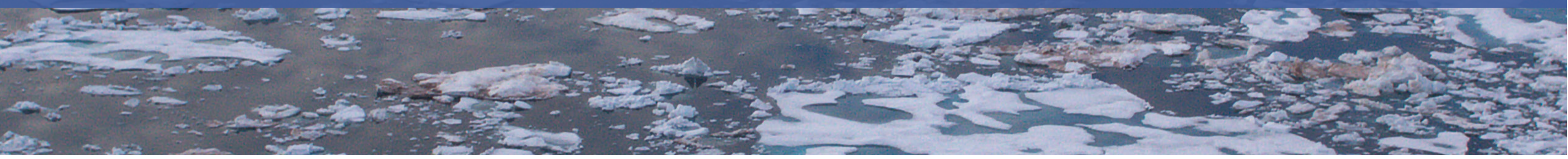
ASSESSING AND MONITORING PERMAFROST USING A COMMUNITY OUTREACH PERSPECTIVE IN KUGLUK TERRITORIAL PARK, NUNAVUT



S. Coulombe[1 *], M.-A. Ducharme[2], M. Allard[2], L. Papatsie[3], G. Atatahak[3], L. Adjun[3], S. Bilodeau[2] and S. Page[4]

[1] Polar Knowledge Canada, Canadian High Arctic Research Station, Cambridge Bay, Nunavut, Canada

[2] Centre d'études nordiques, Université Laval, Quebec City, Quebec, Canada

[3] Nunavut Parks & Special Places, Government of Nunavut, Iqaluit, Nunavut, Canada

[4] Climate Change Secretariat, Government of Nunavut, Iqaluit, Nunavut, Canada

* stephanie.coulombe@polar.gc.ca

Abstract

The All-Terrain Vehicle trail in Kugluk Territorial Park is experiencing significant damage due to permafrost thaw, melting of ice wedges, multiple landslides, and intense gully erosion. Annual alterations and rerouting of some of the trail are needed to keep it usable, but the Government of Nunavut's Parks and Special Places (NP&SP) and community leaders would like to plan a suitable long-term route for the trail. A collaborative project involving the Government of Nunavut's Parks Division, the Community of Kugluktuk, the Government of Nunavut Climate Change Secretariat (CCS), Centre d'études Nordiques (CEN) of Université Laval, and Polar Knowledge Canada is evaluating geomorphological processes and changes of permafrost conditions to help meet this goal. This community-based research project has three key objectives:

1. to gain new knowledge of the permafrost conditions and slope erosion processes;
2. to monitor changes in the landscape; and
3. to support capacity building and knowledge transfer by providing training in data collection and analysis.

Fieldwork includes mapping of geomorphological changes, thaw-depth measurements, permafrost coring, and ground-penetrating radar (GPR) surveys. Indigenous knowledge and the involvement of community members from multiple generations, in all phases of the research project, are providing critical information and insights on the terrain sensitivity and inspiration for solution finding and decision making.

Introduction

The Arctic is currently experiencing rapid warming with future temperature increases in the region expected to be two to three times the global average (AMAP, 2017; Bush and Lemmen,

Suggested citation:

Coulombe, S., Ducharme, M.-A., Allard, M., Papatsie, L., Atatahak, G., Adjun, L., Bilodeau, S. and Page, S. 2019. Assessing and monitoring permafrost using a community outreach perspective in Kugluk Territorial Park, Nunavut. Polar Knowledge: Aqhaliat 2019, Polar Knowledge Canada, p. 32–42. DOI: 10.35298/pkc.2019.04

2019). Climate change will impact permafrost by increasing the depth of the seasonally thawed layer (active layer), and causing ground ice to melt. Thawing of ice-rich permafrost, the resulting ground shifting, and changes in landscapes may have major effects on the efficiency, safety, and reliability of Northern transportation routes, such as roads and aircraft runways (Allard et al., 2012; Doré, Niu and Brooks, 2016; Hjort et al., 2018). Semi-permanent trails (i.e., All-Terrain Vehicle (ATV) trails) used by Inuit to travel on land are also considered highly susceptible to climate change (Prno et al., 2011; Ford et al., 2019). These trails are essential facilities in arctic communities—providing access to traditional hunting and fishing grounds as well as areas of historic and cultural importance to local populations.

Over the last few decades, the ATV trail passing through Kugluk Territorial Park has experienced significant damage due to thawing of permafrost along its route and erosion along the bank of the Coppermine River. The trail provides access to park landmarks and inland resources, but alterations and some rerouting are regularly needed to keep it usable. Long-term practical solutions are being sought by the NP&SP and community leaders to keep the trail operating while maintaining the integrity of the ecosystem. As a major concern for the community, assessing geomorphological and drainage conditions and finding a better route have been identified as priorities in the Kugluk Parks Management Plan. In response to these needs and concerns, the Kugluk CJPMC and NP&SP launched this community-based project in 2017 in collaboration with the Government of Nunavut Climate Change Secretariat, Centre d'études Nordiques (CEN) of Université Laval and Polar Knowledge Canada. The overall objective of this project is to improve access to the land for Nunavummiut, specifically those who travel to and through the Kugluk Territorial Park and its surrounding areas.

Under the guidance of the Kugluk CJPMC, three specific objectives were identified:

1. to increase our knowledge of the permafrost conditions and slope erosion processes in the park, particularly along ATV trails;
2. to monitor changes in the landscape; and
3. to involve local youth in both the terrain sensitivity assessment and the construction phases of the project to provide training opportunities.

This paper presents the research, outreach, and training activities that took place from 2017 to 2019. It includes preliminary results from the first phase of work, focusing on the permafrost conditions and terrain sensitivity along the proposed new ATV trail. From a climate change adaptation perspective, this project will help identify areas where the ground-ice conditions are anticipated to be particularly problematic and may require further attention when constructing the boardwalk trail and maintaining it.

Study area

Kugluk Territorial Park (67.8˚N, -115.3˚W, about 50 metres (m) above sea level) is approximately 12 kilometres (km) from the Hamlet of Kugluktuk (Figure 1). Kugluktuk is located at the mouth of the Coppermine River and the westernmost community in Nunavut. The park area is very important to the community for access to traditional camping and hunting grounds used for subsistence and cultural activities that contribute to community and individual well-being. It has been a site of continuous human use, associated with seasonal fishing and caribou hunting for subsistence for over 3 500 years (Nunavut Parks and Special Places, 2019). The site was targeted for protection as a park in 1969 because of its cultural, historic, and scenic value. With the creation of Nunavut (1999), the responsibility of the park was transferred to the Government of Nunavut.

Kugluktuk has a mean annual air temperature of -10.3 ˚C, with monthly averages of -27.7 °C in February and +10.9 °C in July (Environment and Climate Change Canada, 2019). The area receives average precipitation of 247 millimetres annually,

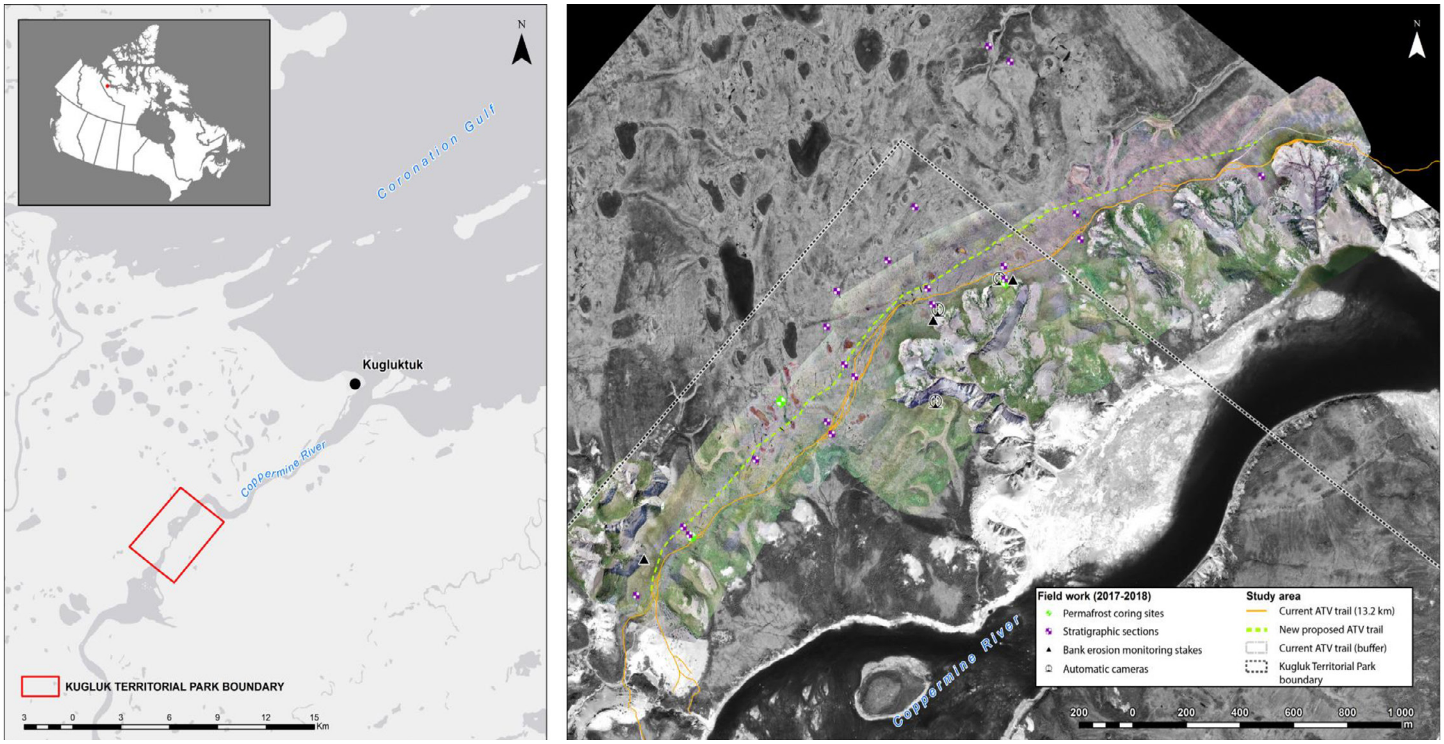


Figure 1: Location of Kugluk Territorial Park, Nunavut (left). Current (orange) and new proposed (green) ATV trail, and coring sites (right).

60% of which falls as rain between June and September (Environment and Climate Change Canada, 2019). The study area is located in the zone of continuous permafrost with a thickness of about 100–500 m based on temperature data (Smith and Burgess, 2002). Permafrost temperatures were recorded at two monitoring sites east of Kugluktuk from 1995–1996 (Wolfe, 2000). The mean annual ground temperature at a depth of about 15 m was approximately -6.4 °C and -6.0 °C during this period (one full year of data). These monitoring stations no longer operate and thus, no recent data were available when this project began.

Large-scale surficial geology mapping was undertaken in the area by St-Onge (1988), Kerr, Dredge and Ward (1997), Dredge (2001), and St-Onge (2012). The present-day landscape of the Kugluktuk area is characterized by coastal lowlands and a series of terraces and deltas rising from about 10 to 170 m above sea level at the marine-limit delta (St-Onge, 2012). The park is located on a delta terrace, where an extensive network of ice-wedge polygons is present.

Material and methods

Fieldwork

The research project began with a preliminary assessment of the surficial geology and periglacial processes in the park guided by the Kugluk CJPMC and the NP&SP. Field activities focused on the current ATV trail and the new proposed trail (Figure 1). High spatial resolution, contemporary satellite imagery (GeoEye, pixel = 0.5 m; 2017), and historical aerial photography (photos dated 1950, 1993, and 2010) was used to quantify changes in thermokarst lakes and ponds from 1950 to 2010. Besides the visual interpretation techniques for mapping, a semi-automated classification function was used to extract lakes and ponds from the satellite image and aerial photographs. All geomorphological processes and landforms (e.g., areas subject to thaw slumping, gullies, ice-wedge polygons) were identified and digitized manually on-screen in a geographic information system to produce an accurate map of the area.

There are many archaeological sites in the park registered at the Department of Culture and Heritage (Government of Nunavut) and Inuit Heritage Trust. As a result, an archaeologist was involved in our field activities to ensure no archaeological artefacts were disturbed. Intact permafrost core samples were collected using a portable earth drill equipped with a 4-inch diamond carbide core barrel. Two shallow boreholes were drilled to depths of 5 and 4.5 m, respectively. All frozen cores and grab samples were photographed and described in the field for sediment type and cryostratigraphy with emphasis on sediment type, ice content, and ice patterns (French and Shur, 2010; Gilbert, Kanevskiy and Murton, 2016). The samples were kept frozen, then shipped to laboratory facilities at Université Laval for further analysis (e.g., ice content). The grain-size distribution of the soil and its ice content are essential information for assessing the potential for thaw subsidence. Thaw depths were measured at numerous locations (n = 24) in the park by digging soil pits.

The two boreholes were instrumented with automatic data loggers (LogR Systems Inc.) and thermistor cables. Both thermistor cables were equipped with 16 temperature sensors installed between 0.15 m and about 5 m below the ground surface. The cables were placed in PVC pipes filled with silicon oil to ensure optimal thermal contact. Hourly data acquisition began on July 25, 2018. These monitoring sites will provide valuable records of active layer thickness and the temperature regime of the permafrost in the study area. Such measurements are needed to assess how climate change will affect the stability and behaviour of the ground which are highly influenced by ground temperature.

A GPR survey was carried out in July 2018 to study the frozen ground beneath the new proposed ATV trail (Figure 1). GPR systems use separate transmitting and receiving radar antennas. A transmitting antenna produces a series of electromagnetic pulses that propagate into the ground, which are reflected when changes in the ground properties occur. This tool is well suited for mapping active layer thickness (non-frozen surface layer/frozen permafrost) and the stratigraphy of permafrost because of the large contrasts in dielectric properties between different subsurface layers and structures (Hinkel et al., 2001; Kneisel et al., 2008). GPR is very useful for detecting ice wedges and estimating their depth and size as they generate specific reflection patterns called hyperbolic reflectors (Fortier and Allard, 2004; Jørgensen and Andreasen, 2007; LeBlanc et al., 2012). The instrument used in this project was a Sensors and Software pulseEKKO PRO controller with 100 megahertz (MHz) and 200 MHz antennas. Higher frequency measurements (e.g., 200 MHz) generally have better vertical resolution for detecting near-surface structures in the permafrost (e.g., ice wedges), but reach only shallow depths. Conversely, low-frequency antennas (e.g., 50 and 100 MHz) reach greater depths but with lower resolution. GPR profiles were calibrated and correlated with the soil cores and thaw depth measurements. Profiles were post-processed using Sensor and Software EKKO Project Version 5 proprietary software. Post-processing included time-zero correction and integration of GPS data, topography, and horizontal filtering to improve visualization of horizontal reflectors.

Community involvement in the project

From the beginning, this collaborative project involved knowledge exchange in different stages of the research process (e.g., project design, data collection, interpretation of results). A local elder also participated in this project, bringing knowledge about the changes that have occurred in the park and the surrounding area, how to assess the land for safety, and how similar problems have been dealt with in the past. Such knowledge facilitated local scale understanding of the changes that are taking place in the area. Another important aspect of this project was to provide learning and training opportunities to local youth and community members in permafrost science, monitoring techniques, and knowledge transfer concerning how the assessment is being done. A group of youth from Kugluktuk, together with field technicians from Cambridge Bay, joined the researchers for several days to conduct the land assessment.

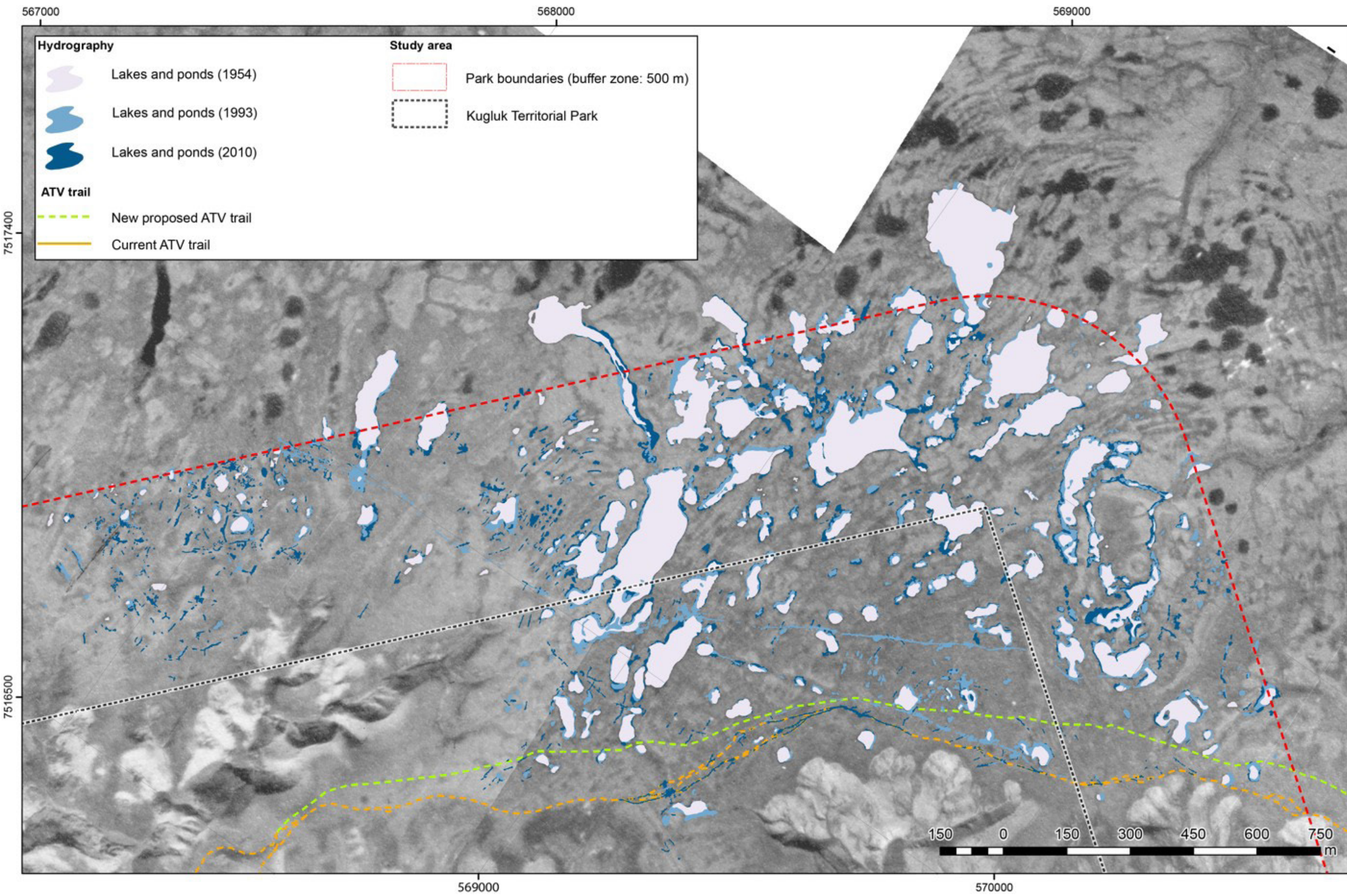


Figure 2: Changes in the number of lakes and ponds and lake area.

Preliminary results

Evolution of lakes and ponds

The number of thermokarst lakes and ponds has increased from 244 in 1954, to 618 in 1993, to 1 413 in 2010–representing a 480% increase during the last 60 years (Figure 2). The total surface also increased (0.363 km^2 to 0.446 km^2 or + 23%) over the sameperiod. It is apparent that there has been an increase in the number of small lakes and ponds as a result of the degradation of ice wedges. These small waterbodies evolve from the enlargement of ponds enclosed in the depression of low-centre ice wedge polygons and the melting of ice wedges (deep trough filled with water). Most large lakes have expanded laterally through thermal and mechanical erosion over this 60-year period. The detailed mapping also highlights a possible degradation caused by an old ATV track (1993). It often results in a longitudinal degradation of troughs (or ice wedges).

Permafrost conditions

The drilling logs presented in Figure 3 indicate a sequence of medium to coarse sand and fine-grained sediments (silt and clay). Thaw depths measured in mid-July (2017 and 2018) range between 0.4 to 1.2 m (mean: 0.75 m) depending on soil moisture and peat layer. From the surface down to about 0.5 m, the upper unit (C) is composed of fibrous peat mixed with sandy material. Unit B is composed of ice-poor medium to coarse sand interbedded with layers of silt and clay featuring a suspended cryostructure. The sand layers have an ice-poor sediment cryofacies with a structureless cryostructure, essentially comprising pore ice. This type of ground ice occurs in the pores of soils and is not visible to the naked eye (ice content: about 12%). The bottom unit (A) is composed of coarse sand and gravel with subrounded to rounded pebbles. No ice could be observed in this unit since the heat generated during the coring process thawed the soil and the material ended being remoulded. This sequence of sediment is interpreted as a deltaic deposit forming a post-glacial marine delta. These observations are consistent with the area's postglacial history described by St-Onge (2012). Ground temperature from the two newly drilled boreholes will be collected in July 2019 (1 full year of data), which will provide a snapshot of current permafrost conditions in the area.

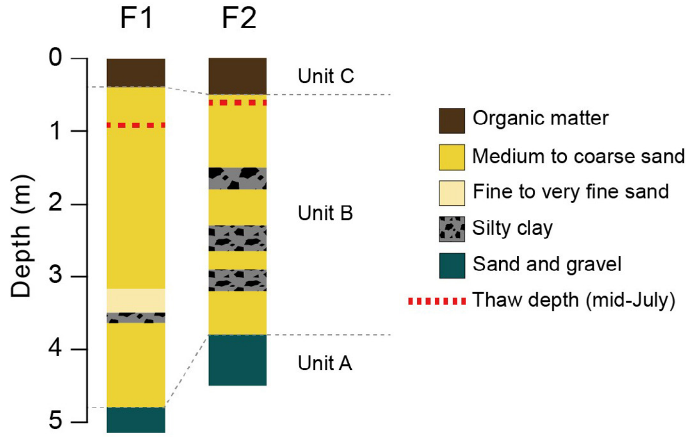


Figure 3: Logs of the two boreholes drilled in July 2017 (F1) and 2018 (F2).

Ground penetrating radar surveys

GPR provided deeper subsurface information than the mapping and drilling data. In the GPR images, an irregular layer was observed at depths ranging from 0.5 to 1.5 m, which represents the contact between the thaw front (i.e., bottom of the unfrozen layer) and the frozen soil beneath (Figure 4). Near-surface hyperbolic reflections more or less equally spaced within the GPR profile are interpreted as ice wedges. In total, 79 ice wedges were detected beneath the new proposed trail, 30% of them were visible from the ground surface during the survey. In most cases, there were no

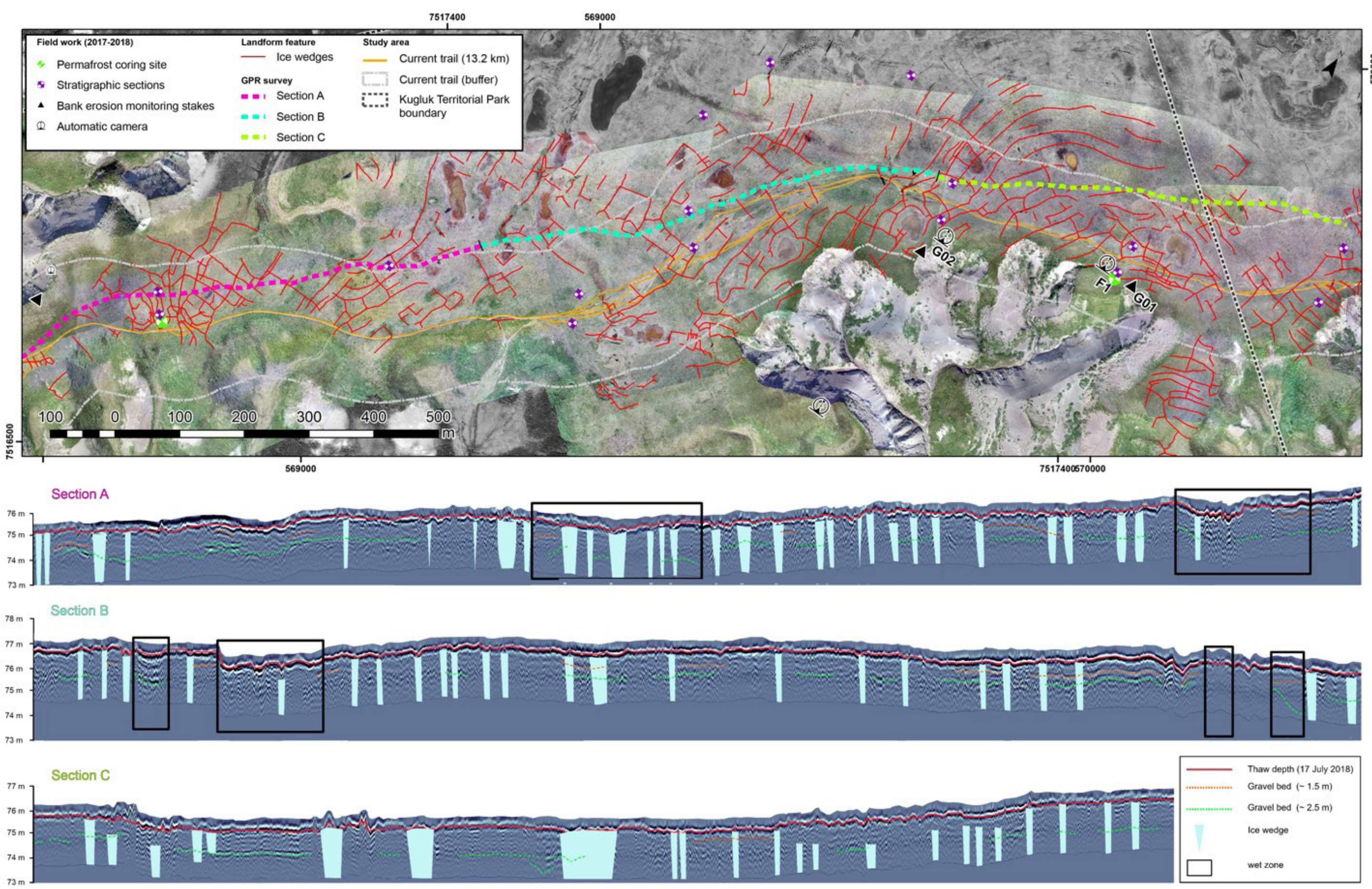


Figure 4: Aerial photo with all the digitized ice wedges, and the GPR profile of the proposed new ATV trail and ice-wedge interpretation.

visible troughs, ridges, or fissures on the ground surface. The ice wedges have widths of about 3 to 6 m at the permafrost table. The tops of the ice wedges are located about 1 to 1.5 m beneath the ground surface and the ice wedges extend down to at least 4 m. The maximum vertical extent of the ice wedges remains unknown because 4 m represented the maximum penetration by the signal. Positions of the ice wedges observed on GPR profiles were consistent with the troughs over ice wedges that outline the polygons visible from the high-resolution satellite image (Figure 4). This confirms that the ATV trail is underlain by numerous ice wedges. This high ice content makes the study area very vulnerable to thermokarst and thermal erosion. In addition, numerous gullies have been observed in the area and many of them show evidence of active thermal erosion. It was also observed that the erosion and retreat of head scarps of landslides is controlled by the pattern of ice wedges in the permafrost. Any future disturbances to the thermal regime of the ground surface, such as vegetation clearing, increase in snow or water accumulation, or increase in mean annual air temperature, could potentially lead to further permafrost degradation and thaw settlement. As a result, NP&SP is building a new floating boardwalk segment approximately 3.2 km long and 2.4 m wide. The work started in 2019 and is expected to be completed in 2020. This new boardwalk route will help reduce the cumulative effects of ATVs on vegetation and soils (i.e., vegetation removal and peat layer compaction), which creates an imbalance in the thermal regime of the active layer as well as of permafrost.

Training and outreach activities

Over the past two years, members of the project team also hosted and participated in numerous outreach activities to share information and keep community members up to date with the project (Figure 5). The goal of these activities was to increase awareness of permafrost in the local population and of the potential risks related to climate change. Events and activities undertaken during the project included:

- **Kugluk CJPMC meetings:** Four meetings were organized with the Kugluk CJPMC to discuss objectives and project design and to provide feedback and results as key milestones were achieved. The goal of these meetings was to ensure that the committee's priorities and concerns were adequately captured throughout the project.
- **Nunavut Parks Day:** In 2017, members of the project team participated in Nunavut Parks Day and provided an explanation the project using maps and satellite images. In addition, many community members shared their observations of the past and current state of the landscape and how these changes are affecting community life.
- **Participation in scientific conferences:** This project has been co-presented at three scientific conferences with Frank Ikpakohak (community elder), Darryl Havioyak (CJMPC board member), and Larry Adjun (NP&SP employee and chair of the Kugluktuk Hunters and Trappers Organization (HTO)). During the Arctic Change conference (December 11–15, 2017), members of our team participated in a documentary on climate change adaptation in Western Nunavut, which was presented during the Arctic 2018 Expedition (Students on Ice).
- **Radio interviews:** Members of the project team participated in interviews at the local radio station to talk about climate change, permafrost issues, and share the research results with the community. Community members called in and shared observations of climate change that they experienced and also asked questions about the project.
- **Community nights:** The team hosted three community nights to present the project and gather local perspectives on the changes observed in the area. During these evenings, short documentaries on climate change in the Arctic were also presented.
- **Permafrost 101:** An introductory course was offered on basic concepts about permafrost to a variety of participants from the Kugluk CJPMC, HTO, Kitikmeot Inuit Association, and Hamlet of Kugluktuk.

Figure 5: Outreach and training activities: a) Kugluk CJPMC meeting; b) Nunavut Parks Day; c) Interview at the local radio station given by Michel Allard; d) Drilling in the permafrost; e) Youth conduct real-time kinematic surveys to map riverbanks; f) Youth and NP&SP staff operate the monitoring station and download temperature data.

Future work

The next phase (2019–2020) of this community-based project will assess the sensitivity of permafrost along the new road that will provide access from the community of Kugluktuk to the park. Additional GPR and unmanned aerial vehicle surveys will be conducted along this new road to characterize the permafrost conditions. These results will help assess thaw sensitivity and potential future impacts along the road. Moreover, a key priority will be to train community-based monitors within the community to enable them to carry on the permafrost monitoring activities in the park (i.e., analysis and interpretation of ground temperature data, maintenance of the data loggers). Members of the project team would like to provide additional training sessions over the next year at the Canadian High Arctic Research Station in Cambridge Bay, Nunavut, and the CEN in Quebec City, Quebec. As in previous years, the team will organize and participate in a variety of events that will engage youth and in which community members will be invited to meet the team and learn more about the project. This research project will continue to place the community in a leadership role in assessing and responding to the environmental changes that are already being experienced and ensure that the semi-permanent transportation routes are more durable and resilient to climate change and permafrost thawing.

Conclusions

This research project has improved our understanding of how thaw-sensitive permafrost is affecting the ATV trail in Kugluk Territorial Park. Preliminary work shows that:

1. Ice wedge polygons are well developed in the area. This ice-rich permafrost landscape could be affected by thaw subsidence and thermal erosion. It may be caused by natural processes under the conditions of climate warming or by human activities (e.g., surface disturbance by off-road vehicles).
2. The majority of thermokarst lakes and ponds are actively expanding and new ponds were formed are as a result of permafrost degradation. The analysis of lakes abundance and area over the 60-year study period reveal natural permafrost degradation in the study area, and not just along the trail.
3. The trail is marked by the presence of numerous deep troughs caused by the melting of the tops of ice wedges causing differential ground subsidence. This often results in water pooling and greater snow accumulation, which can further accelerate ice wedge degradation.
4. Thawing of ice wedges has initiated the development of gullies and affected bank erosion patterns in the park.
5. Increased ice wedge degradation is expected to occur with increasing air and ground temperatures. Given future climate projections, determining areas with ice-rich permafrost is important in predicting which sections of the trail are more sensitive to damage by permafrost thaw. Adopting good planning and management practices, such as the construction of a boardwalk, will help to minimize or prevent terrain disturbances along the new trail.
6. Involving community members in permafrost research is essential to better enable them to document permafrost and landscape changes, and adapt to climate change. To facilitate community involvement in research, monitoring, and adaptation efforts, this project emphasizes building capacity through training and making information on permafrost easily available to the community.

Acknowledgements

Financial support for this project was provided by Crown Indigenous Relations and Northern Affairs Canada's Climate Change Preparedness in the North Program. Special thanks goes to NP&SP staff for their advice on site selection and installation of the instrumentation, and their continued maintenance of the monitoring sites and collection of data. We are grateful to OJ Berhardt, Andrew Jack Atatahak, Zachary Kunana, Kevin Kamoayok, Aili Pedersen, Alysha Maksagak, Jennifer Kilabuk, Joanna MacDonald, and Sara Holzman for their assistance in the project. We also wish to thank Frank Ikpakohak, the members of the community of Kugluktuk, and the Kugluk CJPMC for their interest in the project and their valuable knowledge of the landscape that were essential to the success of this project.

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