Overview of OWML's National Science Foundation Project

Stanley Grant, Co-Director Occoquan Watershed Monitoring Laboratory

09/11/20

Outline

- National Perspective on Freshwater Salinization
- New National Science Foundation (NSF) Growing Convergence Research (GCR) Project
- Next Up—NSF Engineering Research Center (ERC) Pre-Proposal

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- **National Perspective on Freshwater Salinization**
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Freshwater salinization syndrome on a continental scale

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Contributed by Gene E. Likens, November 30, 2017 (sent for review June 28, 2017; reviewed by Jacqueline A. Aitkenhead-Peterson, W. Berry Lyons, Diane M. McKnight, and Matthew Miller)

Salt pollution and human-accelerated weathering are shifting the chemical composition of major ions in fresh water and increasing salinization and alkalinization across North America. We propose a concept, the freshwater salinization syndrome, which links salinization and alkalinization processes. This syndrome manifests as concurrent trends in specific conductance, pH, alkalinity, and base cations. Although individual trends can vary in strength, changes in salinization and alkalinization have affected 37% and 90%, respectively, of the drainage area of the contiguous United States over the past century. Across 232 United States Geological Survey (USGS) monitoring sites, 66% of stream and river sites showed a statistical increase in pH, which often began decades before acid rain regulations. The syndrome is most prominent in the densely populated eastern and midwestern United States, where salinity and alkalinity have increased most rapidly. The syndrome is caused by salt pollution (e.g., road deicers, irrigation runoff, sewage, potash), accelerated weathering and soil cation exchange, mining and resource extraction, and the presence of easily weathered minerals used in agriculture (lime) and urbanization (concrete). Increasing salts with strong bases and carbonates elevate acid neutralizing capacity and pH, and increasing sodium from salt pollution eventually displaces base cations on soil exchange sites, which further increases pH and alkalinization. Symptoms of the syndrome can include: infrastructure corrosion, contaminant mobilization, and variations in coastal ocean acidification caused by increasingly alkaline river inputs. Unless regulated and managed, the freshwater salinization syndrome can have significant impacts on ecosystem services such as safe drinking water, contaminant retention, and biodiversity.

emerging contaminants | drinking water | land use | anthropocene | carbon cycle

The abundance, integrity, and distribution of Earth's fresh water are critical for human welfare. Only 2.5% of Earth's water is fresh, and dissolved salts within this water determine the degree to which it can be used for drinking, industry, agriculture, and energy production (1, 2). The primary causes of freshwater salinization around the world are agriculture, resource extraction, and land clearing (3, 4). Relatively recently, human salt inputs are increasingly becoming recognized as important over large geographic scales (5, 6). Alkalinization has received relatively less recognition as a related environmental issue, but increases in alkalinity are also generated by salt pollution, accelerated weathering, and microbial processes that influence water chemistry (7). Salinization and alkalinization of fresh water can be interconnected processes that deteriorate water quality over a range of climates, but it is typically assumed that these processes are related only in arid regions (6–9). In particular, increasing concentrations of dissolved salts with strong bases and carbonates can increase the pH of fresh water over time, linking salinization to alkalinization.

We propose a concept, the freshwater salinization syndrome, which links salinization and alkalinization processes along hydrologic flow paths from small watersheds to coastal waters. The freshwater salinization syndrome manifests to varying degrees as concurrent trends in specific conductance, pH, alkalinity, and base cations (i.e., sodium, calcium, magnesium, and potassium). There are at least three primary categories of salt sources driving the freshwater salinization syndrome: (*i*) anthropogenic salt inputs (e.g., road salts, sewage, brines, sodic/saline irrigation runoff); (*ii*) accelerated weathering of natural geologic materials by strong acids (e.g., acid rain, fertilizers, and acid mine drainage); and (*iii*) human uses of easily weathered resource materials (e.g., concrete, lime), which cause increases in salts with strong bases and carbonates (6, 9–13). Although previous work has focused primarily on sodium chloride as a dominant form of salt pollution, increases in different mixtures of salt ions such as sodium, bicarbonate, magnesium, sulfate, etc., as part of the freshwater salinization syndrome produce differential toxicity to aquatic life (14, 15), and further supports the need for studying the dynamics of dissolved salts holistically. Although environmental impacts of the freshwater salinization syndrome are still poorly understood, symptoms can include: changes in biodiversity due to osmotic stress and desiccation, corrosion of infrastructure, increased contaminant mobilization, enhanced river carbonate transport, and impacts on coastal ocean acidification caused by increasingly alkaline river inputs.

Over geologic time, salinization and alkalinization of water have naturally influenced the distribution and abundance of Earth's life (16). However, rates of salinization and alkalinization in the Anthropocene are strongly influenced by three primary

Significance

Salinization and alkalinization impact water quality, but these processes have been studied separately, except in arid regions. Globally, salinization has been largely attributed to agriculture, resource extraction, and land clearing. Alkalinization has been attributed to recovery from acidification, with less recognition as an environmental issue. We show that salinization and alkalinization are linked, and trends in these processes impact most of the drainage area of the United States. Increases in salinity and alkalinity are caused by inputs of salts containing strong bases and carbonates that originate from anthropogenic sources and accelerated weathering. We develop a conceptual model unifying our understanding of salinization and alkalinization and its drivers and impacts on fresh water in North America over the past century.

Author contributions: S.S.K., G.E.L., and M.L.P. designed research; S.S.K., R.M.U., S.H., J.G., and M.G. performed research; R.M.U., S.H., J.G., and M.G. contributed new reagents/analytic tools; S.S.K., R.M.U., S.H., J.G., and M.G. analyzed data; and S.S.K., G.E.L., M.L.P., R.M.U., S.H., J.G., and M.G. wrote the paper.

Reviewers: J.A.A.-P., Texas A&M University; W.B.L., The Ohio State University; D.M.M., University of Colorado; and M.M., USGS.

The authors declare no conflict of interest.

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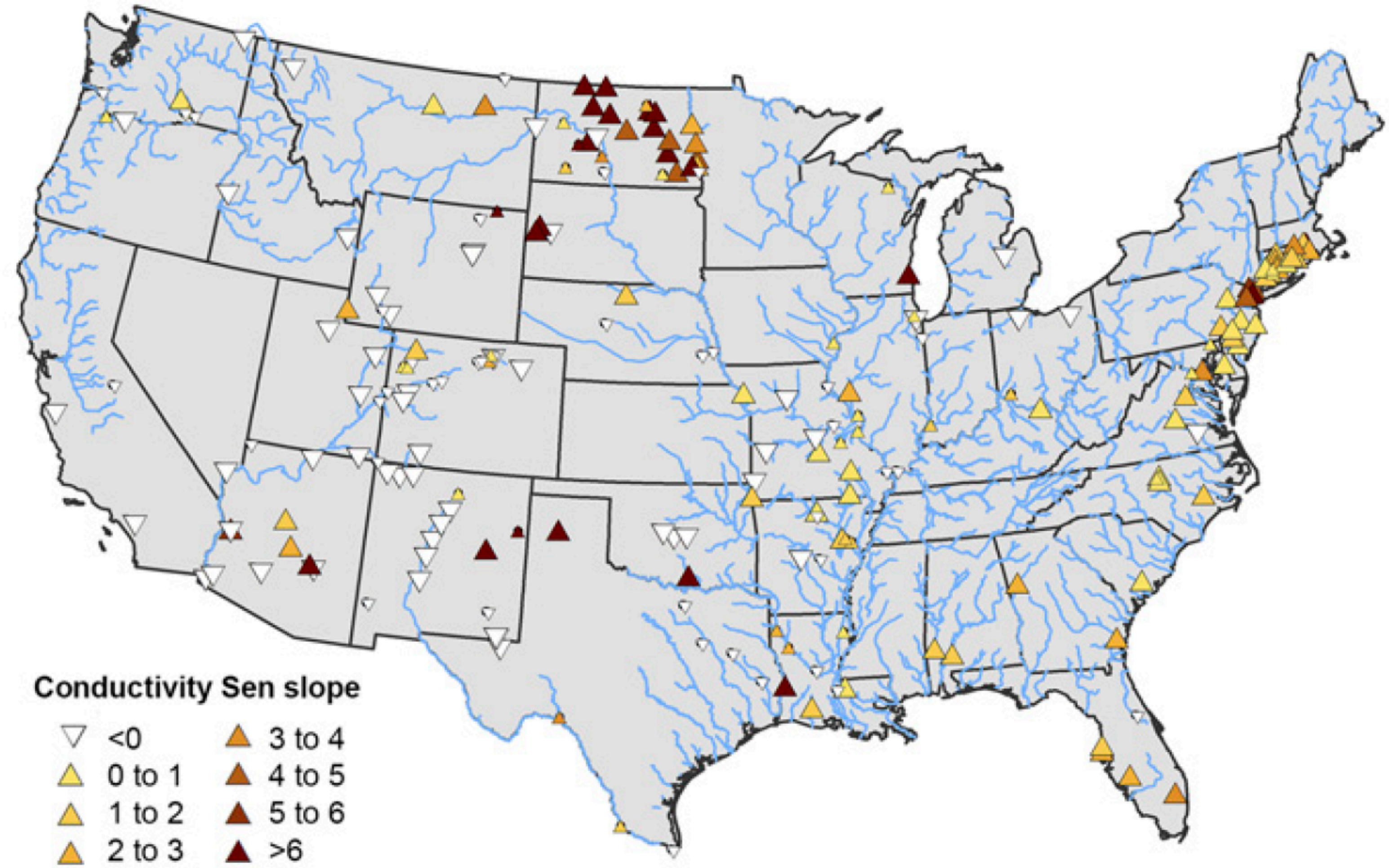
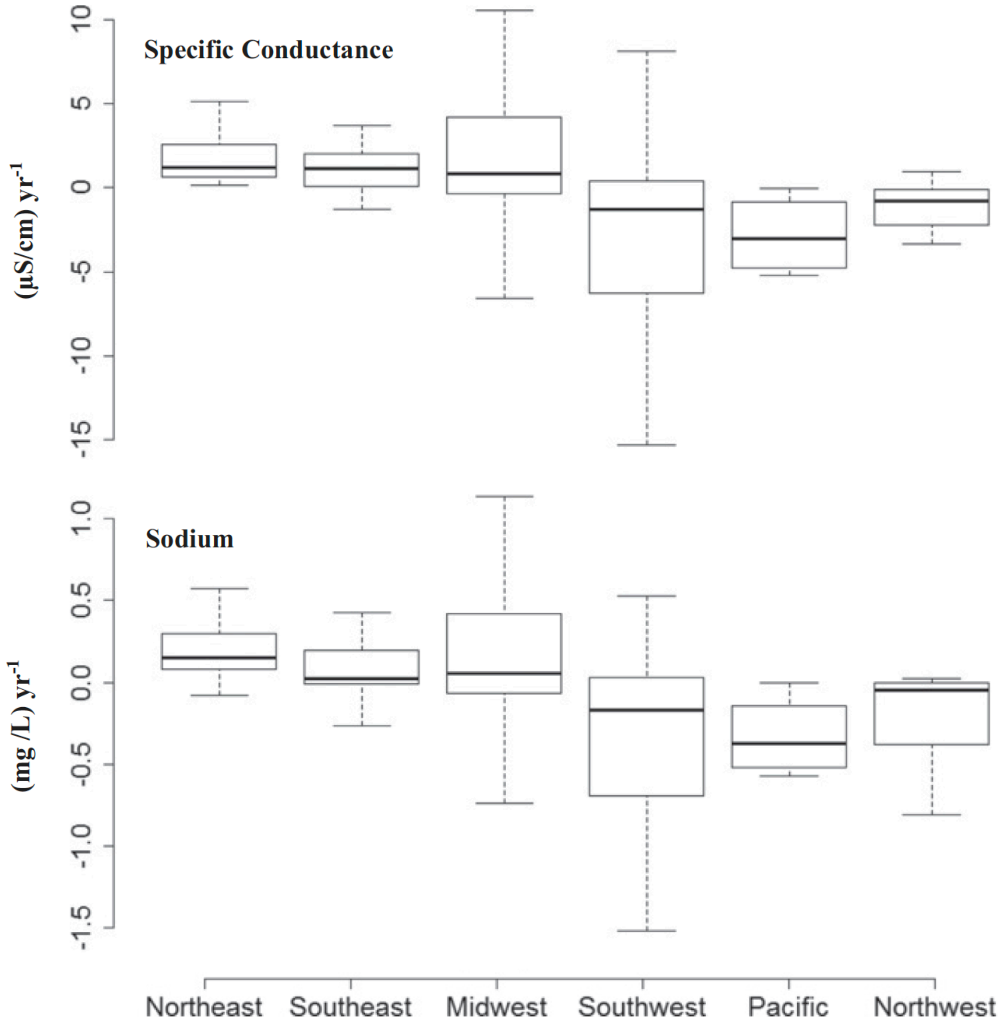
This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1711234115/-/DCSupplemental.

Conductivity Trends (232 USGS Monitoring Sites)



Kaushal et al. (2018) "Freshwater salinization on a continental scale" Proceedings of the National Academy of Sciences (PNAS), USA 115, E574-E583.

Conductivity and Sodium Trends



Kaushal et al. (2018) “Freshwater salinization on a continental scale” Proceedings of the National Academy of Sciences (PNAS), USA 115, E574-E583.

Environmental Science & Technology

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Landscape Drivers of Dynamic Change in Water Quality of U.S. Rivers

Edward G. Stets,* Lori A. Sprague, Gretchen P. Oelsner, Hank M. Johnson, Jennifer C. Murphy, Karen Ryberg, Aldo V. Vecchia, Robert E. Zuellig, James A. Falcone, and Melissa L. Riskin

Cite This: *Environ. Sci. Technol.* 2020, 54, 4336–4343 Read Online

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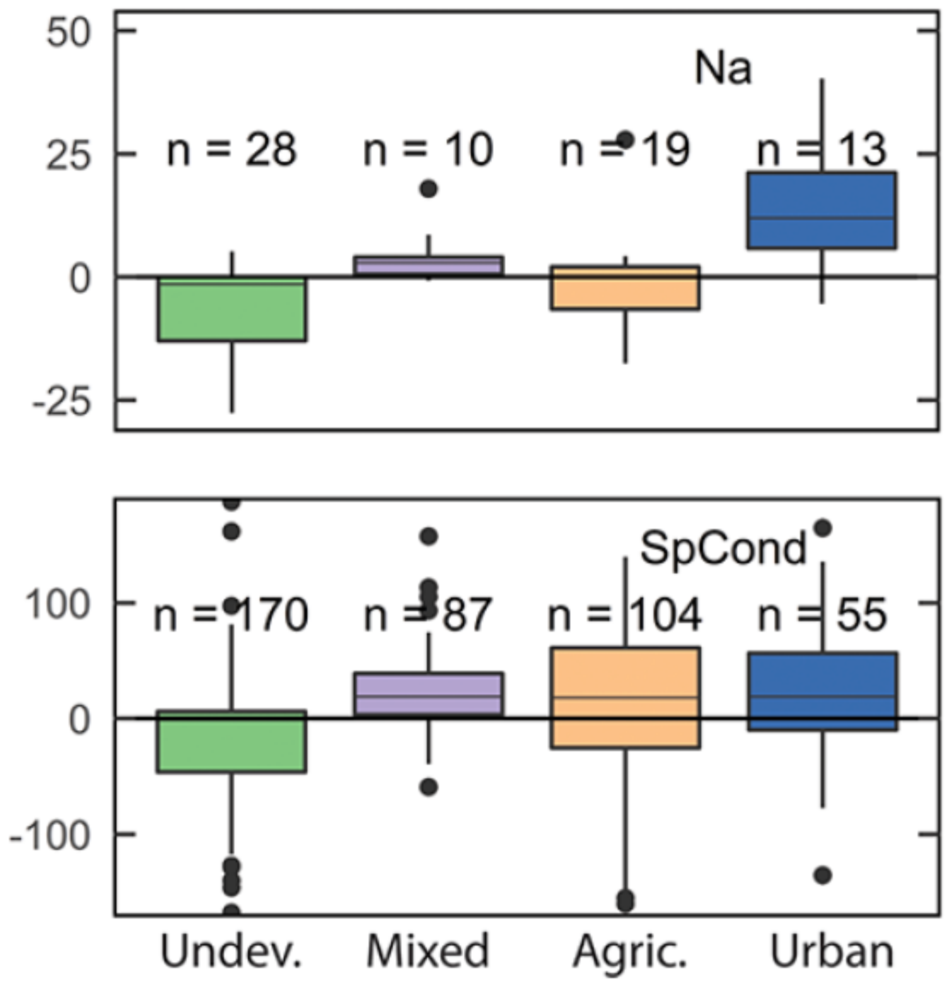
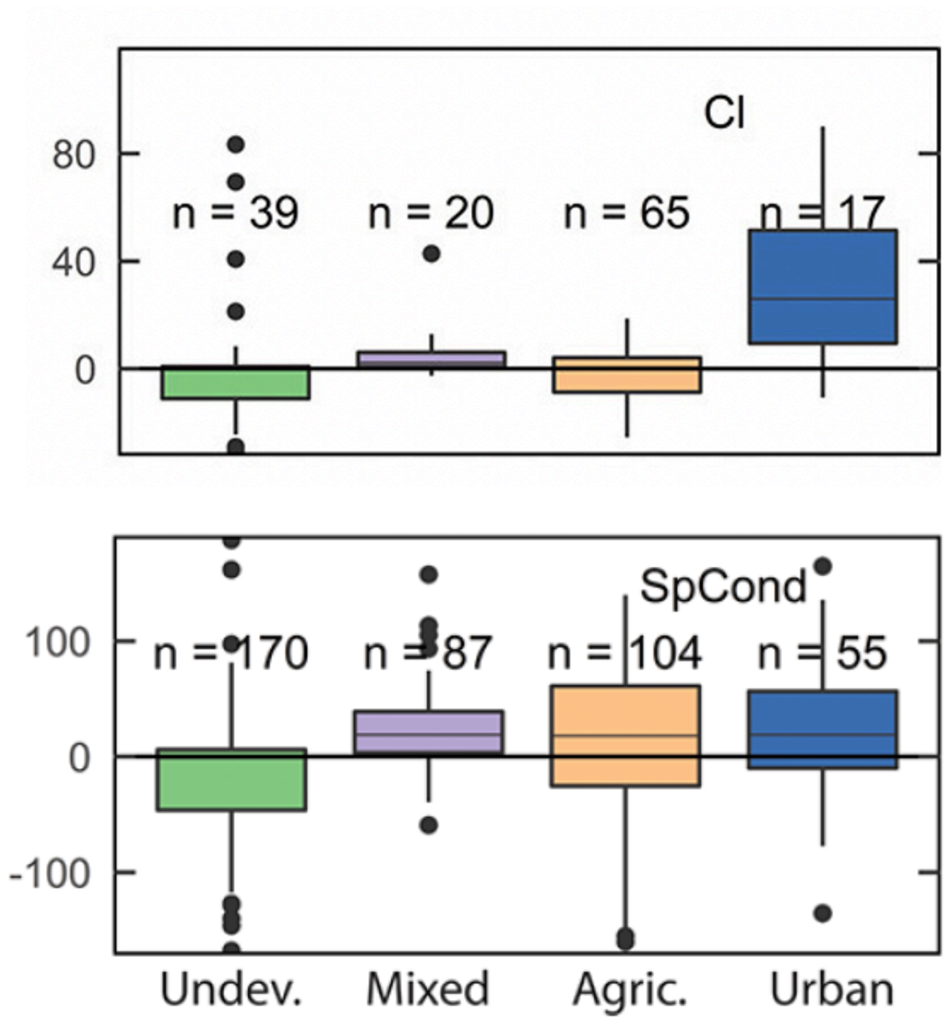
*Product of the USGS NAWQA (National Water Quality Assessment) Program
*Evaluated Trends of nutrients, major ions and sediment (~500 sites across the US)
*Reported trends are flow weighting (i.e., taking into account time varying stream flows) (Weighted Regressions on Time, Discharge and Season, WRTD) implemented in EGRET

National Trends (1992-2012)



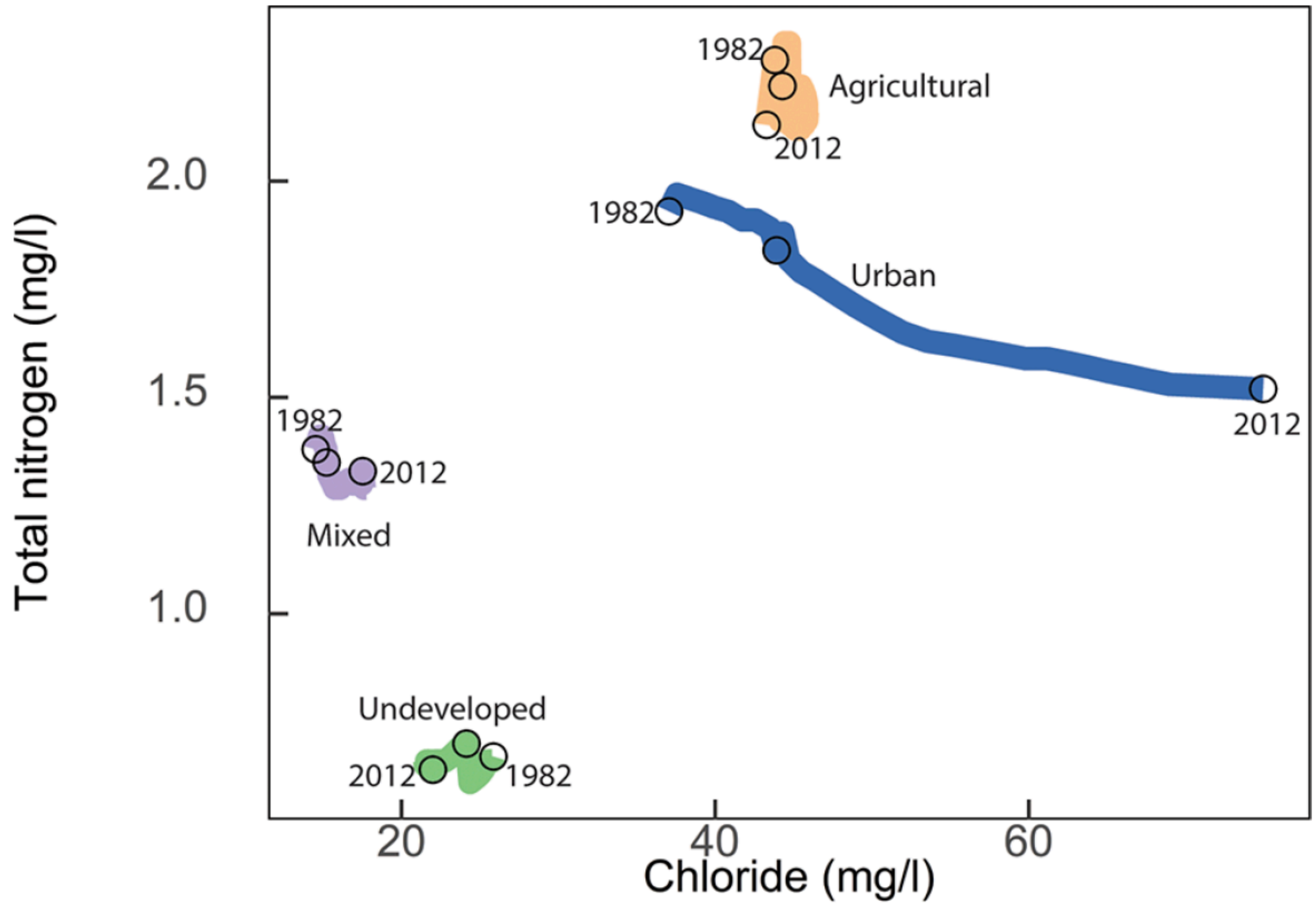
Stets et al. (2020) “Landscape drivers of dynamic change in water quality of U.S. rivers” Environmental Science and Technology, 54, 4336-4343.

National Trends (1992-2012)



Stets et al. (2020) “Landscape drivers of dynamic change in water quality of U.S. rivers” Environmental Science and Technology, 54, 4336-4343.

Marginal National Means (1982-2012)



Stets et al. (2020) "Landscape drivers of dynamic change in water quality of U.S. rivers" Environmental Science and Technology, 54, 4336-4343.

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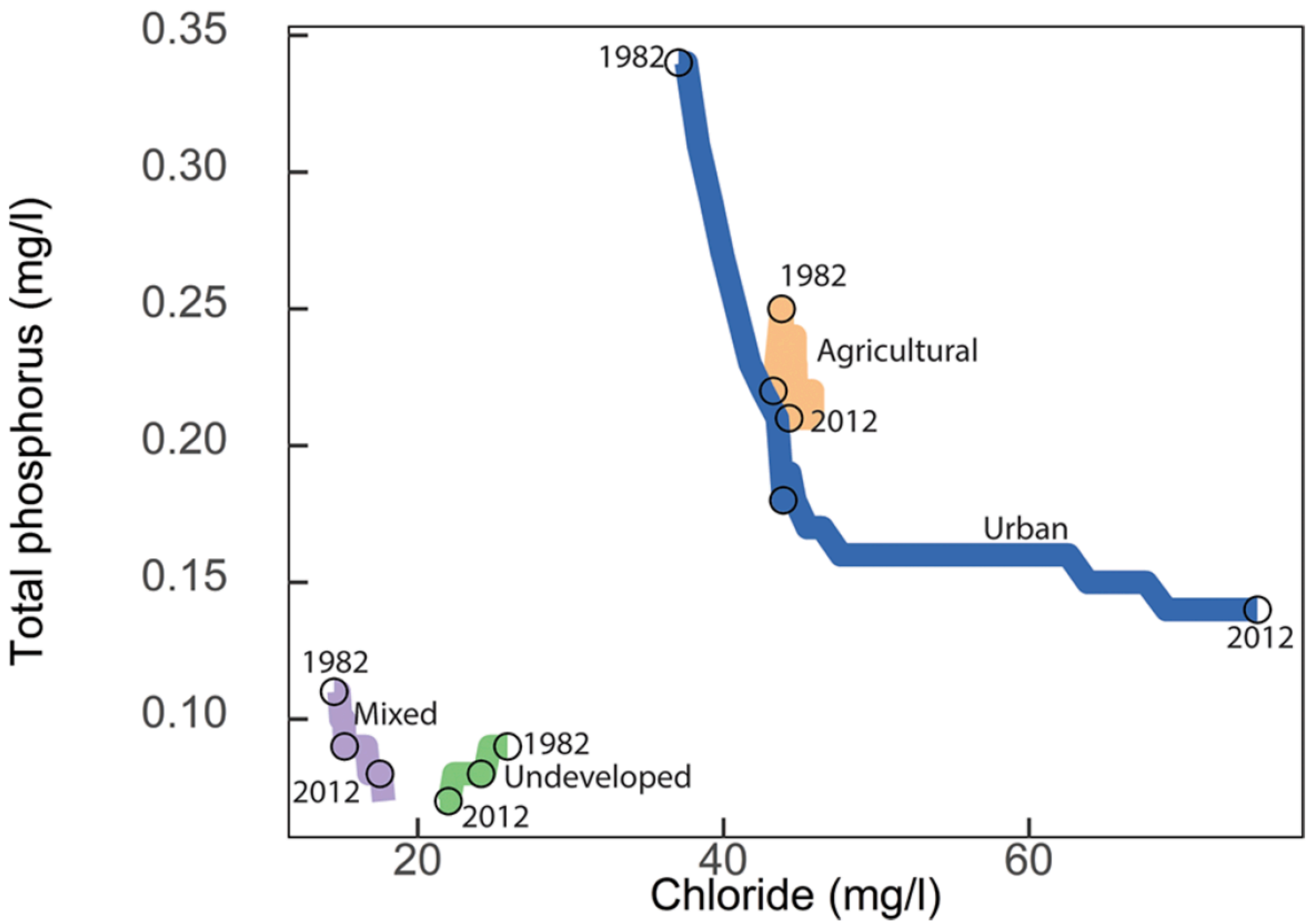


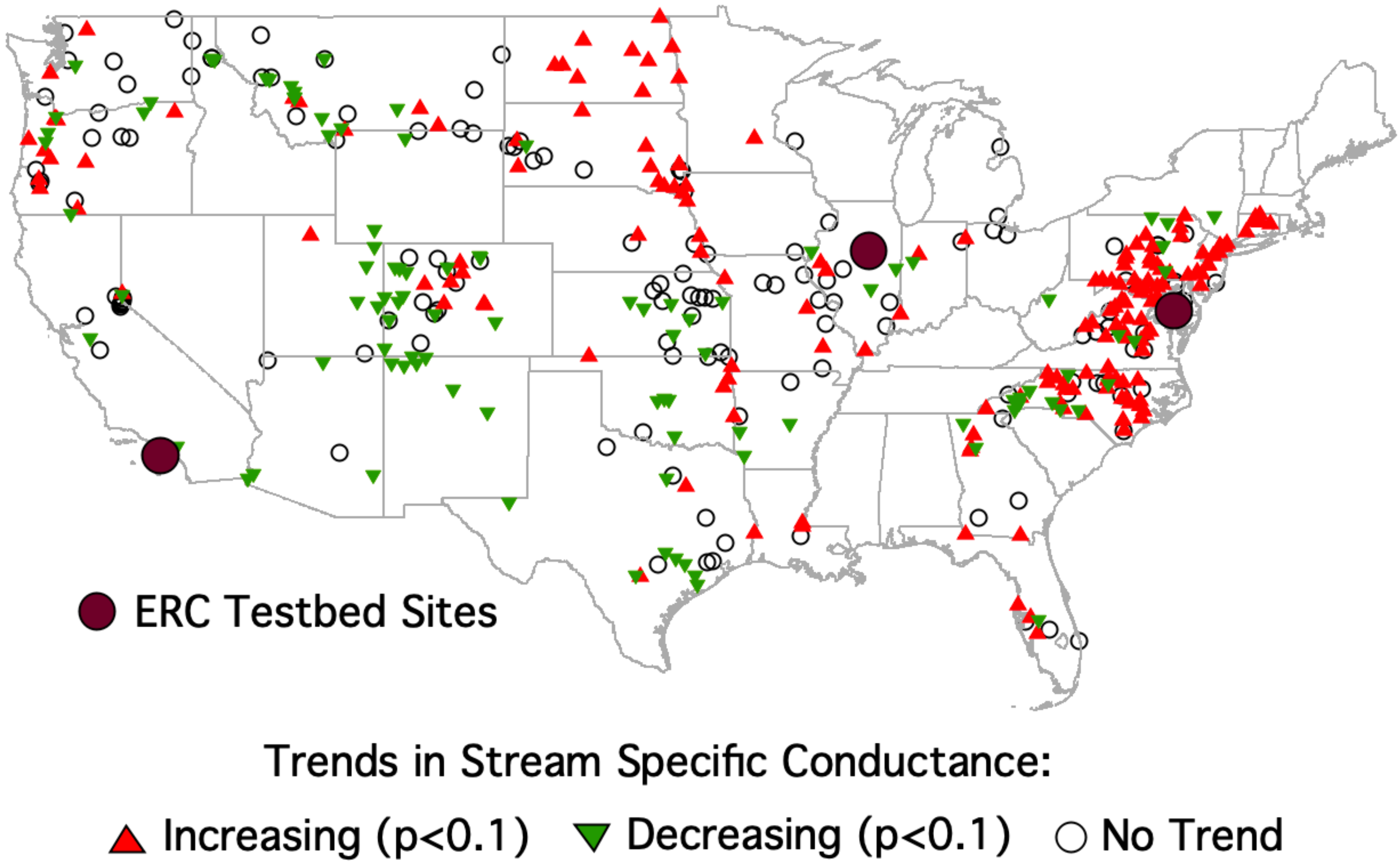
Stets et al. (2020) "Landscape drivers of dynamic change in water quality of U.S. rivers" Environmental Science and Technology, 54, 4336-4343.

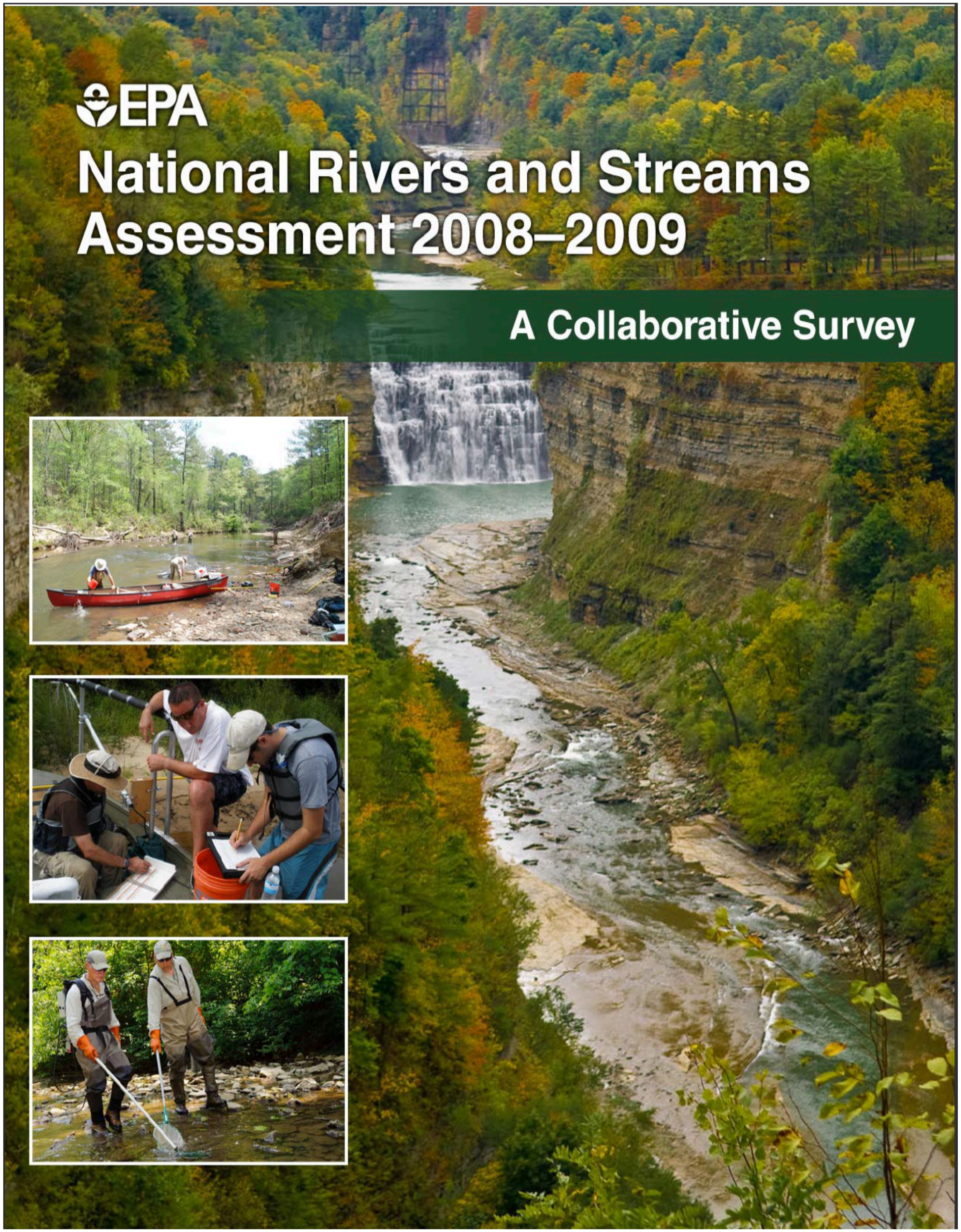
Winning the battle losing the war?

While many of our nation's streams and rivers carry less nutrients and suspended solids today than they did 20 or 30 years ago, *"freshwaters are being salinized rapidly in all human-dominated land use types."*

Stets et al. (2020) "Landscape drivers of dynamic change in water quality of U.S. rivers" Environmental Science and Technology, 54, 4336-4343.

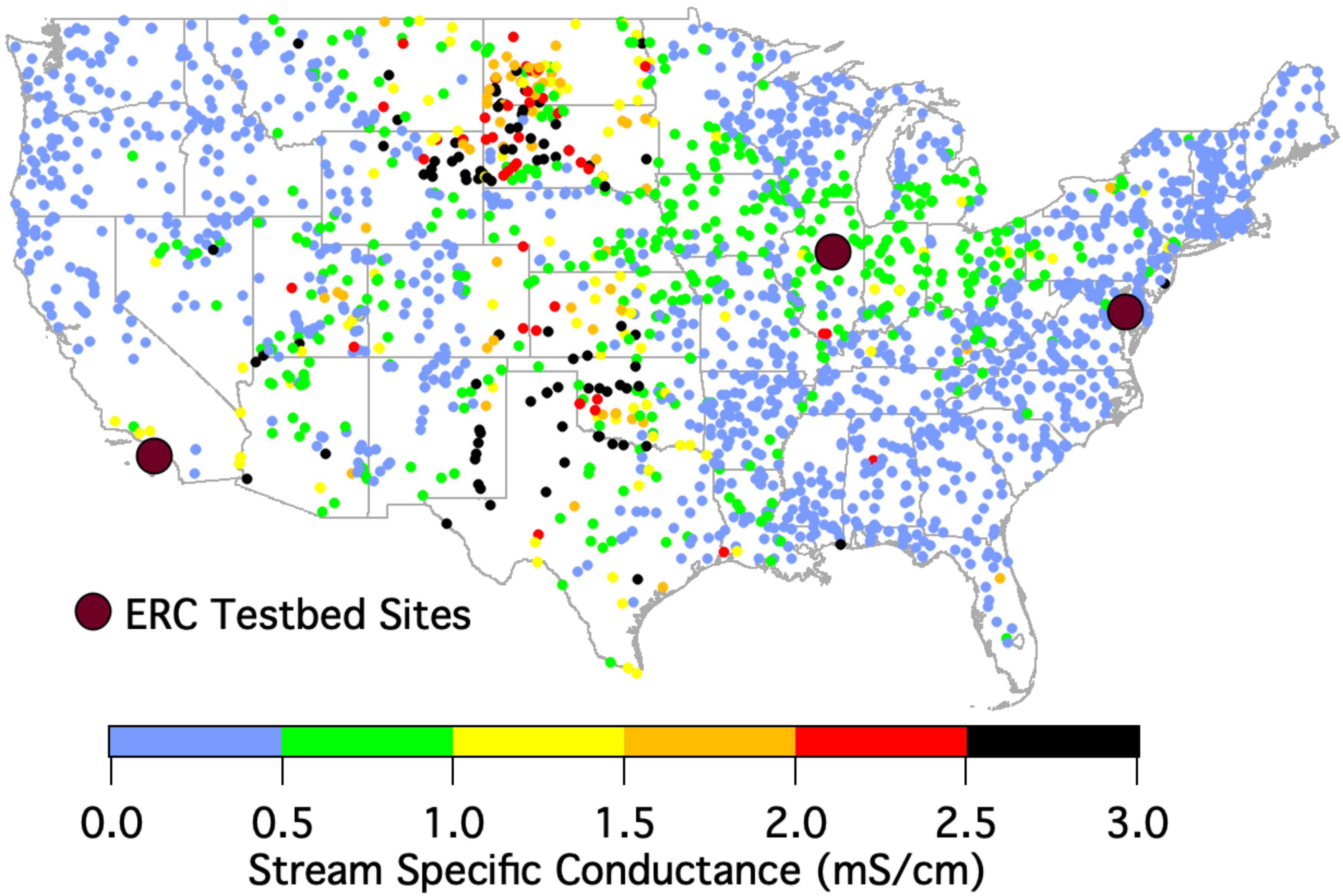
National Trend Distribution (Sp Cond)





*Sampled 1924 rivers and streams in 2008/09
*Provides a ”snapshot” of water quality status across the nation

National Patterns of Sp Cond



Winning the battle losing the war? (amended)

While many of our nation's streams and rivers carry less nutrients and suspended solids today than they did 20 or 30 years ago, *"freshwaters are being salinized rapidly in all human-dominated land use types."*

(the Mid-Atlantic and Northeast regions are "hot spots" for rising salinity (USGS NAWQA and Sujay's trend analysis) but they also have relatively low baseline salinity compared to many other parts of the US (EPA NRSA))

Stets et al. (2020) "Landscape drivers of dynamic change in water quality of U.S. rivers" Environmental Science and Technology, 54, 4336-4343.

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A New “Grant” (no, not the kind with two legs, two arms,…)

NATIONAL SCIENCE FOUNDATION

Award Notice

Award Number (FAIN): 2021015

Managing Division Abbreviation: OIA **Amendment Number:** 000

AWARDEE INFORMATION

Award Recipient: Virginia Polytechnic Institute and State University
Awardee Address: Sponsored Programs 0170 300 Turner Street NW, Suite 4200 Blacksburg, VA 240610001
Official Awardee Email Address:nsfawards@vt.edu
Unique Entity Identifier (DUNS ID): 003137015

Growing Convergence Research (GCR) Program at the National Science Foundation (NSF)

- One of NSF's "Ten Big Ideas"
- $3.6M over five years, Starts 9/1/20
- **Virginia Tech**, University of Maryland, North Carolina State University, Vanderbilt
- Focus on salt management in the Occoquan Watershed testbed

Department of Civil and Environmental Engineering, Virginia Tech

Stanley Grant
Fate/Transport
Modeling

Peter Vikesland
Environmental
Chemistry

Marc Edwards
Environmental
Chemistry

Megan Rippy
Ecological
Engineering

Department of Biology, Virginia Tech

Erin Hotchkiss
Stream Ecology/
Biogeochemistry

Department of Urban Affairs and Planning, Virginia Tech

Todd Schenk
Collaborative
Governance

Department of Geology, University of Maryland

Sujay Kaushal
Geochemistry

Department of Public Administration, NCSU

Thomas Birkland
Public Policy

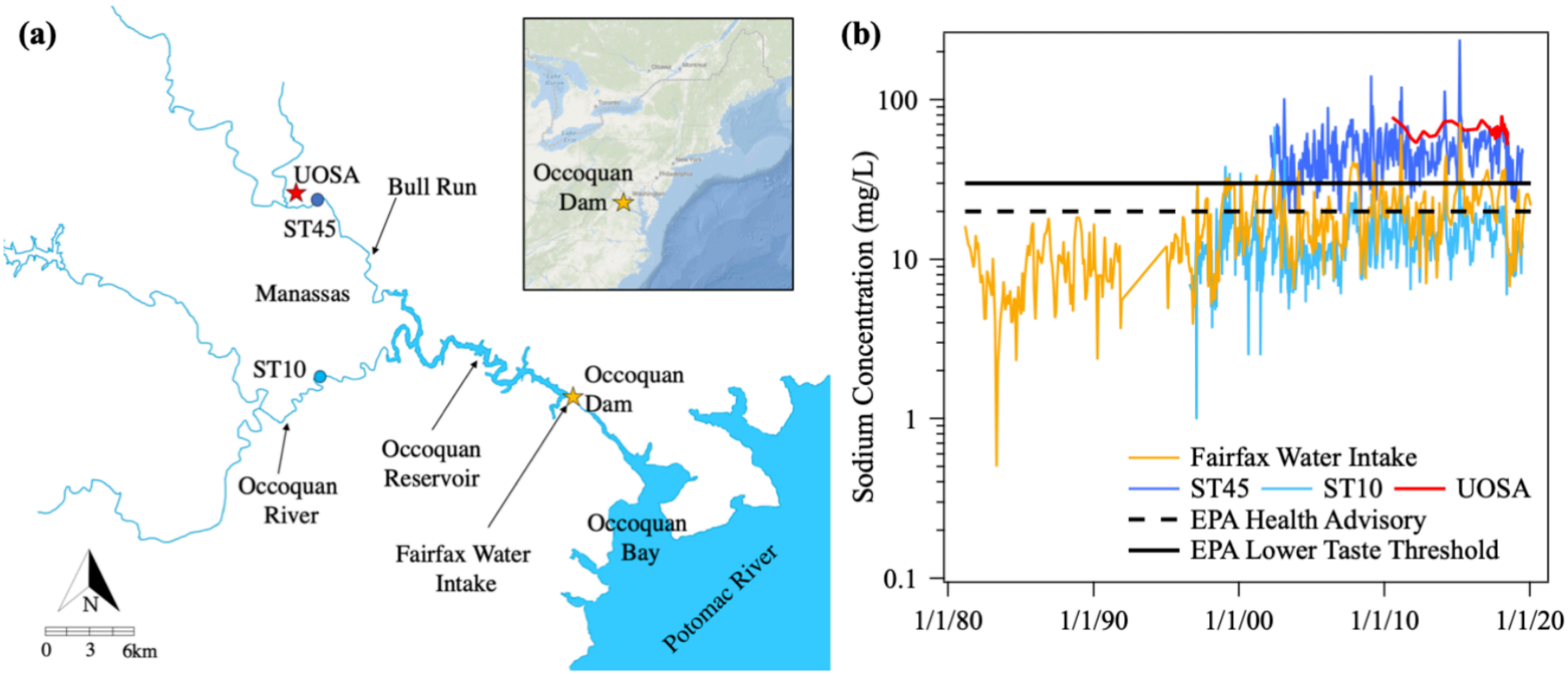
Department CEE, Vanderbilt University

Jesus (“Chucho”) Gomez-Velez
Hydrology

Policy Works, LLC

Kristin Rowles
Facilitation/Engagement

“Common Pool Resource Theory as a Scalable Framework For Catalyzing Stakeholder-Driven Solutions to the Freshwater Salinization Syndrome”



Bhide, S.V., Grant, S.B. et al, (2020) “Addressing the contribution of indirect potable reuse to inland freshwater salinization” *Nature Sustainability*, submitted

Elinor Ostrom's Common Pool Resource Theory—an answer to the 'Tragedy of the Commons'

- **Motivation**: because salinity is rising in the Occoquan Reservoir, its salt budget is out of balance
- **Goal**: to foster collaborative learning and discovery, leading to stakeholder-driven bottom-up management of the salt budget for the Occoquan Reservoir (as opposed to top-down regulatory control)

NSF Grant Timeline

- Grant Awarded 9/1/20
- Executive Committee on the Occoquan Sewershed (ECOS)
- Phase I (Y1,Y2): Contribution of UOSA to Occoquan Reservoir Salt Budget
  - Ion concentrations, loads and ratios
  - Effects of effluent on mobilization of nutrients and heavy metals, biological toxicity
  - Ion sources in the sewershed
  - Develop predictive capability—if intervention X occurs, Y response is likely
  - Iterative process—ECOS involved in formulation of research questions, research approach and interpretation of results
  - Hypothesis: process will improve common understanding and spur bottom up management interventions

NSF Grant Timeline

- Reverse Site Visit (6/2022) (full panel review at NSF)
- NSF decides whether to continue funding the project
- If so, Executive Committee on the Occoquan Watershed (ECOW)
- Phase II (Y3-Y5): Contribution of Watershed to Occoquan Reservoir Salt Budget
  - Ion concentrations, loads and ratios
  - Effects of discharges on mobilization of nutrients and heavy metals, biological toxicity
  - Ion sources in the watershed
  - Develop predictive capability—if intervention X occurs, Y response is likely
  - Iterative process—ECOW involved in formulation of research questions, research approach and interpretation of results
  - Hypothesis: process will improve common understanding and spur bottom up management interventions

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What is an National Science Foundation Engineering Research Center (NSF ERC)?

- NSF's "Grand Prize" for Engineering (program started in 1985)
- $50M from NSF over 10 years, + matching funds from university & industrial partners
- VT had one in Power Electronics (1998 to 2008), but none since (a priority for the university)
- This "Gen-4" NSF ERC competition cycle focuses on:
  - Convergent Engineering
  - Societal Grand Challenge

“Convergent Engineering”

“Integrates knowledge, tools, and ways of thinking across disciplinary boundaries…to form a synthetic framework for tackling scientific and societal challenges”

National Research Council, “Convergence: Facilitating Transdisciplinary Integration of Life Science, Physical Sciences, Engineering, and Beyond” (2014). doi: 10.17226/18722

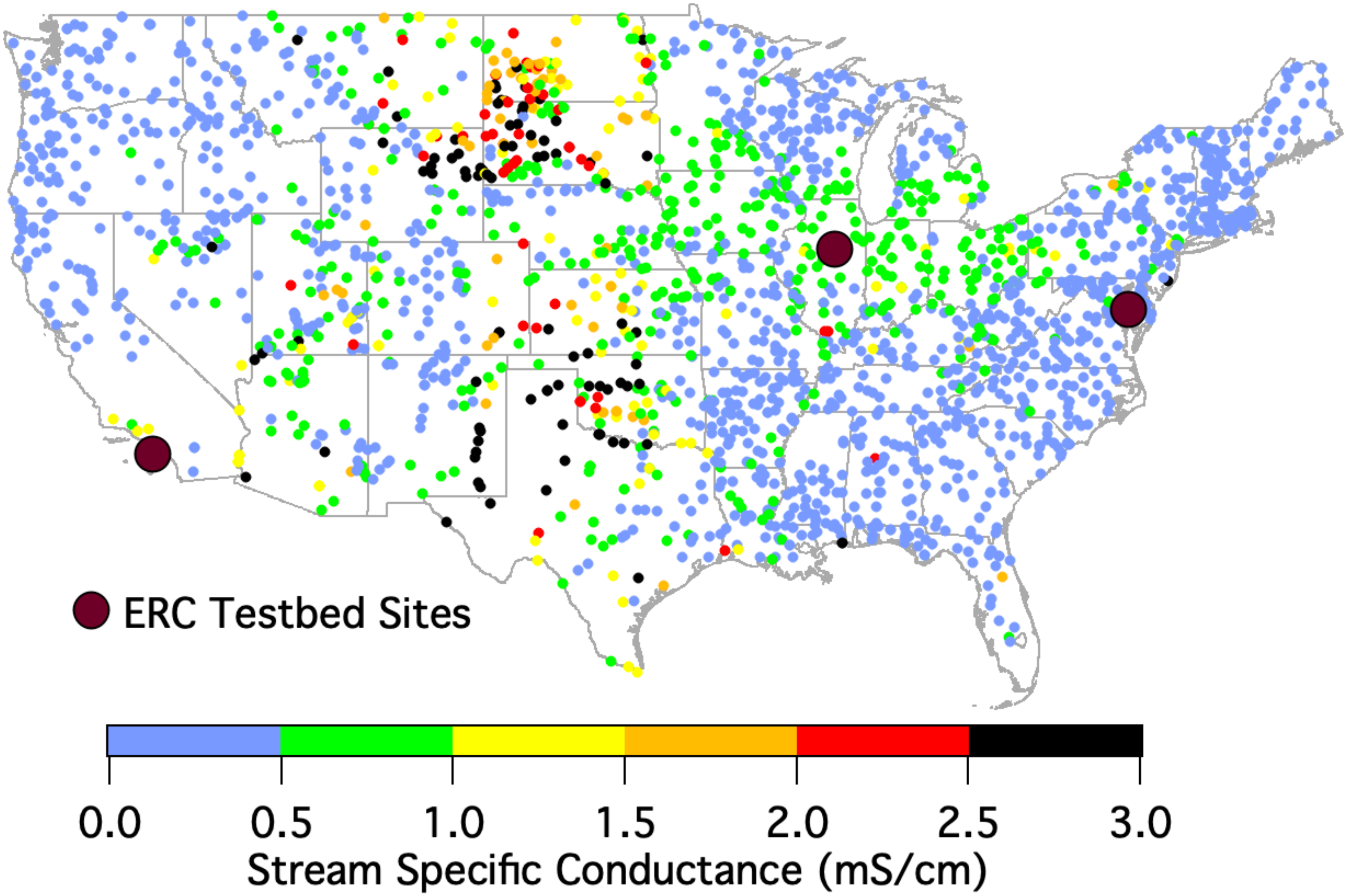
Engineering Research Center for Reversing Freshwater Salinization (ReFRESH)

- Four “Core Partner” Universities
  - Virginia Tech, Howard U., University of Illinois Urbana Champaign, UCLA (+/- RPI)
  - Three Testbeds in Northern Virginia, Illinois, and Southern California (+/- Jefferson Project, Lake George, NY)
- Affiliated Institutions
  - UMD, UCR, NC State U, University of Melbourne, UC Denver
  - WRF

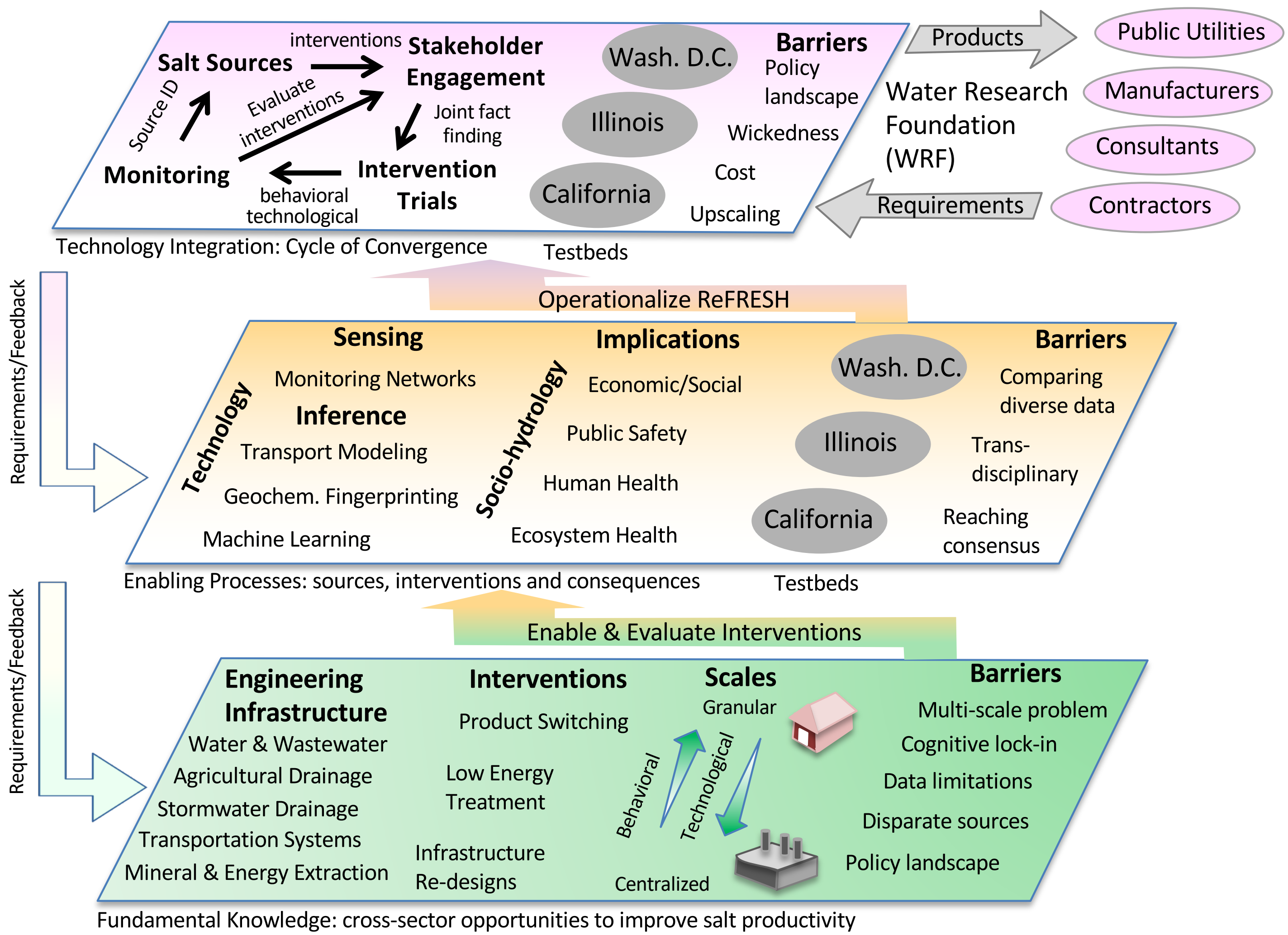
ERC Process

- Letter of Intent (due Sept 2, 2020)
- 10-page pre-proposal (due October 2, 2020)
- NSF Panel decides whether to invite or not
  - No Invitation—relax!
  - Invitation—Full Proposal due May 7, 2020
- NSF Panel reviews Full Proposal
  - Rejected—relax!
  - Site visit—sometime in 2021
- If all hurdles are cleared, funded in 2022

National Patterns of Sp Cond



Reversing Freshwater Salinization (ReFRESH)-Draft Three Plane Diagram



Researcher Lineup

Workforce Development	Scott Case (LEAD)	Grant Warner	Art Schmidt	Sanjay Mohanty	Jack Lesko					
Diversity and Inclusion	Katherine Picho (LEAD?)	Scott Case	Art Schmidt	Sanjay Mohanty	Bevlee Watford					
Innovation Ecosystem	Kevin Heaslip (LEAD)	Brendan McGinty	Kimberly Jones	Eric Hoek	Brian Pianfetti					
Convergent Research										
	Interventions	Amy Pruden	Eric Hoek	Marc Edwards	Kurt Schwabe	Kimberly Jones	Jeseth Delgado Vela	Megan Rippy	Art Schmidt	David Jassby
	Sensing	Jennifer Druhan	Peter Vikesland	Kevin McGuire	Rick Relyea	Andrea Dietrich	Sujay Kaushal	Erin Hotchkiss		
	Inference	Allison Goodwell	Praveen Kumar	Volodymyr Kindratenko	Stanley Grant	Kevin McGuire	Judd Harvey			
	Socio-Hydrology	Thomas Birkland	Katherine Picho	Landon Marston	Erin Hotchkiss	Sally Entrekin	Michael Stewardson			
	Boundary/Translation	Todd Schenk	Harry Zhang	Thomas Birkland	Kurt Schwabe	Kevin Heaslip	Sally Entrekin	Brendan McGinty	Brian Pianfetti	
Testbed sites										
	DC	Stanley Grant	Harry Zhang	Judd Harvey	Kevin McGuire					
	Illinois	Jennifer Druhan	Praveen Kumar							
	Southern California	Eric Hoek	Kurt Schwabe	Sanjay Mohanty	David Jassby					
	Stakeholder Facilitation:	Kristin Rowles								
				Not confirmed!!						
				Virginia Tech	UC Riverside	U Melbourne				
				Howard University	NC State Univ	WRF				
				UCLA	U Maryland					
				UIUC	UC Denver					

Questions?