CANADIAN PERMAFROST ASSOCIATION
ASSOCIATION CANADIENNE DU PERGÉLISOL

# Virtual Annual General Meeting

November 16 & 17, 2020

# ABSTRACTS

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# Content

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# A Word from the President

Dear Members of the Canadian Permafrost Association,

A very challenging 2020 slowly comes to an end and despite all the difficulties I'm excited to present this proceeding of abstracts. Earlier this year, when we all struggled understanding how to best adopt to the new circumstances it was not clear where and if we'll be able to have a technical session with our annual general meeting. I'm therefore very grateful that the CPA Board decided to move forward with a virtual meeting. The general interest and the number of presentations confirms that this was the right decision. Initially, I had concerns that because of the pandemic and the cancelation of many field programs, not sufficient material would exist for presentations. But I was very wrong. We have a total of 21 presentations, of which two are keynotes, one engineering and one earth science. Of the remaining 19 presentations, covering a wide variety of topics, about 2/3 are from students / early career members. The interest of the next generation of permafrost scientists and engineers to present their work is stimulating and the ratio representative for the overall CPA membership. The interest in permafrost research and engineering seems to be constantly growing and I'm pleased to see how this meeting materialized and I look forward listening to the various presentations.

I'd like to thank the CPA Board members for their support during my first year as president, and specifically Ashley Rudy and Peter Morse for their support in making this AGM a success. Finally, thanks to Barb Fortin for correcting my French.

I wish everyone all the best for 2021 and stay healthy.

**Lukas Arenson**
CPA President

# Le mot du président

Chers membres de l'Association canadienne du pergélisol,

Une année 2020 très difficile s'achève lentement et malgré toutes les difficultés, je suis enthousiaste à l'idée de présenter cette collection de résumés. Au début de l'année, lorsque nous essayions tous de nous adapter aux nouvelles circonstances, il était incertain si nous allions pouvoir tenir une réunion technique durant notre assemblée générale annuelle. Je suis donc très heureux que le conseil d'administration de l'ACP ait décidé d'aller de l'avant avec une réunion virtuelle. L'intérêt général et le nombre de présentations confirment que ce fut une bonne décision. Au départ, je craignais qu'en raison de la pandémie et de l'annulation de nombreux programmes sur le terrain, il n'y ait pas suffisamment de matériel pour les présentations; mais j'avais tort. Nous avons un total de 21 présentations, dont deux qui sont des présentations principales, une dans le domaine de l'ingénierie et une dans le domaine des sciences de la terre. Sur les 19 présentations restantes, qui couvrent une grande variété de sujets, environ les deux tiers proviennent d'étudiants ou membres en début de carrière. L'intérêt de la prochaine génération de scientifiques et d'ingénieurs spécialisés dans le pergélisol pour présenter leurs travaux est stimulant et le ratio est représentatif de l'ensemble des membres de l'ACP. L'intérêt pour la recherche et l'ingénierie du pergélisol semble être en constante augmentation. Je suis heureux de voir comment cette réunion s'est matérialisée et j'ai hâte d'entendre les diverses présentations.

J'aimerais remercier les membres du conseil d'administration de l'ACP pour leur soutien au cours de ma première année de présidence, et plus particulièrement Ashley Rudy et Peter Morse pour leur soutien qui a permis de faire de cette assemblée générale un succès. Enfin, merci à Barb Fortin pour avoir corrigé mon français.

Je vous souhaite à tous une excellente année 2021 et de rester en bonne santé.

**Lukas Arenson**
Président de l'ACP

## Keynote 1: Ryley Beddoe

Dr. Ryley Beddoe received her B.Sc. in Civil Engineering, as well as her B.Ed., M.Sc., and Ph.D. at Queen's University, and is now an Associate Professor at the Royal Military College. Her time at RMC is spent teaching and conducting research, where she is focused on understanding the overarching geotechnical impact of climate change in Canada's Arctic. Current and recent research include geohazard impacts on infrastructure in the Arctic and along the Hudson Bay Railway, ice road investigations along the Joint Venture Highway, ice road reinforcement studies, and climate drive embankment stabilization. Ryley is a co-investigator with PermafrostNet, a Research director in the GeoEngineering Centre at Queen's-RMC, and is an active member in national and international permafrost and geoengineering societies. Her research is supported by multiple NSERC Grants, as well as industry sponsors including Transport Canada, Government of Northwest Territories, Associate Engineering/NOR-EX Ice Engineering, National Research Council, and the Department of National Defence.

# Shifting perspective – Planning today for Arctic GeoEngineering of tomorrow

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As permafrost in the Canadian Arctic undergoes climate driven degradation and changes, the stress and impact it will have on current and linear infrastructure networks will be significant. Now, more than ever, it is critical to work towards an understanding of not only ‘why’ but also ‘how’. How will we learn from today to plan and design adaptation and mitigation techniques for resilient infrastructure in the future? How can we develop models that will allow us to ‘dig deeper’ in our understanding? In her current research in this field Dr. Beddoe is exploring questions like these, including: How can numerical modelling techniques allow us to predict future infrastructure risk? What adaptation techniques will limit the impact of permafrost degradation for infrastructure networks? How do they change if the network is a railway? An ice road? A highway? In this presentation, Dr. Beddoe will present her and her team’s most recent research results aimed at answering these, and other questions related to arctic geoengineering.

# Keynote 2: Duane Froese

Dr. Duane Froese is Professor in the Department of Earth and Atmospheric Sciences and Canada Research Chair in Northern Environmental Change at the University of Alberta, Edmonton. His research focuses on the Quaternary geology and geologic setting of permafrost and its properties in northwestern Canada. He has carried out field-based studies in Yukon, Alaska and the central Mackenzie valley since the mid 1990s. He and his colleagues established the Permafrost Archives Science Laboratory at the University of Alberta in 2018, a unique $4M ice core style archive and analytical laboratory focused on permafrost. He is co-lead of Theme 1 of PermafrostNet (Characterisation of permafrost), a recipient of the Hutchison medal of the Geological Association of Canada, the J. Ross Mackay award from the Canadian Geomorphology Research Group, and a member of the College of the Royal Society of Canada.

## Ancient permafrost and past lessons from a thawing Arctic

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Ancient permafrost represents that part of the cryosphere that has survived through at least the last interglaciation, 130,000 years ago, and thus shows evidence for long-term preservation of permafrost from thaw. Several sites exist in northwestern Canada, Alaska and Siberia, but seem to largely be confined to areas of moderate relief and show protection from hillslopes and colluvial processes. New dating of tephras, ancient DNA from fossils and other biomolecular indicators, have confirmed these observations and set records for the oldest ice in the northern hemisphere, and for the reconstruction of past life and ancient genomes. More sites are certain to exist, but establishing the antiquity of ancient permafrost still represents a substantial chronological challenge. The limits to ancient permafrost appear to be the Early to Middle Pleistocene transition, 780,000 year ago, and it is likely that Early Pleistocene interglaciations lacked permafrost. Interglaciations through the Middle Pleistocene show evidence for substantial thaw unconformities, mostly reconstructed as past retrogressive thaw slumps. Only a decade ago it appeared these were harbingers for future thaw through the Holocene, but in the last few years observations in the western Arctic indicate we may well be meeting or exceeding rates of thaw from the warmest intervals of the last 780,000 years.

# The Moosehide and Sunnydale slides near Dawson City, YT

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The Moosehide Landslide and the Sunnydale Slide are two active slides located in close proximity to Dawson City, YT. In response to potential developments and ongoing changes in climate conditions, the Yukon Geological Survey tasked BGC Engineering with evaluating the current level of activity and provide recommendations for further investigation and/or monitoring. In addition, a preliminary runout analysis was completed for the Moosehide Landslide. Since Dawson City is situated within the zone of extensive discontinuous permafrost, potential impacts from permafrost degradation were also evaluated. Due to inverted surface lapse rates in the region, which promote cold air drainage to valley bottoms during the winter months, the highest probability of permafrost presence is in the valley bottoms where both landslides are situated. Indicators of local permafrost include the presence of a rock glacier within the middle portion of the Moosehide Landslide debris; however, no surface indicators were observed at the Sunnydale Slide. Based on the current understanding, permafrost degradation does not appear to control the overall kinematics of the two slides, but it may, however, have an impact on the cohesion and the bond-strength along rock mass discontinuities. The presentation provides an overview of what is known today about these two slides.

# Observations of watershed-scale channelization in a periglacial environment

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Polar regions on Earth are undergoing rapid environmental change due to a warming climate. Examples include large mass wasting events due to retrogressive thaw slumps, and emergence of valleys and hillslopes where the landscape was covered by ice. Expansion of channel networks and gullies has previously been attributed to permafrost thaw and removal, which leads to tunneling, subsequent ground collapse, and channel establishment. Here we examine channelization at the drainage basin scale, using a ground-based kinematic high-resolution 3D LiDAR survey, combined with historical aerial imagery of a valley located on the east side of Axel Heiberg Island, Canadian Arctic Archipelago. Results indicate that channelization is discontinuous along the valley floor, and where it occurs, there is a spatial correlation between the flow path direction and the orientation of ice-wedge polygons. Thermal erosion may play a role in the channelization process, however, mechanical erosion along pre-existing weaknesses of the ground surface via thermal expansion cracks and polygon troughs is also important. This observation highlights the need to articulate how channels form within periglacial landscapes, and to link this understanding to existing theories of channelization envisioned for non-polar settings.

# Pragmatic thermal analysis of permafrost

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Design of roads, pipelines, building foundations and other engineered structures in permafrost typically requires assessment of the existing ground thermal regime within an area of interest along with predictions of ground temperature change over time during construction and operations, including the potential for climate change to adversely impact the long-term performance of the structure. With this necessity, thermal analysis for engineering design using commercially available numerical modelling tools is used to answer a specific set of posed questions regarding design alternatives and trade-offs. Although many numerical modelling tools for thermal analysis are readily available today (commercially or otherwise), appropriate and successful use of these tools depends entirely on the knowledge and experience of the analyst, as is true for all modelling efforts. Several issues and questions arise when completing a thermal analysis: What is the context of the analysis? What required input data is available, and what can we do when it is not? How are boundary conditions specified appropriately? What can be done in the absence of directly-measured ground temperature data? How are climate normals data used? How is a thermal model calibrated? What options are available for modelling climate change? How is uncertainty handled? Although there may not be adequate time available to address all of these questions, this presentation will endeavour to answers as many of them as possible, based on more than two decades of thermal analysis experience.

# Predicting permafrost probability in a variable boreal environment utilizing a multiple logistic regression model

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For remote communities access to permafrost information for hazard assessment is a considerable challenge. This study applies analytical methods illustrating a time- and cost-efficient method for conducting community-scale permafrost mapping in the community of Whatì, NT. A binary logistic regression model (BLR) was created using a combination of field data, DEM-derived variables, and remotely sensed products. Independent variables included vegetation, topographic position index (TPI), and elevation breaks used as categorical inputs. The dependent variable is sourced from approximately 140 physical checks of permafrost presence or absence. Vegetation was shown to be the strongest predictor of permafrost. The model predicts 50.0% of the vegetated area is underlain by permafrost with a model accuracy of 91.4% and an agreement between model and ground truthing points of 72.8%. Compared to existing permafrost products, the predicted extent of permafrost locates Whatì, NT near the lower margin of current classification (50 to 90% for extensive discontinuous permafrost extent) illustrating there could be less permafrost than presumed.

# The lifecycle of a talik: from formation to fen with an eye for function

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Climate warming in fragile discontinuous permafrost peatlands is causing permafrost loss and changes in ecosystem dynamics at an unprecedented rate. In the discontinuous permafrost region, the formation of a talik (perennially thawed soil) between the base of the active layer and the top of the permafrost table signals the beginning of permafrost degradation. A coupled mass and heat transfer 1-D finite volume model of cryotic soils identified soil moisture and surface temperature (a combination of surface albedo and incoming radiation) as the major drivers of talik formation, while advection through existing taliks accelerated permafrost degradation rates. Field data collected at the Scotty Creek Research Station, located in the Northwest Territories, was analyzed over the course of the formation of a connection between two wetland features to determine the thermodynamic and hydraulic function of the talik. This connection increases the hydrologic connectivity of the landscape. Regardless of the stage of talik formation, taliks act as reservoirs of thermal energy, and once formed they represent a tipping point for the underlaying permafrost which will eventually degrade. The identified patterns of permafrost degradation point to a trajectory of thaw, clearing the path for predictions of thaw rates and subsequent expected changes in this landscape.

# Remote sensing and geophysical techniques to detect and map ice wedges

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Transportation infrastructure is essential for the economic and social development of the Canadian North. Ice wedges are particularly problematic because their degradation can cause thaw settlement, water ponding and rapid linear erosion with collapses, which in turn can affect the structural integrity of roads and airstrips. Therefore, detecting and mapping ice wedges has become essential to build sustainable transportation infrastructure and implement the appropriate mitigation techniques. To better understand the limitations and applicability of different techniques to map and characterize ice wedges, this study investigated three remote sensing techniques (LiDAR, multispectral satellite imagery, photogrammetry by drone) and four geophysical techniques (GPR, CCR, ERT, microgravimetry). The results of the techniques were compared and calibrated with field measurements made in three study sites with different permafrost conditions near highways in north-western Canada. Remote sensing techniques were particularly useful when working over large areas, while geophysical techniques were more effective for precise localization of ice wedges and for road design purposes. Almost all techniques proved to be effective to detect ice wedges and results were improved when techniques were combined. We conclude that the applicability of each technique depends on the objective and the scale of interest.

# Utilizing the TTOP model to understand spatial permafrost temperature variability in a High Arctic landscape

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Ground surface and permafrost temperatures in the High Arctic are often considered homogeneous. However, this is generally incorrect due to highly variable, topographically redistributed snow cover, which generates a substantial degree of heterogeneity. The objective of this study is to describe and spatially model the variability in the ground thermal regime within the Cape Bounty Arctic Watershed Observatory (CBAWO), Nunavut, using the TTOP model, for current conditions in addition to a series of climate change scenarios. While observed air temperature was mostly uniform, annual mean ground surface and permafrost temperatures were estimated to range between -3.8 to -13.8 °C and -3.9 to -14 °C, respectively. The spatial models showed higher ground surface temperatures in topographic hollows and lower temperatures in areas of topographic prominence, following the spatial pattern of snow accumulation and redistribution. Under projected climate change, the models predicted areas with the coldest permafrost to have the largest magnitude of warming, while areas of warm permafrost approached 0 °C. This thermal heterogeneity may have implications for ground instability such as permafrost-related mass movements, hydrological connectivity, biogeochemical cycling, and microbial activity, which influence water quality and contaminant mobility.

## Brain-like ridges in the Canadian High Arctic

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Landforms found in the Canadian High Arctic are characterized by a series of anastomosing ridges and troughs forming a brain-like labyrinth. Numerous raised-ridge circular features have been documented in the literature and are interpreted to have formed as a result of either periglacial or glacial processes. These features can be differentiated based on morphology, scale, material, sorting, and association with other periglacial or glacial features, or both. High resolution drone imagery of this landform was collected in 2018. Digital elevation models have allowed us to characterize the surface in detail. Trenches were dug in the field in search for the permafrost table and massive ice. Based on our observations, we interpret this High Arctic landform to be glacial in origin rather than periglacial in origin, with post-depositional periglacial modification.

# Modelling water release from permafrost in response to climate change in Chile

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Numerical cryo-hydrogeology models can be useful tools for understanding thermal and hydrological feedbacks that influence water availability in periglacial regions. However, such models often are restricted to idealized environments due to scarce data from high altitudes or latitudes. With climate change expected to modify permafrost distribution across the globe, there is growing interest in the availability of cryo-hydrogeological models for planning purposes. To increase the reliability of predictive analyses, such models must link hydrological and thermal processes to observational data. In this presentation, potential climate change effects on the ground thermal and hydrological regime at a permafrost site in Chile are explored using the coupled finite element codes TEMP/W and SEEP/W. Approximately six years of meteorological and ground thermal data (surficial and in boreholes) were used to calibrate a one-dimensional model, using a surface energy balance approach. Model properties were informed by drilling, test-pit and geophysical data.

# Estimating the cost of climate change-induced permafrost thaw on Canadian infrastructure

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A methodology to assess the costs of maintaining or replacing roads, airports and buildings due to permafrost thaw, previously developed for Alaska, was modified to enable its application across northern Canada. Potential thaw-induced damage as the climate warms was directly related to excess ice content and was set to start at TTOP temperatures exceeding -2 °C when bearing capacity starts to decline, to peak as temperatures pass through 0 °C, and to continue at progressively lower rates until modelled ground temperatures reach 3 °C. A lag of one decade between air and ground temperatures was applied in acknowledgement of non-instantaneous thaw processes. Preliminary results for reactive scenarios indicate annual costs for 2040-2070 averaging almost $200 million, with relatively little difference between RCP4.5 and RCP8.5. Proactive investments can reduce these costs for RCP4.5 but have no positive effect for RCP8.5 because the scale of the projected warming means that in many locations, damage due to thaw can be postponed but not prevented.

# Laboratory characterization of permafrost samples using the ultrasonic pulse velocity technique

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The accelerating permafrost degradation due to climate change threatens the structural integrity of northern infrastructure. Characterizing foundation soils is the first step in the design and construction of civil infrastructure. Design of foundation in permafrost zones adds unique considerations that may control the design. The measurement of physical and mechanical properties of soils requires extensive *in-situ* or laboratory tests, which can be time-consuming and costly. In this presentation, we proposed an innovative ultrasonic-based system and method for the laboratory characterization of permafrost samples. This proposed technology quantifies the physical (e.g., ice content, unfrozen water content and porosity) and mechanical properties (e.g., shear and compression wave velocity) of the permafrost foundation soils. The spectral element-based poromechanical forward solver was developed for ultrasonic wave propagation in permafrost. The neighborhood search algorithm was applied to match the predicted signal with the experimental measurement. Based on the case studies using the ultrasonic pulse velocity technique, it was shown that the developed integrated algorithm can be successfully and efficiently used to determine the physical and mechanical properties of permafrost soils.

# Thaw sensitive terrain, northern Slave Geological Province, NU

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Knowledge of thaw sensitive terrain is required to develop climate-resilient northern infrastructure, identify potential geohazards, and make inferences on past and future landscape evolution. Importantly, little is known about permafrost conditions in the northern Slave Geological Province, a region with rich mineral resources and great northern economic development potential. To address this knowledge gap, we use a landsystem approach to attempt to understand how the region's landscape and thaw-sensitive terrain was formed. We investigate the collection of paraglacial and paraperiglacial landform-sediment assemblages within it, and will attempt to link them to the processes that formed them. Using the proposed Grays Bay Road as a study transect of the region, we map terrain features by modifying a robust terrain feature mapping approach developed earlier and jointly with the Northwest Territories Geological Survey to map the Dempster and Inuvik to Tuktoyaktuk highway corridors using very-high resolution satellite imagery and a digital elevation model. Here we present the preliminary catalog of landforms mapped from available satellite imagery (72% of the 1600 $km^2$ area that is within 5 km of the route). In combination with sparse sedimentological and cryostratigraphic records, we develop a set of preliminary landform–sediment assemblages. Notable are glaciofluvial deposits over massive ice that are dissected by ice-wedge polygons. This assemblage often demonstrates long-term creep, has a high potential for thermal adjustment, and is a potential geohazard throughout this region.

# Analysis of surface-based inversion characteristics in northwestern Canada using radiosonde data between 1990 and 2016

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Assumptions regarding lapse rates in areas prone to frequent and persistent surface-based inversions (SBI) can generate significant errors associated with the prediction of surface air temperature (SAT). This in turn will influence where permafrost is found and is most susceptible to thaw. Few regional studies of SBI characteristics exist, particularly those investigating the impact of SBI on SAT and subsequently permafrost distribution. To address this regional gap, vertical atmospheric temperature profiles for five sites in northwest Canada were analysed using archived radiosonde data (1990-2016). A novel SBI metric 'Inversion Impact' (Iimp) was developed to quantify the theoretical impact of SBI on cooling SAT at annual and seasonal scales. Quantification of Iimp allows for a comparison of how SBI influence on SAT varies spatially and temporally in northwest Canada. Annual Iimp > 5 °C and winter Iimp ~10 °C occur locally, while regional and macroclimatic elements, including sea surface temperature, jet stream position and strength, influence the magnitude of Iimp uniquely at each site. Iimp significantly declined over the study period at most sites due to climate change. The results from our study are important for regions where SBI contribute to boundary layer climatic conditions maintaining permafrost.

# Assessment of coastal erosion processes on Tuktoyaktuk Island, NT, using a 2D finite-element model approach

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Warming in the Arctic leads to the thawing of permafrost, thereby weakening the soil, increasing its susceptibility to settlement and erosion thus threatening the integrity of coastal communities. Recent changes in Arctic climate have accelerated the coastal erosion problem posing significant threat to coastal areas with inadequate, or lack, of shoreline protection measures. Tuktoyaktuk Island found just east of the Hamlet of Tuktoyaktuk, NT, along the Canadian Beaufort Sea coast, has acted as a natural barrier protecting the harbour and community from wave impact. However, longer warmer summers, which lengthen the open-water season, have put the island and community at risk as it allows more storm surges to access the sensitive ice-rich permafrost coastlines. Currently eroding at a rate of ~2 m $year^{-1}$, the island may be breached within the next 15 years. This presentation describes the development of a two-dimensional thermal and mechanical model which aims to understand past, present and future coastal erosion processes and behaviour; how the soil properties of the island's permafrost influence coastal erosion; and the implications to potential erosion mitigation strategies. Background information, model breakdown, and preliminary model results are included in this presentation.

# A check on PERD 1998 climate change forecasts for Canada

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Over the past 20 years several guidance documents have been prepared for engineers to account for climate change impacts on the design, construction, operations and closure of northern infrastructure. In the late 1990s the Panel on Energy Research and Development's (PERD) published the Climate Change Impacts on Permafrost Engineering Design. They provided decadal temperature change estimates (referenced to 1960-1990) on a quarterly annual basis by latitude (50, 60, 70, 80 degrees North) for northwestern Canada. These temperature change estimates were useful when conducting ground thermal analyses for the design of landfill covers and frozen core dams located on permafrost in the Canadian Arctic. Now that three decades have passed since the PERD forecasts were prepared, an estimate of their accuracy can be made. The presentation compares three PERD decadal forecasts (1990 to 2000, 2000 to 2010, and 2010 to 2020) to the Environment Canada and Climate Change meteorological data for stations at Edmonton, AB, Yellowknife, NT, Resolution NU, and Alert, NU. Data were averaged over each of the three decades for the four quarters (December to February, March to May, June to August and September to November). In general, the PERD forecasts underpredicted the measured air temperature increases for December to February quarter and the September to November quarter. Among the four locations the discrepancy between measured and forecasted air temperature increased with latitude.

## Coastal erosion mitigation project in Tuktoyaktuk, NT

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The Hamlet of Tuktoyaktuk, NT, located on a low-lying peninsula at the Arctic Ocean, has been experiencing coastal erosion and flooding that resulted in the loss of buildings and housing, and inundation during surge events. The shoreline erosion rates are in the range of 0.8 m $year^{-1}$ along the Hamlet and 1.7 m $year^{-1}$ along Tuktoyaktuk Island, which would mean that much of the Hamlet and all of Tuktoyaktuk Island would be lost to erosion by the year 2050. Baird & Associates with sub-consultant BGC Engineering was retained in 2018 to develop an erosion mitigation plan for the Hamlet and Tuktoyaktuk Island. Learning from past efforts to protect the shoreline, which had varying levels of success, the objective of this project is to provide a longer term, comprehensive mitigation approach considering climate change impacts. This presentation provides an overview of design considerations, geotechnical site investigations, numerical modelling and how climate change is considered in the process.

# Initial thermal performance of a tailings retaining frozen foundation dam, Nunavut, Canada

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This presentation will cover the design, construction, and initial thermal performance of a tailings retaining frozen foundation dam located in Nunavut, Canada. Design of the dam was based on maintaining a perennially frozen foundation to ensure infrastructure stability and containment. Phase-1 construction of the dam was completed in the winter of 2018. Thermal performance to date has been the result of the winter construction sequences, design of the structure for passive heat transfer with the atmosphere, and proper tailings management to develop a continuous tailings beach along the upstream face of the dam to limit water seepage and heat transfer to the foundation. The maximum annual ground temperature beneath the key trench has ranged from -6.0 °C to -7.3 °C and -3.2 °C to -5.7 °C for the thickest and thinnest sections of dam fill, respectively. Initial ground temperature monitoring has confirmed that the dam is generally performing as thermally designed. Numerical thermal modeling with consideration of climate change over the 25-year design life predicts near-term ground cooling following the Phase-2 dam raise and cessation of tailings deposition. The initial findings support similar designs and the use of frozen foundation dams as a safe technology to retain tailings in cold climates.

# An aerial inventory of rock glacier distribution and activity level assessment in Banff National Park, Alberta, Canada

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Rock glaciers are perennially frozen masses of ice and debris that creep downslope under the weight of gravity. These features are often tongue-shaped, lobate landforms containing longitudinal or transverse flow structures, with a surface that consists of poorly sorted, angular, rock debris. Although rock glaciers are abundant geomorphological features in the alpine periglacial environments of the Alberta Rocky Mountains, their spatial distribution and characteristics are largely unknown. Over 500 intact (active or inactive) rock glaciers were identified within the study area, as well as over 100 features requiring further validation of surface kinematics and morphometric quantification. Aspect was found to be a topographic parameter that strongly influences rock glacier distribution in this region, as most features were found to occur on the north and northeastern facing slopes. The manual inventorying of these features were done using high-resolution satellite imagery that is available through ArcGIS Online and Google Earth. As rock glaciers contain frozen fresh water and can be potential geohazards, inventories are crucial in the assessment of the activity status of these landforms. The derived rock glacier classification method developed a proof of concept within a small area that verifies the applicability of this method at a regional scale.

# A long-term, 1-km resolution daily meteorological dataset for modeling and mapping permafrost in Canada

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Climate warming is causing permafrost thaw and there is an urgent need to understand the spatial distribution of permafrost and its potential changes. This study developed a long-term (1901-2100), 1-km resolution daily meteorological dataset in Canada for modelling and mapping permafrost. The dataset includes eight climate variables (daily minimum, maximum, and mean air temperatures, precipitation, vapor pressure, wind speed, solar radiation, and downward longwave radiation). The dataset was developed based on four coarser gridded meteorological datasets for the historical period. Future values were developed using the output of a Canadian regional climate model under medium-low and high emission scenarios. These datasets were down-scaled to 1-km resolution using the re-baselining approach based on the WorldClim2 dataset as spatial templates. We assessed the generated dataset by comparing it to climate station observations across Canada and a gridded monthly anomaly time series dataset. The accuracy of the dataset is similar to or better than the four coarser gridded datasets. The error occurs mainly in day-to-day fluctuations, thus the error decreases significantly when averaged over 5 to 10 days. The dataset can easily be updated, and the method can be used to generate similar datasets for other regions, even for the entire global landmass.