Riverbank erosion and its consequences in the Yukon River Basin

Woodward W. Fischer[1], Michael P. Lamb[1], Marie E. Lowe[2], Edda Mutter[3], Joel C. Rowland[4], A. Joshua West[5], Samantha R. Baker[1], Rain Blankenship[5], James L. Dickson[1], Hannah Dion-Kirschner[1], Madison M. Douglas[1], Kieran B.J. Dunne[1], Emily C. Geyman[1], Yutian Ke[1], Nelson Kempt[2], John S. Magyar[1], Kimberly L. Miller[1], Jocelyn N. Reahl[1], M. Isabel Smith[5], Alakanuk Traditional Council, Beaver Village Council, Huslia Tribal Council, First Chief Norman Burgett[6], President Raymond Oney[7], First Chief Rhonda Pitka[8]

[1]California Institute of Technology – Division of Geological and Planetary Sciences
[2]University of Alaska Anchorage – Department of Public Policy and Administration
[3]Yukon River Inter-Tribal Watershed Council
[4]Los Alamos National Laboratory
[5]University of Southern California – Department of Earth Sciences
[6]Huslia Tribal Council
[7]Alakanuk Traditional Council
[8]Beaver Village Council

Overview:

Rivers and floodplains are particularly susceptible to a warmer climate due to permafrost thaw that can lead to accelerated erosion. This erosion threatens critical infrastructure and disrupts community life. Here we summarize objectives and early findings from a new NNA project to understand riverbank erosion and its impact on contaminants including heavy metals, such as mercury, along with carbon, nutrients and pathogens. In tandem, we are working to understand regional adaptive capacity and how actionable plans and policies can be used to meet local challenges presented by riverbank erosion. The project involves a collaboration across the natural and social sciences, the Yukon River Intertribal Watershed Council, and with three partner communities in the Yukon River basin.

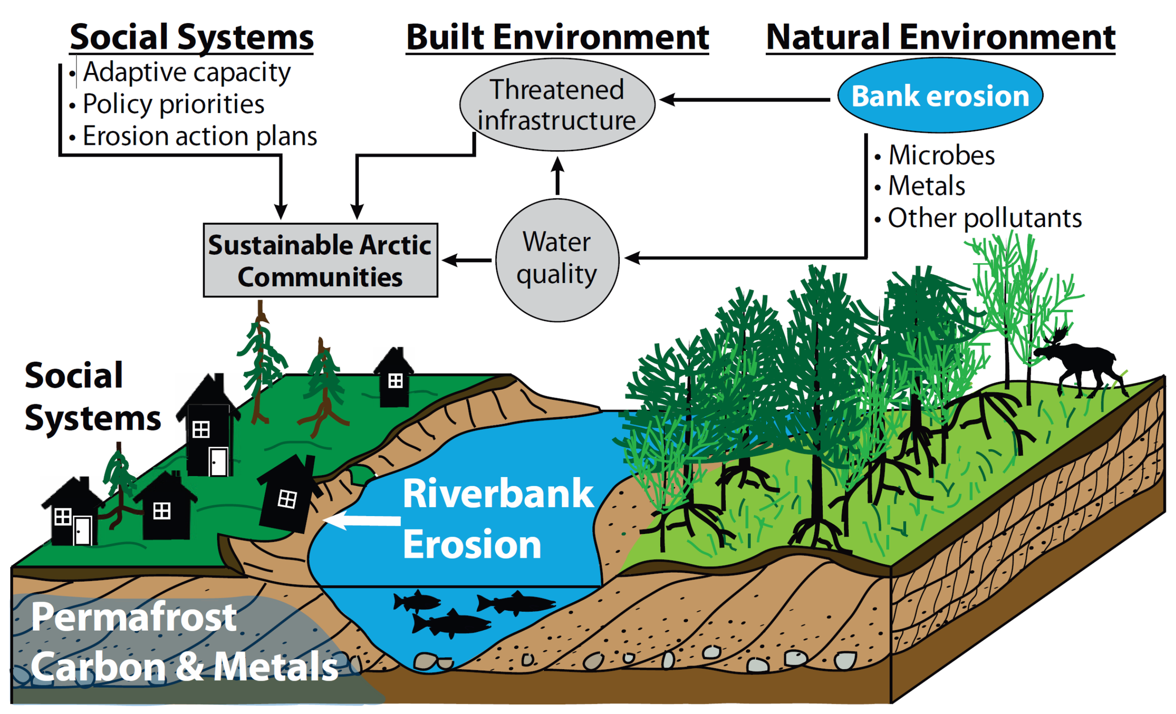

Fig 1: Riverbank erosion impacts human and ecosystem health by damaging community infrastructure and releasing metals and other pollutants sequestered in riverbanks. Effective adaptation plans requires assessment of adaptive capacity and policy priorities. Understanding the connected natural and social system requires an interdisciplinary team and a community-based approach

Field Campaign:

This project involves field campaigns at three locations centered around three Alaskan communities within the Yukon River Basin. Each location offers a different substrate and geomorphic setting:

1. **Beaver – Yukon River**
   - Gravel-bedded
   - Anabranched channel system
2. **Huslia – Koyukuk River**
   - Sand-bedded
   - Single-threaded, meandering channel system
3. **Alakanuk – Yukon River**
   - Deltaic environment
   - Silt-bedded

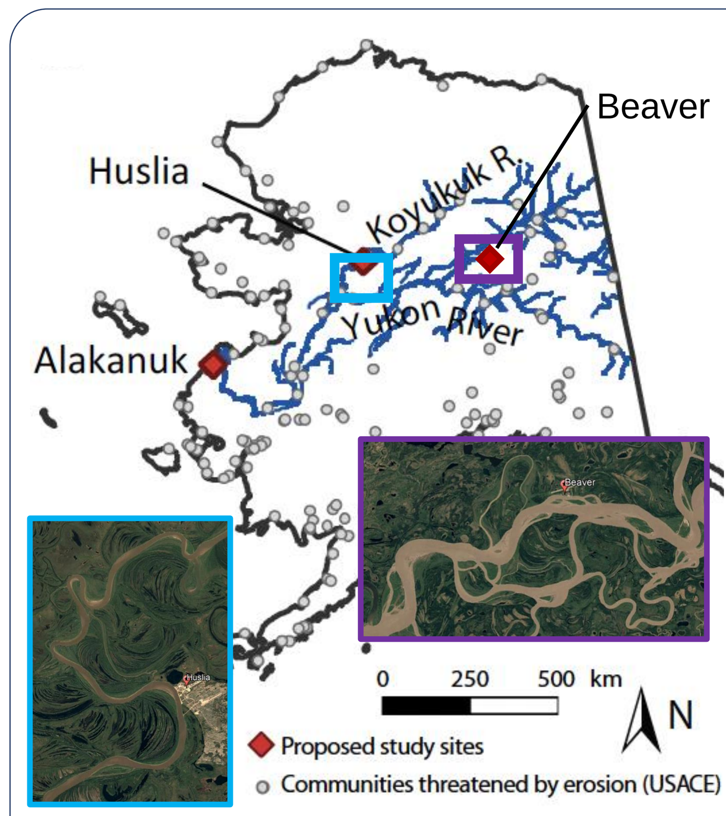

Fig 2: Field work in Huslia and Beaver was conducted over the summer of 2022. Field work will be conducted in Alakanuk in the coming years. Insets: Satellite imagery of channels at Huslia (cyan) and Beaver (purple) (source: Google Earth).

All field sites were selected to be in regions of discontinuous permafrost in order to provide points of comparison between permafrost and non-permafrost riverbanks in the same regions. At each sites, three river bends were selected for continuous erosion monitoring using time lapse cameras and water temperature and stage height sensors. Surveys of bank materials and properties, water column samples, and UAV imagery were taken at these bends during field deployments.

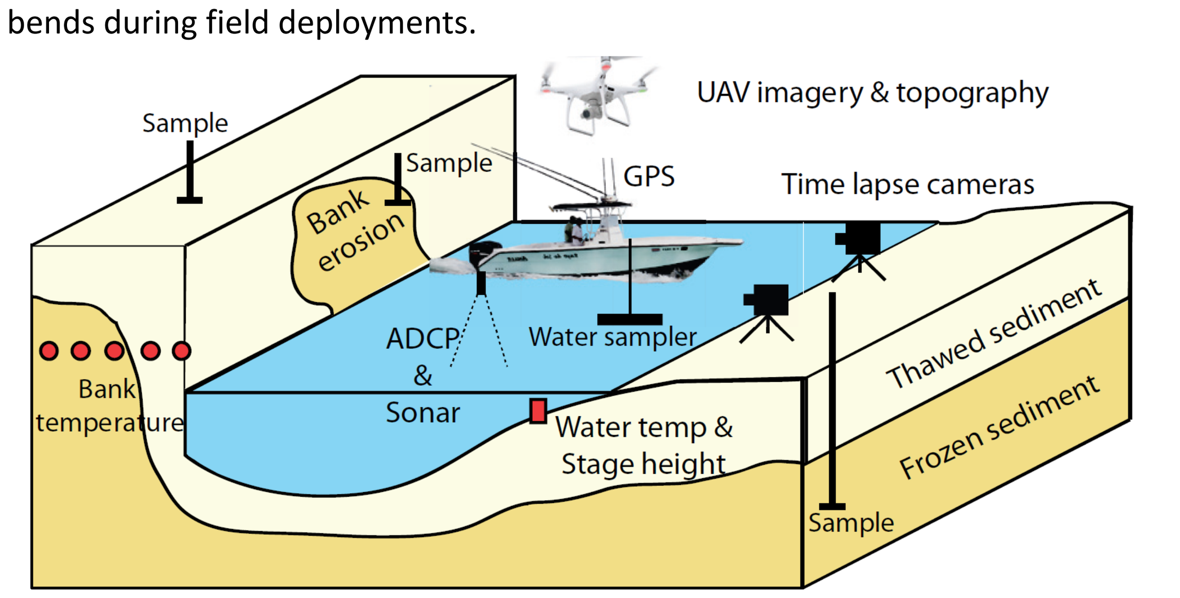

Fig 3: Field sampling and survey methods for riverbanks and water columns.

Community Engagement:

This project has been developed with support of the Beaver Village Council, the Huslia Tribal Council, and the Alakanuk Traditional Council to enhance their communities' climate-change adaptive capacity. In September, the project team hosted community meetings in Huslia and Beaver to build community connections and to engage in discussion about their research objectives and activities. The meetings also gave the team an opportunity to listen and learn from community members about their environmental observations and erosion impacts in their region. The knowledge shared with the team will further inform the physical and social data collection. The meetings also gave the opportunity to discuss the establishment of the Erosion Action Group, an advisory group consisting of community members, that will serve to ensure project tasks are aligned with community concerns, and to support the Yukon River Inter-Tribal Council efforts in establishing a community driven Erosion Action Plan. The research team engaged with the local schools and teachers to explore additional outreach opportunities for the upcoming field season.

Fig 4: Photos from the community meeting in Huslia during Fall 2022 field campaign. Team members discussed spatial patterns of riverbank erosion and chemical composition of riverbank materials with members of the Huslia community. Photos: John Magyar.

Geobiology:

During the field campaigns in both June and September 2022, we collected samples of bank sediment and suspended sediment (via water filtration) for microbial community analysis. We will connect microbial abundance, community composition, and activity measurements to geochemical, hydrological, sedimentological, and geomorphic metadata to construct landscape-scale maps and estimates of geochemical and microbiological processes associated with bank erosion and evaluate how these change throughout the season and year-to-year. We are particularly interested in the potential role of microbes in water quality—in particular their role(s) in mobilizing/immobilizing mercury and other heavy metals in the environment, as well as transformations involving the sediment and carbon liberated from bank erosion. We will also investigate whether or not there is evidence for mobilization of pathogenic microbes in these ecosystems. Sampling sites include banks and bars on the main rivers (Koyukuk and Yukon), depth profiles of the main river channel (for suspended sediment), and suspended sediment collected from a variety of adjacent clearwater sloughs, oxbow lakes, ponds, and tributary streams within the watershed.

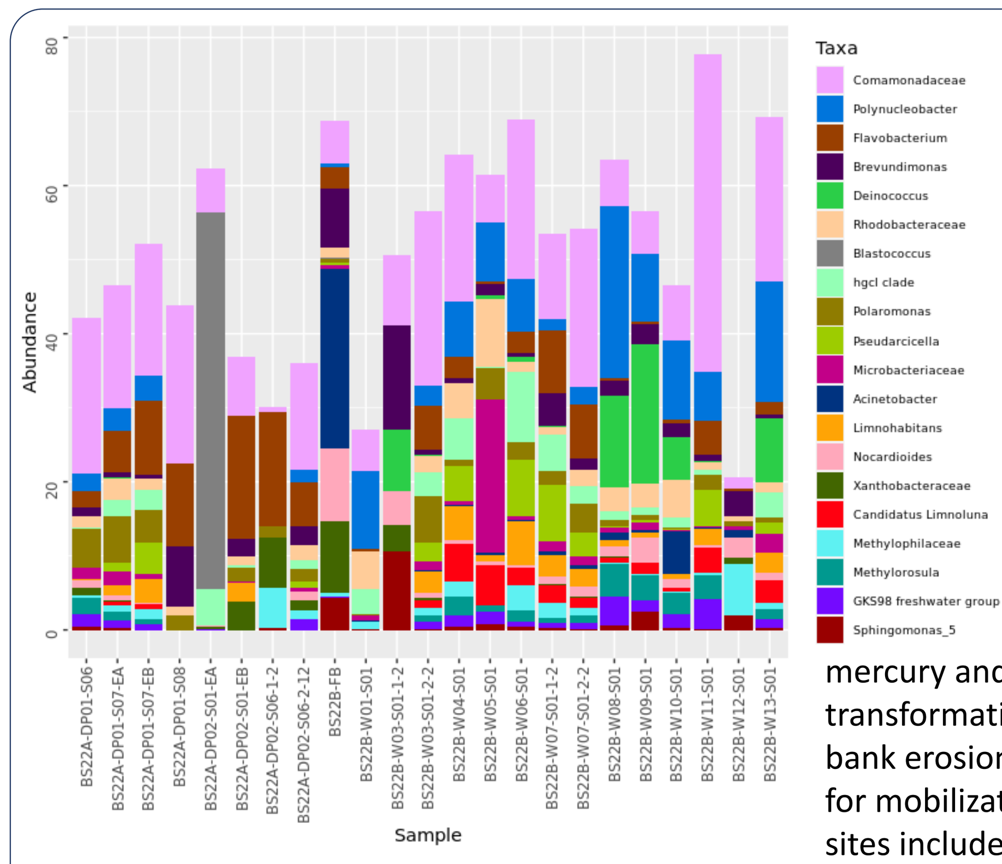

Fig 5: Preliminary data from 16S rRNA amplicon sequencing revealed that the microbial communities associated with suspended sediments within the river are very different from those from bank samples (data not shown).

Organic Carbon:

Arctic permafrost contains approximately 1300 ×10³ Mt of organic carbon (OC), accounting for around 50% of global soil organic carbon in only 15% of land area and more than two times the size of the global pre-industrial atmospheric carbon (1, 2, 3). Eroded solids are transported in the form of suspended particulate matter (SPM) in the fluvial system, carrying terrestrial OC in the form of particulate organic carbon (POC), redistributing eroded OC to varying geomorphic units and leading to different fates. In this project, we seek to quantify the effects of permafrost riverbank erosion on transport, fluxes, and fates of OC.

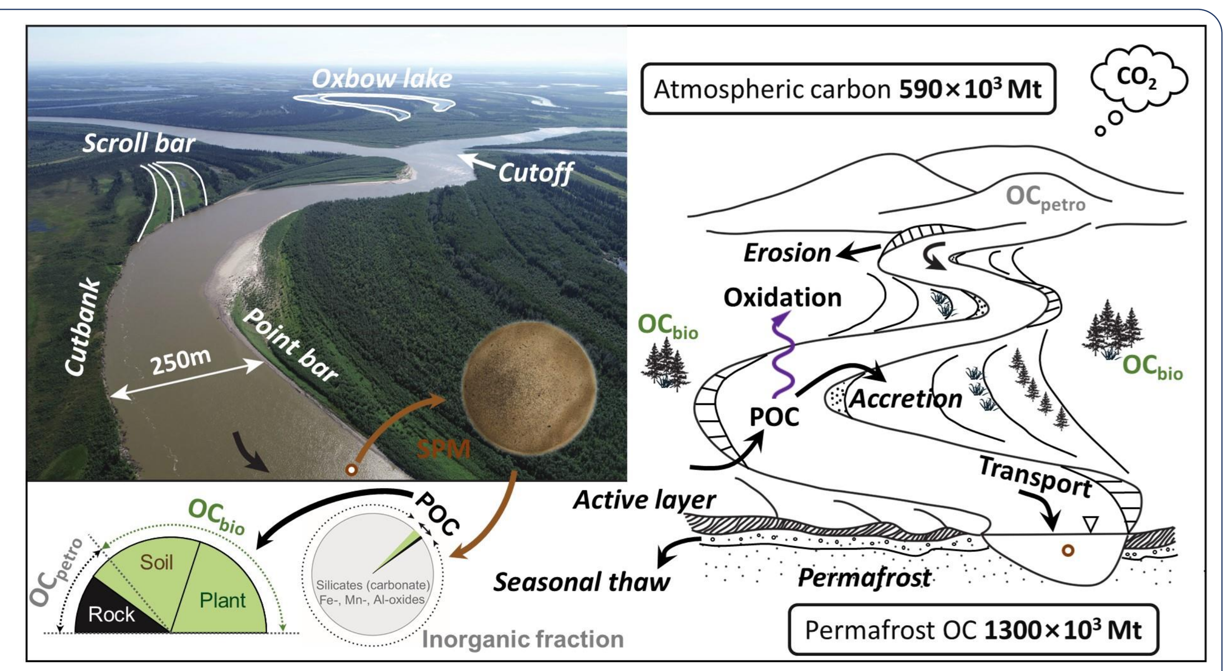

Fig 6. Erosion, transport, and fates of terrestrial organic carbon in permafrost fluvial systems (updated from (4)). Fluvial particulate organic carbon (POC) can be explained by a binary mixing of OC derived from the terrestrial biosphere (OC_{bio}) and OC_{petro} eroded from sedimentary rocks (5, 6), oxidation of both fractions has positive feedback on elevating atmospheric CO_2 level.

Remote Sensing:

Remotely sensed imagery allows for the quantification of erosion, deposition, and water temperature through change detection over meters to 100s of kilometers of river reaches. We have developed an integrated workflow that extracts pixel-scale measurements of riverbank dynamics using SCREAM software (7) which has been widely applied to river systems across the Arctic. This analysis of topographic change is being coupled with remote sensing of water temperature to understand how changing water temperature under the warming climate affects rates of riverbank erosion over both local and regional spatial scales. Observations will be evaluated against developed riverbank erosion theory and model development through other aspects of this project.

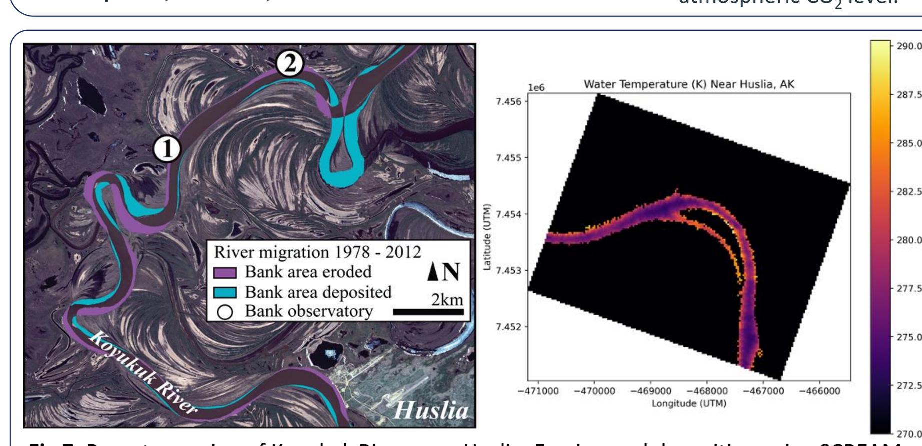

Fig 7: Remote sensing of Koyukuk River near Huslia. Erosion and deposition using SCREAM from 1978-2012 (left). Remote sensing of water temperature near Huslia (right).

Adaptive Capacity, Institutional Barriers, and Policy Priorities

Fig 8: Huslia riverbank erosion and impacts to infrastructure. Sept 2022. Photo: Marie Lowe

Fig 9: Huslia is adapting in place by building new housing away from the riverbank. Sept 2022. Photo: Marie Lowe

Fig 10: FEMA assistance specialist and Alakanuk resident discuss flooding disaster. July 2013. Photo: Adam DuBrowa/FEMA

Watershed communities are facing multiple stressors in addition to riverbank erosion that include: a severe collapse in salmon fisheries, water quality problems, housing shortages, and a lack of opportunities for youth. The UAA team is focusing on the social context for communities adapting to climate change-driven riverbank erosion by:

1. Evaluating regional adaptive capacity in co-developing a vulnerability index with the Yukon River Intertribal Watershed Council (YRITWC).
2. Understanding opportunities for and institutional barriers to adaptation using a Critical Institutional Analysis and Development framework.
3. identifying policy priorities via structured interviews with stakeholders, community leaders, and policymakers.

The vulnerability approach is important for applying climate risk assessments to planning efforts and policy strategies because it focuses the analyses on people and communities most affected by these risks. The broader impact goal is to collaborate with the YRITWC and project partner communities in efforts to draft, adopt, and implement Erosion Action Plans.

Bank Erosion:

Rapid warming in cold regions has been hypothesized to lead to the destabilization of riverbanks and drive more rapid rates of bank erosion and fluvial morphodynamic activity through the accelerated thawing of permafrost (8, 9). To determine how rates of bank erosion and lateral river channel migration might be affected by the warming climate, we are actively monitoring the erosion of riverbanks and the properties of the river water at each of the three sites over the course of the summers. By exploring the relationships between water temperature, discharge, fluid shear stress, and bank erosion we are investigating the driving mechanism behind permafrost riverbank erosion in order to understand how riverine activity in cold regions may change under the changing climate.

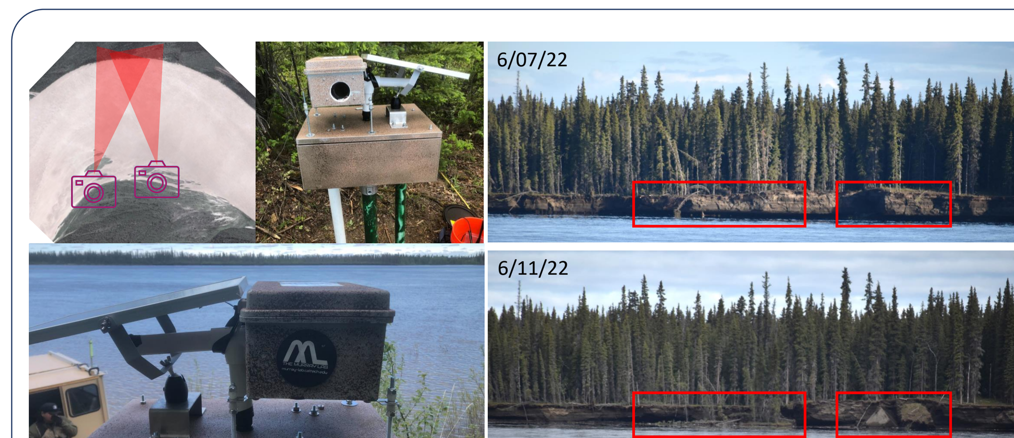

Fig 11: Camera stations were set up at multiple river bends to track bank erosion over the course of the summer. Each station consists of two cameras taking timelapse imagery with overlapping fields of view (left). Cameras captured images of large bank collapse events (right). Future work will use stereoimagery to create 3D models of banks to measure amounts of eroded bank material over time.

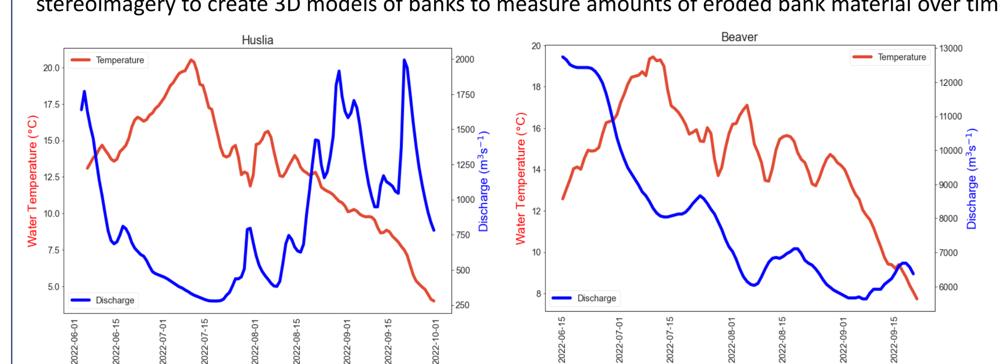

Fig 12: Measured time series of water discharge and temperature in the Koyukuk River at Huslia, AK (left) and the Yukon River at Beaver, AK (right). This work will explore how variations in water temperature and discharge drive rates of bank erosion in permafrost and non-permafrost riverbanks

Mercury:

Arctic permafrost contains many emergent pollutants like viruses, bacteria (10, 11, 12), anthropogenic (13, 14) contaminants, and biogeochemicals (15) that may pose great threats but are not well studied. The project will study water quality specifically looking at the release of mercury (Hg) from permafrost into Arctic rivers and how microbial response may change mercury methylation rates.

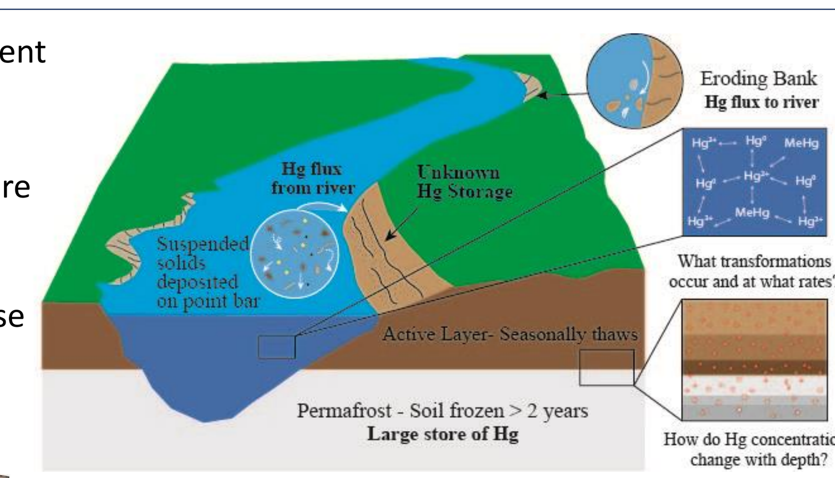

Fig 13. We have collected sediment and water samples from different parts of the floodplain to try to better understand the sources of Hg and its distribution throughout the river system. This information will help us to better constrain the net Hg flux budgets in these erosional systems and possibly provide insight on how these budgets may change as climate change progresses.

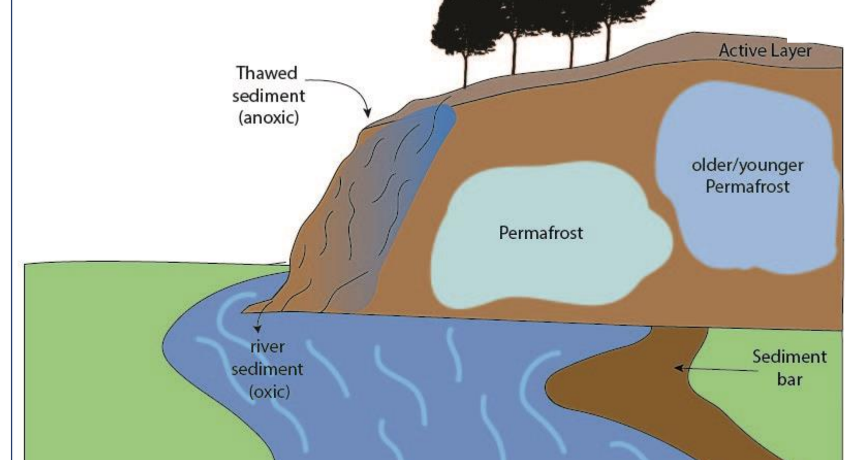

Fig 14: While in the environment, Hg can undergo transformations such as methylation by microbes (O'Connor et al, 2019). Methylmercury (MeHg) poses great risks as it has ability to bioaccumulate in organisms. As permafrost melts, microbial activity may change resulting in changes to methylation rates. To understand controls on mercury methylation, incubation experiments using Hg isotopes and paired DNA sequencing were conducted to analyze microbial communities across the erosion system and determine their potential to perform methylation.

Fig 15: We are interested in the microbial communities present in the clear waters of sloughs and oxbow lakes as well as higher-sediment-load waters of the mainstem river. Here, an oxbow (clear) meets the Yukon (turbid with suspended sediment).

1. Schurr et al., 2015. *Nature.*
2. Jorgenson et al., 2013. *Environmental Research Letters*
3. Hugelius et al., 2014. *Biogeosciences*
4. Douglas et al., 2022. *Earth Surface Dynamics*
5. Galy et al., 2015. *Nature*
6. Leihold et al., 2015. *Nature*
7. Rowland et al., 2016. *Remote Sensing of Environment*
8. Rowland et al., 2010. *Eos, Transactions American Geophysical Union*
9. Costard et al., 2007. *Geophysical Research Letters*
10. Edwards et al., 2020. *Microbial Genomics*
11. Polar Research Board *et al.*, 2020. *Proceedings of a Workshop*
12. Emerson et al., 2018. *Nature Microbiology*
13. Zolkos, et al., 2020. *Environ. Sci. Technol.*
14. Ewing et al., 2015. *Geochemica et Cosmochimica Acta*
15. Toohey et al., 2016. *Geophysical Research Letters*