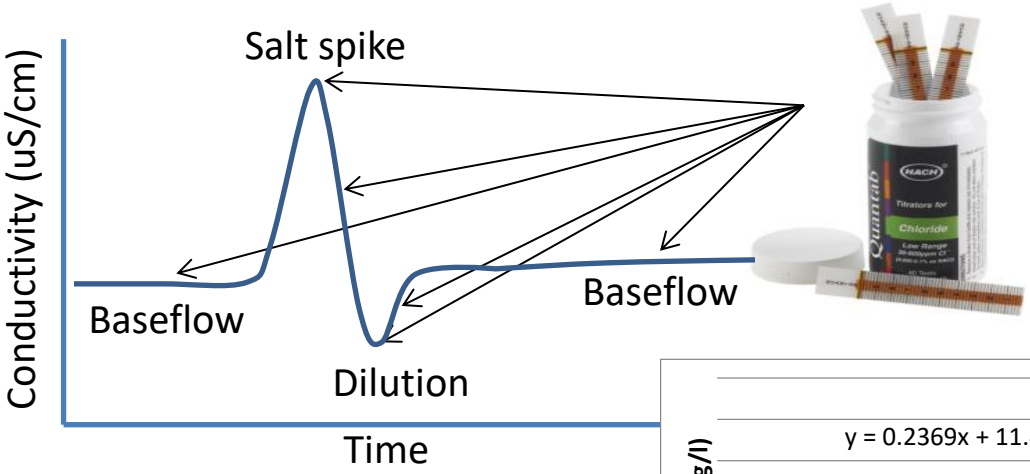
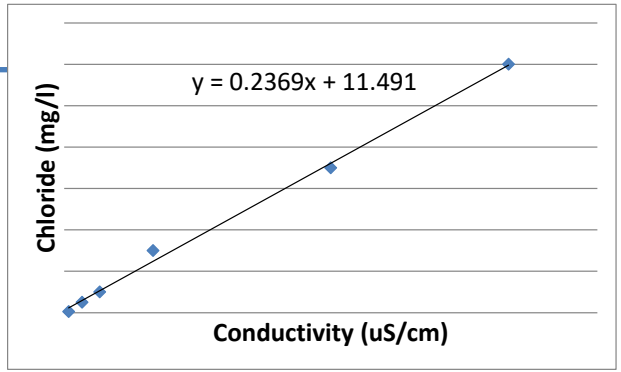
Developing and using a Conductivity-Chloride Rating Curve





**Example data – do not use*

Overview

- Goals:
  - Document Chloride levels across full range of conductivity
    - At Baseflow
    - Throughout road salt flush event associated with winter storm(s) AND
    - During dilution events
  - Develop site-specific Rating Curve (an equation) between Conductivity and Chloride
- Purpose:
  - Via rating curve, convert continuous conductivity data to chloride data
    - Compare to Chloride toxicity criteria/thresholds, natural levels, biotic thresholds, etc.
    - For calculation of amount of salt flowing in stream (i.e., load)
  - Give more meaning to site-specific conductivity data (conductivity is easier to measure, e.g., hand held meters, continuous sensors, etc.)

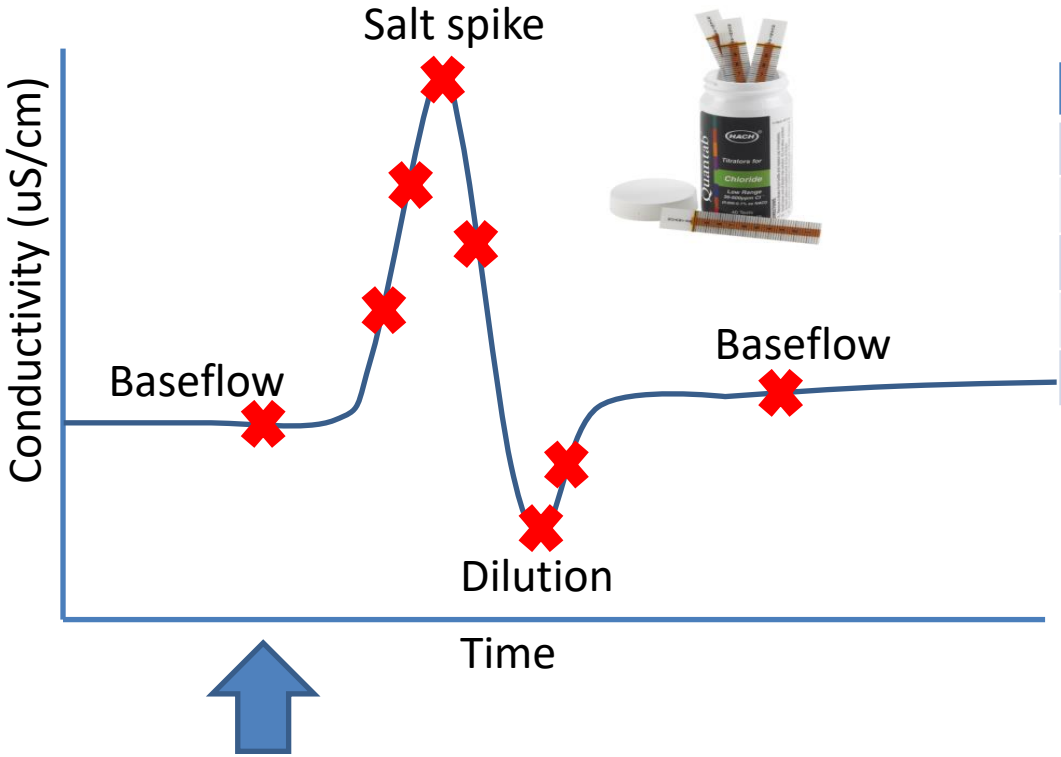
Conductivity and Chloride

- Higher conductivity generally means higher salt
- Confirm this at a site via direct measurement of chloride
- Conductivity is an indirect way to measure salt, but there is natural conductivity (which has to be accounted for)
- Develop conductivity/chloride rating curve to explicitly see this relationship for a site
  - Allows us to see site specific cond/chl relationships, including natural influences
  - Allows confirmation of the influence of road salt and de-icers

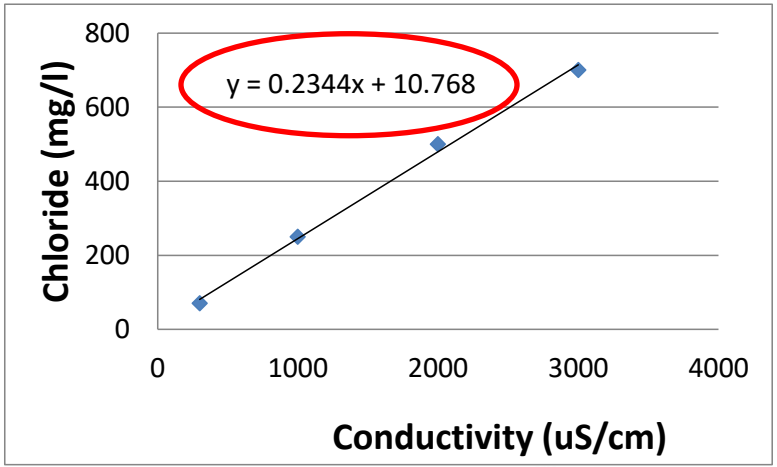
The Process:

1. Measure and record chloride and conductivity at different times: 1) baseflow, 2) salt spikes, 3) dilution events
2. Plot range of conductivity and chloride values as a scatterplot in Excel (or other graphing program)
3. Fit a curve to the scatterplot and display the curve equation
4. Use curve equation to convert continuous conductivity data to chloride OR to simply add context to future conductivity measurements

The Process (steps 1-3):



Date/Time	Conductivity	Chloride
	300	70
	1000	250
	2000	500
	3000	700
	….	….



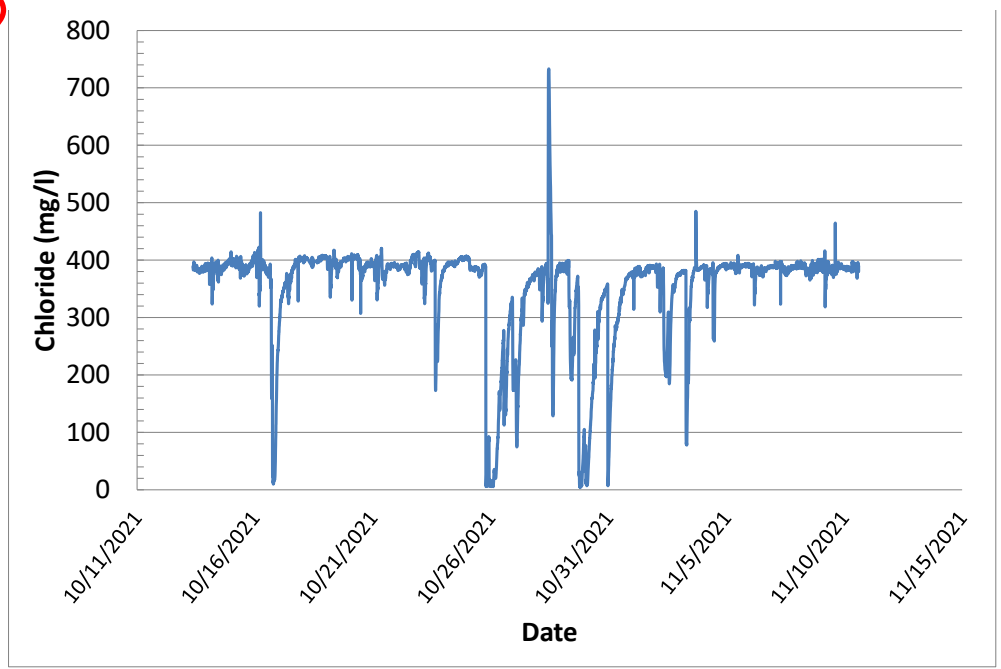
***You can do this over one event and/or multiple events**

**Example data – do not use*

The Process (step 4):

C2 | fx | =0.4148*B2 - 124.92

	A	B	C
1	DateTime	Conductivity (uS/cm)	Chloride (mg/l)
2	10/13/21 9:15	1400.3	456
3	10/13/21 9:20	1424.7	466
4	10/13/21 9:25	1409.8	460
5	10/13/21 9:30	1426.8	467
6	10/13/21 9:35	1420.5	464
7	10/13/21 9:40	1432.3	469
8	10/13/21 9:45	1425.8	467
9	10/13/21 9:50	1447.7	476
10	10/13/21 9:55	1441.3	473
11	10/13/21 10:00	1428.2	467
12	10/13/21 10:05	1441.8	473
13	10/13/21 10:10	1430	468
14	10/13/21 10:15	1425.8	467
15	10/13/21 10:20	1424.5	466
16	10/13/21 10:25	1426.7	467
17	10/13/21 10:30	1438.5	472
18	10/13/21 10:35	1425.5	466
19	10/13/21 10:40	1421.5	465

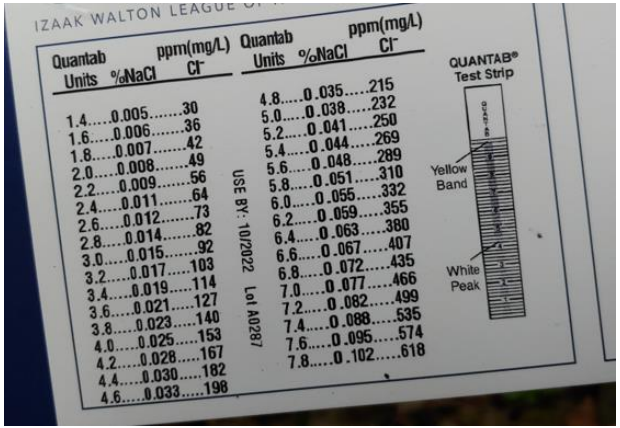


https://monitormywatershed.org/sites/PUSH1S/

What you'll need:

- Specific to this work
  - Chloride QuanTab® Test Strips
    - Low range 30-600 mg/L
    - High range 300-6000 mg/L
  - Conductivity-Chloride Rating Curve Sampling Sheet
  - Smartphone (to access Monitor My Watershed) OR calibrated handheld Conductivity meter
  - Sensor brush (if using EnviroDIY station for conductivity data)
  - *Can also incorporate Izaac Walton League Winter Salt Watch – user-friendly directions
- General
  - Waders or knee boots
  - Clipboard
  - Pencils
  - Other supplementary items
    - Camera
    - First Aid kit

What you'll need:



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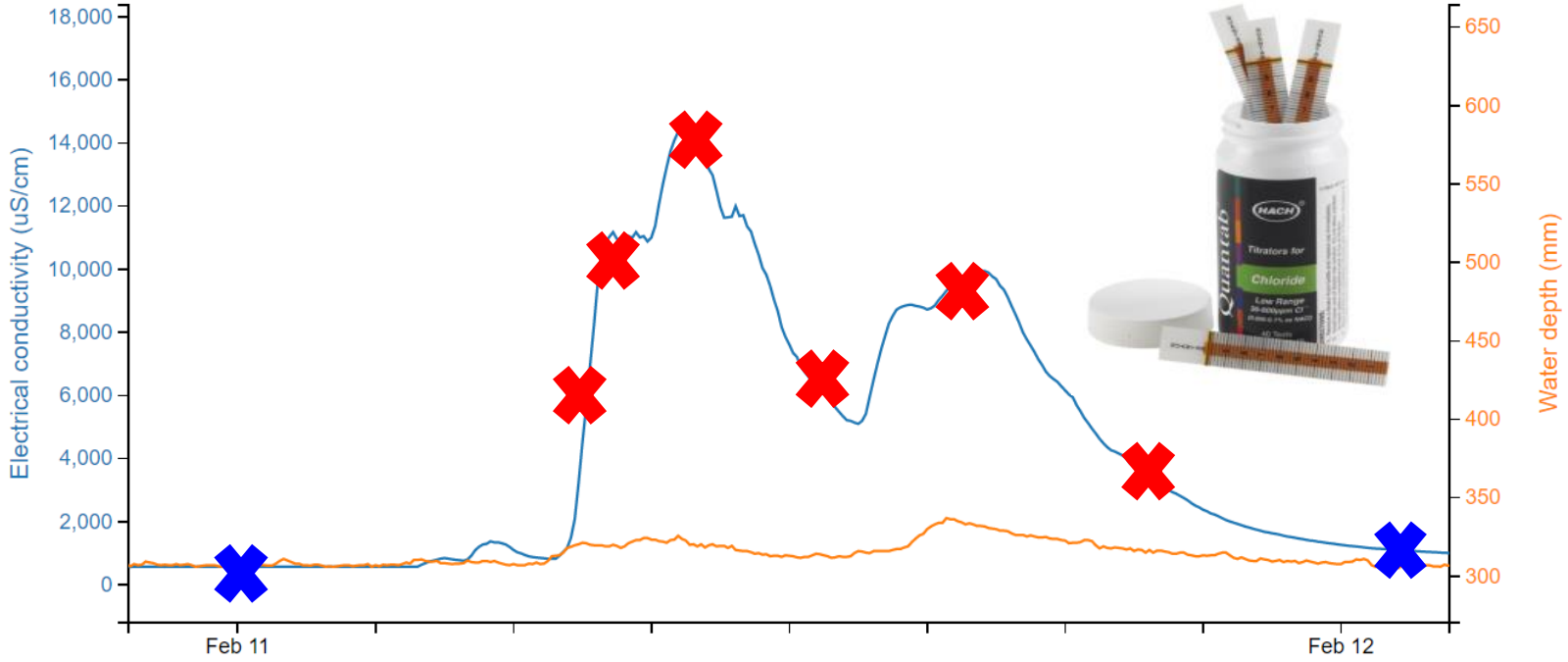
Where to do the sampling:

- At an EnviroDIY monitoring station
- At a USGS monitoring station (one that has conductivity data)
- Anywhere you want

When to measure:

- ✖ At baseflow when conductivity is at its usual level
- ✖ When conductivity is elevated during and after winter storms (road salt/de-icer runoff)

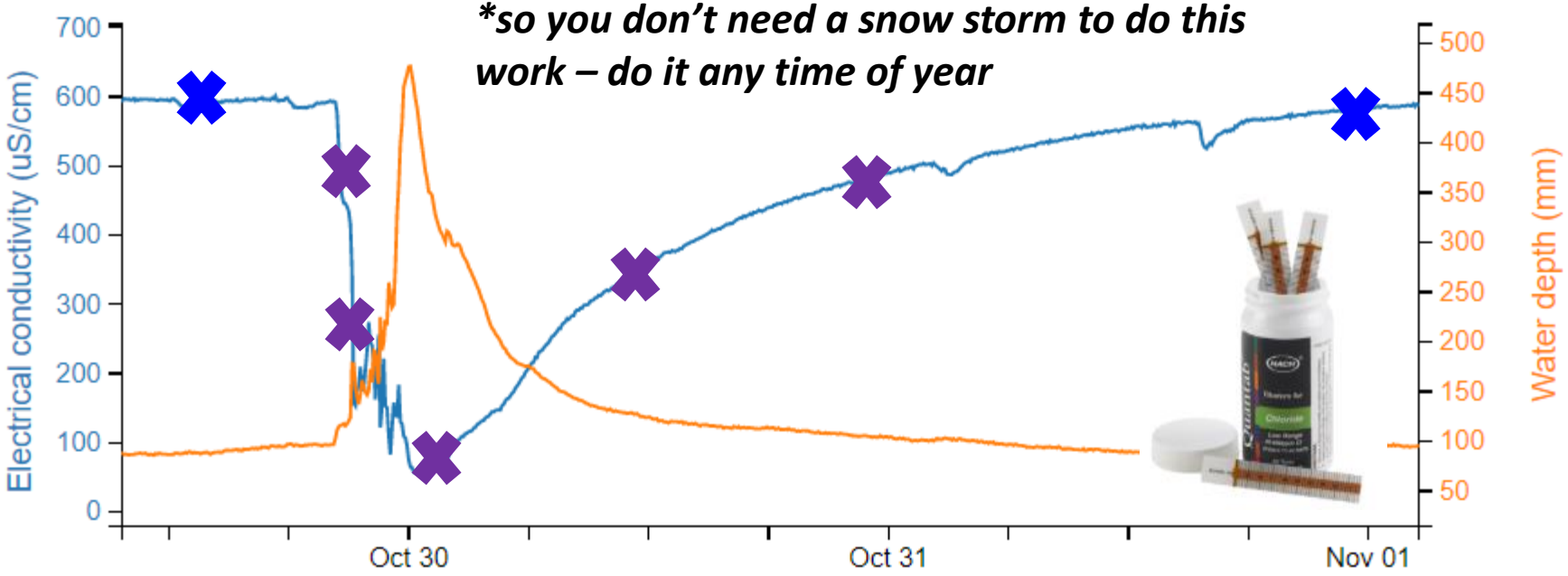


https://monitormywatershed.org/sites/PUCC2S/

When to measure:

- ✖ During storms when conductivity levels are reduced (i.e., stream water is diluted)
  - ✖ Can get baseflow around this time too

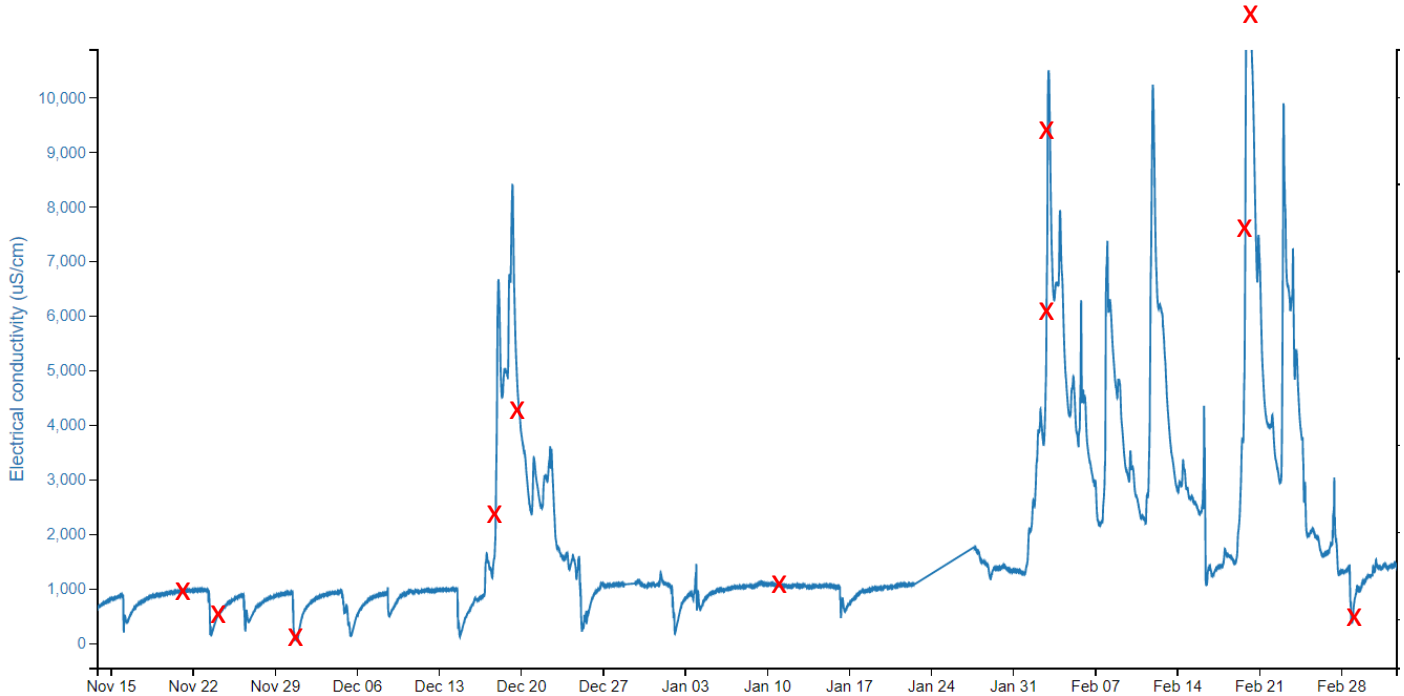
***so you don't need a snow storm to do this work – do it any time of year**



https://monitormywatershed.org/sites/BCPR8S/

When to measure:

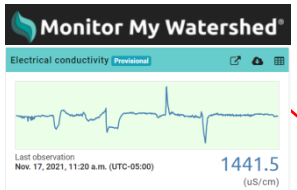
- Remember you can do it over time, multiple events



https://monitormywatershed.org/sites/BCGC1S/

Doing the measurements:

1. Measure conductivity via:
   a) Monitor My Watershed (EnviroDIY station) real time data OR
   b) Calibrated handheld conductivity meter
2. Record conductivity measurement and associated info
3. Measure chloride using Hach test strip according to manufacturer directions
4. Record chloride measurement and associated info



OR

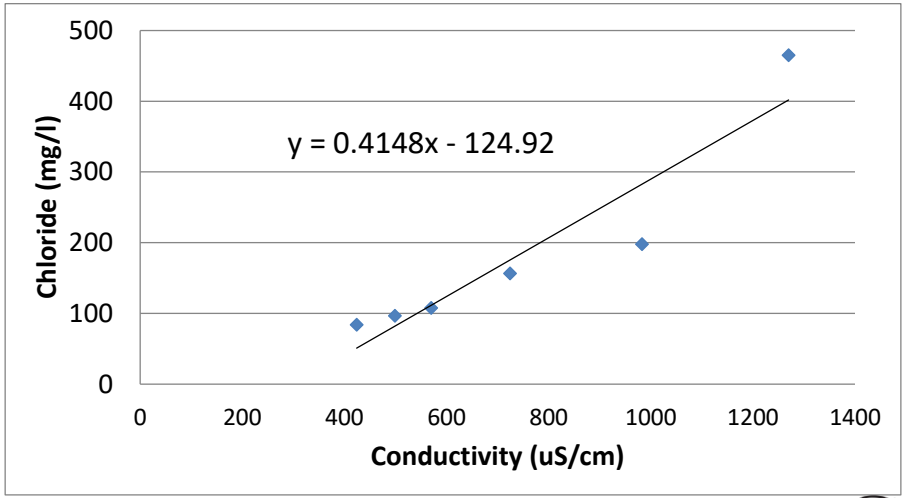
Conductivity/Chloride Rating Curve Sampling Sheet

Site ID:							
Stream:							
Location:							
Conductivity			Chloride			Conductivity method, e.g., continuous data station or hand-held meter	Chloride method, e.g., Cl test strips
Date	Time	Conductivity (uS/cm)	Date	Time	Chloride (mg/l)		

Creating the rating curve:

- Enter values from Conductivity/Chloride Rating Curve Sampling Sheet into Excel (can use electronic version of data sheet)
- Graph conductivity on the x-axis and chloride on the y-axis
- Add trend line and display equation

Conductivity (uS/cm)	Chloride (mg/l)
424	83
499	96
570	107
983	198
725	156
1270	465



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Using the rating curve:

- Use equation to convert conductivity data to chloride

C2 | f_x | =0.4148*B2 - 124.92

	A	B	C
1	DateTime	Conductivity (uS/cm)	Chloride (mg/l)
2	10/13/21 9:15	1400.3	456
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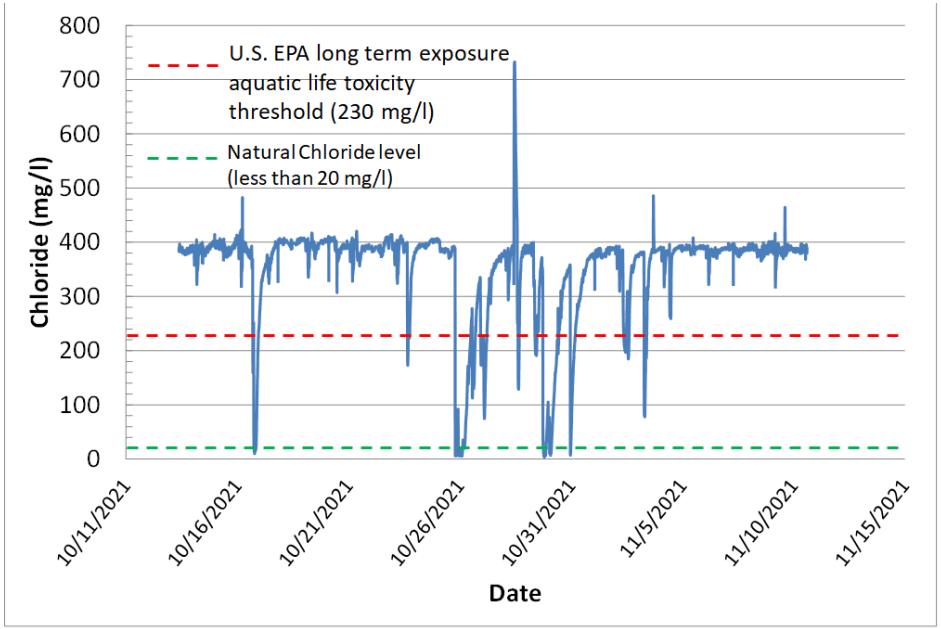

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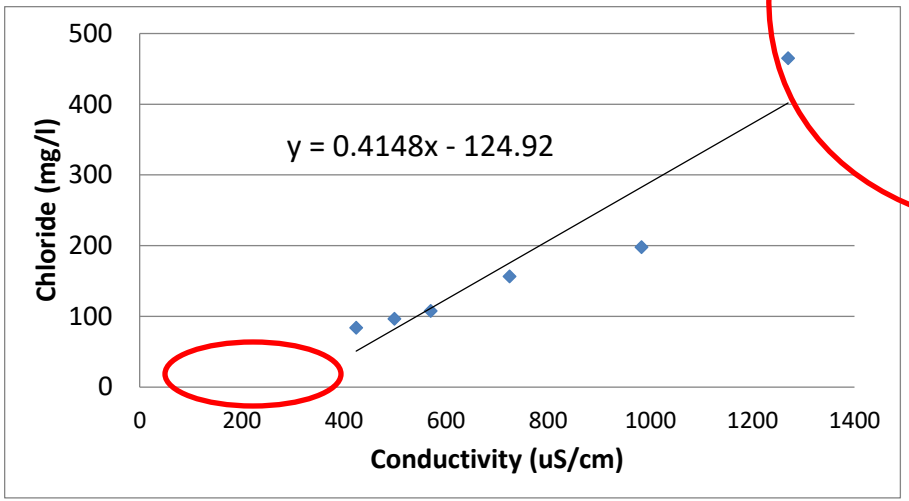
Example real-data rating curve



Maximum conductivity at this site ~7000 uS/cm
Minimum conductivity at this site ~10 uS/cm

Ideally, the rating curve covers that entire range – for a more complete curve should have more samples during salt flush and dilution events

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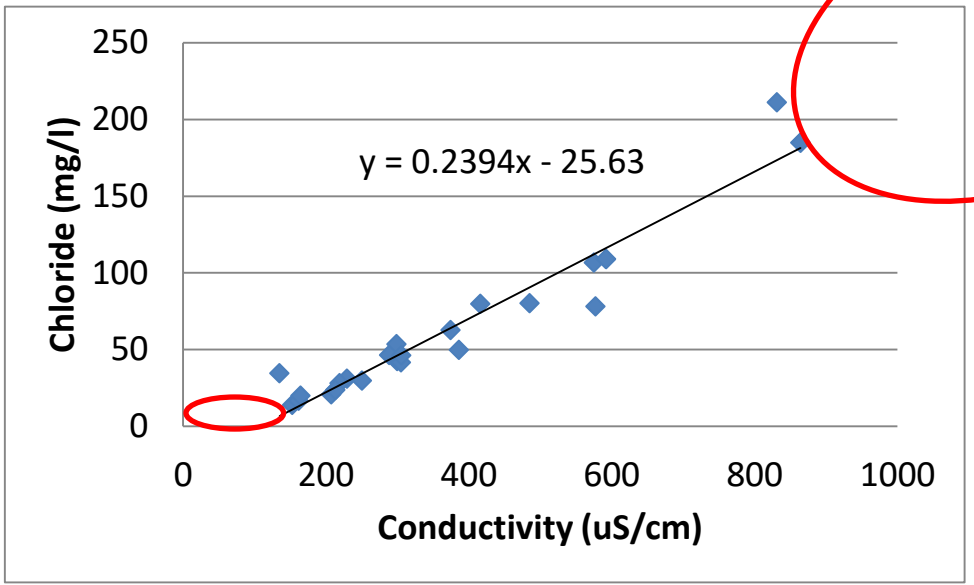
Example real-data rating curve



Max conductivity at this site ~1500 uS/cm
Minimum conductivity at this site ~60 uS/cm

This rating curve gets fairly close to that range

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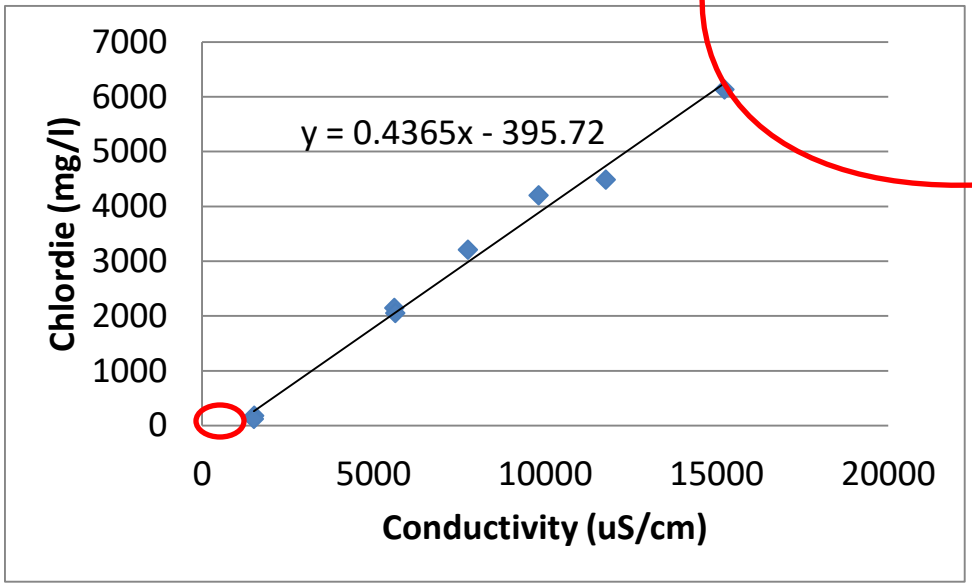
Example real-data rating curve



Max conductivity at this site ~40,000 uS/cm
Minimum conductivity at this site ~30 uS/cm

This rating curve gets close to that range, but need samples during dilution events (low end) and in severe salt flush events (high end)

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Federal and state chloride toxicity criteria:

Organization and standard	Natural Chloride Level (mg/l)	
	5-15	
	Chronic/Long-Term Threshold (mg/l)	Acute/Short-Term Threshold (mg/l)
U.S. EPA Aquatic Life	230	860
U.S. EPA Secondary Drinking Water	250	
Michigan Surface Water Quality	150	640
Canadian Council of Ministers of the Environment	120	640
New York Ambient Water Quality	250	
Delaware River Basin Commission, Delaware River Zone 3	180	
Delaware River Basin Commission, Delaware River Zone 2	50	
Maryland Dept of Environment, MD Bio Stressor ID Process	50	

- When chloride exceeds any of these threshold it is evidence that salt is creating conditions that are stressful/lethal

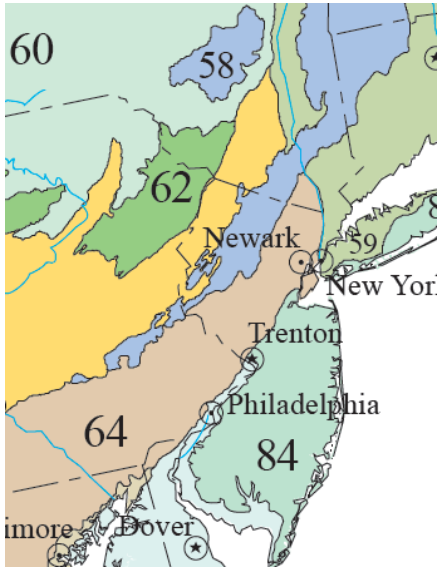
Are thresholds the whole answer?

- Does crossing a threshold mean dramatic things will happen?
- Extirpation, gradual decline, a gradient stressfulness , Moore et al. 2020:
  - "Substantial changes in macroinvertebrate and fish communities have been observed at chloride concentrations of approximately **50-90** (Morgan et al, 2012) and **33-108 mg/L** (Wallace, et al. 2016), respectively…"

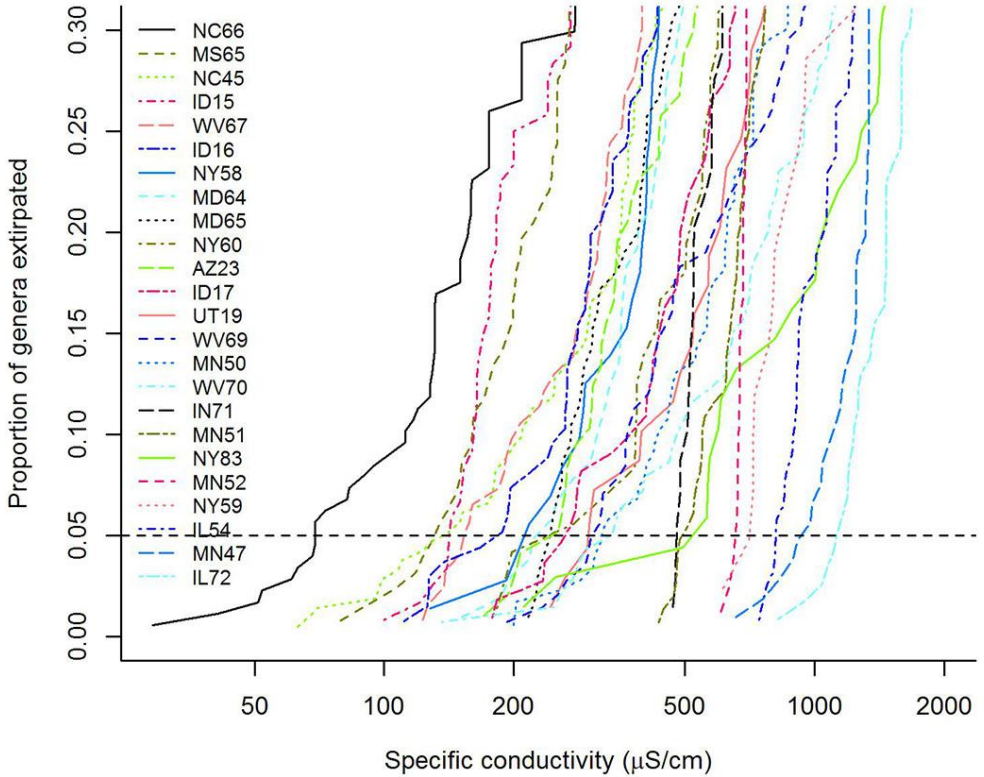
Why are there thresholds?

- Extirpation, gradual decline, a gradient stressfulness , Moore et al. 2020:
  - "Additionally, recent studies suggest that the **current EPA chloride criteria may be insufficient** for the protection of sensitive freshwater organisms…" (Cormier et al 2013, Pond et al 2017, Cormier et al 2018, Brown et al 2015, Elphick et al 2011)
    - EPA chronic = 230 mg/l; acute = 860 mg/l

Extirpation



Level III Ecoregions



Cormier, S. M.; Zheng, L.; Flaherty, C. M. A Field-Based Model of the Relationship between Extirpation of Salt-Intolerant Benthic Invertebrates and Background Conductivity. Sci. Total Environ. 2018, 633, 1629−1636.

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Harm to biota

- SUMMER BASEFLOW IS IMPORTANT – warmer water makes salt much more toxic
  - Salt shown to be far more toxic to mayflies at 20degC than at 10 degC (Jackson and Funk, 2019)
  - 456 mg/l Chloride (767 mg/l NaCl) at 20 degC (68 degF) over 96 hrs killed **half** the *Procloeon fragile* (a mayfly)(LC_{50})
    - This is acute toxicity – chronic stress due to lower salt levels also causes extirpation

For context: 767 mg/l NaCl = 0.5 teaspoon NaCl per gallon of water

Harm to biota

Leptophlebiidae: *Leptophlebia cupida*

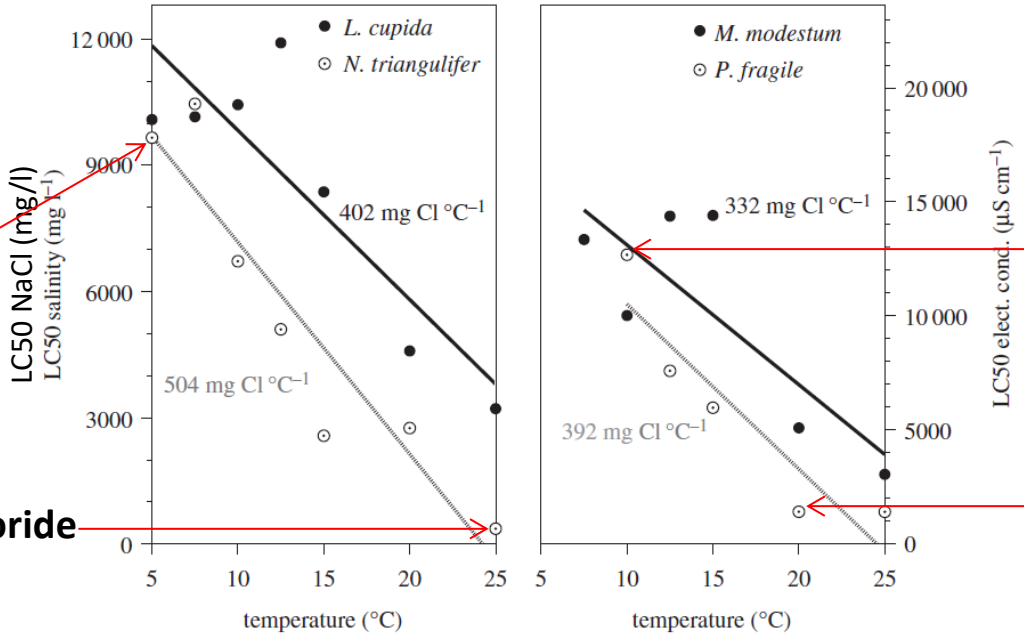
Baetidae: *Neocloeon triangulifer*

Heptageniidae: *Maccaffertium modestum*

Baetidae: *Procloeon fragile*

5857 mg/l Chloride
17829 uS/cm

221 mg/l Chloride
698 uS/cm



4170 mg/l Chloride
12700 uS/cm

465 mg/l Chloride
1447 uS/cm

**Short term (4-day average) toxicity shown here – consider how these salt levels might affect bug communities when they're at these levels all the time or for much longer periods*

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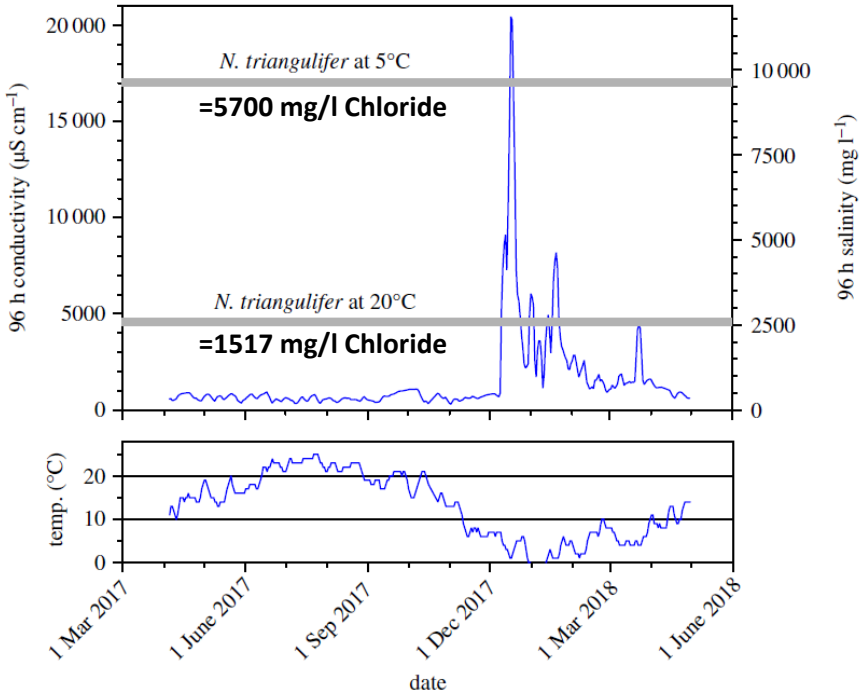
Photos: http://www.troutnut.com/; https://www.usgs.gov/media/; https://bugguide.net/; https://www.discoverlife.org/

Harm to biota

- WINTER SPIKES ARE IMPORTANT
  - Spikes in urban areas are often exceeding acute Cl thresholds
  - If there are spikes then it's likely groundwater is becoming increasingly contaminated
    - i.e., baseflow chloride is increasing as more spikes happen (Moore et al. 2020)



Jackson and Funk, 2019

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Step-by-step instructions

Will be posted at https://wikiwatershed.org/drwi/

Instructions for developing Conductivity-Chloride Rating curves

Method Overview:

1. Measure and record conductivity and chloride during: 1) baseflow, 2) salt spikes, 3) dilution events.
2. Plot range of conductivity and chloride values as a scatterplot in Excel (or other graphing program).
3. Fit a curve to the scatterplot and display the curve equation.
4. Use curve equation to convert continuous conductivity data to chloride OR to simply add context to future conductivity measurements.

What you'll need:

Specific to this work	General

• Conductivity-Chloride Rating Curve Sampling Sheet
• Chloride QuanTab® Test Strips: Low range 30-600 mg/L and High range 300-6000 mg/L
• Smartphone (to access Monitor My Watershed) OR calibrated handheld Conductivity meter
• Sensor brush (if using EnviroDIY station for conductivity data)
	• Waders or knee boots
	• Clipboard
	• Pencils
	• Other supplementary items
	  ○ Camera
	  ○ First Aid kit

Where to sample:

- At an EnviroDIY continuous monitoring station.
- At a USGS continuous monitoring station.
- Anywhere you want (exclude step 4)

When to collect samples:

- At baseflow when conductivity is at its usual level.

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Stroud Center support

- If you would like to do this Stroud Center can provide Chloride strips
- Please keep us in the loop – we are looking for as many curves as possible from different streams

Jackson and Funk, 2019

Citations

- Moore J, Fanelli RM, Sekellick AJ. 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. Environ Sci Technol. 2020 Jan 21;54(2):778-789. doi: 10.1021/acs.est.9b04316. Epub 2019 Dec 31. PMID: 31845802.
- Morgan, R. P.; Kline, K. M.; Kline, M. J.; Cushman, S. F.; Sell, M. T.; Weitzell, R. E., Jr; Churchill, J. B. Stream Conductivity: Relationships to Land Use, Chloride, and Fishes in Maryland Streams. N. Am. J. Fish Manage. 2012, 32, 941−952.
- Wallace, A. M.; Biastoch, R. G. Detecting Changes in the Benthic Invertebrate Community in Response to Increasing Chloride in Streams in Toronto, Canada. Freshwater Sci. 2016, 35, 353−363.
- Cormier, S. M.; Suter, G. W.; Zheng, L.; Pond, G. J. Assessing Causation of the Extirpation of Stream Macroinvertebrates by a Mixture of Ions. Environ. Toxicol. Chem. 2013, 32, 277−287.
- Pond, G. J.; Krock, K. J. G.; Cruz, J. V.; Ettema, L. F. Effort-Based Predictors of Headwater Stream Conditions: Comparing the Proximity of Land Use Pressures and Instream Stressors on Macroinvertebrate Assemblages. Aquat. Sci. 2017, 79, 765−781.
- Cormier, S. M.; Zheng, L.; Flaherty, C. M. A Field-Based Model of the Relationship between Extirpation of Salt-Intolerant Benthic Invertebrates and Background Conductivity. Sci. Total Environ. 2018, 633, 1629−1636.
- Brown, A. H.; Yan, N. D. Food Quantity Affects the Sensitivity of Daphnia to Road Salt. Environ. Sci. Technol. 2015, 49, 4673−4680.
- Elphick, J. R.; Bergh, K. D.; Bailey, H. C. Chronic Toxicity of Chloride to Freshwater Species: Effects of Hardness and Implications for Water Quality Guidelines. Environ. Toxicol. Chem. 2011, 30, 239−246.
- Jackson JK, Funk DH. 2019. Temperature affects acute mayfly responses to elevated salinity: implications for toxicity of road de-icing salts. Phil. Trans. R. Soc. B 374:20180081. http://dx.doi.org/10.1098/rstb.2018.0081

Thanks, questions?

- Contact:
  - Dave Bressler, dbressler@stroudcenter.org, 410-456-1071, 610-268-2153 ext 1312
  - John Jackson, jkjackson@stroudcenter.org, 610-268-2153 ext 1226