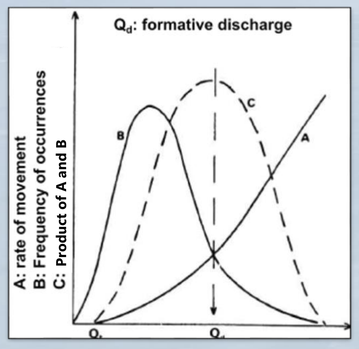
Using a hydraulic model to identify the formative discharge for gravel-bedded rivers that fill with ice

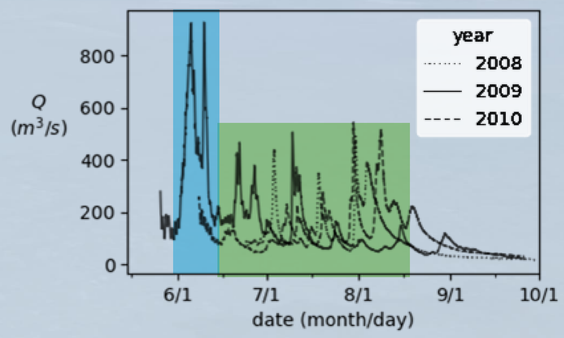
Josie Arcuri[1,2], David F. Vetsch[3], Irina Overeem[1,2]

[1]Institute for Arctic and Alpine Research, CU Boulder, [2]Department of Geological Sciences, CU Boulder, [3] VAW, ETH Zurich, Switzerland



Introduction

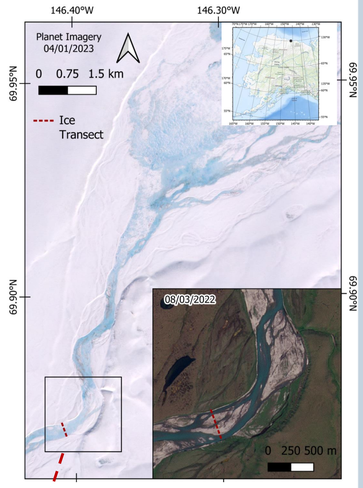
Over time, certain floods do the most "geomorphic work" on river beds and banks by maximizing the product of sediment transport rate and frequency. The flood that does the most geomorphic work is known as the "formative flood" and is characterized by a certain "formative discharge" [1]. However, it is unclear if this concept applies to freshet-dominated rivers in the Arctic that may be occupied by river ice for 7-9 months each year. Freshet-dominated rivers in this region receive a peak flood following snow melt while river ice can resist breakup for weeks. In contrast, summer floods generated by storm runoff occur when ice is absent, multiple times per year.

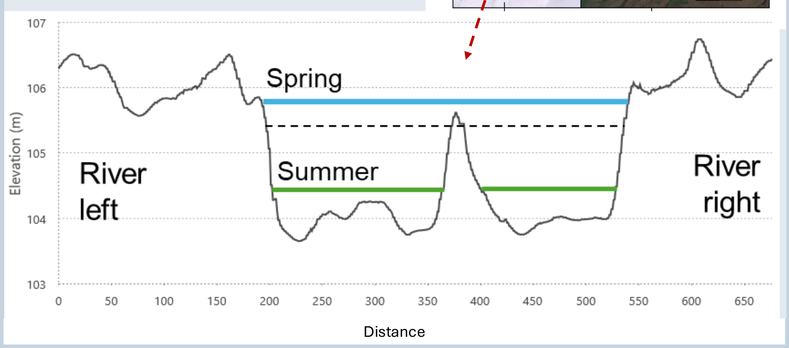


Research Question: What is the formative discharge for rivers that fill with ice over winter?

Study Site: Canning River, AK

- Contributing Area : 4999 km^2
- Bankfull river bank height: ~2.6 m
- Bankfull channel width: ~500 m
- Bed slope: 0.003 m/m
- MAAT: -8 C
- D50: 64mm



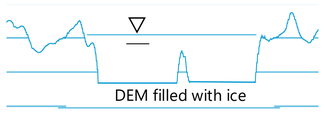


Modeling hydraulics with Basement V4.1

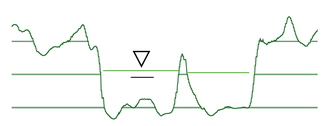
freeware
https://basement.ethz.ch/

- Numerical model for 2-D hydro- and morphodynamics [2]
- Irregular mesh generation in QGIS with BASEmesh plugin
- ArcticDEM for bed surface elevation [3]
- Generate ice-filled DEM with a relative elevation model
- Uniform roughness (gravel manning's n = 0.02, vegetation n = 0.04)
- Vary incoming discharge at inlet, run to steady state

Spring Freshet
low frequency, high magnitude



Summer Flood
high frequency, low magnitude



Assessing geomorphic work

Gravel –bedded rivers tend to widen when water fills channels and bank toe gravel is mobile[1,4,5]

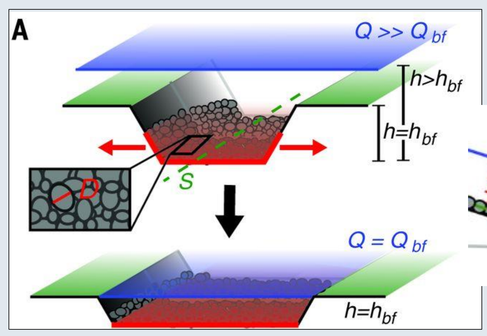


Figure from Phillips and Jerolmack (2016)

We model potential for widening as bank shear velocity to relative to a threshold for bank toe gravel entrainment [4,5]

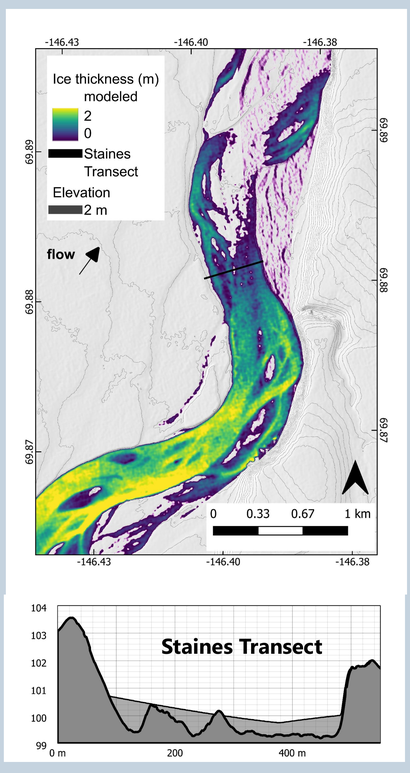
Excess Shear Velocity

U* - U*c

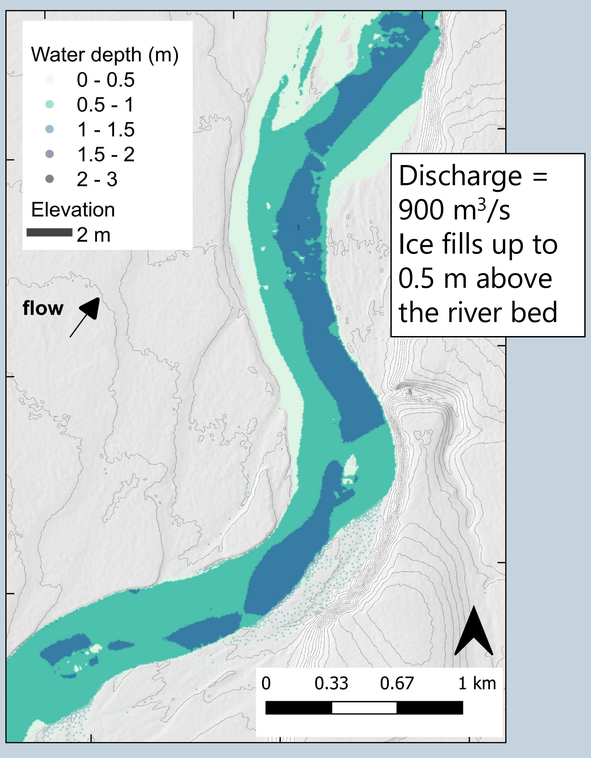
$\tau *_c = 1.18S + 0.02 = 0.0554$

$U *_c = \sqrt{\tau *_c \frac{(\rho_s - \rho_w)}{\rho_w} D_{50} g}$

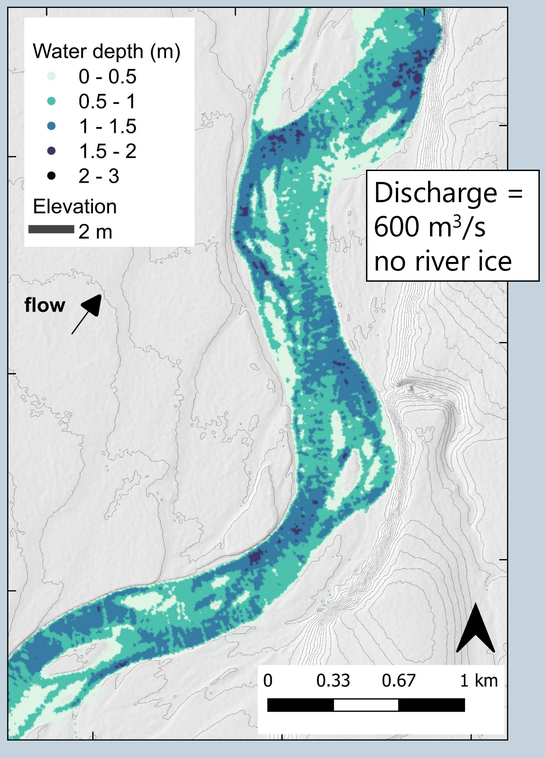
River Ice Thickness



Spring Freshet



Summer Flood



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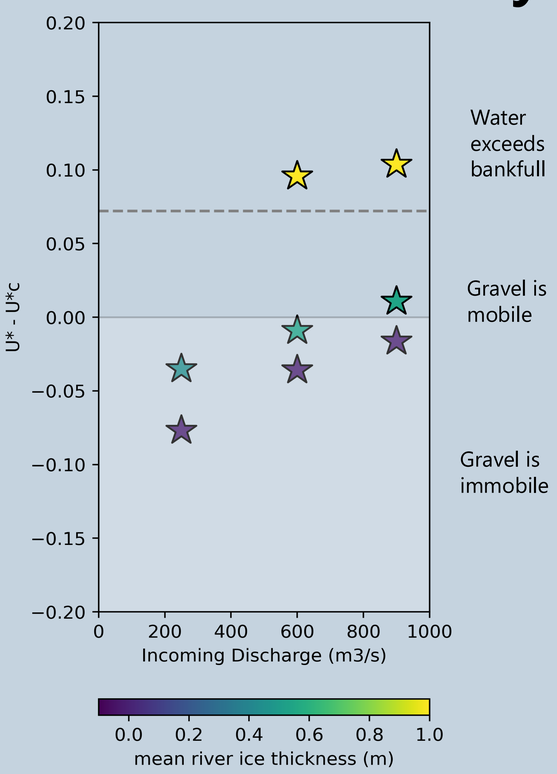

Discussion

- Water depth: dependent on velocity, can we assume open-channel flow?
- Water velocity: dependent on roughness, is ice smoother or rougher than gravel?
- Arctic DEM does not represent permanently wetted surfaces in low-flow channels
- River widening model assumes threshold channel' conditions, such that banks are easier to erode that river beds. It is unclear bank erodibility is seasonally variable, which is not included in the model
- Might need to consider frequency in addition to magnitude is summer storms can entrain gravel

Conclusions

- Summer storm runoff events might move gravel in rare events, but are unlikely to fill the bankfull channel
- The spring freshet might be the formative floods because ice seems to increase bank shear velocity enough to move gravel, over top river banks, and cause planform morphologic change
- Still, if ice changes roughness, the spring freshet might not be the formative flood
- If magitude and frequency of floods adjust from climate change, rivers could change shape

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contact: Josephine.Arcuri@colorado.edu

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