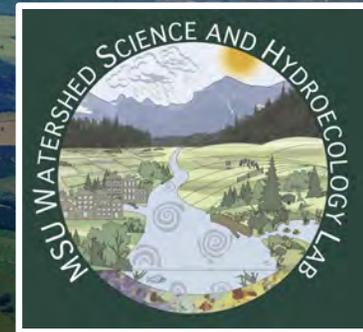


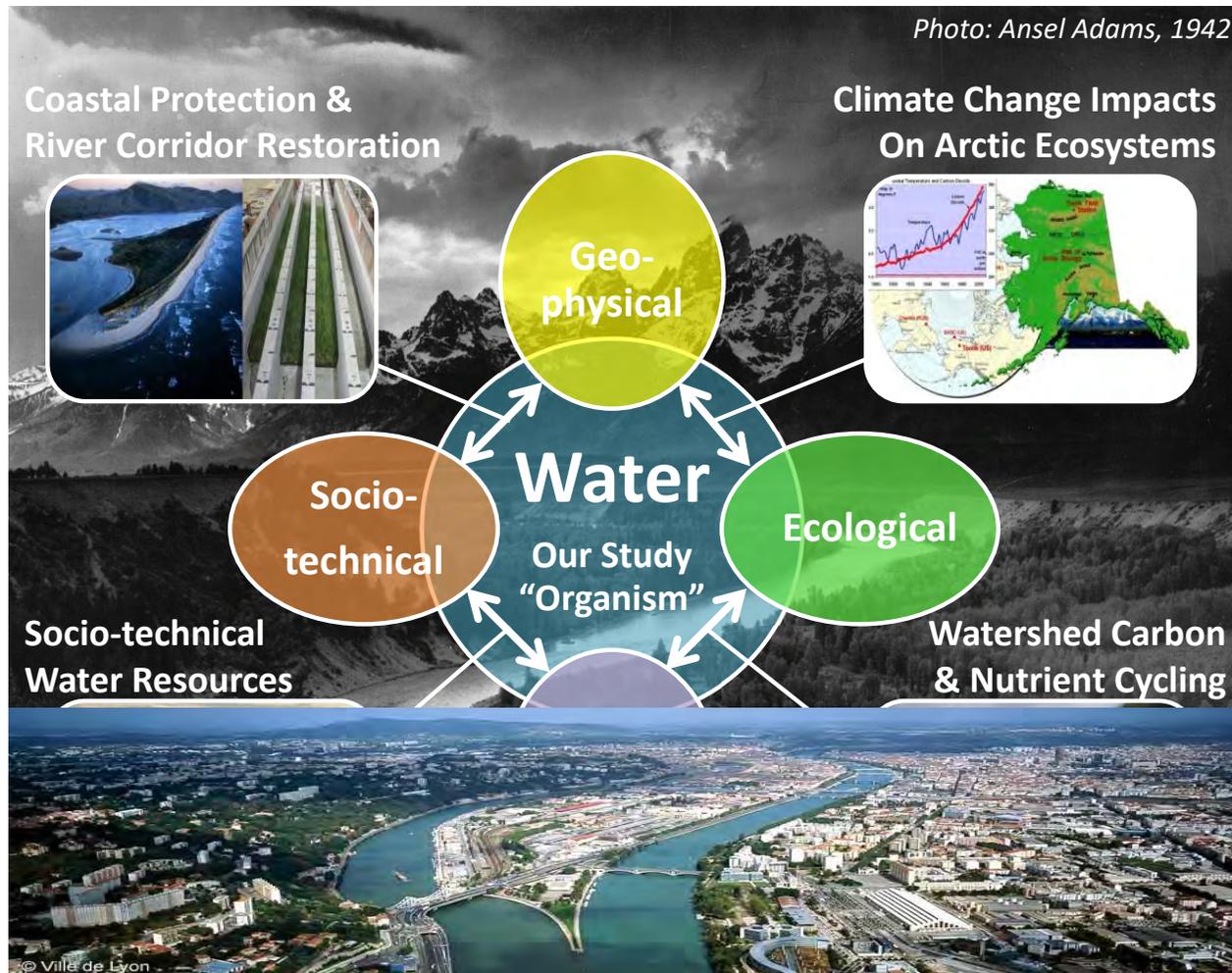
*Telling the “hidden” stories of water:
Revealing connections between climate,
land, water, and human systems*



Jay P. Zarnetske
Earth & Environmental Sciences

MICHIGAN STATE
UNIVERSITY

A Perspective: Water Connects Us All



Telling the “Hidden” Stories of Water

Physics set the limits and Biology gets it done.

Method development:
Hydrology \cap Biogeochemistry \cap Ecology

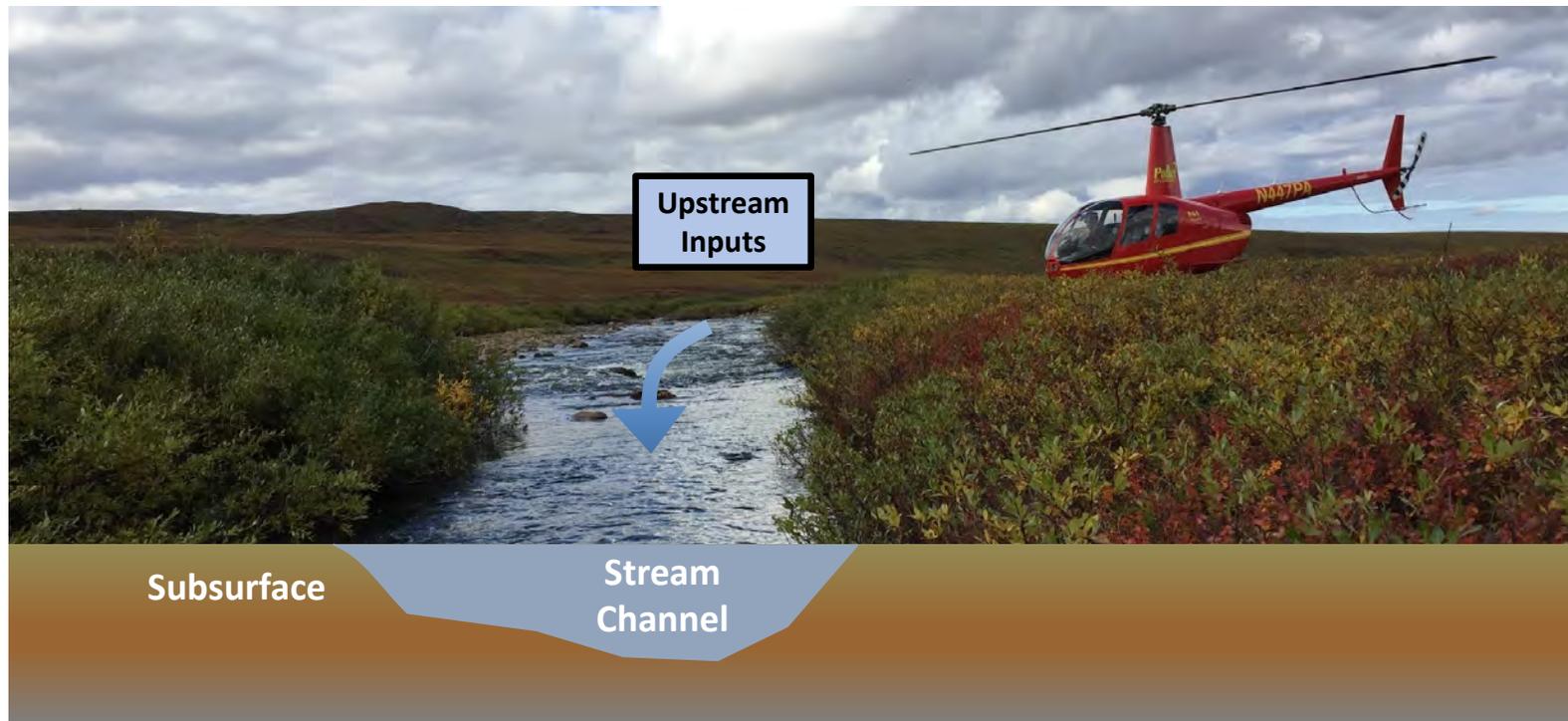
Streams as Sensors of
Climate-Land-Water
Interactions

Assessing the world from the perspective of stream water...



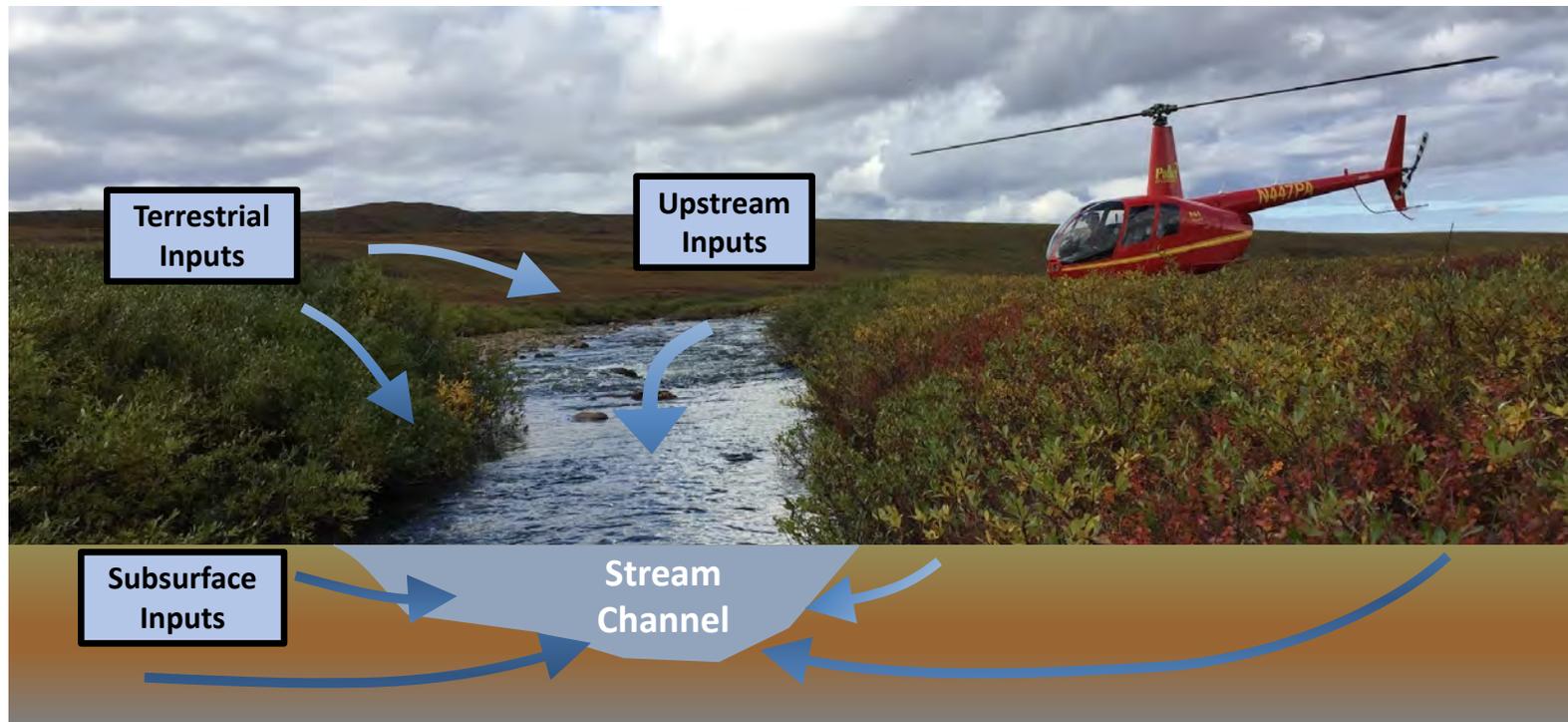
***What is the water telling you as it flows past you?
What story does it have to tell?
What can you sense in the water?***

Stream water is telling you where it has been...



*Geologist might see:
"The gutters down which flow the ruins of continents..."
Luna Leopold (1964)*

Stream water carries and integrates signals that reveals terrestrial & aquatic processes...



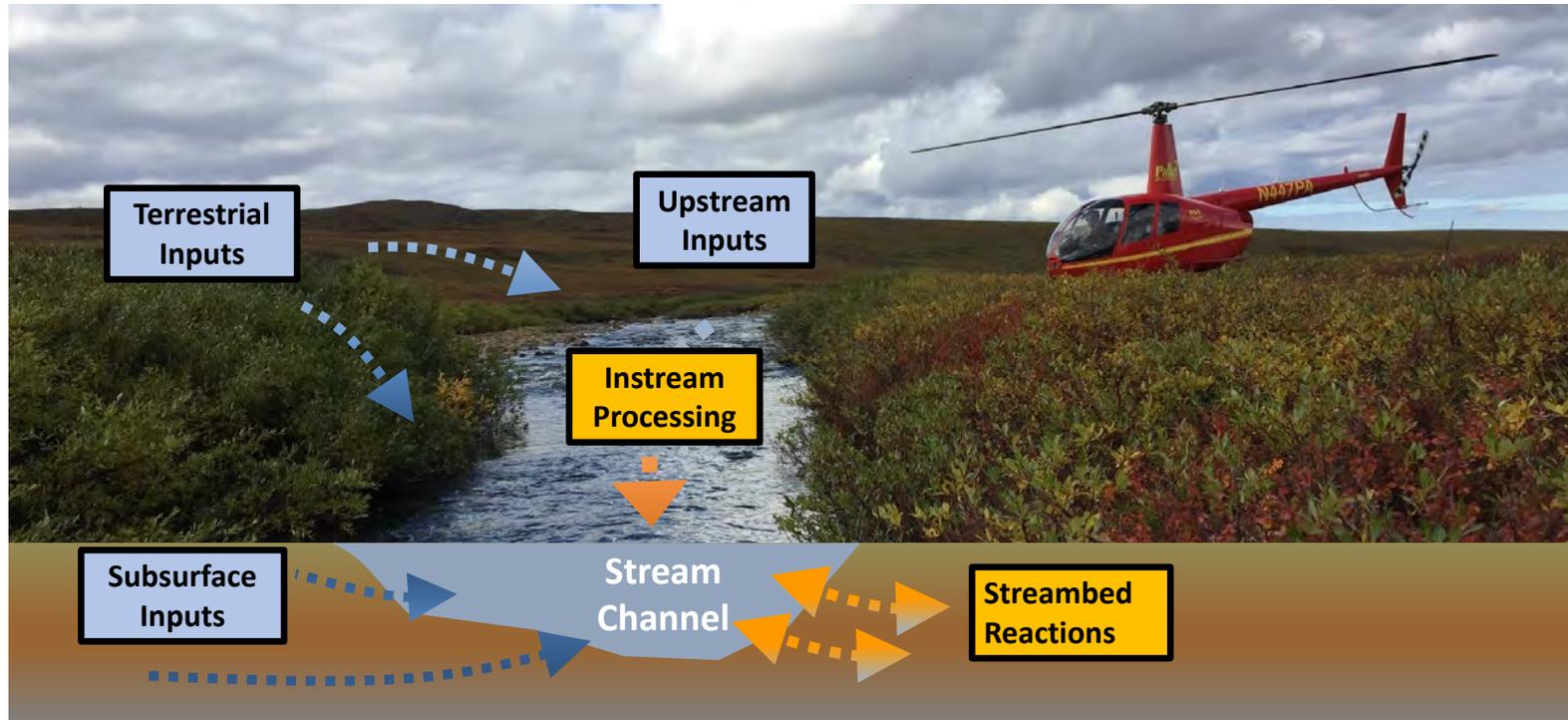
Hydrologist might see:

"Rivers are just expressions of precipitation runoff and groundwater."

"There are many paths to a stream, each is unique."

"We all live downstream."

Streams also change materials...



Ecologists and Biogeochemists might see:

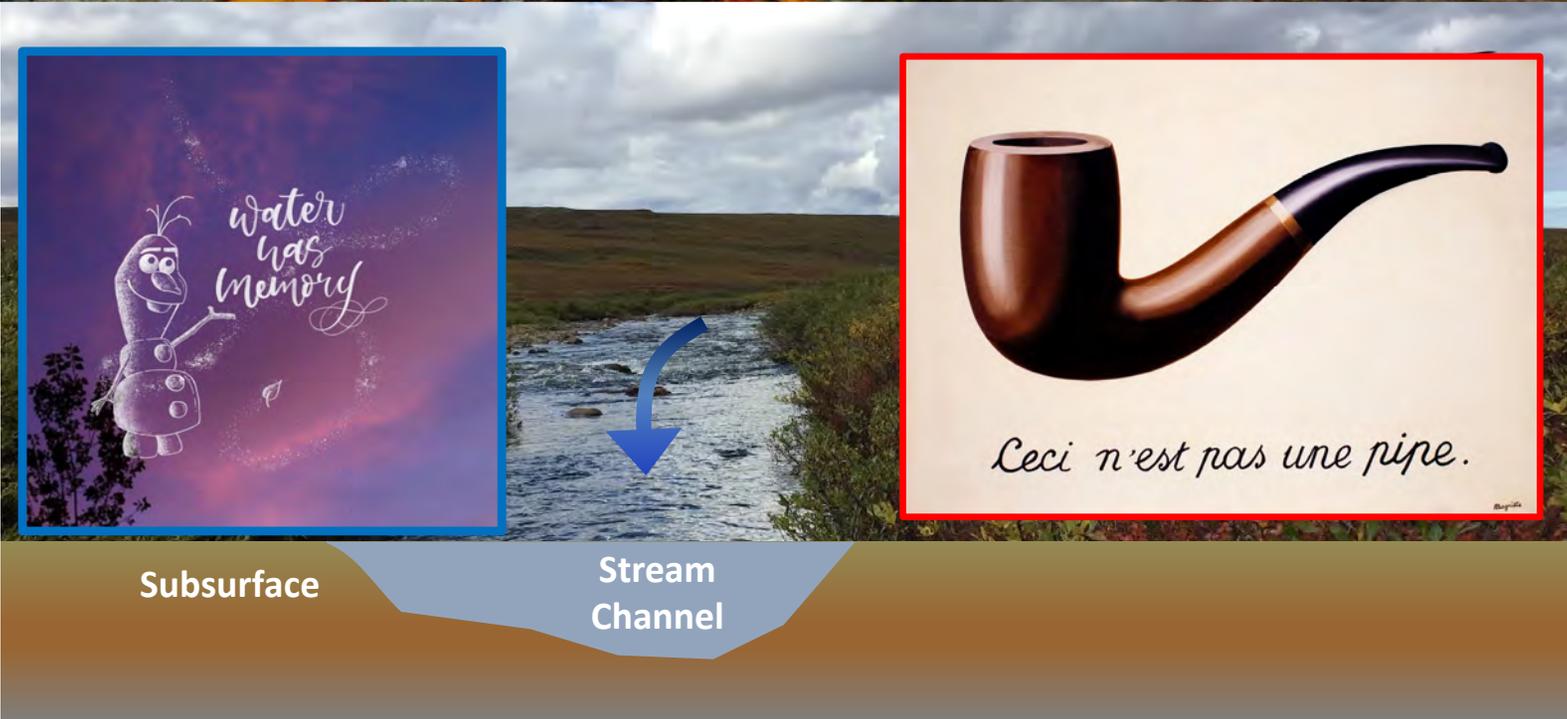
“Everything, everywhere, all at once!” ...Connectivity of ecosystems and streams mixing and transforming organisms and materials from land and water

“The tortuous path of an atom during its downstream journey” - Aldo Leopold (1949)

Hence, stream networks can be used as sensors of environments.

Telling us stories...

But how do we “see” and “read” these stories???



Subsurface

Stream
Channel

What a philosopher might see:

René Magritte – *The Treachery of Images* (“This is Not a Pipe”), 1929

“Water has memory”
Olaf (*Frozen 2*, 2019)

Two Quick Stories of Water From Our Group

Photo: Ansel Adams, 1942

**“Writing” the story of Arctic change
as seen through stream water**

**Improving how we “tell” the stories
of water to society**



Arctic landscapes experiencing rapid changes

Rapid changing seasonality and hydrologic intensification

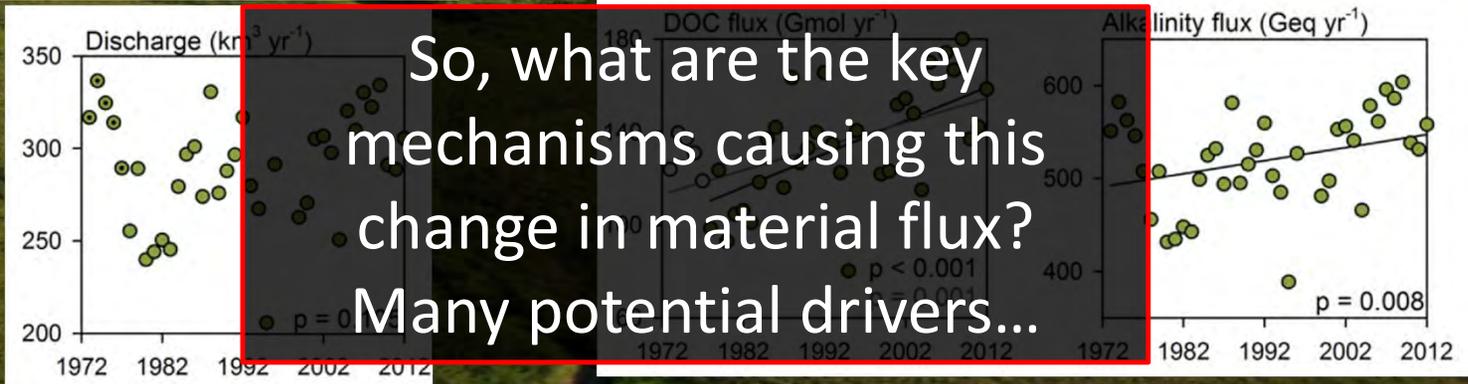
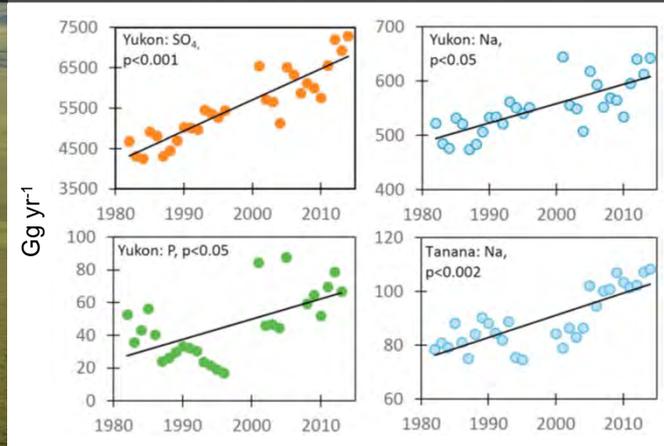
Major shifts in fate the of carbon, nutrient and contaminant fluxes

Arctic Rivers Telling a Story: Sentinels of Land to Ocean Changes

Mixed trends in discharge



Systematic increase in solutes

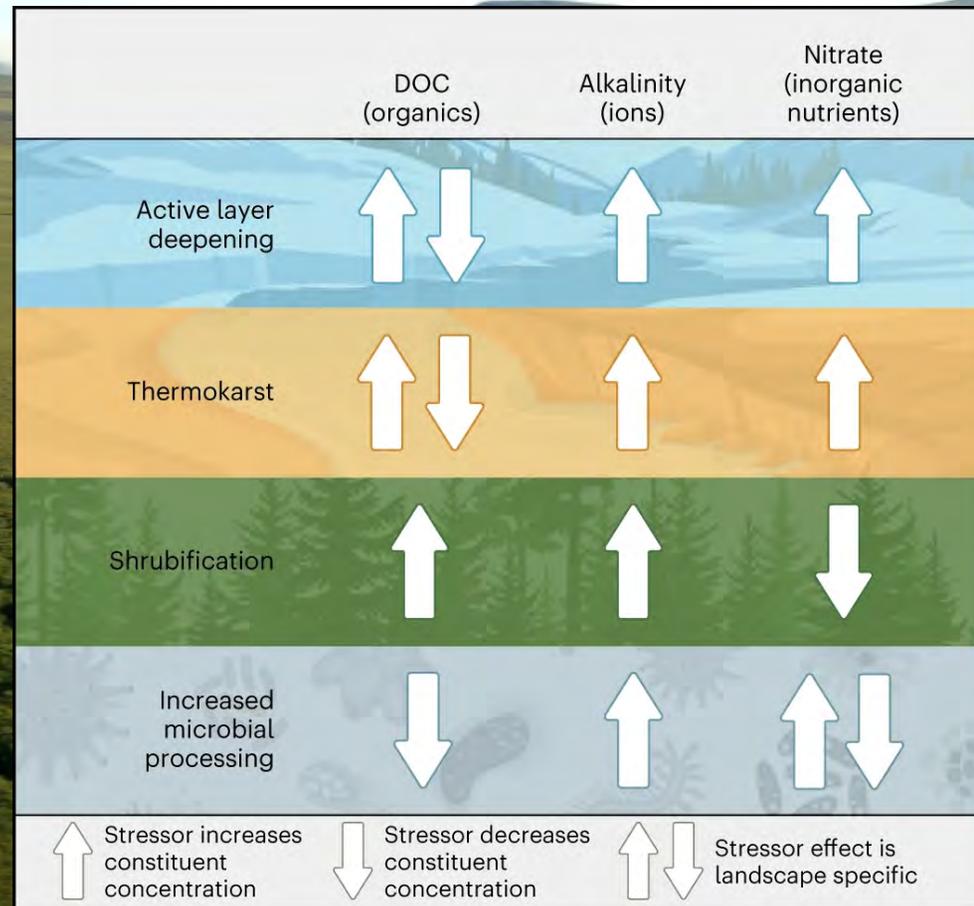


So, what are the key mechanisms causing this change in material flux?
Many potential drivers...

Tank et al. 2016 (Mackenzie)

Toohey et al. 2016 (Yukon) Tank et al. 2016

Many hypothesized drivers of this story of change



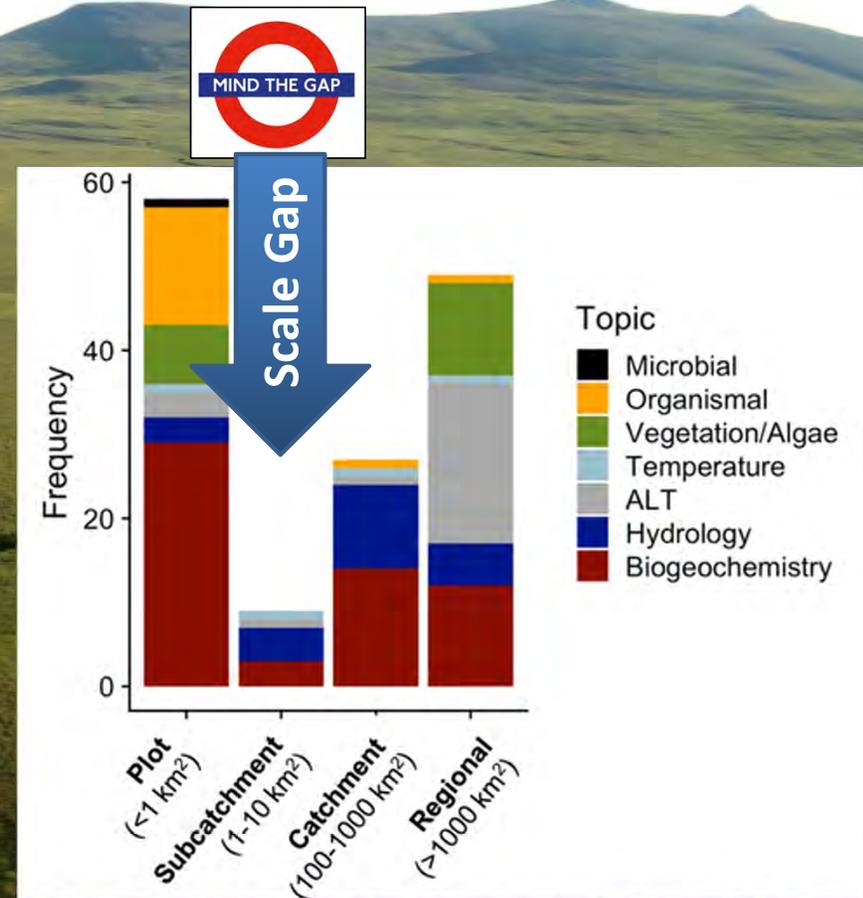
Tank et al., Nature Geosci 2023

Arctic Science stories have many blind spots

What story will be told by streams?

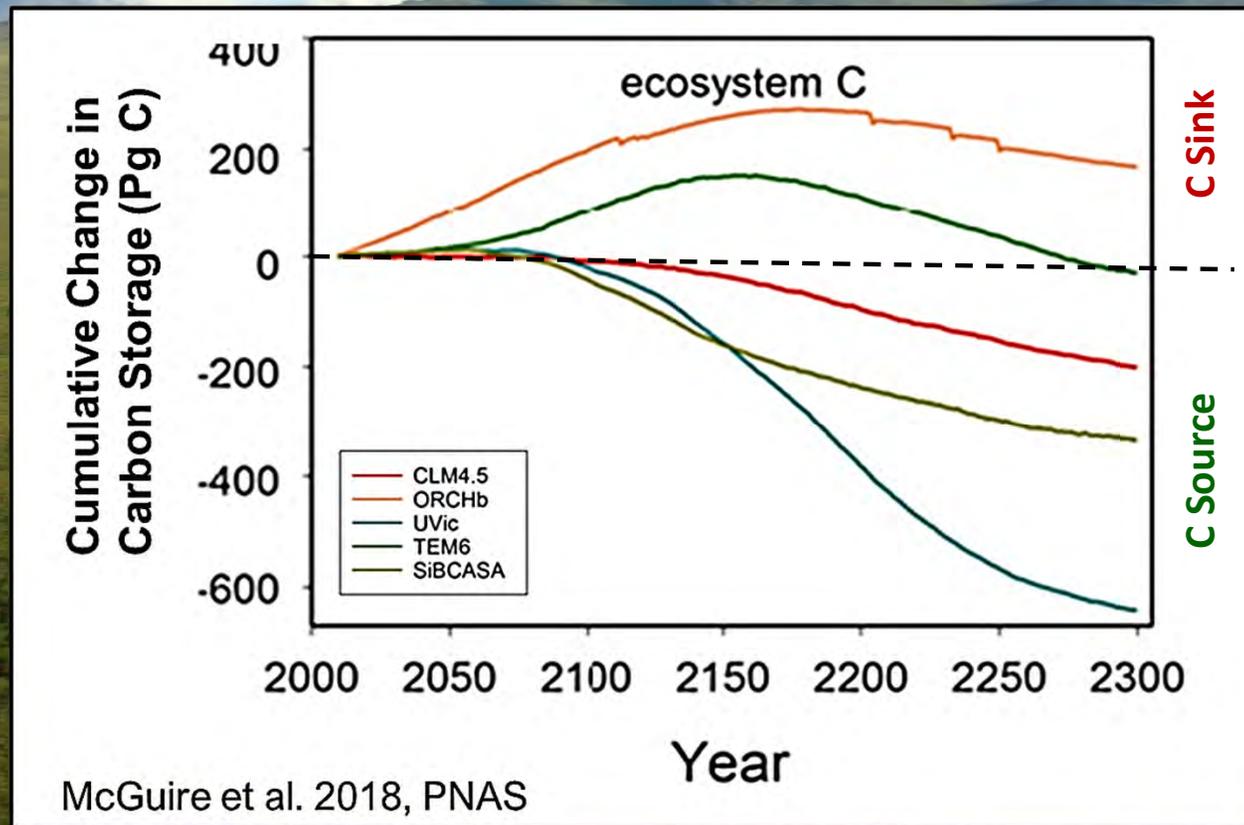
Why care about watershed spatial scale?

- Most Arctic studies occur at the plot (<1 km²) or at the regional scale (>10,000 km²).
- Many conflicting results for the fate of permafrost carbon and nutrients in Arctic ecosystems.

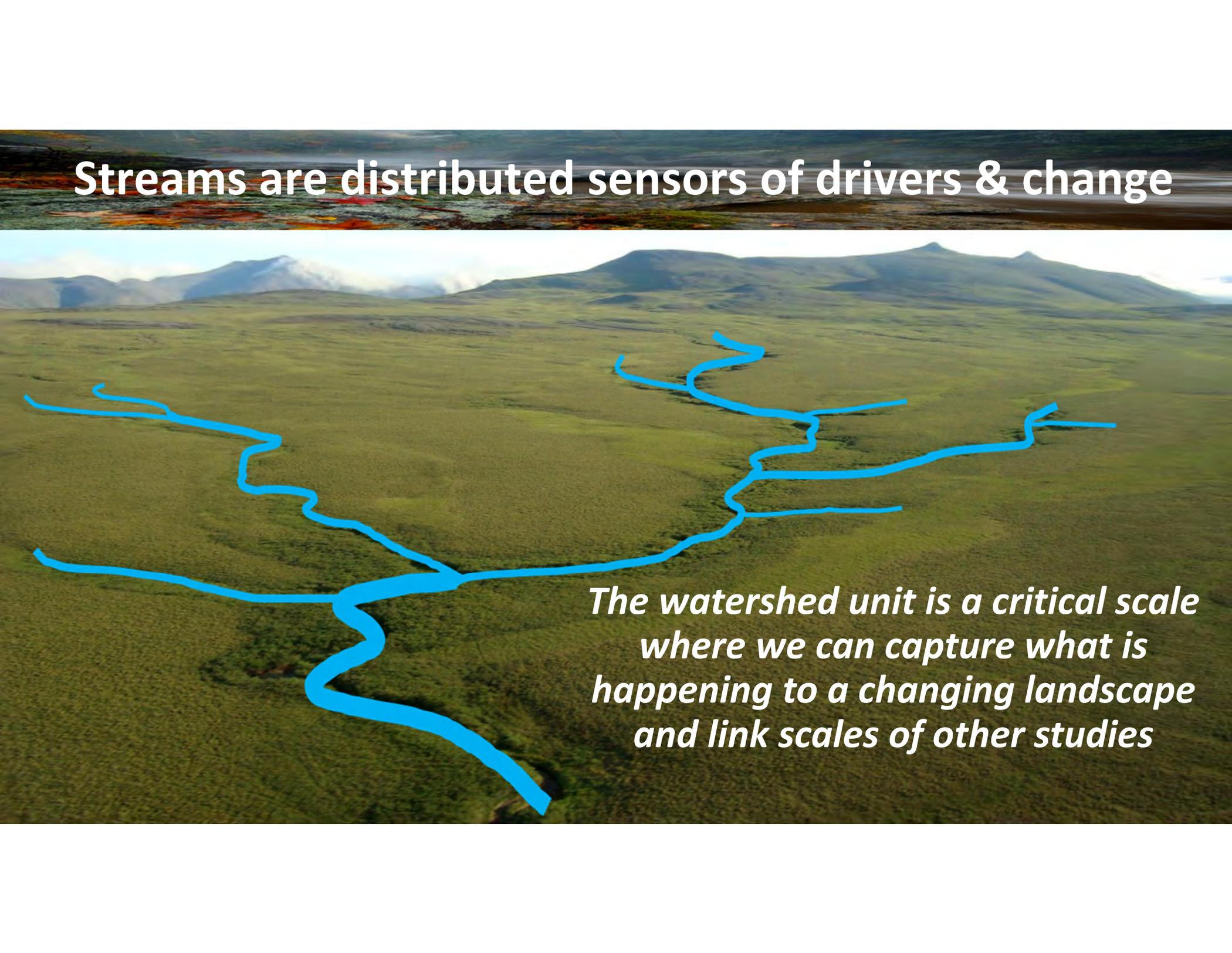


Shogren et al., ERL 2020

Lots of uncertainty in this story of change



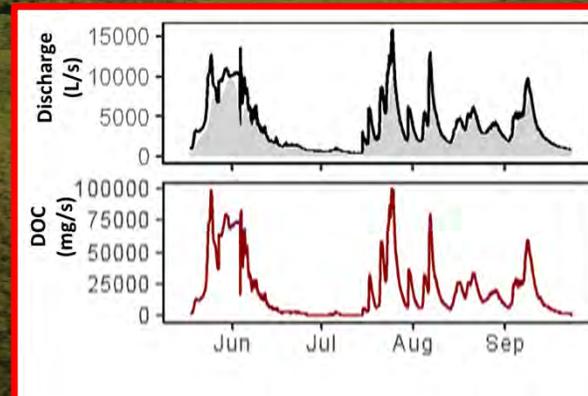
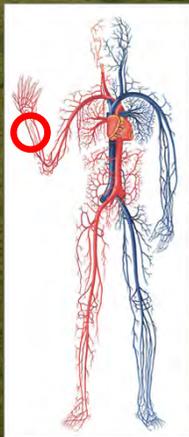
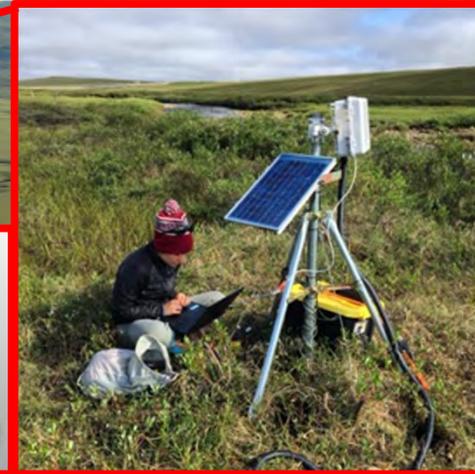
Earth System Models

An aerial photograph of a vast, green landscape with a network of blue lines representing a river system. The rivers flow from the top right towards the bottom left. In the background, there are rolling hills and mountains under a clear sky. The top of the image has a dark, textured band.

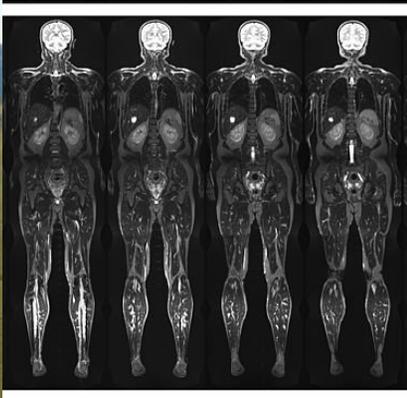
Streams are distributed sensors of drivers & change

The watershed unit is a critical scale where we can capture what is happening to a changing landscape and link scales of other studies

New technology to read the “pulse” of river flows and the materials carried in the water



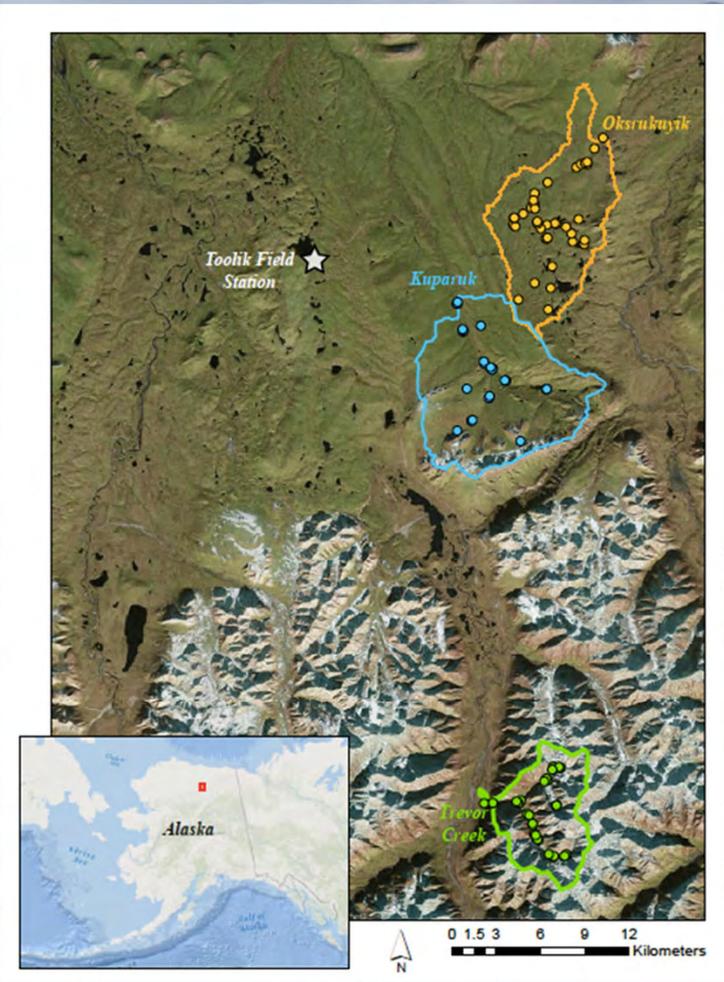
We developed new approach to use streams as sensors of detecting ecosystem change



Where are the specific signals originating? Is the structure and stability of material source and sink signals at the watershed scale?

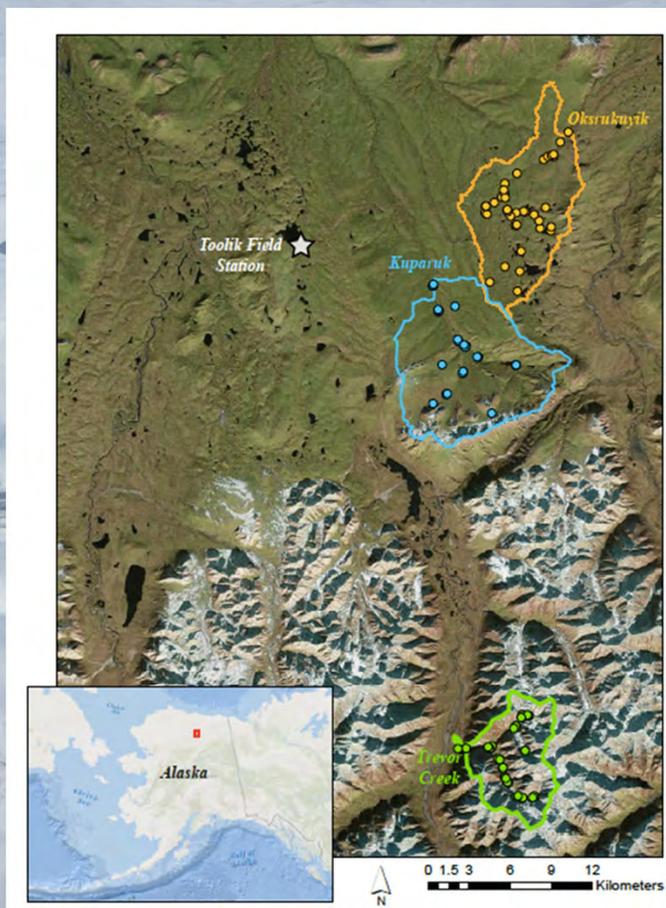


Big team science observing Arctic watersheds



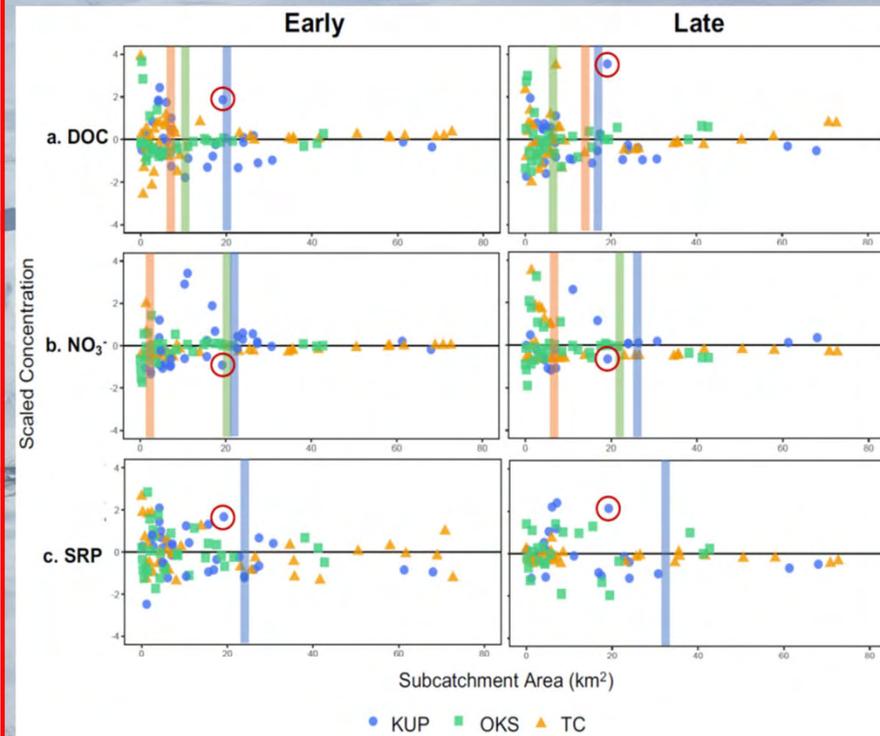
New unique synoptic water chemistry data set

- Arctic US LTER Watersheds
- 3 different landscape types
- 128 subwatersheds
- 5 years start to end of thaw season (*despite COVID!*)
- >1800 unique sampling events
- >25 chemicals, including major nutrients, carbon, ions, metals
- Goals:
 - Identify drivers of chemical signals
 - Improve chemical and nutrient balances
 - Enable new data-driven analyses and ESM model validation



A few highlights of the stories discovered by using streams as sensors

- **Landscape matters!**
 - Lake and Alpine watersheds controls operate at smaller ecosystem patch scales than in Tundra watersheds
- A “*representativeness*” issue found
- Generated the first intermediate spatial scale benchmark data set for use by ESMs

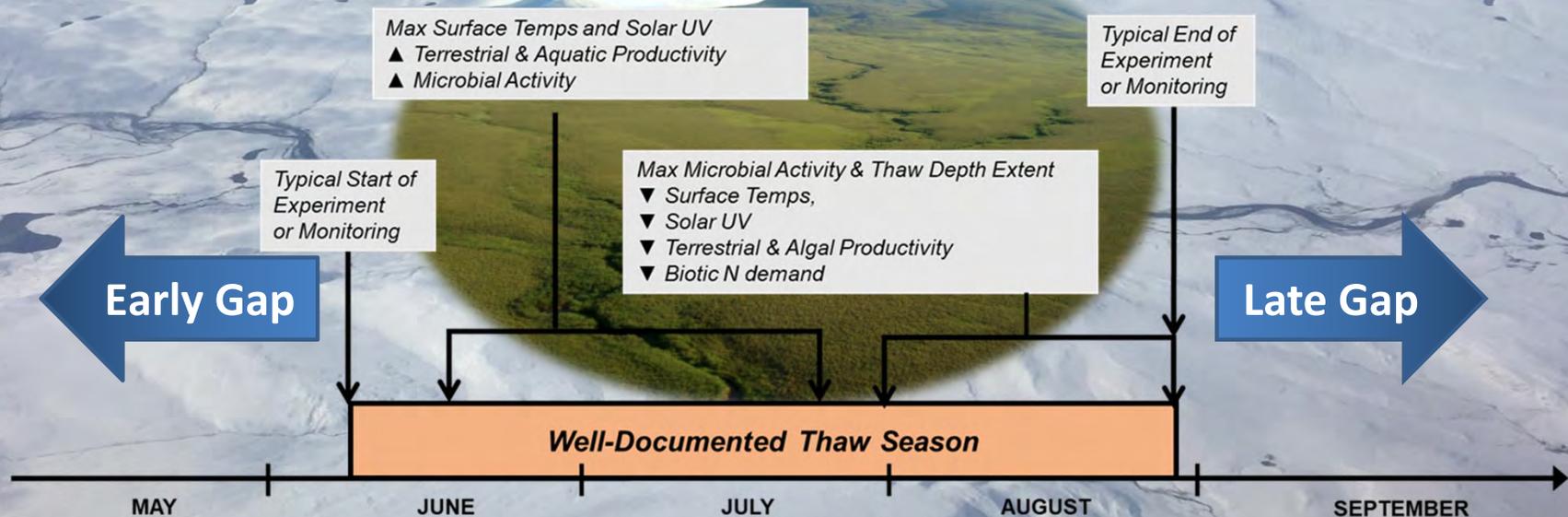


Shogren et al., Scientific Reports, 2019
Shogren et al., ESSD, 2022
Abbott et al., Ecology Letters, 2018

Also revealing huge “hidden” parts of the Arctic story

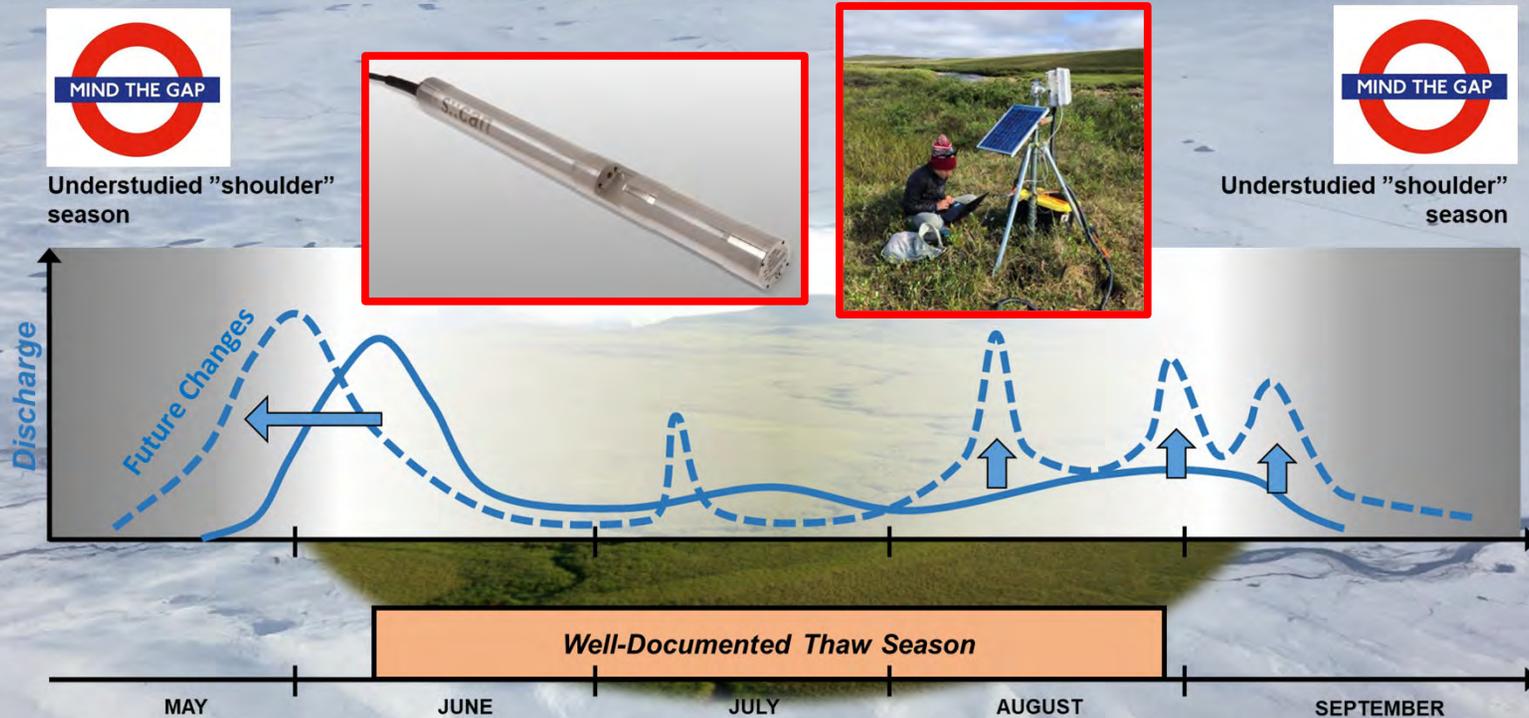
Most disciplines bias toward studying the middle of thaw season, ignoring rapid changes in the dynamic transition seasons

What ecosystem information are we missing by ignoring these transition “shoulder” seasons?



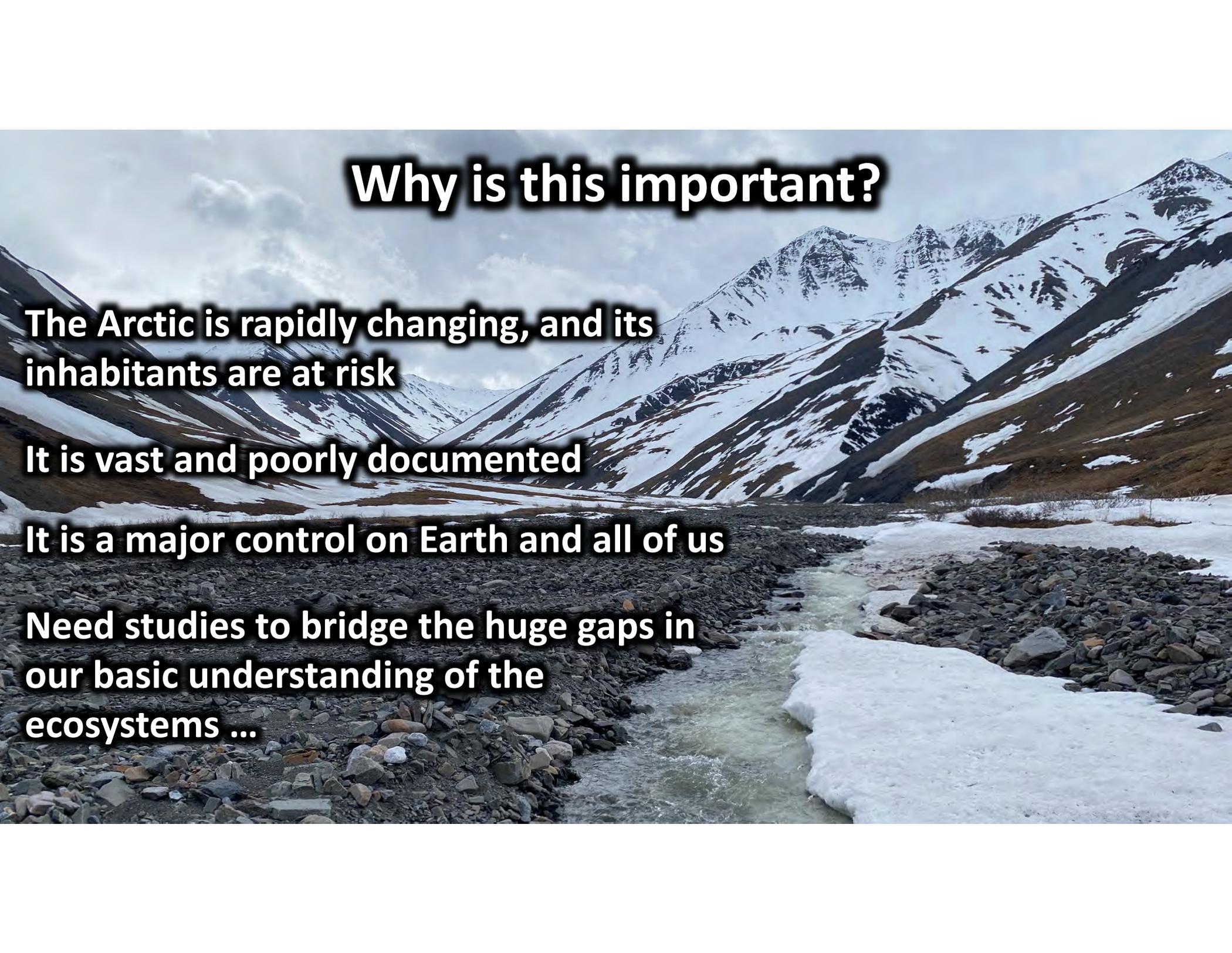
Shogren et al., ERL, 2020
Shogren et al., JGR, 2024

A lot of the story is still hidden from us!



~30% of annual DOC and NO_3^- river export occurred during these poorly documented "shoulder" seasons!
Together helping explain those large Arctic Ocean river changes

Shogren et al., ERL, 2020

A photograph of a mountain valley with snow-capped peaks and a rocky stream in the foreground. The sky is overcast and grey. The mountains are covered in patches of snow and brownish vegetation. A stream flows through a rocky bed in the foreground, with a large patch of snow on the right side.

Why is this important?

The Arctic is rapidly changing, and its inhabitants are at risk

It is vast and poorly documented

It is a major control on Earth and all of us

Need studies to bridge the huge gaps in our basic understanding of the ecosystems ...



Second Quick Story of Water From Our Group



Photo: Ansel Adams, 1942

**Improving how we “tell” the
stories of water to society**

Global freshwater is most limiting natural resource



Society's Largest Misconception: So much water to use

Only 3.5% of water is freshwater

And Only 0.5% is accessible and usable freshwater...and
that amount is decreasing each year!

Hidden water in our lives?

1 loaf = 150 gal



Avg Car = 30-100k gal



Appreciate water, we need it!



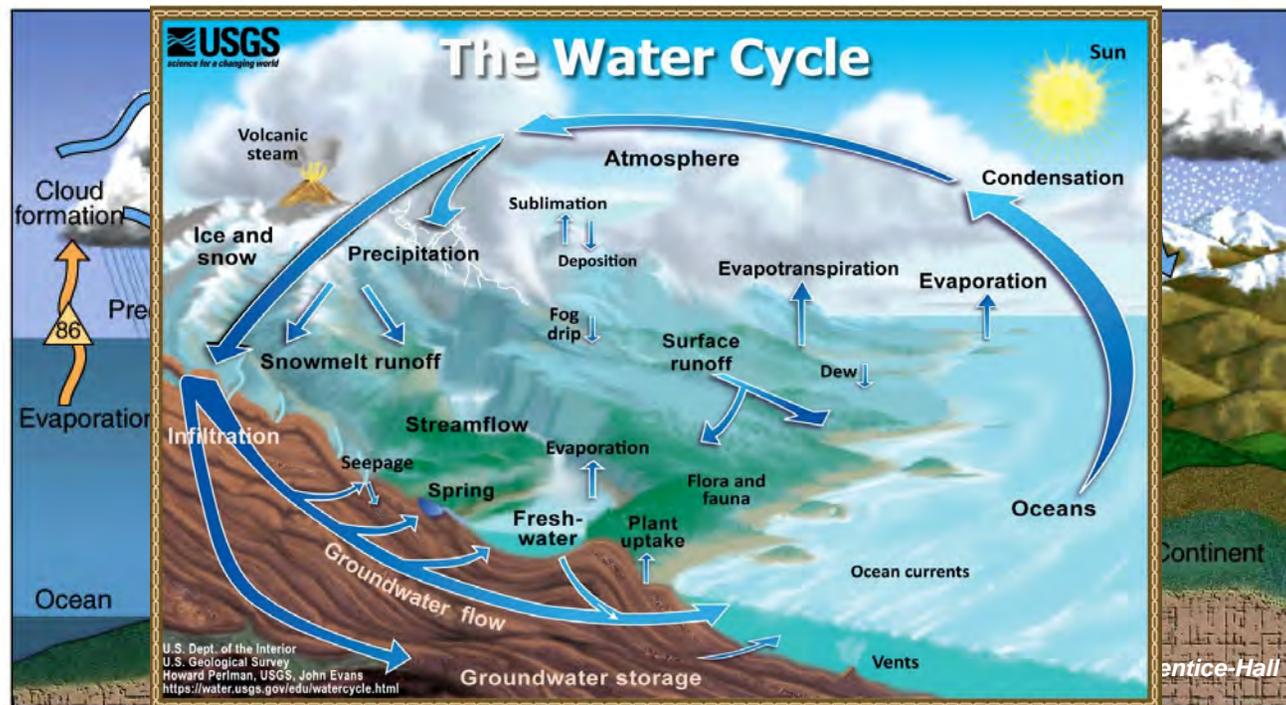
2 lb cotton = 4,000 gal

1C coffee = 37 gal



Are we telling an accurate story of the Water Cycle

Most widely taught Earth cycle and visual of mass balance.



So, what is missing in here?

What aspects are we most uncertain about?

Are we telling an accurate story of the Water Cycle?



The Water Cycle

Sun

Pools of cycle 10^3 km^3 (\pm % uncertainty)



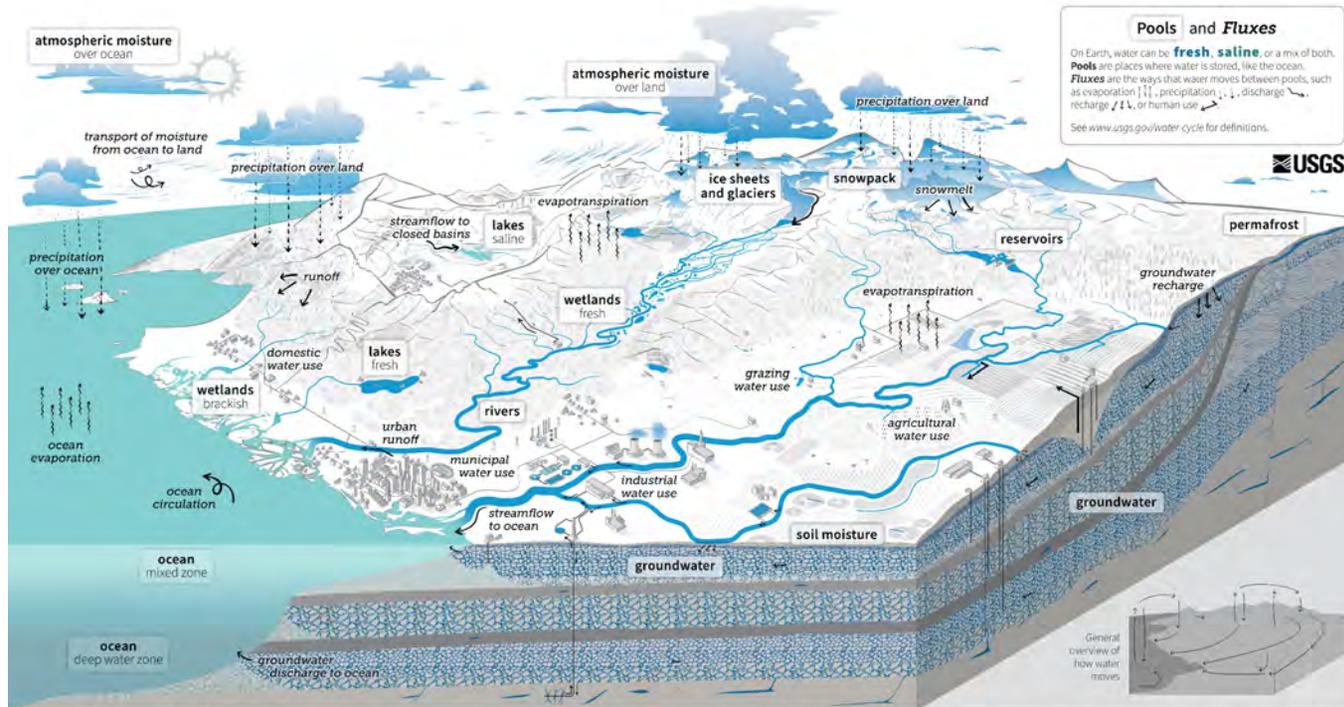
Analyzed All Major Pools and Fluxes of Water & >450 Diagrams
Major Gaps (Uncertainties) to fill:
Everything Groundwater
Everything High Latitude – Permafrost
Misconceptions:
People (<15%), Places & Climate (<2%)



Abbott et al., 2019 *Nature Geoscience*
Abbott et al., 2019, *Hydro. Processes*

New official USGS Water Cycle created thanks to our MSU research!

Released in 2023!



Pools and Fluxes
 On Earth, water can be **fresh, saline**, or a mix of both. **Pools** are places where water is stored, like the ocean. **Fluxes** are the ways that water moves between pools, such as evaporation, precipitation, discharge, recharge, or human use. See www.usgs.gov/water-cycle for definitions.



The Water Cycle

The water cycle describes where water is found on Earth and how it moves. Water can be stored in the atmosphere on Earth's surface, or below the ground. It can be in a liquid, solid, or gaseous state. Water moves between the places it is stored at large scales and at very small scales. Water moves naturally and because of human interaction, both of which affect where water is stored, how it moves, and how clean it is.

Liquid water can be fresh, saline (salty), or a mix (brackish). Nearly six percent of all water is saline and stored in oceans. Places like the ocean, where water is stored are called **pools**. On land, saline water is stored in **saline lakes**, whereas fresh water is stored in liquid form in **freshwater lakes**, artificial **reservoirs**, **rivers**, **wetlands**, and in soil as **soil moisture**. Deeper underground, liquid water is stored as **groundwater** in aquifers, within the cracks and pores of rock. The solid, frozen form of water is stored in **ice sheets**, **glaciers**, and **snowpack** at high elevations or near the Earth's poles. Frozen water is also found in the soil as **permafrost**. Water vapor, the gaseous form of water, is stored as **atmospheric moisture** over the ocean and land.

As it moves, water can transform into a liquid, a solid, or a gas. The different ways in which water moves between pools are known as **fluxes**. **Circulation** mixes water in the oceans and transports water vapor in the atmosphere. Water moves between the atmosphere and the Earth's surface through **evaporation**, **evapotranspiration**, and **precipitation**. Water moves across the land surface through **snowmelt**, **runoff**, and **streamflow**. Through infiltration and **groundwater recharge**, water moves into the ground. When underground, groundwater flows within aquifers and can return to the surface through **springs** or from natural **groundwater discharge** into rivers and oceans.

Humans alter the water cycle. We redirect rivers, build dams to store water, and drain water from wetlands for development. We use water from rivers, lakes, reservoirs, and groundwater aquifers. We use that water (1) to supply our **homes and communities**, (2) for **agricultural** irrigation and **grazing** livestock, and (3) in **industrial** activities like thermoelectric power generation, mining, and aquaculture. The amount of available water depends on how much water is in each pool (water quantity). Water availability also depends on when and how fast water moves (water timing, how much water is used (water use), and how clean the water is (water quality).

Human activities affect **water quality**. In agricultural and urban areas, irrigation and precipitation wash fertilizers and pesticides into rivers and groundwater. Power plants and factories return heated and contaminated water to rivers. Runoff carries chemicals, sediment, and sewage into rivers and lakes. Downstream from these types of sources, contaminated water can cause harmful algal blooms, spread diseases, and harm habitats. **Climate change** is also affecting the water cycle. It affects water quality, quantity, timing, and use. Climate change is also causing ocean acidification, sea level rise, and extreme weather. Understanding these impacts can allow progress toward sustainable water use.

A Water Cycle for the Anthropocene

Many anthropogenic stressors creating water resource crises around globe



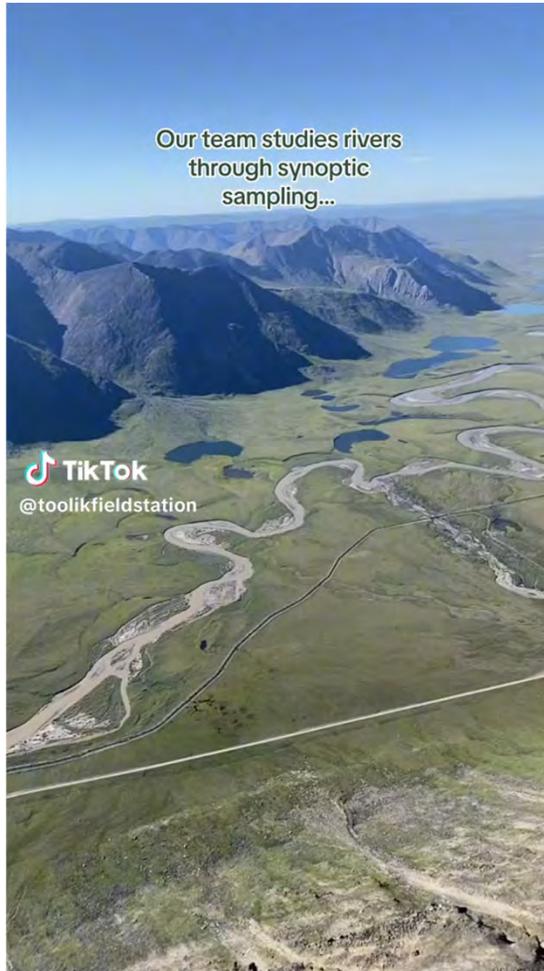
Abbott et al., *Nature Geoscience*, 2019

Abbott et al., *Hydro. Processes*, 2019

**Need to improve our story telling...to
achieve sustainability goals**



Demystify the Science (and the Scientist!) More Accessible and Relatable



Transferable and Adaptable Learning Environments

Welcome!
Please explore our virtual classroom to learn how much water is 'hidden' in your everyday life!

Presented by:

How much water is "hidden" in your everyday life?
Can you guess how much water went into everyday items?

START HERE

[Link to video](#)

Click on the objects above to learn more!

Additional Resources

Exit Survey

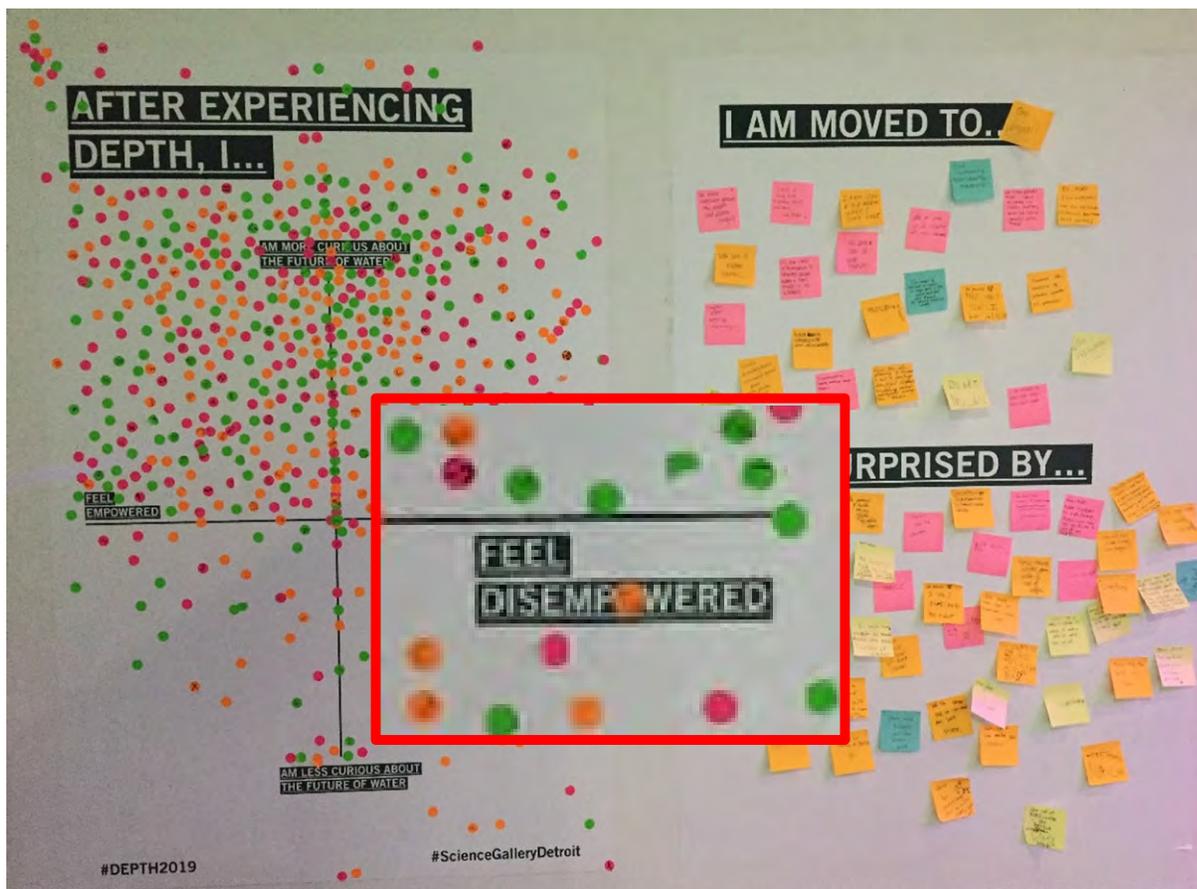
The virtual classroom features a chalkboard with a welcome message, a video player with a play button and a red arrow pointing to it labeled 'START HERE' and a link 'Link to video', a central infographic about hidden water in everyday items, a 'Presented by:' section with a Michigan State University logo, a shelf with various objects (shoes, pants, shirt, phone, book, coffee, water bottle, burger, chips, eggs), a smaller shelf with books labeled 'Additional Resources', a cartoon character holding a pointer, and an 'Exit Survey' button with a door icon.

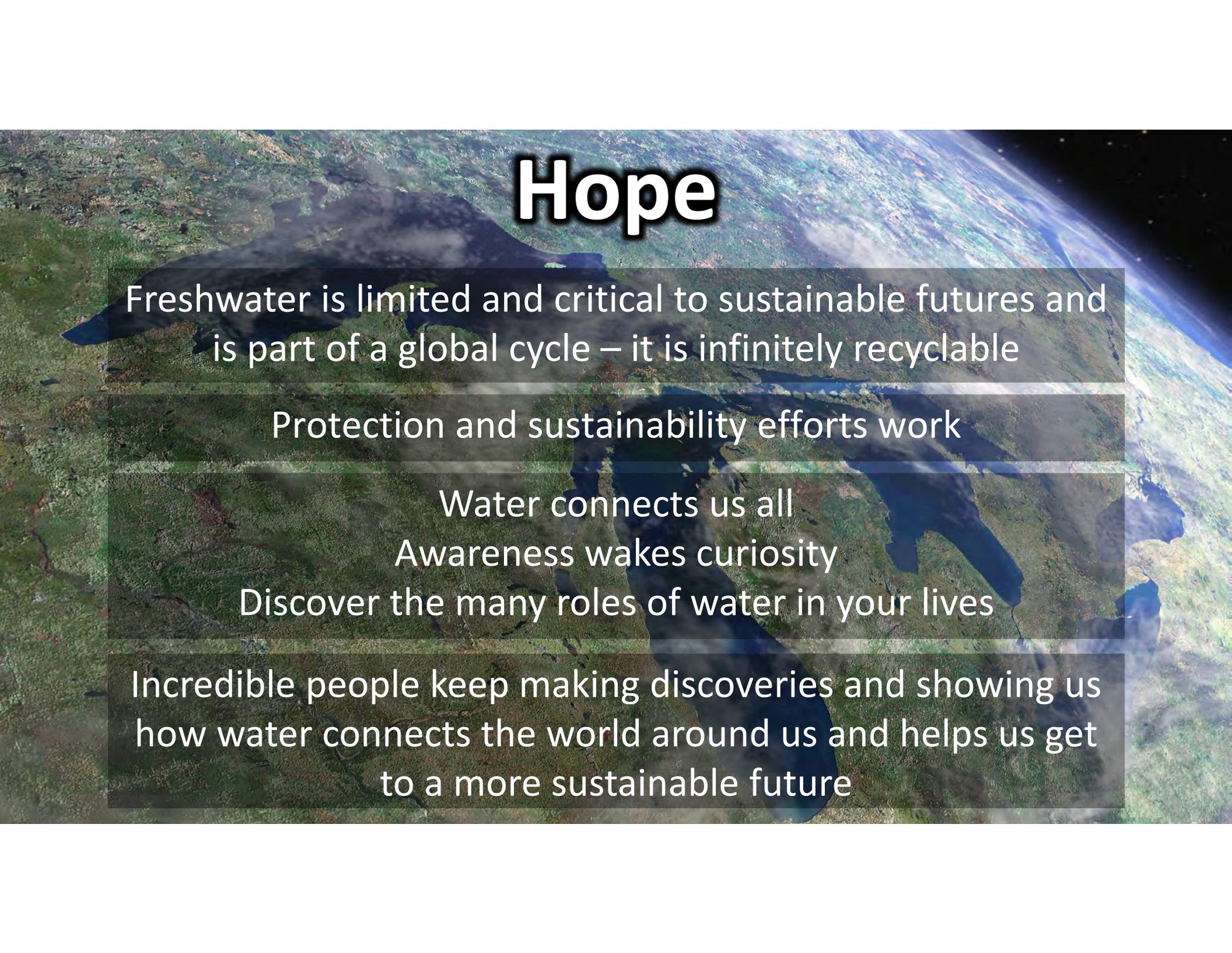
Transferable and Adaptable Learning Experiences



Impacts of Telling Better Water Stories?

Listen to the audience!





Hope

Freshwater is limited and critical to sustainable futures and is part of a global cycle – it is infinitely recyclable

Protection and sustainability efforts work

Water connects us all

Awareness wakes curiosity

Discover the many roles of water in your lives

Incredible people keep making discoveries and showing us how water connects the world around us and helps us get to a more sustainable future

Acknowledgments



Key Collaborators

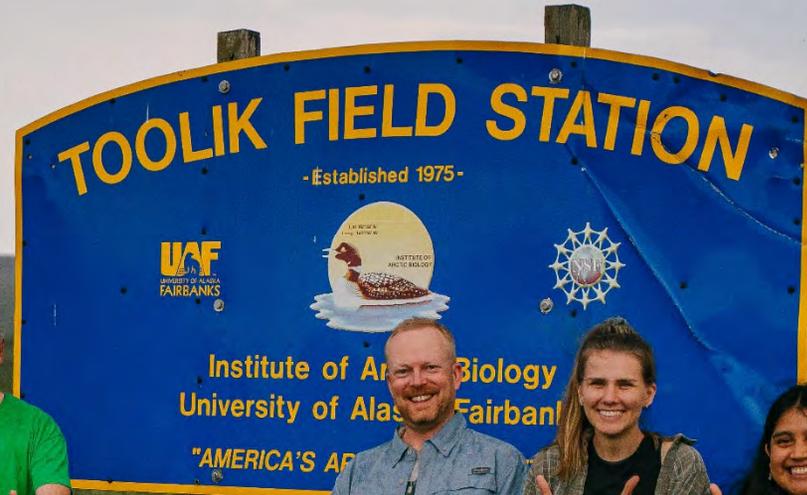
- Colleagues – Ben Abbott, Alba Argerich, Kevin Bishop, Breck Bowden, John Bradford, Martin Briggs, Troy Brosten, Nigel Crook, Fred Day-Lewis, David Hannah, Roy Haggerty, Jud Harvey, Steve Hamilton, Stefan Krause, David Long, Phanikumar Mantha, Florentina Moatar, Mandy Meriano, Gilles Pinay, Kamini Singha, Ariel Shogren, Chao Song, MS Srinivasan, Adam Ward, Steve Wondzell
- Students – Amelia Grose, Caroline Weidner, Abigail Rec, Nudrat Fatima, Jansen Nipko, Tyler Hampton, Joe Lee-Cullin, Frances Ianucci, Sydney Ruhala, Sinchan Roy Chowdhury, Frazaneh MahmoodPoor Dehkordy, Stephen Plont, Sean Kim, Ken Hill, Vincent Adams, Martin Bouda, Rachel Geiger

Data & Funding Resources



--OPP-- --BIO--
--EAR--

Thank you for your time...
...and your Questions



Jay P. Zarnetske
Earth & Environmental Sciences
Email: jpz@msu.edu

