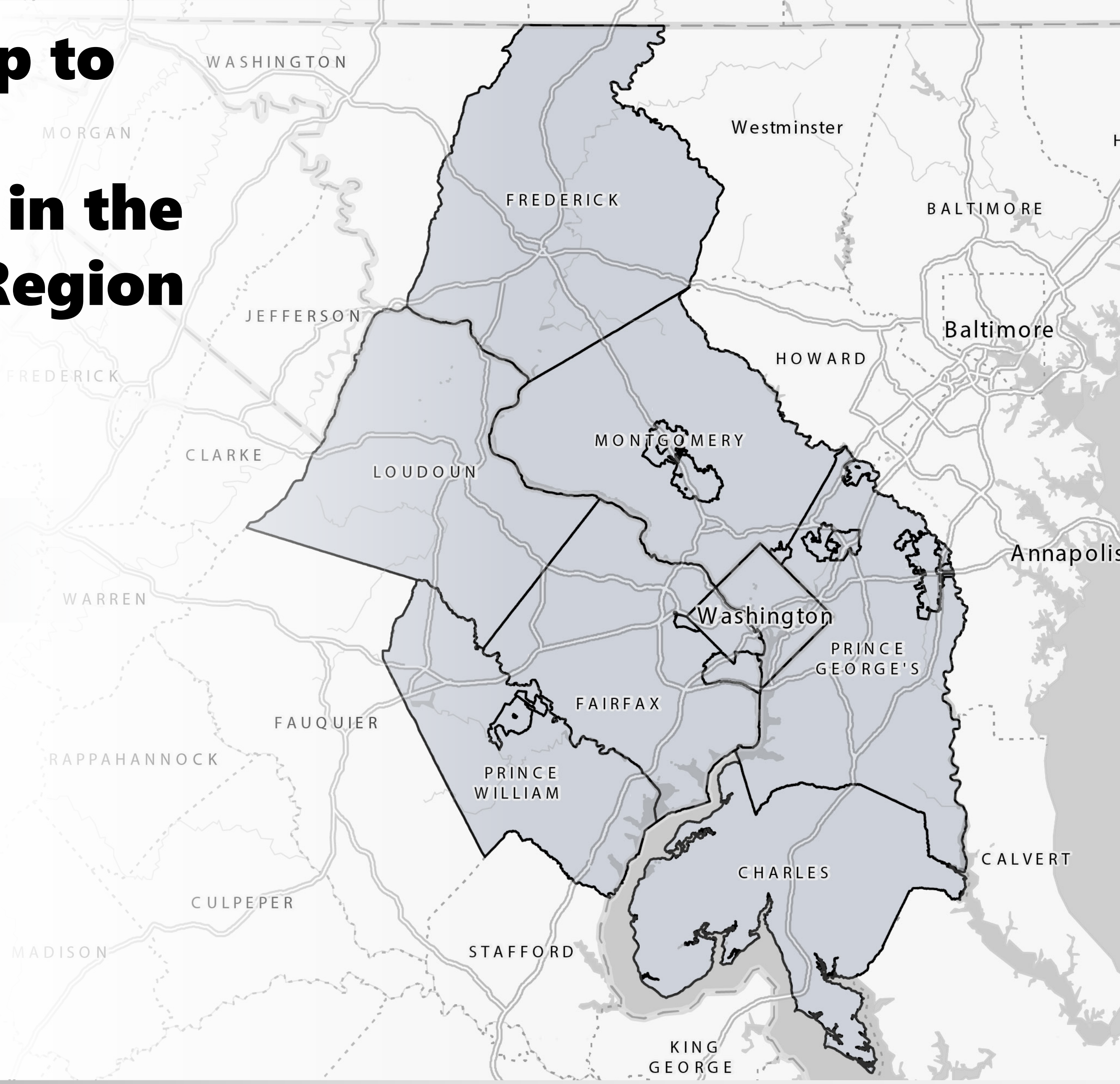
Establishing a Science Partnership to Support Understanding of the Freshwater Salinization Gradient in the Metropolitan Washington, D.C. Region

December 10th, 2021

Stanley Grant[1], Sujay Kaushal[2], John Jastram[3], Andrew Sekellick[3], and Jimmy Webber[3]



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[2]University of Maryland, Department of Geology and Earth System Science Interdisciplinary Center;
[3]U.S. Geological Survey

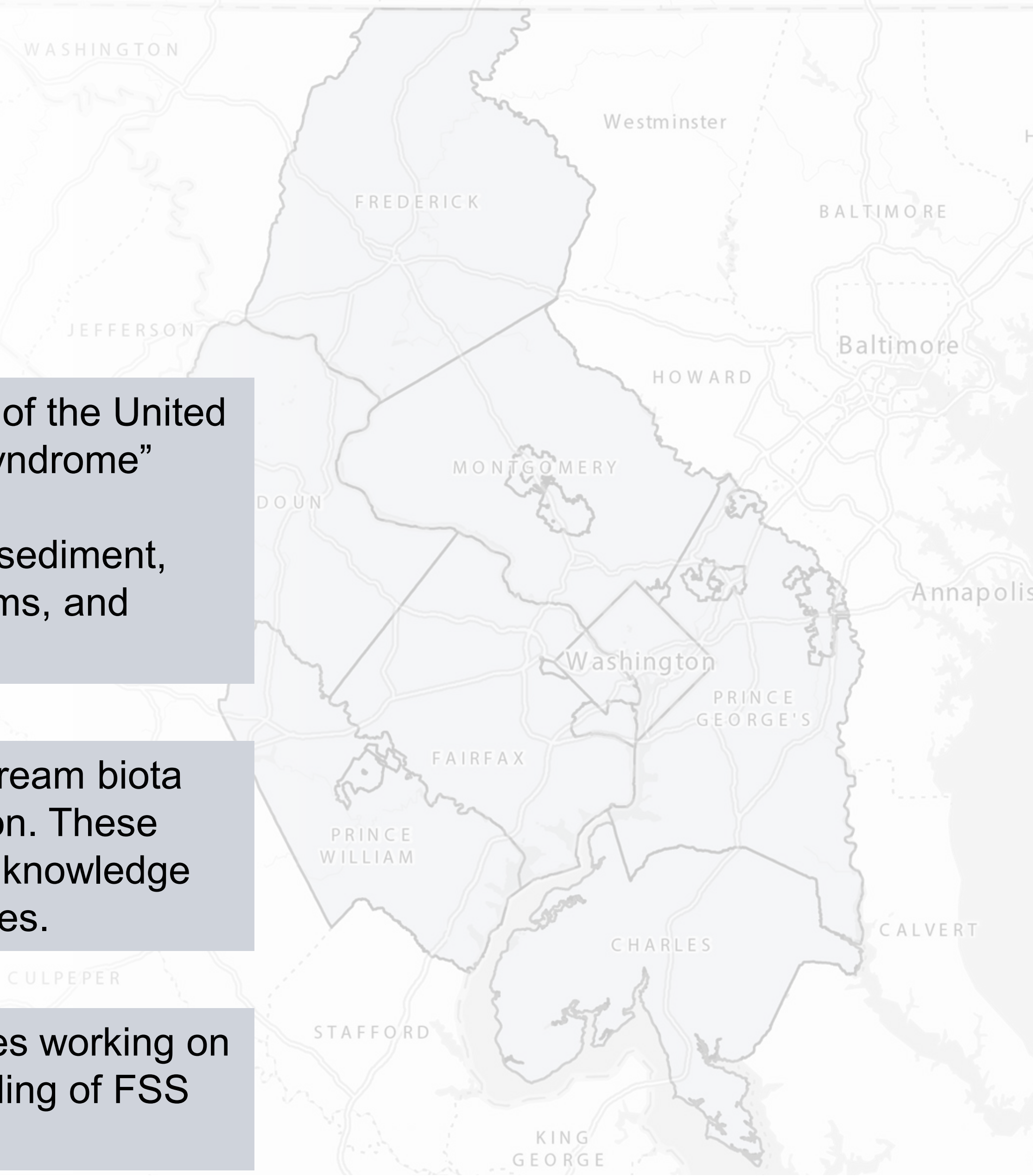
Establishing a Science Partnership to Support Understanding of the Freshwater Salinization Gradient in the Metropolitan Washington, D.C. Region

What is the problem? Freshwater salinity is rising across many regions of the United States and globally - a phenomenon called the “freshwater salinization syndrome” (FSS). This syndrome can:

1. Mobilize chemical constituents previously sequestered in streambed sediment,
2. Alter the structure and function of soil, stream, and riparian ecosystems, and
3. Impact regionally important drinking water supplies

Why should MWCOG care? FSS impacts on drinking water supplies, stream biota and stream health have been documented throughout the MWCOG region. These impacts are expected to continue and may only be mitigated by applying knowledge about ion sources, transport, and transformation to management strategies.

What is our vision? To develop a partnership between scientific agencies working on FSS research in the MWCOG region that can lead to a better understanding of FSS sources, impacts, and effective management strategies.

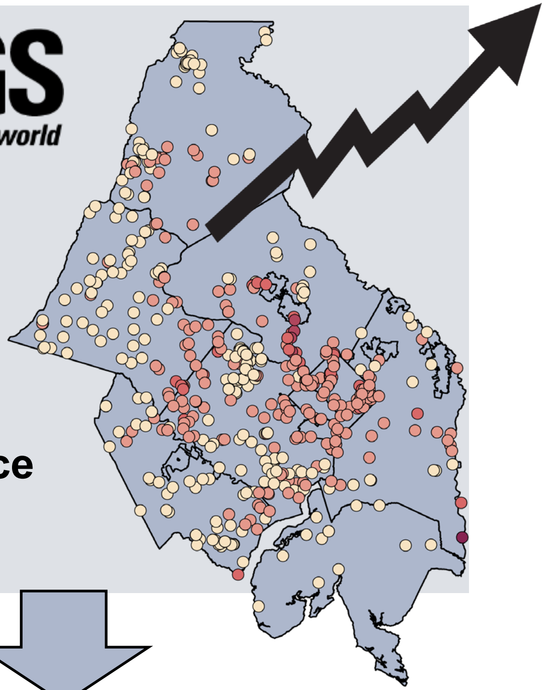


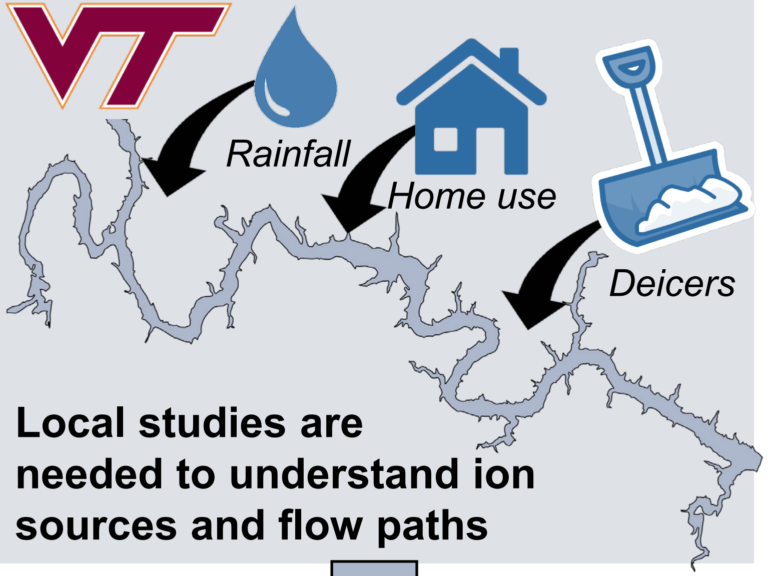
Establishing a Science Partnership to Support Understanding of the Freshwater Salinization Gradient in the Metropolitan Washington, D.C. Region

A collaborative scientific partnership is needed to address a complex, regional issue…

USGS
science for a changing world

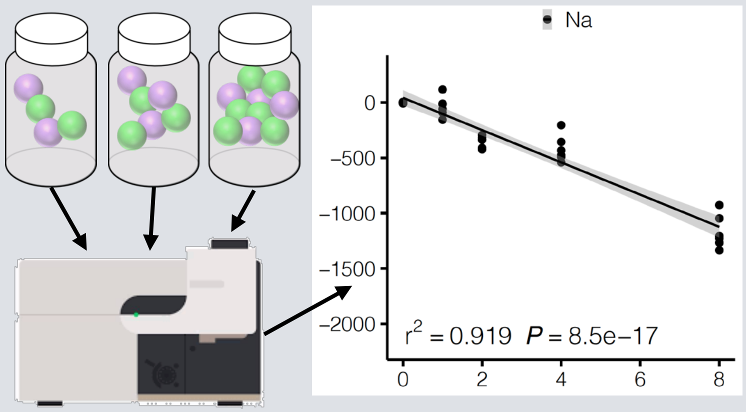
Monitoring networks can characterize patterns over time and space





Local studies are needed to understand ion sources and flow paths

Experimental treatments are needed to evaluate impacts and mechanisms



Synthesizing this knowledge is needed to understand and manage FSS in the MWCOG region

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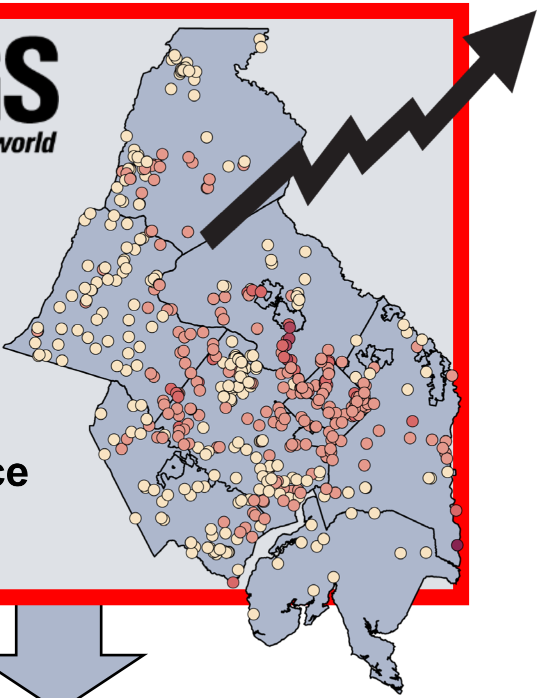

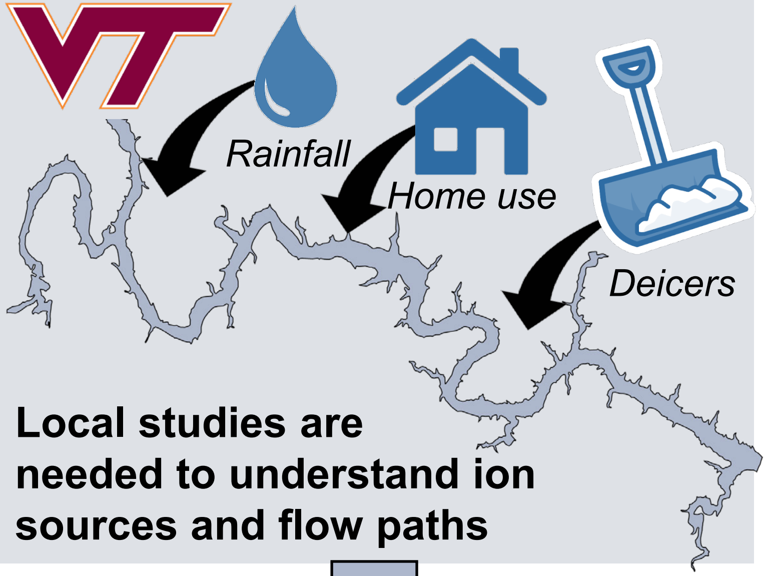

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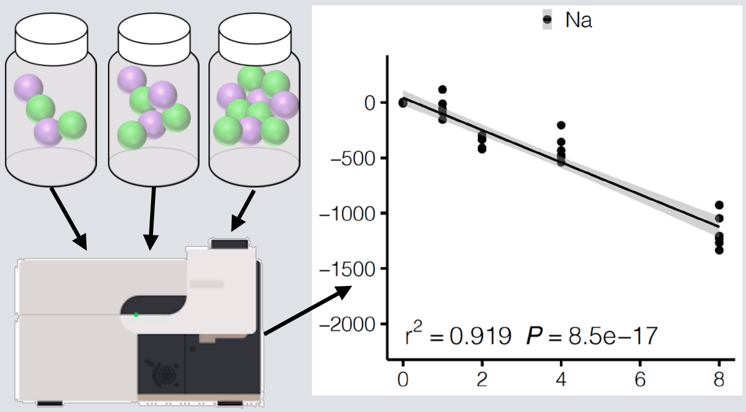
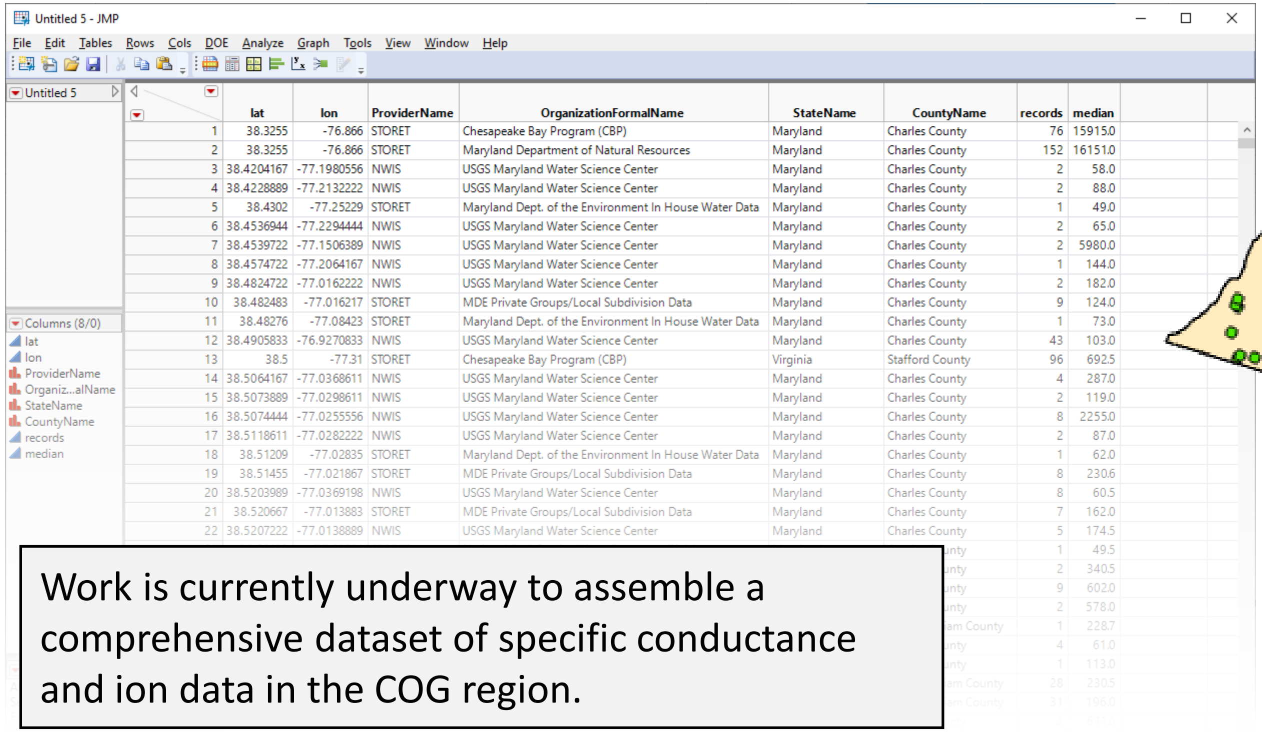


Synthesizing this knowledge is needed to understand and manage FSS in the MWCOG region

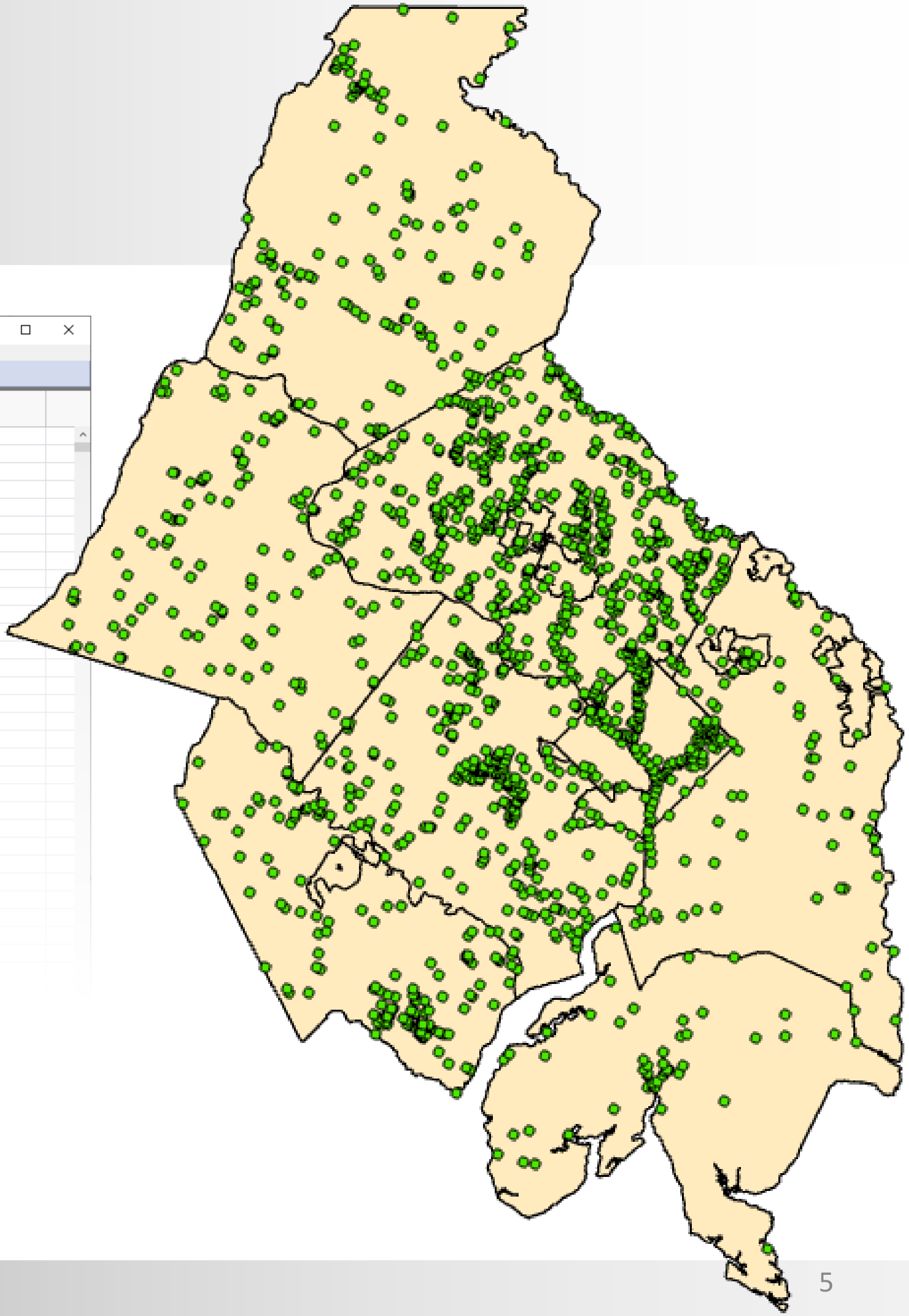
D1a (USGS leads, Year 1): compile continuous and discrete ion monitoring data (initially from the USGS, OWML and UMD) across the COG region into a single data file, explore additional datasets (DEQ, DNR,..) to ultimately include



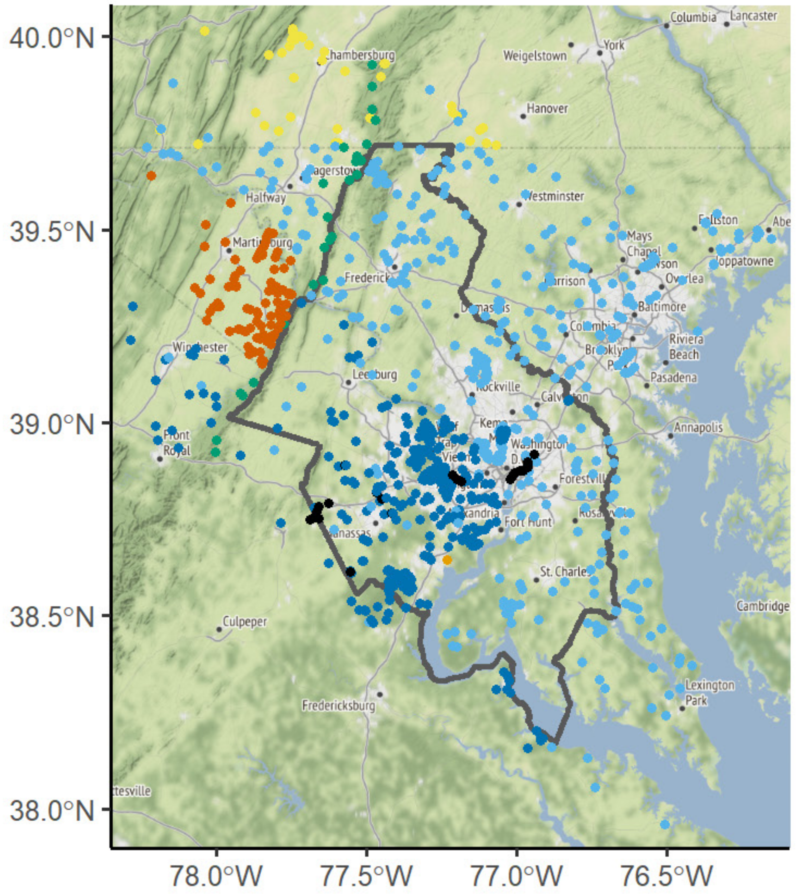
	lat	lon	ProviderName	OrganizationFormalName	StateName	CountyName	records	median
1	38.3255	-76.866	STORET	Chesapeake Bay Program (CBP)	Maryland	Charles County	76	15915.0
2	38.3255	-76.866	STORET	Maryland Department of Natural Resources	Maryland	Charles County	152	16151.0
3	38.4204167	-77.1980556	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	2	58.0
4	38.4228889	-77.2132222	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	2	88.0
5	38.4302	-77.25229	STORET	Maryland Dept. of the Environment In House Water Data	Maryland	Charles County	1	49.0
6	38.4536944	-77.2294444	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	2	65.0
7	38.4539722	-77.1506389	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	2	5980.0
8	38.4574722	-77.2064167	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	1	144.0
9	38.4824722	-77.0162222	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	2	182.0
10	38.482483	-77.016217	STORET	MDE Private Groups/Local Subdivision Data	Maryland	Charles County	9	124.0
11	38.48276	-77.08423	STORET	Maryland Dept. of the Environment In House Water Data	Maryland	Charles County	1	73.0
12	38.4905833	-76.9270833	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	43	103.0
13	38.5	-77.31	STORET	Chesapeake Bay Program (CBP)	Virginia	Stafford County	96	692.5
14	38.5064167	-77.0368611	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	4	287.0
15	38.5073889	-77.0298611	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	2	119.0
16	38.5074444	-77.0255556	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	8	2255.0
17	38.5118611	-77.0282222	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	2	87.0
18	38.51209	-77.02835	STORET	Maryland Dept. of the Environment In House Water Data	Maryland	Charles County	1	62.0
19	38.51455	-77.021867	STORET	MDE Private Groups/Local Subdivision Data	Maryland	Charles County	8	230.6
20	38.5203989	-77.0369198	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	8	60.5
21	38.520667	-77.013883	STORET	MDE Private Groups/Local Subdivision Data	Maryland	Charles County	7	162.0
22	38.5207222	-77.0138889	NWIS	USGS Maryland Water Science Center	Maryland	Charles County	5	174.5

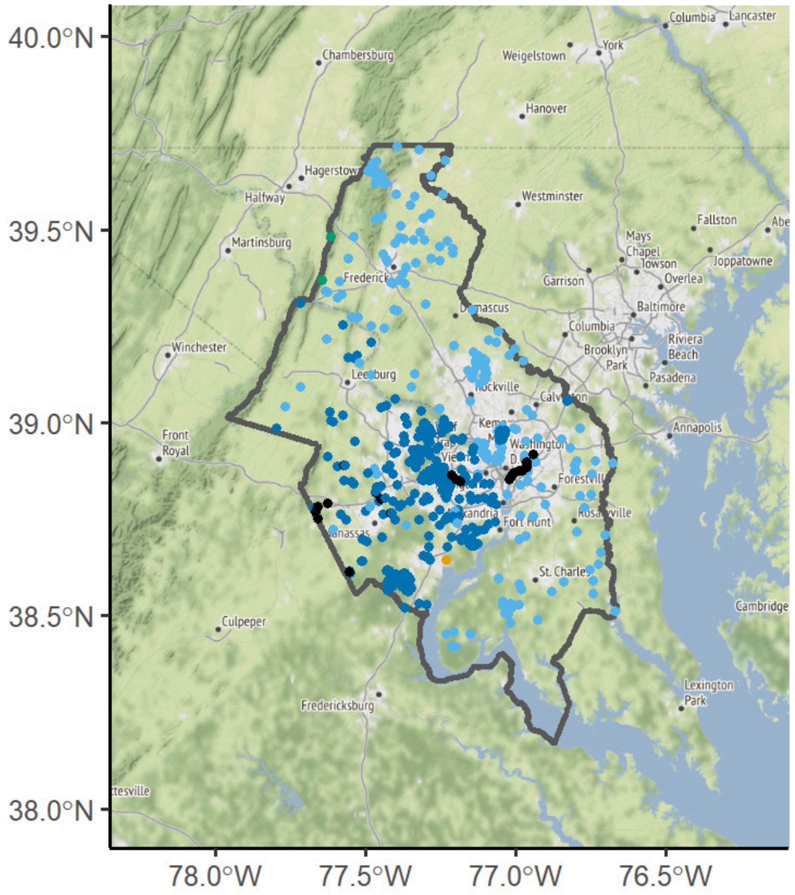
Work is currently underway to assemble a comprehensive dataset of specific conductance and ion data in the COG region.

The research team will target initial efforts at sites that are "well known" (USGS, OWQML, UMD stations) and then expand focus to other locations.



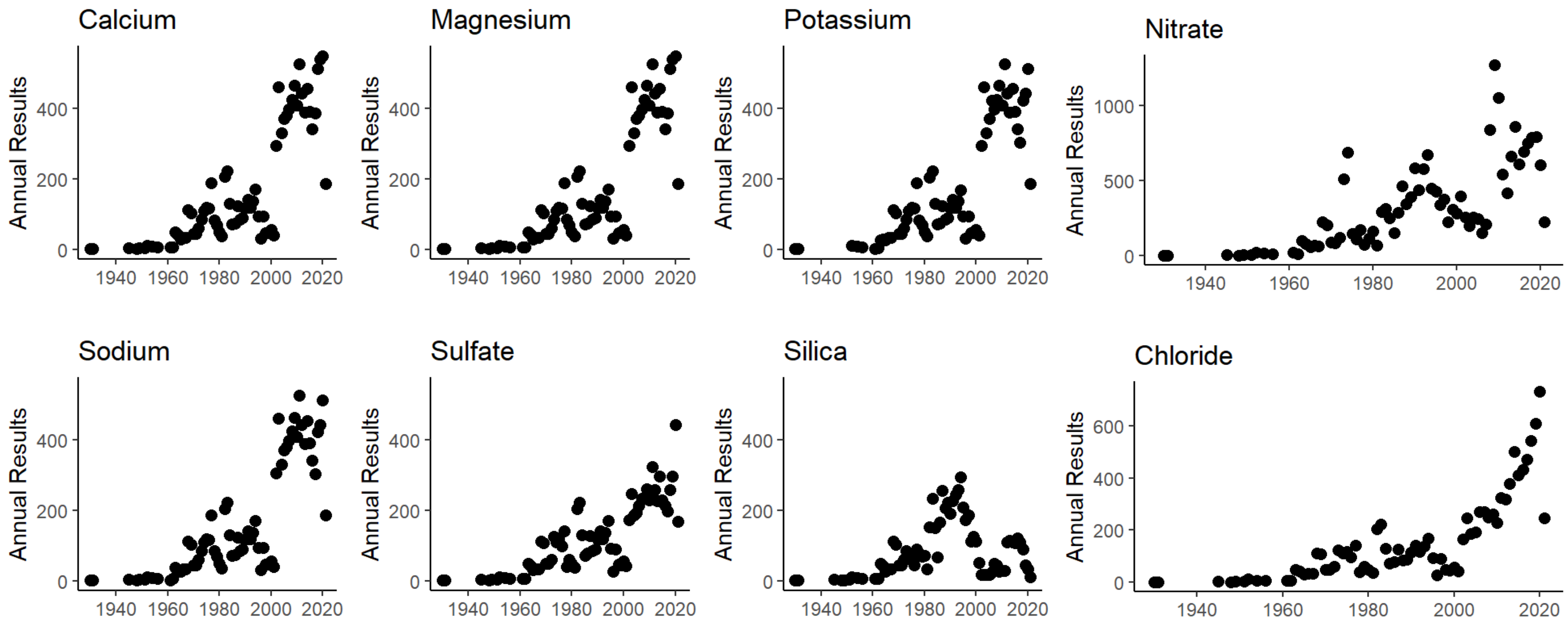
Compilation of available data yielded results from 606 sites within the MWCOG Area

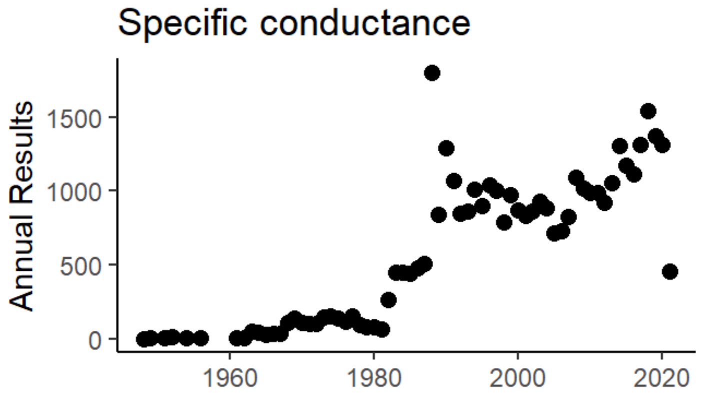




Annual sample counts for ions have increased over time, particularly in the last 2 decades

Measurements of Specific Conductance are much more common





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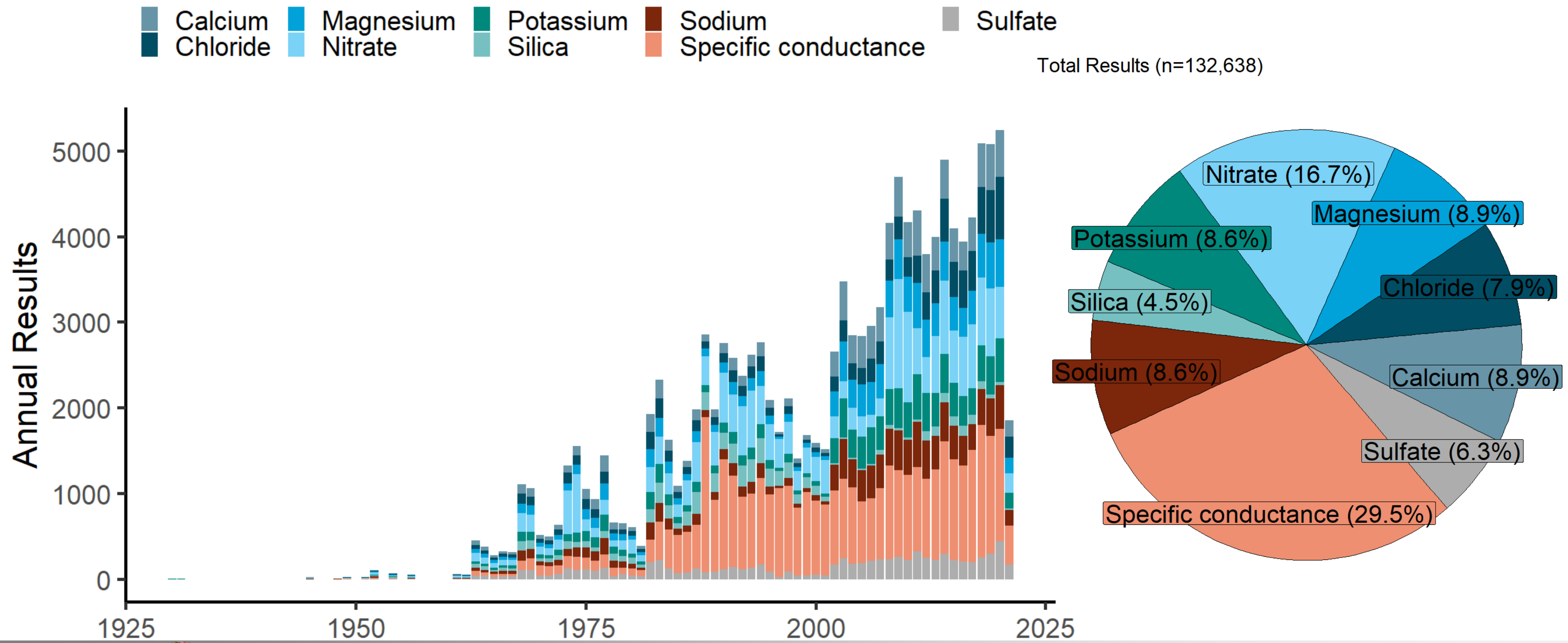
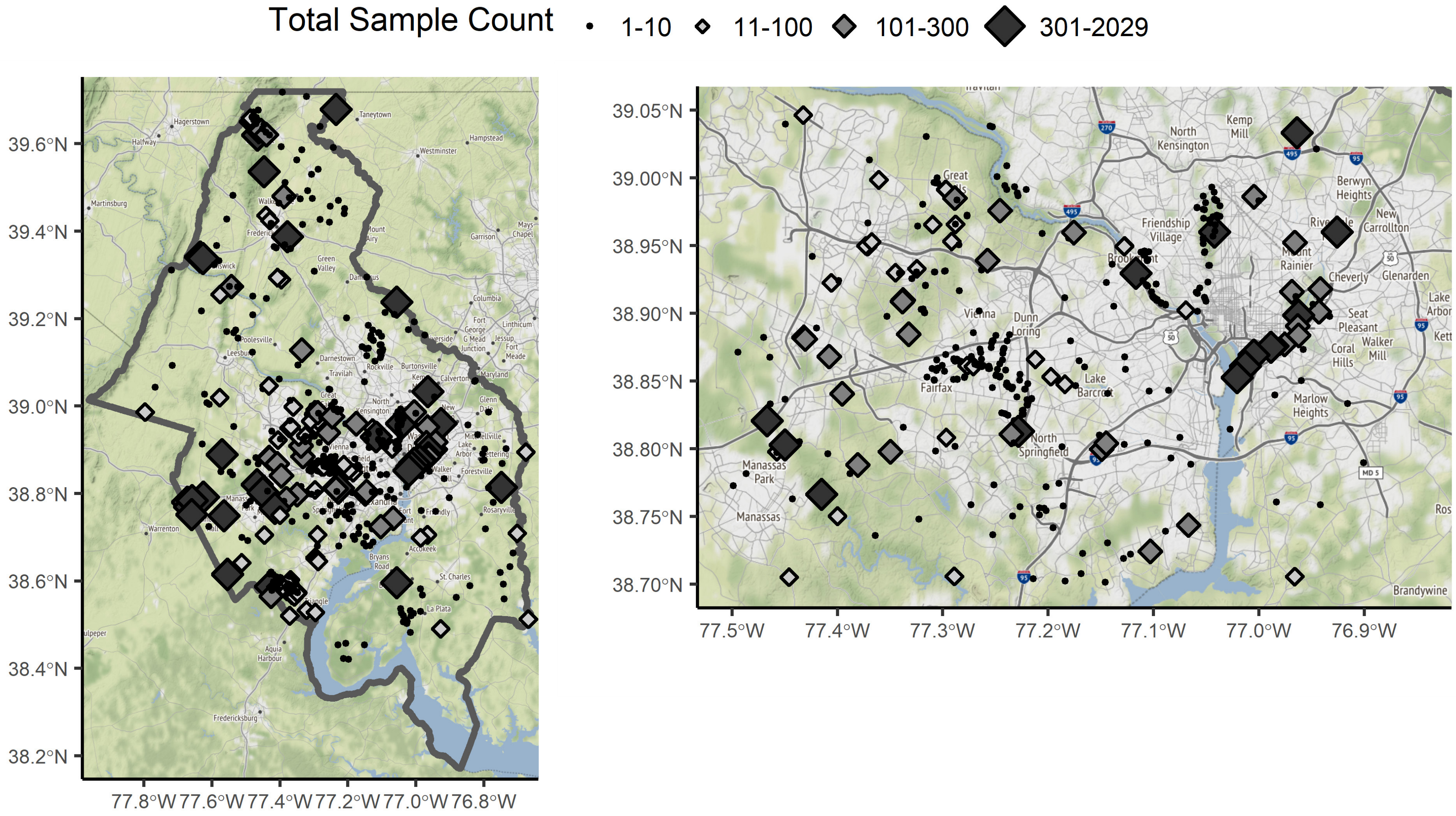
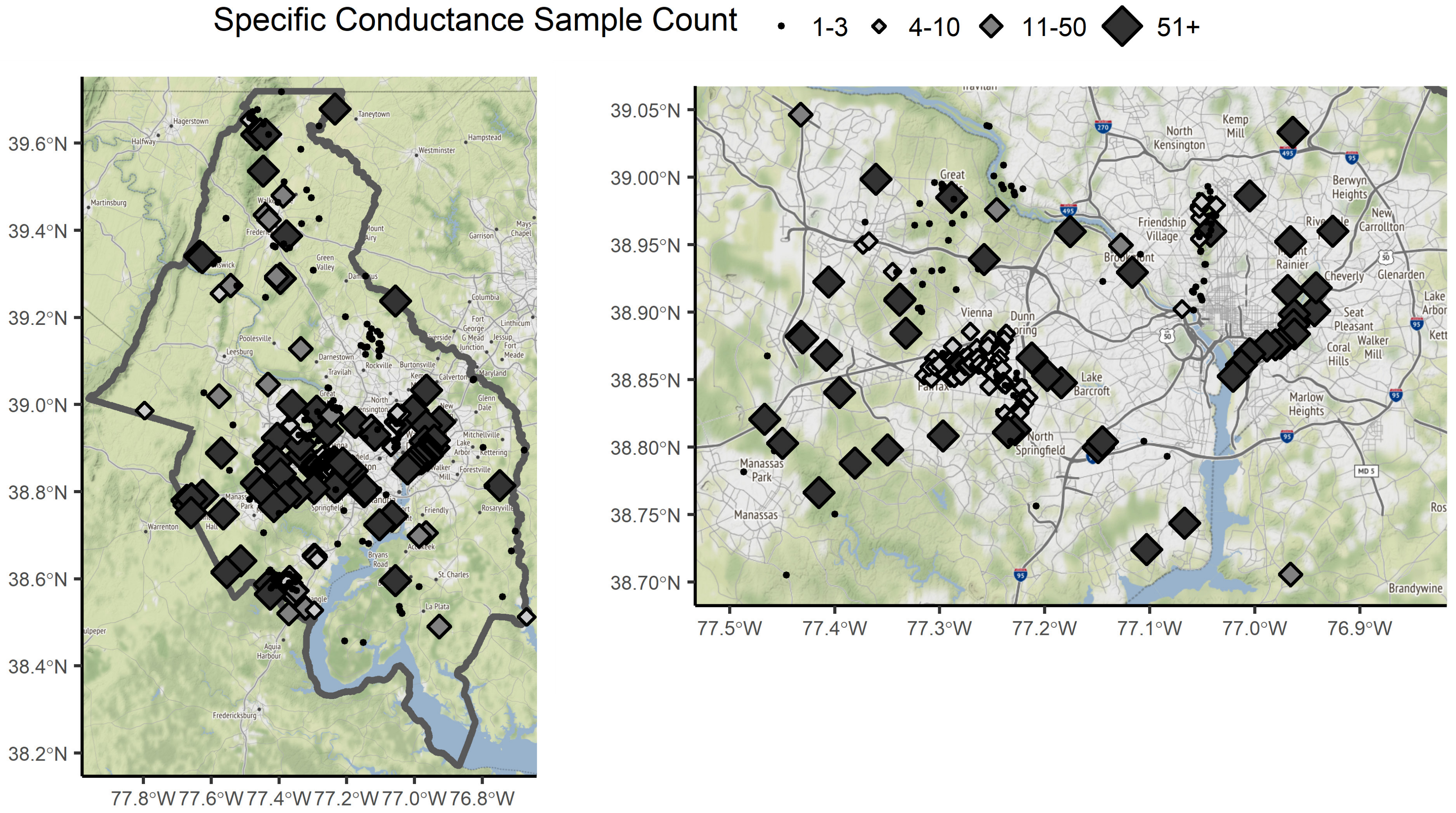


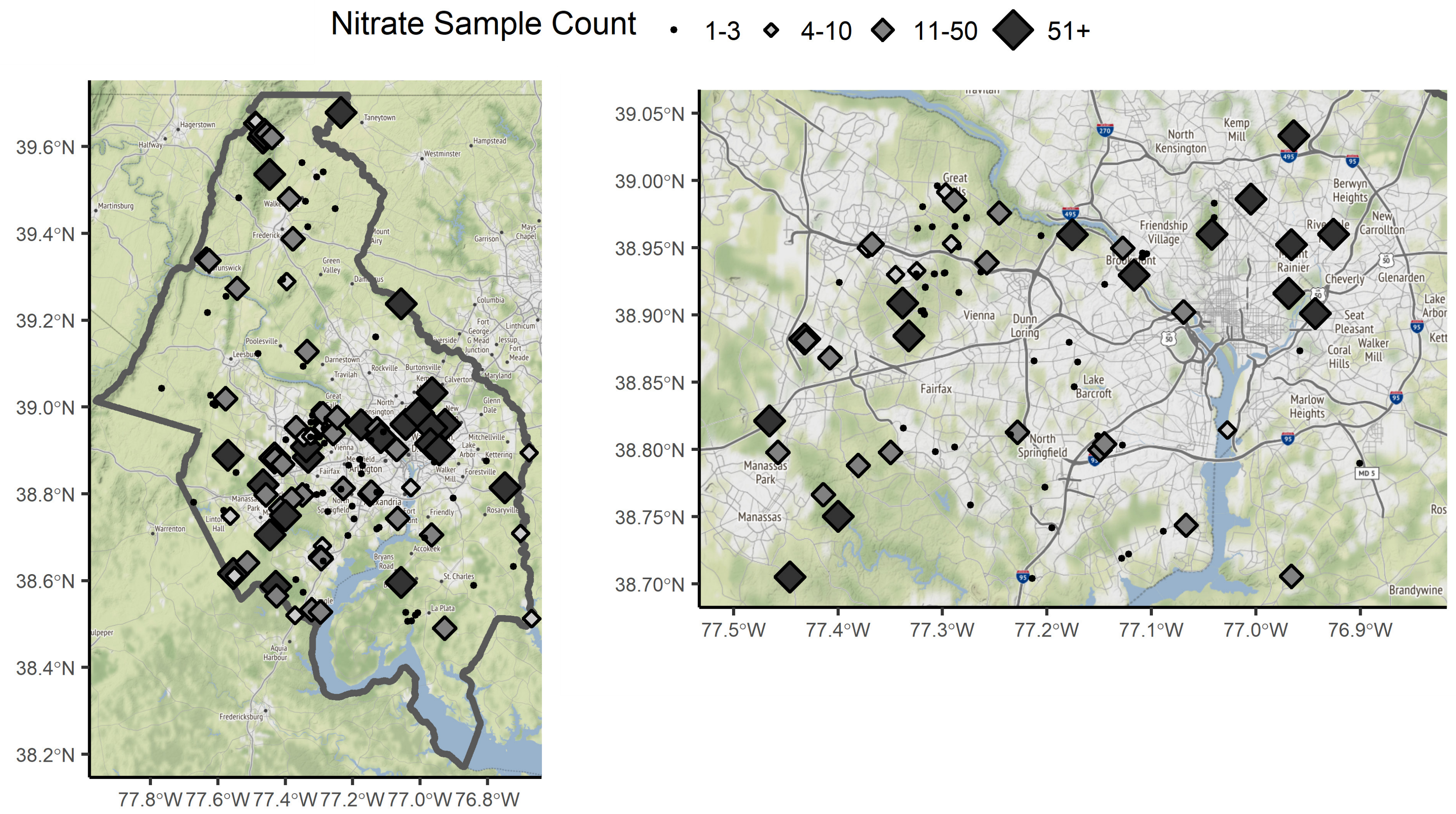
Overall, result counts are relatively well distributed across the area



Specific conductance

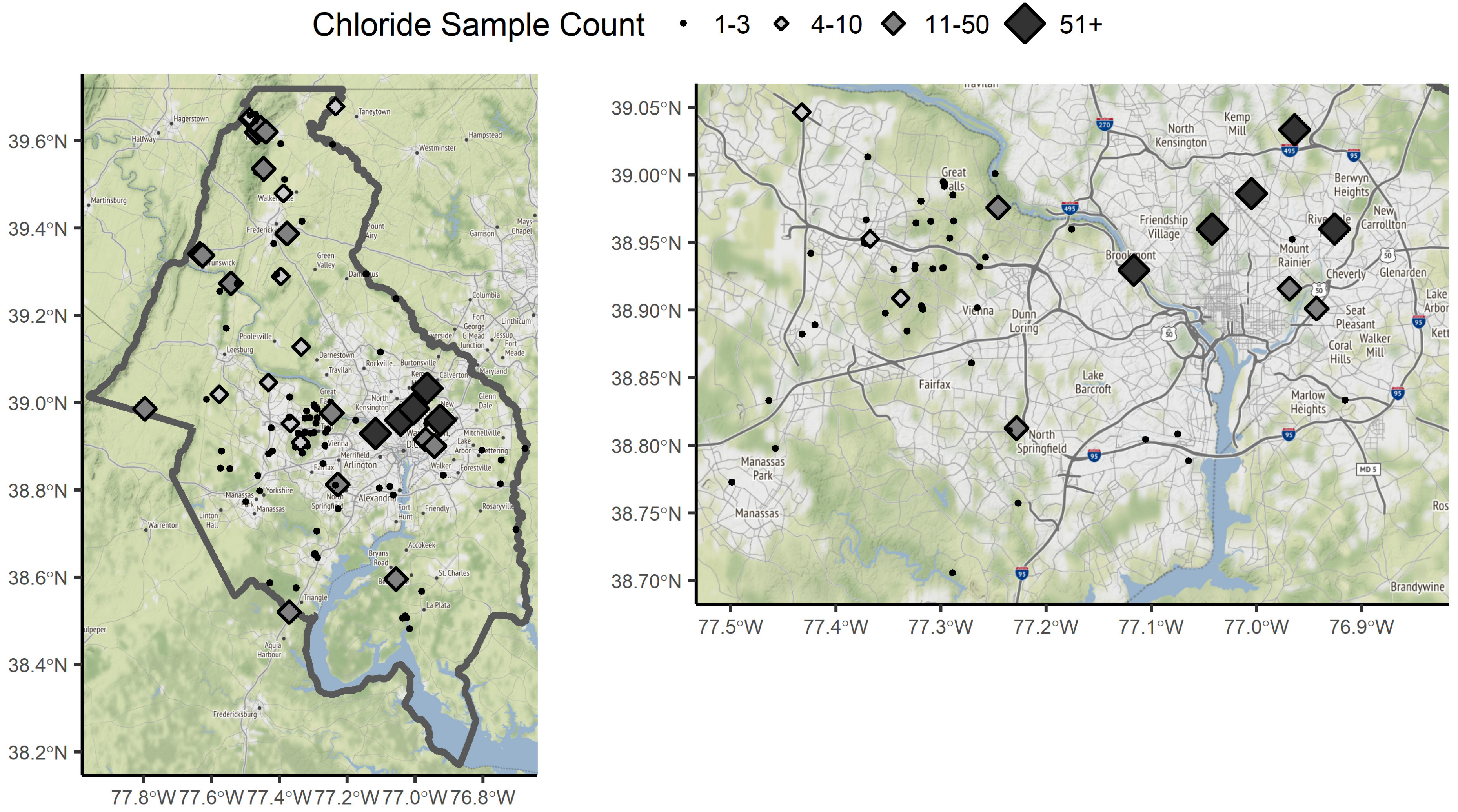


Nitrate



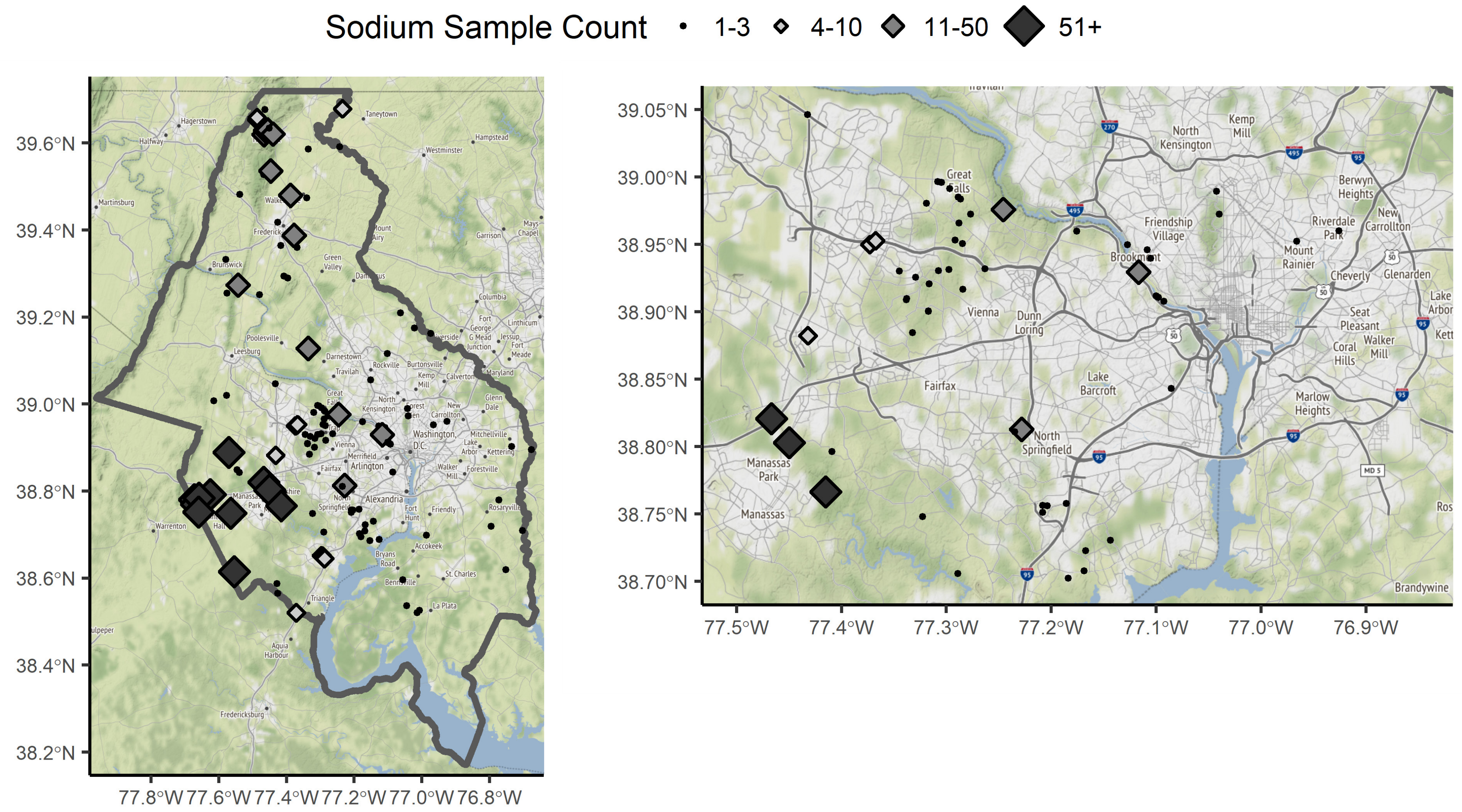
Nitrate Sample Count
1-3
4-10
11-50
51+
39.6°N
39.4°N
39.2°N
39.0°N
38.8°N
38.6°N
38.4°N
38.2°N
77.8°W 77.6°W 77.4°W 77.2°W 77.0°W 76.8°W
39.05°N
39.00°N
38.95°N
38.90°N
38.85°N
38.80°N
38.75°N
38.70°N
77.5°W
77.4°W
77.3°W
77.2°W
77.1°W
77.0°W
76.9°W

Chloride



Chloride Sample Count
1-3
4-10
11-50
51+
39.6°N
39.4°N
39.2°N
39.0°N
38.8°N
38.6°N
38.4°N
38.2°N
77.8°W 77.6°W 77.4°W 77.2°W 77.0°W 76.8°W
39.05°N
39.00°N
38.95°N
38.90°N
38.85°N
38.80°N
38.75°N
38.70°N
77.5°W
77.4°W
77.3°W
77.2°W
77.1°W
77.0°W
76.9°W

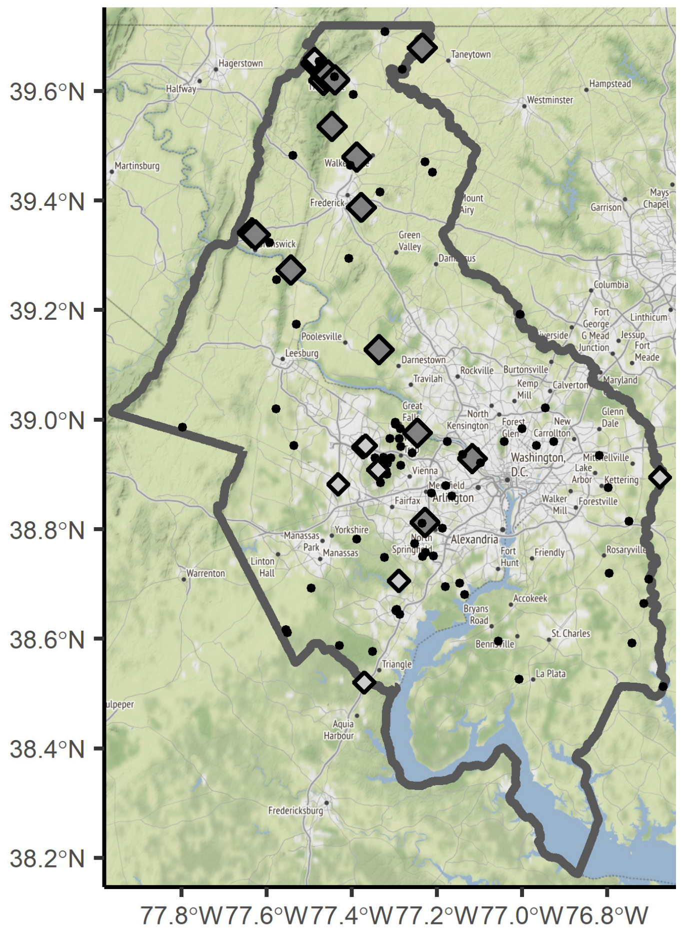
Sodium

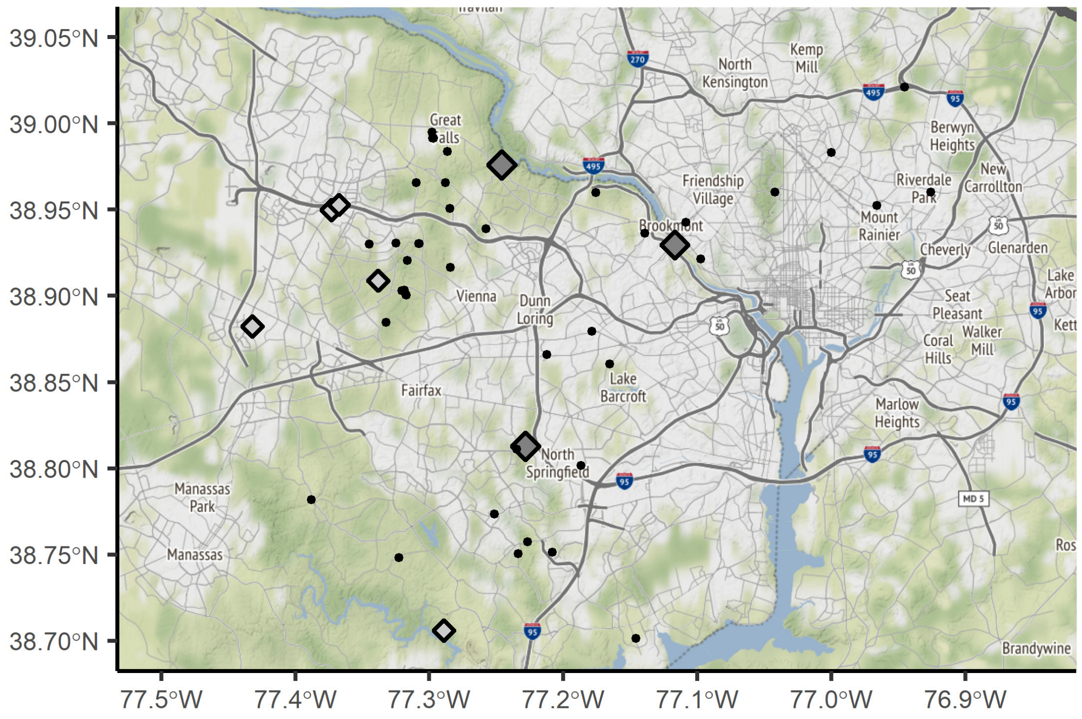


Sodium Sample Count
1-3
4-10
11-50
51+
39.6°N
39.4°N
39.2°N
39.0°N
38.8°N
38.6°N
38.4°N
38.2°N
77.8°W 77.6°W 77.4°W 77.2°W 77.0°W 76.8°W
39.05°N
39.00°N
38.95°N
38.90°N
38.85°N
38.80°N
38.75°N
38.70°N
77.5°W
77.4°W
77.3°W
77.2°W
77.1°W
77.0°W
76.9°W

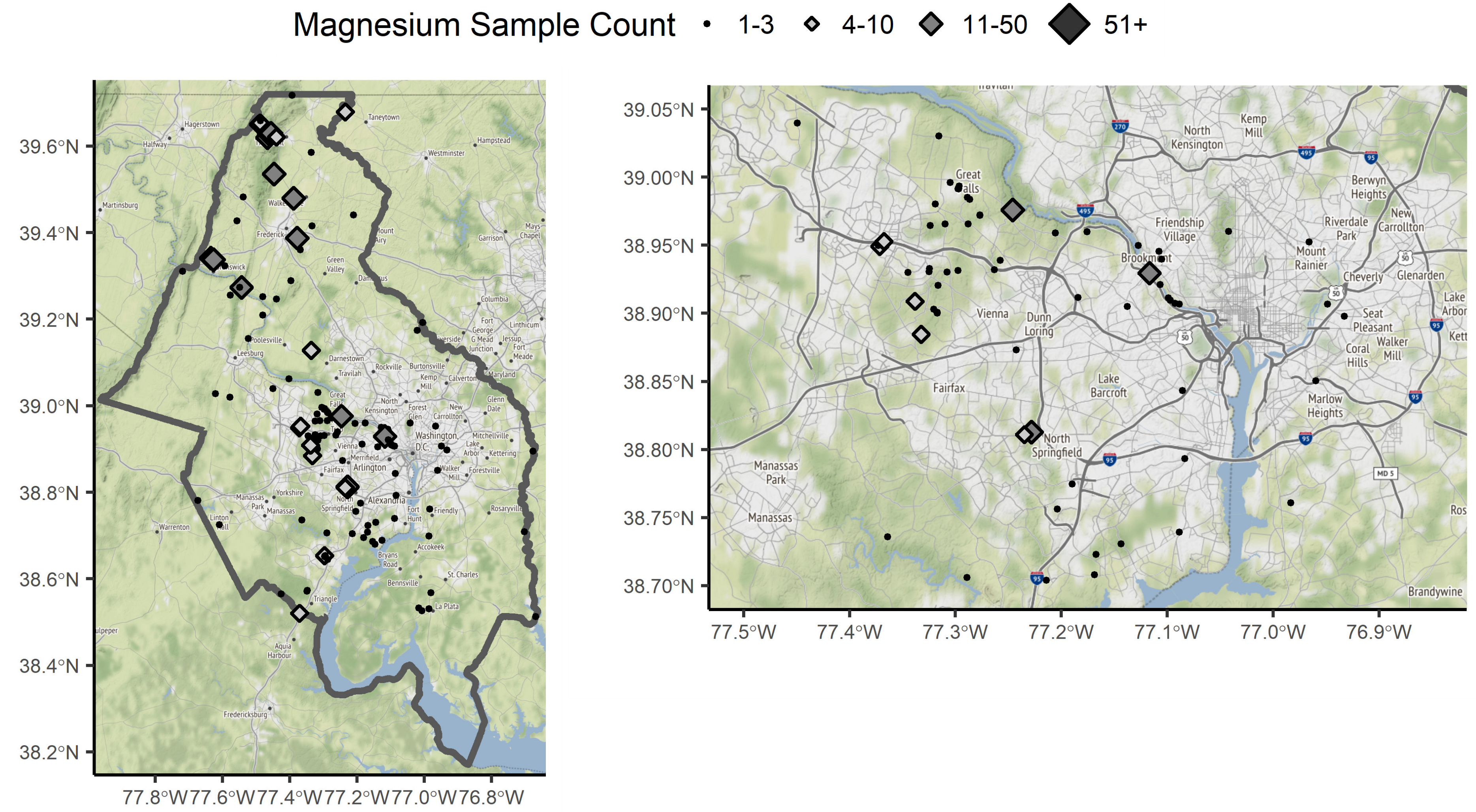
Calcium

Calcium Sample Count • 1-3 ◇ 4-10 ◆ 11-50 ◆ 51+

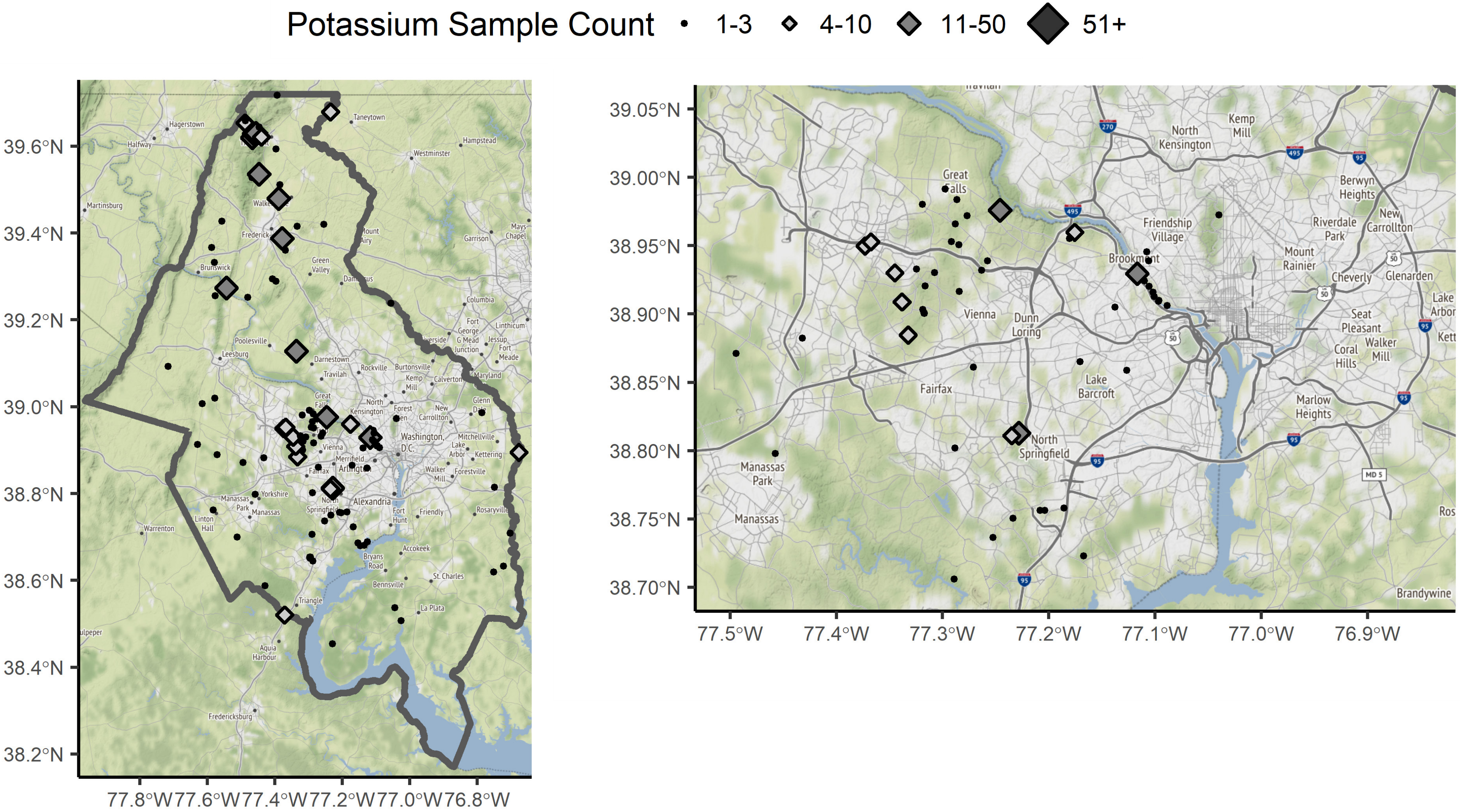




Magnesium


Magnesium Sample Count
1-3
4-10
11-50
51+
39.6°N
39.4°N
39.2°N
39.0°N
38.8°N
38.6°N
38.4°N
38.2°N
77.8°W77.6°W77.4°W77.2°W77.0°W76.8°W
39.05°N
39.00°N
38.95°N
38.90°N
38.85°N
38.80°N
38.75°N
38.70°N
77.5°W
77.4°W
77.3°W
77.2°W
77.1°W
77.0°W
76.9°W

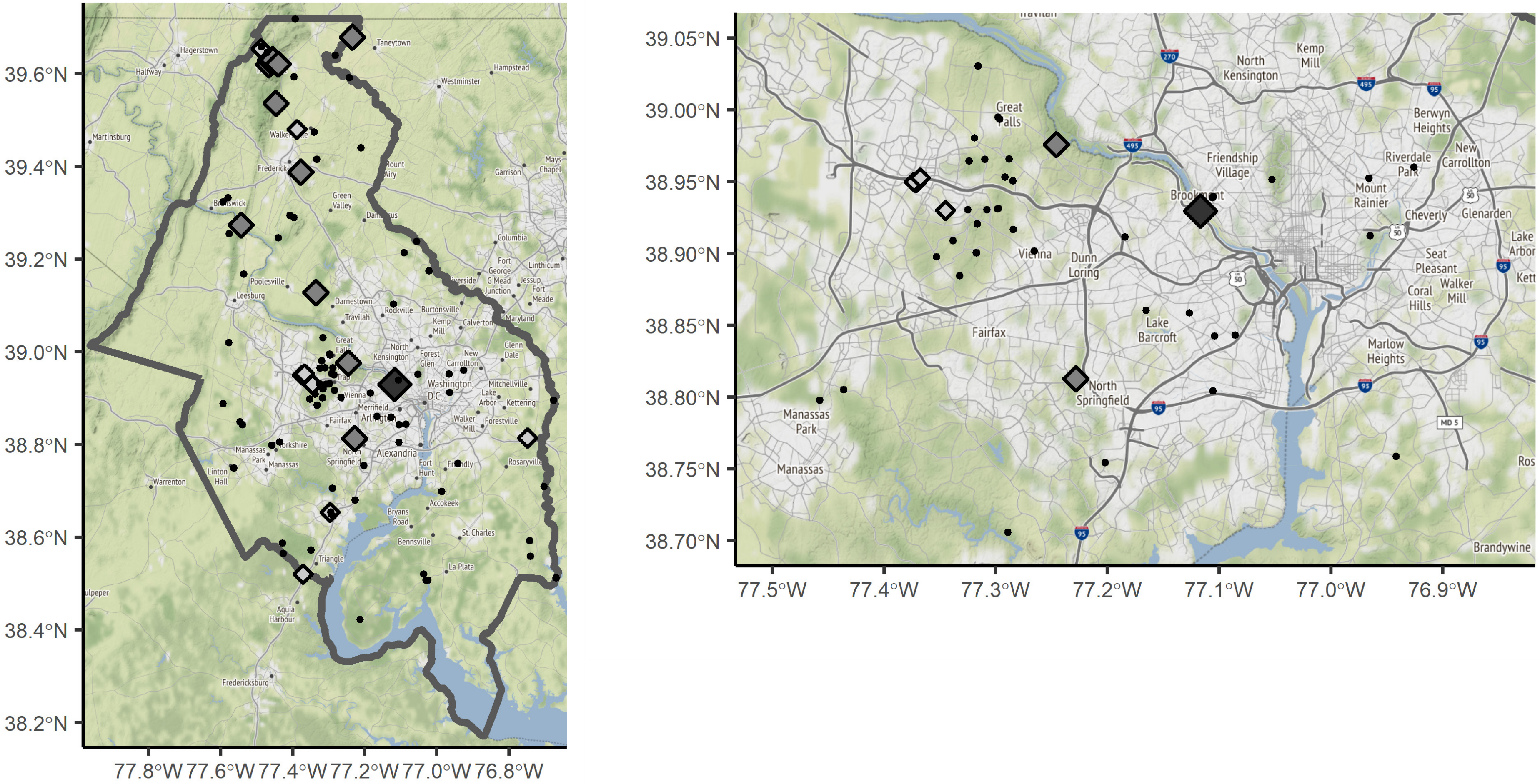
Potassium



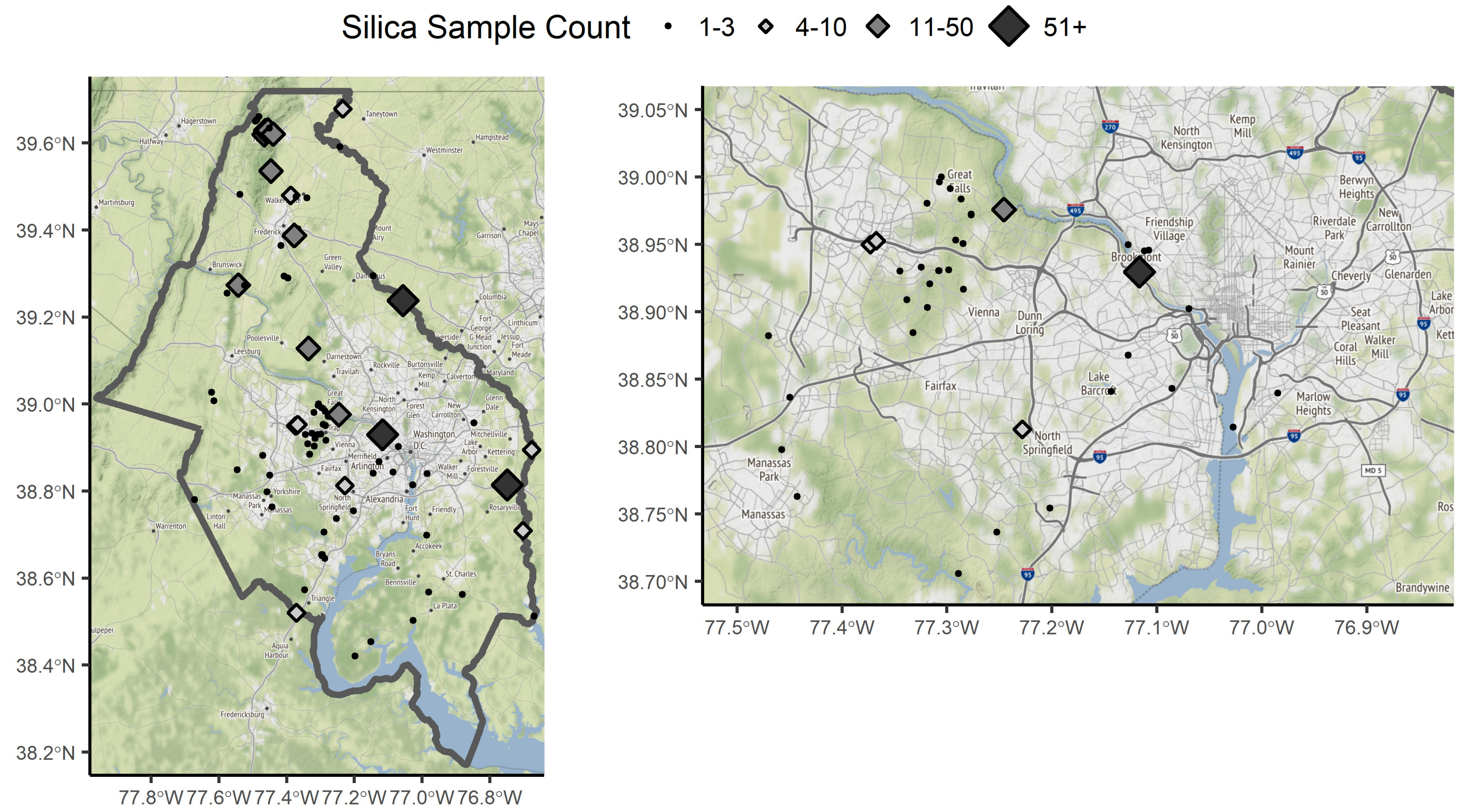
Potassium Sample Count
1-3
4-10
11-50
51+
39.6°N
39.4°N
39.2°N
39.0°N
38.8°N
38.6°N
38.4°N
38.2°N
77.8°W77.6°W77.4°W77.2°W77.0°W76.8°W
39.05°N
39.00°N
38.95°N
38.90°N
38.85°N
38.80°N
38.75°N
38.70°N
77.5°W
77.4°W
77.3°W
77.2°W
77.1°W
77.0°W
76.9°W

Sulfate

Sulfate Sample Count • 1-3 ◇ 4-10 ◆ 11-50 ◆ 51+

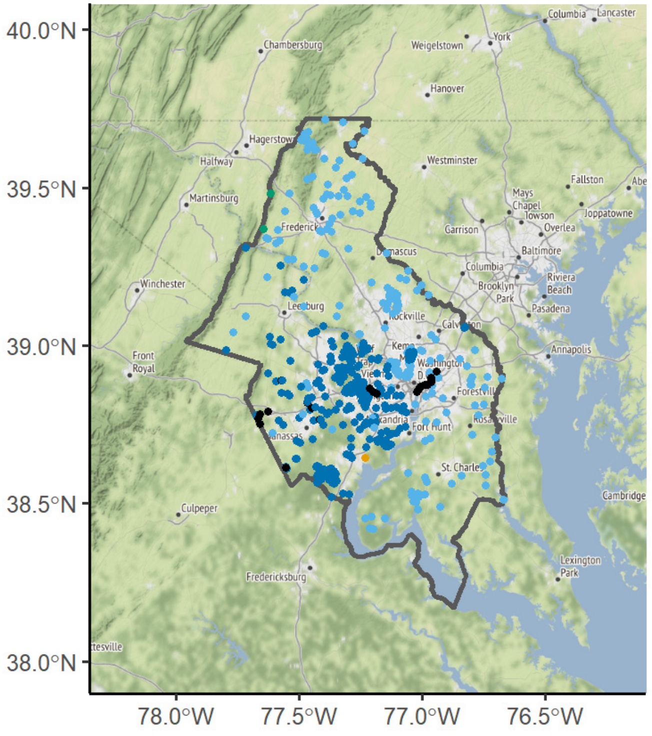


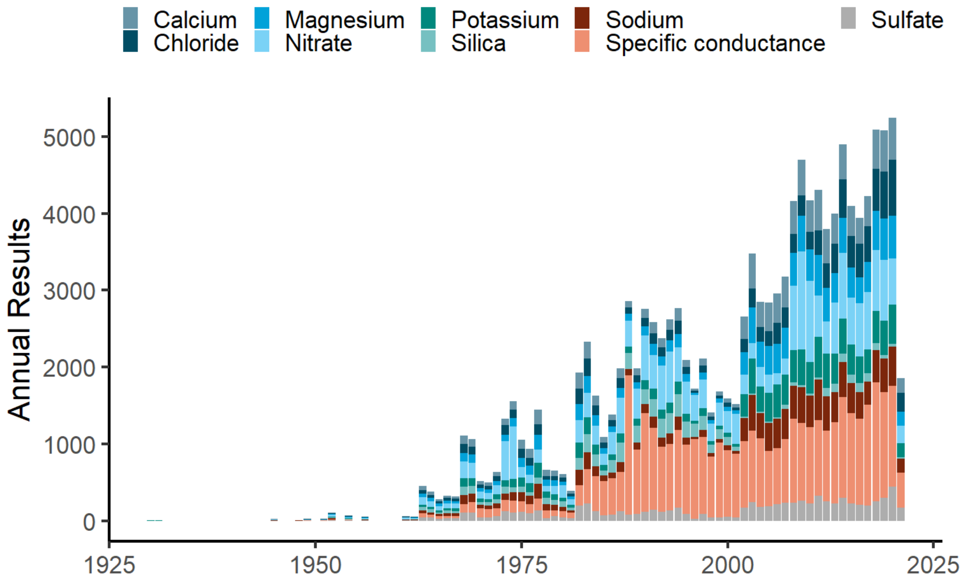
Silica

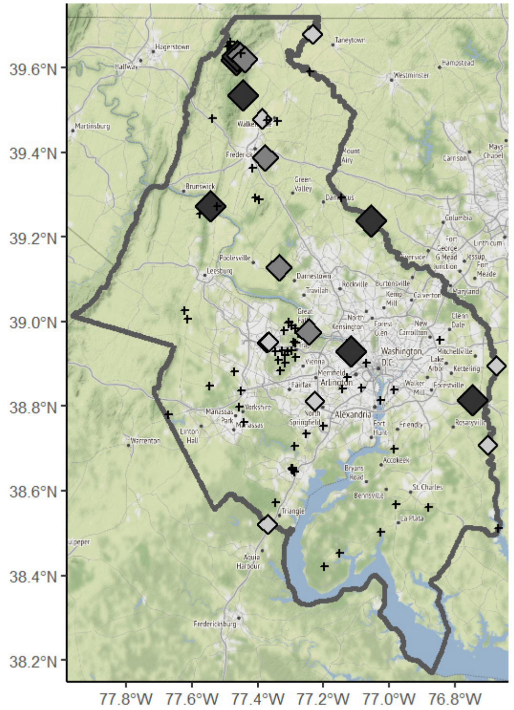


Silica Sample Count
1-3
4-10
11-50
51+
39.6°N
39.4°N
39.2°N
39.0°N
38.8°N
38.6°N
38.4°N
38.2°N
77.8°W 77.6°W 77.4°W 77.2°W 77.0°W 76.8°W
39.05°N
39.00°N
38.95°N
38.90°N
38.85°N
38.80°N
38.75°N
38.70°N
77.5°W
77.4°W
77.3°W
77.2°W
77.1°W
77.0°W
76.9°W

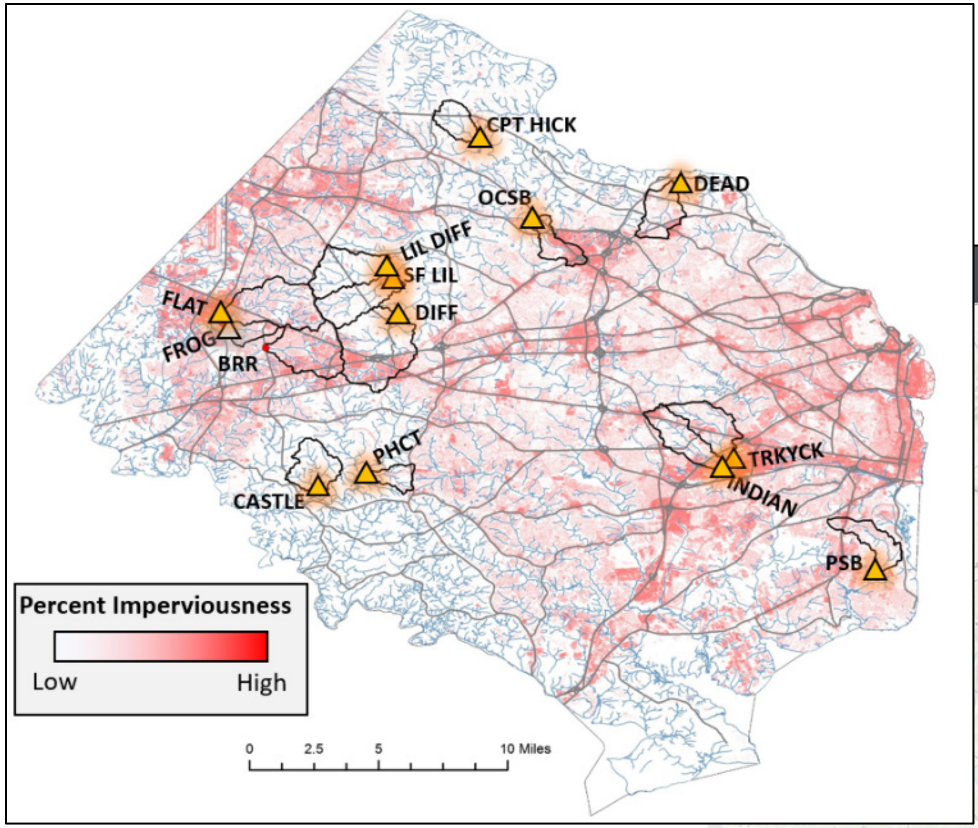
Is additional monitoring needed?





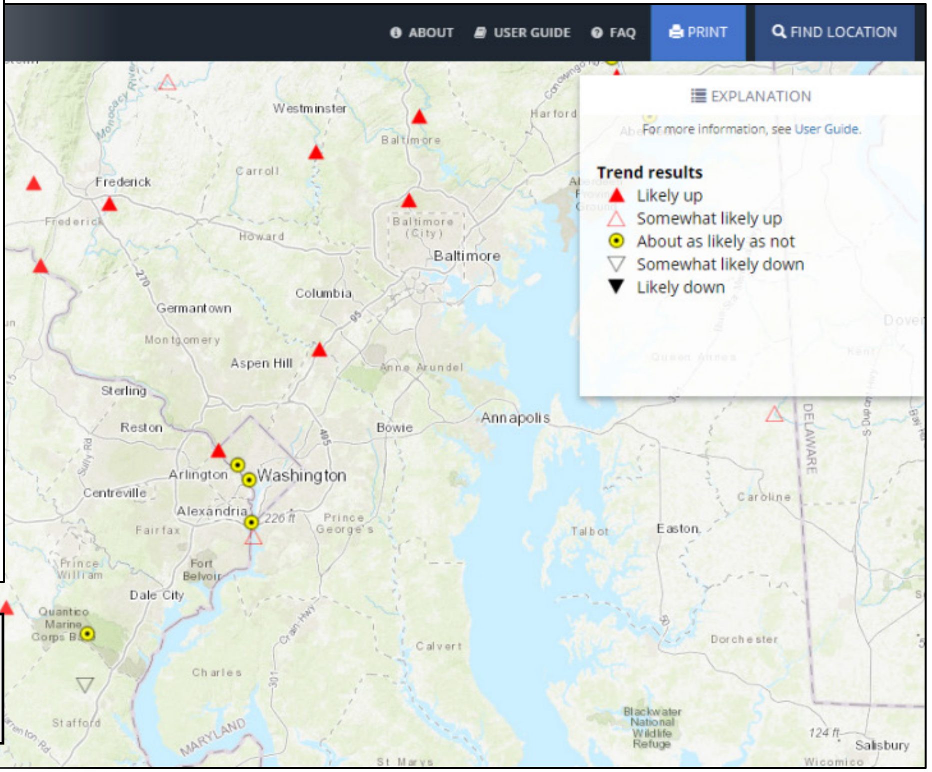


D1b (USGS leads, Year 1): compile and synthesize existing information on ion monitoring and SC data trends in the COG region and compute summary statistics at COG monitoring sites



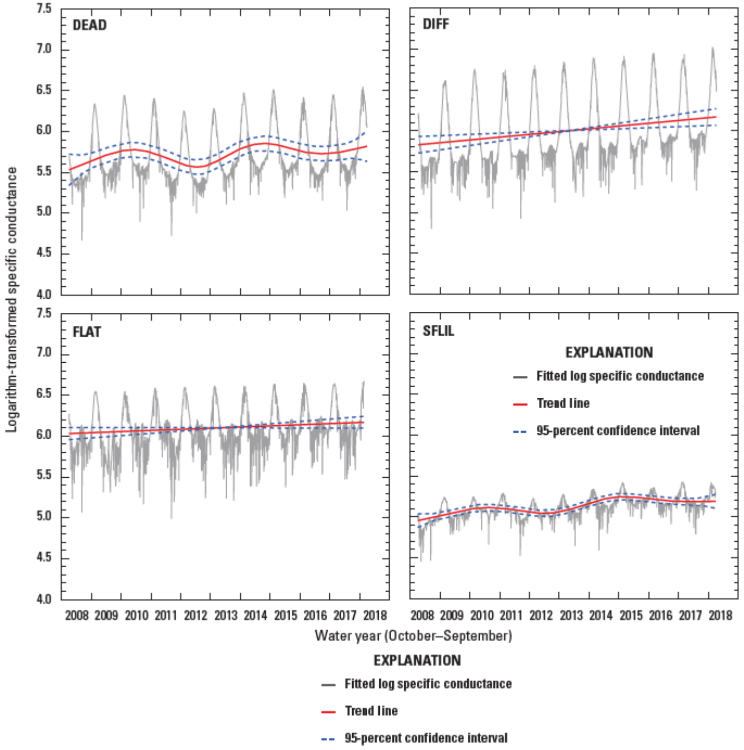
Specific conductance increased in 13/14 headwater Fairfax County streams between 2008 – 2018!

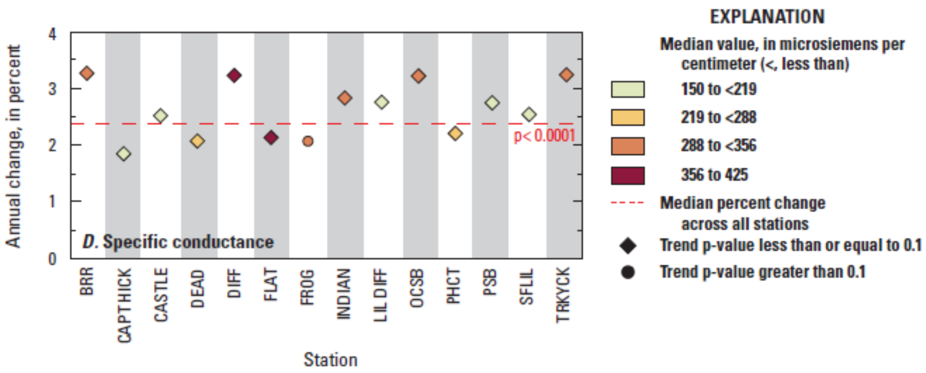
Specific conductance trends have been computed in the COG region as part of multiple water-quality studies.



Increases in SC have been observed in discrete sample and continuous data across Fairfax County…

SC increased 2-3% at from 2008-2018





SC increases were most prevalent in spring and fall

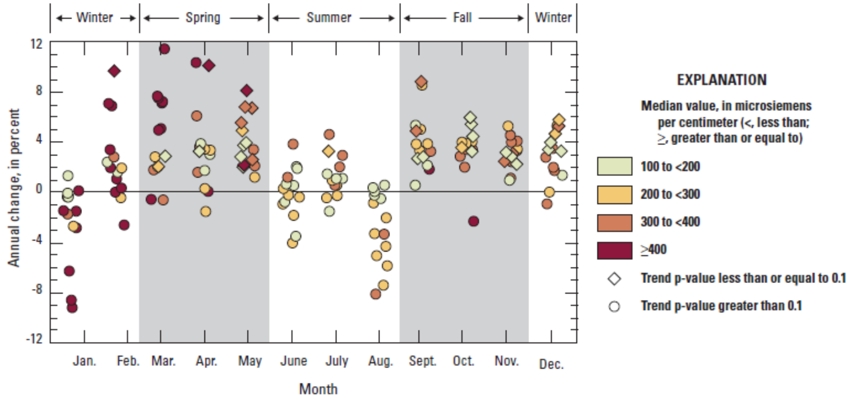
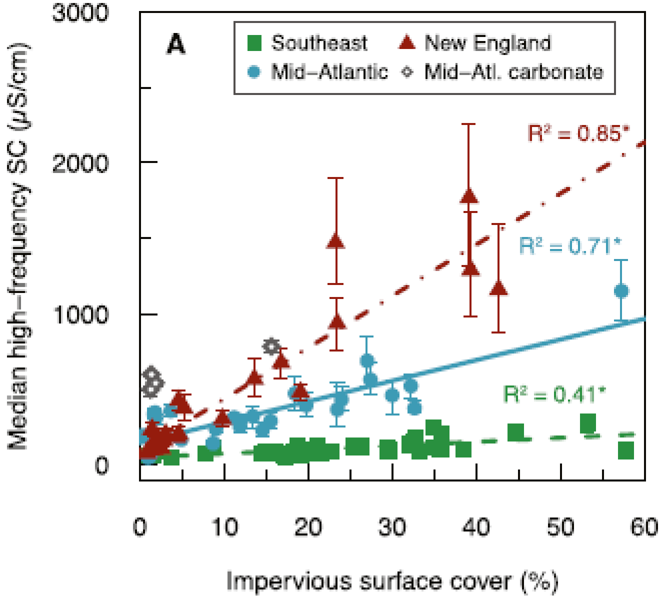


Figure 24. Monthly trends in specific conductance expressed as a percent change per year at 14 monitoring stations between April 2008 and March 2018.

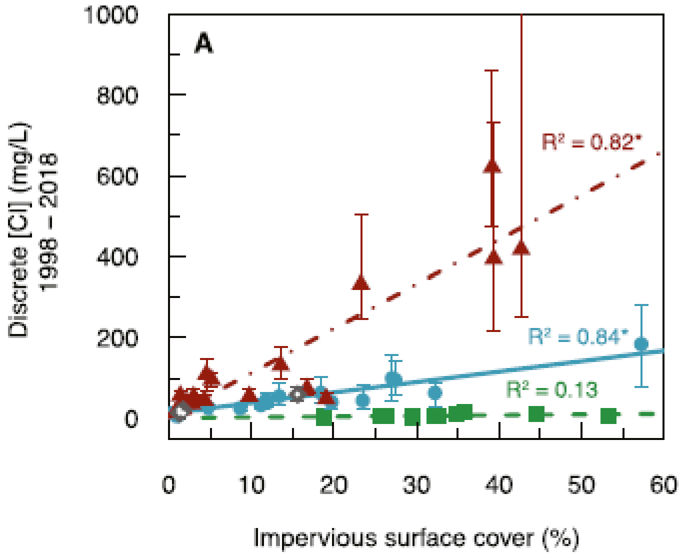
Porter and others, 2020

SC and Cl increase South to North, with impervious cover, and over time…

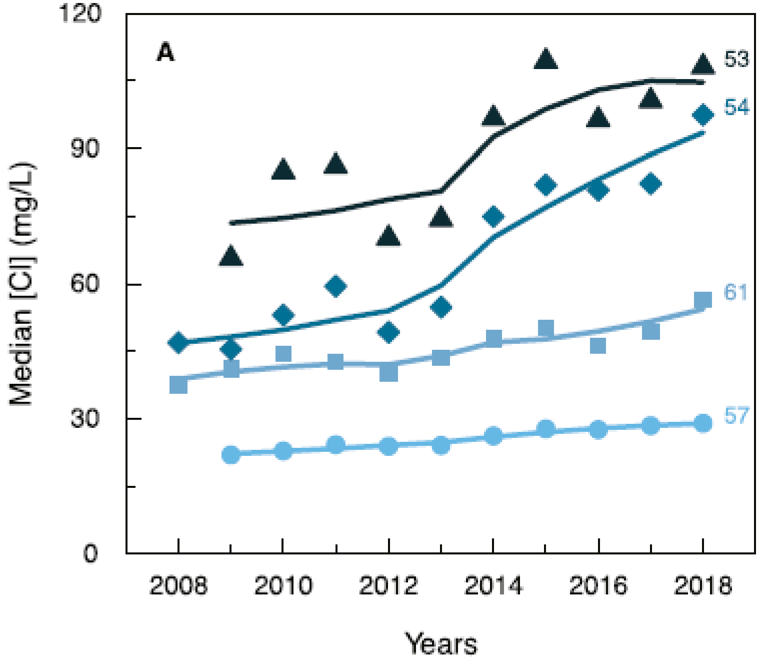
SC



Cl

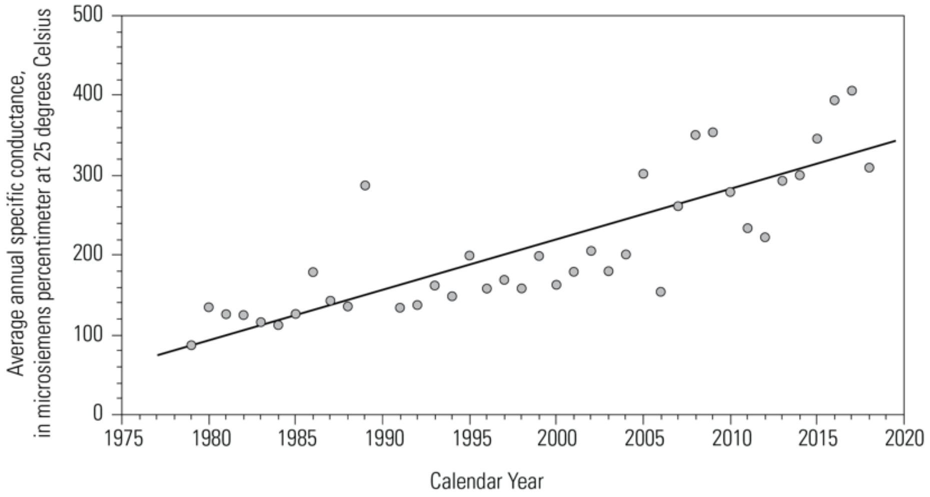


Cl trends in Mid-Atlantic



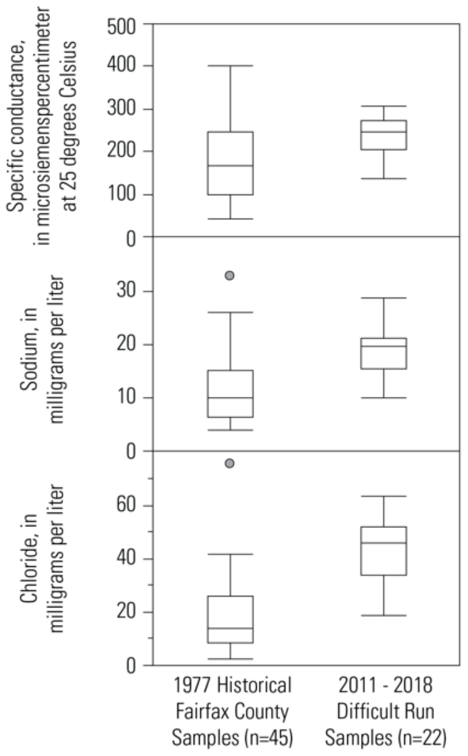
SC and ionic composition has changed significantly over the past 4 decades in Difficult Run…

Average annual SC has tripled since 1979



Plot of average annual specific conductance for water-quality samples collected from the Difficult Run streamgage (USGS station ID 01646000) between 1979 and 2018.

Summer baseflow Na and Cl have doubled since 1979



Boxplots of specific conductance, sodium, and chloride from water-quality samples collected throughout Fairfax County watersheds in 1977 and from Difficult Run (USGS station ID 01646000) between 2011 and 2018.

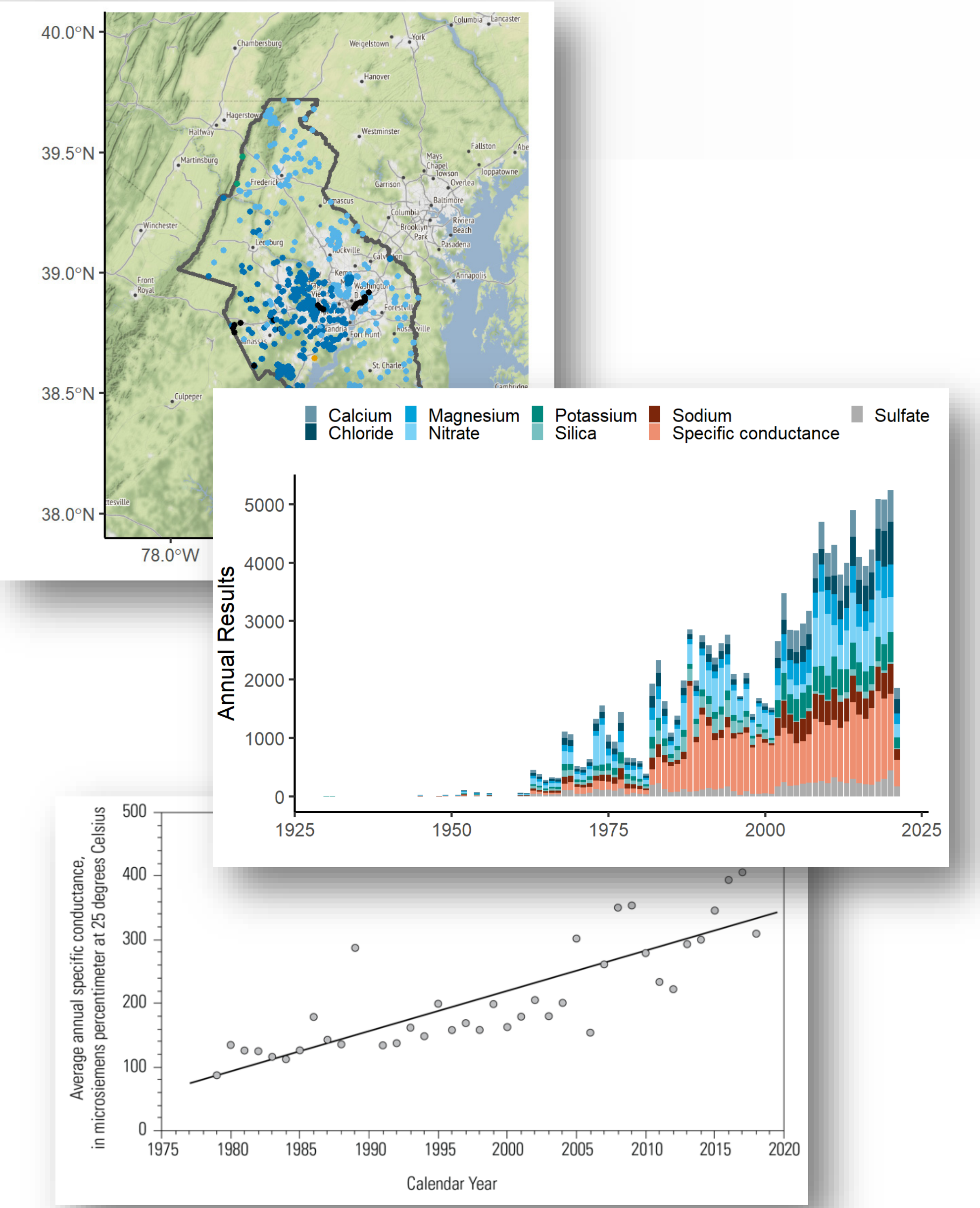
Webber and others, in prep

In summary…

- SC and ion data from the region have been compiled and summarized
  - A spatially and temporally rich dataset is available
  - Suitability for future analyses is question dependent

- Available information about trends in SC and ions has been compiled
  - SC and ions are increasing
    - Over time
    - With increasing impervious cover
    - Along a South to North gradient

  - Additional analyses of trends could be pursued with available data



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USGS
science for a changing world

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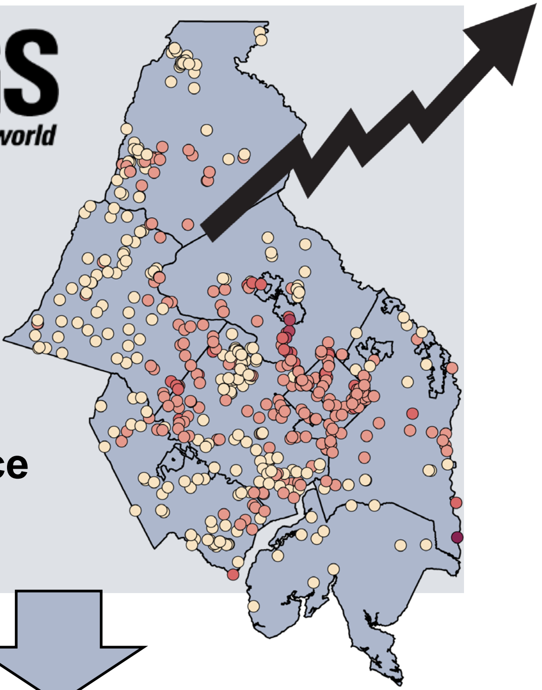

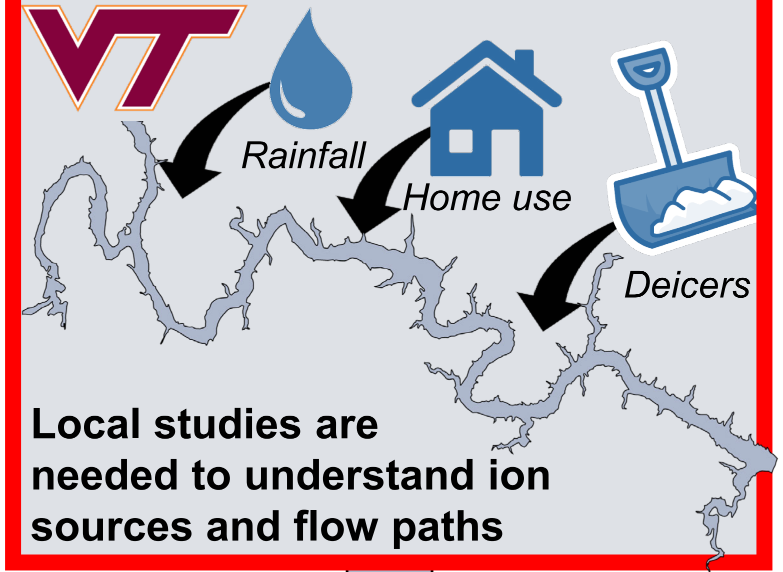

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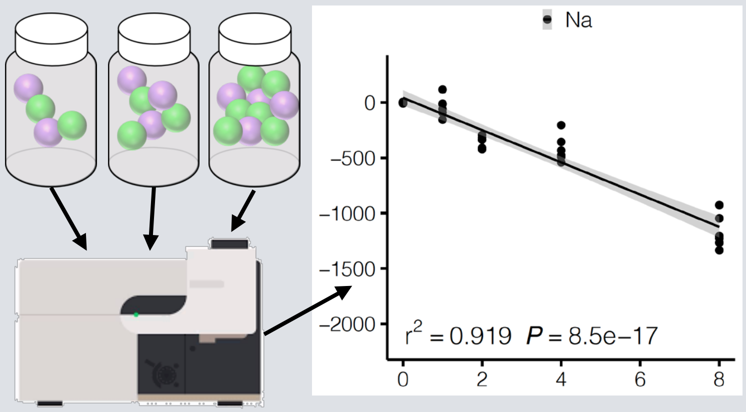
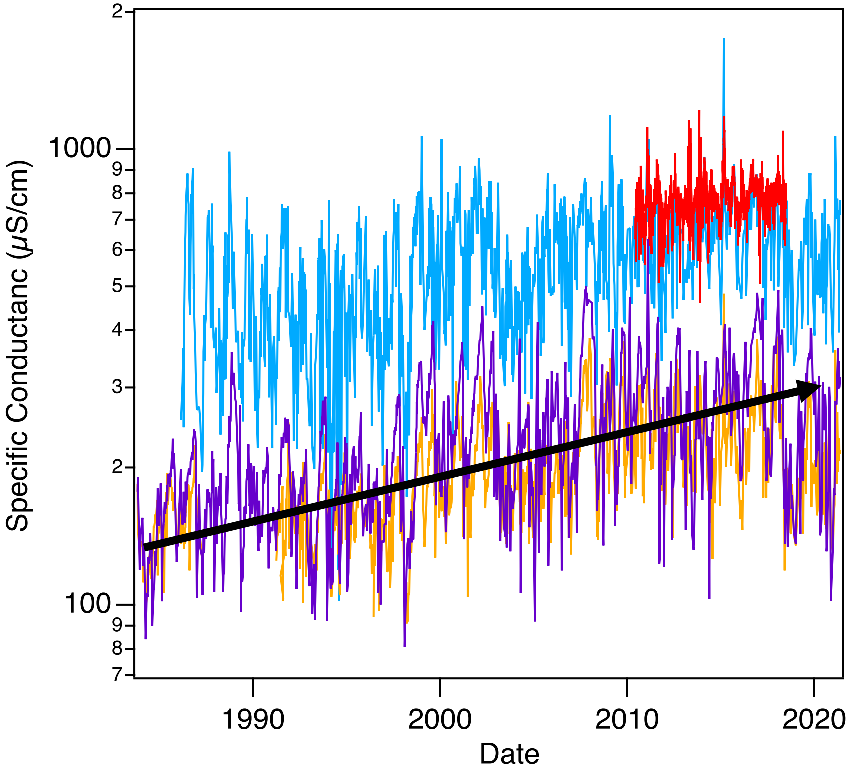
Experimental treatments are needed to evaluate impacts and mechanisms

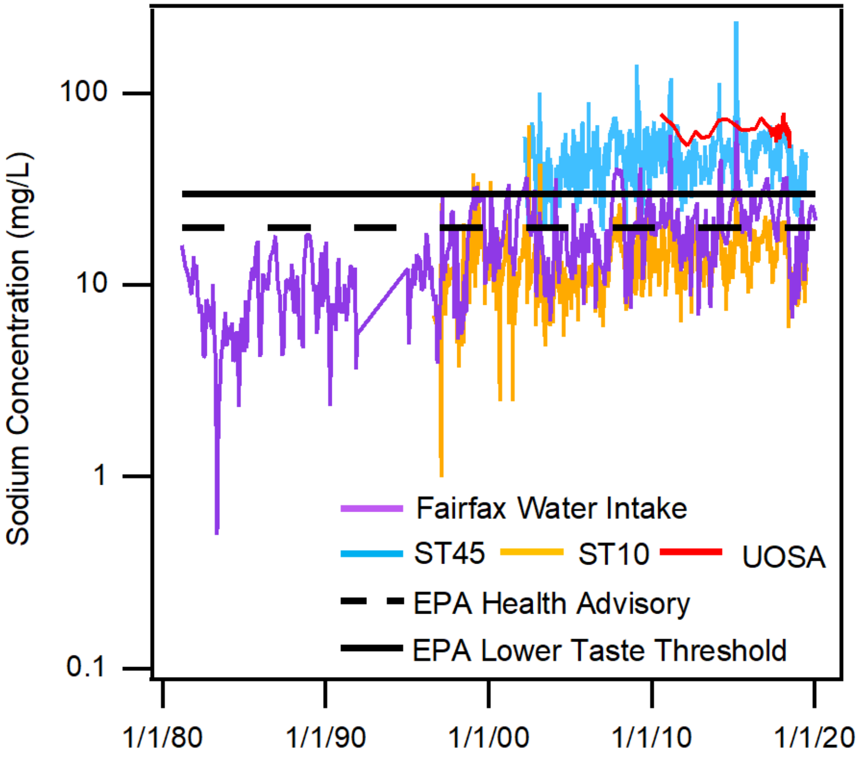


Synthesizing this knowledge is needed to understand and manage FSS in the MWCOG region

Rising Specific Conductance in the Occoquan Reservoir

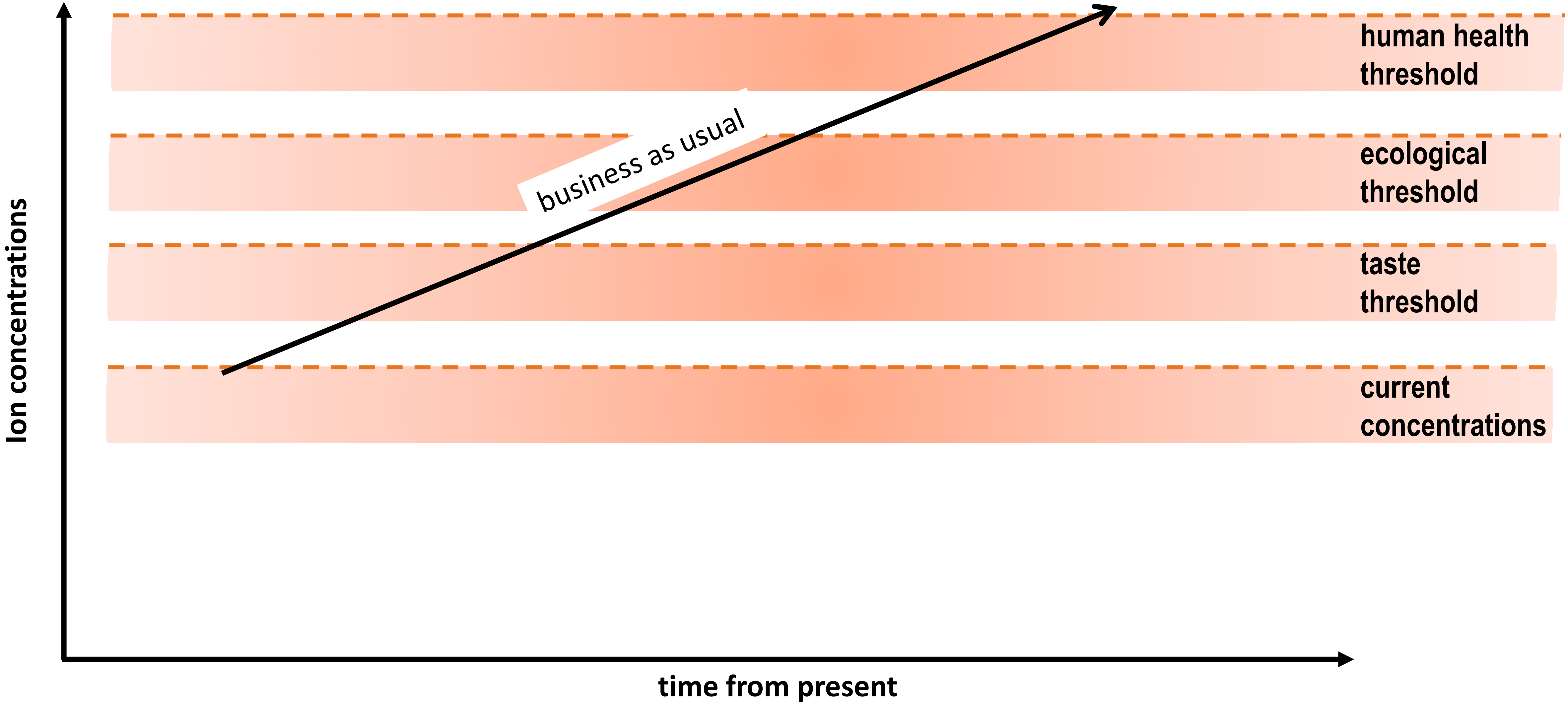


Rising Sodium in the Occoquan Reservoir

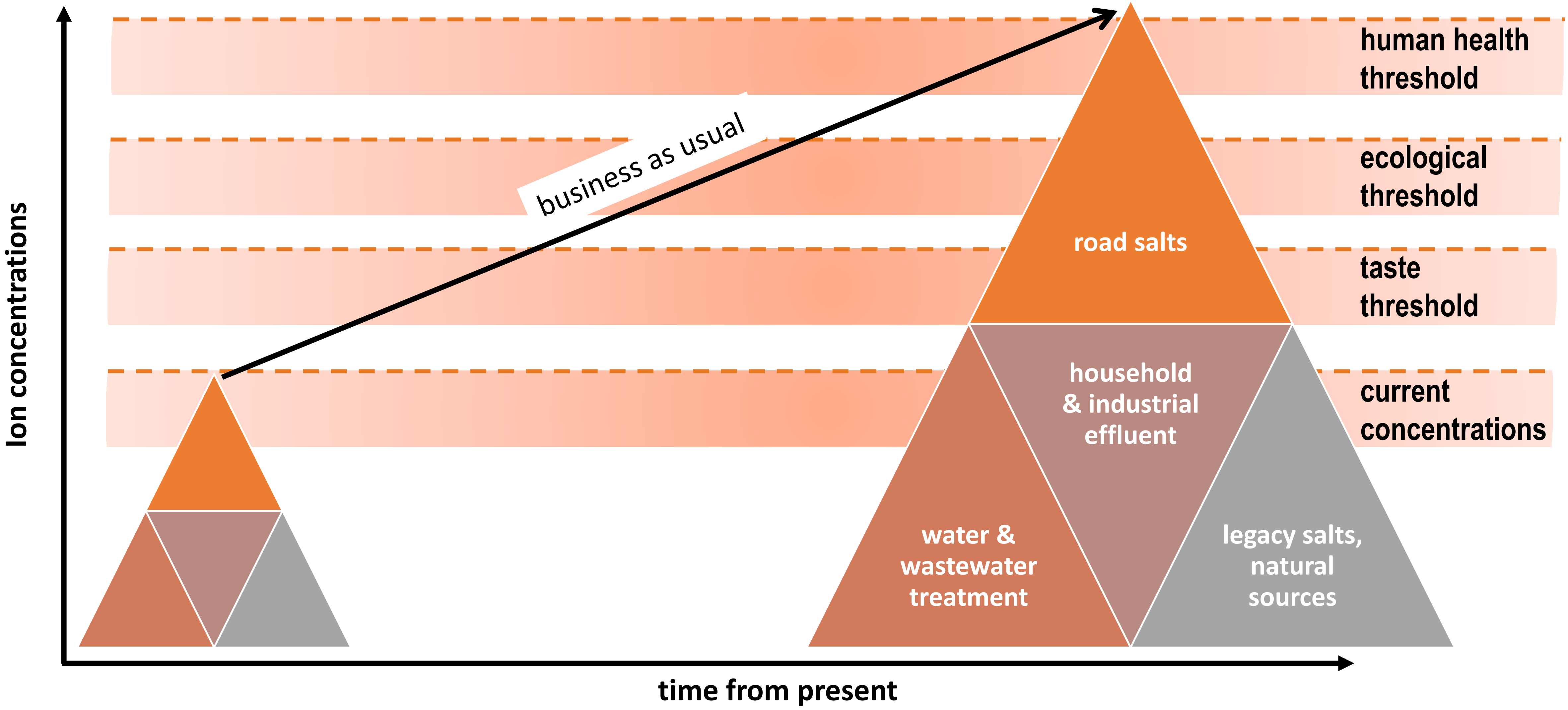


Bhide, S.V. et al. (2021) Addressing the contribution of indirect potable reuse to inland freshwater salinization. *Nature Sustainability*. https://doi.org/10.1038/s41893-021-00713-7

GRAND VISION: nature of system & levers of change



GRAND VISION: nature of system & levers of change



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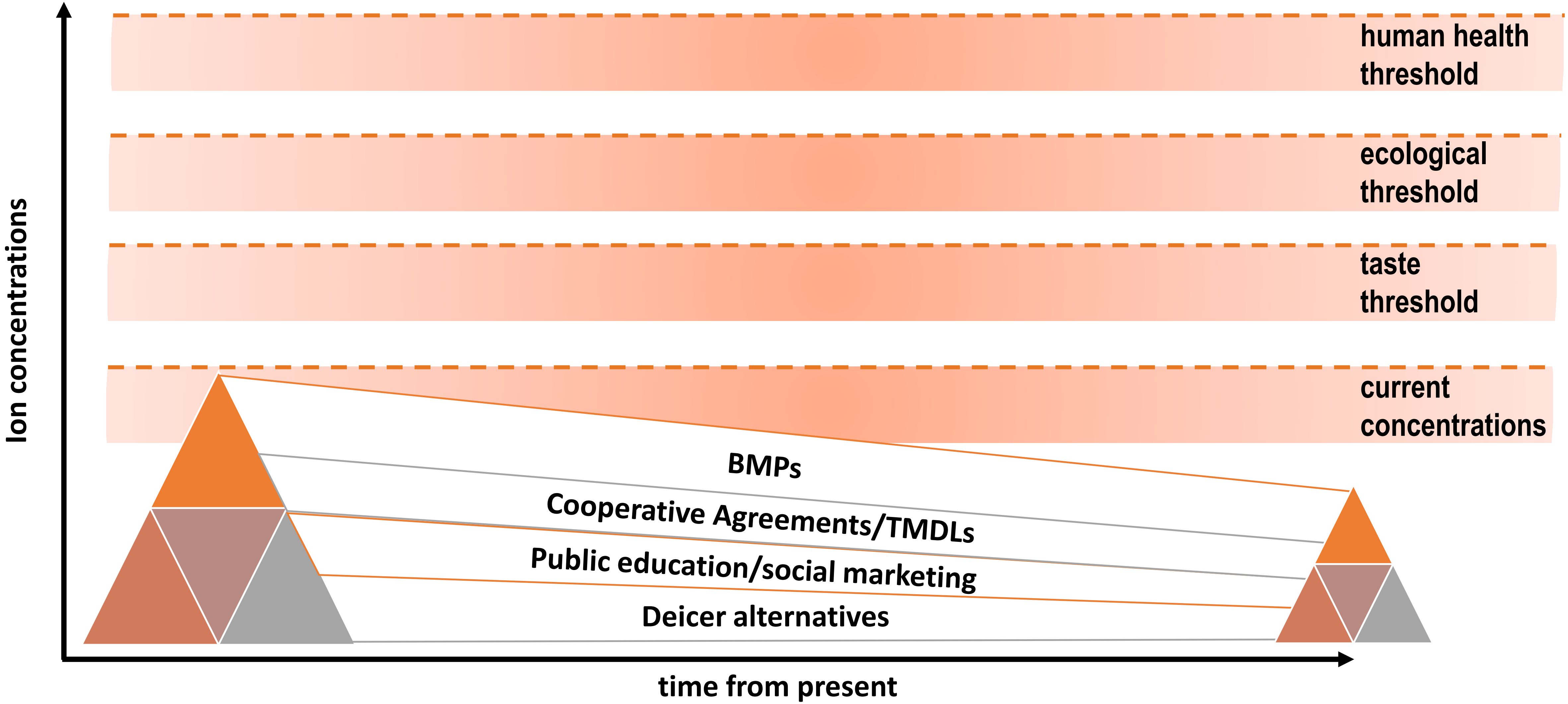

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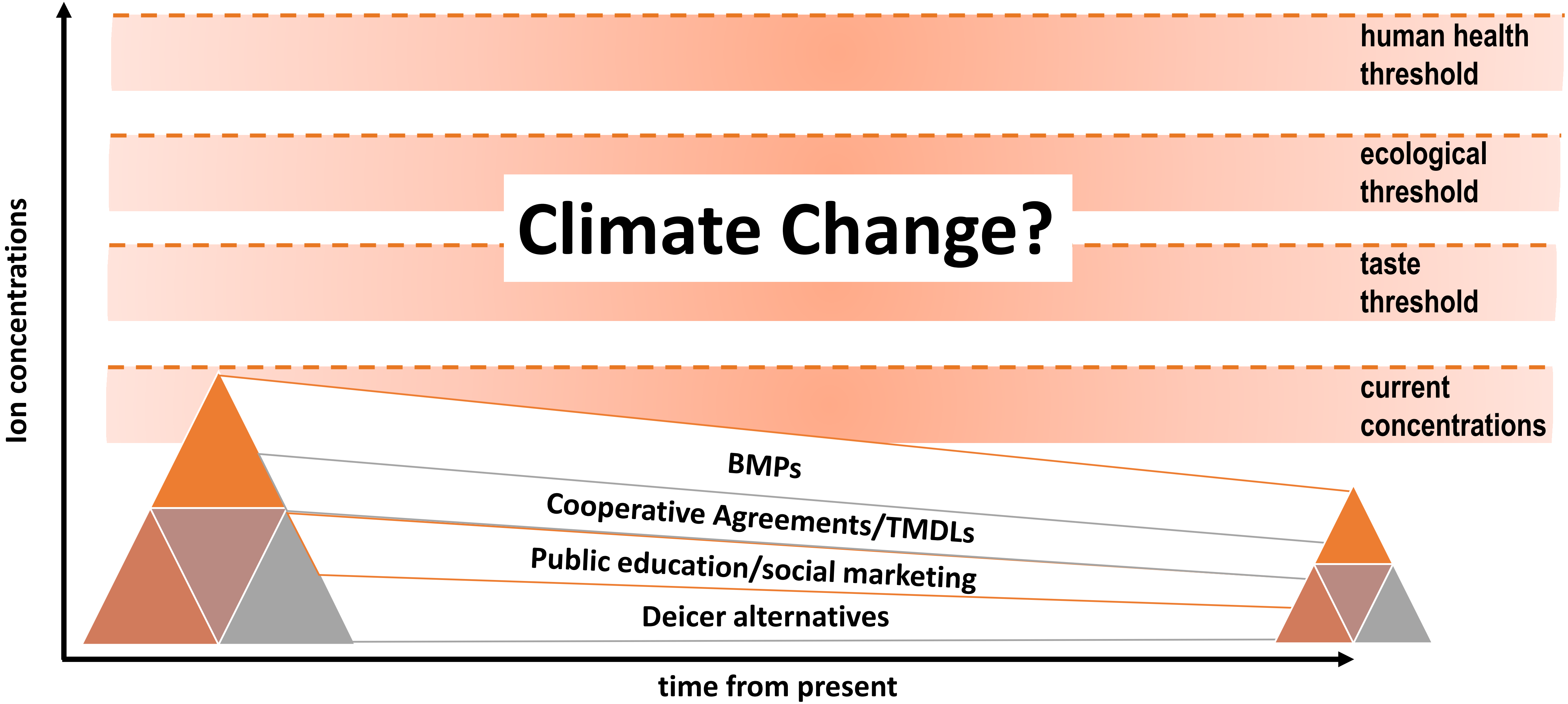
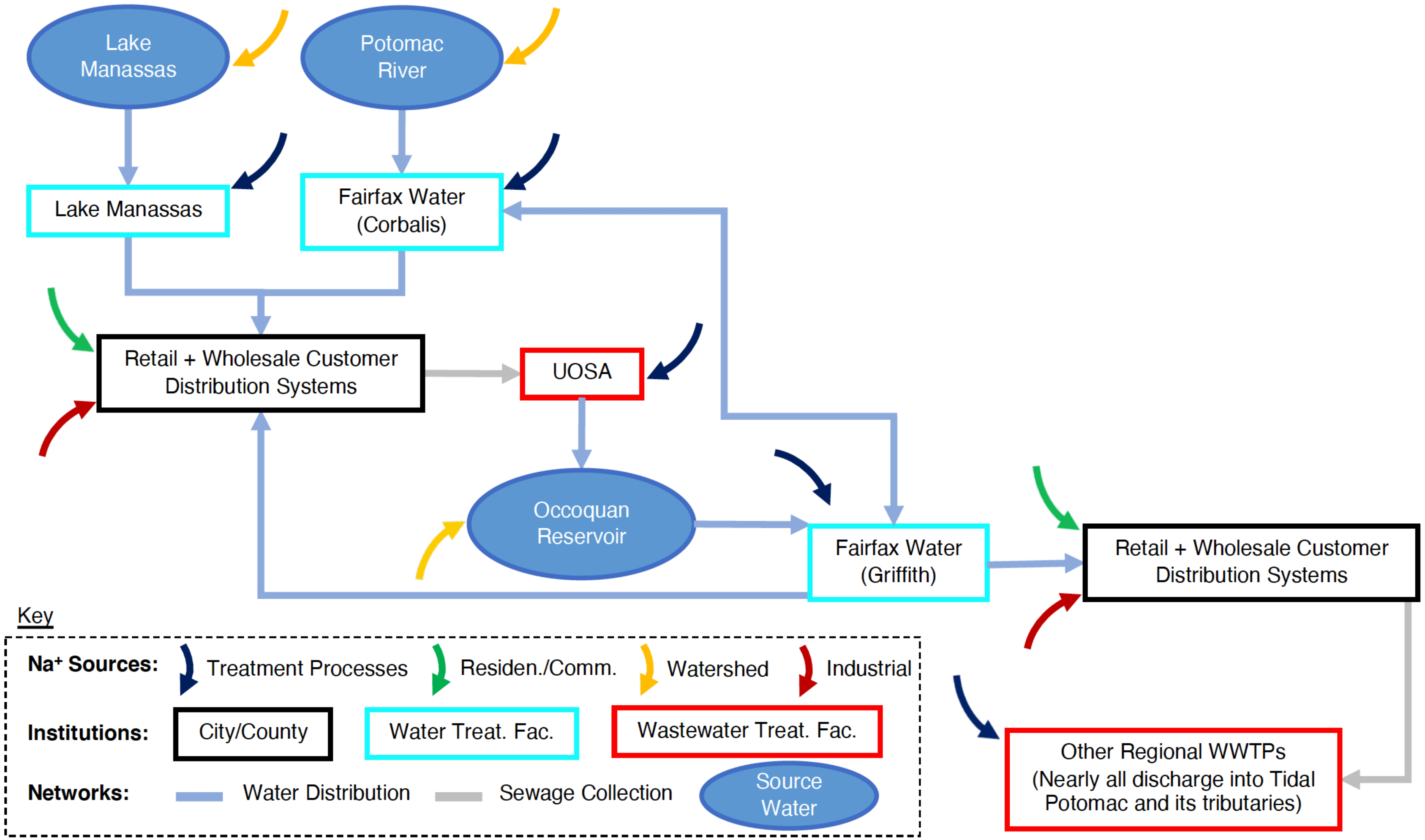


Challenge 1: salt is added all along the flow path



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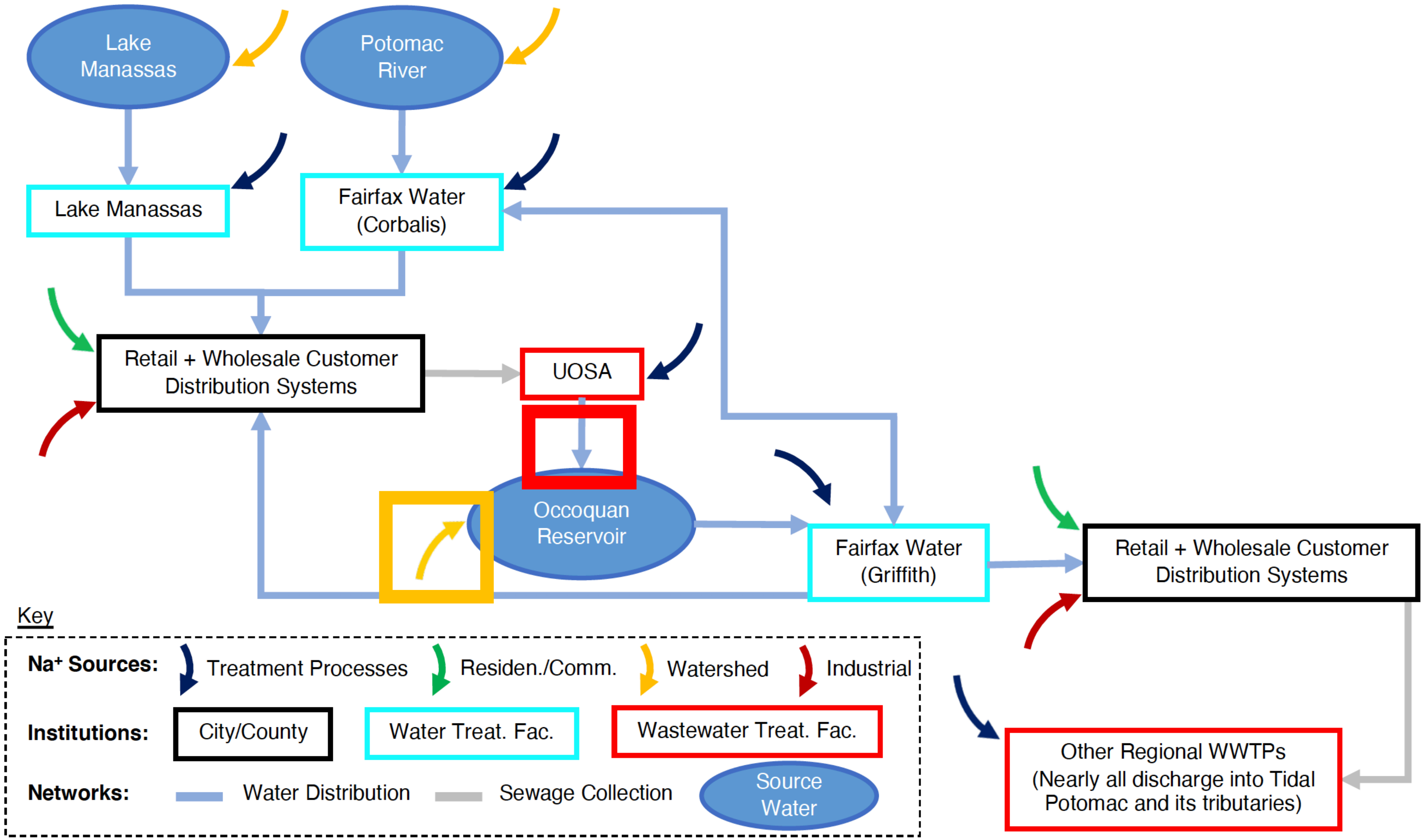
Challenge 2: different sources dominate at different times



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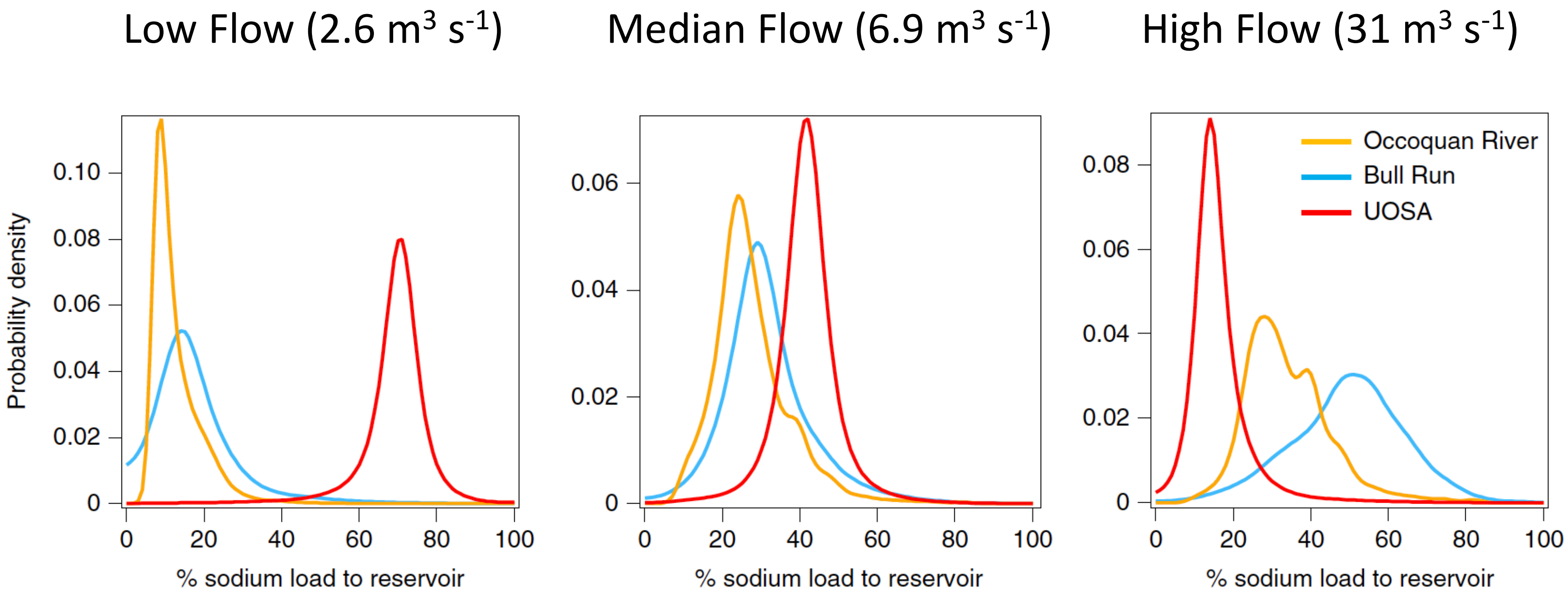
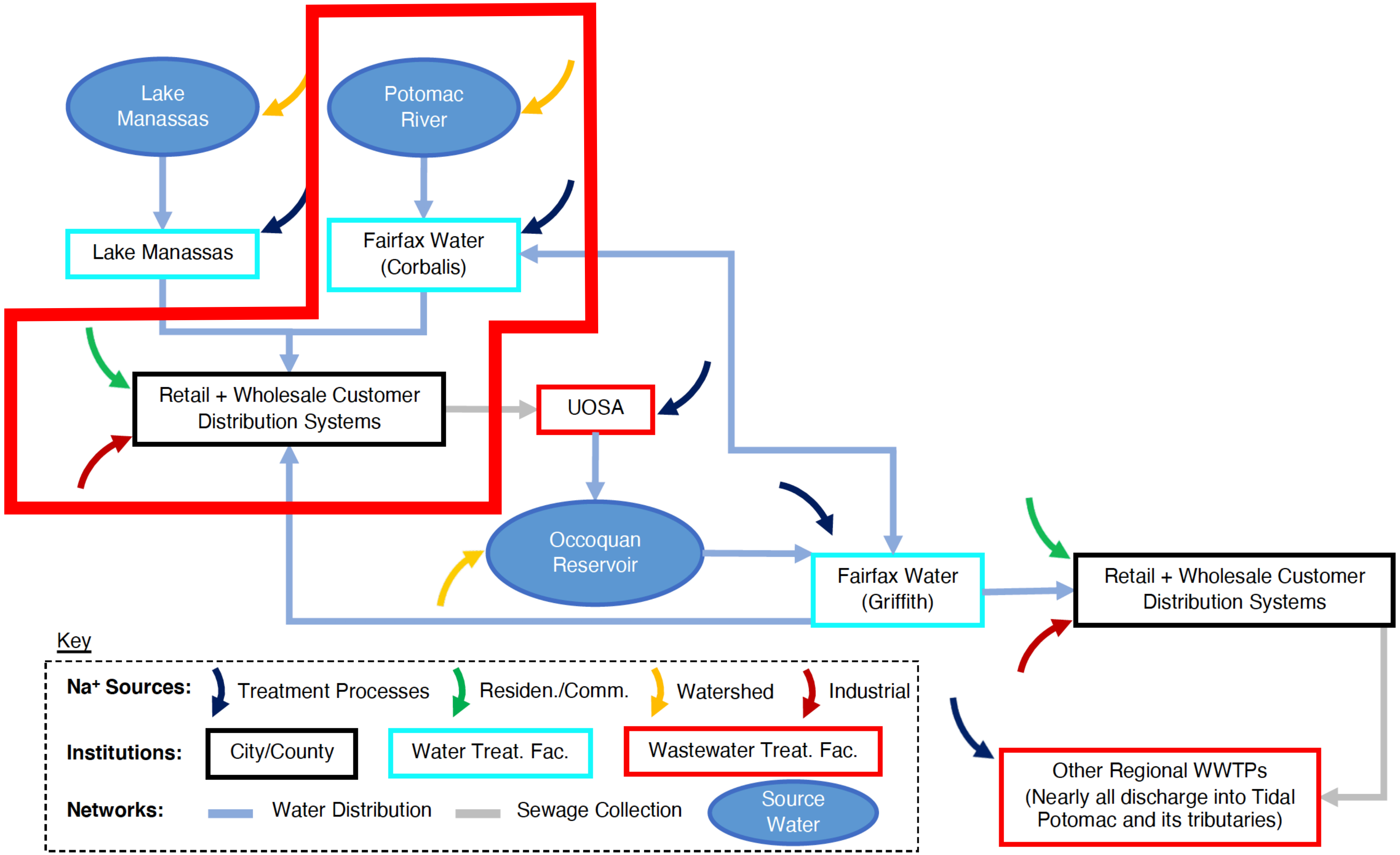
Challenge 2: different sources dominate at different times

Flow in the tributaries to the Occoquan Reservoir

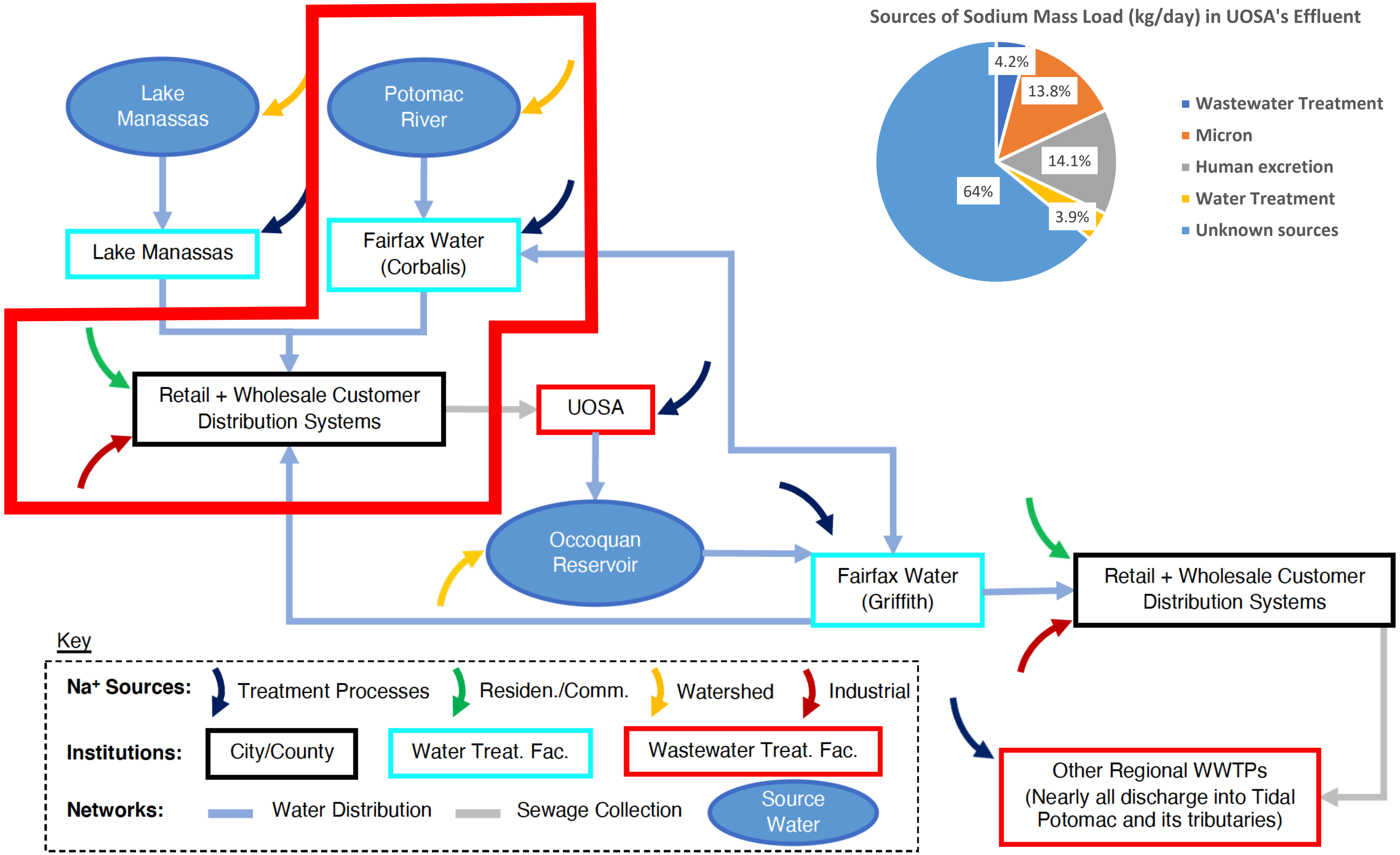


Bhide, S.V. et al. (2021) Addressing the contribution of indirect potable reuse to inland freshwater salinization. *Nature Sustainability*. https://doi.org/10.1038/s41893-021-00713-7

Challenge 3: salt inputs are tied to human behavior

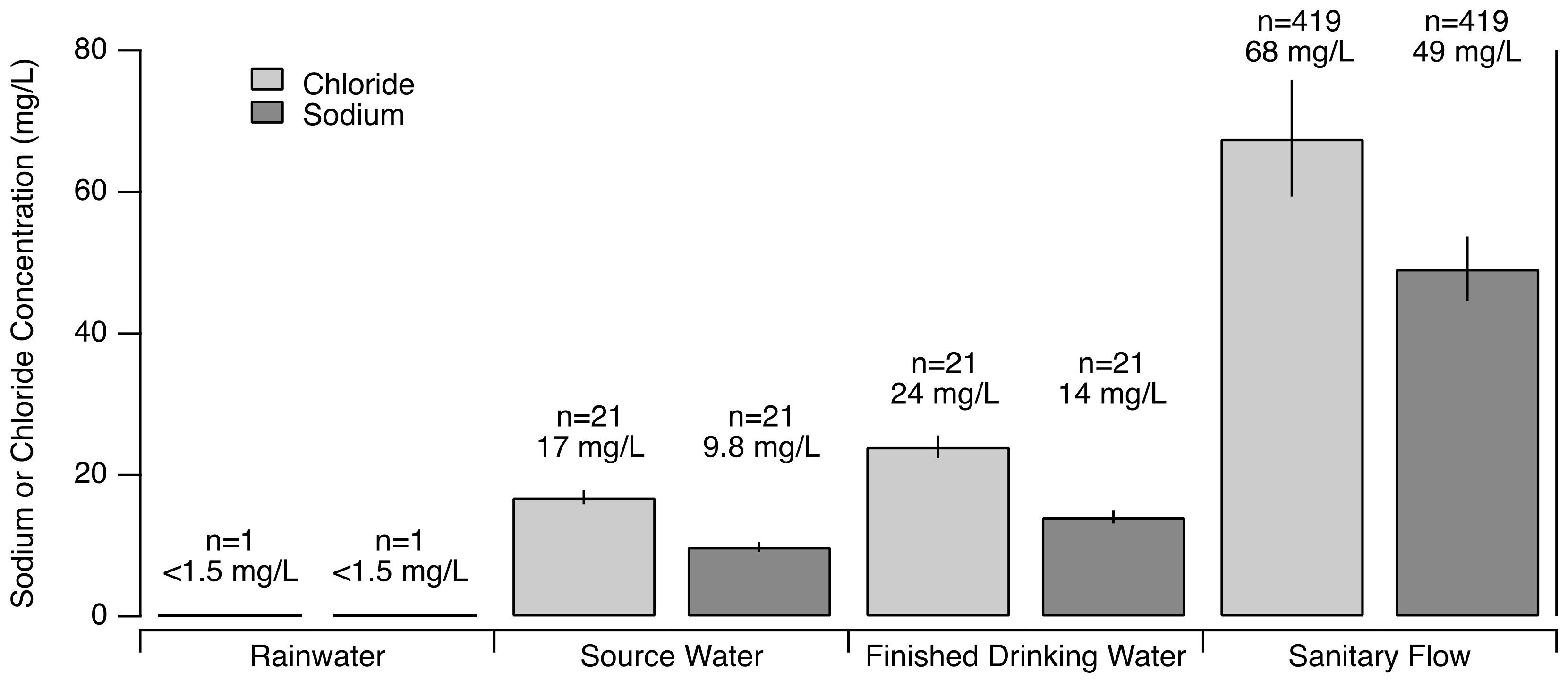


Challenge 3: salt inputs are tied to human behavior



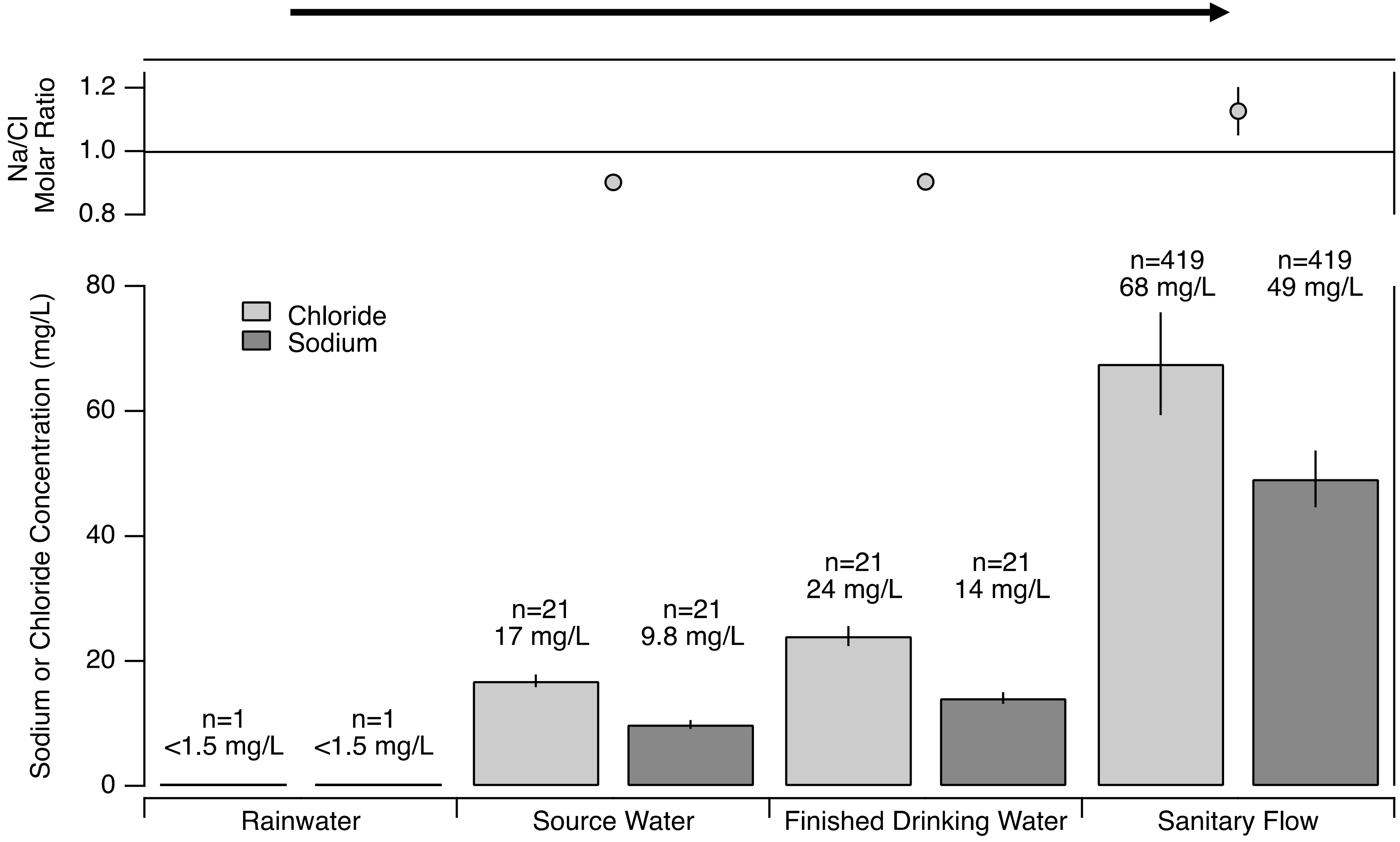
Challenge 3: salt inputs are tied to human behavior

Along the flow path



Challenge 3: salt inputs are tied to human behavior

Along the flow path



This information is preliminary and is subject to revision. It is being provided to meet the need for timely best science.

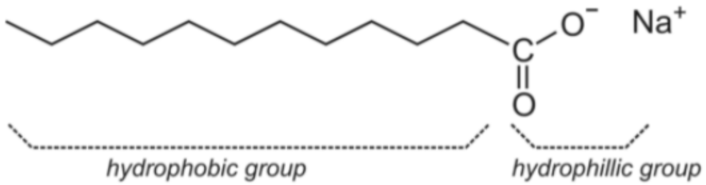
Grant et al., in prep.

Challenge 3: salt inputs are tied to human behavior

Table 1. Molar ratios in water discharged from the CSIRO model house

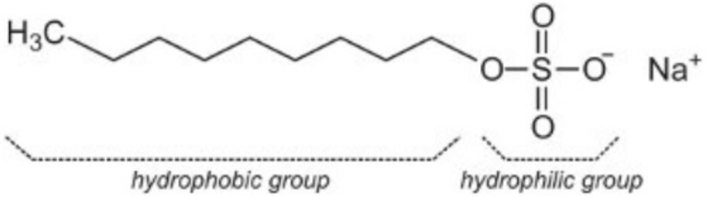
	Washing Machine	Dish Washer	Shower	Kitchen sink	Vanity Unit	Toilet+ Vanity	Total
Cl (g/wk)	6.296	7.580	2.269	5.021	0.5258	15.902	37.595
Cl (mol/wk)	0.178	0.214	0.064	0.142	0.0148	0.449	1.060
Na (g/wk)	55.609	7.456	2.466	3.213	0.766	15.362	84.872
Na (mol/wk)	2.418	0.324	0.107	0.140	0.033	0.668	3.69
Molar Na/Cl	**13.58**	**1.51**	**1.67**	**1.00**	**2.23**	**1.5**	**3.48**

Soaps

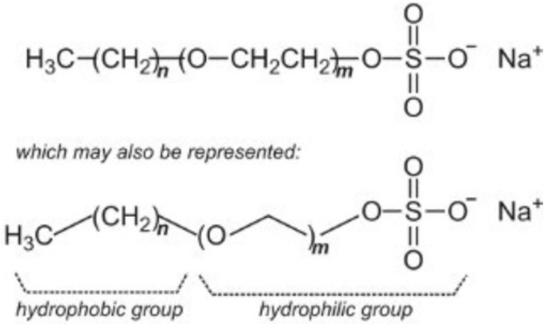


a soap

Detergents

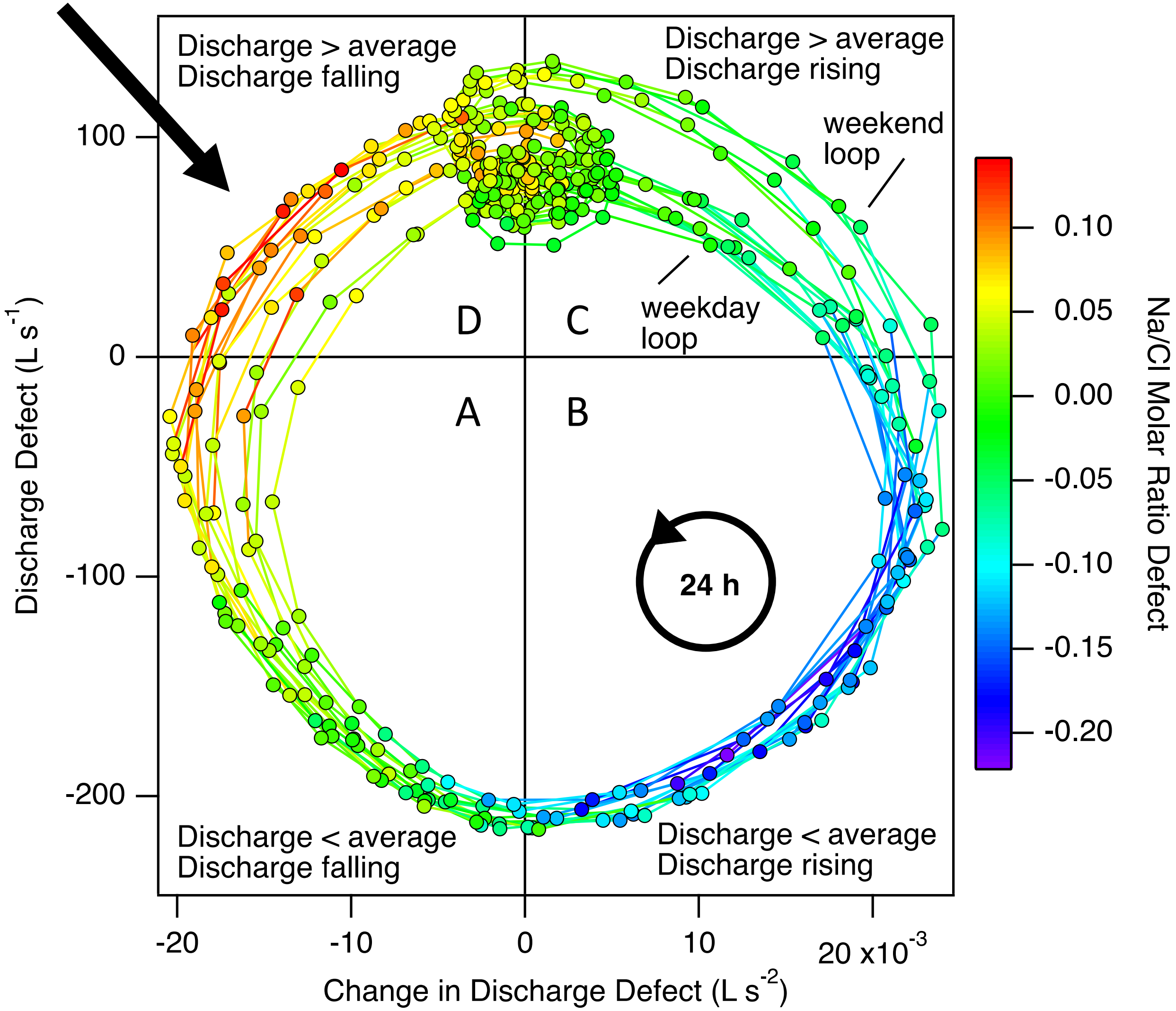


an alkyl sulfate

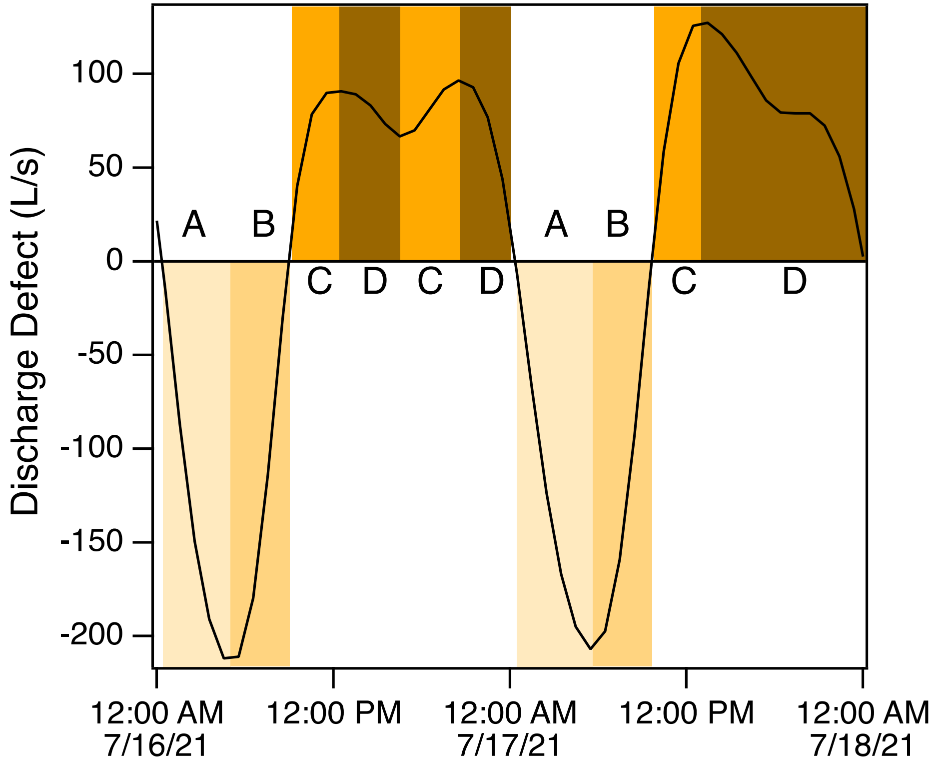


an alkyl ether sulfate

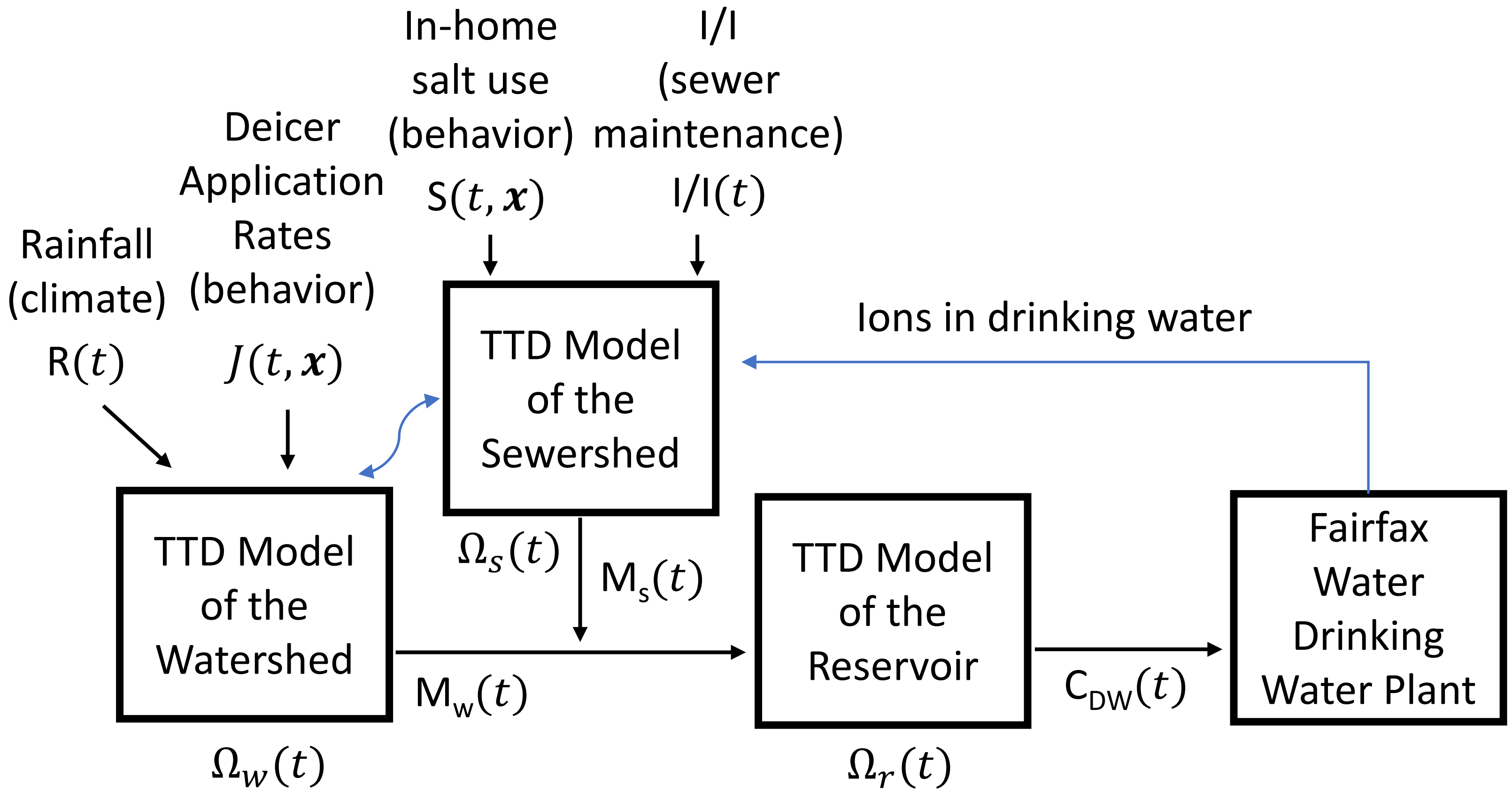
<u>Challenge 3</u>: salt inputs are tied to human behavior



Na/Cl ratio peaks during the falling limbs of the sewer hydrograph (in the middle of the night to early morning) reflecting human behavior + transport through the sewer network)



One way to address the three challenges: integrated models of salt sources & transport

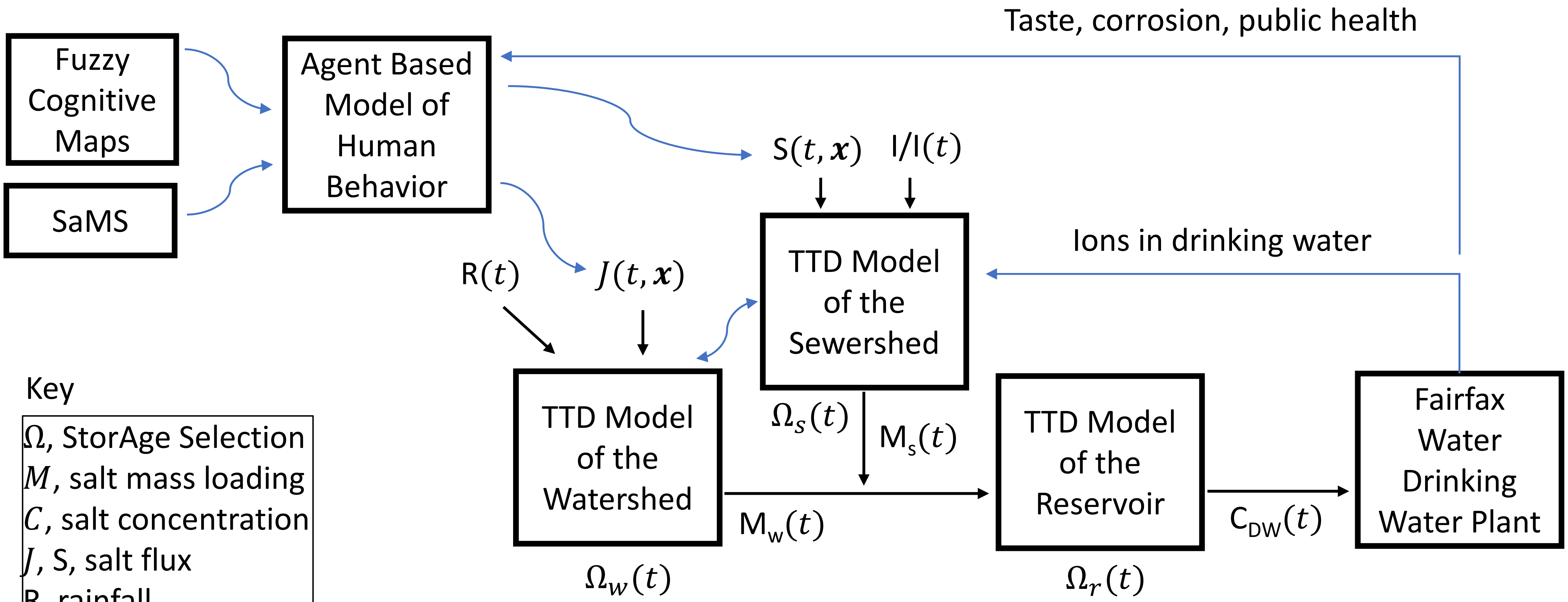


Key

Ω, StorAge Selection
M, salt mass loading
C, salt concentration
J, S, salt flux
R, rainfall

TTD=transit time distribution, tracks evolution of age distribution with time

One way to address the three challenges: integrated models of salt sources & transport



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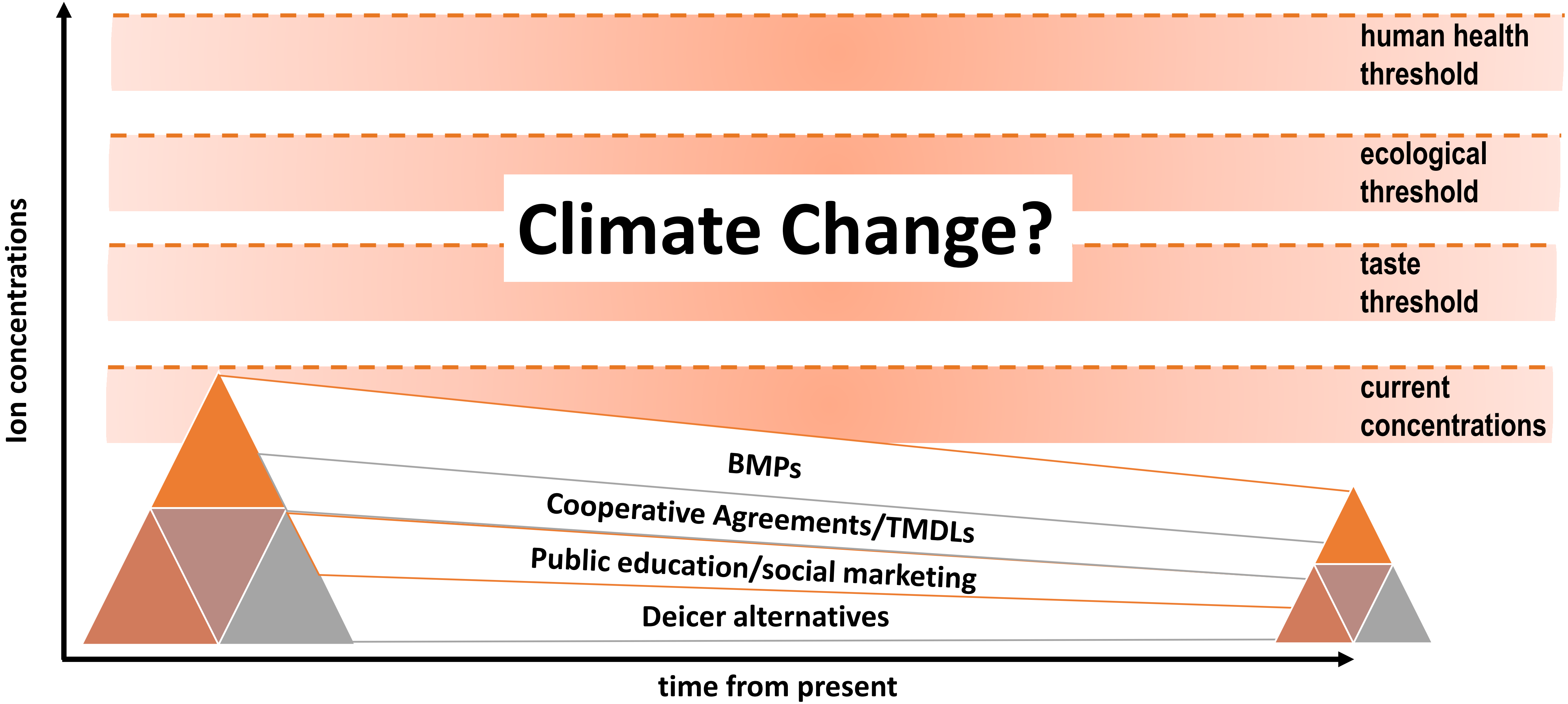
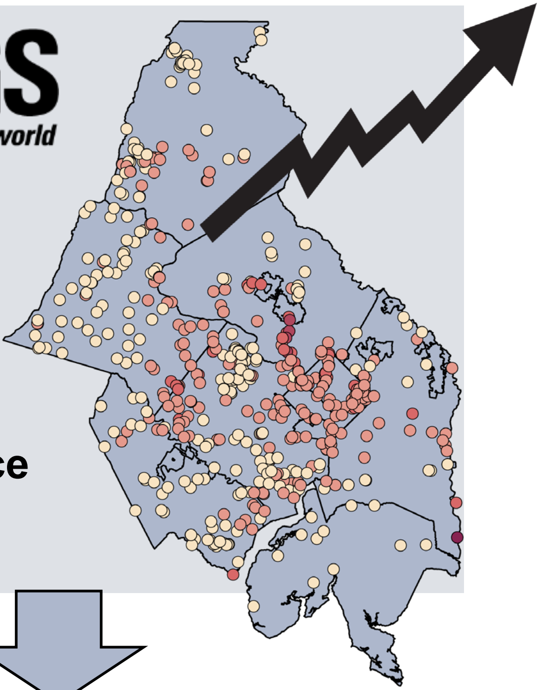
GRAND VISION: nature of system & levers of change



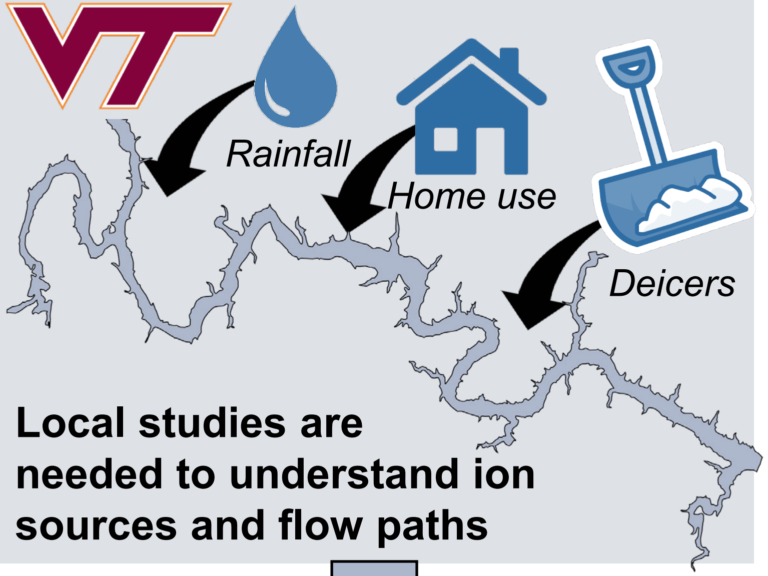
Establishing a Science Partnership to Support Understanding of the Freshwater Salinization Gradient in the Metropolitan Washington, D.C. Region

A collaborative scientific partnership is needed to address a complex, regional issue…

USGS
science for a changing world

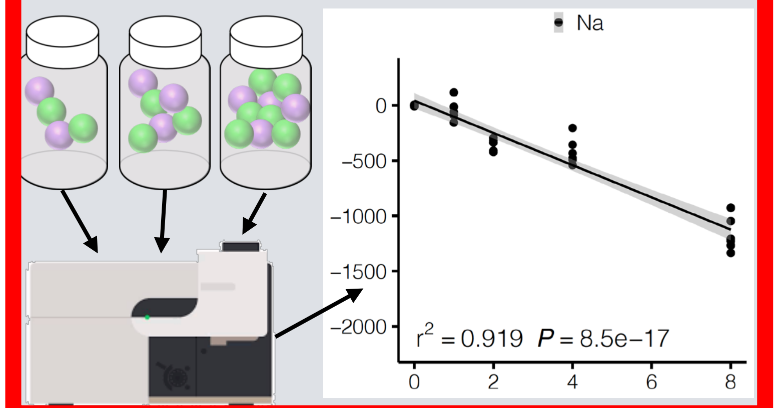


Monitoring networks can characterize patterns over time and space



Local studies are needed to understand ion sources and flow paths

Experimental treatments are needed to evaluate impacts and mechanisms



Synthesizing this knowledge is needed to understand and manage FSS in the MWCOG region

Freshwater Salinization Syndrome along Stormwater Flowpaths

What are the regional trends?
~John, Jimmy, & Andrew

What are the diverse sources and levers of change?
~Stan

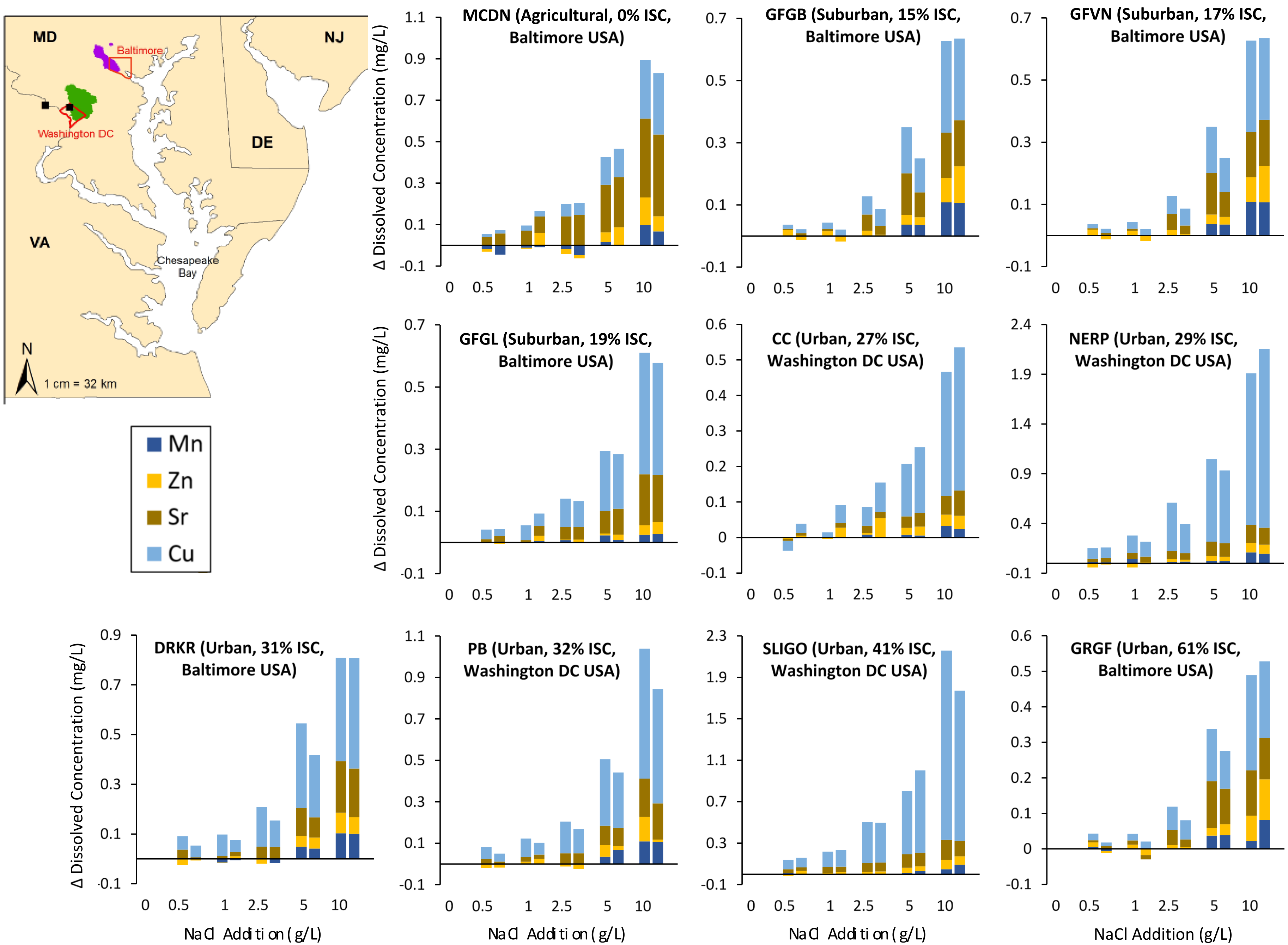
~What are the impacts, mechanisms, and frameworks?
Sujay

How Does Freshwater Salinization Syndrome Impact Stormwater BMPs?

- Are there critical thresholds in concentrations of road salt ions (Na^+, Ca^{2+}, Mg^{2+}) that mobilize nutrients and metals in stormwater BMPs?

- How much do road salt ions increase pulses of metals and nutrients in urban streams and stormwater BMPs?

Acknowledgements: Chesapeake Bay Trust and COG



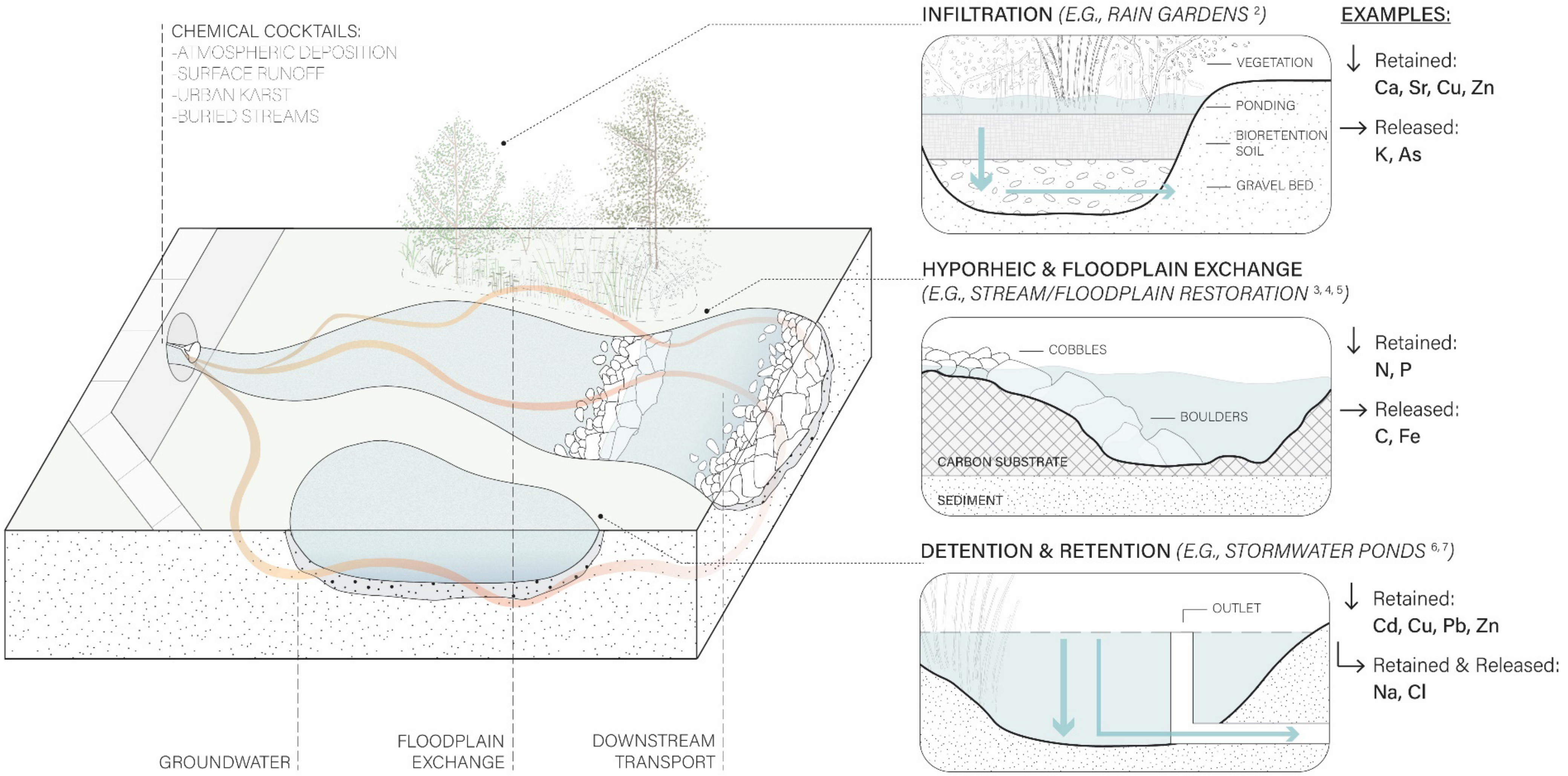
Salinization Mobilizes Metals and Nutrients to Streamwater

Kaushal et al. (2018b)
Philosophical Trans. Royal Society

Duan and Kaushal (2016)
Biogeosciences

Haq et al. (2018)
Biogeochemistry

Retention and Release of Chemical Cocktails along Stream and Stormwater Flowpaths



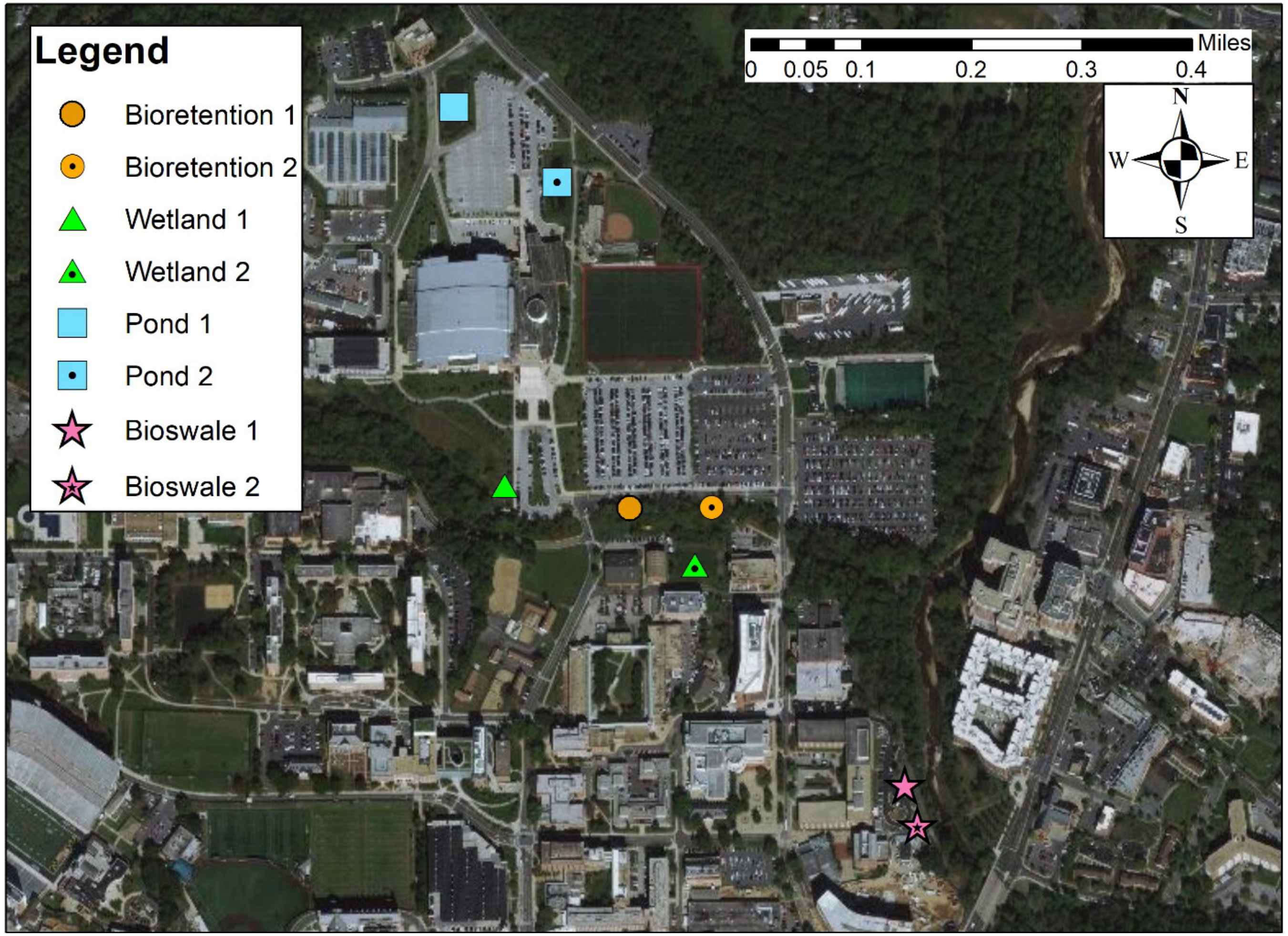
Experimental Design & Examples of Study Sites

Bioretention #1

Bioswale #1

Bioretention #2

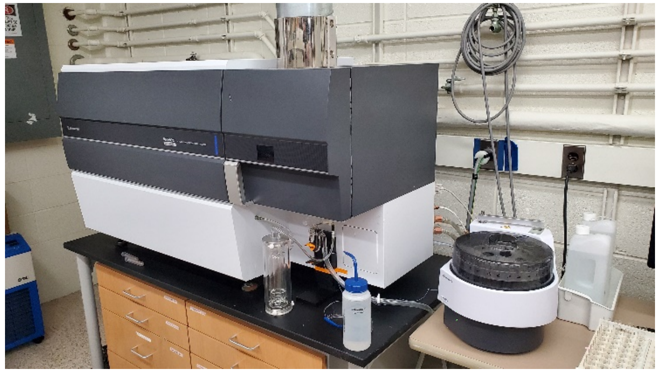
Bioswale #2



In addition, stream restoration/floodplain reconnection sites

Collect sediment and water from stormwater management feature

Add salts (NaCl, $CaCl_2$, & $MgCl_2$) at varying concentrations and incubate on shaking table for 24 hours

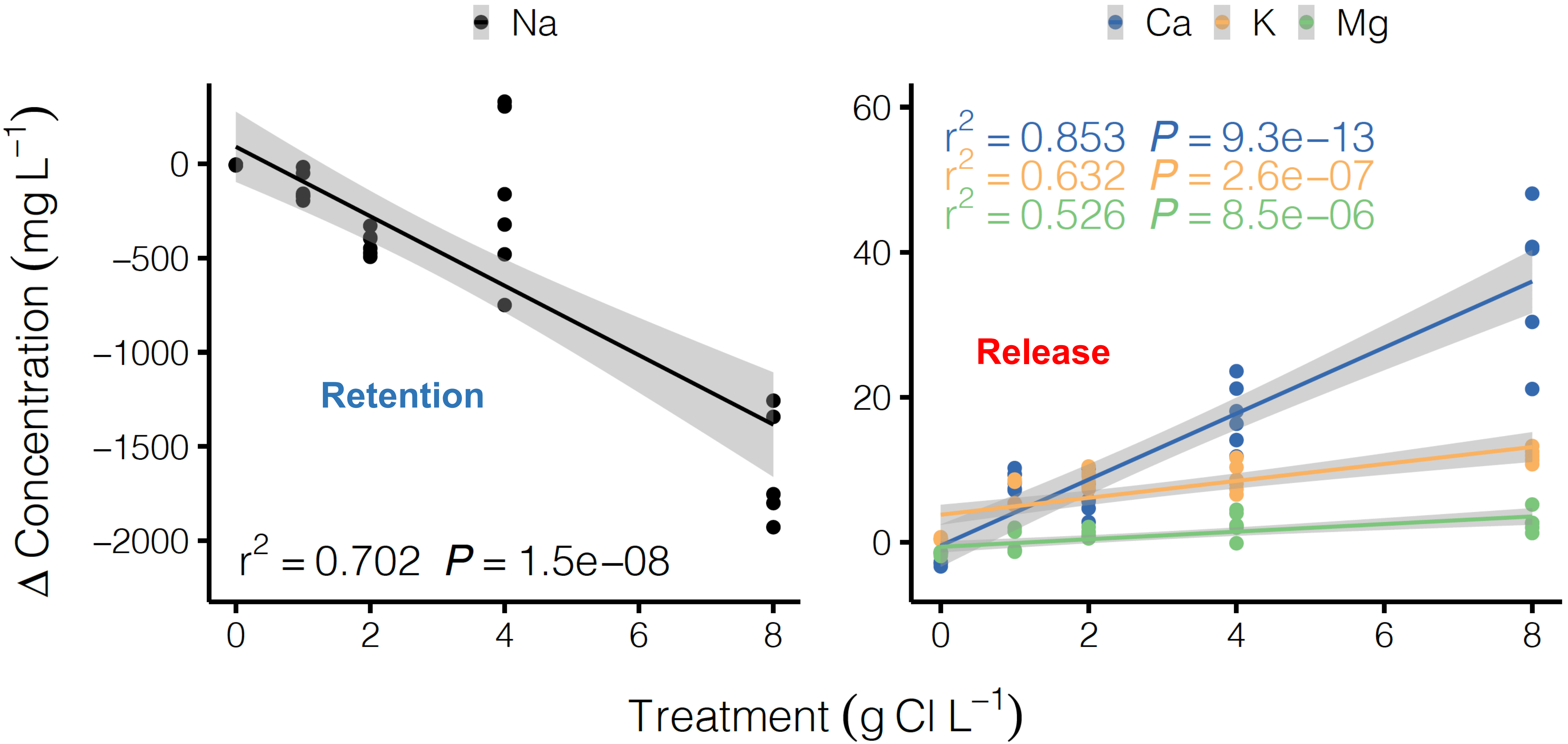


Analyze for major and trace elements, organic / inorganic carbon and nitrogen

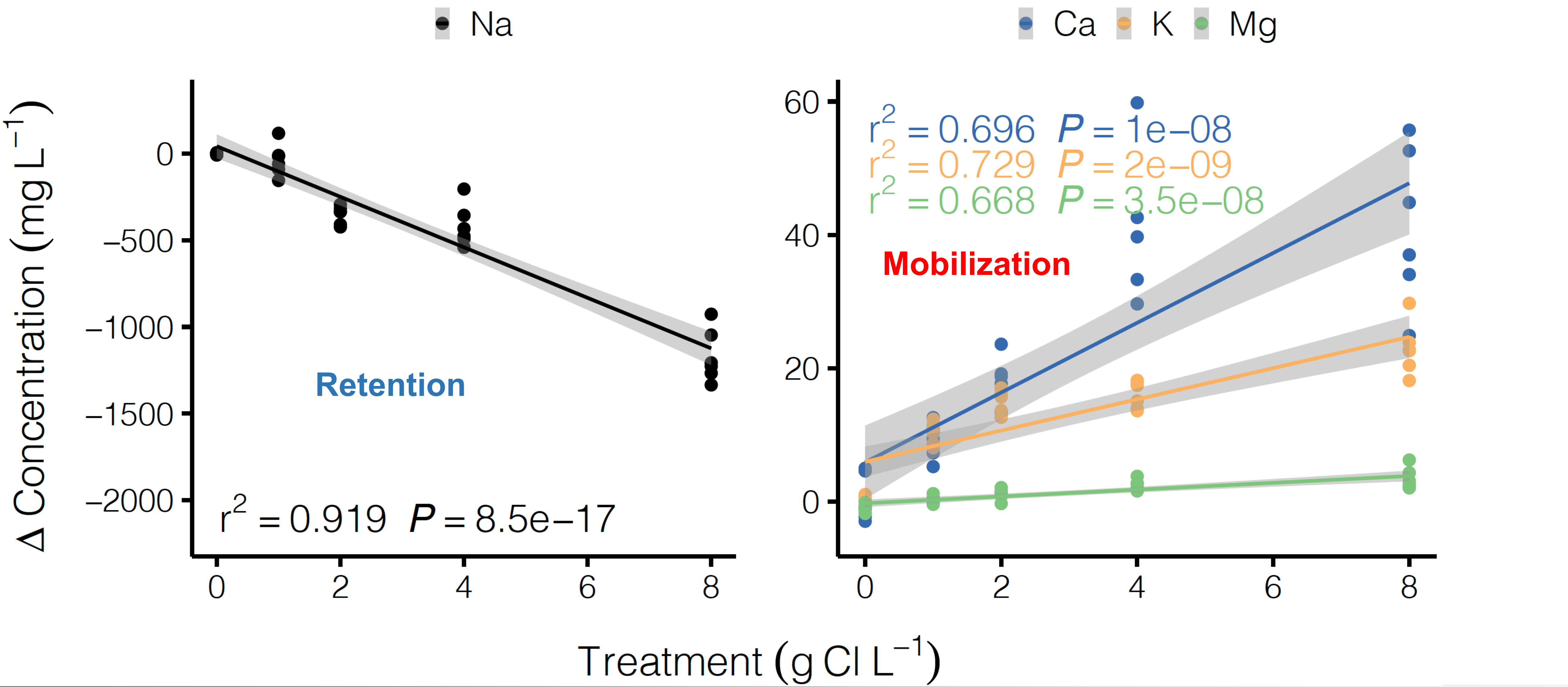
Hold the Salt: How Much Can Be Retained in Sediments?

Retention and Release of Salts and Metals in Different Stormwater Management Features

High Capacity for Sodium Retention in Restored Stream Floodplain Sediments



High Capacity for Sodium Retention in Regenerative Stormwater Conveyance Sediments



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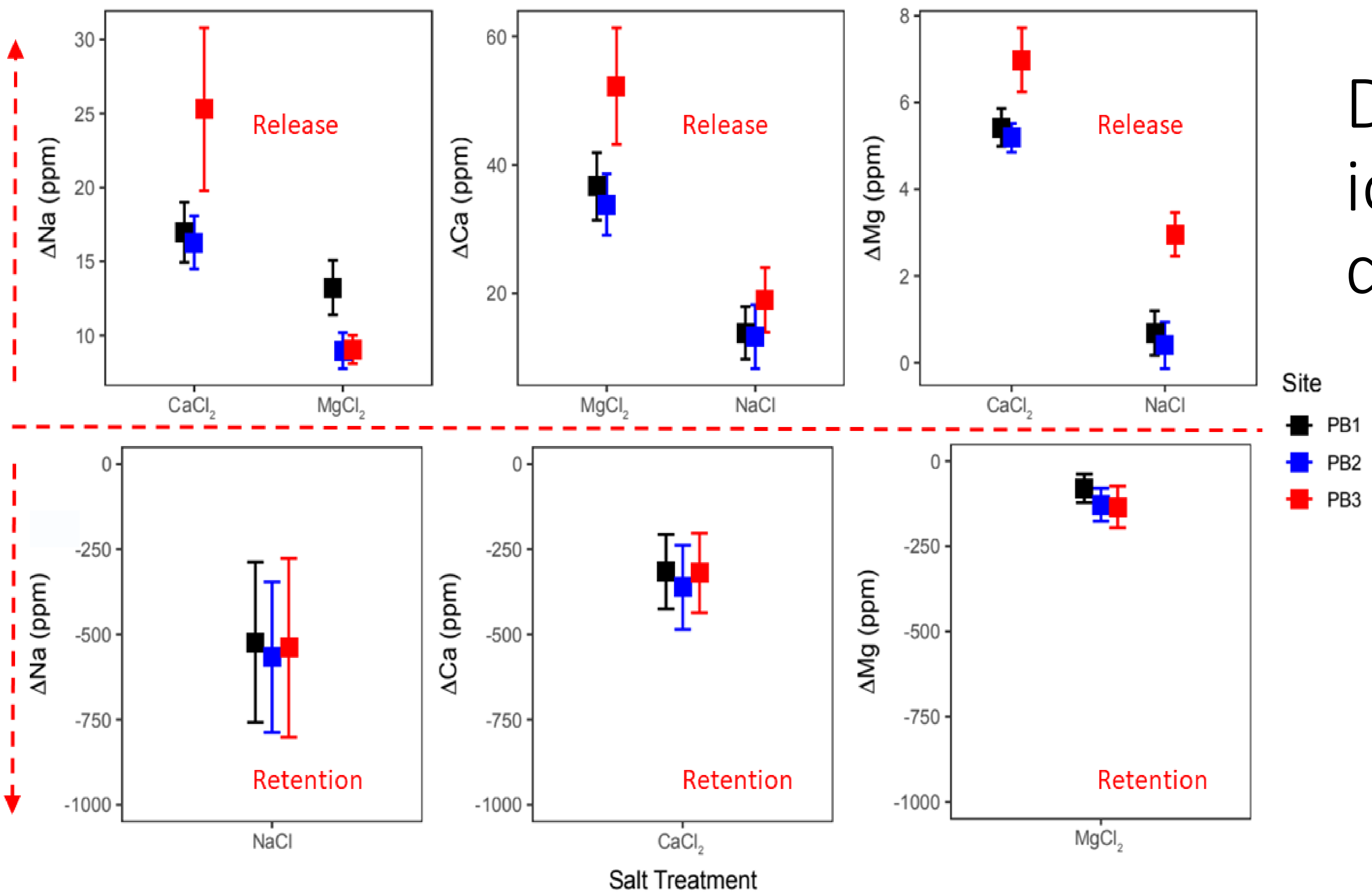
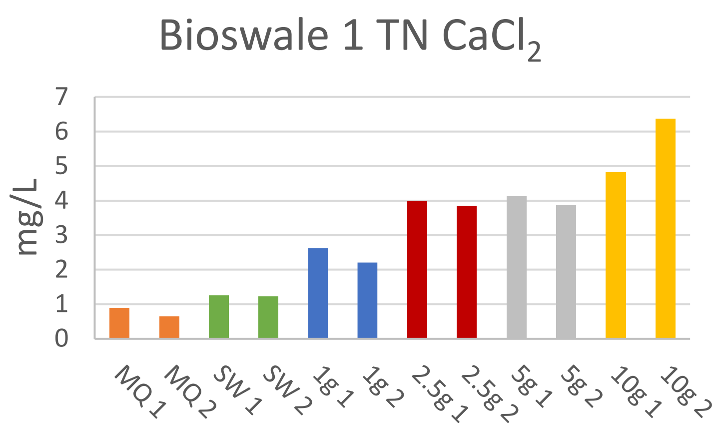
Different salt ions pose different risks

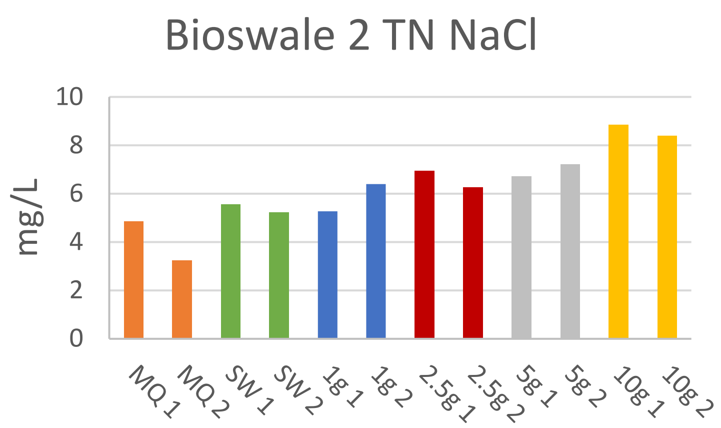


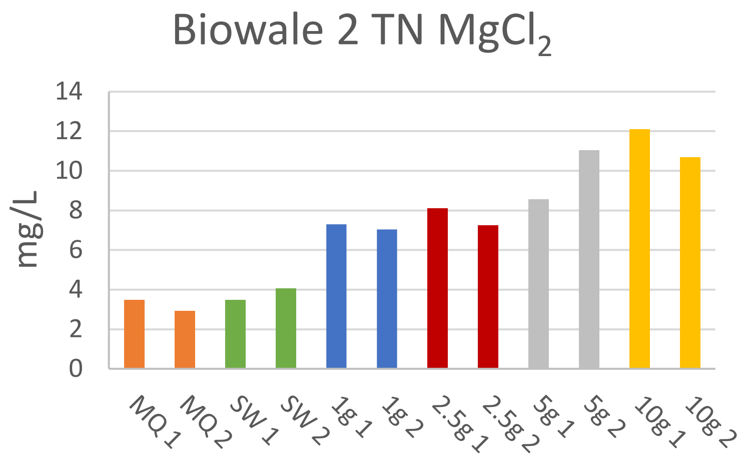
What are thresholds for nitrogen mobilization?

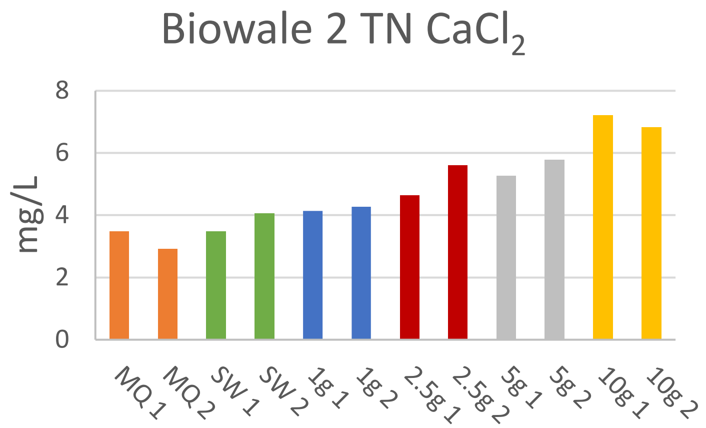
How much nitrogen is mobilized?

What are the effects of different road salt ions?









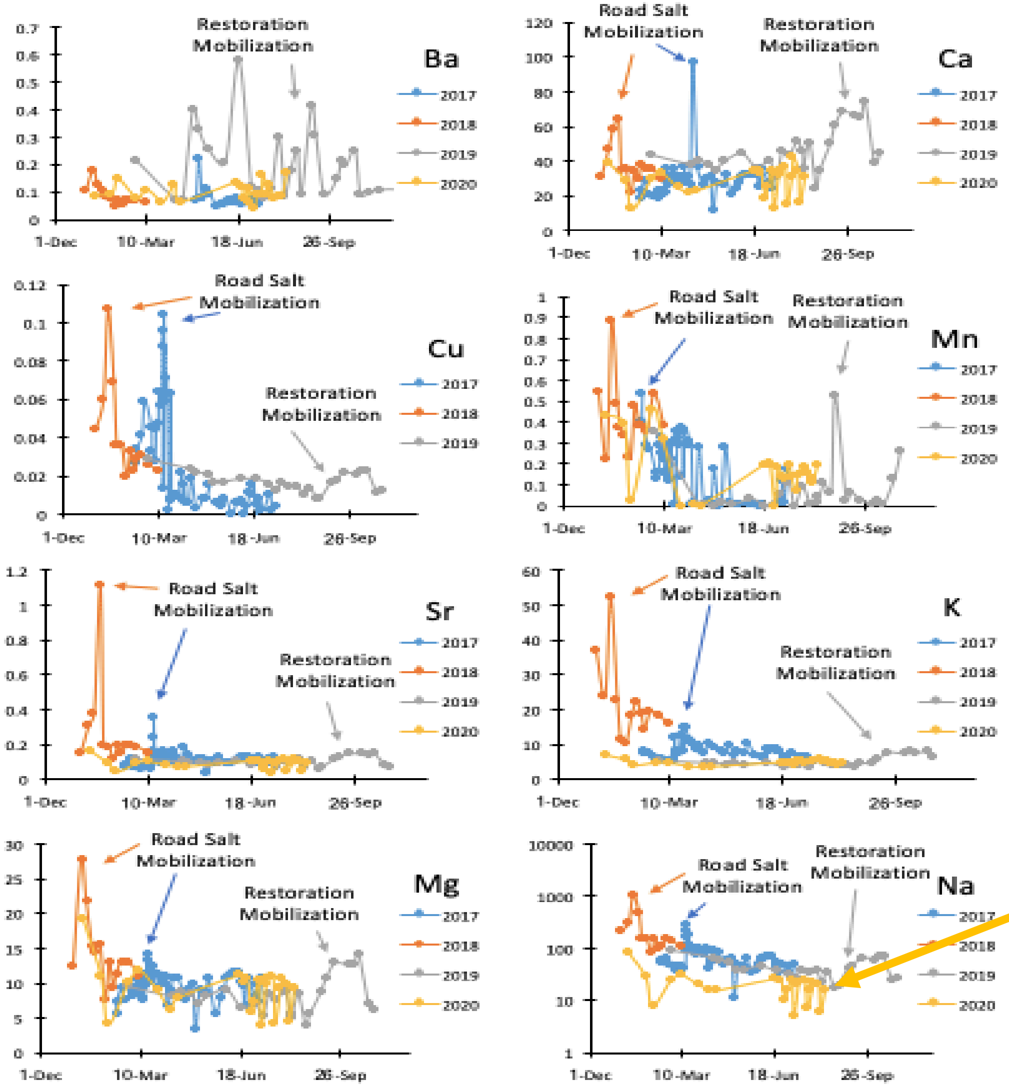
- Increased salt concentrations mobilize nitrogen and organic carbon
- Different salt ions can change magnitude of mobilization

What happens during road salt pulses?

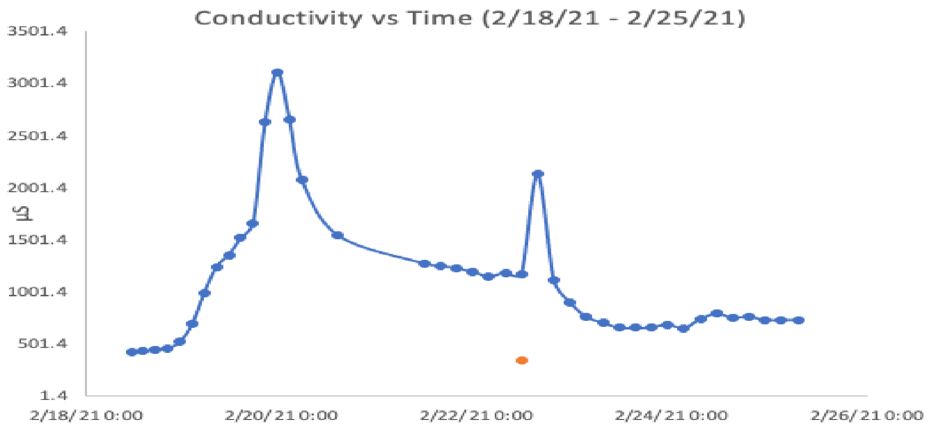
Photos Courtesy: Kelsey Wood

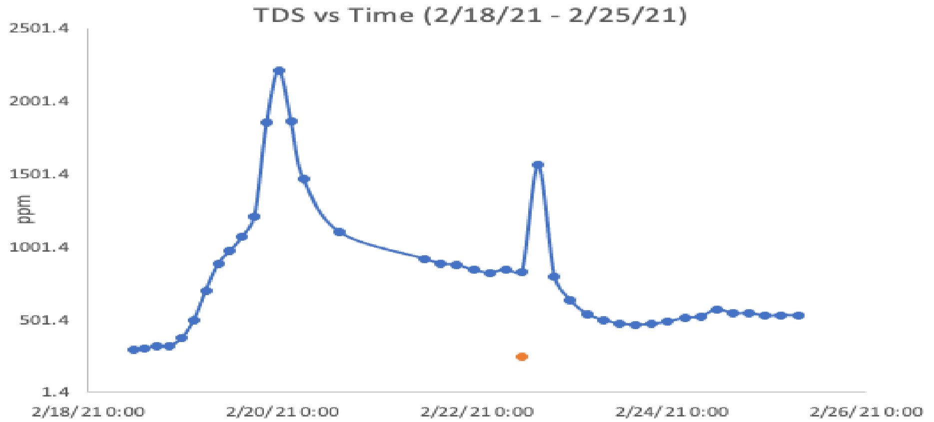
Mobilizing Chemical Cocktails:

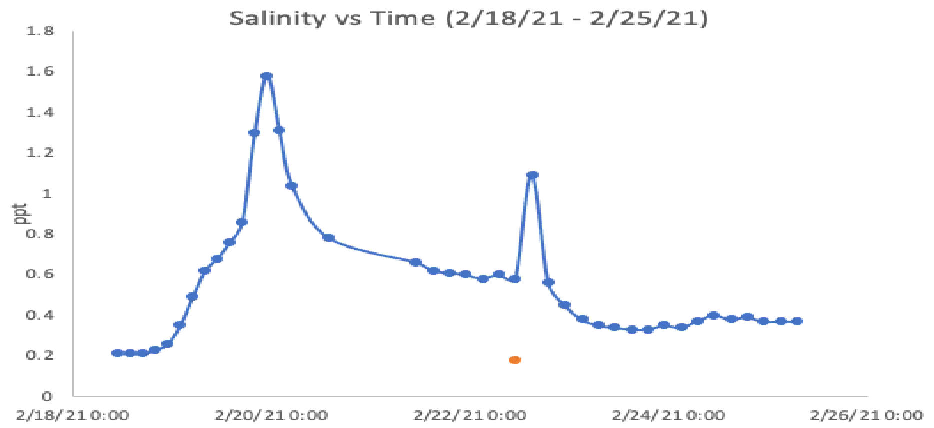
Comparison by Year and Season



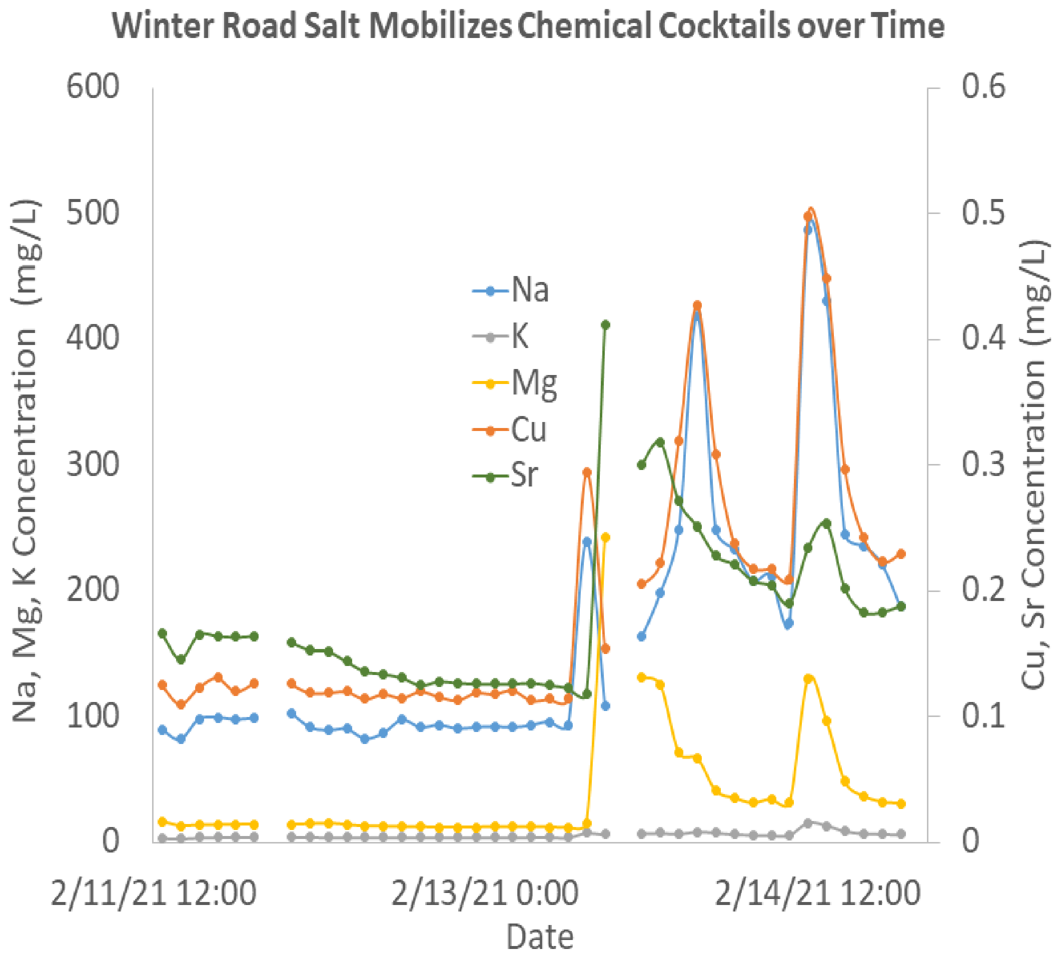
There can be some recovery in water quality depending on amount of road salt use



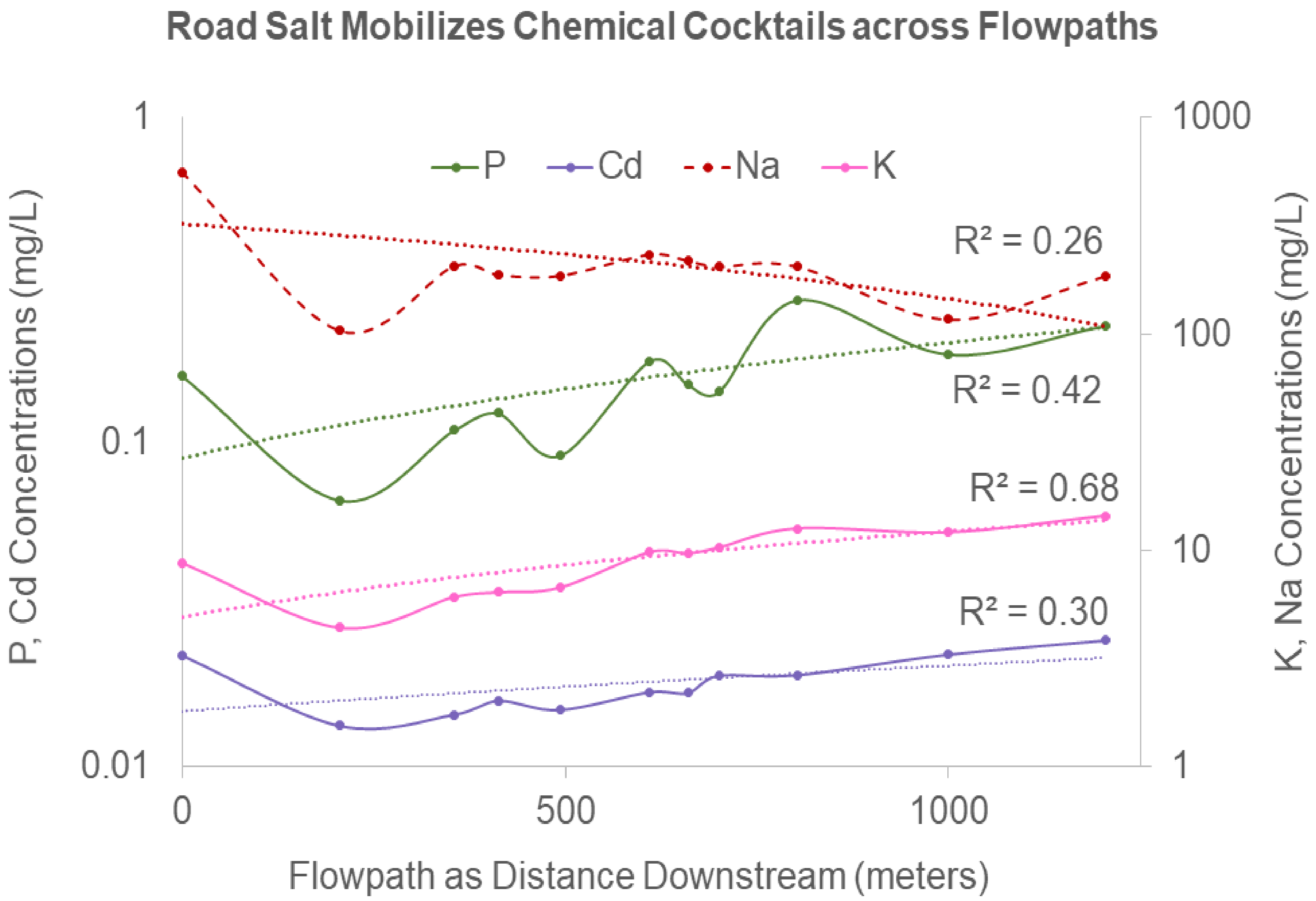




Year 1 Monitoring
2021 Large Winter Ion Pulses
Mobilization of Multiple Chemical Cocktails from BMPs



Year 1: Retention and Release of Chemical Cocktails along Stormwater Management Flowpaths



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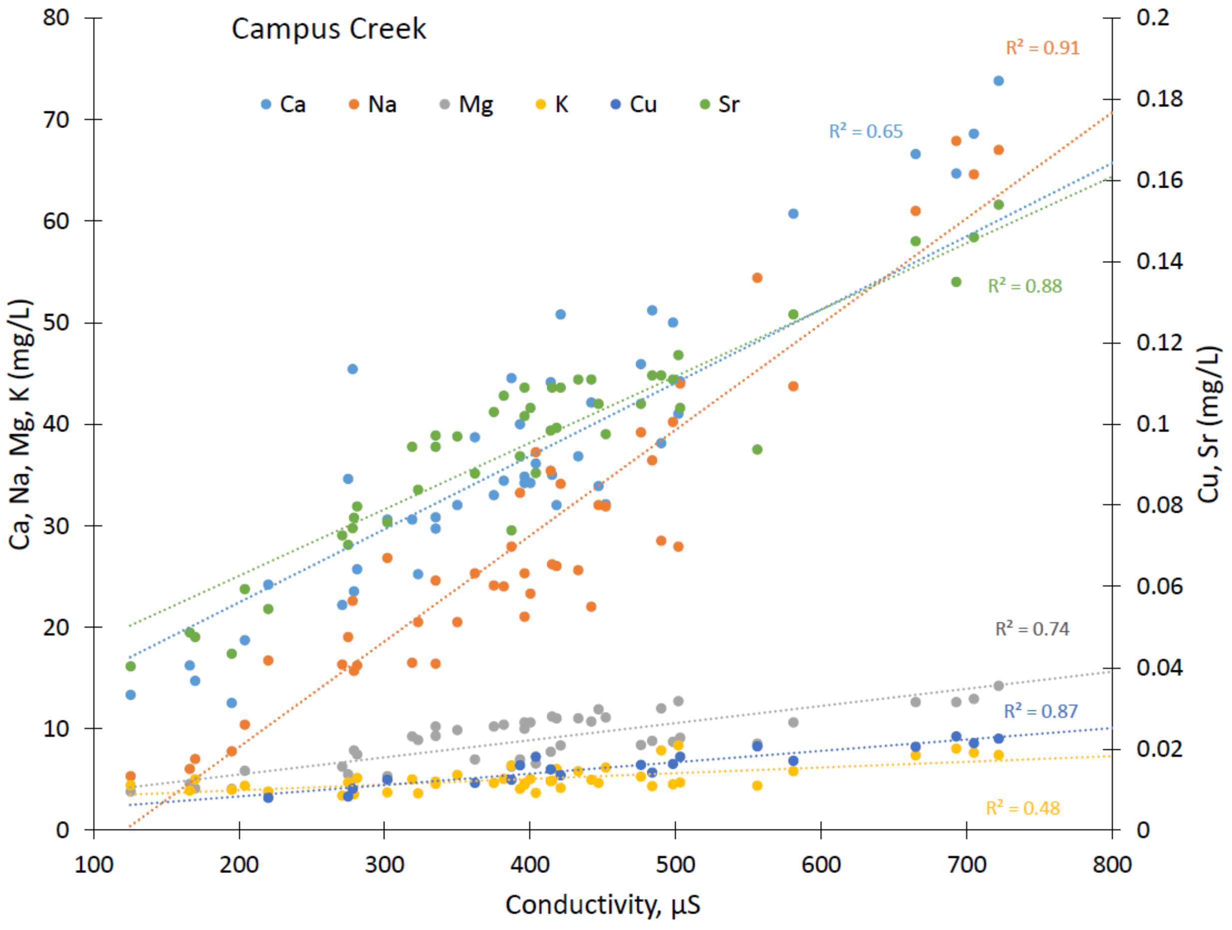
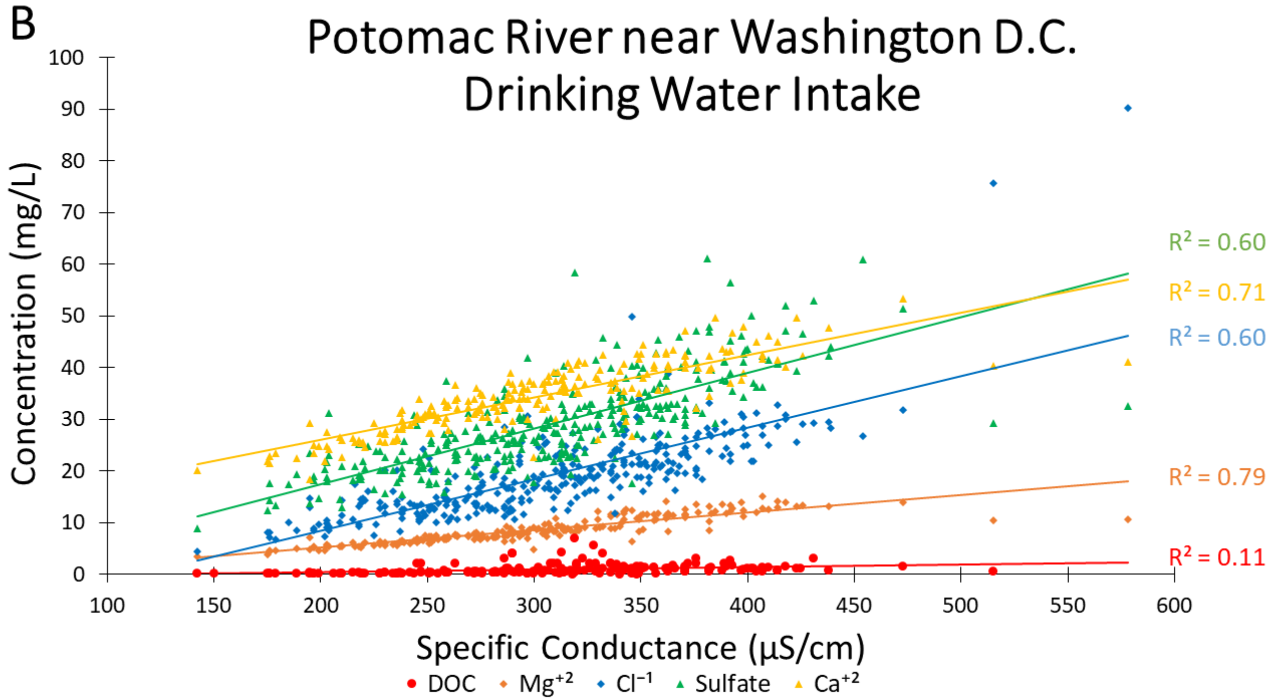
Kaushal et al. (In Review)

Sensor Monitoring Approaches: Specific Conductance as a Proxy





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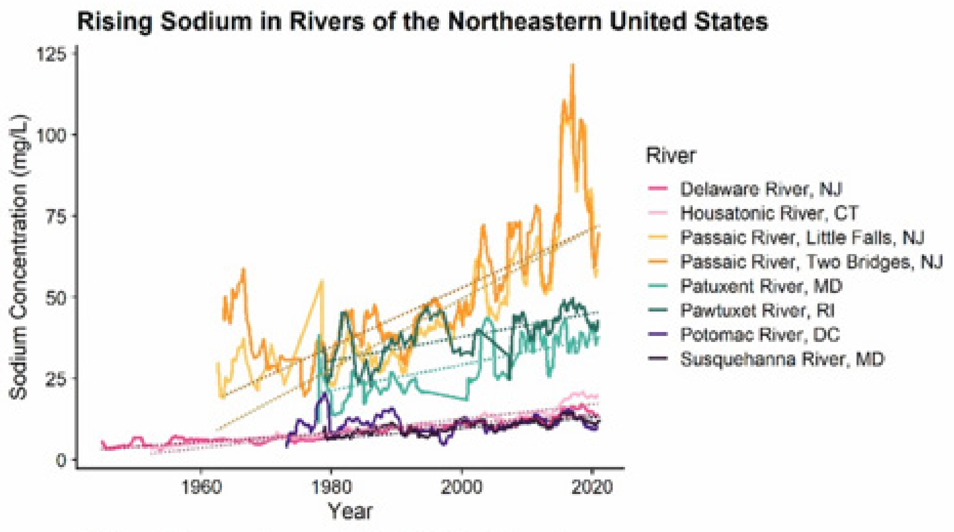
Kaushal et al. (2021) Galella et al. (2021) for Rock Creek

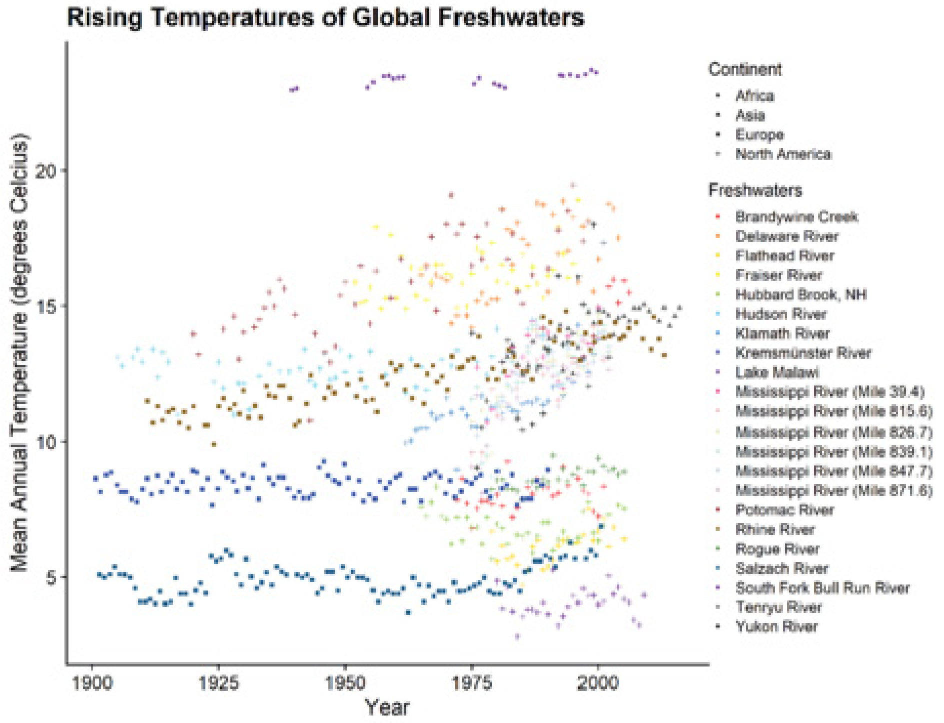
Summary

- Significant retention of salt ions in stormwater sediments
- Release of elements depends on type of deicer ion and site
- Chemical cocktails – multiple ions released along flowpaths
- Developing new practical monitoring approaches using proxies

Management Implications

- Stormwater sediments/soils can enhance ion exchange and retention
- Types of salt ions matter in terms of contaminant mobilization
- Reducing winter NaCl inputs can lead to rapid and year long recovery
- Conductivity can be inexpensive proxy for multiple ions and metals





Mapping Future Risks of Freshwater Salinization Syndrome

-Developing a framework to identify interactive impacts

-Predicting risks using a systems level approach

-Diagnosing stages based on current and future trends

Kaushal et al. (In Review)

Identifying Regional Risk Factors

State Factors Contributing to Freshwater Salinization Syndrome

CLIMATE
can contribute to ion pulses and trends.

Drivers
- -Precipitation[1,20]
- -Evaporation[1,2]
- -Droughts[3]
- -Drying of lakes[4,5]
- -Warming[6,7]
- -Sea level rise and saltwater intrusion[1,8]

GEOLOGY
can enhance sources of ions.

Drivers
- -Lithology[9,10]
- -Weathering rates[11]
- -Soil texture[12,26]
- -Hydraulic conductivity[26]
- -Cation exchange capacity[13,14]
- -Soil fertility[16,38,39]
- -Water-rock interactions[15,16]

HUMAN ACTIVITIES
enrich freshwater with multiple ions.

Drivers
- -Land use[17,20]
- -Road salts[18,19]
- -Water softeners[19,22]
- -Fertilizers[1,8]
- -Agricultural lime[1,21]
- -Household products[22,23]
- -Resource extraction[8,24]
- -Mining[1,25]
- -Wastewater[1,22]
- -Vegetation removal[26]

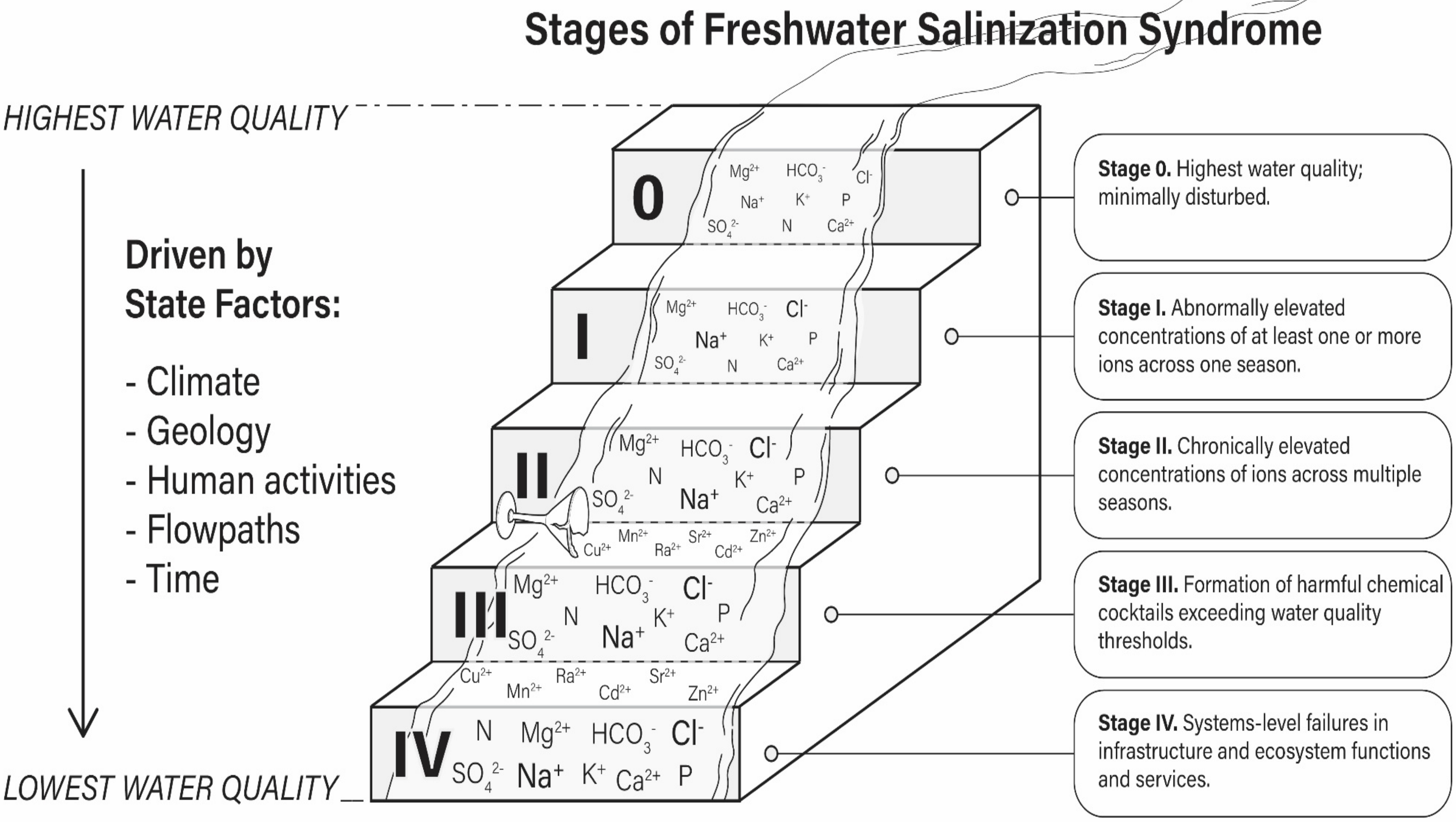
FLOWPATHS
can transport or transform ion signals along watersheds.

Drivers
- -Irrigation return flows[27]
- -Pipes and storm drains[28,29]
- -'Urban karst'[30]
- -Agricultural tile drains[31]
- -Groundwater pumping[32]
- -Mine drainage[33]
- -Wastewater discharges[22,34]
- -Water treatment[22]
- -Saltwater intrusion into groundwater[35]

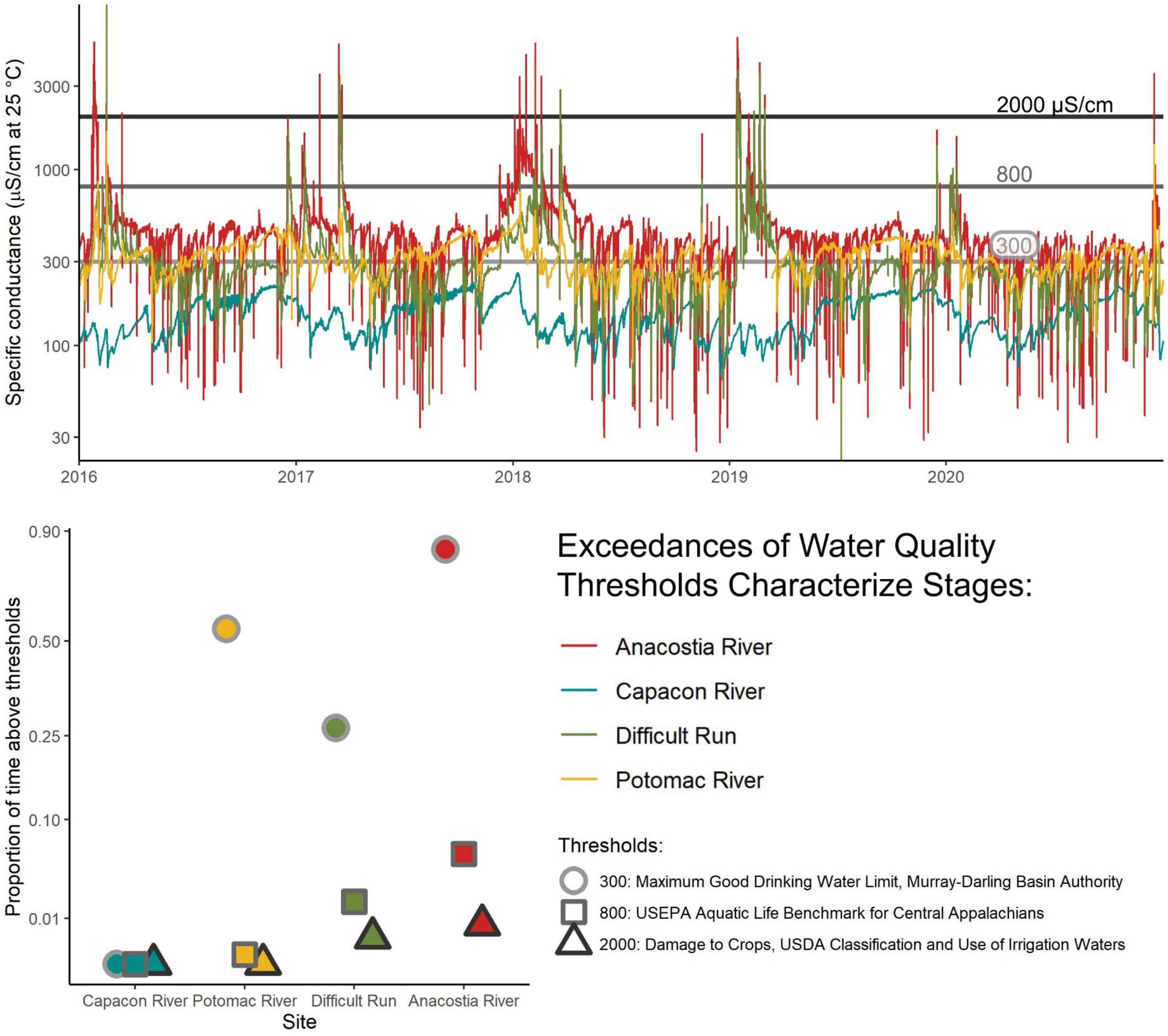
TIME
reveals stages due to pulses and trends.

Drivers
- -Long-term trends[18,28]
- -Salt pulses[36,41]
- -Lag times[8,19,36]
- -Legacy effects[8,19]
- -Ecological succession[3,37]
- -Alternative stable states[40]
- -Infrastructure life cycles[29]

Diagnosing and Predicting Stages



Kaushal et al. (In Review)



Diagnosing Stages Using Exceedances of Thresholds

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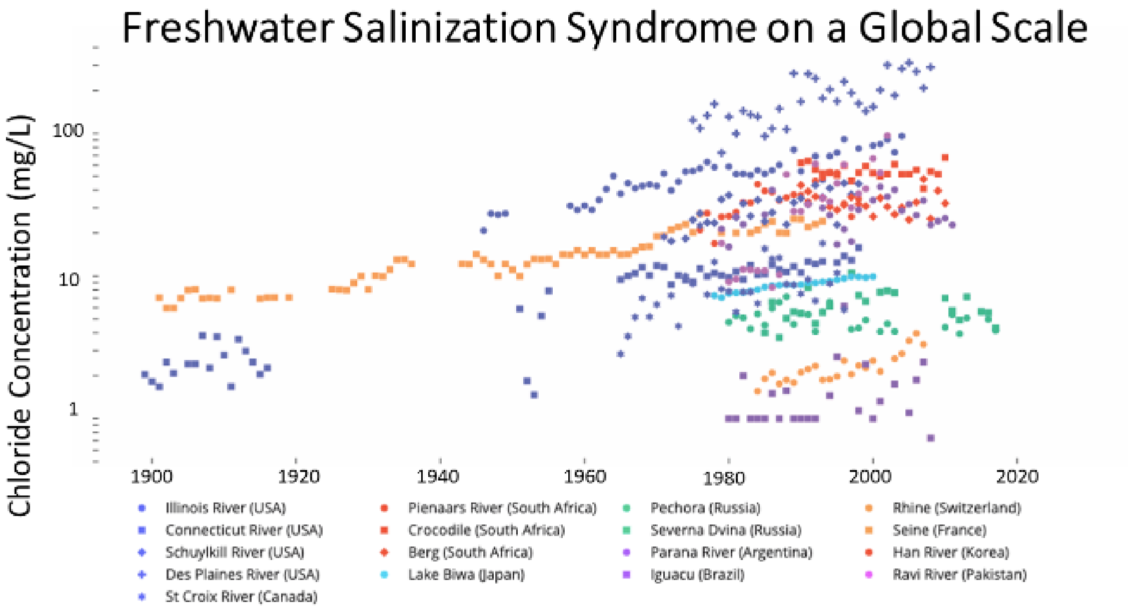
Kaushal et al. (In Review)

COG Salt Team: from Diagnosis to Prognosis to Cure

- Mapping/predicting interactive and growing problem requires a lot of teamwork!
- Need to integrate trends with mechanisms to regional models and management
- Year 1: Developing diagnostic monitoring frameworks to manage interactive risks across systems **John (*operations*), Stan (*models*), Jimmy (*trends*), Andrew (*GIS*)**



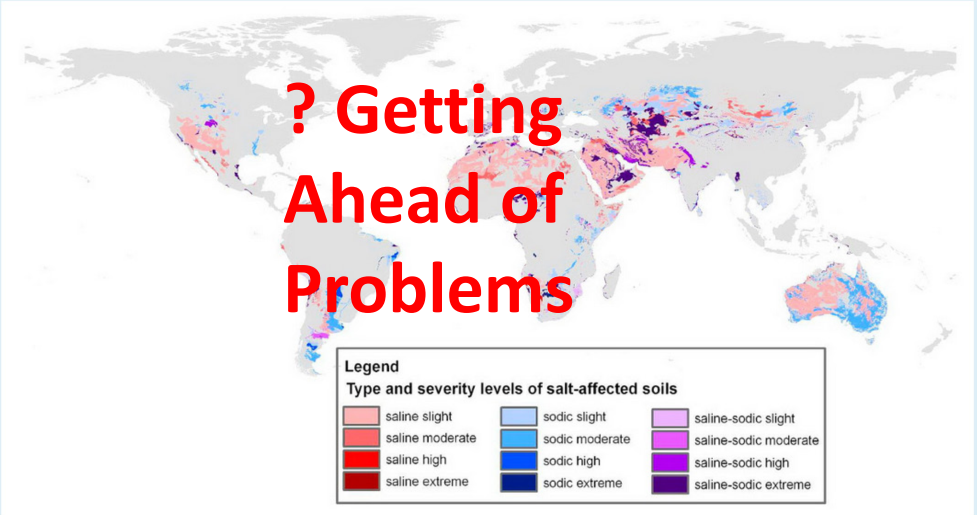


Figure. The distribution of saline, sodic and saline-sodic soils in the world. Source: Energy Environ. Sci., 2011,4, 2669-2681

Kaushal et al. (2021)