The Arctic LTER
Landscape Interactions

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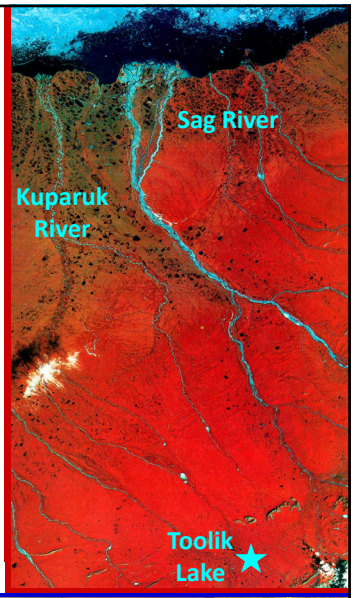

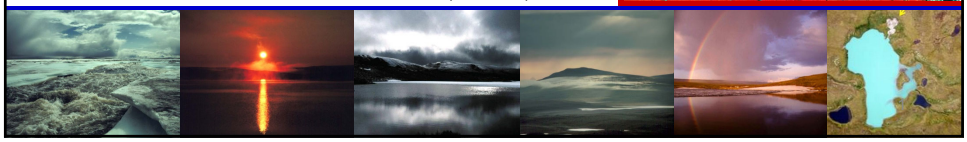

*Mapping the ARC-LTER **Goal** to Land-water Interactions Research*

Determine how system ***openness*** and landscape ***connectivity*** interact to shape the response of arctic systems to ***disturbance***

Disturbance =
Pulse – Fire, thermokarst failures
Press – Climate change, permafrost thaw

Ongoing, long-term research:

1. Monitor changes in chemical fluxes
2. Monitor changes in thaw depth
3. Monitor landscape distribution and dynamics of microbes
4. Determine controls on catchment C and N dynamics

New Research Activities:

Activity #1. *(Ongoing 1,4)*
Determine the biogeochemical openness of land, lake, and stream sediments for C and N

Activity #2. *(Ongoing 1,2,3,4)*
Determine openness and controls on DOM fluxes from land to water

Activity #3. *(Ongoing 1,4)*
Determine if photo-production of NH_4^+ from DOM increases connectivity between land and water

Activity #4. *(Ongoing 3,4)*
Determine the genomic potential and metabolic functioning of microbial communities altered as species move from soils to streams to lakes

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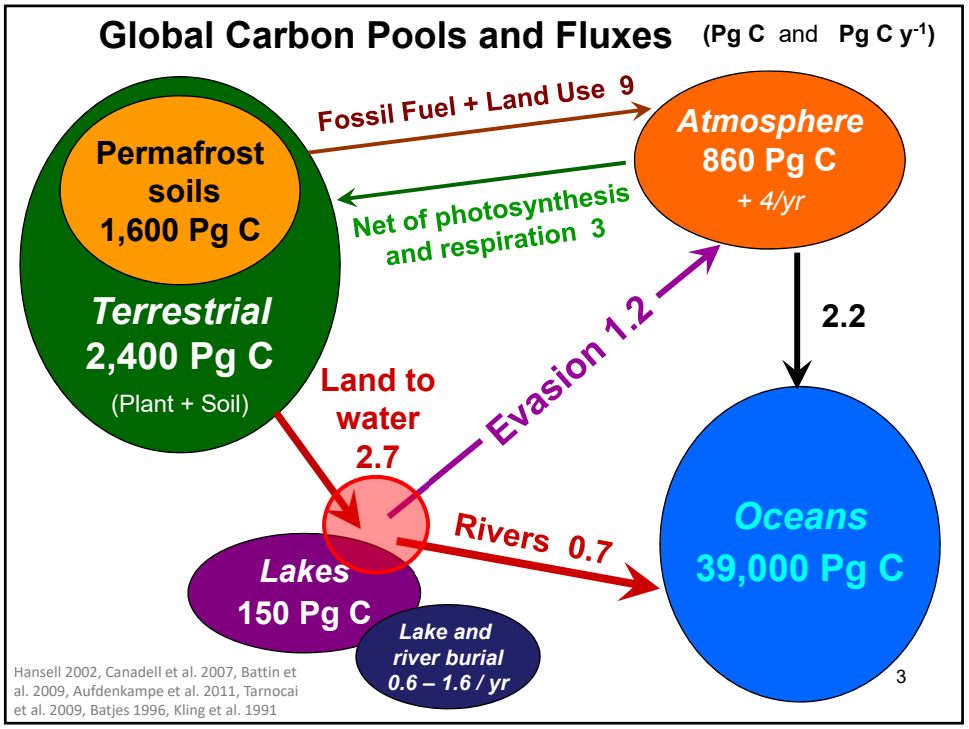
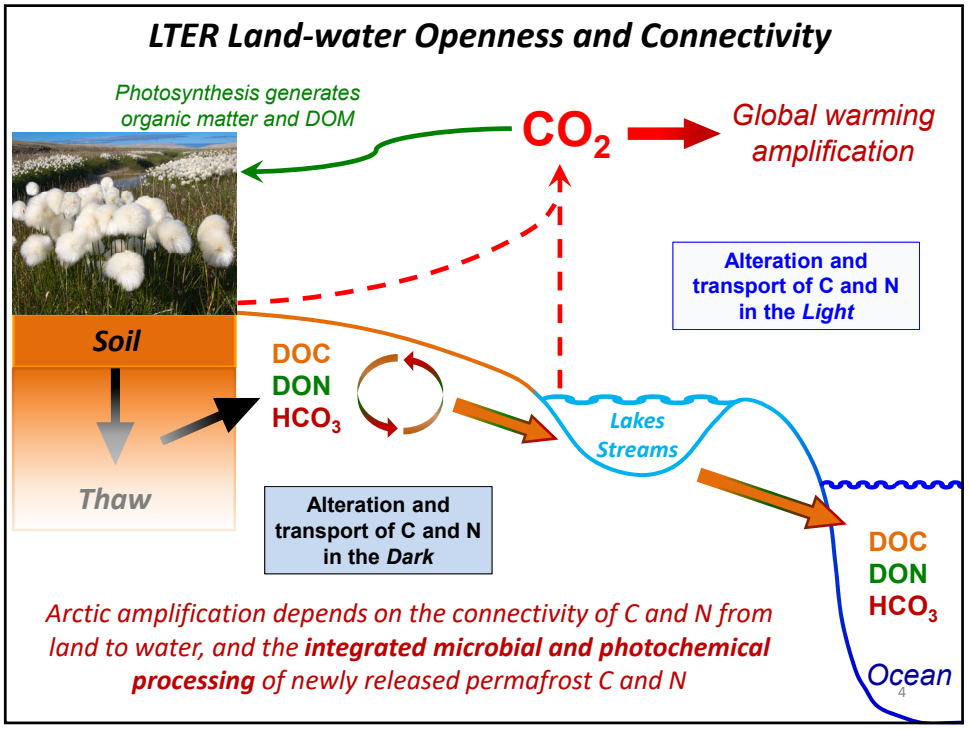
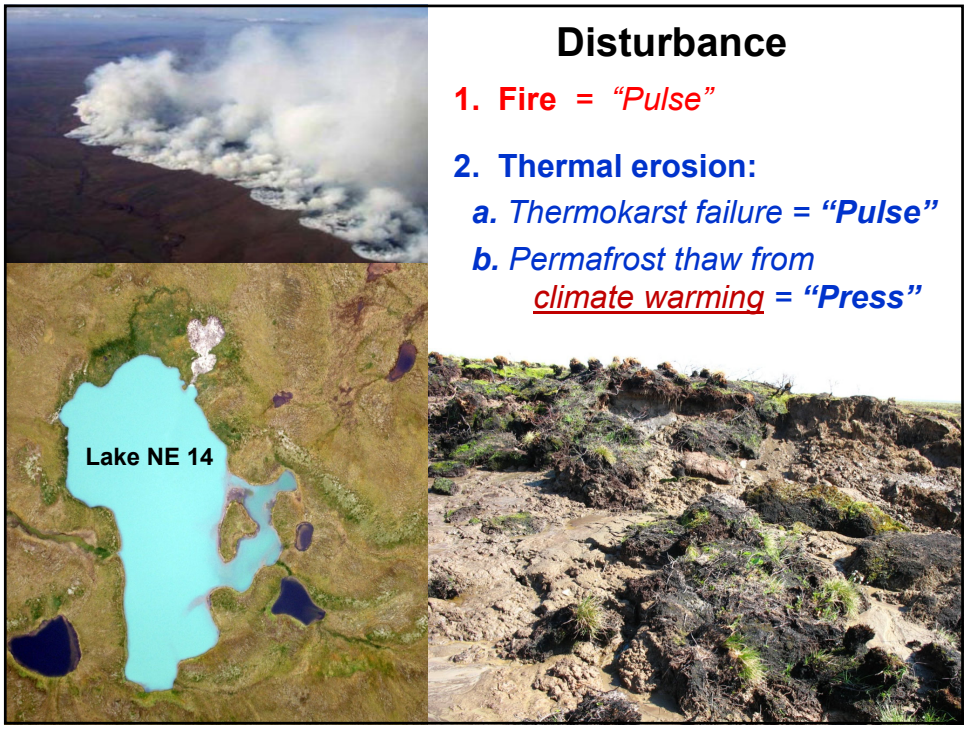
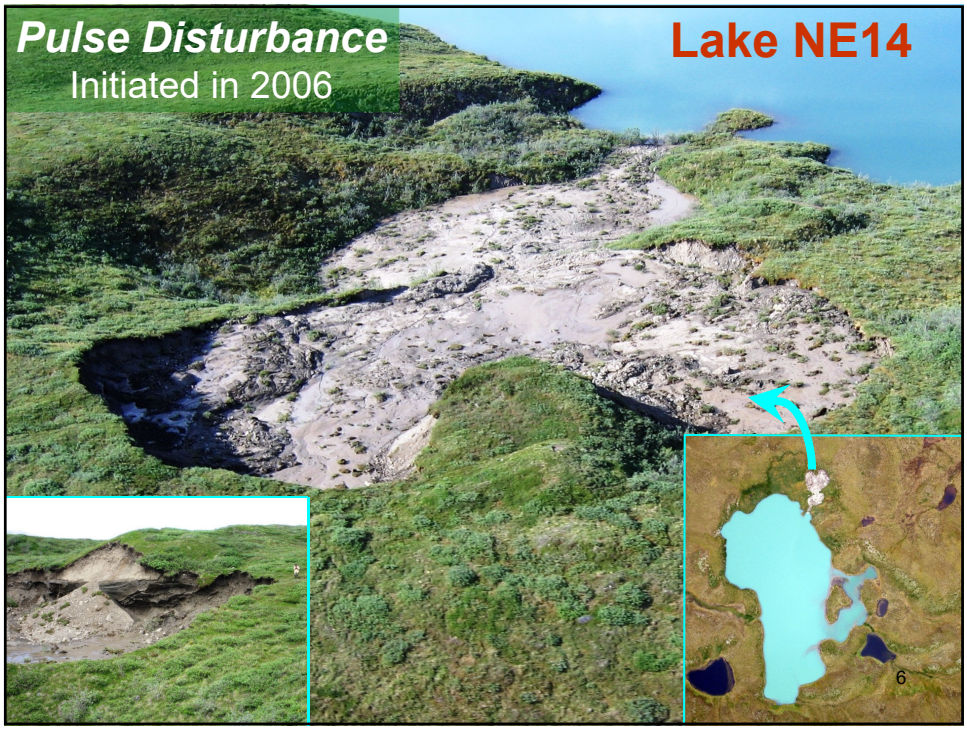

Global Carbon Pools and Fluxes (Pg C and Pg C y-1)
Permafrost soils 1,600 Pg C
Terrestrial 2,400 Pg C
(Plant + Soil)
Fossil Fuel + Land Use 9
Net of photosynthesis and respiration 3
Atmosphere 860 Pg C
+ 4/yr
2.2
Land to water 2.7
Evasion 1.2
Rivers 0.7
Lakes 150 Pg C
Lake and river burial 0.6 – 1.6 / yr
Oceans 39,000 Pg C
Hansell 2002, Canadell et al. 2007, Battin et al. 2009, Aufdenkampe et al. 2011, Tarnocai et al. 2009, Batjes 1996, Kling et al. 1991
3


LTER Land-water Openness and Connectivity
Photosynthesis generates organic matter and DOM
CO2
Global warming amplification
Alteration and transport of C and N in the Light
Soil
Thaw
DOC
DON
HCO3
Lakes
Streams
Alteration and transport of C and N in the Dark
DOC
DON
HCO3
Ocean
Arctic amplification depends on the connectivity of C and N from land to water, and the integrated microbial and photochemical processing of newly released permafrost C and N
4


Lake NE 14
Disturbance
1. Fire = "Pulse"
2. Thermal erosion:
a. Thermokarst failure = "Pulse"
b. Permafrost thaw from climate warming = "Press"


Pulse Disturbance
Initiated in 2006
Lake NE14
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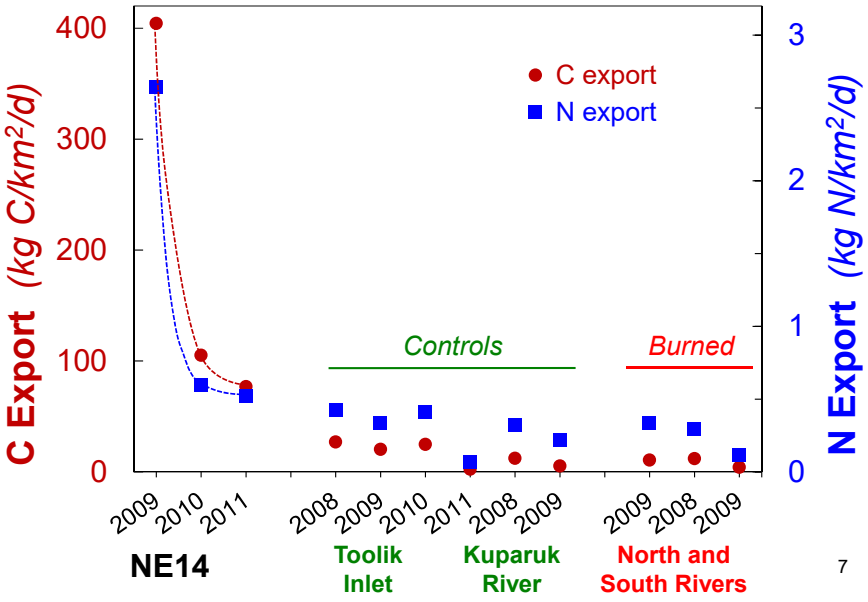
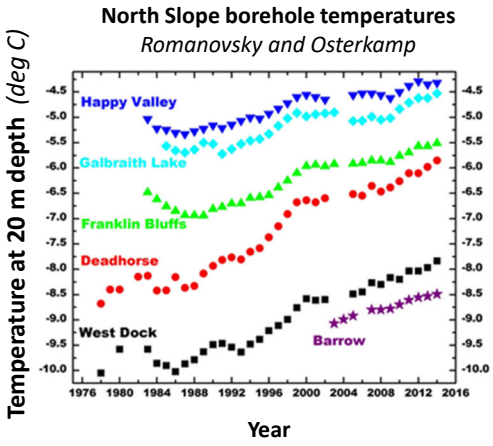
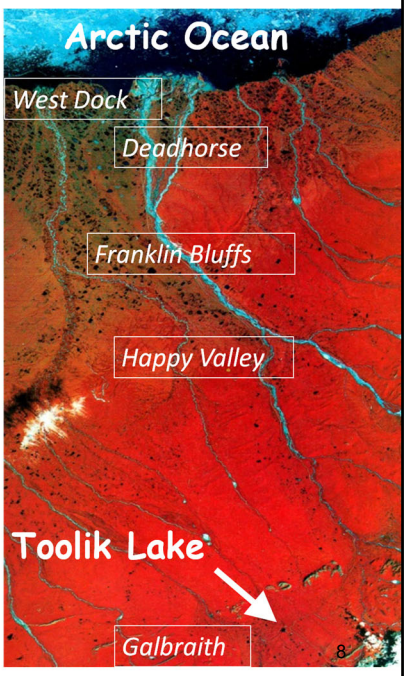
Pulse disturbance propagated from land through the lake, and C and N export increased *(but recovered…)*

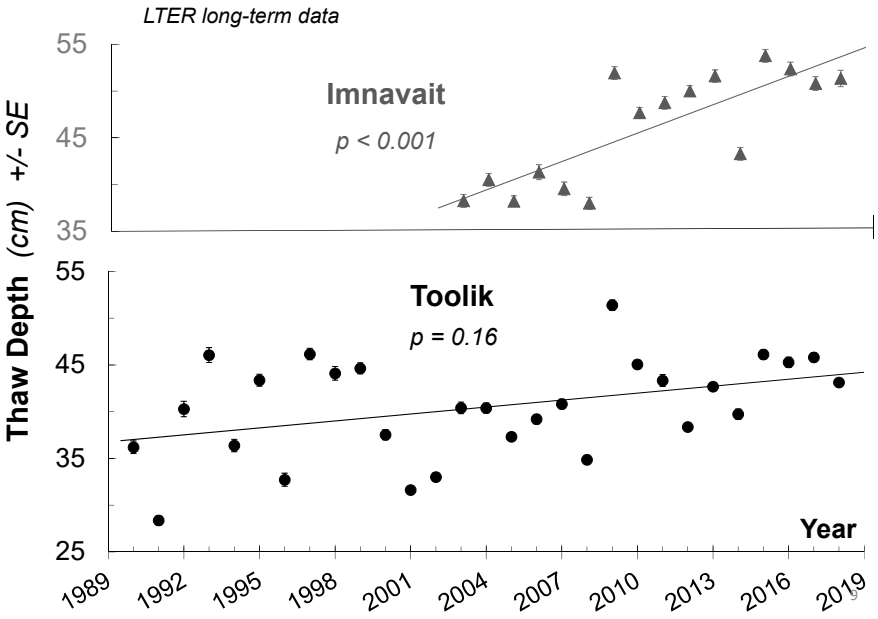


Permafrost temperatures on the Alaskan North Slope *have increased*

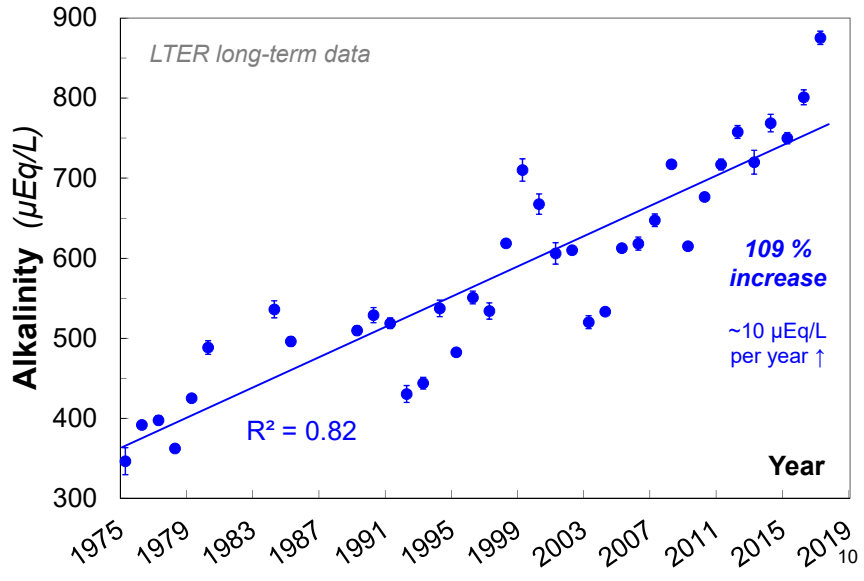




Late summer thaw depth near Toolik has increased

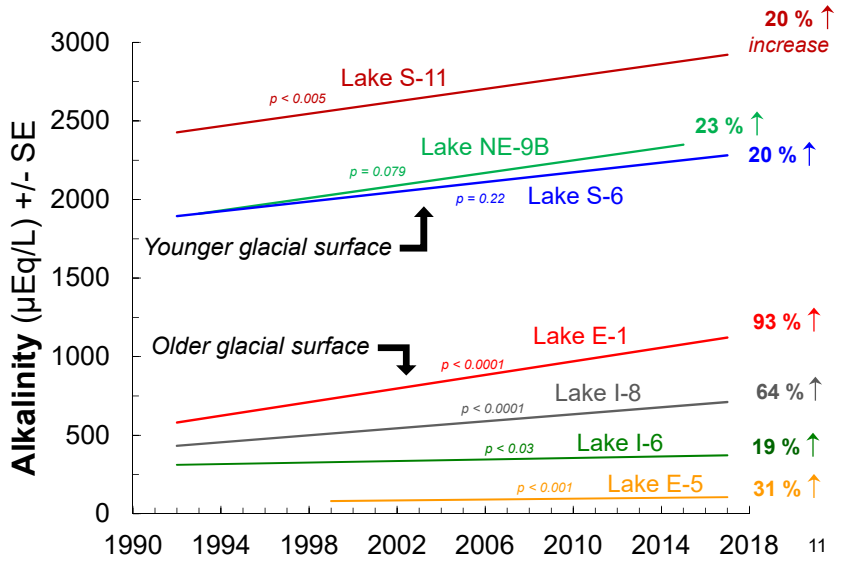


Toolik Lake alkalinity *has doubled* in 40 years, due to increased weathering of deeper, carbonate-rich soils



Regional LTER lakes have increased alkalinity

~20 - 93% increase in 25 years



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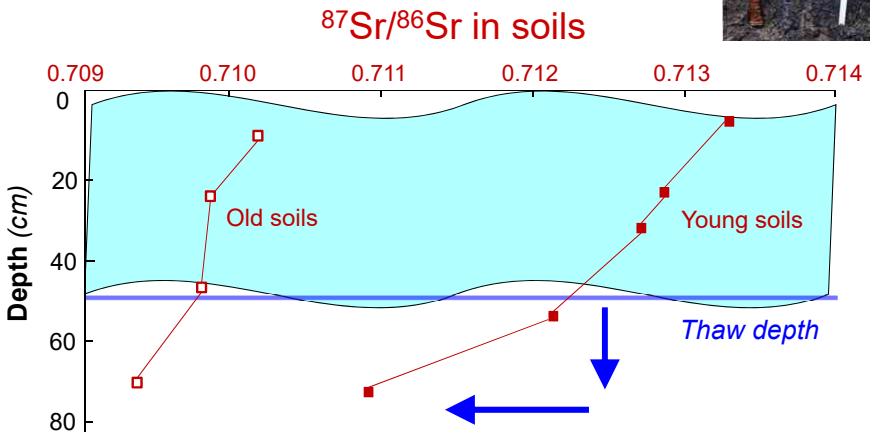
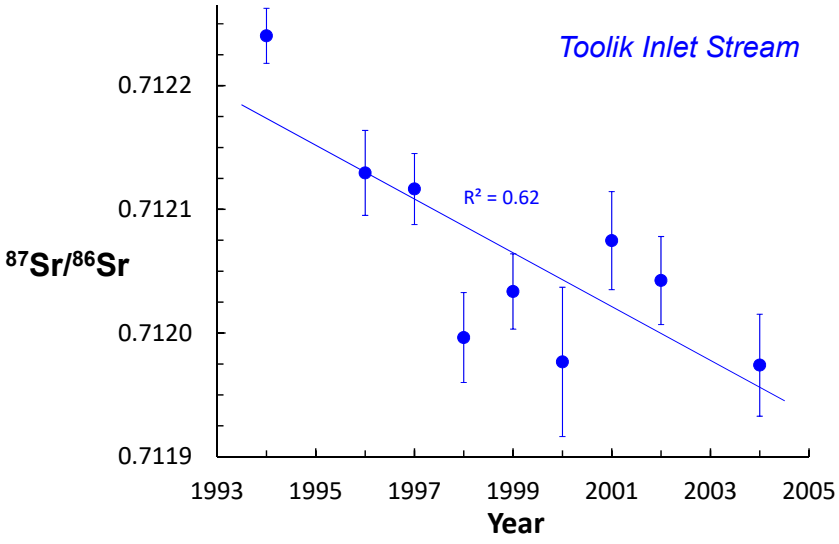
Geochemical Patterns in Soils:

- *Less weathering at depth*
- *More carbonate at depth*



Stream geochemistry reflects *hydrologic flowpaths* in soils

Stream Water $^{87}Sr/^{86}Sr$ has Decreased over Time



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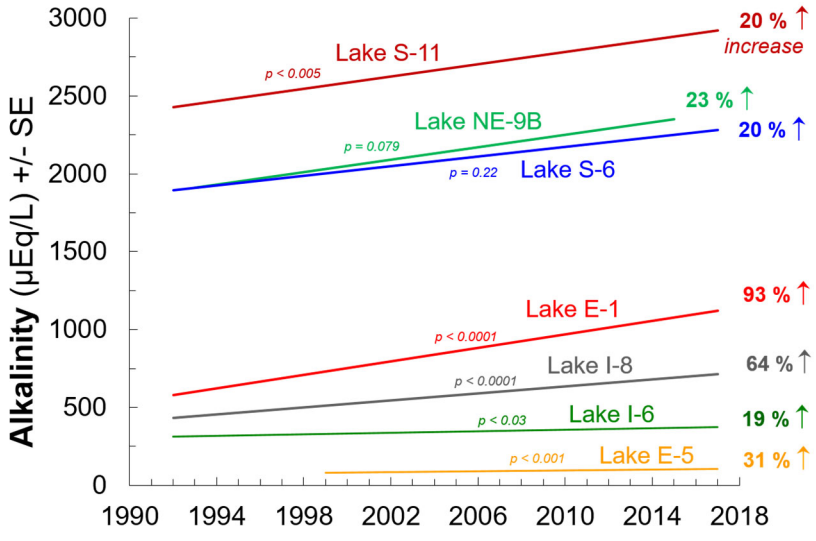
The influence of a press disturbance depends on the "inherent system limitations"



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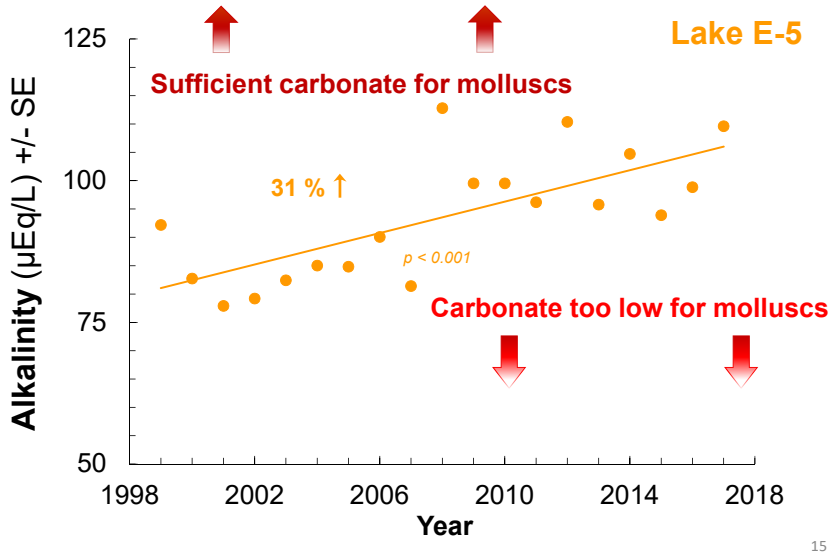
Disturbance impacts depend on inherent "system limitations"



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What *controls* openness and connectivity of C and N from land to water?

Where does the high DOC in snowmelt runoff come from when the ground is still frozen?

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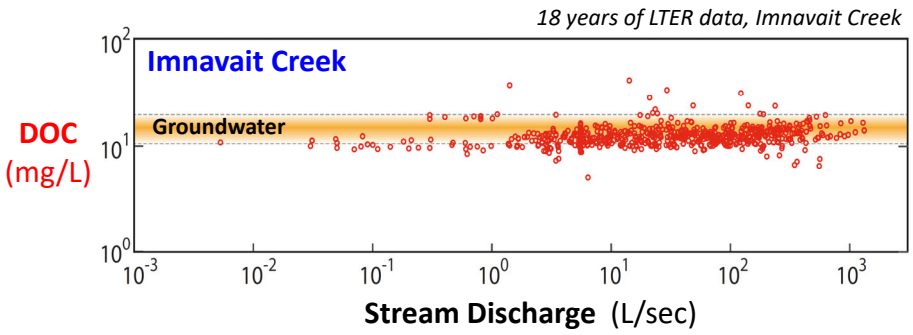
What keeps DOC concentrations similar over almost 6 orders of magnitude of discharge?



The mechanism of this "chemostasis" is rapid leaching of organic material and vertical mixing of DOC in soils

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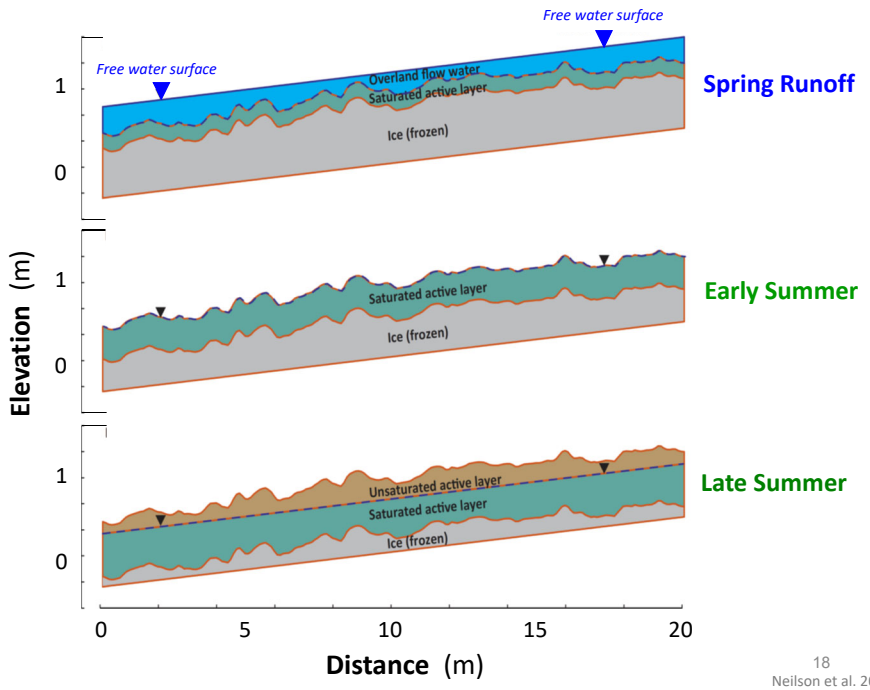
Neilson et al. 2018



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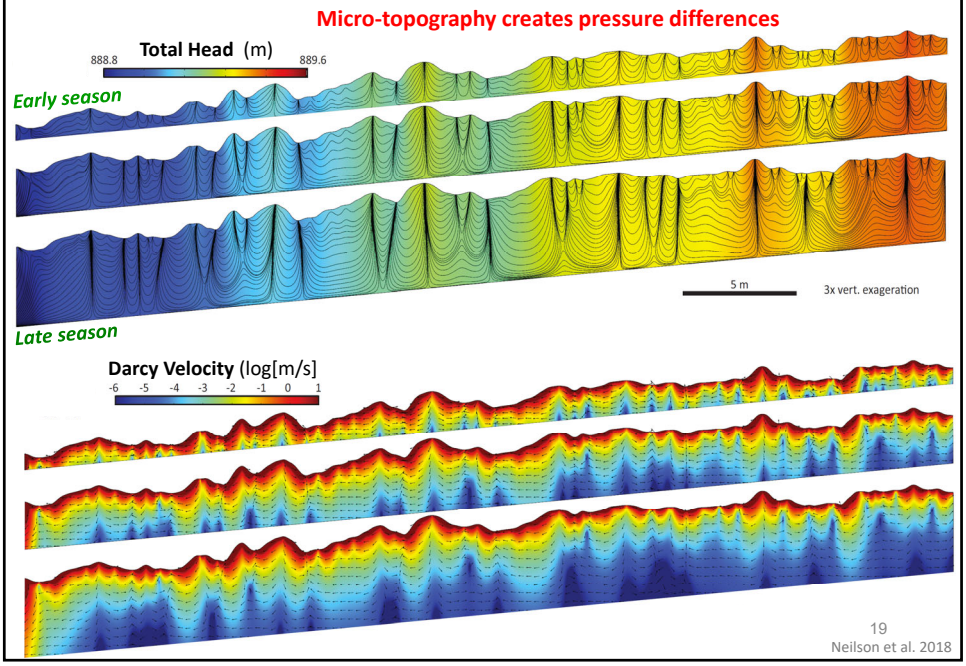
Neilson et al. 2018

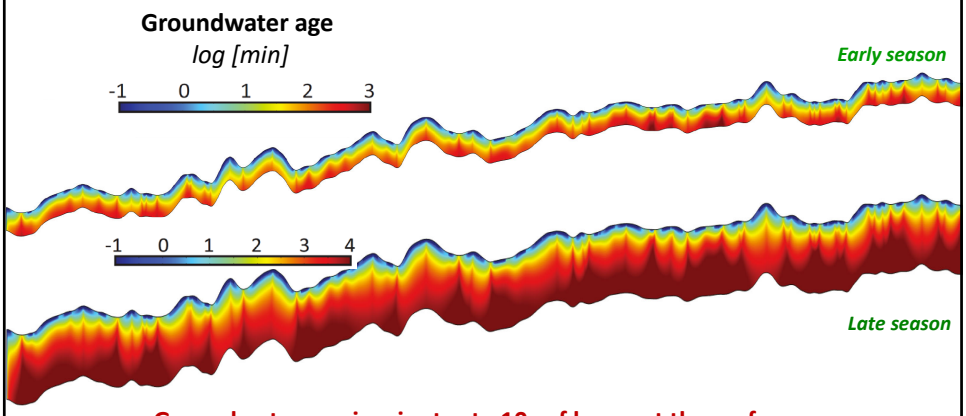
Flow modeling of *saturated* conditions on the hillslope



19
Neilson et al. 2018

Is leaching rapid enough to affect groundwater DOC?

Leaching produces **2–12 mg C/L/day**



Groundwater age is minutes to 10s of hours at the surface

The groundwater ages allow sufficient time for leaching of DOC from soils as water moves downslope

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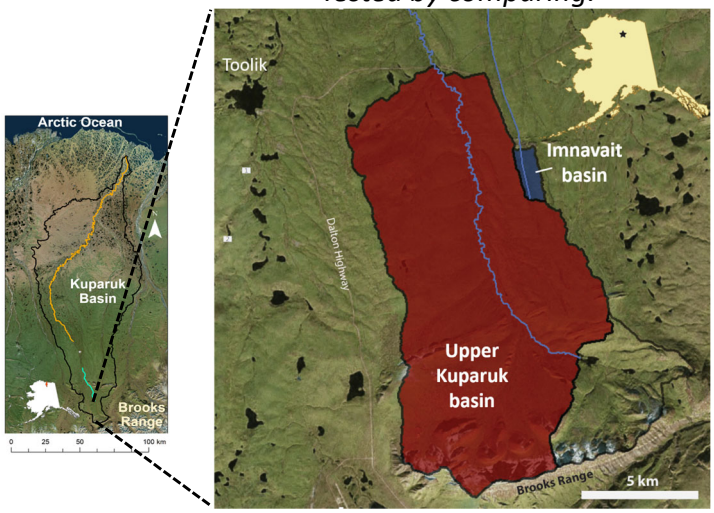
Do these mechanisms that control basin C output (connectivity) operate at larger scales?

Our hypothesis is YES, they should

Tested by comparing:



Imnavait basin

Headwater stream, 2.2 km² area

Upper Kuparuk basin

Fourth order river, 43 km² area

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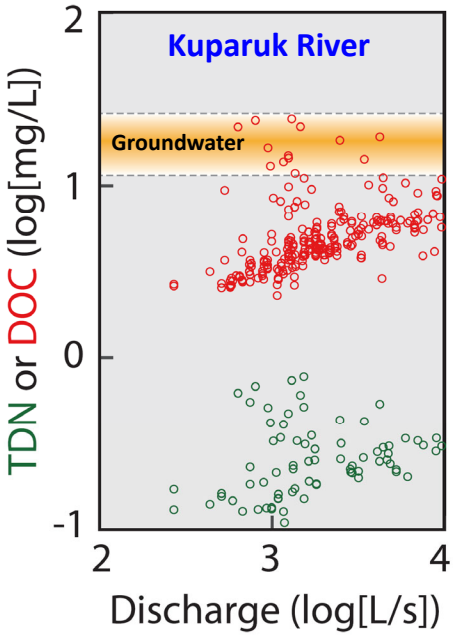

DOC concentrations in the larger Kuparuk River are ***lower*** than groundwater concentrations

It is possible that:

1. *The mechanisms that control DOC in Imnavait basin and its surface stream do not operate at larger scales*
2. *Additional controlling mechanisms are important at larger scales…*

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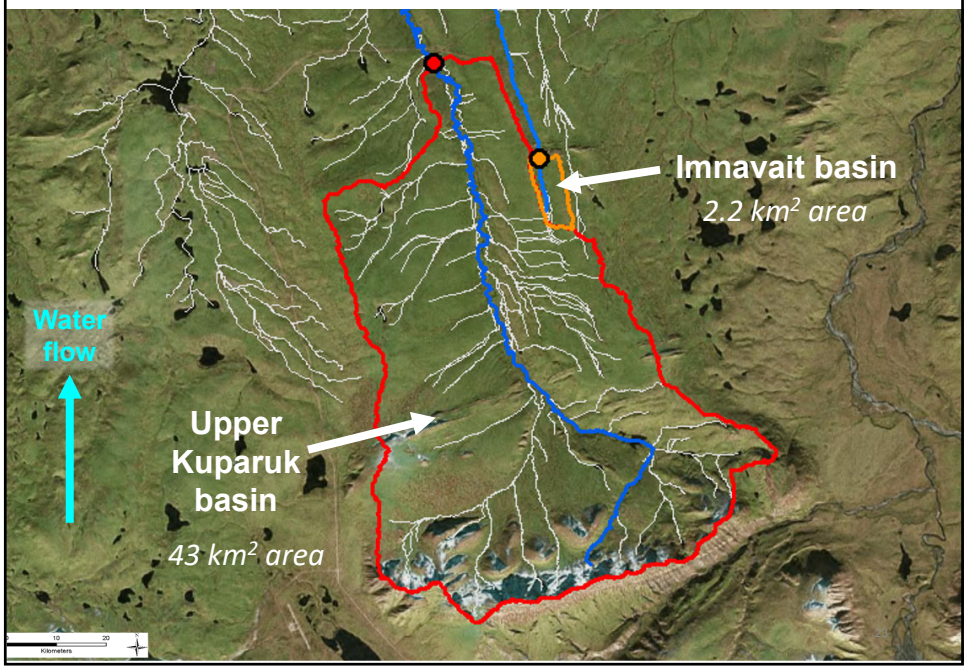
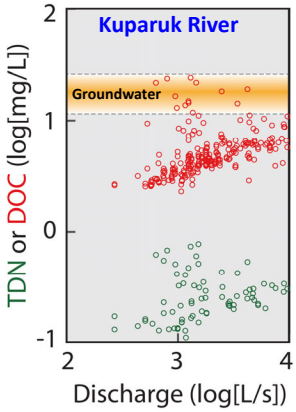
Travel times of surface water are longer in larger networks



The lower DOC in surface waters than in groundwaters is due to microbial and photochemical consumption of DOC in the river network



$DOC_{groundwater}$
– *(microbial respiration)*
– *(photomineralization)*

= DOC_{river}

What about DON?

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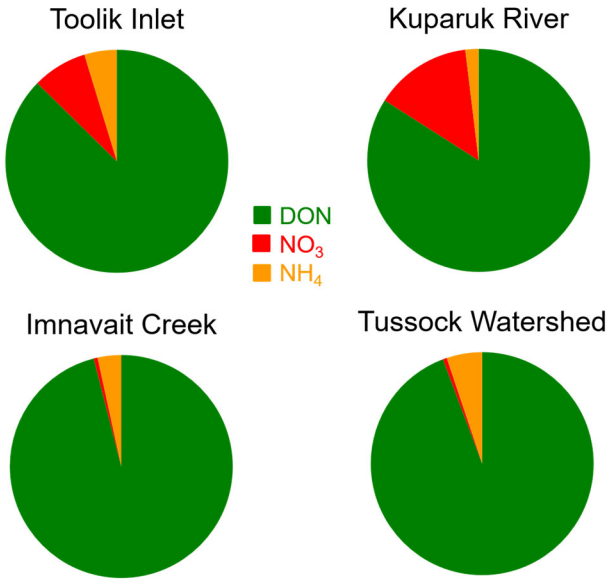
DON dominates land-to-water N export



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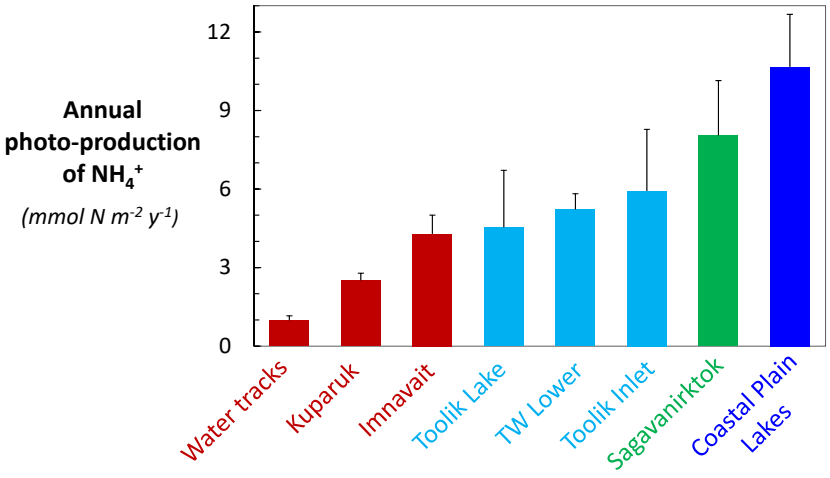
Activity #3. *Does NH_4 photo-production increase land to water connectivity?*

Rates of DOM → NH_4^+ photo-production are similar to other net fluxes of N in arctic surface waters



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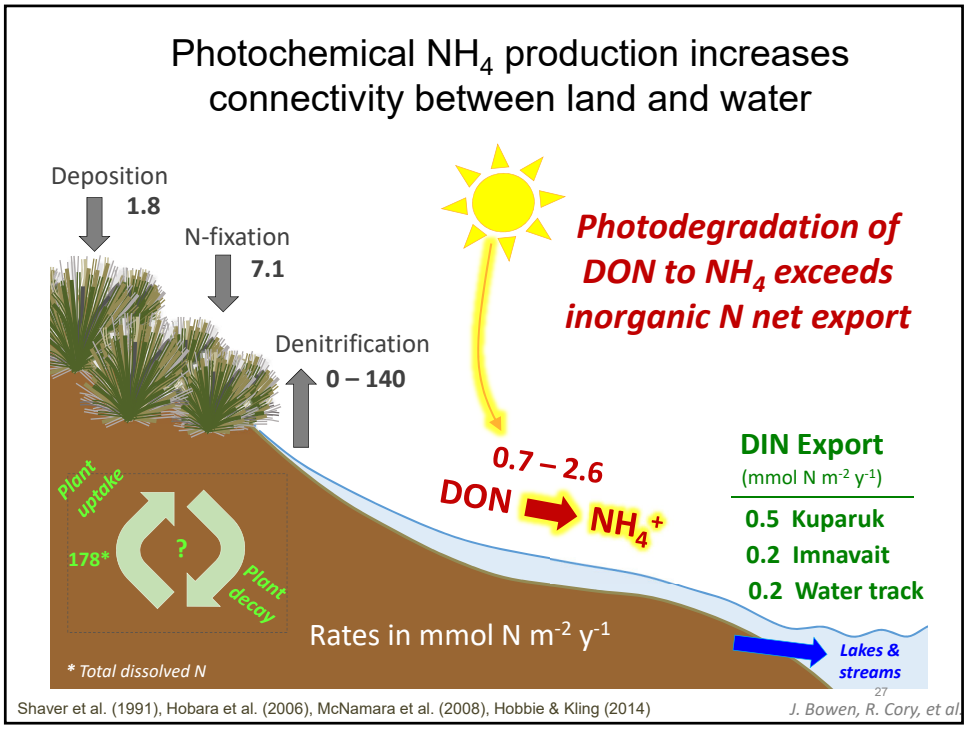
J. Bowen, R. Cory, et al.


Photochemical NH4 production increases connectivity between land and water
Deposition
1.8
N-fixation
7.1
Denitrification
0 – 140
Photodegradation of DON to NH4 exceeds inorganic N net export
0.7 – 2.6
DON
NH4+
DIN Export
(mmol N m-2 y-1)
0.5 Kuparuk
0.2 Imnavait
0.2 Water track
Plant uptake
178*
?
Plant decay
Rates in mmol N m-2 y-1
* Total dissolved N
Lakes & streams
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Shaver et al. (1991), Hobara et al. (2006), McNamara et al. (2008), Hobbie & Kling (2014)
J. Bowen, R. Cory, et al.

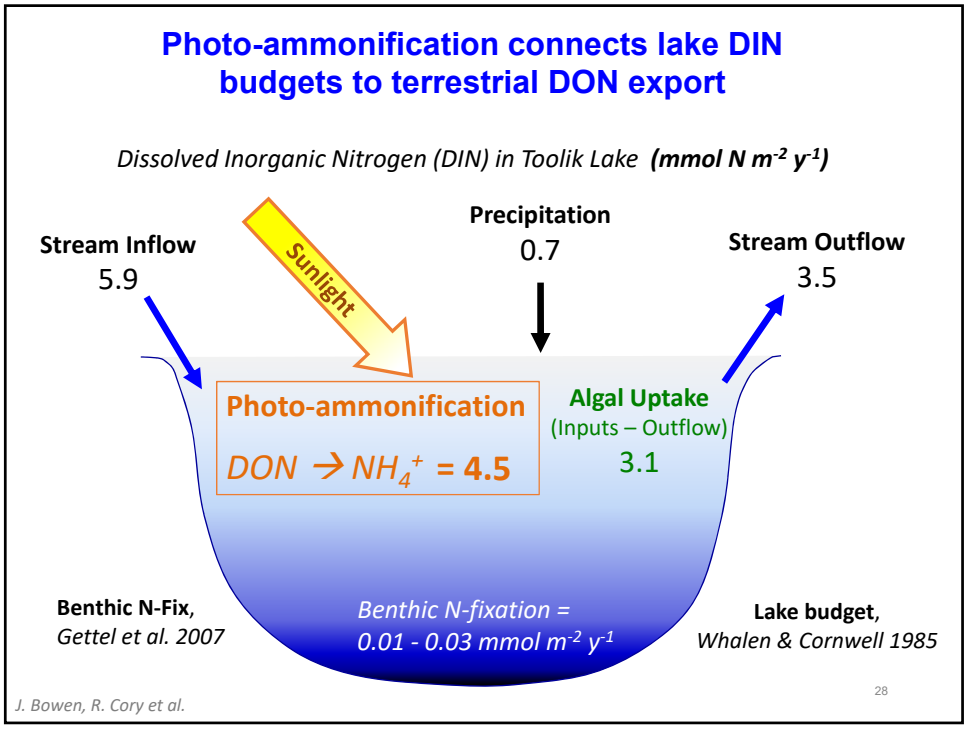
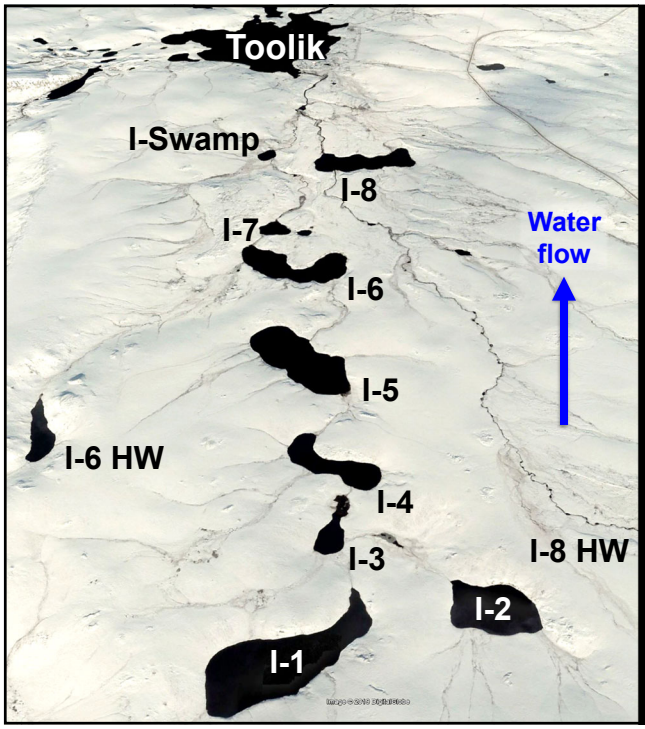


Photo-ammonification connects lake DIN budgets to terrestrial DON export
Dissolved Inorganic Nitrogen (DIN) in Toolik Lake (mmol N m-2 y-1)
Stream Inflow
5.9
Sunlight
Precipitation
0.7
Stream Outflow
3.5
Photo-ammonification
DON → NH4+ = 4.5
Algal Uptake
(Inputs – Outflow)
3.1
Benthic N-Fix,
Gettel et al. 2007
Benthic N-fixation =
0.01 - 0.03 mmol m-2 y-1
Lake budget,
Whalen & Cornwell 1985
28
J. Bowen, R. Cory et al.



The *Inlet Series* of lakes and connecting streams in the Toolik basin

Microbial community openness and connectivity in the Inlet Series (I-Series) of lakes and streams.

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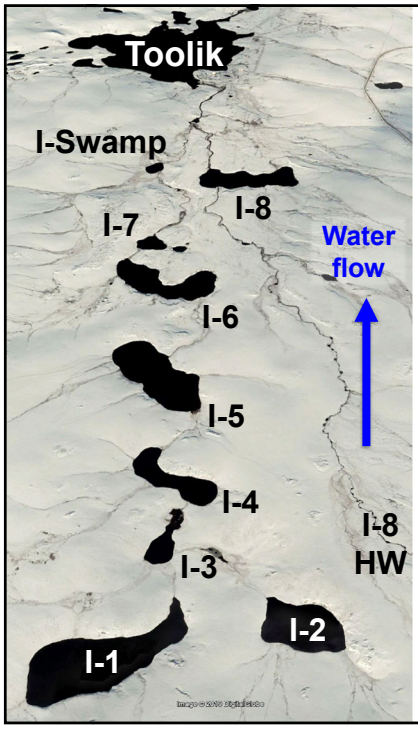
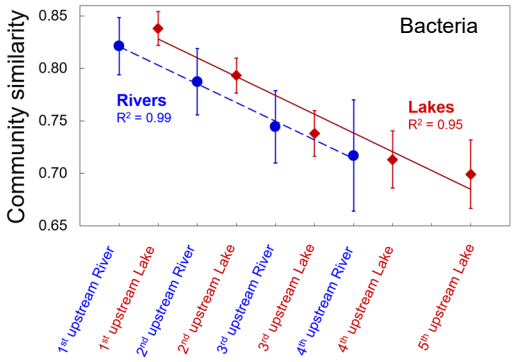


Nearby sites have similar communities



Degree of landscape separation

Suggests both openness and connectivity to disperse microbes, followed by species-sorting in each habitat

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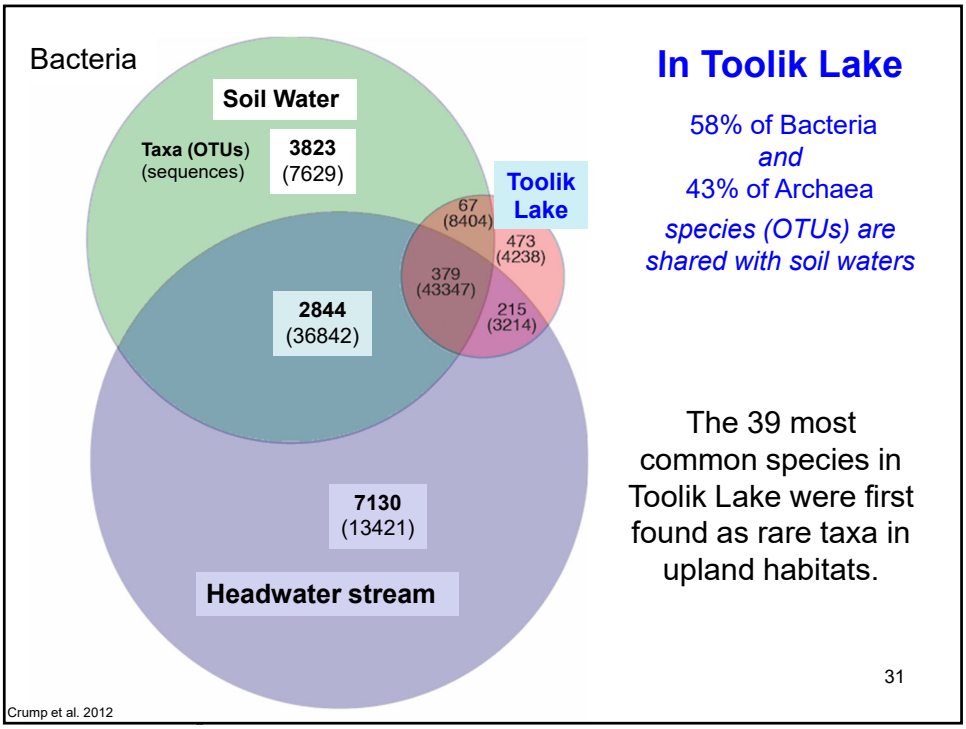
Bacteria
Soil Water
Taxa (OTUs)
(sequences)
3823
(7629)
Toolik
Lake
67
(8404)
473
(4238)
379
(43347)
215
(3214)
2844
(36842)
7130
(13421)
Headwater stream
In Toolik Lake
58% of Bacteria
and
43% of Archaea
species (OTUs) are
shared with soil waters
The 39 most common species in Toolik Lake were first found as rare taxa in upland habitats.
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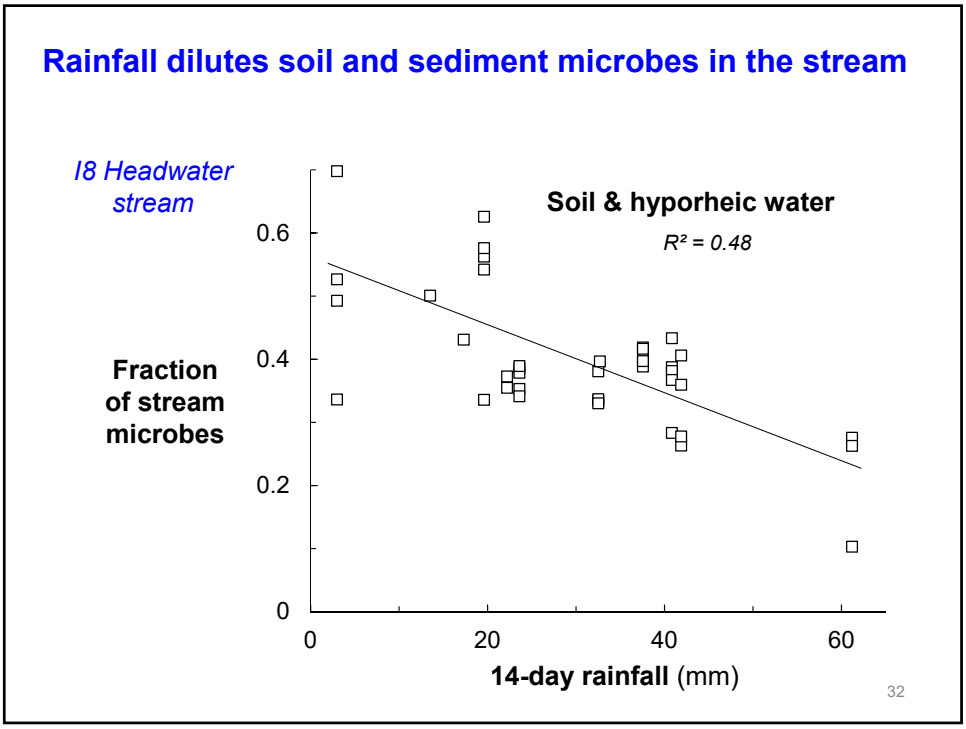
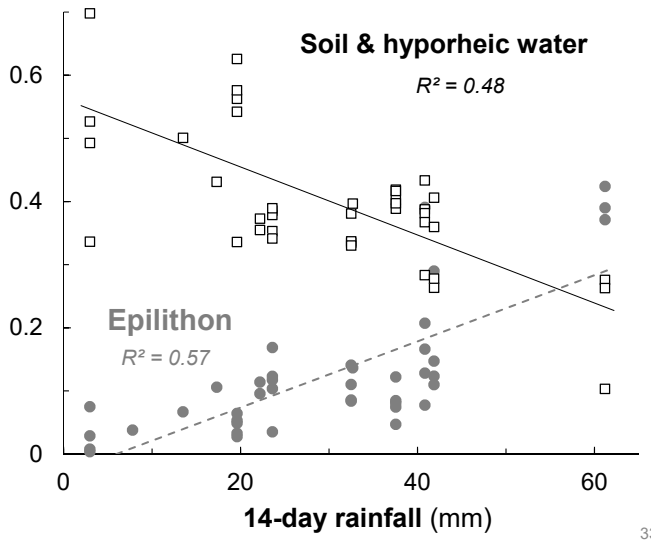
Crump et al. 2012


Rainfall dilutes soil and sediment microbes in the stream
I8 Headwater stream
Soil & hyporheic water
R² = 0.48
Fraction of stream microbes
0.6
0.4
0.2
0
0
20
40
60
14-day rainfall (mm)
32

Rainfall dilutes soil and sediment microbes, and *washes more epilithon microbes* into the stream

I8 Headwater stream



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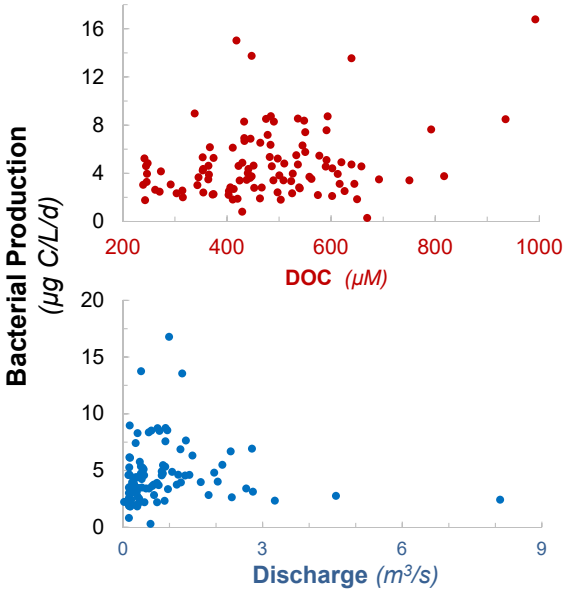
Toolik Inlet stream *2009-2016, all dates*



Future work on genomic analyses to assess how microbial function depends on microbial connectivity across the landscape

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Conclusions

1. Long-term *Press* disturbances *(e.g., climate change)* **increase land-to-water connectivity, and the impacts depend on the inherent "system limitations"** *(e.g., carbonate limitation on mollusc shells)*

2. Short-term *Pulse* disturbances rapidly amplify land-water connectivity, but recovery time is relatively short

3. The processes affecting land-water connectivity change at different scales *(Imnavait vs. Kuparuk)*

4. Photo-ammonification strengthens land-water connectivity, and could be a substantial source of inorganic N in surface waters.

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