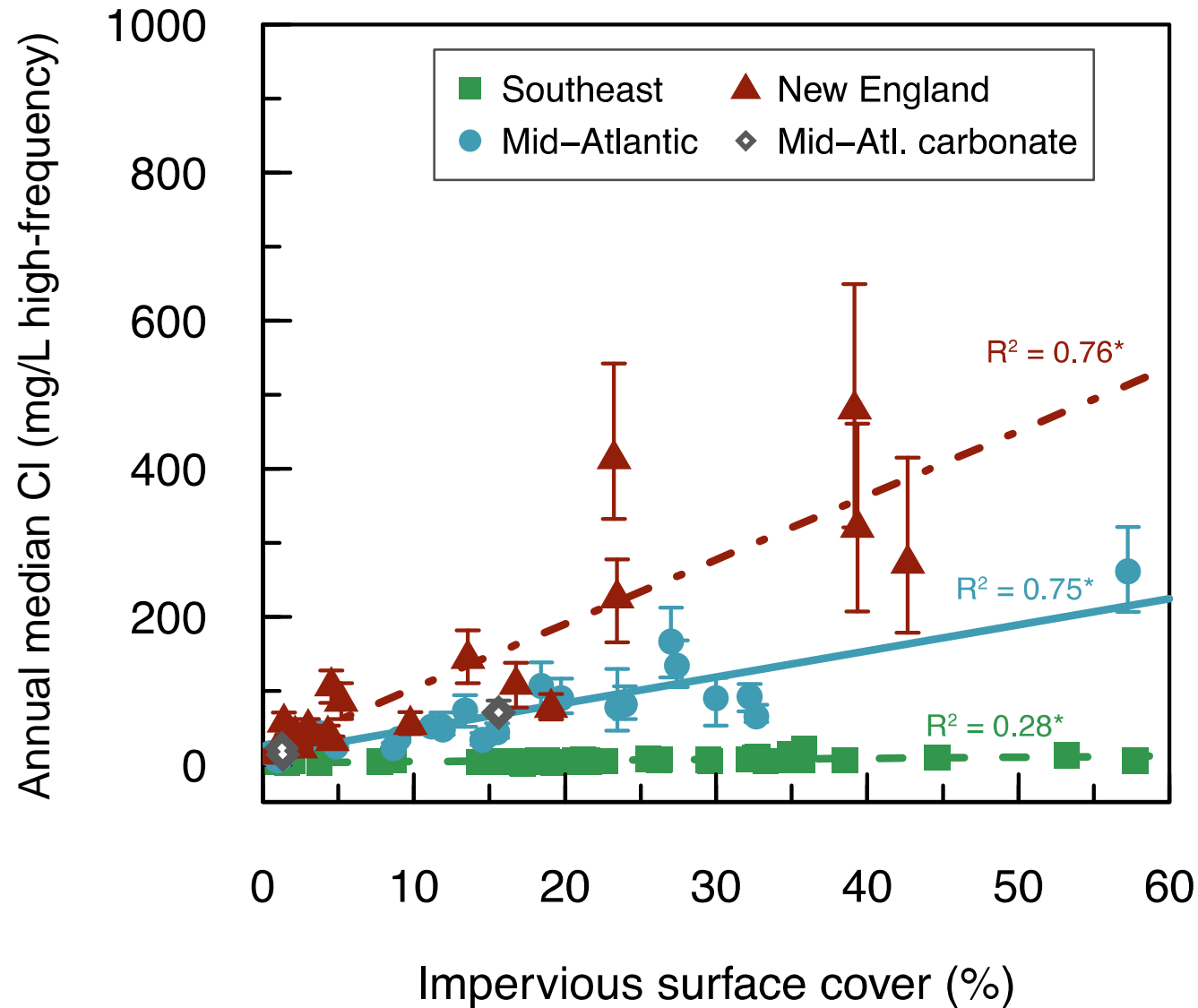
Discrete Cl vs SC High correlation means that high-frequency SC can be used to calculate chloride concentrations *even at (silicate) sites without discrete [Cl] data*



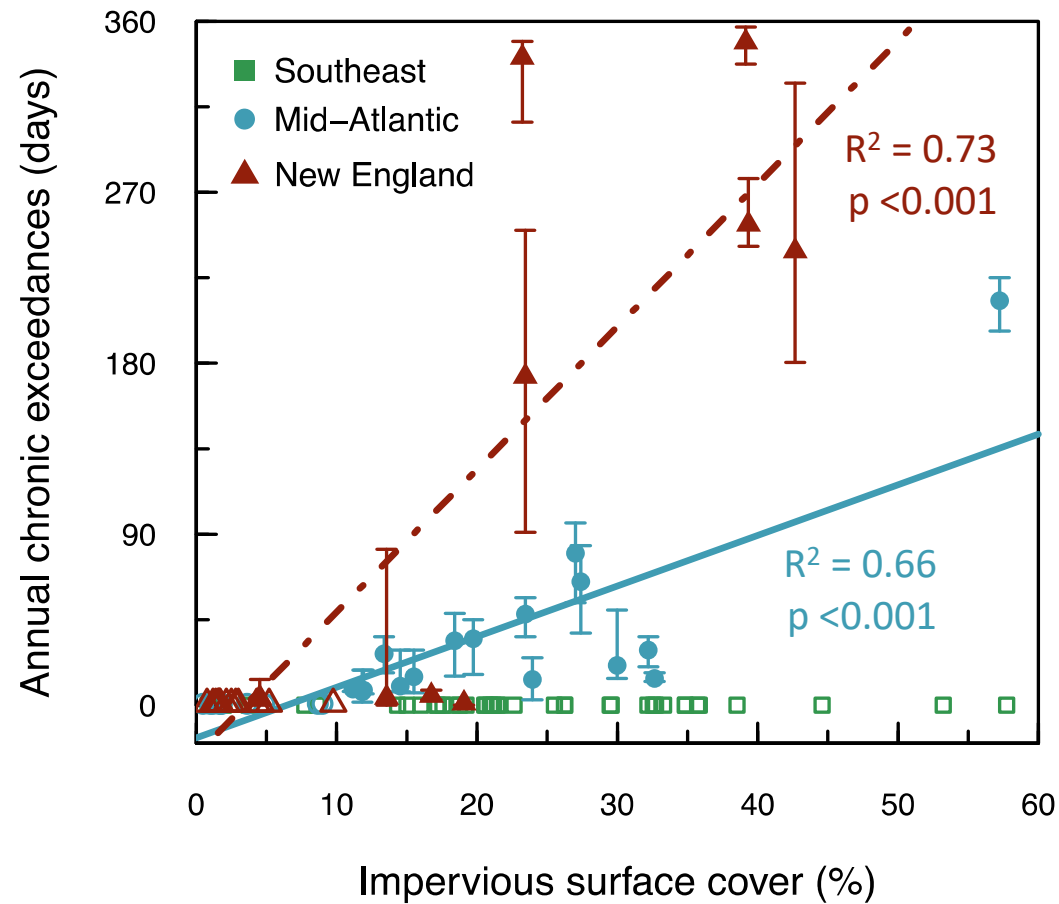
Study #1: Point 1, CI correlation with impervious surface cover



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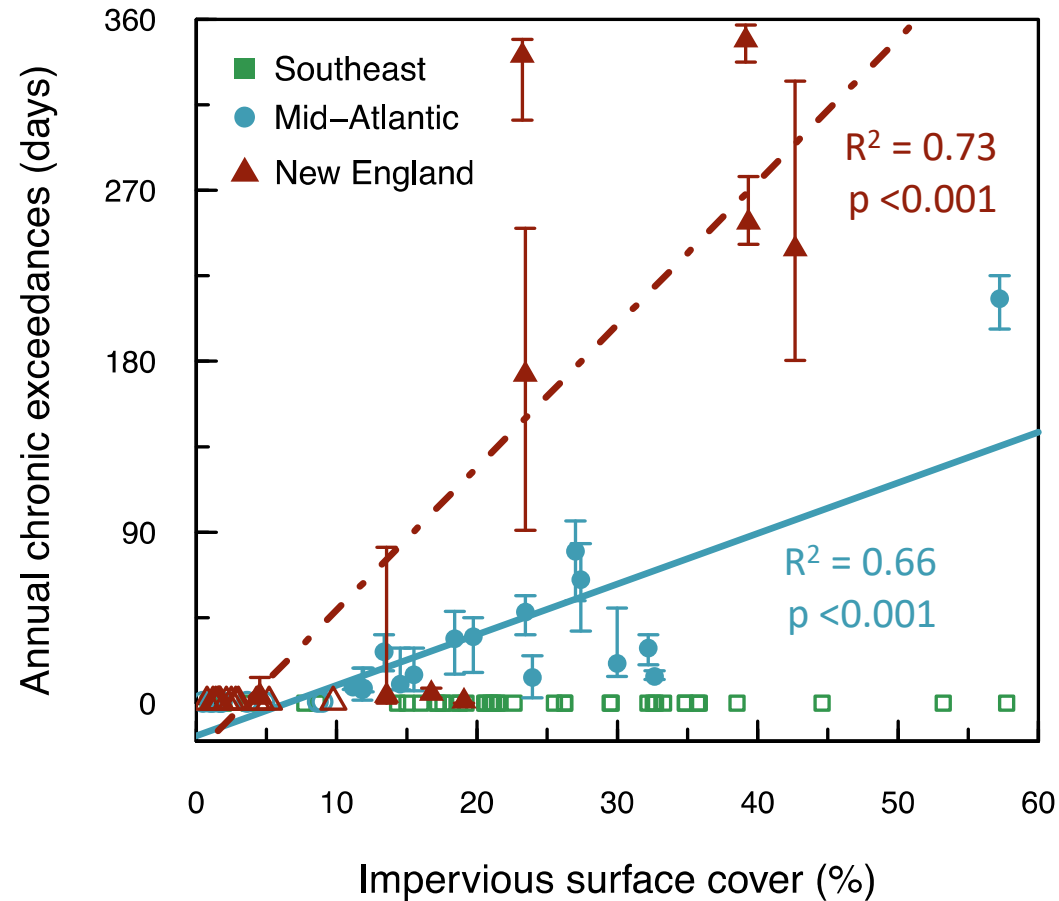
Study #1: Point 2, CI exceedances with impervious surfaces



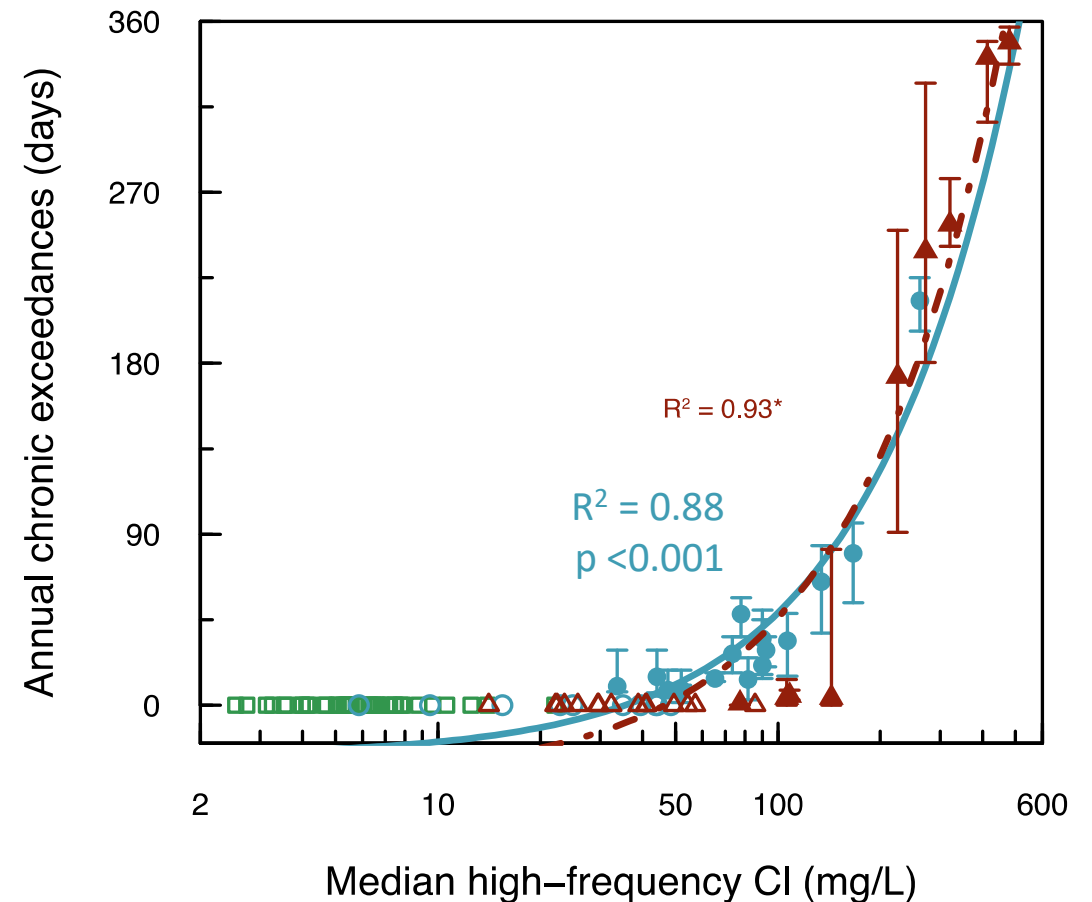
For Mid-Atlantic & New England

All watersheds with >9% ISC
exceed frequently each year

Study #1: Point 2, CI exceedances with impervious surfaces & [CI]



For Mid-Atlantic & New England
All watersheds with >9% ISC
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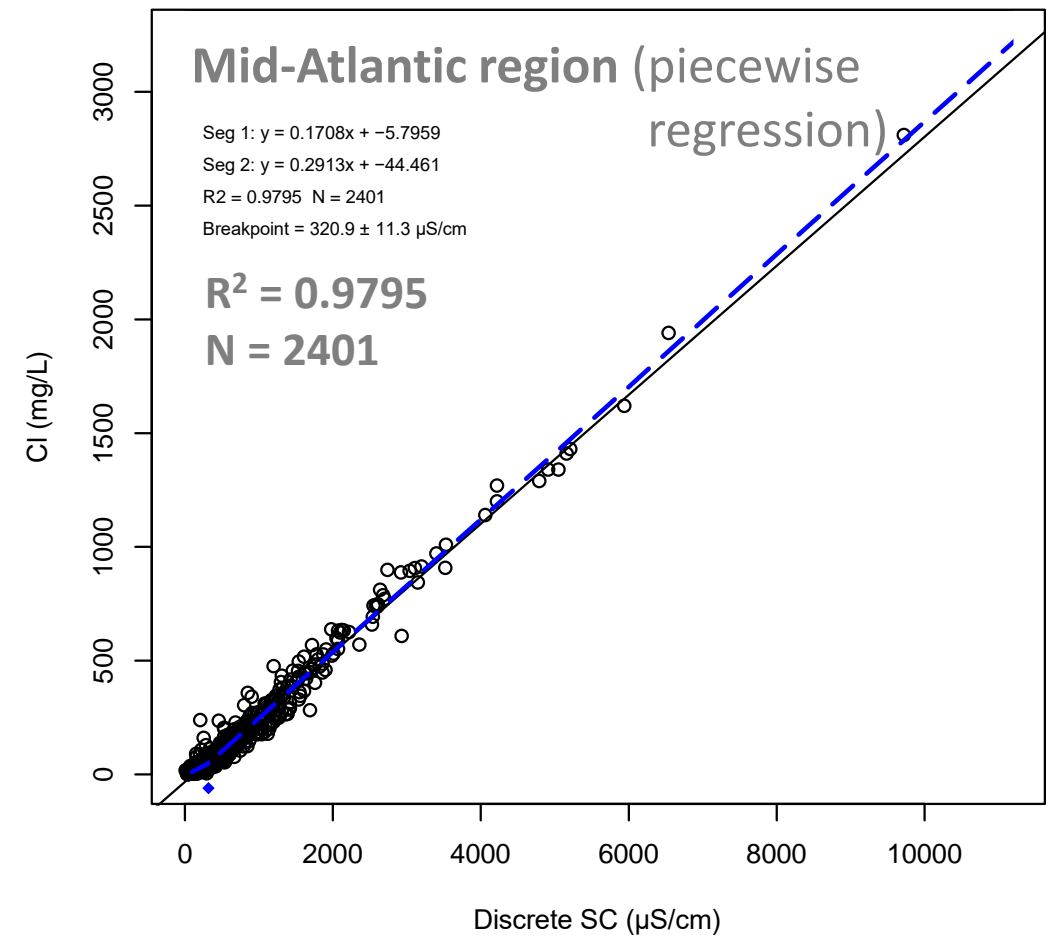
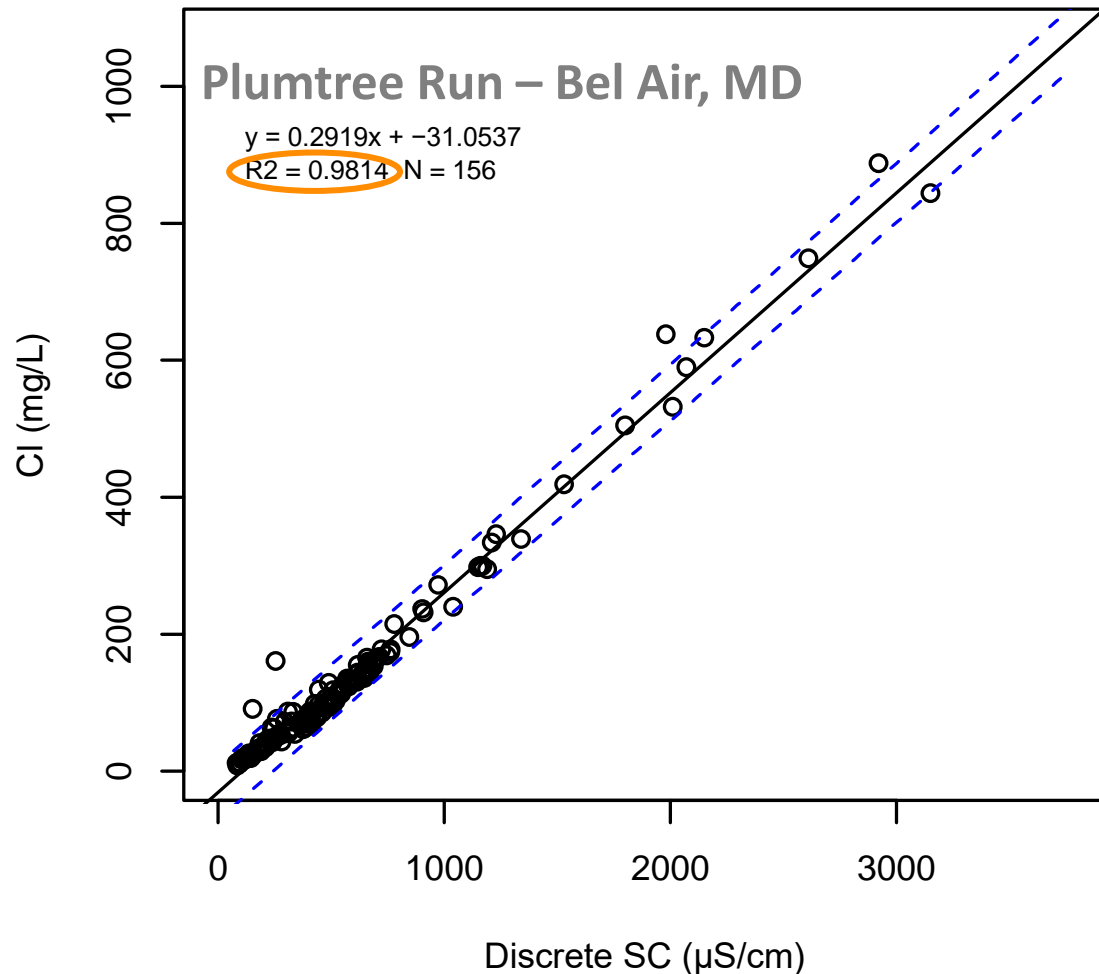


*Watersheds with >30–80 mg Cl/L exceed
frequently each year*

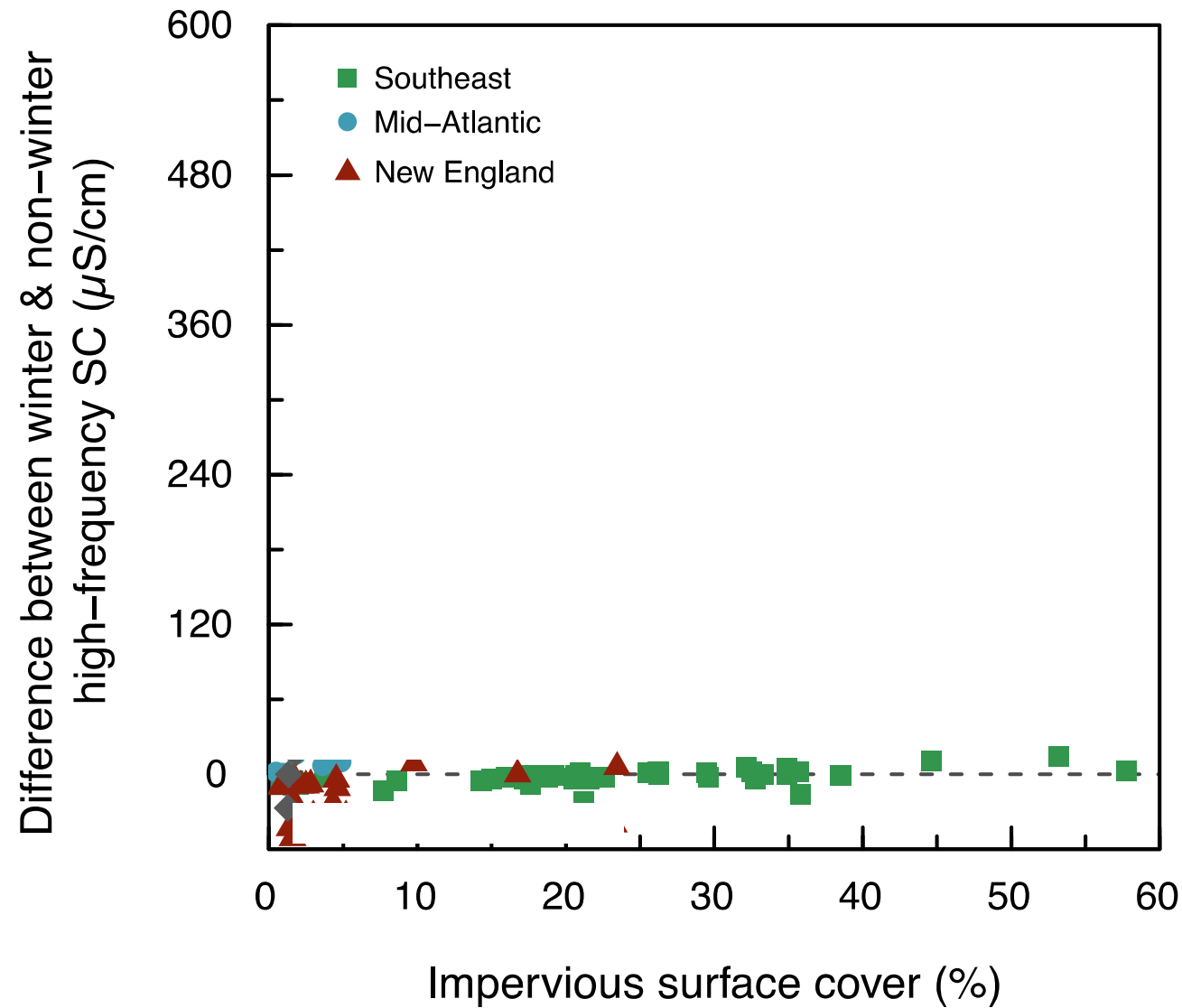
Helps explain ecological findings

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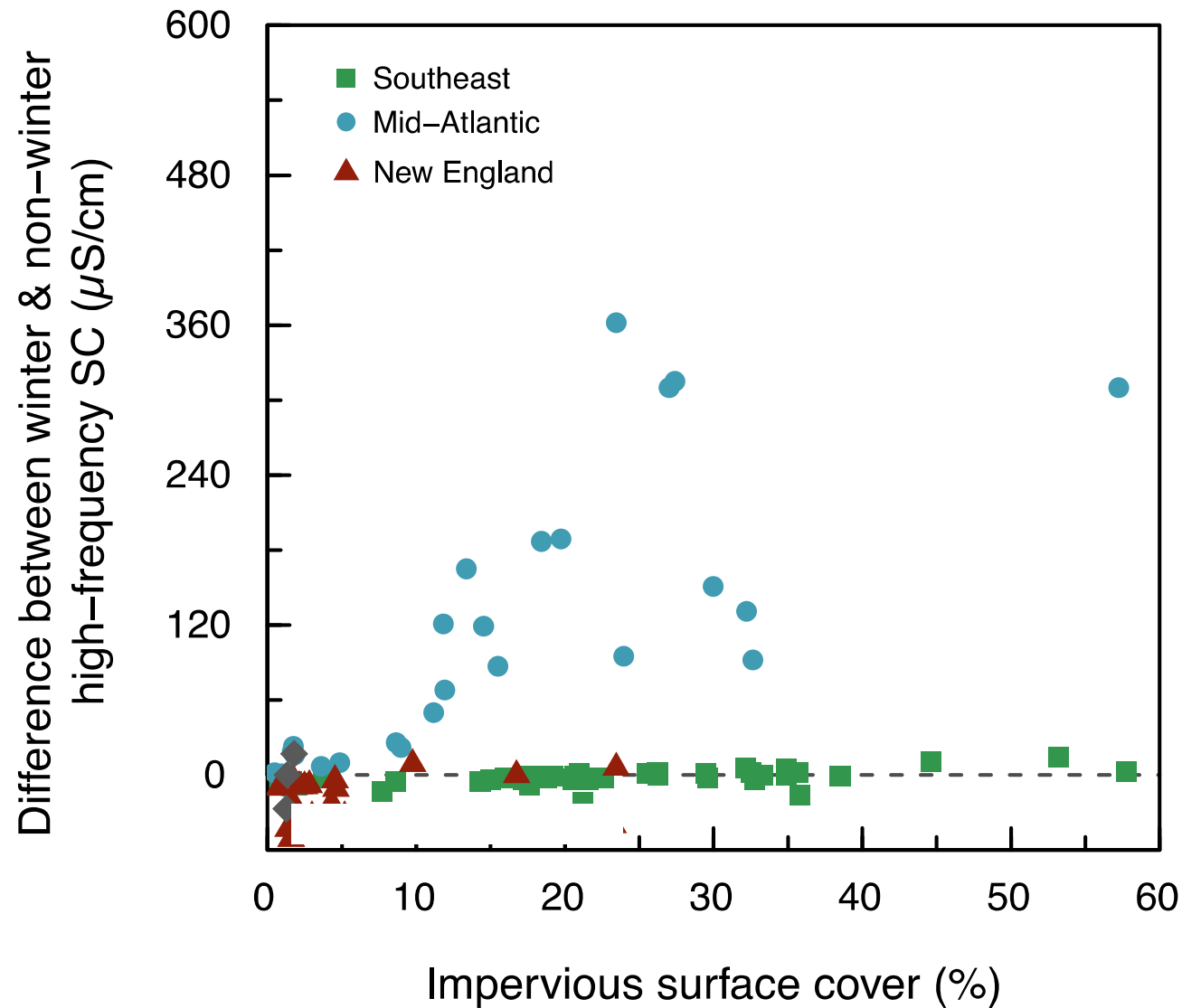


Median winter versus non-winter [Cl] differences suggest differing dynamics



Southeast: same within 2–3 mg/L

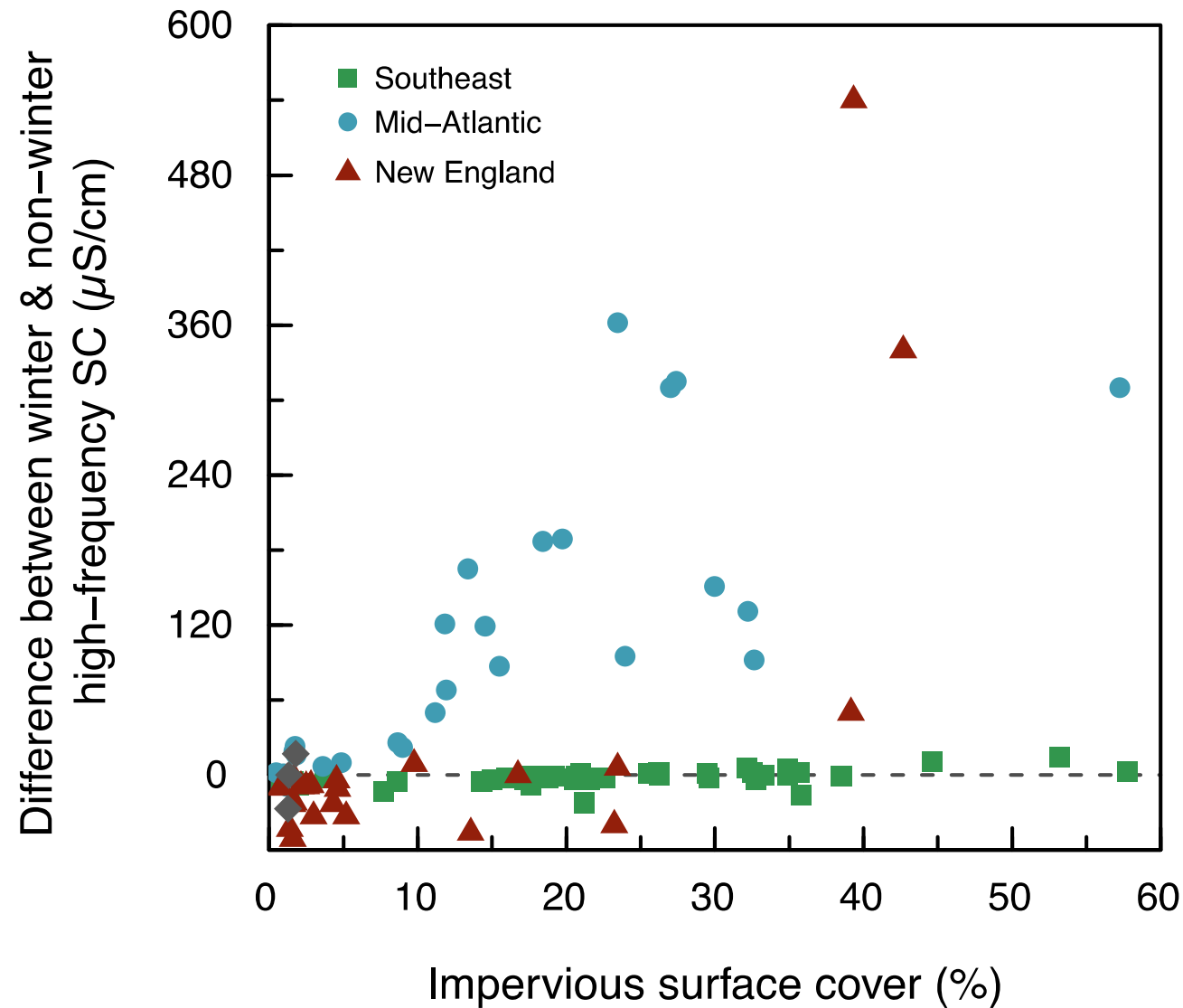
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- Difference generally increases with ISC

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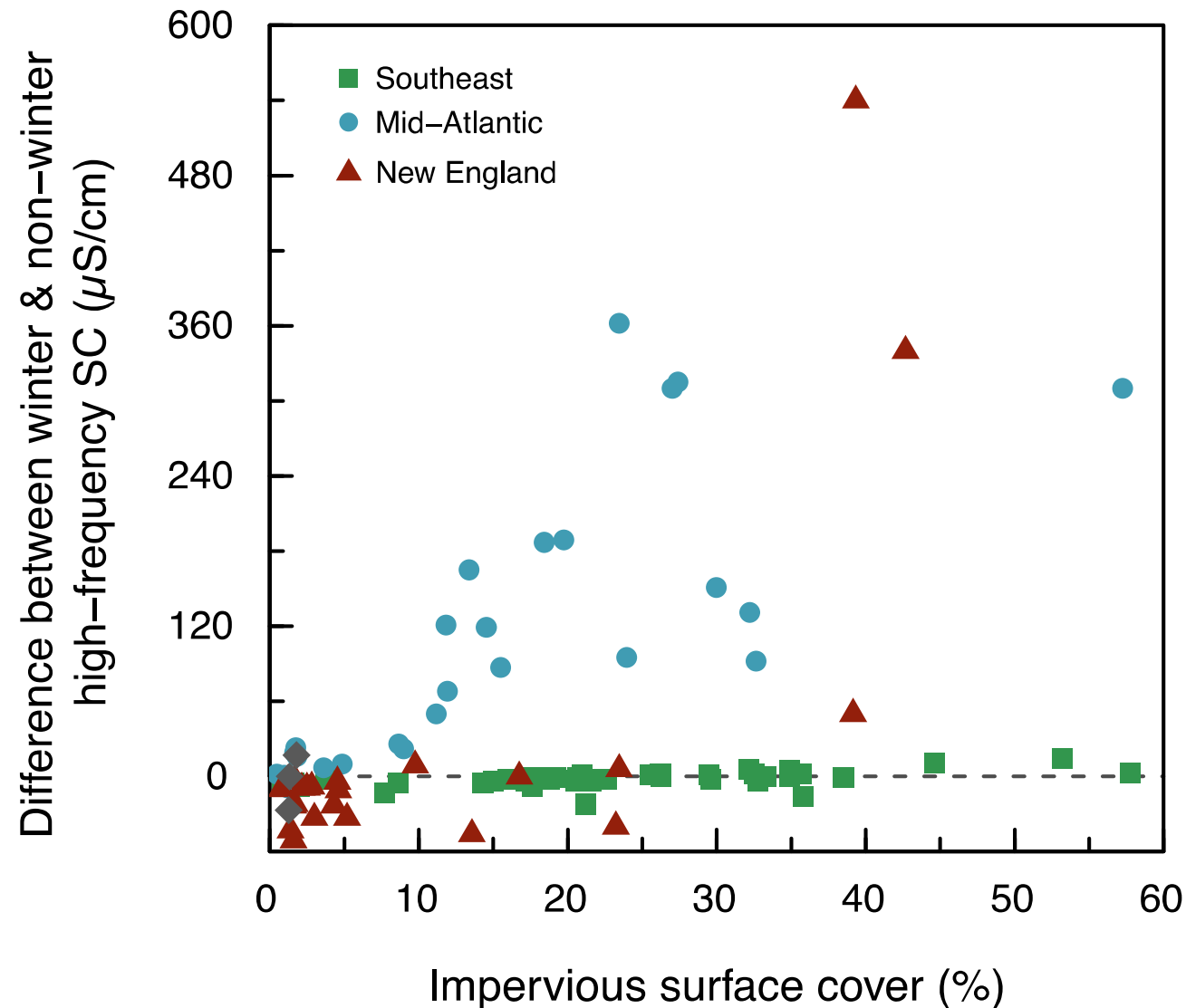


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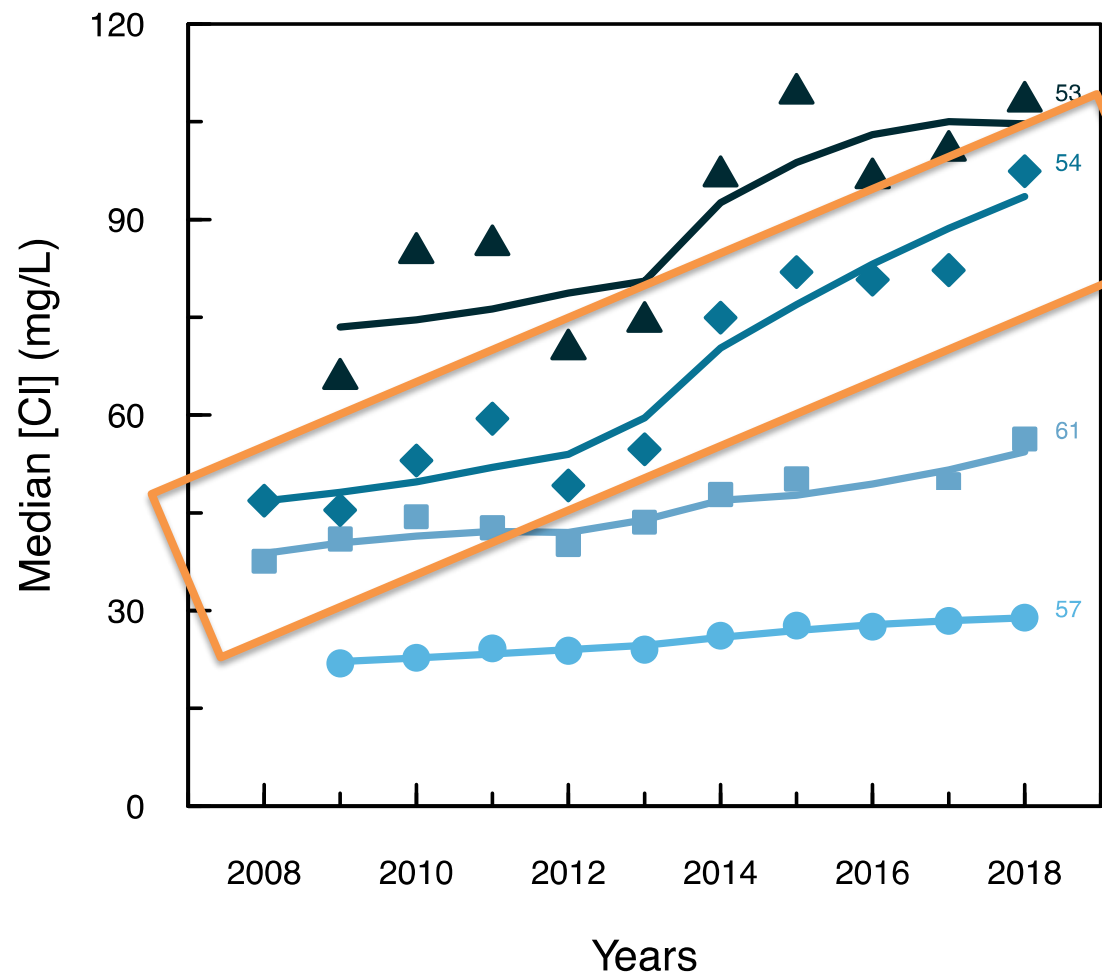
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New England: Winter & non-winter similar within 30–60 mg/L except for 2 sites

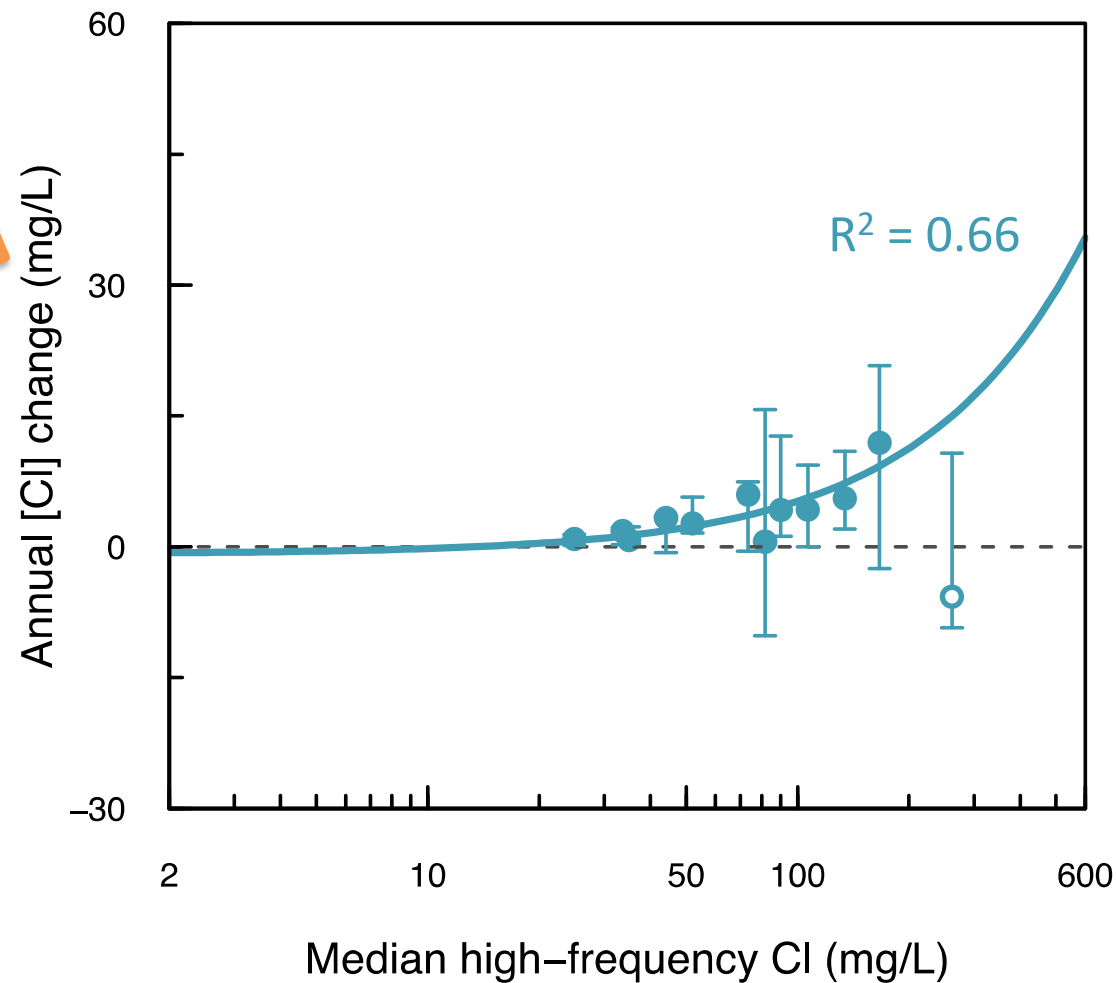
Chloride export dynamics will be different between Mid-Atlantic & New England
- Mid-Atlantic: Primarily winter export
- New England: Maybe more non-winter?

It's getting worse: [Cl] increasing fastest where highest

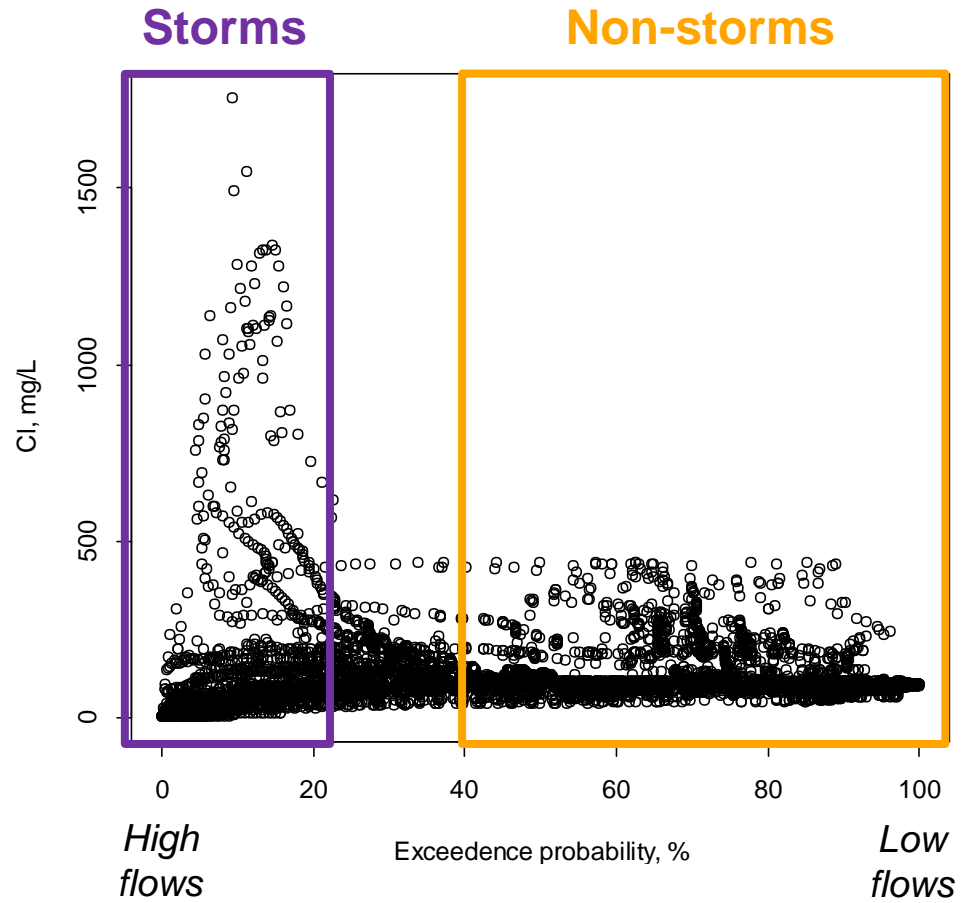
Mid-Atlantic examples: ISC 5–25%



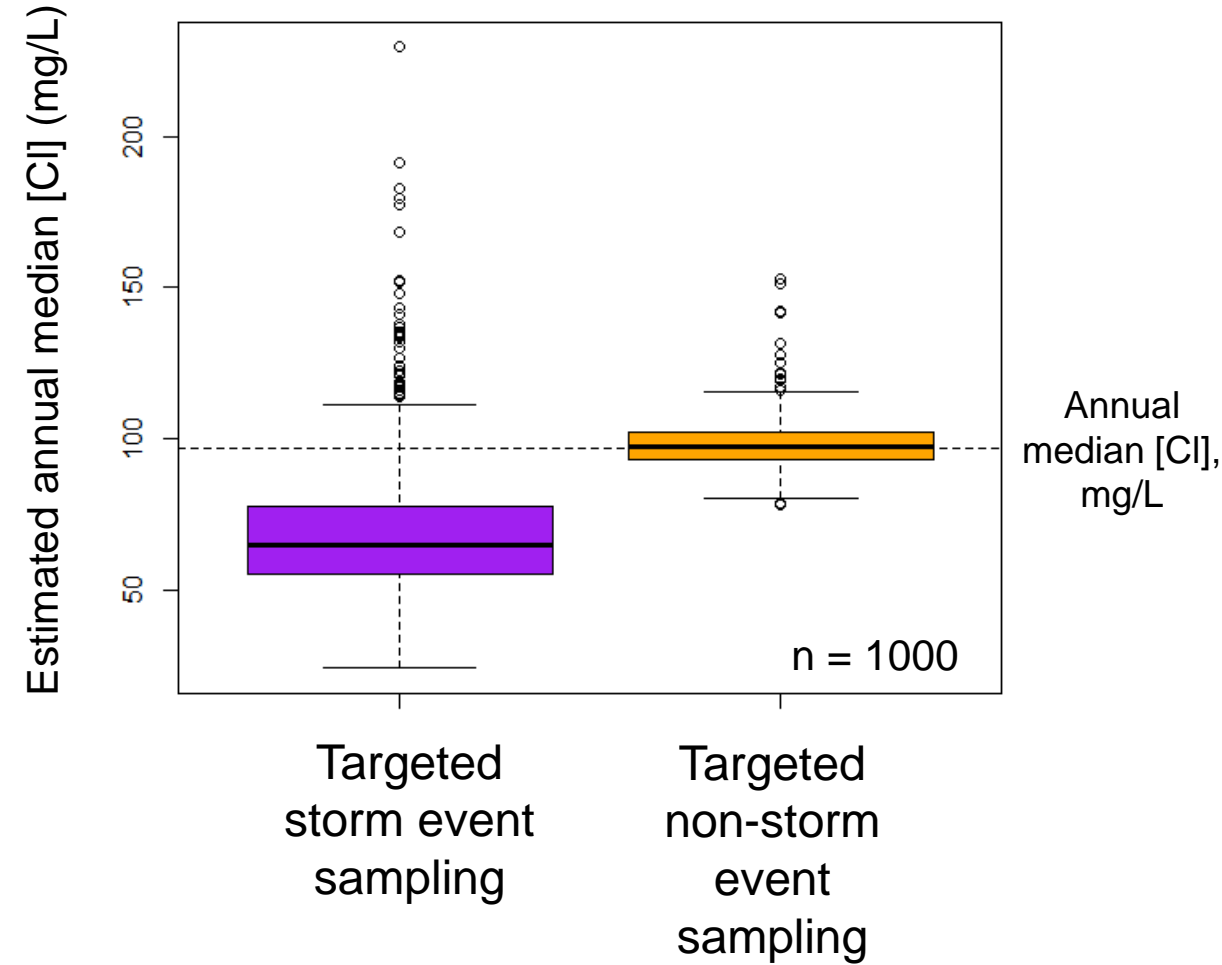
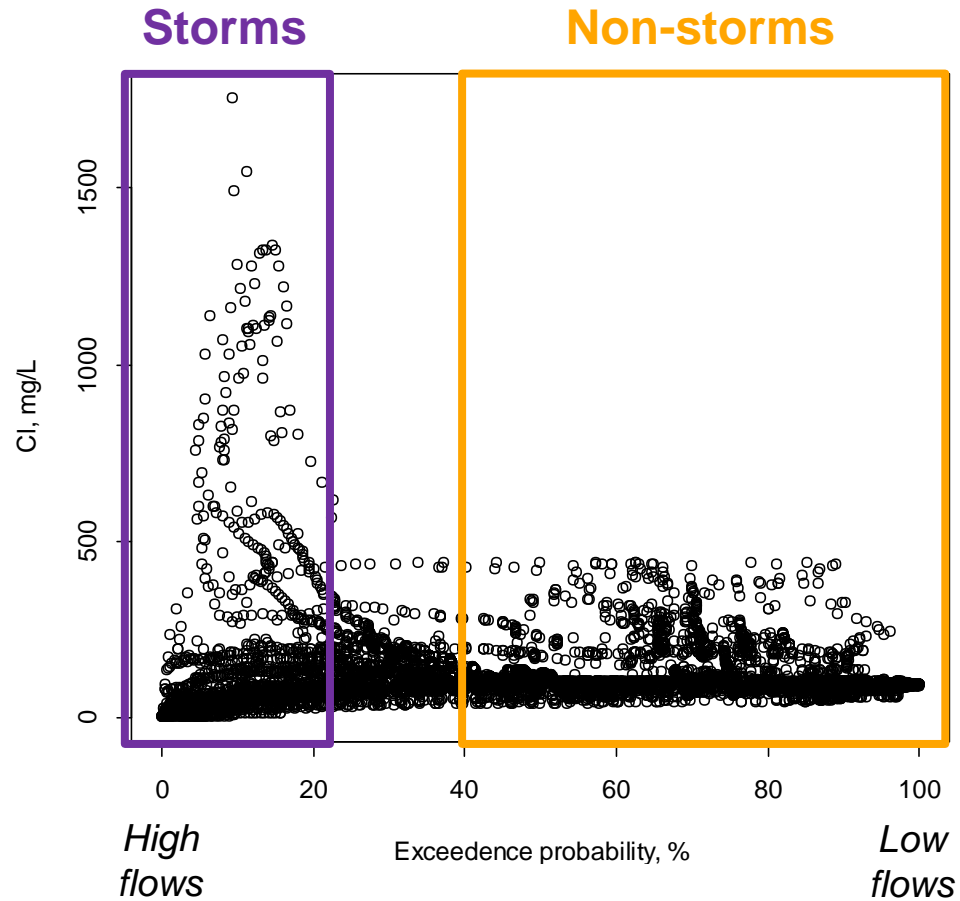
Mid-Atlantic: all ≥ 5 yrs data



Suggested strategies for discrete CI sampling: **non-storms**



Suggested strategies for discrete CI sampling: **non-storms**

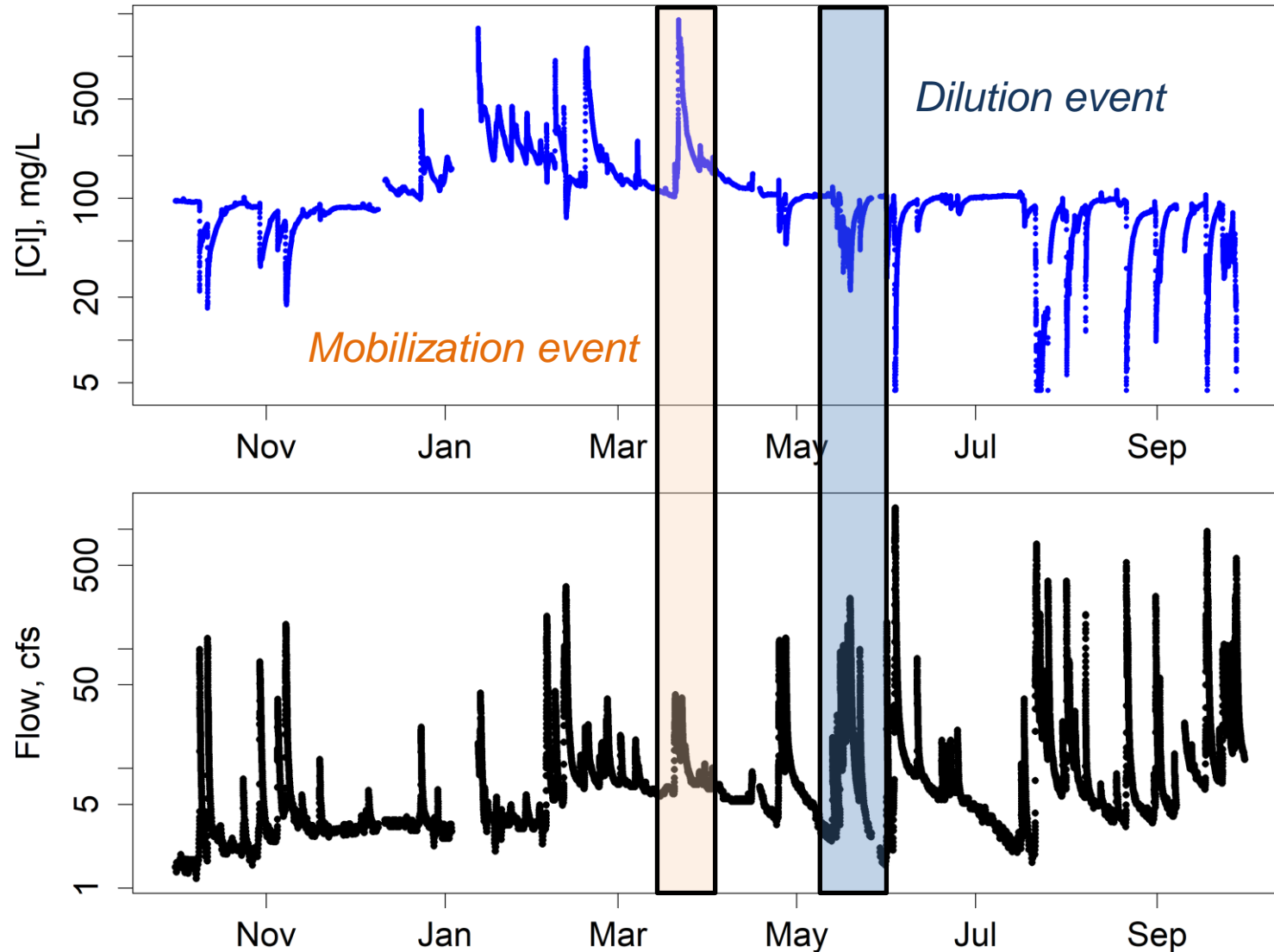


Extracted 12 random samples reflecting **storm** and **non-storm** conditions

Repeated 1000 times

Discharge and chloride concentrations [Cl] are **not** highly correlated

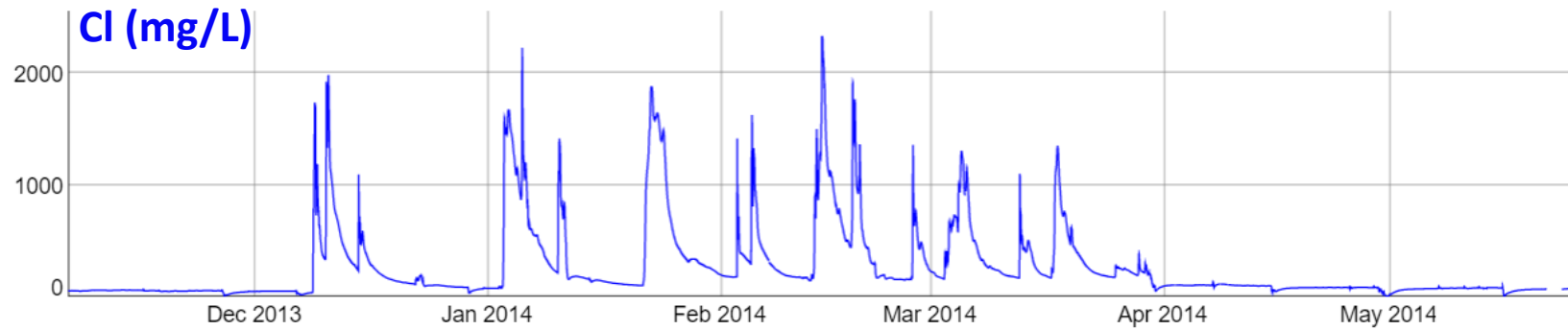
Paint Branch (Maryland) WY 2018: Relationship between discharge and [Cl] varies seasonally



Intra-annual connections between salt application & stream Cl

Nov. 2013 – May 2014

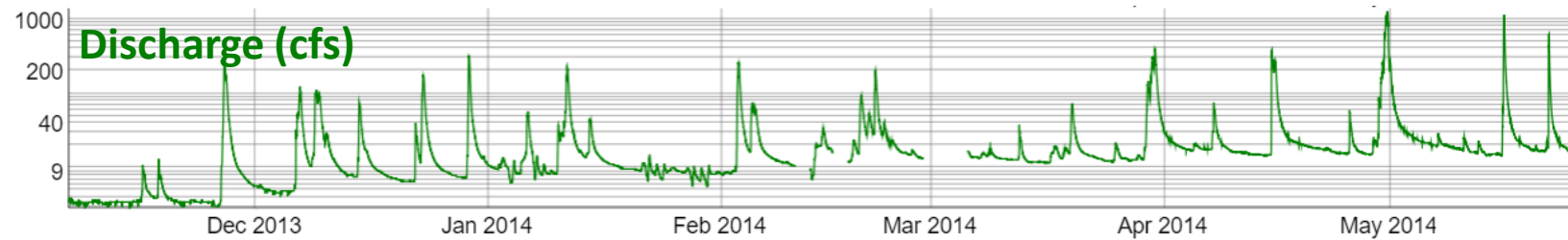
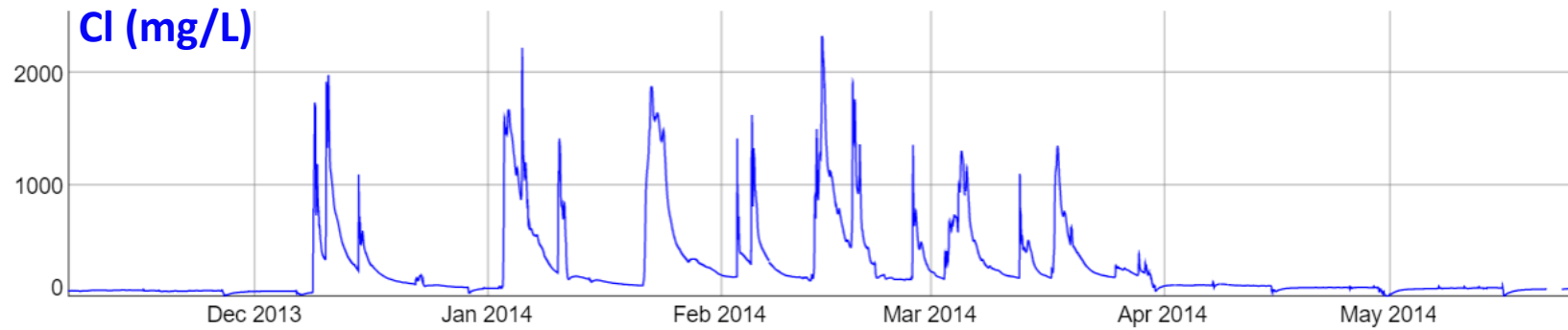
Paint Branch watershed in Montgomery County, MD (near College Park)



Intra-annual connections between salt application & stream Cl

Nov. 2013 – May 2014

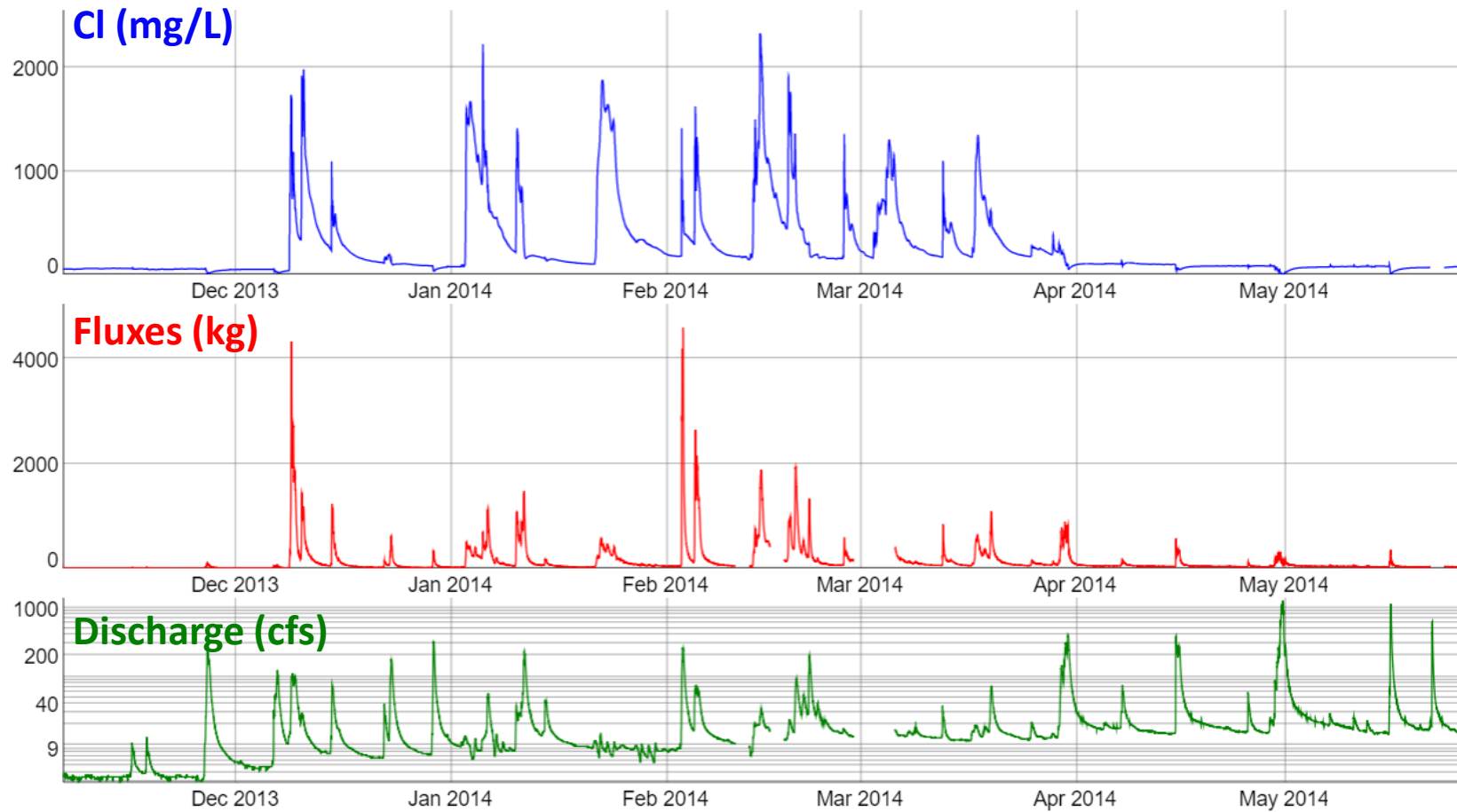
Paint Branch watershed in Montgomery County, MD (near College Park)



Intra-annual connections between salt application & stream Cl

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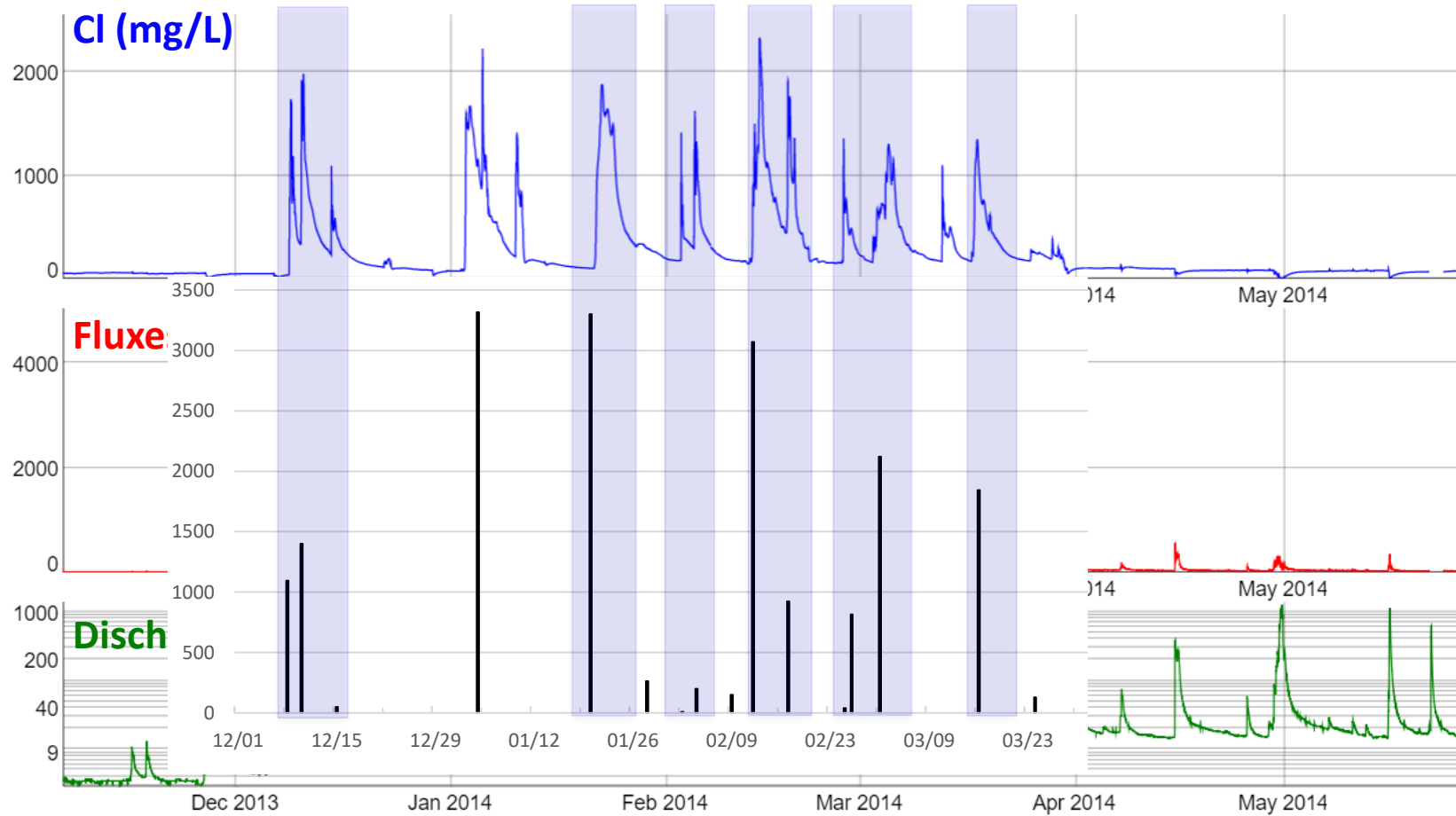


Intra-annual connections between salt application & stream Cl

Nov. 2013 – May 2014

Paint Branch watershed in Montgomery County, MD (near College Park)

Blue box = good match of application & stream



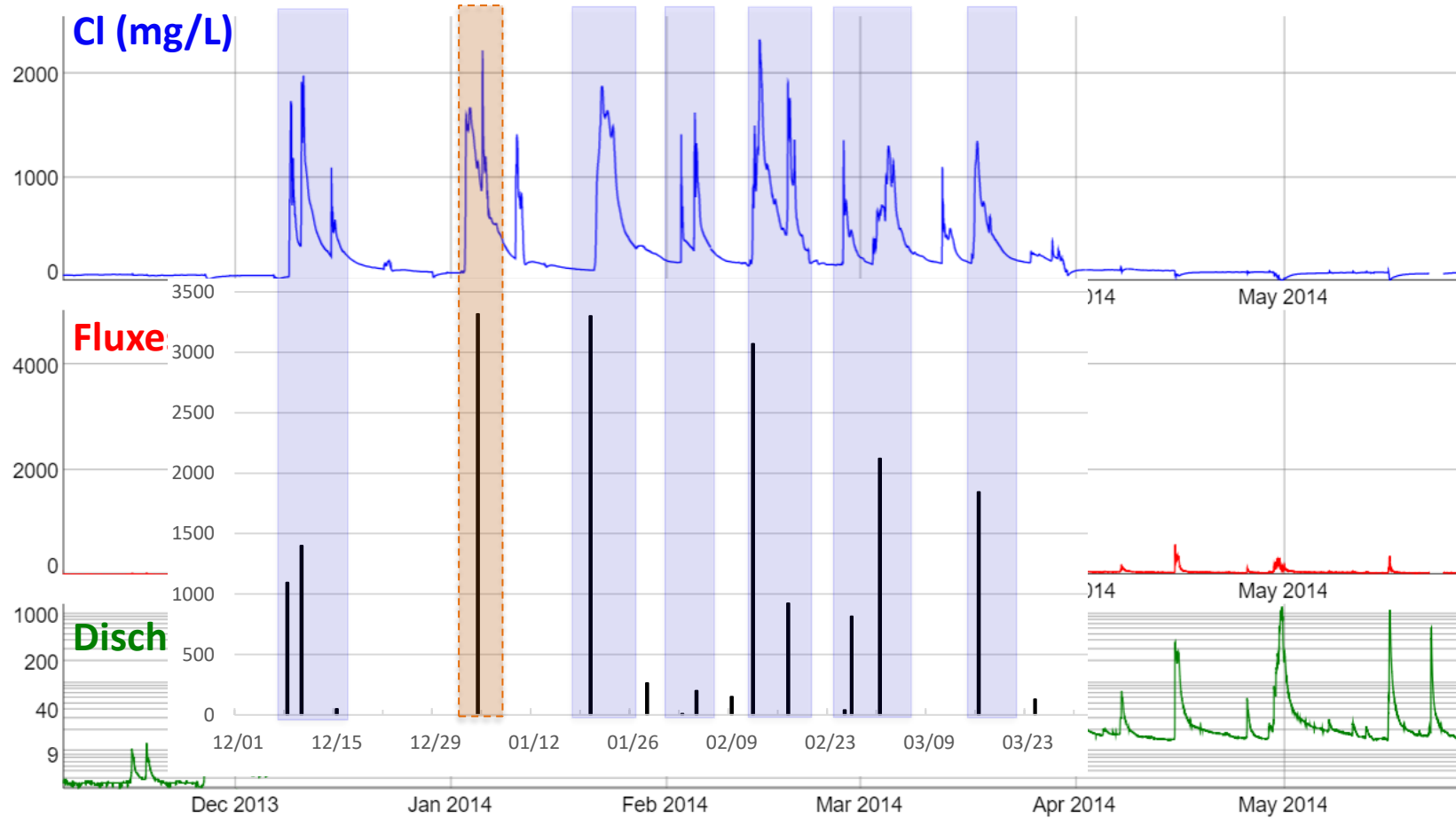
Intra-annual connections between salt application & stream Cl

Nov. 2013 – May 2014

Paint Branch watershed in Montgomery County, MD (near College Park)

Blue box = good match of application & stream

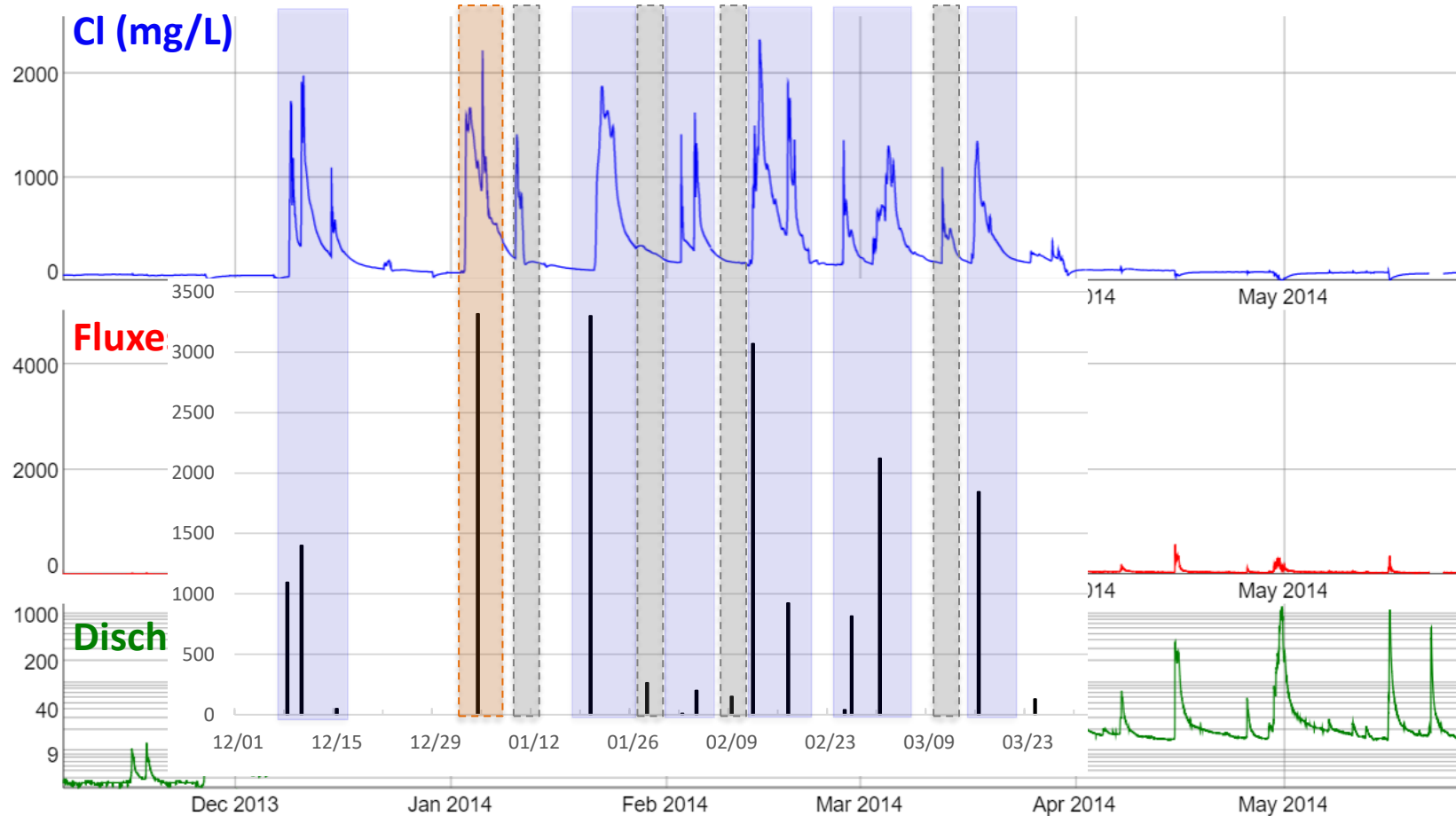
Orange box = sort of match (timing off)



Intra-annual connections between salt application & stream Cl

Nov. 2013 – May 2014

Paint Branch watershed in Montgomery County, MD (near College Park)



Blue box = good match of application & stream

Orange box = sort of match (timing off)

Grey box = mismatch (either application with no peak or no application with peak)

Study #2: Status & trends in Baltimore Reservoir System

Study in progress

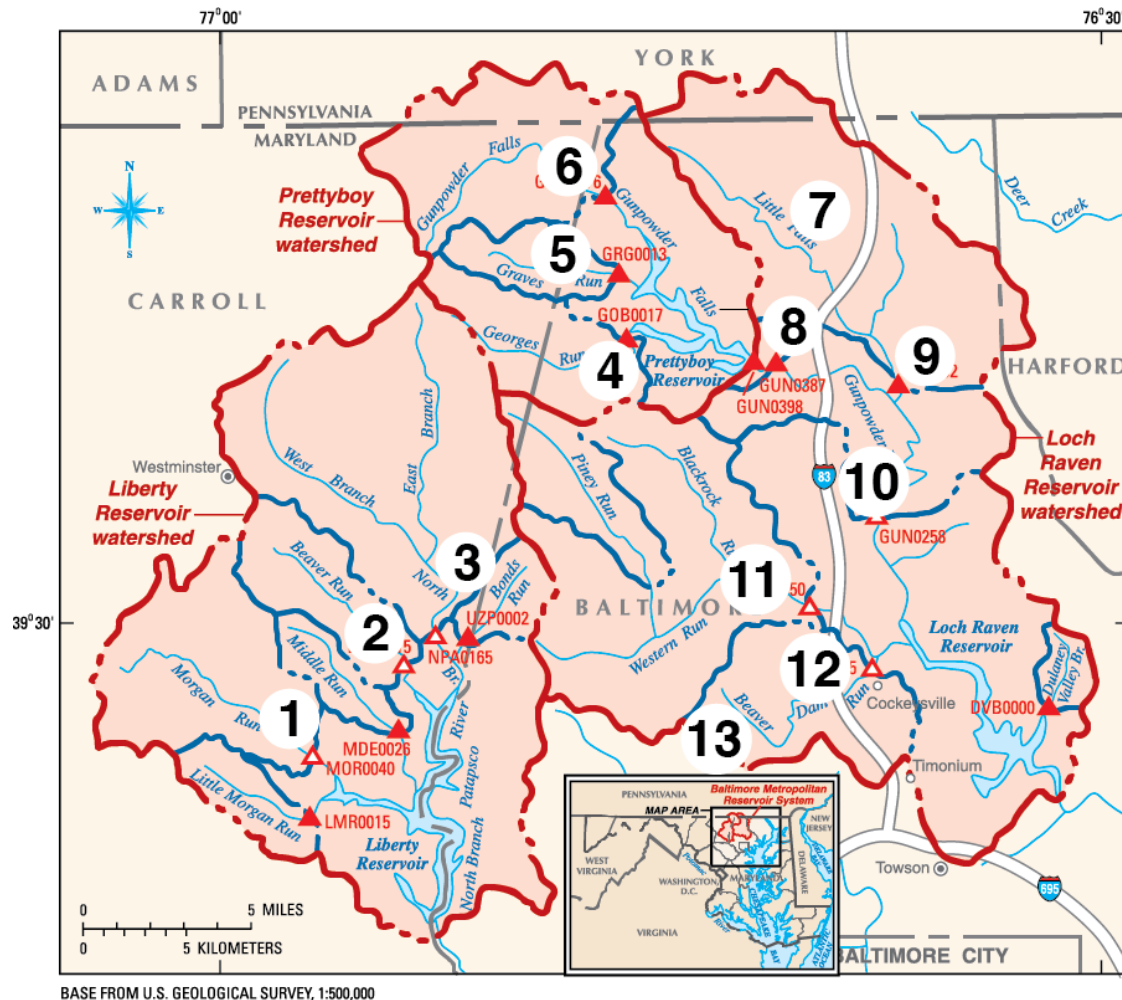
Chloride and sodium

1) Data from Baltimore City DPW monthly monitoring from 1982 – 2019

All ions and high-frequency

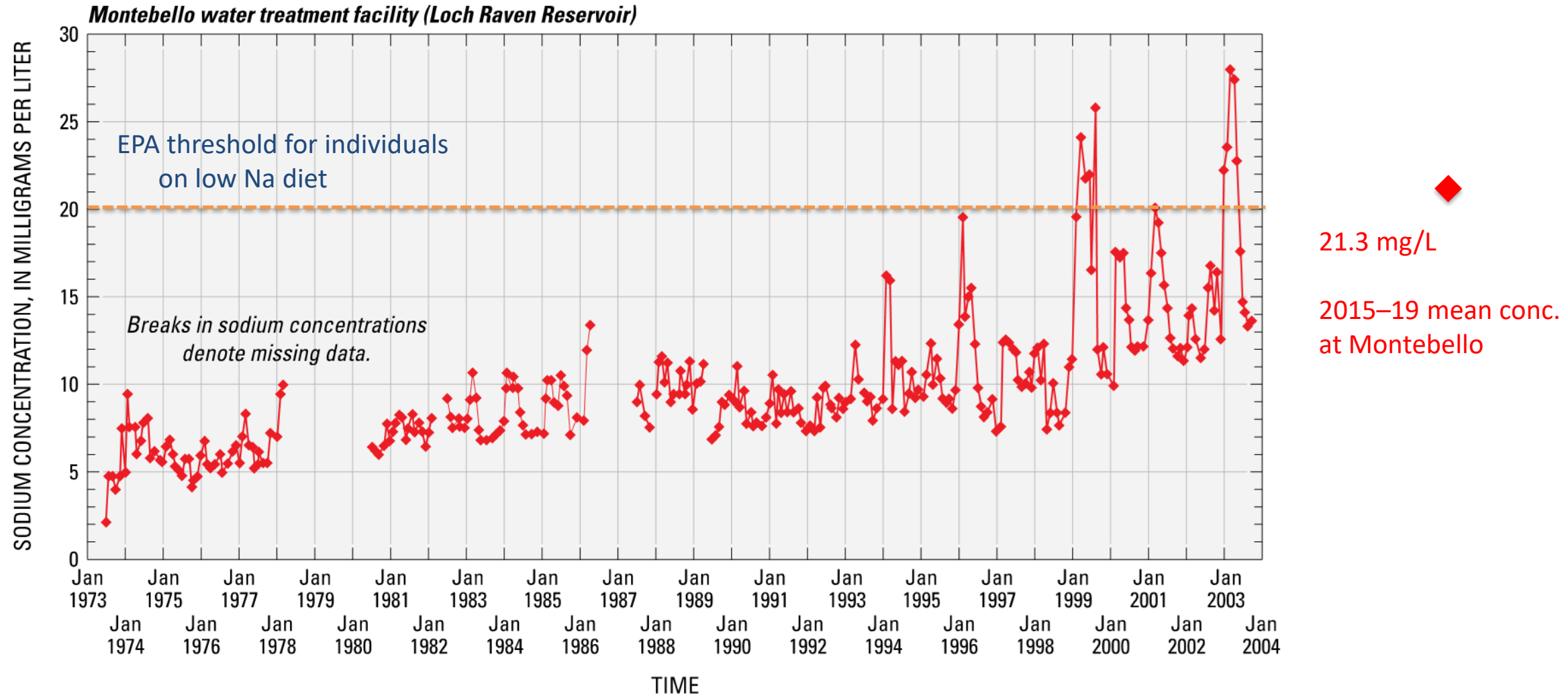
2) Liberty Reservoir tributaries: recent data from Maryland Department of Environment

3) Prettyboy and Loch Raven: data being collected by my laboratory

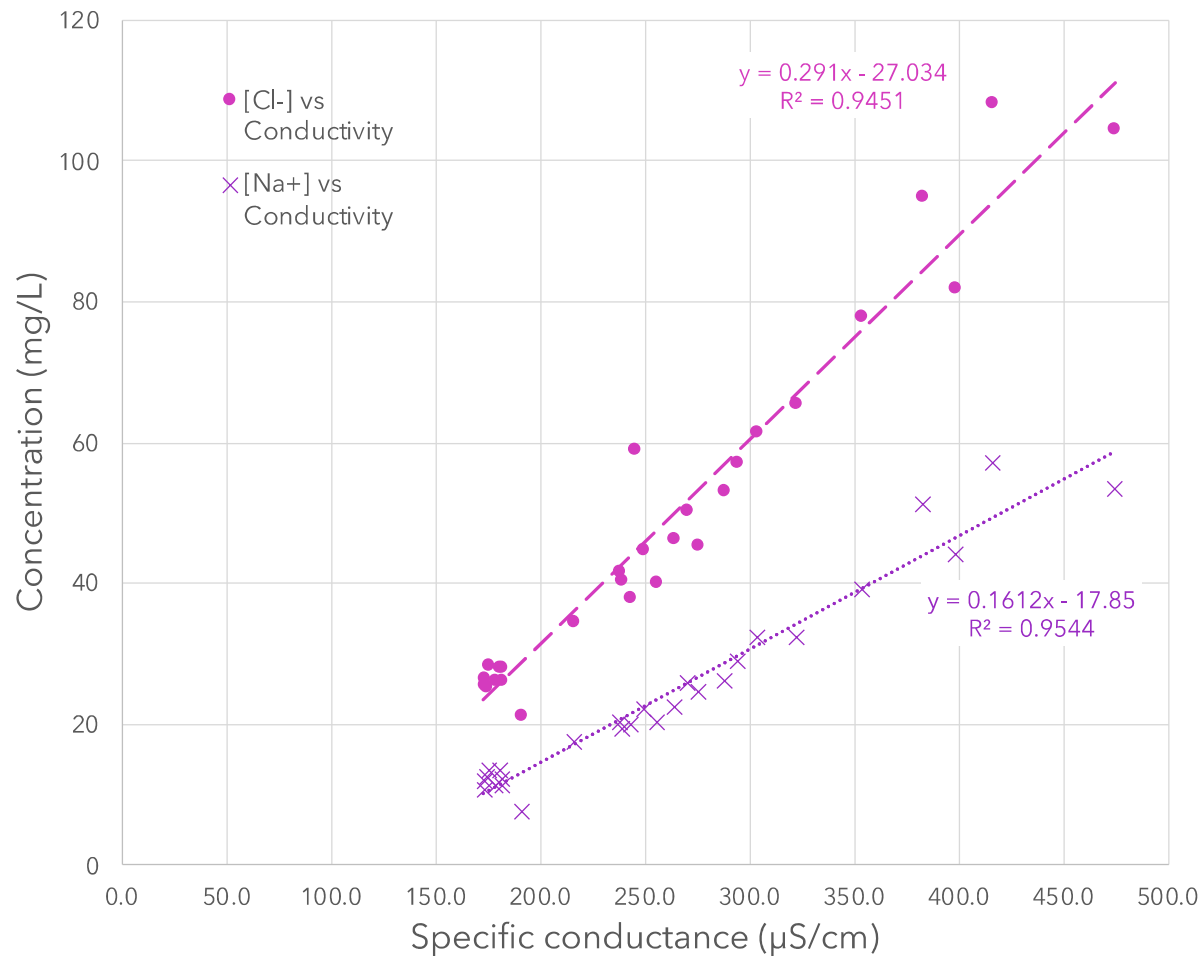


Modified from Koterba et al. (2011) USGS SIR 2011-5101

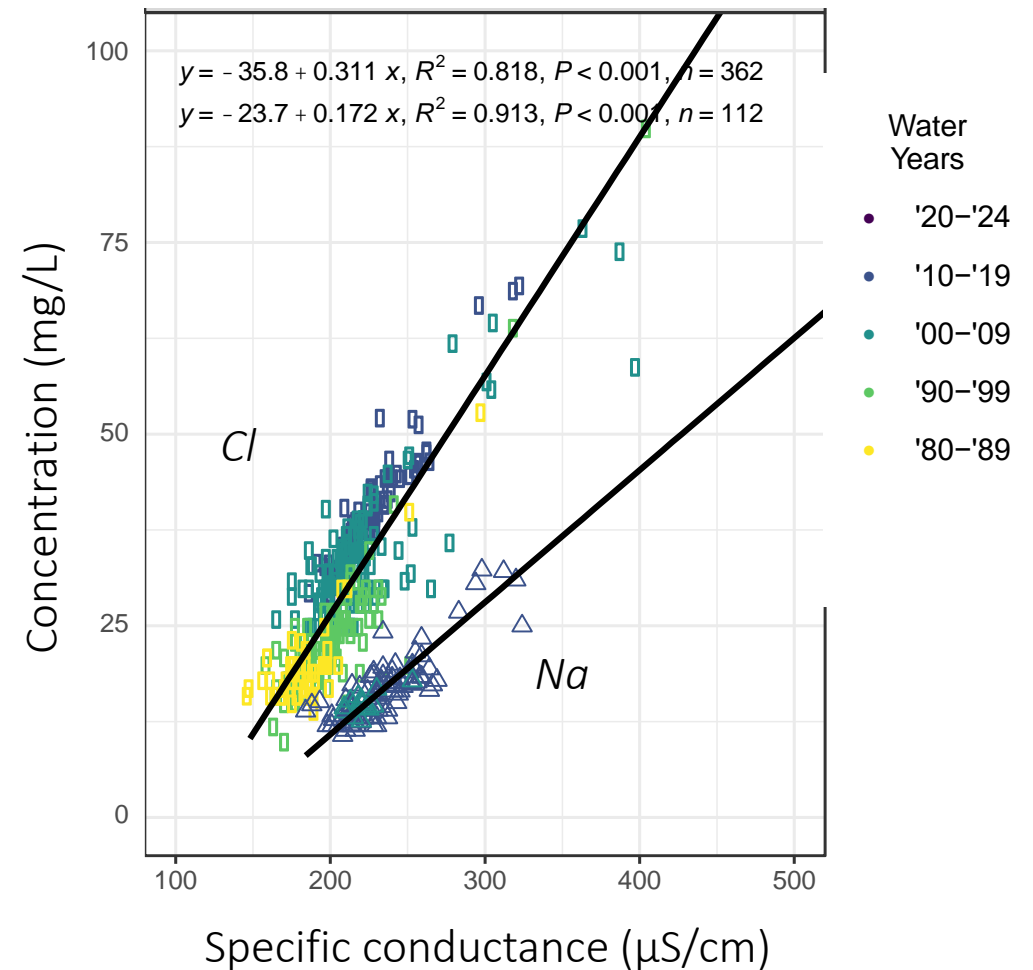
Study #2: increasing Na concentrations (*Loch Raven example*)



Study #2: Point 2, Cl/Na and SC are strongly correlated

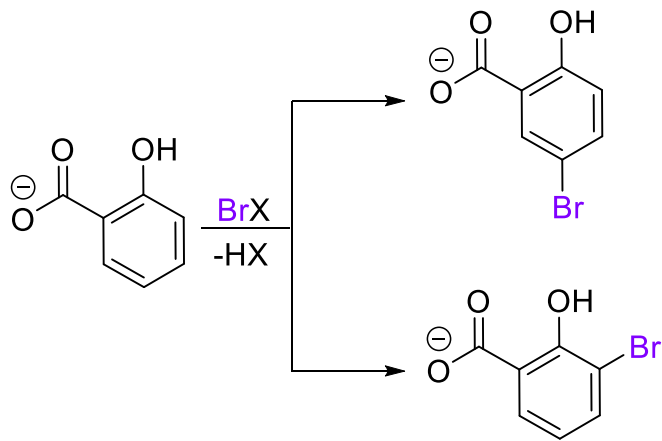


Moore lab data (Nov. 2020 – Feb. 2021) for 8 tributaries (silicate-bedrock) draining into Prettyboy & Loch Raven Reservoirs



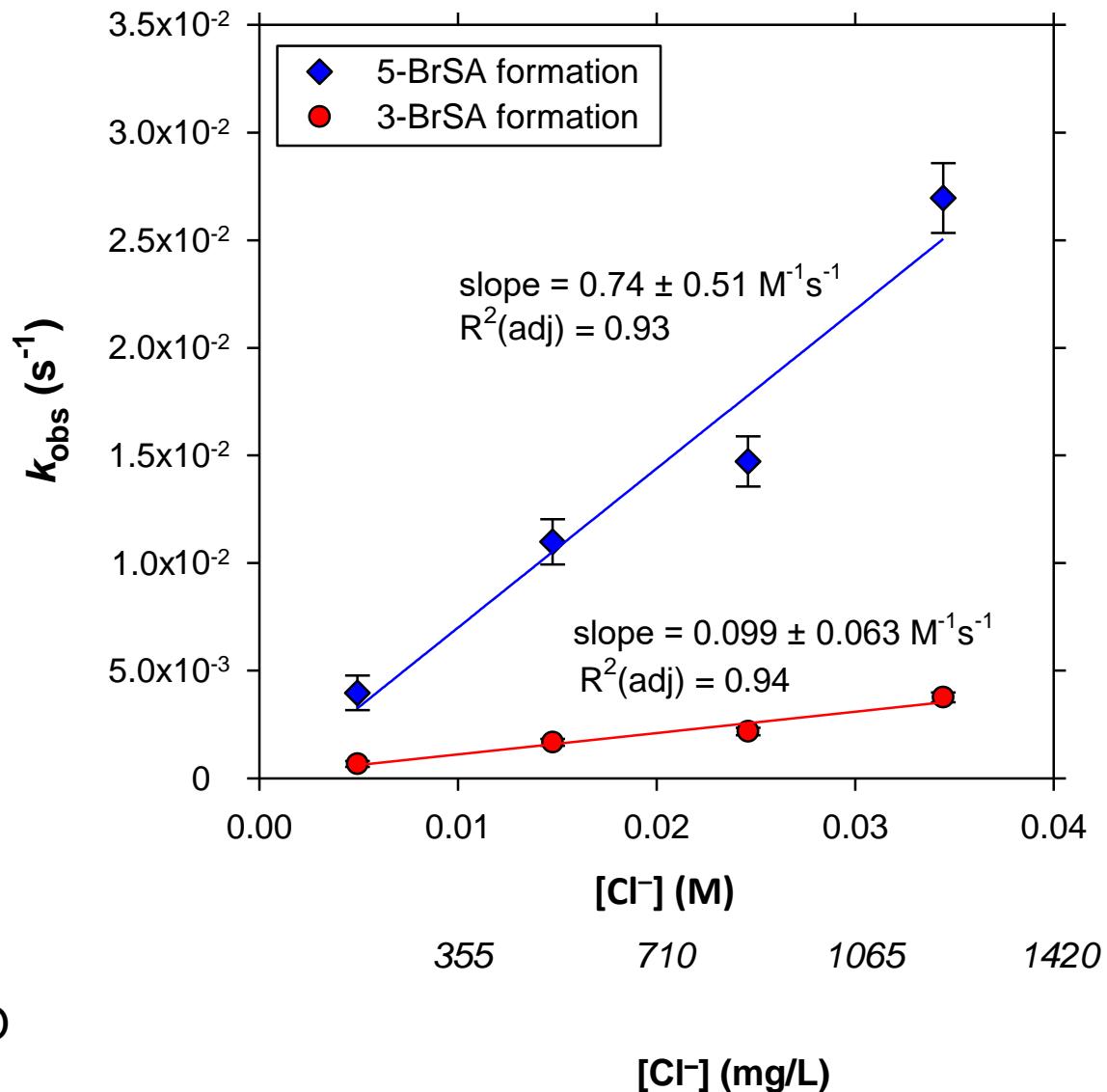
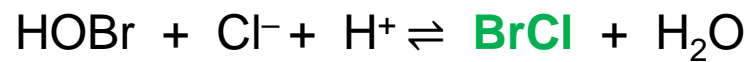
Little Patapsco (Liberty Reservoir)
Baltimore DPW data (1982 – present)

Bromination of Salicylic Acid



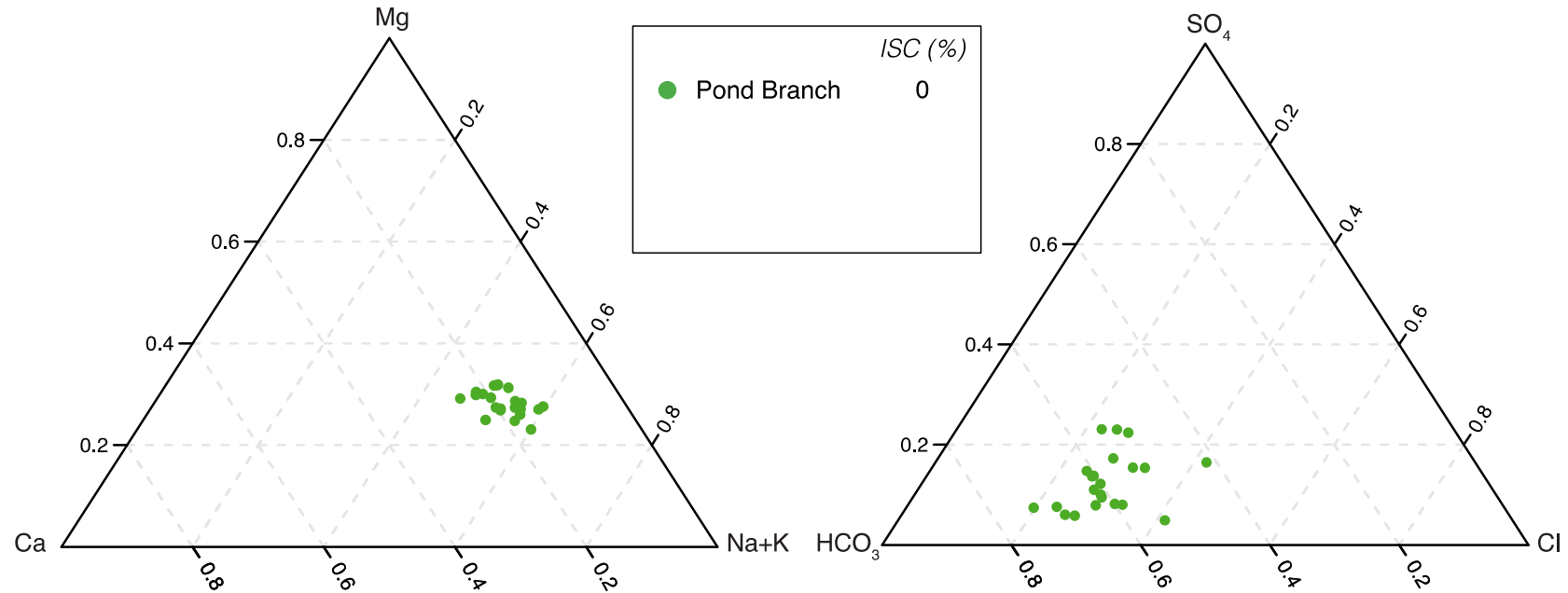
$\text{X} = \text{OH}, \text{Cl}, \text{OCl}, \text{OBr}, \text{Br}$

Chloride influences bromination rate and selectivity.



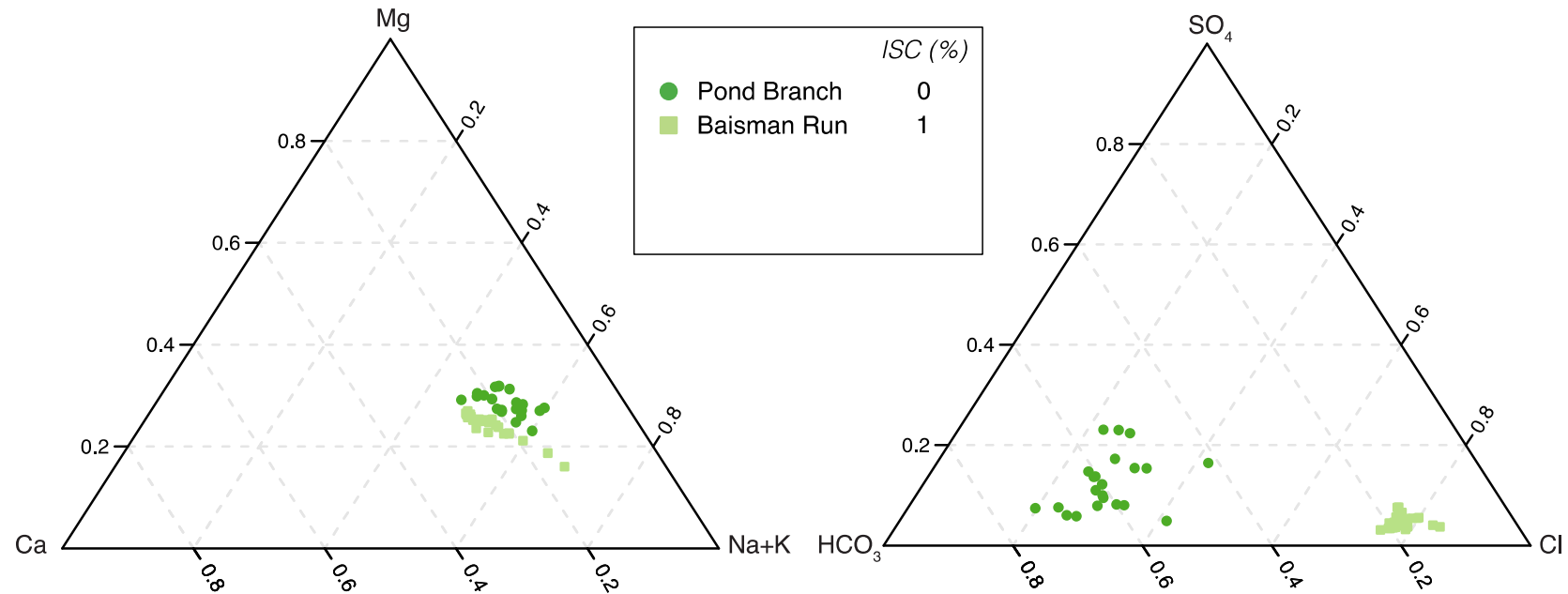
pH = 7.05
 $[\text{Br}^-]_0 = 20 \mu\text{M}$
 $[\text{ClO}^-]_{\text{tot},0} = 27 \mu\text{M}$
 $[\text{salicylic acid}]_0 = 20 \mu\text{M}$
 $[\text{NaCl}] + [\text{NaNO}_3] = 0.100 \text{ M}$

Proportional ions



0% ISC: Plagioclase weathering as predominant control (Cleaves et al. 1970)

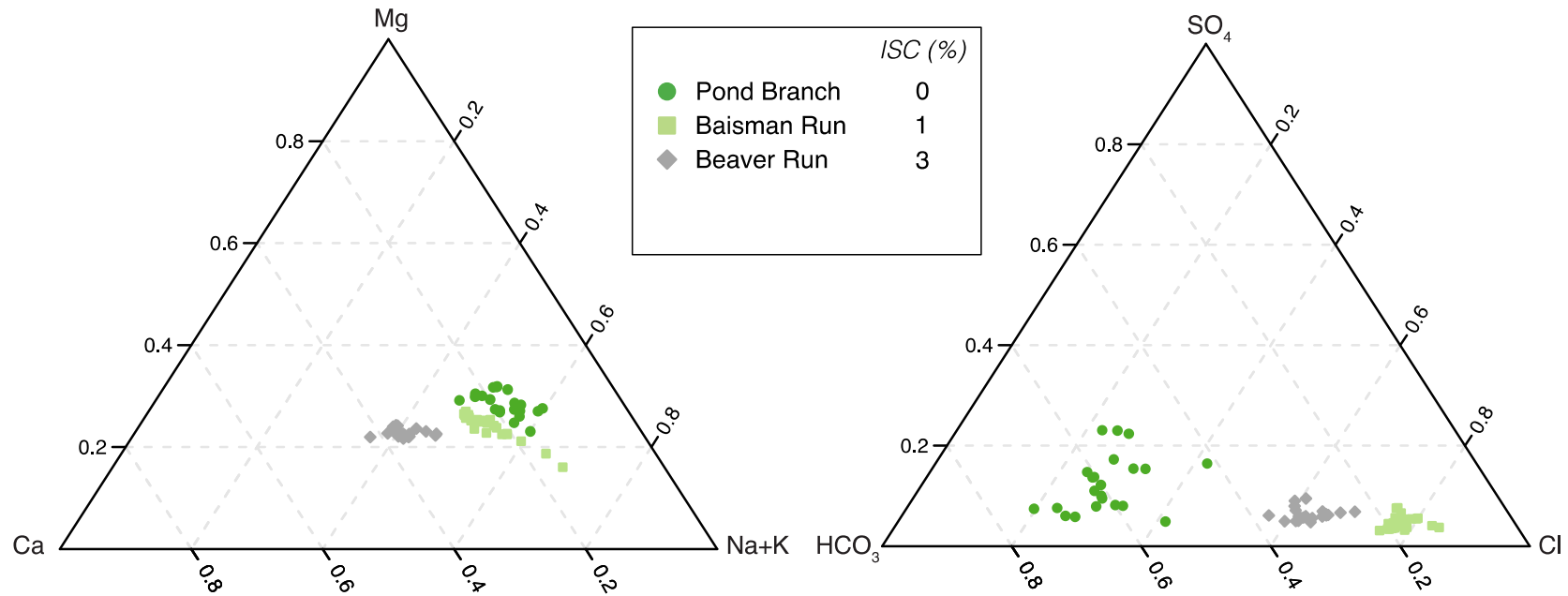
Proportional ions



0% ISC: Plagioclase weathering as predominant control (Cleaves et al. 1970)

1% ISC: Road salt (+ minor septic)

Proportional ions

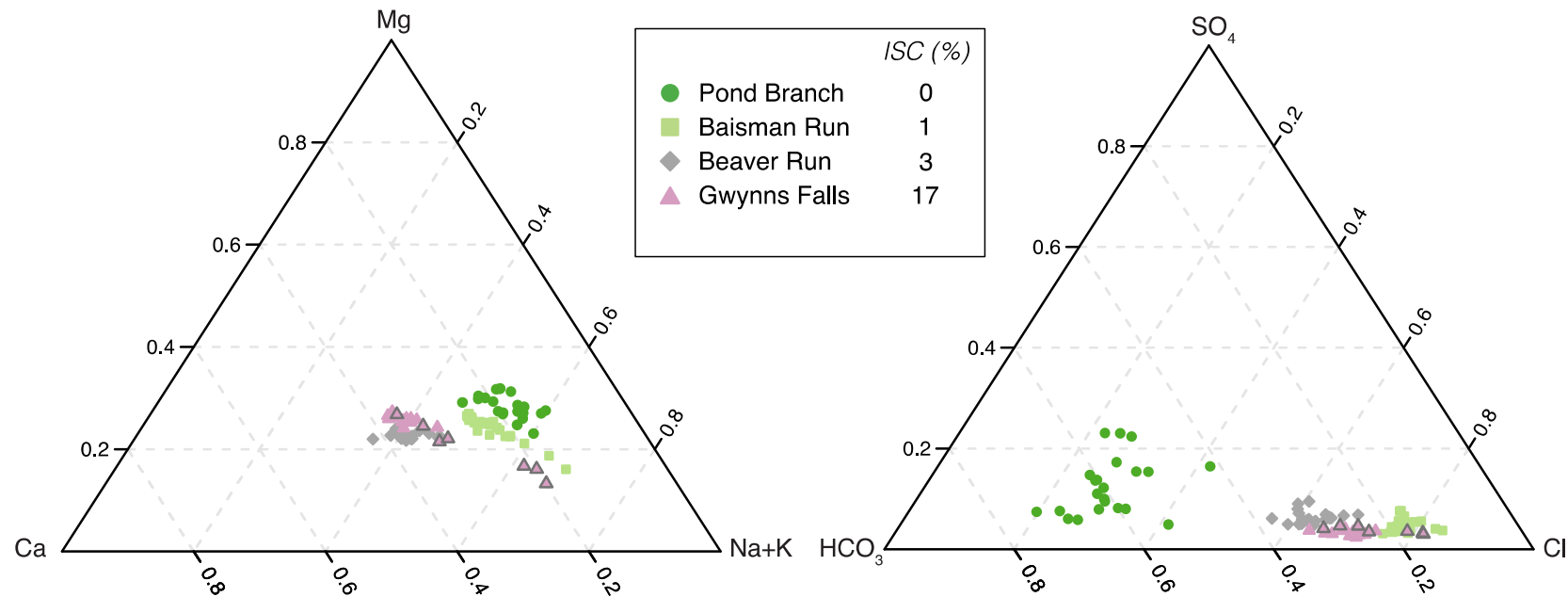


0% ISC: Plagioclase weathering as predominant control (Cleaves et al. 1970)

1% ISC: Road salt (+ minor septic)

3% ISC: Road salt + concrete / carbonate (liming)

Proportional ions



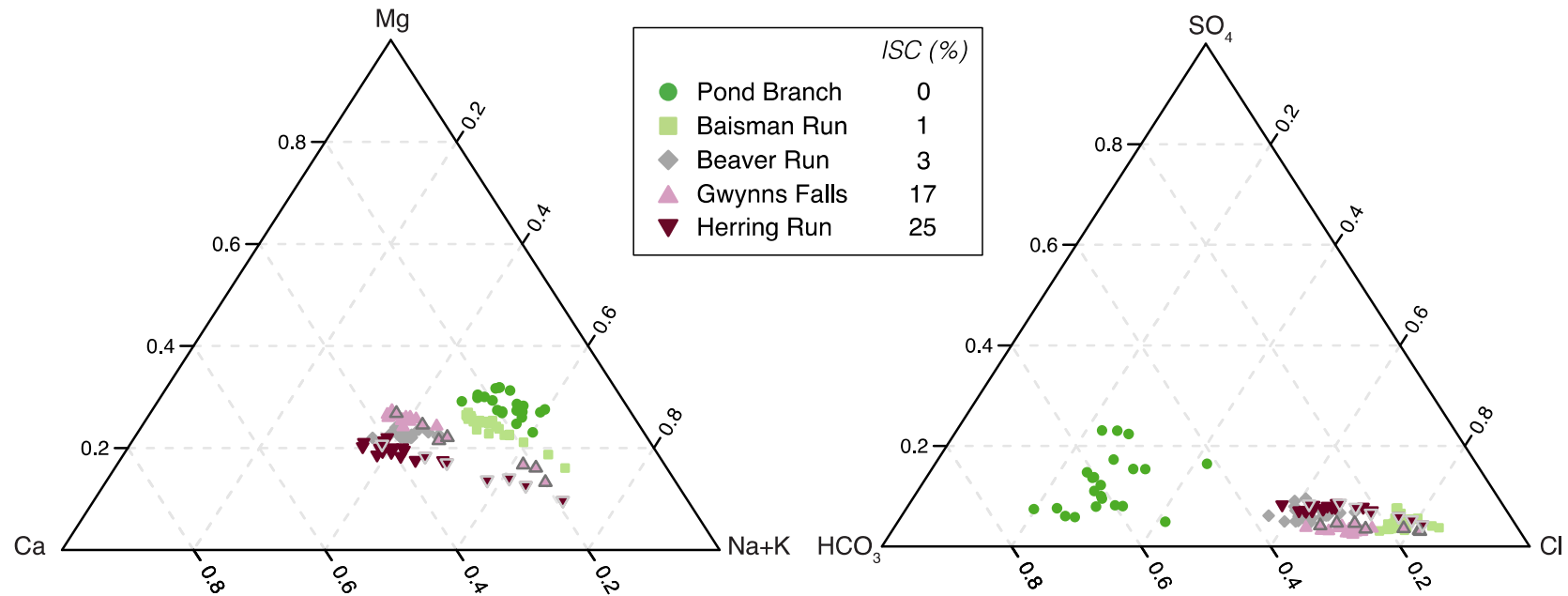
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3% ISC: Road salt + concrete / carbonate (liming)

17% ISC: Road salt + significant concrete (along with cation exchange)

Proportional ions



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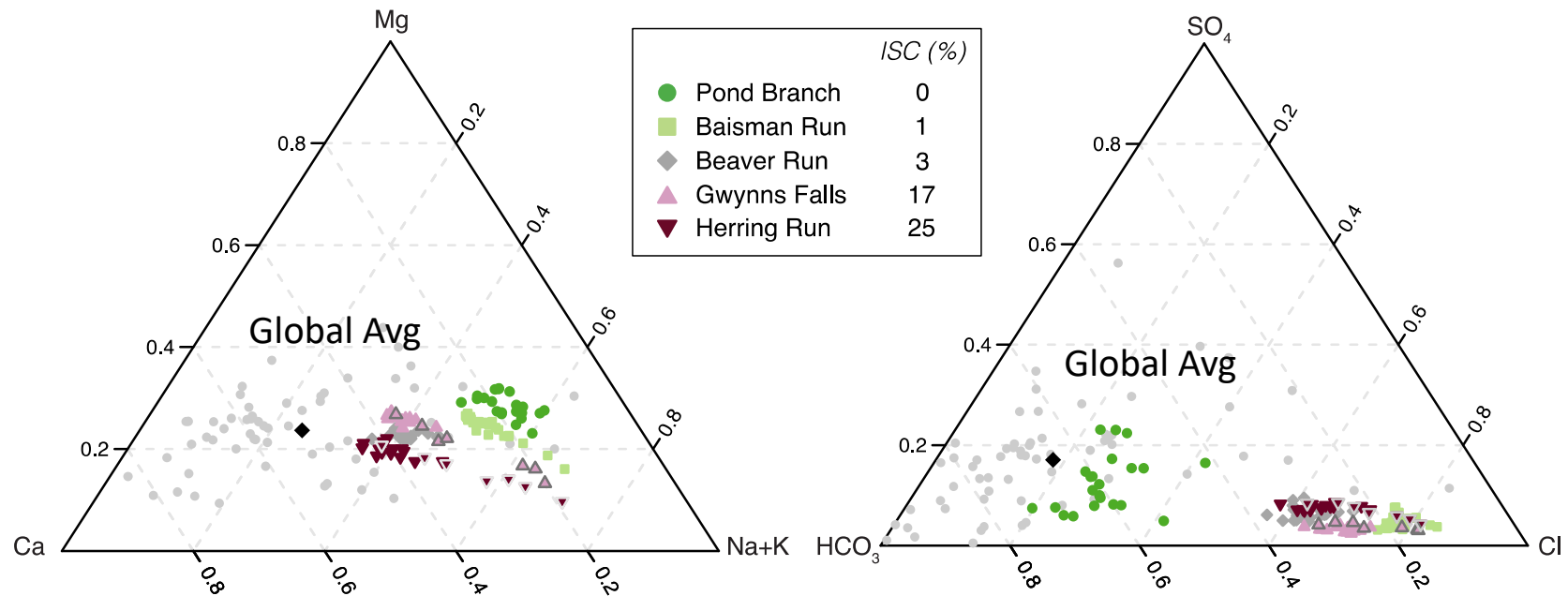
3% ISC: Road salt + concrete / carbonate (liming)

17% ISC: Road salt + significant concrete (along with cation exchange)

25% ISC: Road salt + significant concrete (along with cation exchange)

Proportional ions: “odd” chemistry

Similar cation charge to carbonate rivers (~5000 $\mu\text{eq/L}$) *but* very different chemistry (higher Na + Cl)



0% ISC: Plagioclase weathering as predominant control (Cleaves et al. 1970)

1% ISC: Road salt (+ minor septic)

3% ISC: Road salt + concrete / carbonate (liming)

17% ISC: Road salt + significant concrete & exchange

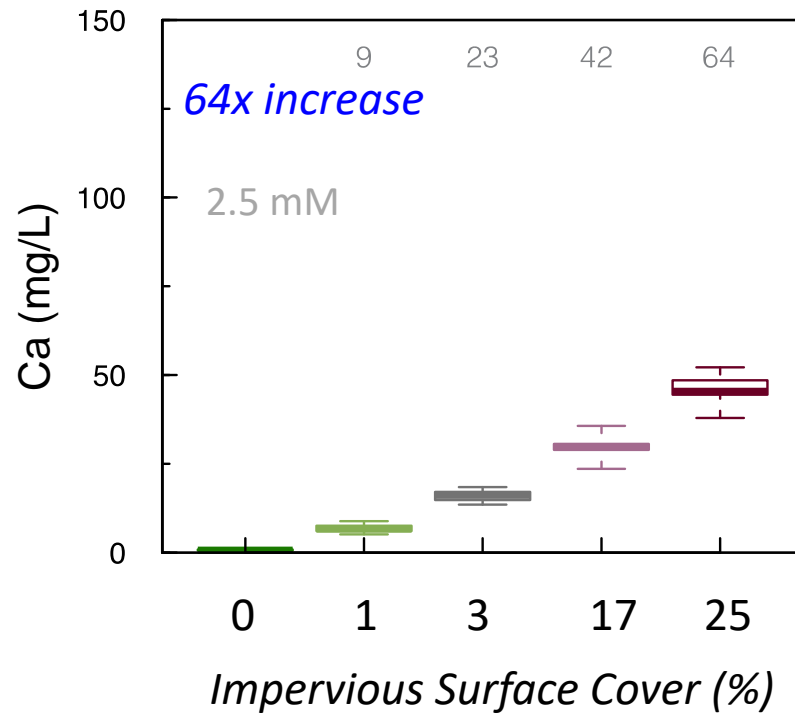
25% ISC: Road salt + significant concrete & exchange

Global avgs

Gaillardet et al. 1999 *Chem Geo*

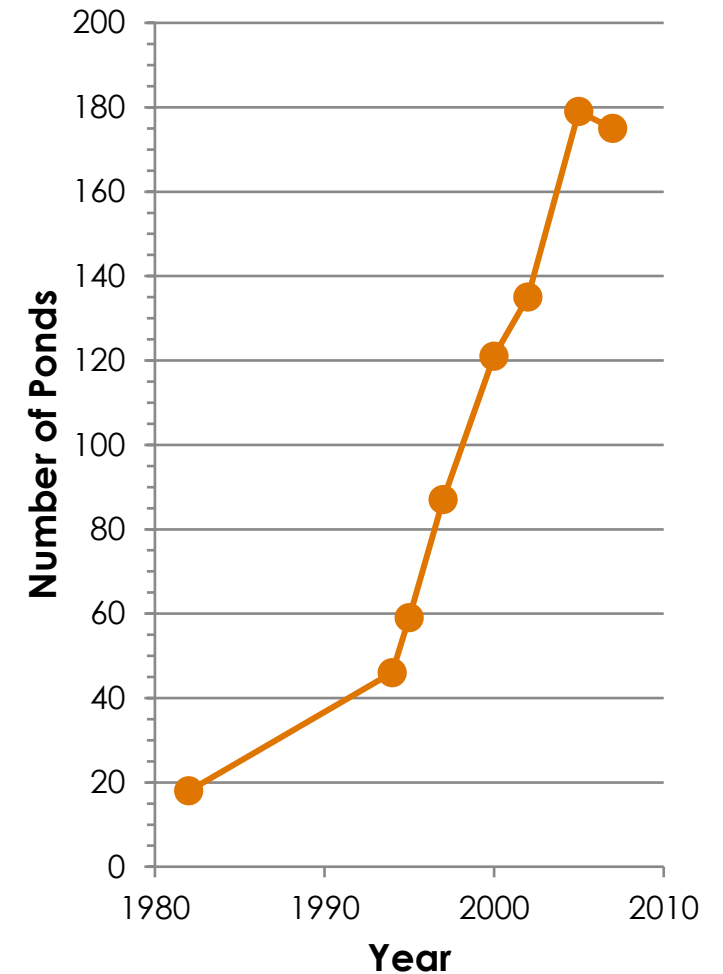
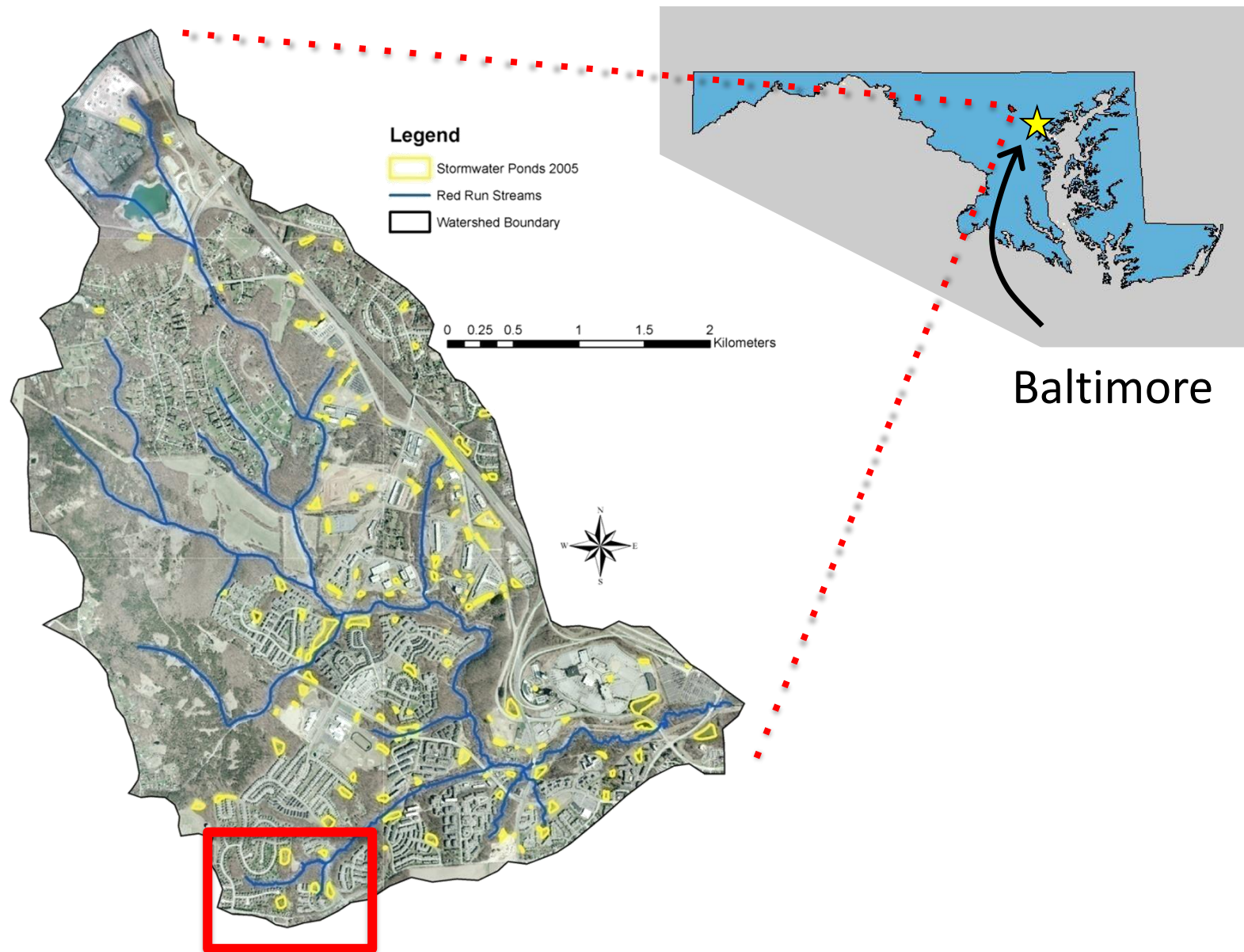
Meybeck 2003 *TOG*

Ca²⁺ and HCO₃⁻



- Driven by concrete + cation exchange (Ca²⁺)
- 0% ISC far from equilibrium with calcite, 25% ISC stream is at/near equilibrium

Stormwater basin buildout in suburban Baltimore, MD

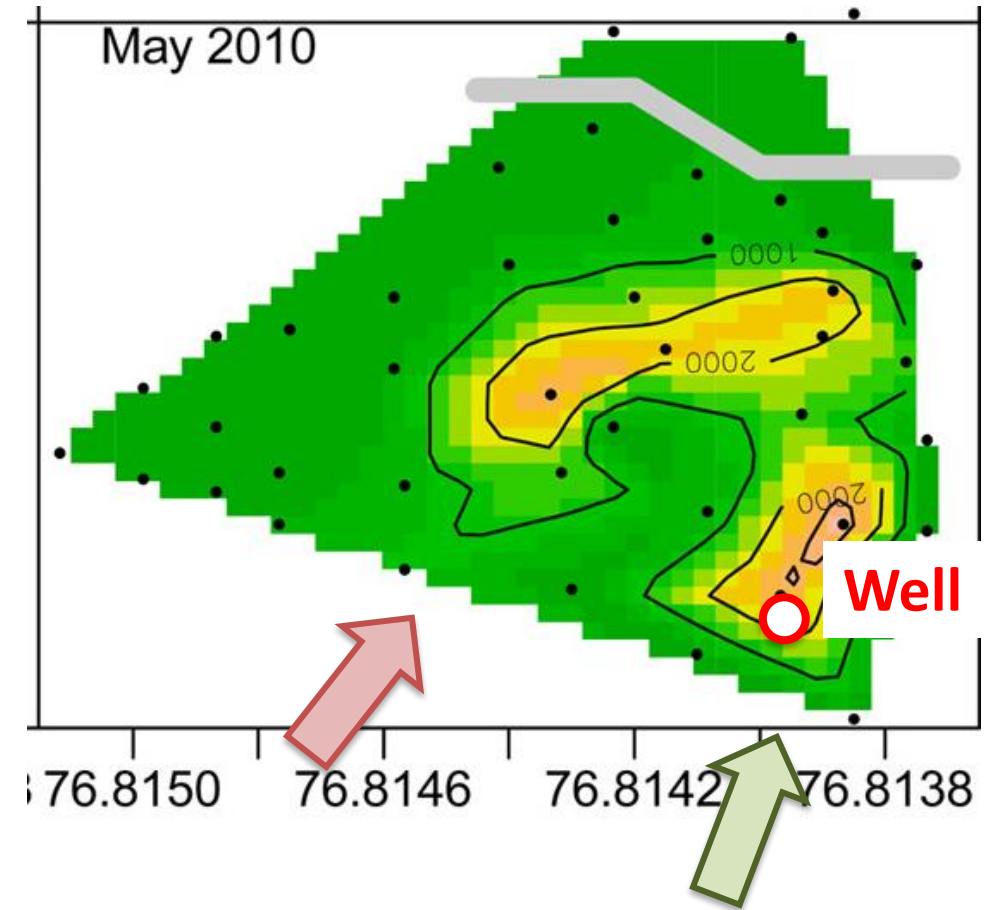
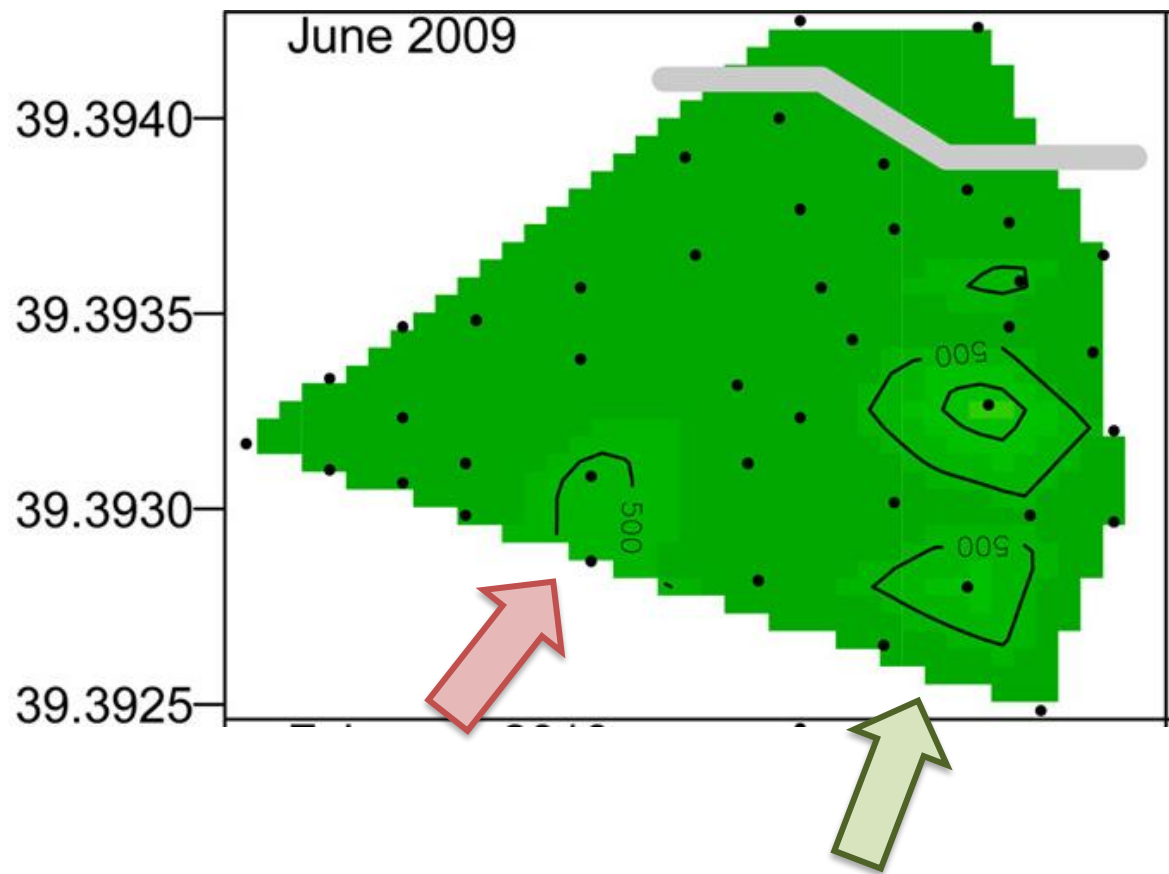


Gallagher et al. (2011) *Urban Ecol.*

Lev & Snodgrass (TU)

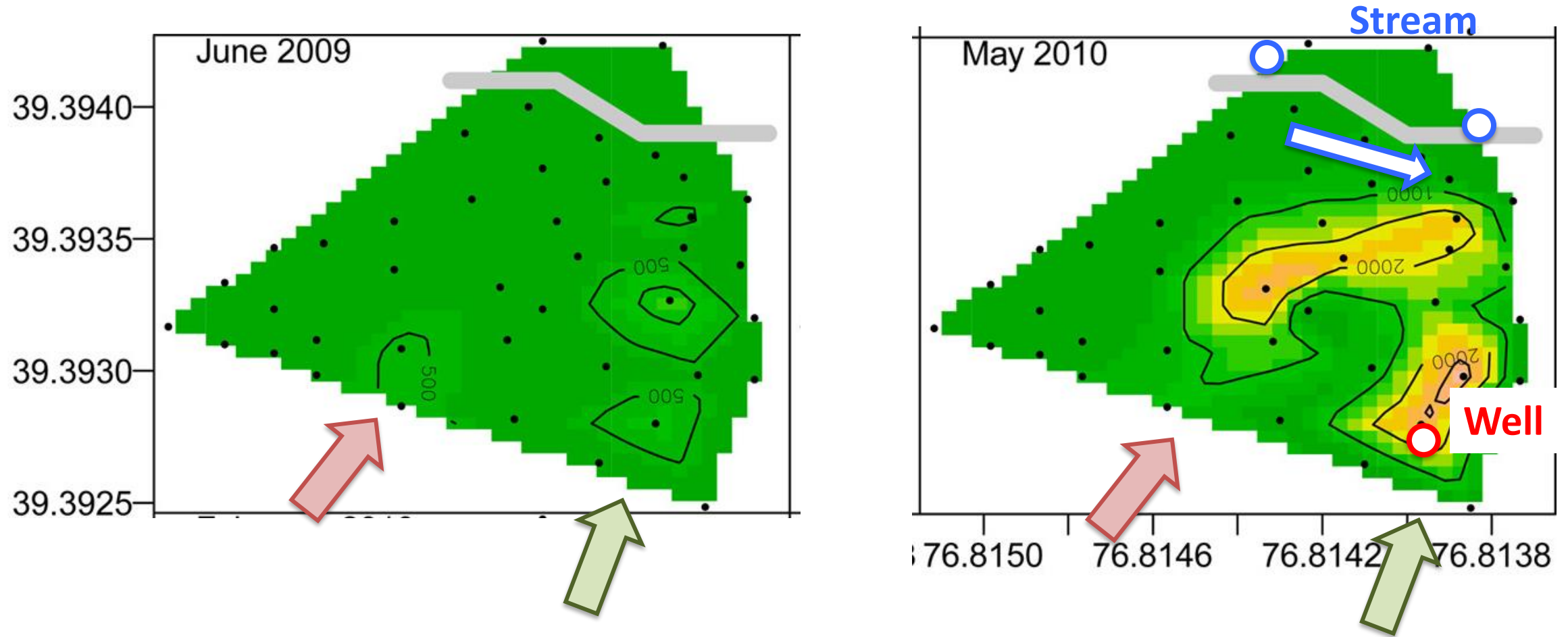


Persistent chloride plumes downgradient of stormwater basins



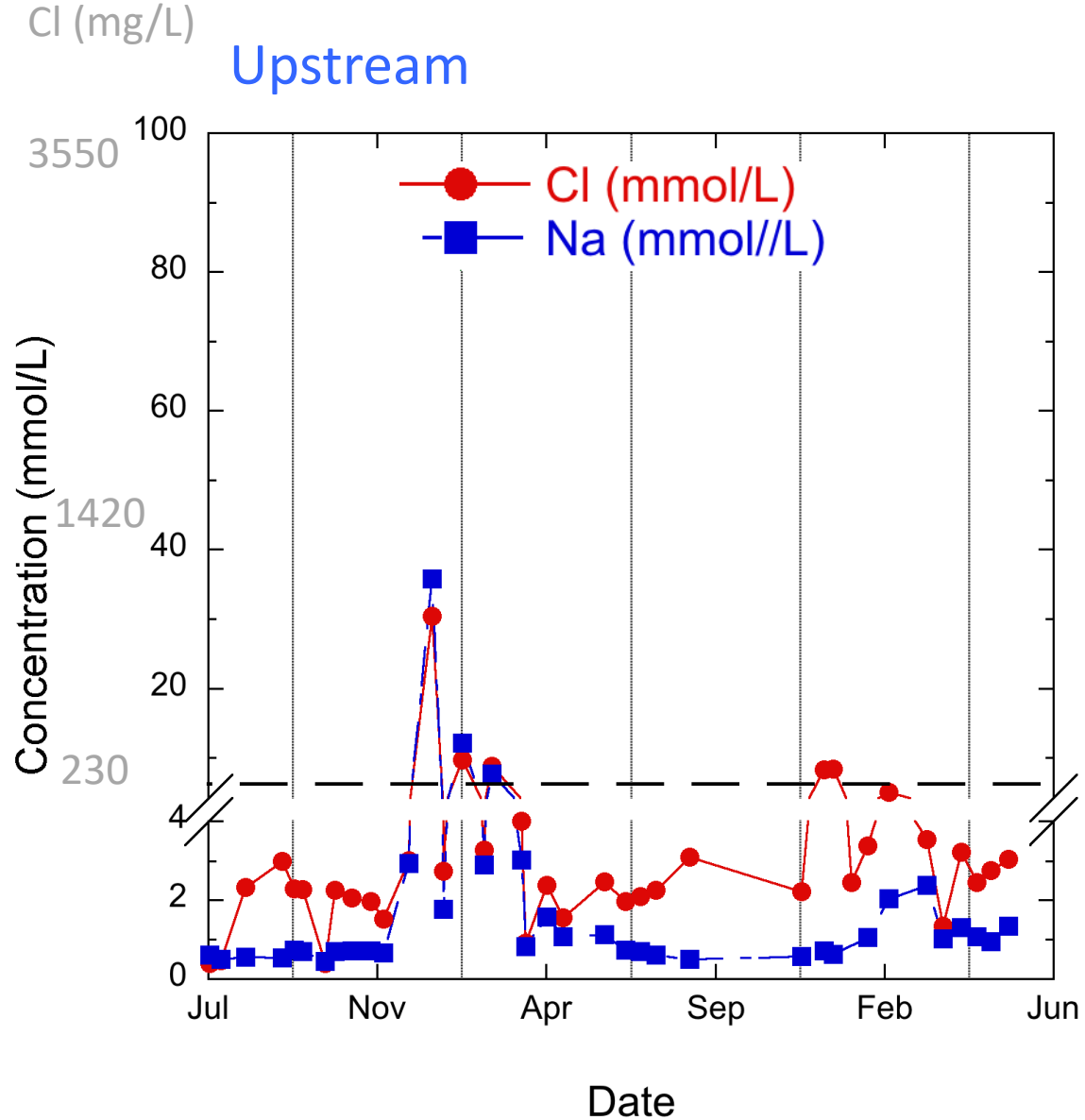
For floodplain aquifers, see Ledford et al. (2016) *Environmental Science & Technology*

Persistent chloride plumes downgradient of stormwater basins

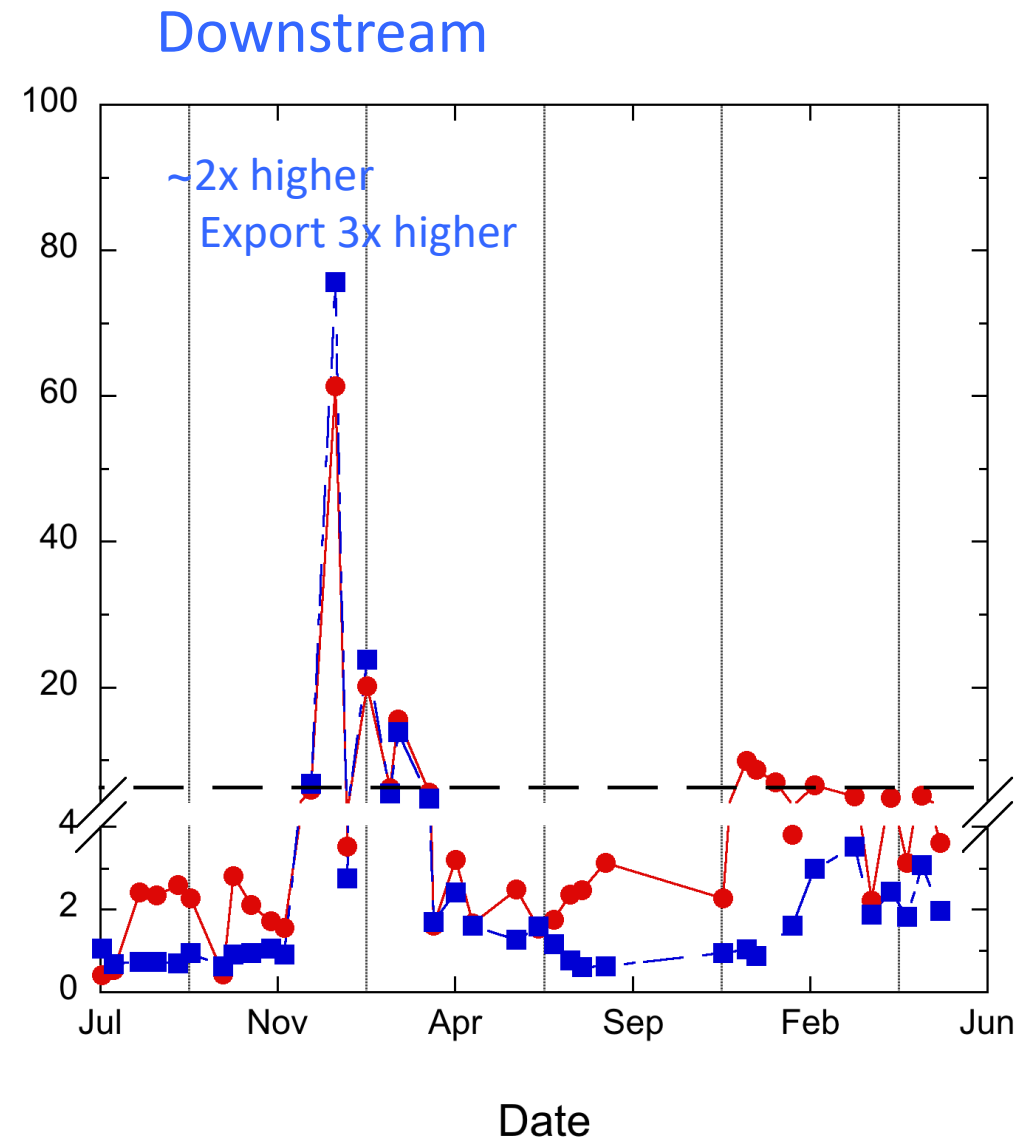
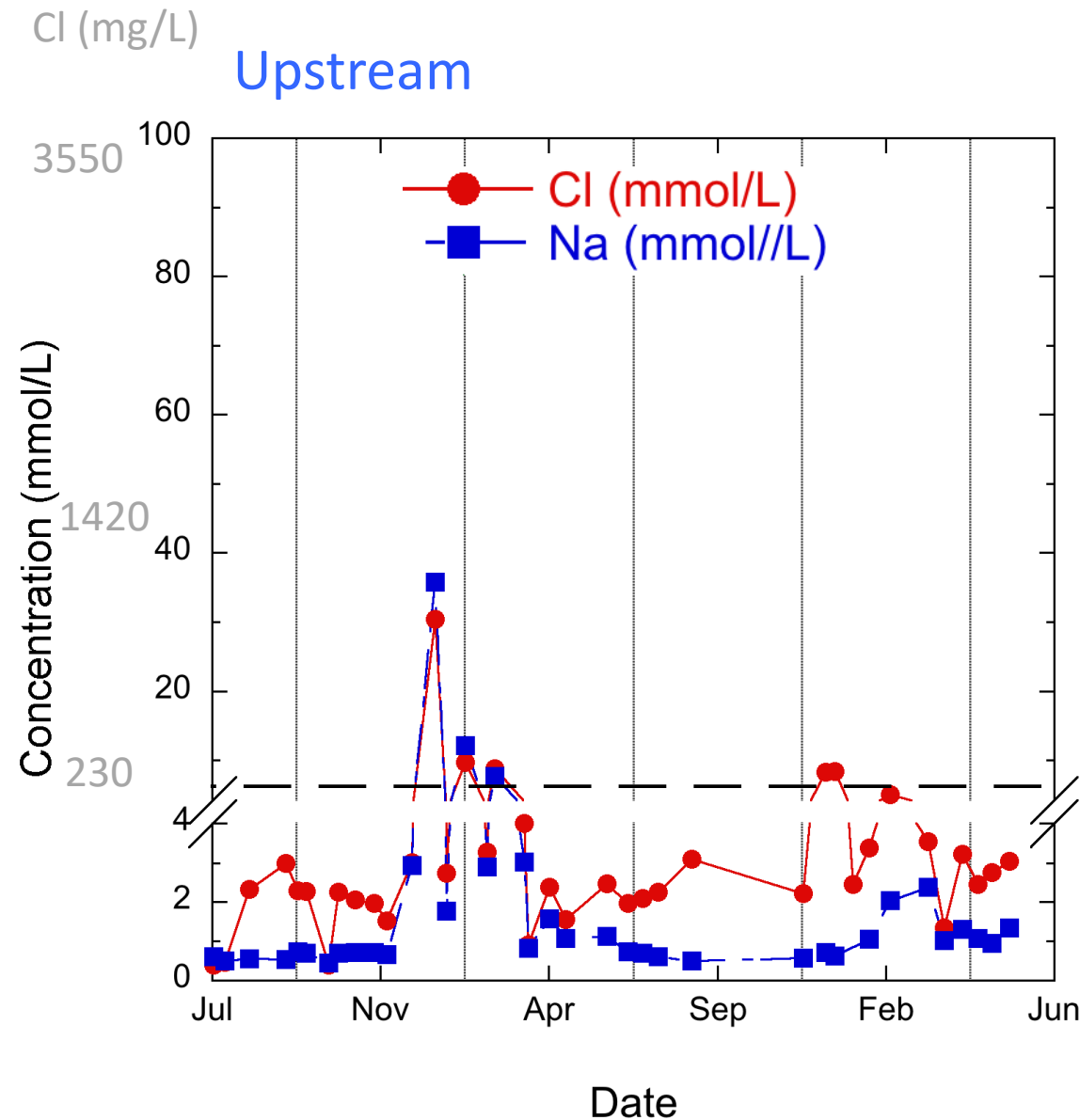


For floodplain aquifers, see Ledford et al. (2016) *Environmental Science & Technology*

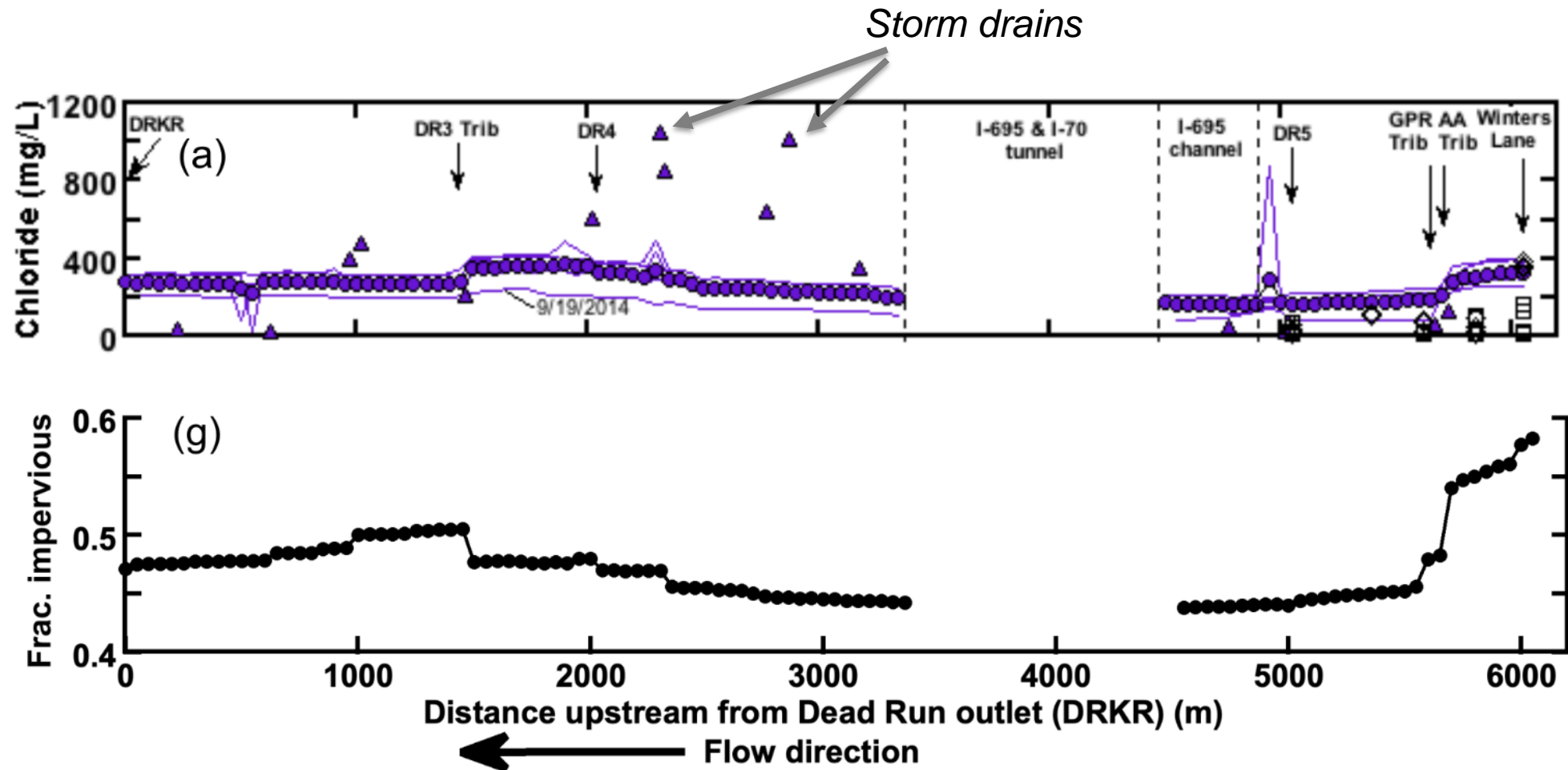
Stream chloride concentrations above EPA chronic criterion freq.



Stream chloride concentrations above EPA chronic criterion freq.



Elevated baseflow Cl in stream & storm drains throughout year



Knowledge & research gaps 1

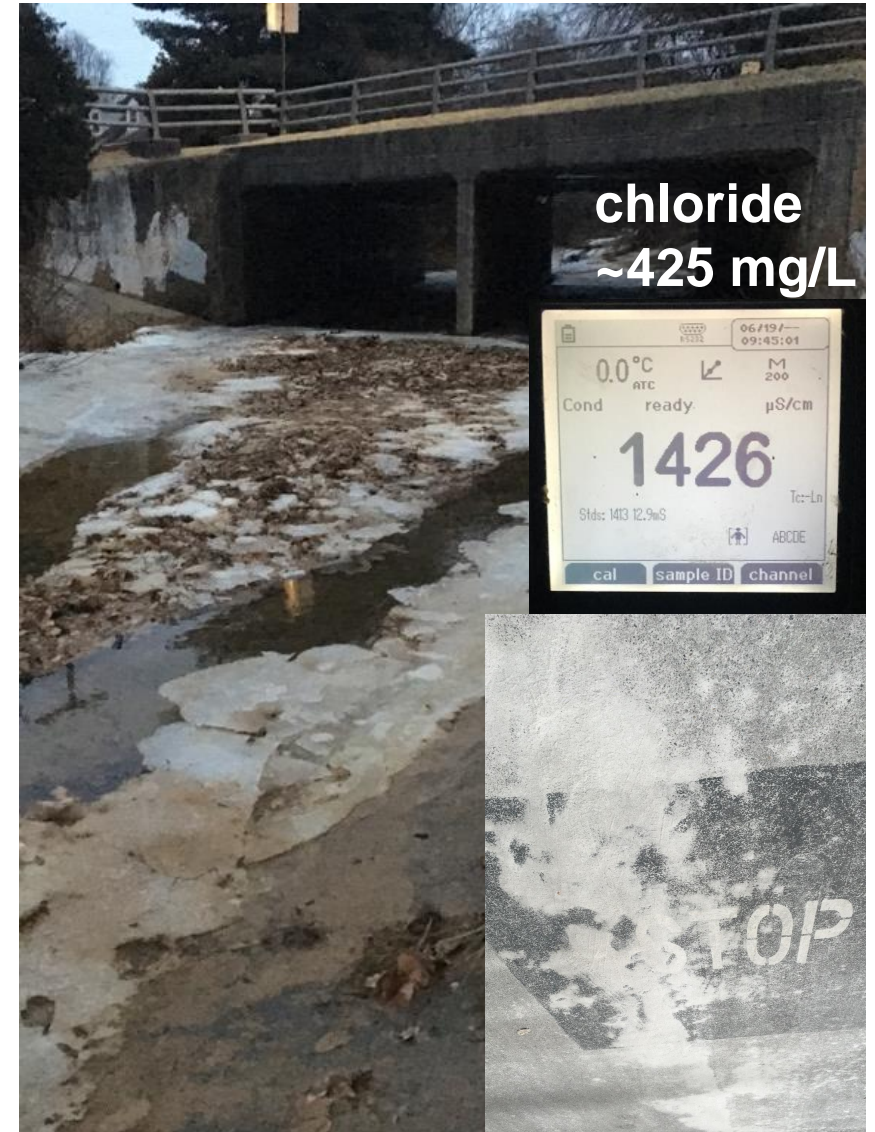
- 1) How much are private entities applying? And how encourage & implement best practices?
 - Often apply at higher rates
 - 14 – 40% of total application with higher end for dense urban
(Perera et al., 2013)



Knowledge & research gaps 1

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 - Often apply at higher rates
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(Perera et al., 2013)
- 2) What is the residence time of chloride in watersheds?

Related, if application rates are reduced, how long will it take to see reductions in stream concentrations?



Knowledge & research gaps 1

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Related, if application rates are reduced, how long will it take to see reductions in stream concentrations?
- 3) How do freshwater *communities* respond and change to stress from chloride (and chloride from different sources, e.g., NaCl versus MgCl₂).



Knowledge & research gaps 1

- 1) How much are private entities applying? And how encourage & implement best practices?
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- 2) What is the residence time of chloride in watersheds?

Related, if application rates are reduced, how long will it take to see reductions in stream concentrations?
- 3) How do freshwater communities respond and change to stress from chloride (and chloride from different sources, e.g., NaCl versus MgCl₂).
 - Of course will vary across (eco)regions, etc.
 - What are key thresholds? Maybe focus on low impervious watersheds?

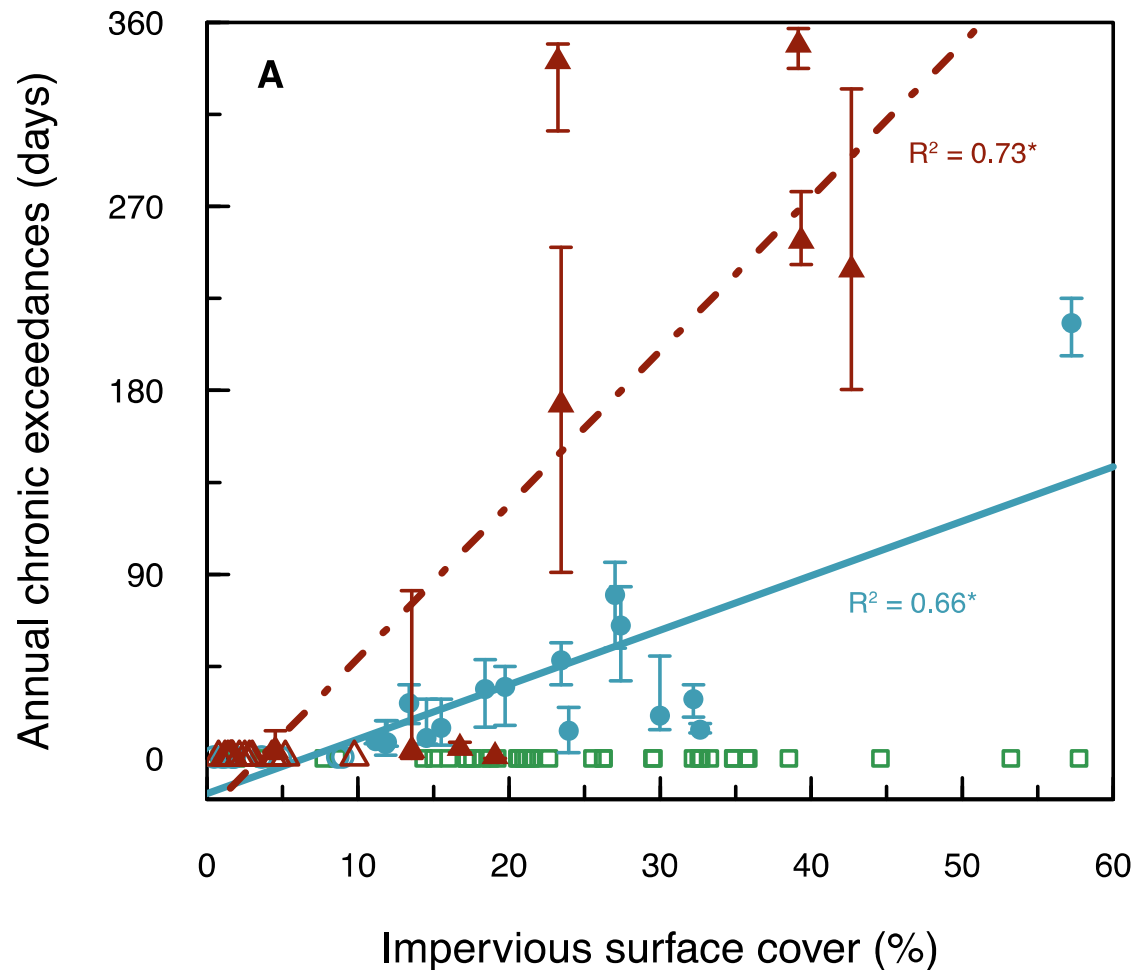


Knowledge & research gaps 2

- 4) How can existing data be used and extrapolated to non-monitored (or less frequently monitored) streams?
- 5) What are long-term effects on nutrient fluxes?

Knowledge & research gaps 2

4) How can existing data be used and extrapolated to non-monitored (or less frequently monitored) streams?



For Mid-Atlantic & New England

All watersheds with >9% ISC frequently exceed EPA chronic criterion each year

Median chloride concentrations correlate even better with exceedances
Can probably get reasonable picture with non-winter baseflow sampling

Dugan et al. (2020) *ES&T* is great for lakes

Update on Fairfax County's adoption of the Northern Virginia Salt Management Strategy (SaMS)

Bay-wide Stormwater Partners Retreat

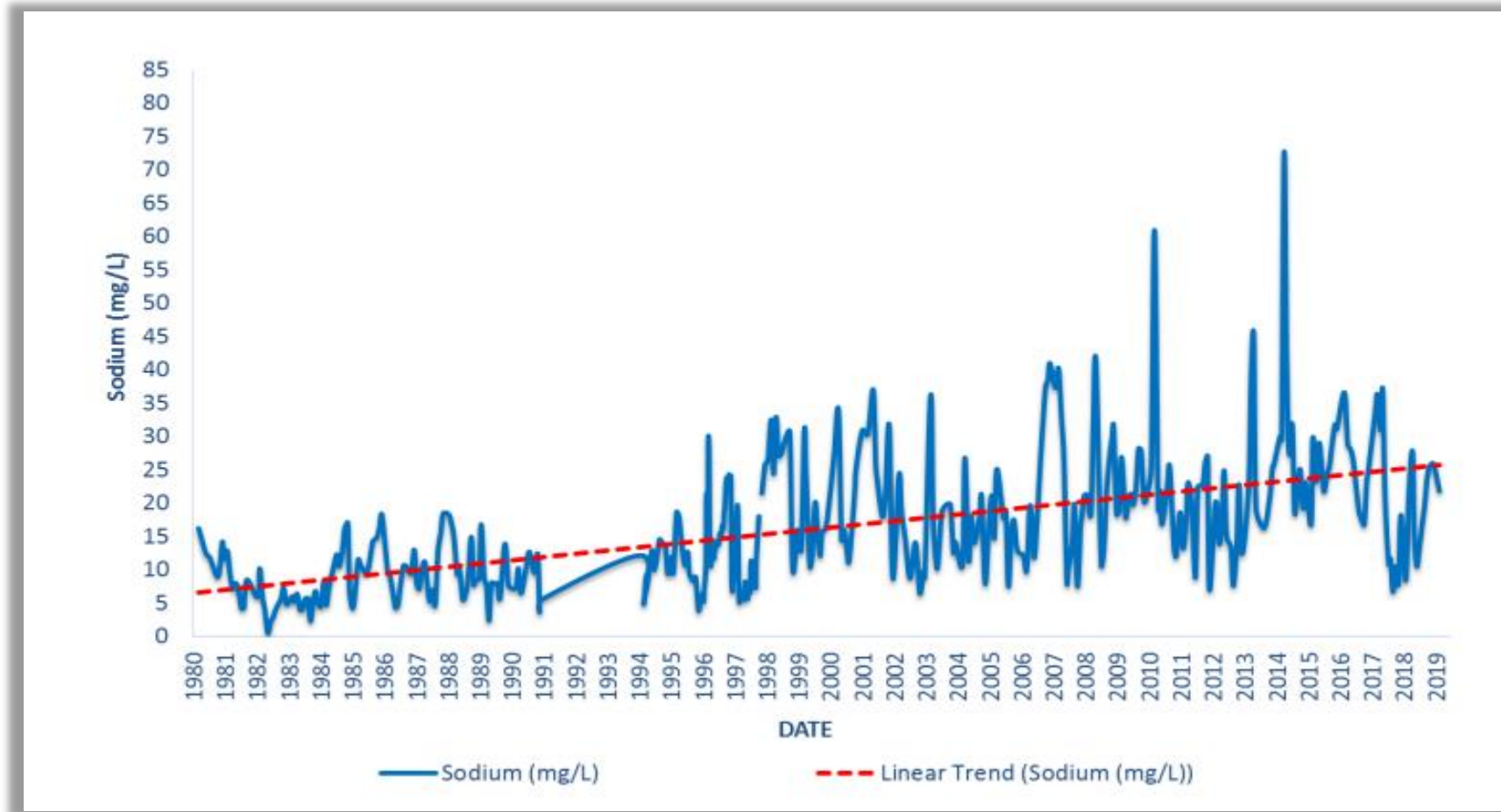
Department of Public Works and Environmental Services
Working for You!



A Fairfax County, VA, publication
2023

Impacts to Drinking Water

Trends in sodium levels at the drinking water intake on the Occoquan Reservoir.

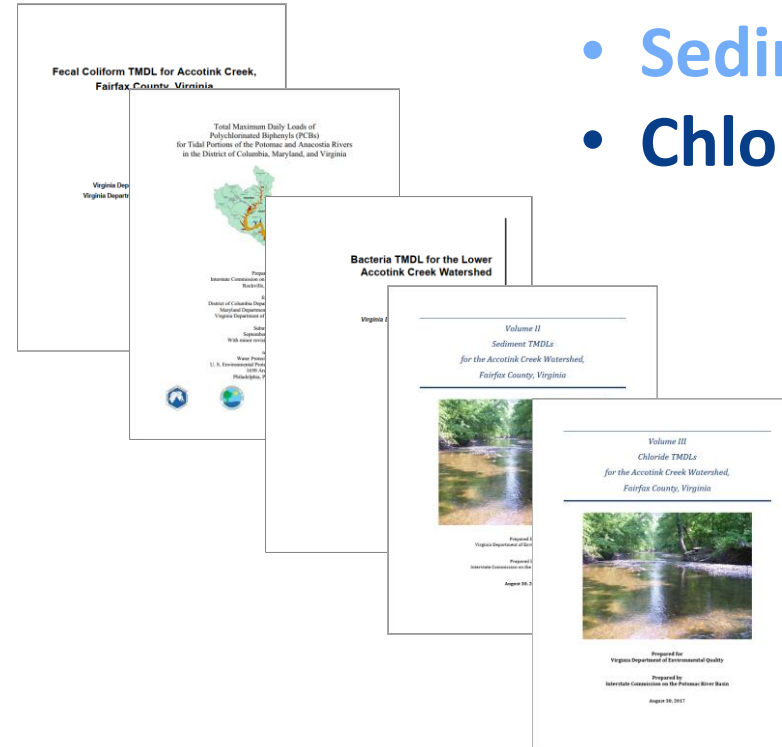


Accotink Creek TMDLs



Accotink Creek TMDL WLAs:

- Bacteria
- PCBs
- Sediment
- Chloride



Winter Operations – Level of Service



FAIRFAX COUNTY PUBLIC WORKS AND ENVIRONMENTAL SERVICES 2022-23 Snow Brief

FACILITY PRIORITIZATION

The Board of Supervisors has approved the prioritization of snow removal at county facilities as follows:

- **Priority 1 sites**
 - Government Centers/Judicial Complex
 - Police and Fire Stations
 - Emergency Operations/Communications Centers
 - Emergency Health Services
 - Mass Transit Facilities
- **Priority 2 sites**
 - Health Centers and 24-Hour Shelters
 - Other Essential Facilities
- **Priority 3 sites**
 - Community Centers, Libraries, Training Facilities
- **Priority 4 sites**
 - Developer Default/Neighborhood Road Segments
 - Metro Pilot Trails

ACTIVATION LEVELS

We monitor the forecast closely and mobilize crews and resources.

The amount and timing of the event factor into the activation level.

FOUR ACTIVATION LEVELS:

- Level 1 – Less than 2"
- Level 2 – More than 2"
- Level 3 – More than 4"
- Level 4 – More than 15"

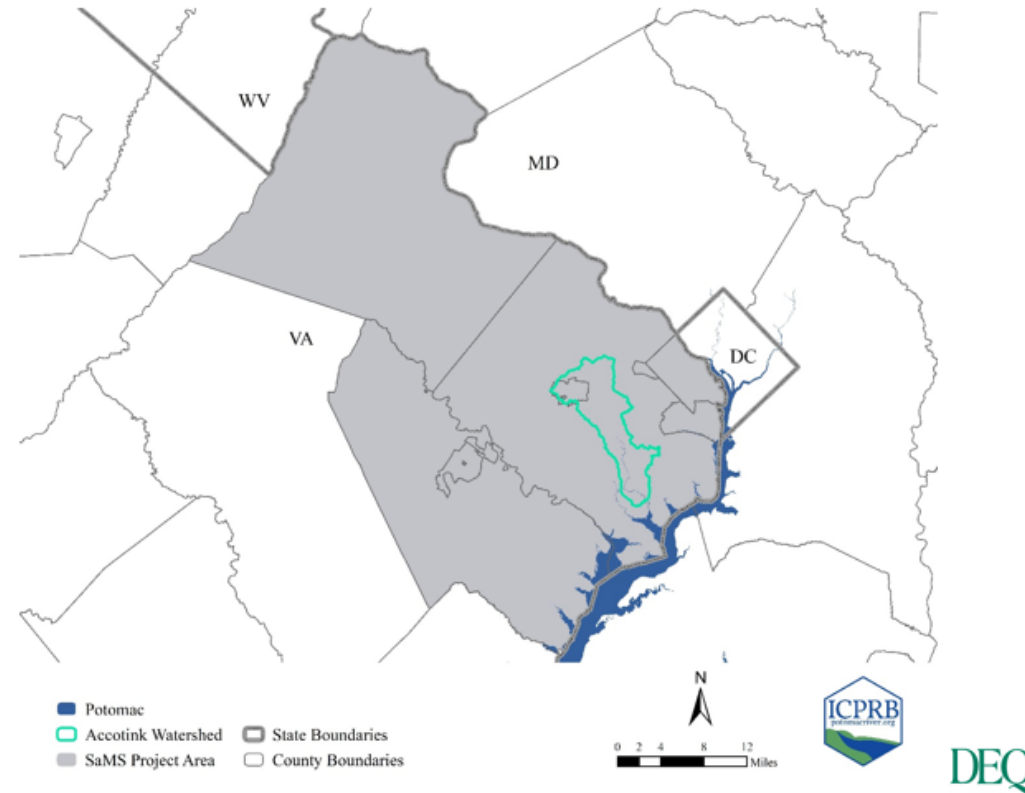
Our snow teams are assigned facilities based on the activation level and work on 12-13 hour shifts until all facilities are cleared.



DEQ and SaMS

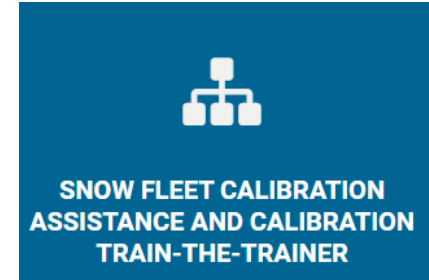
Salt Management Strategy (SaMS)

- A broad, proactive and voluntary approach to develop solutions to minimize impacts while maintaining public safety
- A toolbox for multiple audiences
 - Optimize winter practices
 - Raise awareness
 - Monitor efforts
 - Adaptive implementation



4

Training and Calibration



Over-application



Correct application



NEWS

April 14th, 2021

Fairfax County Salt Dome Projects Receive Building Design and Construction Award



When preparing for snow, Fairfax County, VDOT work to limit salt use

Angela Woolsey January 20, 2022 at 11:00am



Fairfax County and the Northern Virginia Salt Management Strategy

Updating Contract Language



- **Stress Importance of Safety**
- **Referencing SaMS Best Practices**
- **Remove language incentivizing material application**
- **Requiring material usage reporting**

A poster for "2022 WINTER SALT MANAGEMENT TRAINING". The poster has a blue and white background with a photograph of a road curb. The text includes: "2022 WINTER SALT MANAGEMENT TRAINING", "September 20, 2022", "9 am - 4 pm", "3040 Williams Drive Ste #200", "Fairfax, VA", "ABOUT THE TRAINING", and "Join other winter salt management professionals for a day-long training on effective, environmentally-friendly salt application planning and practices."/>

**2022
WINTER SALT
MANAGEMENT TRAINING**

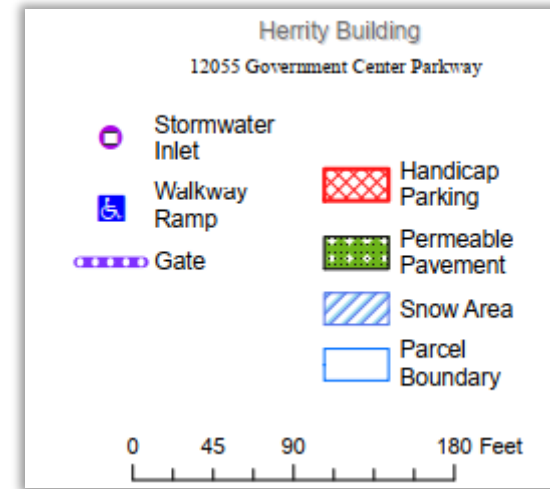
September 20, 2022
9 am - 4 pm
3040 Williams Drive Ste #200
Fairfax, VA

ABOUT THE TRAINING

Join other winter salt management professionals for a day-long training on effective, environmentally-friendly salt application planning and practices.



Snow Book – Site Characterization



- Highlight storm drains and special areas
- Quantifies areas treated
- Provide estimates / expectations for material use

Education & Outreach



Salt and Sand Piles Storage Guidance

Business and property owners who plan to store loose or bagged salt or sand outside may not know that improper storage may harm the environment, destroy natural habitats and pollute the Chesapeake Bay.

Salt contains chloride, which is toxic to aquatic and plant life. It corrodes equipment and damages infrastructure. Salt also contains sodium which, once it enters our waterways, is not removed by wastewater treatment or even drinking water treatment processes. Salinization of the nation's waters is a growing concern and regulatory efforts are currently underway to reduce salt inputs to the environment.

Sand-laden runoff from developed areas clogs storm drains, degrades aquatic environments, and harms aquatic life.



Illicit Discharge & Improper Disposal Responses

Material Category	Number of Responses
Uncategorized	64
Salt	47
Unknown	37
Pool Discharge	36
FOG	32
Sediment	17
Sewage	16
Paint	14
Oil/Fuel	13
Litter	12
Yard Waste	11
Potable Water	8
Suds/Foam	8
Vehicle Washing	8
White Substance	8
Oily Sheen	7
Concrete/Granite Slurry or Dust	5
Algae	4
Groundwater	4
Blue Substance	3
Dog Waste	3
Cooling Tower	2
Fish Kill	2
Construction Material	1
Odor	1
Sump Water	1
Total	358

2021



3

Monitoring and Assessment

USGS
science for a changing world

USGS Home Contact

Fairfax County Water Resources Monitoring Network

Home Study Overview Partners Maps Data Publications

Study Overview

Problem

In the past decade, hundreds of millions of dollars have been invested into the implementation of Best Management Practices (BMPs), with the explicit goal of improving water quality. Earlier research has demonstrated that these implemented BMPs are effective at the plot-scale and the field-scale; however, less information is available to document the effectiveness of these BMPs at the watershed scale - precisely the scale at which water-quality compliance and water-quality improvements are typically judged. Because of the costs associated with the implementation of these BMPs, federal, state, and local agencies are asking:

1. Are the implementation activities working?
2. How long will it take for the BMPs to work?
3. Are there more time-efficient, cost-effective methods for detecting these improvements?

Answers are needed to these questions to support the development of watershed implementation plans, to motivate BMP implementation by stakeholders, and to ensure the vitality of the cost-share programs that have supplemented the cost of implementing these BMPs.

Objectives

Develop and initiate a water-resources monitoring network within Fairfax County to describe surface-water quantity and quality in numerous County streams. The data collection will be designed to provide a long-term record that can be used to address two fundamental objectives...

Objective 1. Develop four integrated water-resources monitoring stations throughout the County that can be used to describe current conditions and trends in both water quality and water quantity. These water-resources data also will be used to compute loads in water-quality constituents, such as sediment and nutrients. Finally, these data will be used to evaluate water-quality improvements that are associated with BMP implementation activities.

Objective 2. Evaluate the transferability of the results from the intensive water-resources monitoring stations to other watersheds. After determining the water-quality improvements that have occurred in the intensively monitored watersheds, evaluate whether the interpretations developed in these intensively monitored basins are consistent with trends and patterns in other less-intensively monitored (partial-record) watersheds. These partial-record trend sites will have slightly varied basin characteristics as the intensively monitored watersheds and will likely have differing amounts of BMP implementation activities.



Addition of major ions to sampling programs:

- Calcium
- Sodium
- Potassium
- Magnesium
- Chloride

Education & Outreach

Board of Supervisors Environmental Committee Meeting: Feb. 15, 2022



Public Meetings

2/15/2022 11:00 am to 2/15/2022 12:30 pm

Event Description

The Board of Supervisors [Environmental Committee](#) is scheduled to meet at 11:00 a.m. on Feb. 15, 2022 in the Board Auditorium of the Fairfax County Government Center.

MEETING MATERIALS

- **Item 6 - Quarterly Review of Environment and Energy NIPs**
 - [Maryland EV Incentives NIP](#)
 - [Vehicle Emissions Standards NIP](#)
 - [Fairfax Green Initiatives NIP](#)
 - [CECAP Implementation NIP](#)
 - [Chloride TMDL and Salt Management Strategy NIP](#)



Snow and Ice Maintenance Tips for Residents

Do you know...

- It only takes one teaspoon of salt to permanently pollute 5 gallons of water.
- Salt seeped into the environment can:
 1. Raise sodium levels in our drinking water and increase treatment costs.
 2. Harm fish, plants, and other wildlife.
 3. Corrode vehicles, roads, bridges, and parking lots.
- Salt can make it safer for us to walk and drive around. It helps keep roads open, and allows businesses, government, and social services to stay open with little interruption.
- Since there's no easy or cheap way to remove salt from our environment, we can all do our part to reduce the amount of salt we use and be #WinterSaltSmart by following the below tips.

What should you do before a storm?

- **Have your shovel or snow blower ready**
Shovels may be all that you need around Northern Virginia. To make it easier on your back, there are versions with wheels. Remember to take breaks and avoid overloading your shovel with wet snow.
- **For big storms or heavy weight snow,** snow blowers can be helpful.

Make sure to stock up on enough food, drinks and medicine (including prescriptions) before the storm

nvrc
Northern Virginia Regional Commission

www.wintersaltsmart.com

Education & Outreach

A photograph of a person in winter gear shoveling snow on a sidewalk. In the foreground, a large orange mug is visible. The background shows a snowy residential street with a house and trees.

*Be Winter
Salt Smart*

**12 OUNCE MUG OF
SALT COVERS 10
SIDEWALK SQUARES
OR A 20-FOOT
DRIVEWAY.**

 **FAIRFAX
COUNTY**

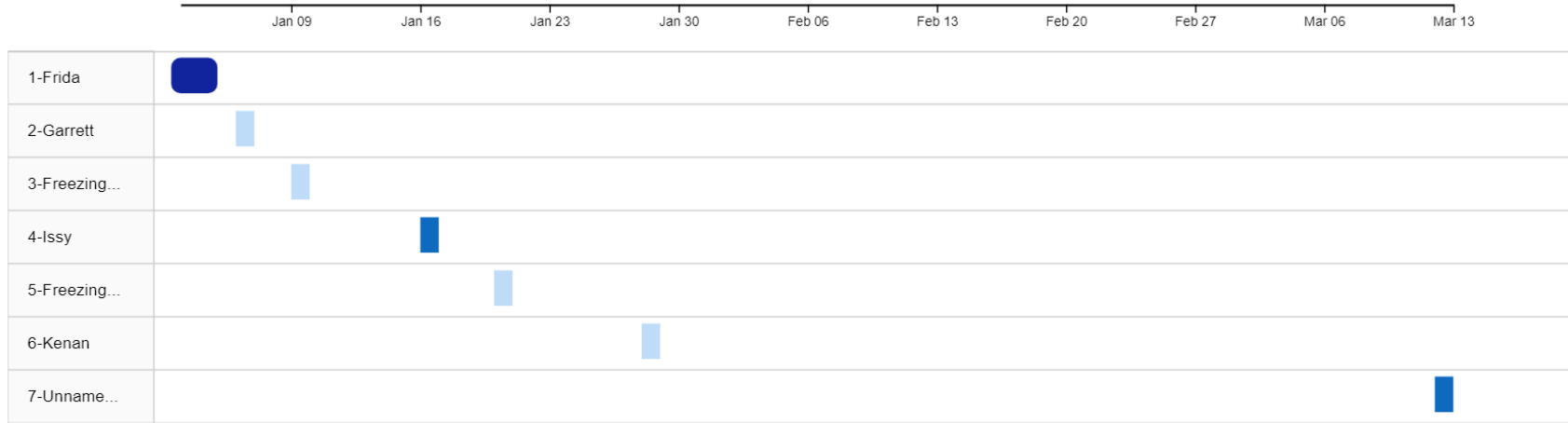
 **DEPARTMENT OF PUBLIC WORKS
AND ENVIRONMENTAL SERVICES**

Public Safety and Essential Services



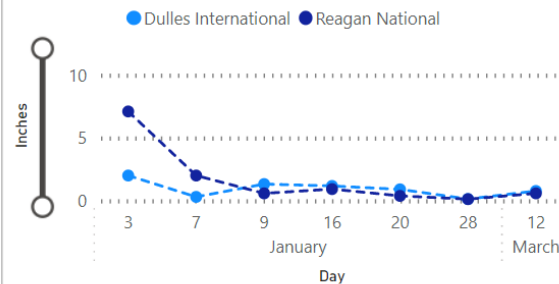
A snowstorm left drivers stranded on Interstate 95 near Fredericksburg, Va., for more than 24 hours.
Virginia Department of Transportation, via Associated Press

Tracking & Reporting – Winter Events



Storm Intensity ● High (>6") ● Light (<2") ● Medium (2-6")

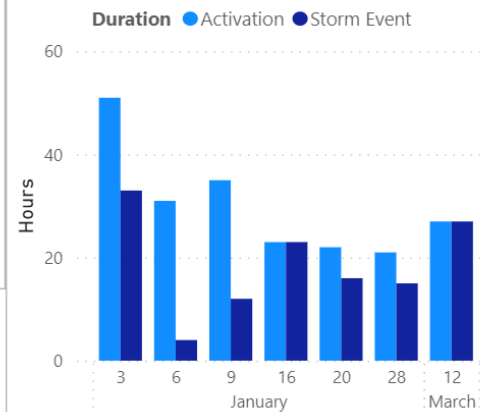
Snowfall Amounts



Storm Intensity



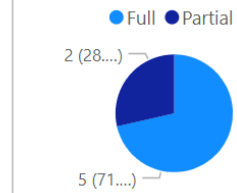
Storm Events and Activations



Precipitation Type and Post Storm Temperature Forecast

Early Storm Conditions	Falling	Rising	Total
Start as Snow	1	2	3
Start as Rain	2	0	2
Start as Freezing Rain	0	1	1
Total	3	3	6

Activation Type



2022

Fiscal Year

7

Number of Events

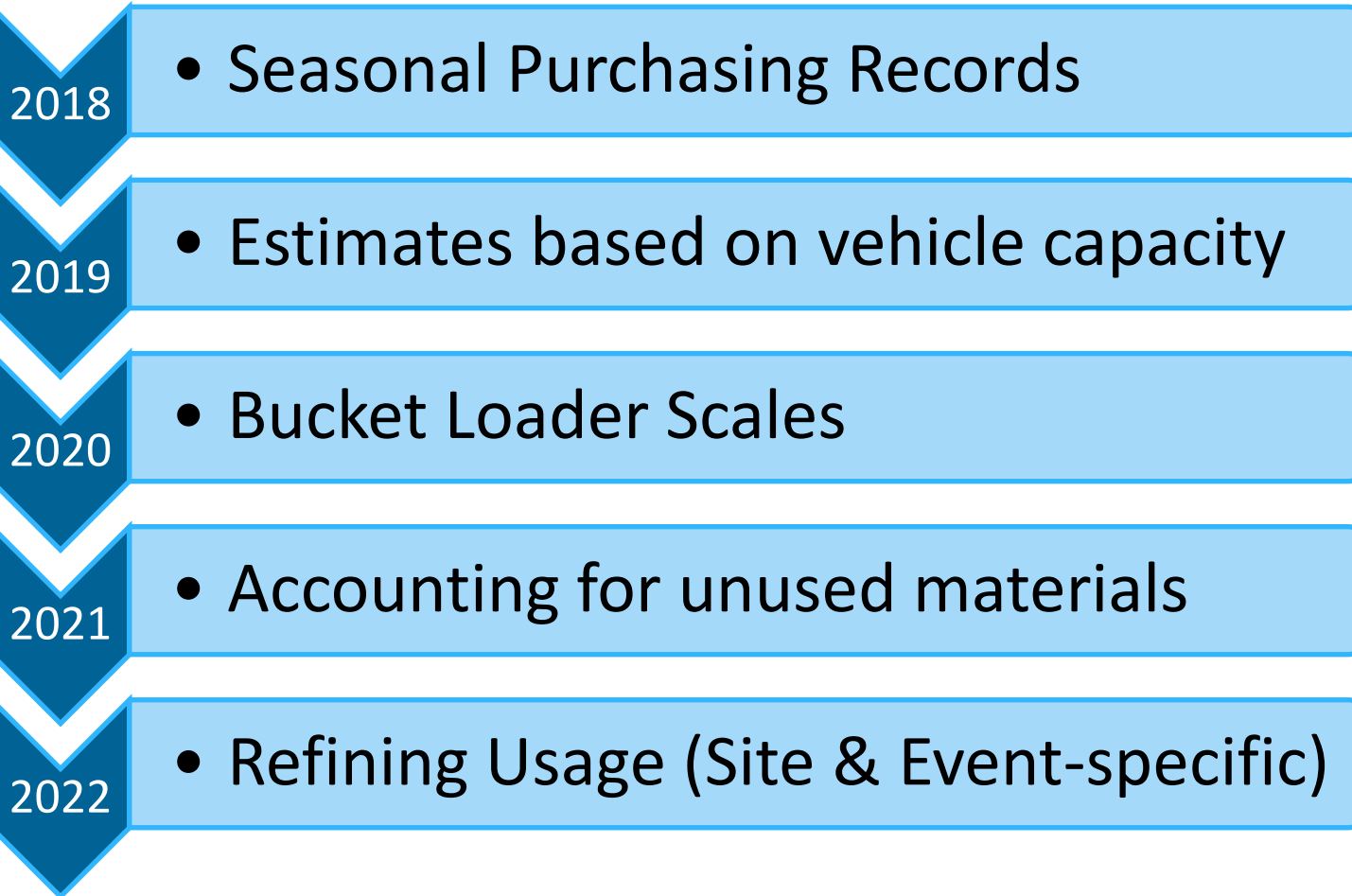
Other/Narrative

State of Emergency

Weather Advisory



Tracking & Reporting – Material Usage



Tracking Implementation

Category	2018	2019-2020	2021-2022	2020 Comment
Level of Service	Good	Good	Good	LOS well documented, includes FCPS & FCPA
Training / Certification	Fair	Trending Good	Good	MSMD, FCPS, FCPA attended training events in 2022
Equipment Calibration	Fair	Trending Good	Good	Records developed for each truck and spreader.
Site Characterization	Fair	Trending Good	Trending Good	Working with FCPA to obtain GIS data for sites.
Operations Plan	Fair	Fair	Trending Good	Snow Plan final draft under review.
Quality Assurance	Fair	Fair	Fair	Update needed.
Salt Usage Documentation	Fair	Fair	Trending Good	Improving process to address lessons learned from year 1. Received material usage from FCPS and FCPA.
Material Storage	Fair	Trending Good	Trending Good	FCPS Woodson storage facility design completed. FCPS construction on hold.
Tracking and Reporting	Poor	Fair	Trending Good	Improved Event Tracking (SmartSheet). Metrics developed for program.
Education & Outreach	Poor	Fair	Trending Good	Developing Flyers, Improving messaging & coordination. Washington Post articles.
Snow Contracts	Poor	Poor	Trending Fair	Working with DMB and contract managers
Monitoring	Poor	Poor	Fair	Added ions to In-stream & MS4 Wet Weather Monitoring Program.



Additional Information

For additional information, please contact



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