The slope thermokarst cascade for Arctic drainage from continuous permafrost, northwestern Canada

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Overview

Acceleration of thaw-driven mass wasting, mainly in the form of *Retrogressive Thaw Slumping* is mobilizing sediments and solutes across glacially conditioned permafrost terrain of northwestern Canada[1,2,3].

Warmer and wetter conditions have increased the frequency and magnitude of thaw-driven mass wasting and coupled slopes with downstream environments (Figure 1)[3,4].

Fundamental knowledge gaps persist in understanding the climate-driven amplification of slope thermokarst, the evolution of downstream linkages and the cascade of consequences[5].

Broad-scale mapping of slope thermokarst has not typically been designed to elucidate connectivity with downstream systems and attendant effects.

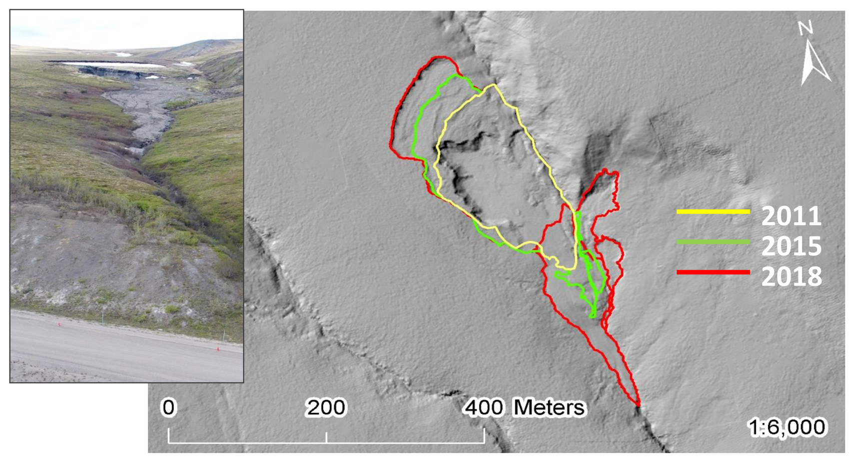


Figure 1. Example of a retrogressive thaw slump, accelerated development, and slope –channel coupling 2011-2018.

Objectives

1. Inventory the effects of slope thermokarst on hydrological networks;
2. Investigate the patterns of slope thermokarst effects across watershed scales; and
3. Project the potential cascade of downstream effects across the stream network

Data and approach

Data

Satellite Imagery:

- SPOT 4/5 orthomosaic[6] (2004-2010)
- Sentinel 2 orthomosaic[6] (2017-2018)

Hydrologic Data:

- 1:50,000 National Hydro Network (NHN)[7]

Approach

1. Lakes, streams and coastal areas affected by thaw-driven mass-wasting were identified for **western Canadian Arctic drainage** from continuous permafrost, covering over **1 million km²** by classifying hydrologic features from the NHN dataset using georeferenced SPOT 4/5 (2004-05) and Sentinel 2 imagery (2017-18).
2. Downstream routing of thaw slump effects, Stream Strahler Order and upstream accumulations were derived using a river network processing tool (RivEx 10.25) and ArcMap 10.6.1. (Figure 2).

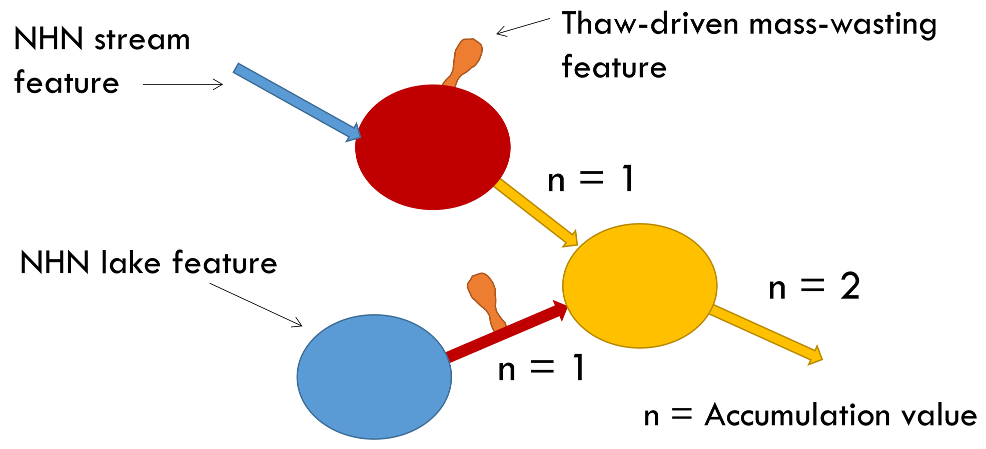


Figure 2. Schematic for downstream routing and upstream accumulation of NHN hydrologic features affected by thaw-driven mass-wasting. Directly affected features (red) propagate downstream to create indirectly impacted features (yellow). The upstream accumulation value indicates the total number of directly impacted features located upstream.

The cascade of slope thermokarst effects

1. Arctic drainage from continuous permafrost, northwestern Canada (1,000,000 km²)

*Table 1. Summary of slope thermokarst affected NHN hydrologic features across Northwestern Canada. *Cumulative denotes direct, and indirect or downstream effects.*

Thermokarst effects	Streams (km)	Lakes (count)	Coast (km)
Direct	>6,750	>1,370	892
Cumulative	48,800	5,630	-

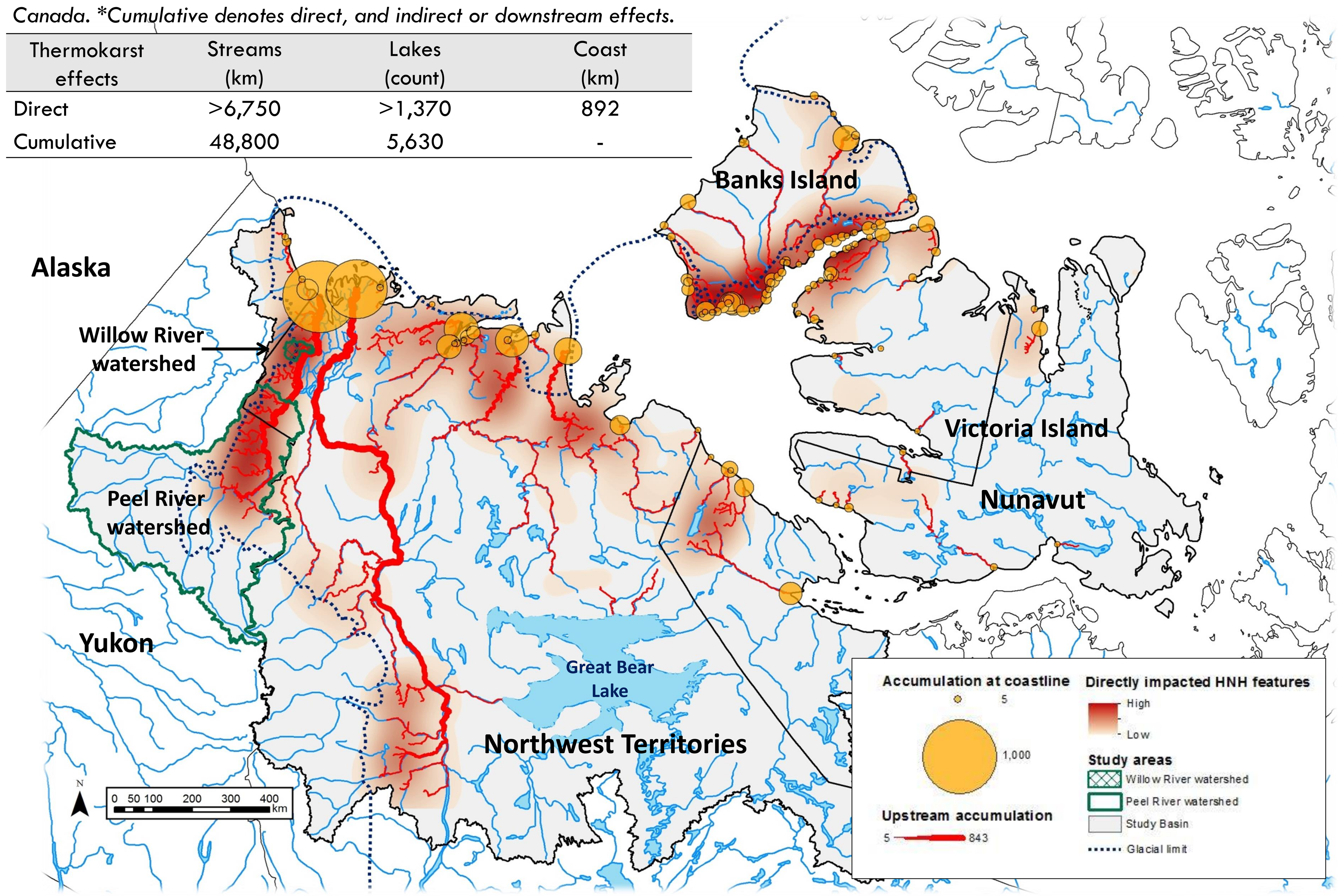
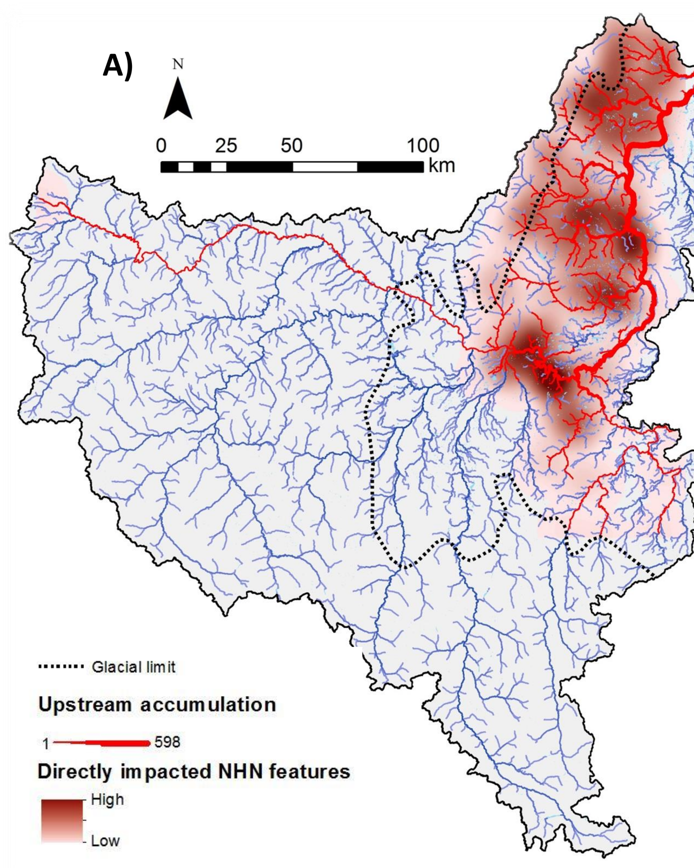


Figure 3. Slope thermokarst hotspots, potential downstream routing and accumulated effects at coastal outflows of Arctic drainage from continuous permafrost, northwestern Canada. Downstream routing shows accumulations > 5. Heat map depicts all directly affected stream, lake and coastal features from the mapped NHN dataset. At the coast, upstream accumulation values are represented by proportional circles, where values > 4. Mackenzie Delta outflow is partitioned to the Mackenzie River and Peel River.

2. Peel River watershed, NWT/Yukon (71,300 km²)



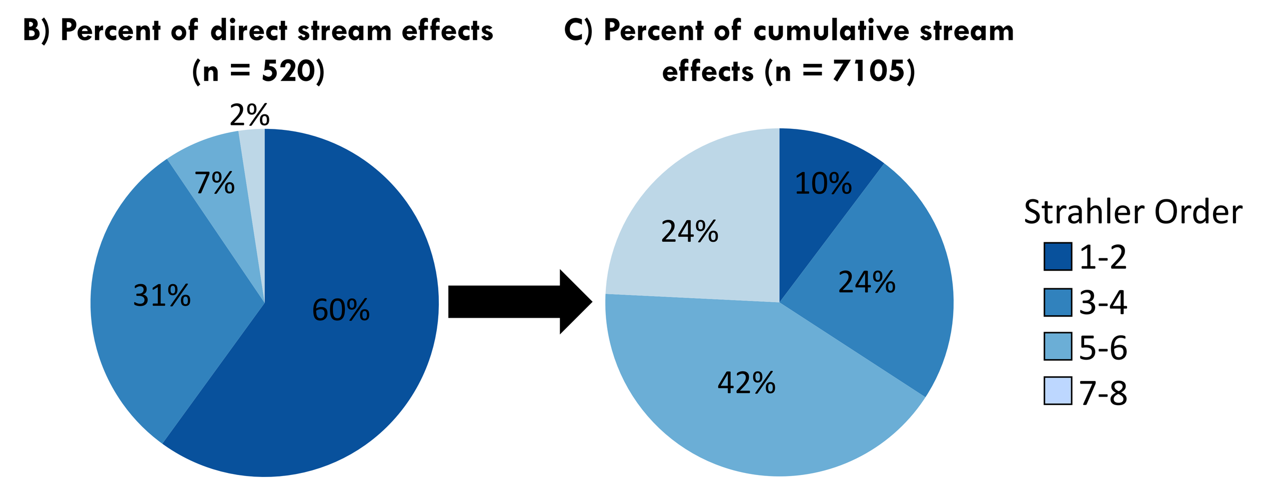


Figure. 4. A) Peel River watershed showing distribution of slope thermokarst effects to NHN features and downstream accumulation, where Strahler Orders are > 2. B) Slope thermokarst predominantly affects low-order streams. C) Redistribution of thermokarst effects to higher order streams with the cascade through fluvial networks.

3. Willow River, NWT (800 km²), downstream accumulation based on disturbance area

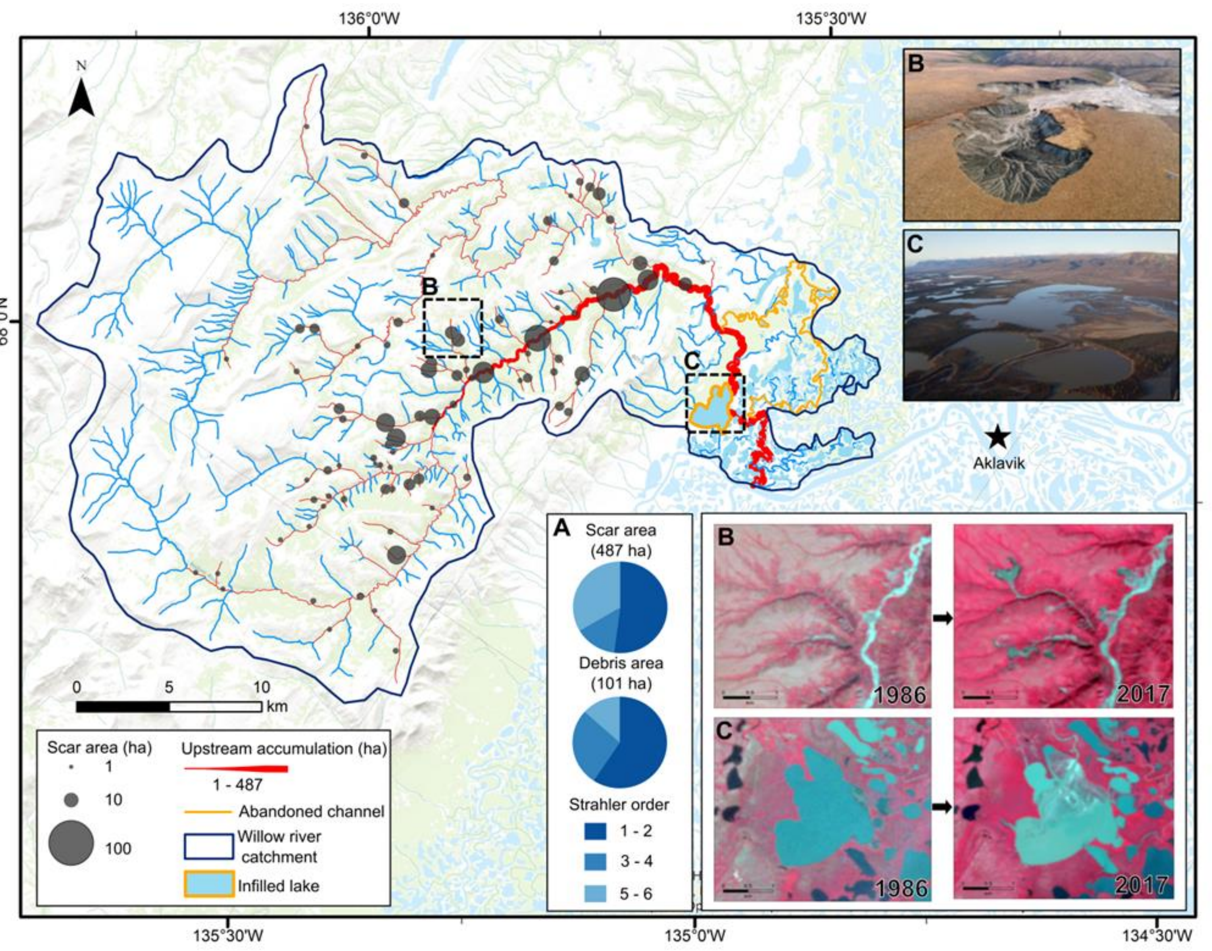


Figure. 5. Thaw-driven landslide impacts to the fluvial network of the Willow River, Mackenzie Delta area. Red lines along the drainage network highlight impacted stream segments, weighted by cumulative slope thermokarst area (ha), and the downstream accumulation of impacts through the fluvial system. A. The area weighted distribution of thaw-driven landslide impacts by Strahler order within the Willow River fluvial network. B. Landsat images of thaw-driven landslide erosion developed since the late 1990s, typical of impacts to hundreds of similar catchments across the Peel Plateau region. C. Landsat images of rapid lake infilling and delta deposit where Willow River empties into Mackenzie Delta through Willow Lake. Erosion and increased sediment transport rerouted the outflow channel in 2007-2008.

Key findings

The **acceleration of thaw-driven mass-wasting is rapidly mobilizing sediments and solutes** within the hydrological networks of northwestern Canada.

Identification of hydrologic features affected by thaw-driven mass wasting include:

- 6,759 km of stream
- 1,377 lakes
- 892 km of coastline

Downstream routing of thermokarst effects and areas of flux convergence caused:

- 4 fold increase in affected lakes
- 7 fold increase in affected stream length
- 58 coastal hotspots where fluvial systems discharge to the coast and upstream accumulations are > 10

Slope thermokarst mainly affects **headwater regions,** where impacts can propagate downstream, **signalling long-term perturbation of hydrologic systems.**

The distribution and magnitude of slope thermokarst indicate that downstream effects will be amplified through the coming century.

Future work

Continue to improve technical aspects of the product.

Link fine-scale analyses of slope-stream coupling with broad-scale analysis presented here

Derive better representation of geomorphic variation and model the propagation of effects.

Publish data to aid design of effects sampling strategies with Community, Government and Academic partners

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Northern Water Futures
NWT CIMP Northwest Territories Cumulative Impact Monitoring Program
Government of Northwest Territories
SFU SIMON FRASER UNIVERSITY
WILFRID LAURIER UNIVERSITY LAURIER Inspiring Lives.

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NORTHWEST TERRITORIES GEOLOGICAL SURVEY

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