Collaborative workflow among first nations, territorial governments and consultants for mapping geohazards in three communities in northern Canada

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Abstract

The rapidity of landscape response to climate change in Boreal to Arctic regions has spurred geohazard mapping in Canada's northern communities. Such mapping is critical to planning-level decisions regarding existing and proposed land use and infrastructure. Limited availability of geotechnical data, community remoteness, accessibility limitations, and local ground sensitivity pose special challenges for such mapping initiatives. A cost-effective, collaborative workflow for community-scale geohazard mapping involving First Nations, territorial governments and consultants, each of which has distinct roles, is outlined based on experience gained through three case studies in Yukon. In Carmacks, Little Salmon/Carmacks First Nation highlighted its mapping priorities and evaluated different approaches, then Yukon Government contributed funding and field resources to consultant-led mapping initiatives. In Whitehorse, Kwanlin Dün First Nation scoped and commissioned a consultant-led, geohazard and development constraints mapping project that leveraged new, community-scale surficial geology mapping and permafrost investigations completed by Yukon Geological Survey. In Aishihik Village, at the north end of Aishihik Lake, Champagne and Aishihik First Nations meaningfully contributed to permafrost-related geohazard mapping through assistance with field research and sharing of observations and experiences of landscape changes that predate historical (aerial photography) records. These mapping projects highlight the value of multi-party collaboration, which might also or alternatively involve academic institutions, and underscore the importance of territorial governments and consultants actively seeking opportunities to engage First Nations in northern communities in the development of mapping products on which they will be basing decisions about land use and infrastructure in the years to come.

1 Introduction

Climate is changing more rapidly in northern regions of Canada, where permafrost and remoteness increase the vulnerability of communities, than in the more densely populated southern parts of the country. The effects of climate change differ from community to community, but new challenges for land use and infrastructure planning are common. Northerners are scrambling to adapt to, or mitigate, the risks associated with geohazards, such as thermokarst activity and associated retrogressive thaw-flows (e.g., Kokelj et al. 2015; Kokelj et al. 2017), mass movements including shallow (e.g., active-layer detachments) and deep-seated landslides (e.g., Blais-Stevens et al. 2014), riverine or coastal flooding and erosion (e.g., Irrgang et al. 2019; Douglas and Lamb 2024), and wildfires (e.g., McCoy and Burn 2005; Lipovsky et al. 2006). All are exacerbated by the warming and degradation (thaw) of permafrost, which is accelerating in response to climate change.

Despite exposure to a variety of climate-related geohazards, northern communities tend to have the least and lowest quality information on which to base important decisions regarding existing and proposed land use and infrastructure. Territorial and First Nation governments in Canada have recognized this knowledge gap and have taken steps to better inform northern communities about geohazards that may affect them. Geohazard mapping initiatives spearheaded by government and commonly supported by academia have, for example, produced geohazard maps for a number of communities in Yukon (e.g., Benkert et al. 2015; Cronmiller et al. 2020), regional-scale thermokarst mapping (Kokelj et al. 2023) and community-scale surficial geology mapping in communities in Northwest Territories (various 1:10,000 to 1:30,000 maps awaiting publication as open files), landscape hazard maps for communities in Nunavut (e.g., Forbes et al. 2014), and permafrost-related risk maps for the Nunavik region of northern Quebec (e.g., Allard et al. 2020). Still, many northern communities remain with little to no geohazard-related information.

Consultants offer such communities a means of expediting the preparation of geohazard maps, by drawing on internal resources, flexible scheduling and practical experience, although this efficiency must be weighed against the potential cost-savings and opportunity for additional field rigour associated with academic involvement. Exactly which collaborators are best able to meet the needs of communities, and with what roles and timelines, should be established prior to project commencement.

Drawing on experience from case studies in Carmacks, Whitehorse, and Aishihik Village, Yukon (Figure 1), this paper outlines a collaborative workflow among representatives from First Nations, territorial governments and consultants for community-scale geohazard mapping in northern Canada. It demonstrates effective approaches, the importance of engagement of all parties, and highlights opportunities for improvement. This workflow aims to inspire and guide future collaboration in geohazard mapping projects in northern communities.

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1.1 Effects of Climate Change on Northern Geohazards

The rapidity of climate change in Yukon has important implications for permafrost and associated geohazards. Perrin and Jolkowski (2022) document a consistent increase in average Yukon air temperature since the mid-1900s, with an increase of 2 °C over the past 50 years, and a possible slight increase in average annual precipitation. Wildfire activity may also be increasing in frequency and severity (McCoy and Burn 2005). The resultant thickening of the active layer is altering surface hydrology and flood patterns, accelerating thermokarst activity in areas of ice-rich permafrost, increasing the vulnerability of coastal bluffs and riverbanks to erosion, and increasing the distribution, frequency and magnitude of landslides. Reductions in sea ice extent within the Beaufort Sea (Perrin and Jolkowski 2022) compound the effects of permafrost degradation by increasing exposure of Yukon's northern coastline to waves.

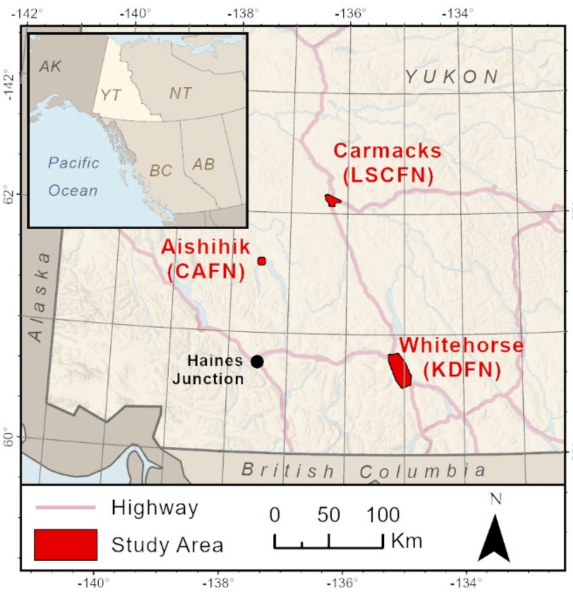


Figure 1. Study areas of community-scale geohazard mapping case studies in Carmacks (LSCFN = Little Salmon/Carmacks First Nation), Whitehorse (KDFN = Kwanlin Dün First Nation), and Aishihik (CAFN = Champagne and Aishihik First Nations) in southern Yukon, Canada.

Air temperatures and precipitation are both expected to continue increasing in Yukon, albeit at rates and with magnitudes that differ depending on the projected greenhouse gas emission scenario (Perrin and Jolkowski 2022). Extrapolation of temperature trend data, for three unique greenhouse gas emission scenarios, projects continued increases by 1.0 °C (RCP 2.6) to 6.0 °C (RCP 8.5) by 2100, while precipitation is projected to increase by 4 to 17% over the next 50 years (Perrin and Jolkowski 2022). The response of geohazards will continue to vary spatially according to differences in topography, surficial materials, vegetation cover, ground temperature and ground ice content. Overall, geohazards are expected to increase in distribution, frequency, and magnitude, which underscores the importance of better informing northern communities of the nature and distribution of these phenomena.

2 Geohazard Mapping Case Studies in Three Yukon Communities

Highlights from community-scale geohazard mapping projects within prioritized areas of the Traditional Territories of Little Salmon/Carmacks First Nation (LSCFN; Carmacks; L), Kwanlin Dün First Nation (KDFN; Whitehorse; K) and Champagne and Aishihik First Nations (CAFN; Aishihik; C) are provided below, with emphasis on the roles of each collaborator (Table 1). The maps informed the communities of the general distribution, characteristics and implications of geohazards, although they are not a substitute for site-specific geotechnical investigation. All three projects were substantially, if not fully, completed prior to release of the Risk-based Approach for Community Planning in Northern Regions – Requirements and Guidance (Bureau de normalisation due Québec 2023), but future similar projects will benefit from review and adoption of applicable elements of this pertinent resource.

Table 1. Summary of collaborator roles and responsibilities in three community-scale geohazard mapping projects in Yukon.

Task	Consultant			Territorial Government		First Nation		
1. Scoping and Kick-off	L	K	C		K	L	K	C
2. Preliminary Mapping	L	K	C		K			
3. Field Investigation	L	K	C	L	(K)		(K)	C
4. Final Mapping and Reporting	L	K	C	L	K	L	K	C

Notes:

Mapping project examples: Little Salmon/Carmacks (L), Kwanlin Dün (K) and Champagne and Aishihik (C) First Nations.

Parentheses indicate participation invited but timing failed.

For clarity, the first row indicates that consultants were involved in scoping all three mapping projects, as were First Nations for their respective mapping projects, but that the territorial government only supported scoping for the project within the Traditional Territory of KDFN (K).

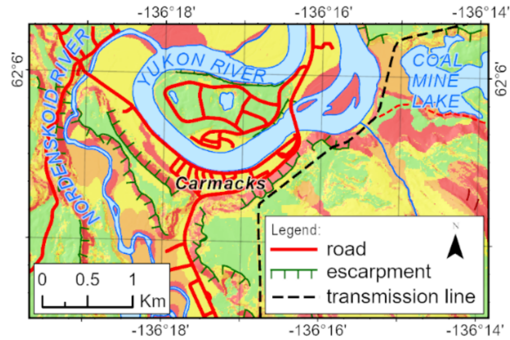
2.1 Carmacks – Little Salmon/Carmacks First Nation

LSCFN was advancing efforts to update its Official Community Plan in Carmacks, Yukon (Figure 1). Carmacks is located in a formerly glaciated, level to hilly section of the Yukon River valley in central Yukon in the zone of extensive discontinuous permafrost (Heginbottom et al. 1995). LSCFN reviewed, helped refine and ultimately commissioned an initial scope of work involving desktop-based, interpretive mapping of land development constraints in its settlement lands within Carmacks. The results of this unpublished mapping emphasized the importance of LSCFN gaining a broader understanding of geohazard susceptibility in the surrounding area, where development interests and plans for government-led upgrades to road infrastructure were being pursued. Yukon Government then spearheaded a consultant-led project to map and field-check local susceptibilities to fluvial, hillslope and permafrost processes within a broader area encompassing LSCFN's settlement lands.

Consultant-led, 1:15,000-scale surficial geology mapping was completed, in accordance with Yukon Geological Survey's adaptation of the Terrain Classification System for British Columbia (Howes and Kenk 1997), based on interpretation of stereo-aerial photography, satellite imagery and LiDAR-derived topographic data (Cronmiller et al. 2020). The surficial geology mapping, with reference to complementary spatial data (e.g., digital elevation models, riverbank erosion mapping, permafrost probability mapping (Bonnaventure et al. 2012)), was then reclassified into individual and composite hazard susceptibilities based on the approach used by Benkert et al. (2015; Figure 2).

Field reconnaissance to enable validation and refinement of the mapping was completed collaboratively by a representative from the consultant mapping team and the Yukon Geological Survey (territorial government). This partnership took advantage of the local knowledge and field resources (e.g., truck, equipment) of the territorial government and the mapping expertise and experience of the consultant. Measurements were made of riverbank position, relative to at-risk property or infrastructure, for baseline reference for any future monitoring undertaken by LSCFN or the territorial government.

A corresponding report drafted by the consulting team, reviewed by the territorial government and shared with LSCFN, was ultimately published by the Yukon Geological Survey to explain and make public the geohazard susceptibility mapping for Carmacks (Cronmiller et al. 2020).



1:50 000 scale topographic base data (incl. 10 m contours) produced by CENTRE FOR TOPOGRAPHIC INFORMATION, NATURAL RESOURCES CANADA

HAZARD SUSCEPTIBILITY CLASSIFICATION

Low susceptibility: Characterized by flat to gently-sloped terrain, devoid of ice-rich permafrost, and distant from watercourses prone to flooding or erosion. This terrain typically comprises well-drained eolian, glaciofluvial, till, bedrock, or anthropogenic materials.

Moderate susceptibility: Characterized by moderately sloping materials and inactive fluvial terraces susceptible to only rare extreme flood events. Fluvial erosion is not expected. Landslide initiation and gully erosion are unlikely. Where permafrost is probable, materials are coarse and susceptibility to thermokarst is low.

Moderately high susceptibility: Characterized by moderately steep to steep slopes where landslide initiation is rare. Permafrost is common but with low to moderate susceptibility to thermokarst. Inactive fluvial plains and active fluvial fans susceptible to uncommon flood events.

High susceptibility: Characterized by steep slopes, landslide initiation, fluvial erosion or frequent flood activity, and permafrost in fine-grained or organic materials. Active fluvial plains or areas of seasonal inundation are included in this category. Includes areas that may be susceptible to fluvial erosion within a 50-year forecast period. Areas of permafrost may be susceptible to thermokarst.

Figure 2. Excerpt from community-scale geohazard mapping for Carmacks, Yukon (reproduced from digital data from Cronmiller et al. 2020). The four-level classification depicted on this map (red = high, orange = moderately high, yellow = moderate, and green = low) represents a composite susceptibility to permafrost (thermokarst), hillslope (landslides) and fluvial (flooding and erosion) hazards.

2.2 Whitehorse – Kwanlin Dün First Nation

KDFN was interested in better positioning itself to evaluate proposals for land and infrastructure development within its settlement lands in the City of Whitehorse and more broadly in its encompassing Traditional Territory. Whitehorse is situated in a broad, formerly glaciated valley of southern Yukon (Figure 1), with diverse landform assemblages, including glaciolacustrine terraces, hummocky glaciofluvial complexes, and steep bedrock slopes. It is located in the zone of sporadic discontinuous permafrost (Heginbottom et al. 1995). Degrading permafrost slopes, riverine flooding and erosion, and landsliding, in particular, pose challenges for existing and proposed infrastructure. Based on advice received from the territorial government, KDFN retained a consultant to produce maps of land development constraints (including geohazards) within the limits of the City of Whitehorse, to help guide its land use planning.

KDFN was fully involved in project scoping, including the establishment of the mapping area, scale and legend protocols, drawing on its familiarity with previous, similar mapping projects in the region. The consultant-led mapping, which so far remains unpublished, was based on a semi-automated reclassification of 1:15,000-scale surficial geology mapping recently completed by the territorial government for the Whitehorse area (Lipovsky 2023) and complementary spatial data, such as Whitehorse area permafrost thaw sensitivity mapping produced by Roy et al. (2021). Erosion hazard zones were additionally delineated alongside riverbanks based on projection from time-averaged rates and trajectories of channel migration since 1946 (Figure 3). The resultant mapping for KDFN differentiates areas (as defined by pre-mapped surficial geology units) according to the applicability and relative severity of up to seven distinct constraints for development, including geohazards (flooding, erosion, landslides, thermokarst) and phenomena that complicate construction (shallow bedrock, steep topography, compressible/weak soils, poor surface drainage).

Preliminary, desktop-based mapping and reporting were reviewed by representatives from both KDFN and Yukon Geological Survey. Limited field reconnaissance was conducted by the consultant mapping team, when last-minute unavailability meant KDFN members or Yukon Geological Survey staff were unable to participate. Field checks were completed, and representative photographs were taken to help illustrate different geohazards and development constraints for improved understanding and use by KDFN. KDFN subsequently allowed Yukon Government to use and refine the results of the constraints mapping to inform local-scale, comparative evaluation of two areas for future urban expansion.

2.3 Aishihik – Champagne and Aishihik First Nations

CAFN maintain, and seasonally use, a small village at the north end of Aishihik Lake, in southwestern Yukon (Figure 1). Yukon Energy Corporation regulates Aishihik Lake for the production of hydroelectricity through the Aishihik Generating Station. The lake is situated in a valley that, during deglaciation of the region, was occupied by a much larger lake into which fine-grained glaciolacustrine sediments were deposited. It is located within the zone of sporadic discontinuous permafrost (Heginbottom et al. 1995). CAFN was forced to abandon and relocate Aishihik Village from the original, delta-front site to the mainland across a small bay after its citizens expressed concerns about accelerating subsidence and shoreline recession.

CAFN established a collaborative approach to support Yukon Energy Corporation in its relicensing of the Aishihik Generating Station. As part of the relicensing process for the station, a consulting team was tasked with investigating and mapping permafrost-related instabilities along the shoreline of Aishihik Lake (McKillop et al. 2019). Preliminary field reconnaissance in the vicinity of Aishihik Village revealed shoreline landforms comprising fine sands with 0.45 m to more than 1.2 m thick active layers overlying ice-rich permafrost. The ice-rich permafrost was inferred from abundant field evidence of active thermokarst (e.g., tilted trees, tension cracks, retrogressive thaw-flows), as well as relatively rapid recession of lake and inland-pond shorelines that predates hydroelectric operations based on comparative analysis of historical aerial photographs (Figure 4). The current limits of areas of active subsidence or erosion were benchmarked for later comparison to monitoring data.

Subsequent field investigations leveraged the assistance, local knowledge, and historical accounts of a CAFN member. Reporting in support of the relicensing application was thoroughly reviewed by YEC and CAFN to ensure findings provided a wholesome reflection of observations and experiences.

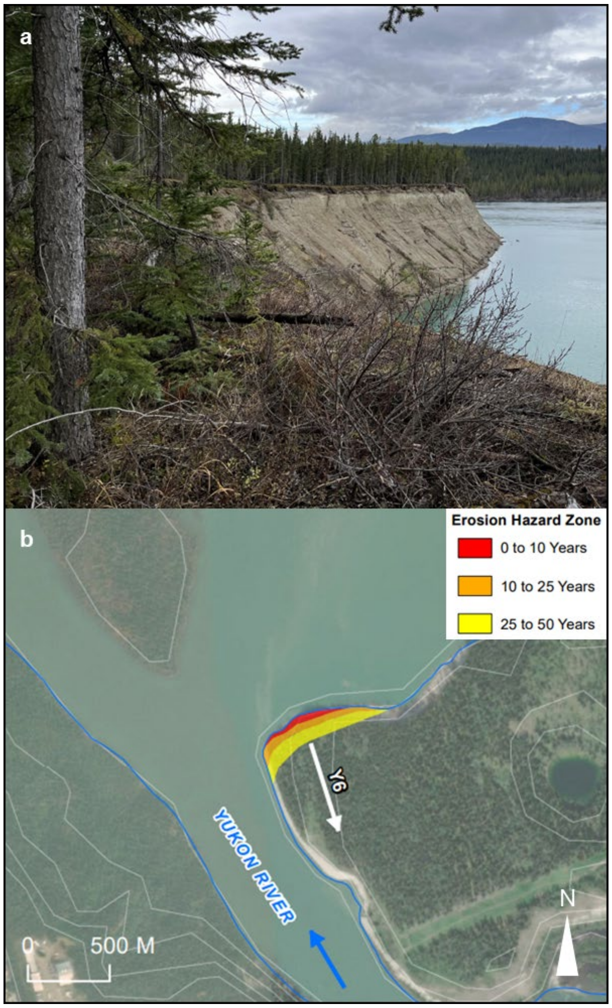


Figure 3. Erosion-prone scarp along Yukon River, within the Whitehorse city limits and Traditional Territory of KDFN (a), and corresponding excerpt of mapping of erosion hazard zones based on extrapolation of time-averaged rates and trajectories of recent bank recession (b) The rate of bank recession at Y6, for example, is 0.9 m/year.

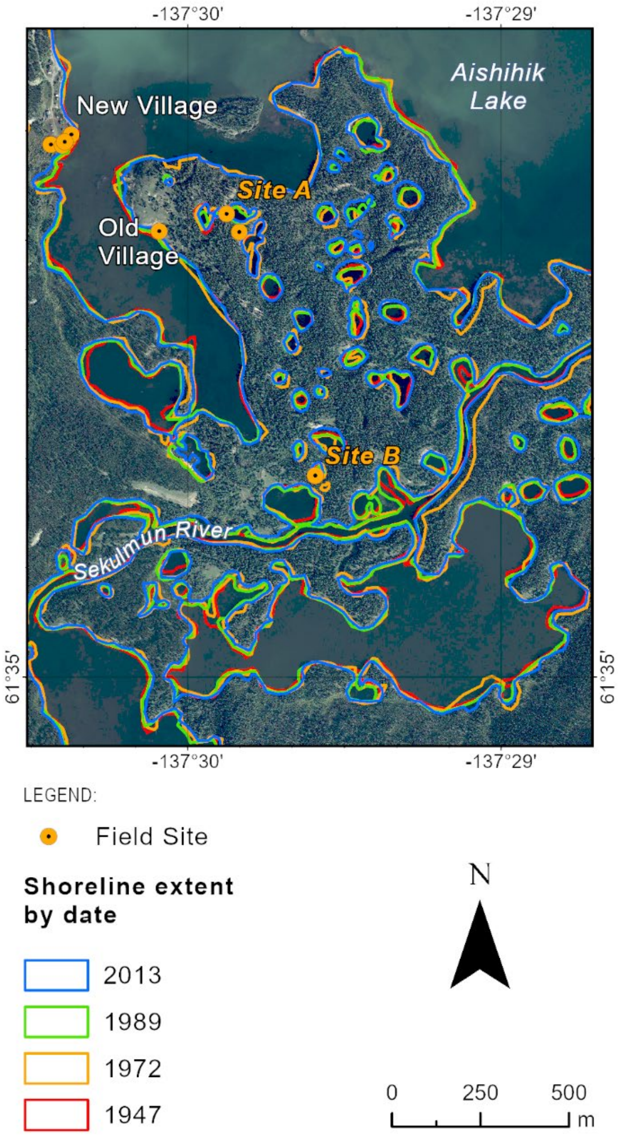


Figure 4. Thermokarst-induced recession of pond and lake shorelines, between 1947 and 2013, near the Aishihik Village sites at the north end of Aishihik Lake, Yukon. Delineations were based on field reconnaissance and comparison of shoreline positions in historical aerial photography. Investigations at sites A and B revealed variable thaw depths in deltaic fine sands, tilted trees and tension cracks along actively slumping shorelines, and pond levels that are elevated above, and isolated from, water levels in Aishihik Lake.

3 Collaborative Workflow for Geohazard Mapping

A collaborative workflow for community-scale geohazard mapping in northern communities is proposed based on the successes and limitations of each of the three case studies outlined above, professional experience in other similar mapping projects, pertinent findings from retrospective evaluations of community-scale geohazard mapping in northern Canada (Flynn et al. 2019; Northern Futures Planning 2019), and the new standard and guidance for risk-based community planning in northern regions (Bureau de normalisation due Québec 2023; Figure 5). The workflow is divided into four sequential "phases", each of which involves the completion of several main tasks. The key contributions to each task of each of the three collaborators – First Nation, Territorial Government, and Consultant – are described along with colour-coded differentiation of lead (green) and supporting (peach) responsibilities. A typical minimum turnaround time for each of the phases, allowing for inter-organizational communication and feedback, is provided for context. Highlights of each phase are summarized below:

- Scoping and Kick-off (Phase 1) is critical to the success of any mapping project. It involves the establishment of study area, objectives, data sources, deliverable format(s), timeline and associated cost. The expected rigour of field investigations is best determined at this stage. The consultant and First Nation must be involved, and territorial government involvement is optional; in some cases, the territorial government advises and assists the First Nation in scoping the project.
- Preliminary Mapping (Phase 2) begins following the completion of a comprehensive background review, consultation with knowledge-keepers within the First Nation and territorial government (especially to identify any relevant, unpublished sources of information), and finalization of mapping protocols and legends to ensure results are understandable to the target audience(s). Interpretations are made based on the best available spatial data (e.g., aerial/satellite imagery, topography, geophysics, geotechnical). Recognition of surface indicators of existing or potential instability, and corresponding landform associations, is fundamental to extrapolation of results over broad areas with limited site-specific data. The consultant leads this task, with optional input from the territorial government and/or First Nation.
- Field Investigation (Phase 3) is necessary, at least at a reconnaissance level, to ground truth desktop-based interpretations and collect additional information that cannot be interpreted remotely. It also provides a valuable opportunity to take photographs representative of the diversity of conditions within the study area, which can help illustrate the meaning of different map units to community members and other stakeholders. Field investigations could additionally involve geotechnical drilling, geophysical surveys, and/or instrumentation for long-term monitoring purposes (ideally supported by the local First Nation, especially in dynamic landscapes). The consultant typically leads this task, but is encouraged to involve representatives of the territorial government and/or First Nation to maximize opportunities for on-site information sharing.

2-4 months (assuming timed for non-winter field work)

Typical Min. Duration	Phase	Task/Element	Primary Roles and Contributions		
			First Nation	Territorial Government	Consultant
2-4 weeks	1: SCOPING AND KICK-OFF	Study area	Proposes and approves	Contributes local knowledge re: focus areas and considerations	Suggests refinements (e.g., steep upslope areas, 50-75-year timeline)
		Objectives	Proposes and approves	Inquires about end use (publication?)	Refines; confirms intended use and audience; discusses pros/cons of different approaches
		Data sources	Identifies sources of spatial data and local/Traditional Knowledge	Highlights data availability – published/unpublished	Confirms access, format compatibility, etc.
		Deliverable format(s)	Proposes, with focus on accessibility	Draws attention to compatibility with other related datasets or mapping	Offers options (e.g., PDF, shp/gdb, kmz, web-viewer); confirms content expectations
		Schedule and cost	Reviews and approves, considering milestones	Offers realistic (in-kind?) support, advises on budget	Proposes what is possible within timeframe and budget
1-2 months	2: PRELIMINARY MAPPING	Background review and consultation	Shares knowledge through documents or interviews	Allows time to compile and send data and answer questions	Compiles and reviews pertinent material, conducts interviews
		Mapping protocols and legend	Reviews and approves	Reviews and offers feedback; prioritizes use of existing (standardized) classification schemes	Drafts and updates based on feedback
		Mapping	Reviews initial samples to confirm meet expectations	Reviews initial samples to confirm meet applicable standards	Completes based on interpretation/analysis; internal QA/QC important
1 day to 1 week	3: FIELD INVESTIGATION	Health and safety	Reviews and approves	Optionally reviews	Provides project-specific H&S plan
		Logistics and equipment	Offers assistance (e.g., personnel, vehicle)	Offers basic support (e.g., personnel, vehicle), where possible	Coordinates; arranges and checks equipment; considers merits of instrumentation installation and monitoring
		Examination and sampling	Confirms site access; acts as safety monitor; shares local knowledge; helps collect/bag samples (if applicable)	Helps interpret landscape and samples (if applicable)	Pre-selects and prioritizes sites, documents georeferenced observations (notes, photos), stores/ships samples
2-4 weeks	4: FINAL MAPPING AND REPORTING	Data entry and organization	Shares any photos	Reviews and offers feedback	Enters data, compiles photos, prepares logs
		Map updates and final production	Reviews, offers feedback and approves	Reviews and offers feedback	Implements refinements to mapping and report; produces maps in agreed-upon format(s)
		Report outline and preparation	Reviews (confirms accessibility), offers feedback and approves	Reviews mainly for technical content	Drafts and circulates outline for comment prior to report; ensures plain language

Note: Green and peach shading denote lead role and support role, respectively. Durations are typical minima, depending on scope, size and complexity of the study area, and collaborator availabilities.

Figure 5. Framework for collaborative geohazard mapping workflow among First Nations, territorial governments and consultants.

- Final Mapping and Reporting (Phase 4) involves updating and finalizing mapping based on observations and measurements from field investigations (Phase 3). An accompanying report explains the mapping and its implications for the First Nation, with at least a plain-language summary to ensure understanding. All mapping is provided digitally, optimally including in accessible formats such as a Google Earth KMZ file, and is accompanied by applicable metadata. Delivery of hard copy maps is also an option. Although reporting is led by the consultant, it is expected that the First Nation and, potentially, the territorial government will review and provide feedback. The territorial government may also publish the results, if acceptable to the First Nation, thereby improving broader accessibility.

4 CONCLUSIONS AND GEOHAZARD MAPPING PRIORITIES

The geohazard mapping projects that have been showcased for three Yukon First Nations demonstrate the value of, and a variety of opportunities for, collaboration among First Nations, territorial governments, and consultants. First Nations must have a role in scoping mapping projects so that deliverables best meet their current and future needs and are easily understood by a diverse audience. Preliminary mapping is typically led by a qualified consulting team, but can be coordinated with related initiatives by the territorial government for efficiencies. Field investigations are optimally coordinated among at least two of the three collaborators to provide opportunities for on-site information exchange. Where possible, key field sites should be instrumented as a comparative reference for future monitoring. Consultant-led reporting to accompany and explain the map product(s) is best reviewed by both the First Nation and the territorial government to ensure representation of different perspectives.

Post-mapping follow-up with each of the three communities is warranted to better understand how the geohazard information is being used to support prioritization of geotechnical investigations and overall risk management. Future geohazard mapping initiatives should prioritize meaningful and ongoing engagement of First Nations, from scoping and kick-off to final mapping and reporting, and clear communication with territorial governments to streamline mapping and leverage opportunities for complementary investigations or long-term monitoring. Collaborations involving participation of academic institutions offer cost-effective alternatives, when timelines allow, given the opportunity they provide for longer-term data collection and analysis by graduate students.

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