

# Feasibility and Design of a Novel Airborne Geophysical Survey Method to Map Permafrost Discontinuity in Northern Environments



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## **Executive Summary**

Mapping the occurrence and continuity of permafrost within Canada's northern landscape is a challenging task considering the remote location of the terrain, highly variable nature of the permafrost, particularly within the discontinuous permafrost regions and the very large regional spatial scales of interest. Recently, advanced airborne geophysical survey methods have shown promising capability for mapping permafrost occurrence and continuity over large terrestrial scales. The airborne electromagnetic (AEM) method offered by Xcalibre Multiphysics, the Resolve6 system, has been used for this application in Alaska with very good results. Within the Central Mackenzie Valley of the Northwest Territories (NWT), discontinuity and rapid change within the regional permafrost is anticipated to be influencing landscape, habitat and ecosystem characteristics along with presenting challenges for the stability of constructed infrastructure and water resource management. Detailed field investigations have been completed near Norman Wells, NWT over the last decade related to environmental monitoring in advance of hydrocarbon exploration and changing climatic conditions. Much of this work has been focused within the Bogg Creek watershed situated along the western shore of the Mackenzie River between Norman Wells and Tulita, NWT. Field data have indicated a high variability in the depth to the permafrost table and the overall thickness of permafrost across this watershed region. The area contains a wide range of lake and stream sizes, diverse landscape conditions and road infrastructure. Utilizing the information available from the Bogg Creek watershed, a Resolve6 AEM survey is proposed to map the occurrence and continuity of permafrost within the watershed area. A series of survey areas are considered, which incorporate a wide range of targets of interest that were anticipated to influence the nature of the underlying permafrost. Close survey line spacing will permit a high degree of resolution in the subsurface imaging and will provide detailed insight into the capabilities of this AEM method to map permafrost continuity within this type of environment.

## Introduction

The occurrence and continuity of permafrost in Canada's northern environment is a major factor in controlling water circulation and the hydrologic balance within the surface and subsurface environments. Warming climatic conditions are anticipated to accelerate the thawing of permafrost resulting in discontinuities within the frozen materials and the development of hydraulic connections, which enhance groundwater circulation. The thawing processes can be highly non-uniform in nature considering the variability in land cover and subsurface geologic conditions. Permafrost thaw can result in land subsidence and subsequent changes in land surface conditions, enhancement of the connections between deep groundwater flow systems and the near surface environment and groundwater-surface water interactions.

As illustrated in Figure 1, discontinuities within permafrost facilitates complex groundwater flow conditions resulting in direct hydraulic connection between deep sub-permafrost groundwater and the surface water system. As the thawing process advances, these circulation patterns and interactions between the different components of the hydrologic system evolve. Consequences of these changes in the hydrologic balance include variations in the size, quality and flow rates of surface water features, formation of low topographic positions resulting from non-uniform subsidence and the potential surface discharge of deep groundwaters of varying water quality.

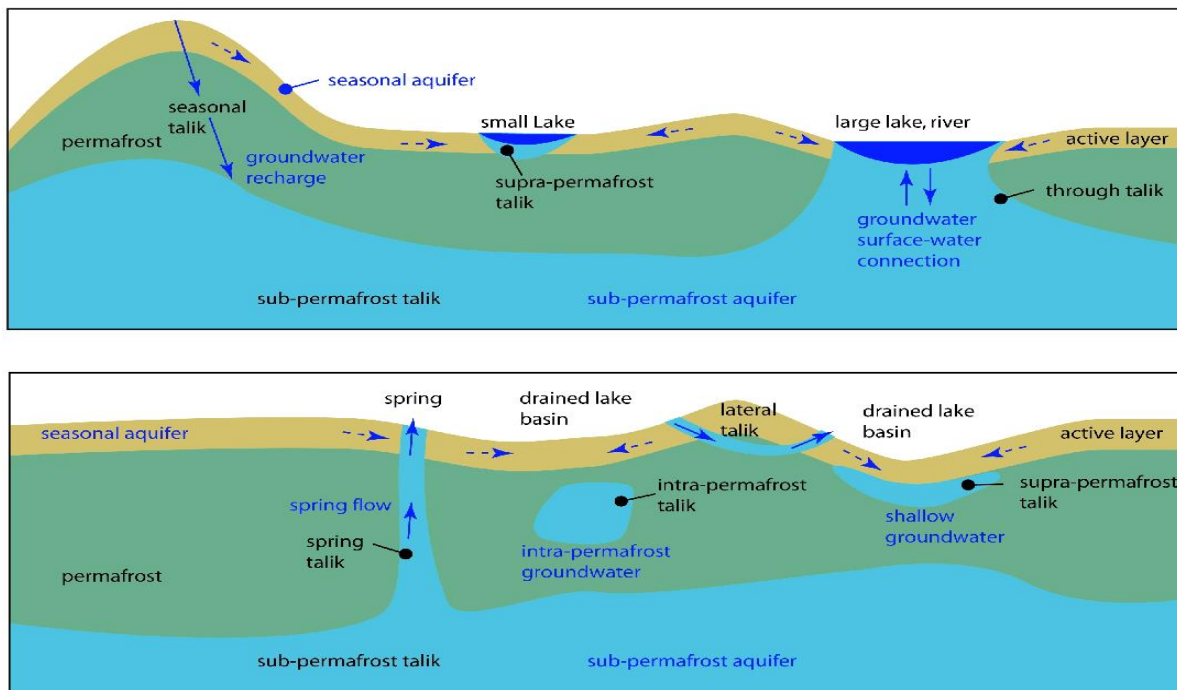


Figure 1. Complex groundwater circulation patterns within discontinuous permafrost environments. (from Scheidegger, J, 2013, after Sloan and Van Everdingen, 1988)

These changing conditions are impacting critical natural ecosystems and habitat relied upon by First Nations communities, specially related to hunting, fishing and mobility over the landscape. In addition, with the development of transportation routes along with buried and terrestrial infrastructure, concerns have arisen regarding the impact of permafrost thaw on the integrity of these constructed features. In addition, as development continues in the north, sustainable allocation and permitting of water resources

will be critical for industrial and municipal requirements and within a warming climatic environment, the occurrence and availability of water from both surface water and groundwater sources is changing and becoming more difficult to quantify. In many regions of northern Canada there is increasing interest in oil and gas development in areas where permafrost degradation is occurring, which could lead to new surface and groundwater pathways and have an impact on potential contaminant fate and transport. Permafrost continuity is therefore of critical interest to a wide range of stakeholders in northern Canada and particularly in regions of discontinuous permafrost such as those encountered within the Central Mackenzie Valley (CMV) of the Northwest Territories.

### *Mapping Permafrost Continuity*

Identifying and mapping permafrost continuity and evolution is extremely difficult and generally impractical with conventional terrestrial investigative methods. Where the permafrost table is shallow (within the upper 2 m of the ground surface), manual methods including hand-driven permafrost sounding probes can be very effective at detecting and mapping the depth to the upper surface of the permafrost (Wicke and Rudolph, 2020). Where the permafrost table is deeper and where the lower boundary of the permafrost is of interest, drilling methods need to be employed. Due to the limited access and remote nature of the terrain within the northern landscape, it is highly costly and not general feasible to bring drilling equipment into a location of interest. In addition, a drilled borehole provides a local measurement of the permafrost occurrence and considering the highly variable nature of the permafrost within a discontinuous environment, this may be of limited use.

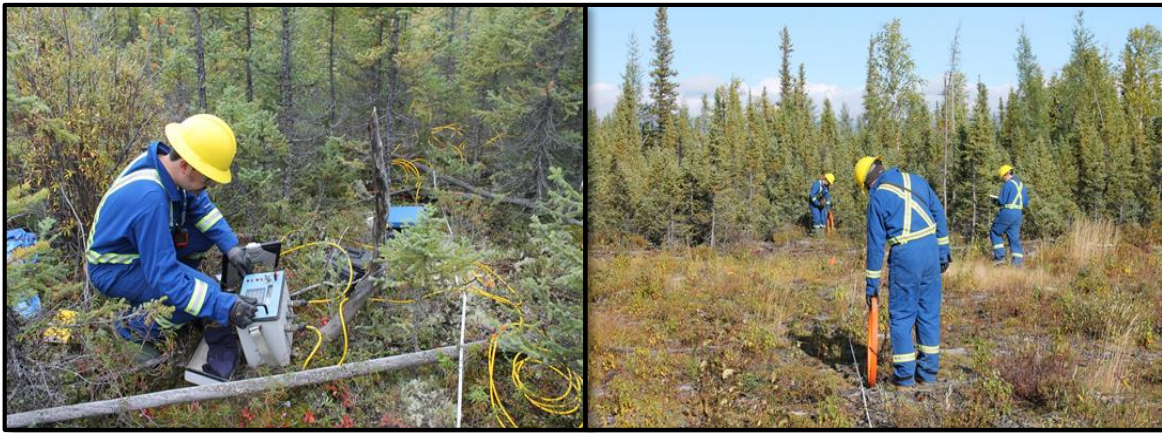
As an alternative to direct measurements of permafrost occurrence, non-invasive, geophysical techniques have been shown to provide valuable information regarding the depth and continuity of permafrost. Both terrestrial-based methods and remote, airborne systems have been employed to map permafrost depth and continuity on a larger scale than is possible with individual bore holes (Walvoord et al., 2012; Minsley et al., 2012 and Wicke and Rudolph, 2020). The portable and more regional nature of these mapping techniques provide significant benefits in remote terrain, such as that encountered in the Canadian north, but their applicability depends on both the terrestrial and subsurface conditions at a given site (Rudolph, 2019, Minsley et al., 2015).

In this current report, the practicality of employing low-elevation, airborne geophysical survey methods to map both the upper and lower surface of permafrost within a region of discontinuous permafrost in the Sahtu region of the CMA is quantitatively assessed. Site specific conditions at a field observatory near Norman Wells that has been under investigation with the collaboration of the Government of the Northwest Territories for 5 years will be the focus of the methods assessment. The site is referred to as the Bogg Creek watershed. Relevant terrestrial information will be used to support numerical modeling experiments to examine different probable subsurface scenarios that are likely to be encountered at the site. Based on the results of the modeling and utilizing the terrestrial information collected by our research team within the Bogg Creek field site, a detailed survey design will be proposed including the flight lines, required ground support and costing. This study will provide the information required to determine if this type of survey can be used to map permafrost continuity within this area and other similar areas with the specific goal of providing information of water resources availability for water licencing projects, infrastructure and habitat vulnerability and regional hydrogeologic conceptual model development.

## Background

### *Terrestrial Geophysical Methods*

Several terrestrial geophysical methods have proven effective at mapping the presence of permafrost in the shallow environment (Mühll, Hauck, and Lehmann 2000, Douglas et al. 2016). Two of the most common methods include electrical resistivity tomography (ERT) and electromagnetic induction (EMI). Both systems are portable and can be managed by a small field crew. The ERT method involves the installation of surface electrode arrays with continuous subsurface data collected along the electrode array. The EMI, which is also based on the electrical properties of the subsurface, does not require the installation of a terrestrial array and can be hand carried along a survey line making it a faster and less labor-intensive option (Walvoord et al., 2012) (Figure 2).



(a).

(b).

*Figure 2. Terrestrial geophysical methods including electrical resistivity tomography (ERT) (a), which involves a ground surface installed electrode array (Iris Systems Syscal™ Junior 48) and (b) electromagnetic induction (EMI) utilizing a set of hand-held coils that are moved along a survey line at various coil spacings (Geonics Limited EM-34-3). (Rudolph, 2019).*

With the ERT method, an electric current from two electrode pairs penetrates into the soil and depending on the nature of the subsurface material, the current flow is conducted through the subsurface and measured between the electrode pairs permitting a measurement of the resistivity of the soil. The depth of investigation is proportional to the distance between electrodes so that different electrode arrays that can be selected to measure different depth profiles. The EMI systems, on the other hand, consist of a transmitter and receiver coil, whereby the transmitter generates a primary electromagnetic field that generates a secondary electromagnetic field within the subsurface that is measured at the receiver coil. Because there is a major contrast between the electrical conductivity and resistivity of sediments containing frozen water as compared to sediments with liquid water, these methods have proven useful in tracking the depth and continuity of the permafrost table (Walvoord et al., 2012; Rudolph, 2019).

### *Airborne Geophysical Methods*

Considering the access limitations in remote northern landscapes and the local spatial scale of data collection associated with borehole logging or terrestrial geophysical surveys, low-elevation, airborne

geophysical surveys hold potential advantages in regional mapping of permafrost continuity. A method that has had demonstrated success in delineating frozen ground conditions associated with permafrost occurrence has been the airborne electromagnetic imaging (AEM) system (Fraser, 1978, Minlsey et al. 2012). This EM survey method is based on a conventional terrestrial EM design where a transmitter emits an electromagnetic field that induces electrical currents in materials within the vicinity of the transmitter. The induced electrical currents generate a secondary electromagnetic field that is detected and measured at a single or multiple receivers. The nature of the induced secondary electromagnetic field depends on the resistivity/conductivity of the material the transmitted field passes through. The spatial AEM raw data are then converted to values of apparent resistivity through a numerical transformation process involving various half-space subsurface models that utilize different components of the received secondary electromagnetic field (Huang and Fraser, 1998). The transmitter-receiver system is flown at low elevations (30 m -50 m) above the land surface with a helicopter and the exact elevation and spatial positioning are recorded continuously in order to correct the raw data and develop a spatial mapping of the results.

One commercial system that has proven capable at delineating the limits of permafrost in northern environments is the Xcalibur RESOLVE™ system (Slattery, S. R. and Andriashek, L.D.). This AEM method utilizes six operational frequencies between 0.4 and 133 kHz and has the ability to produce a higher degree of vertical and horizontal resolution of apparent resistivity within the subsurface as compared to a single transmitter and receiver system. Figure 3 presents a photo of the AEM system along with an illustration of the electromagnetic fields and the resulting cross section of the subsurface electrical conductivity. The induced EM field generated within the subsurface materials is influenced by the lithological composition, water content, salinity and thermal state of the water (frozen or liquid), all of which influence the relative resistivity of the subsurface region (Rey et al. 2019). Although the combined influence of these different physical properties can prove challenging when interpreting the raw survey data, recent advancements in the inversion methods combined with support from terrestrial data can improve the uniqueness and specific interpretation of the survey results (Huang and Fraser, 1998, Minsley et al., 2015).

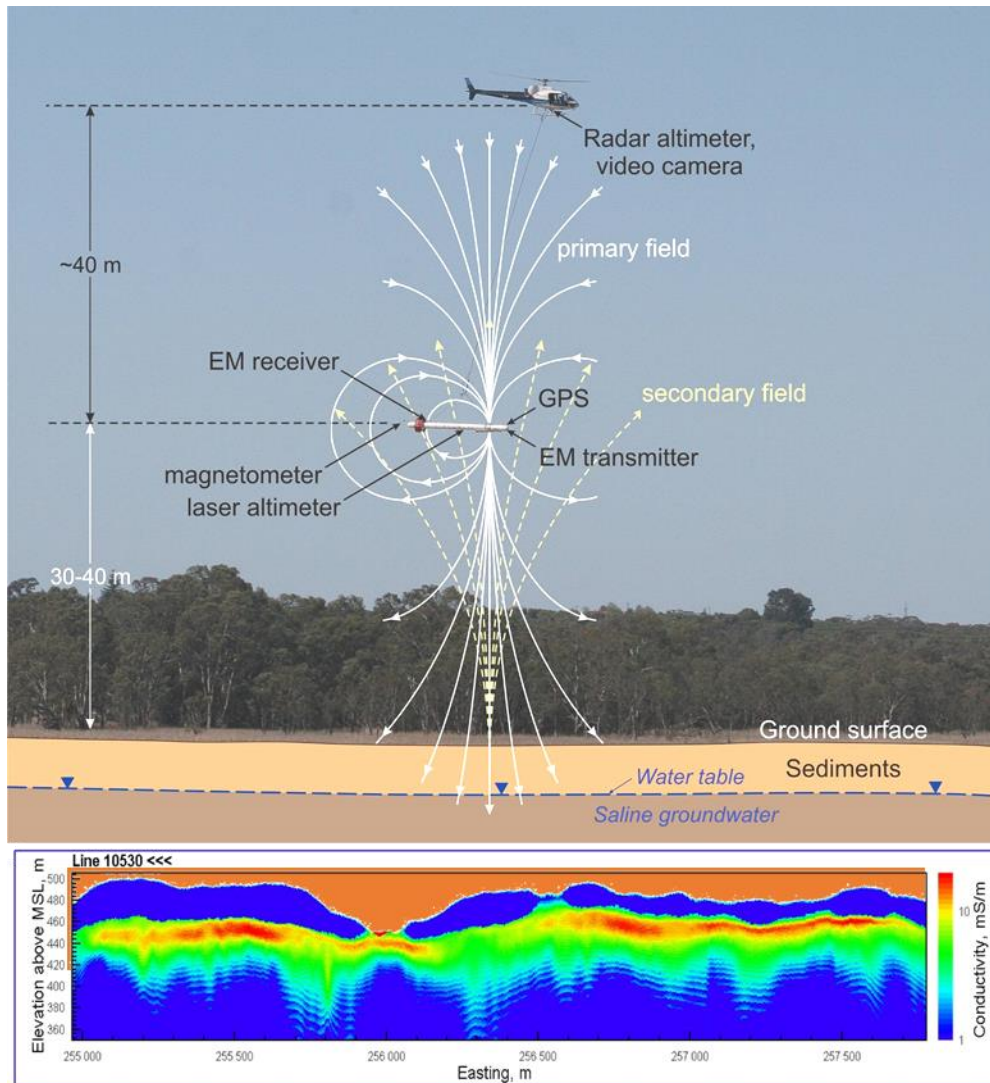


Figure 3. Resolve airborne electromagnetic system in operation along with an illustration of the generated and induced EM fields and a resulting cross section of subsurface conductivity. (from Xcalibur Multiphysics, 2022).

Recent applications to the mapping of permafrost continuity using the Resolve AEM system has been completed in Alaska, USA. The field work was centered within the Yukon Flats area approximately 200 km northeast of Fairbanks, Alaska. The main objectives of the combined research in this area was to employ and evaluate the utility of the AEM method to distinguish and delineate permafrost and various lithologic features within the floodplain of a major river system (Yukon River). Initial work completed by Minsley et al., (2012) demonstrated the ability to detect unfrozen regions below surface water bodies that may be open or through taliks where the permafrost has completely thawed (Figure 4).

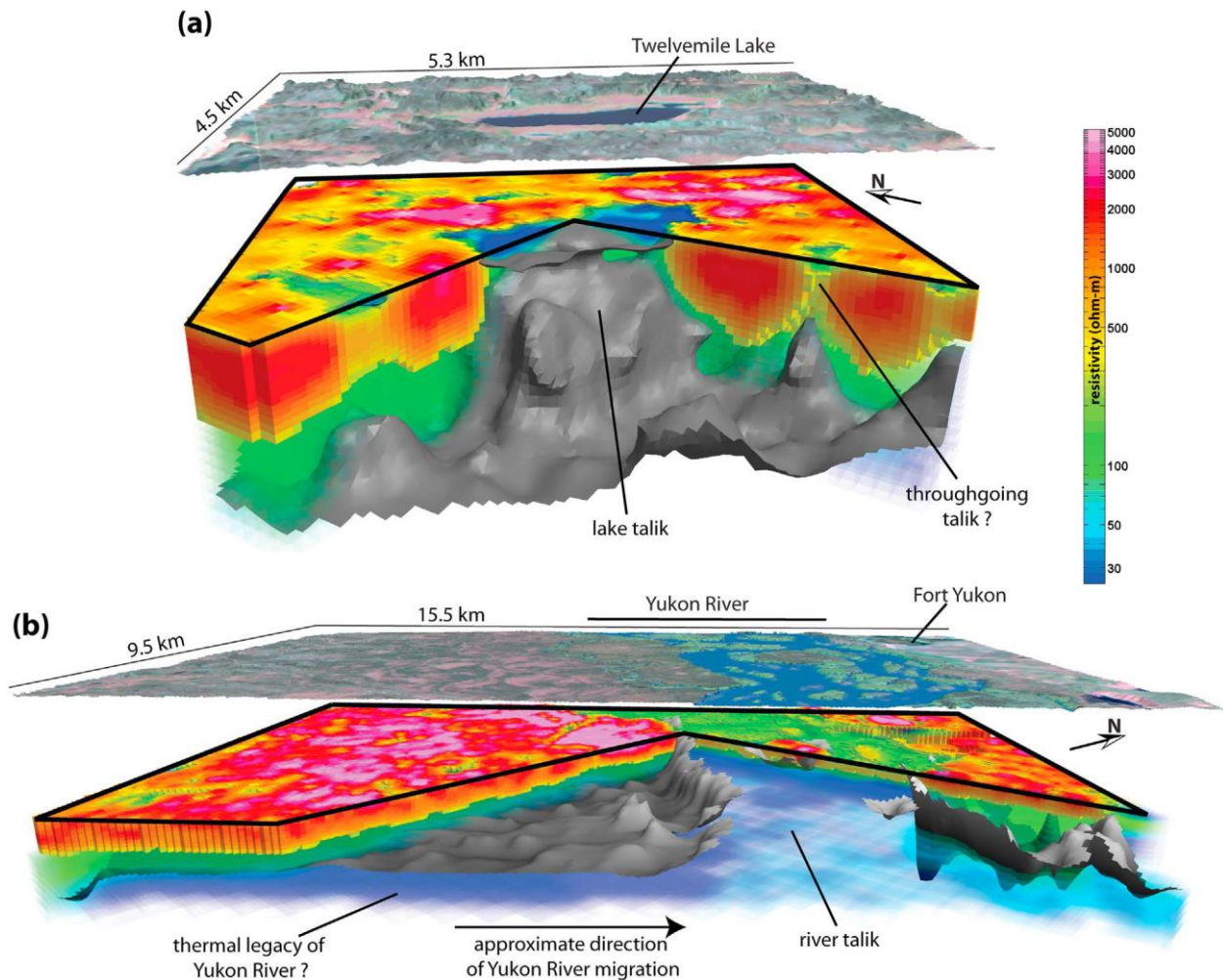


Figure 4. Location of taliks beneath a large lake and a river channel within the Yukon Flats area based on resistivity data from a Resolve AEM survey. (from, Minsley et al., 2012).

Additional AEM survey work completed within the Yukon Flats area by Rey et al., (2019) demonstrated the ability of this method to investigate the influence of spatial and temporal variations in surface water features on the occurrence and continuity of permafrost. This work also demonstrated the utility of replicate AEM surveys to track temporal changes in permafrost within a discontinuous permafrost environment (Figure 5).

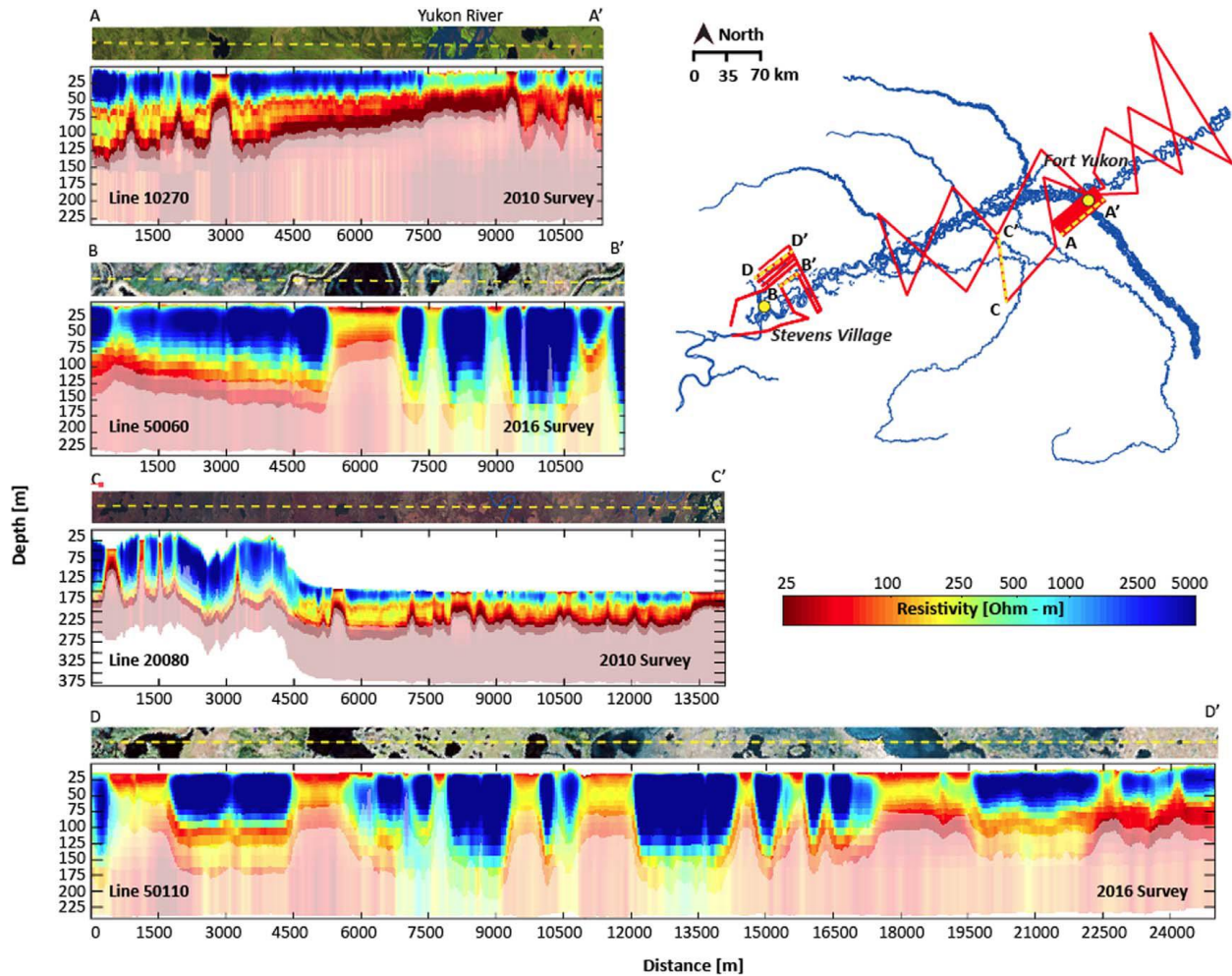


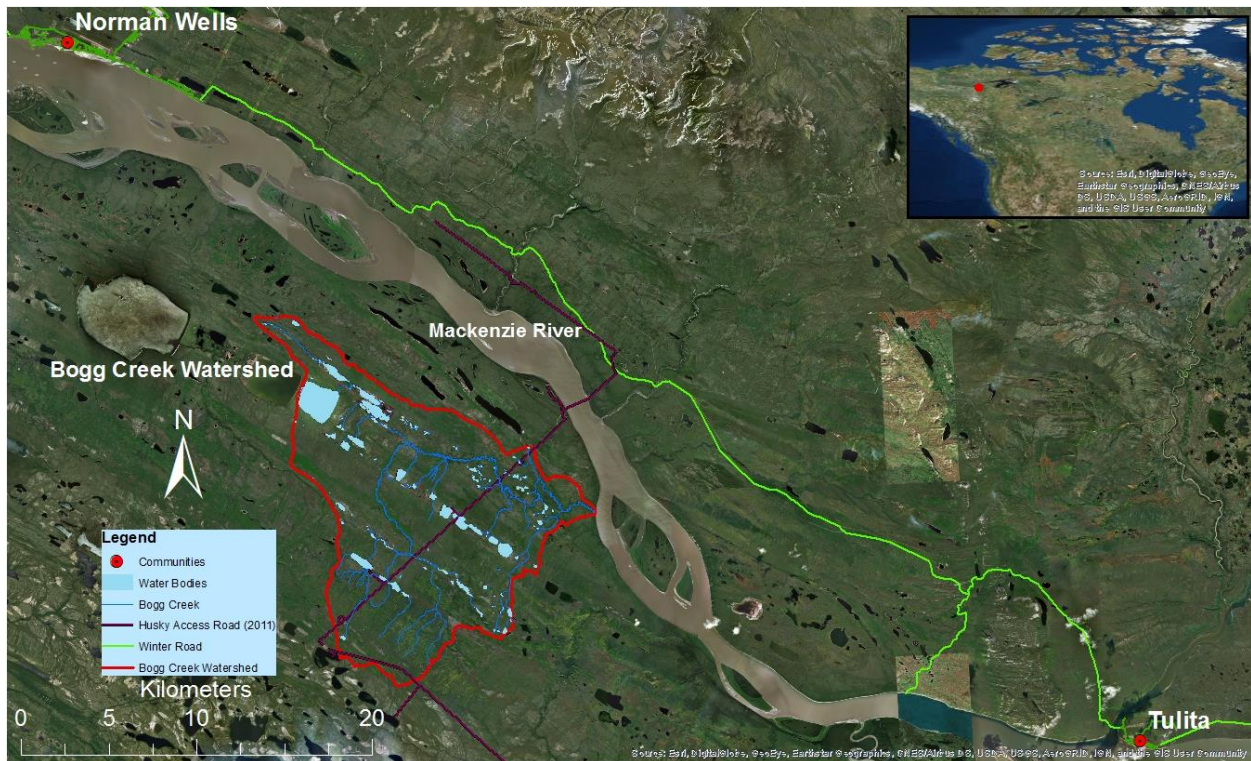
Figure 5. Comparison of replicate AEM survey lines demonstrating changes in the subsurface distribution of permafrost over time based on measurements of apparent resistivity. (from Rey et al., 2019).

The successful performance of the Resolve AEM method within the Yukon Flats area, as demonstrated by these recent studies, provides encouraging potential for the systems' application within the CMV region, with the objectives of mapping the continuity of the discontinuous permafrost.

#### Bogg Creek Field Site, CMV

The field area considered for the airborne geophysical surveys is located 30 km south-southeast of the town of Norman Wells and approximately 40 km northwest of Tulita, NWT within the CMV (Figure 6). Much of the CMV, including this field area, lies within the Sahtu Settlement Area, a land claim agreement which allocated the traditional 41,000 km<sup>2</sup> region to the Sahtu Dene First Nations and Metis People. Oil exploration and production has occurred in and around Norman Wells since the 1920s and this area has recently been the site of exploration for nonconventional petroleum reserves including shale oil and gas by Husky Energy, now owned by Cenovus (Rudolph, 2018; Wicke, 2021). This area has been the focus of detailed hydrologic and ecologic baseline monitoring by Husky Energy and the University of Waterloo over the last decade (Rudolph, 2019 and 2020). The detailed site investigation work associated with this historical baseline monitoring work and the planned air borne geophysical surveys are focused within the Bogg Creek watershed (Figure 6).

The Bogg Creek watershed is a small tributary of the Mackenzie River draining an area of around 190 km<sup>2</sup>. Bedrock underlying the region consists of folded and faulted sedimentary shales and sandstones of Devonian to Cretaceous ages (Fallas et al., 2013; Maclean, 2012). Glacial materials consisting of silts, fine sands and clays overly the area. The glacial overburden thicknesses vary considerably ranging from areas of exposed bedrock in the south west to depths of approximately 30 m with a general thickening trend towards the Mackenzie River (Waterline Resources Inc., 2013a, 2013b). The main channel of Bogg Creek, its tributaries and many of the lakes within the watershed appear to be strongly controlled by bedrock structure. Many lakes are rectangular in shape and aligned roughly parallel to the strike direction of bedrock (northwest-southeast) and the streams tend to follow an orthogonal orientation (Figure 6). Wetlands such as fens and bogs are common, and channel fens and tributaries act as major purveyors of surface water in addition to streams (Aylsworth and Kettles, 2001). The water table tends to be shallow throughout the watershed region (Wicke, 2021).



*Figure 6. Map of study area and regional context. The Bogg Creek watershed is shown as a red outline and nearby communities as red dots. Winter and all-weather roads in the watershed provide access to several monitoring sites (Wicke, 2021)*

The area is underlain by discontinuous permafrost (by definition, a zone is designated as discontinuous permafrost when permafrost underlies 30-90% of the land surface). The occurrence and continuity of permafrost beneath the Bogg Creek watershed is not well known. During field monitoring campaigns in the region, depth to the permafrost table as determined with manual permafrost probe soundings was typically between 0.5 to 2 m below the ground surface. Near surface water bodies and in land clearings, the depth to the permafrost table was much greater and not detectable with manual equipment. The

thickness of continuous permafrost is estimated to range between 5 m and 45 m in the general area (S. L. Smith et al., 2017). Taliks are known to exist beneath some water bodies in the region, with open taliks residing below smaller lakes and streams and through taliks below larger water bodies such as the Mackenzie River (Burgess and Smith, 2001, Taylor et al., 2001). The occurrence and nature of taliks within the Bogg Creek watershed is largely unknown (Wicke, 2021)

An all-season access road was constructed by Husky Energy in 2012 to provide access for heavy exploration drilling equipment within the Bogg Creek watershed (Figure 6). This road provides terrestrial access to the watershed and has facilitated monitoring and site investigation work.

#### *Previous Site Characterization*

Baseline hydrologic monitoring within the Bogg Creek study area has been underway since 2012, through the initial and on going work of Husky Energy (now Cenovus) and more recently by researchers from the University of Waterloo (Wicke, 2021). Field monitoring studies in these types of remote environments are complex and expensive to undertake due mainly to limited access, lack of infrastructure and presence of variable permafrost conditions. The overall investigative work completed in this area has combined remote sensing techniques and terrestrial geophysics (discussed below) with portable field monitoring methods and geochemical/isotope tracing to map regions of groundwater discharge and improve the understanding of groundwater flow characteristics.

Orbit-based optical imagery provided evidence of recurring icings within the study area suggesting locations of groundwater discharge (Glass et al, 2020). Low elevation IR camera surveys conducted during late summer, identified temperature anomalies indicative of cold groundwater discharge (Rudolph, 2019). Physical hydrogeologic data confirmed groundwater discharging conditions with evidence of upward groundwater flow in the shallow subsurface. A range of geochemical and isotopic signatures suggested the existence of several different groundwater sources including water from the shallow active zone and from deeper bedrock aquifers. Surface water and groundwater collected along the length of the main channel of Bogg Creek illustrated variability in groundwater–surface water interaction and provided evidence of suprapermafrost and subpermafrost groundwater exchange.

#### *Terrestrial Geophysical Surveys*

Two portable geophysical survey methods were used to map the permafrost table at several sites of interest within the Bogg Creek watershed. A primary objective of the terrestrial geophysical surveys was to assess the ability of electromagnetic methods to detect variations in depth to permafrost within the subsurface conditions present at the site. The data from these surveys were also used to assess the capacity of the airborne methods to detect the occurrence and extent of permafrost in the subsurface at this site. This is discussed in more detail below. Both the ERT and the EMI methods described above were employed for these surveys.

Two field locations of interest were chosen to evaluate the surface geophysical methods. The first was across a recently cleared (7 years) forested setting where it was hypothesized that the clearing activity could have resulted in enhanced thaw processes at the ground surface and a relative lowering of the permafrost table (Site 1, Figure 7). The second site was chosen near the shoreline of a relatively large lake where it was anticipated that the permafrost would become progressively deeper towards the shore of the water body (Site 2, Figure 7).

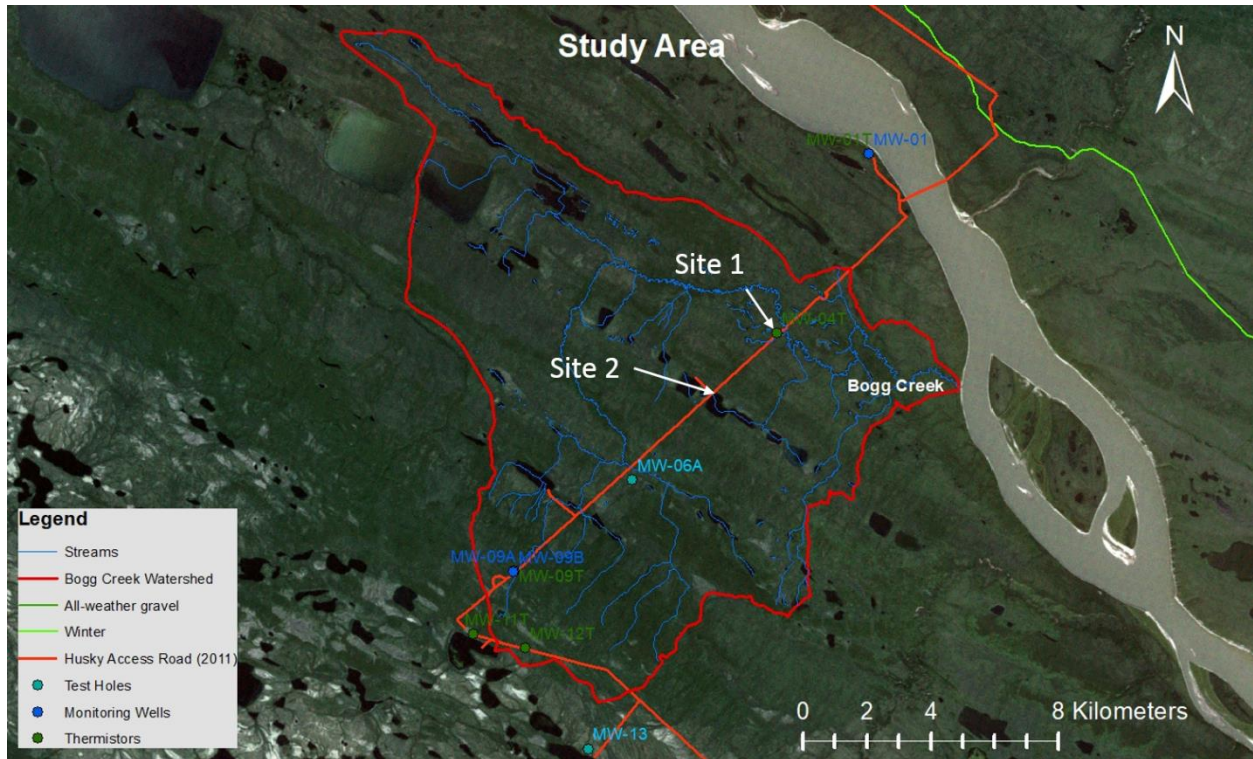
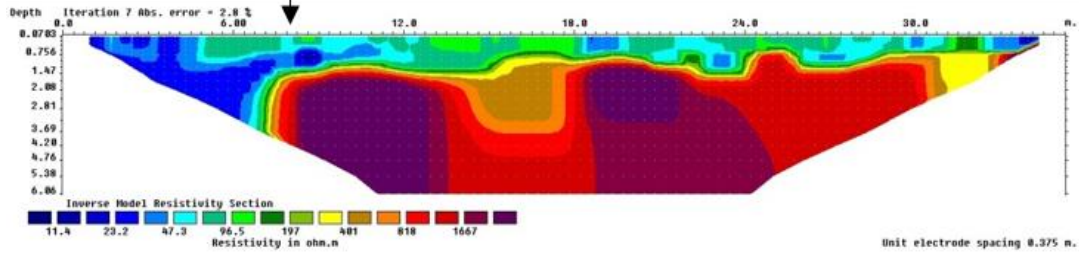


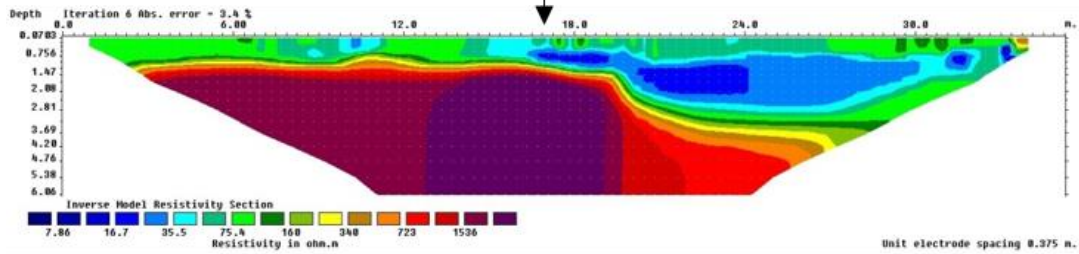
Figure 7. Field locations of ERT and EM geophysical surveys within the Bogg Creek watershed. (Rudolph, 2019).

At both of the sites, manual measurements of permafrost depth were made along the survey lines with a handheld, steel permafrost probe to ground truth the geophysical results. Data from several of the ERT surveys lines (50 cm and 75 cm electrode spacings) are presented in Figure 8. The system used for this investigation is the Iris Systems Syscal<sup>TM</sup> Junior 48. The ERT method was able to clearly delineate changes in permafrost depth at both field sites and illustrated the deepening of the permafrost table under the clearing and close to the lake shore as anticipated. The geophysical profiles closely match the trend of the manual measurements of permafrost depth made along the survey lines.

## Edge of Clearing – Site 1



## Edge of Clearing – Site 1



## Shoreline – Site 2

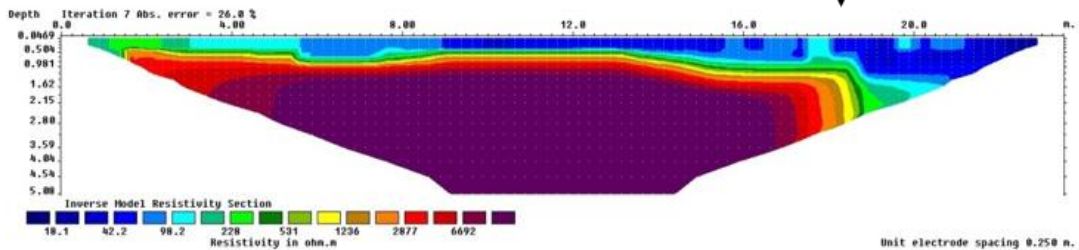


Figure 8. ERT profiles from clearing Site 1 and lake shore Site 2 indicating the position of the clearing edge and lake shore based on an electrode spacing of 75 cm at the clearing site and 50 cm for shore site. Blue colors are associated with higher electrical conductivity likely indicative of liquid water and low ice content. (Rudolph, 2019).

Data from the EMI method utilized along the same survey lines was derived from the frequency domain electromagnetic (FDEM) method (Geonics Limited EM-34-3™ and EM-31™). Coil spacings of between 10 m and 20 m were selected for the EM-34 surveys, and the fixed 3.4 m is the built in spacing for the EM-31. The coils can be arranged either perpendicular to the ground surface (horizontal dipole) or parallel to it (vertical dipole). With each measurement, one depth-averaged data point is obtained along the survey line as opposed to several data points being collected for different depths with the ERT method, as seen in Figure 8 above. The results of the EMI surveys using both the horizontal and vertical dipole configuration are presented in Figure 9 again for the same line sequence as in Figure 8. As with the ERT method, the EMI approach also clearly detected the change in depth of the permafrost table at each of the sites.

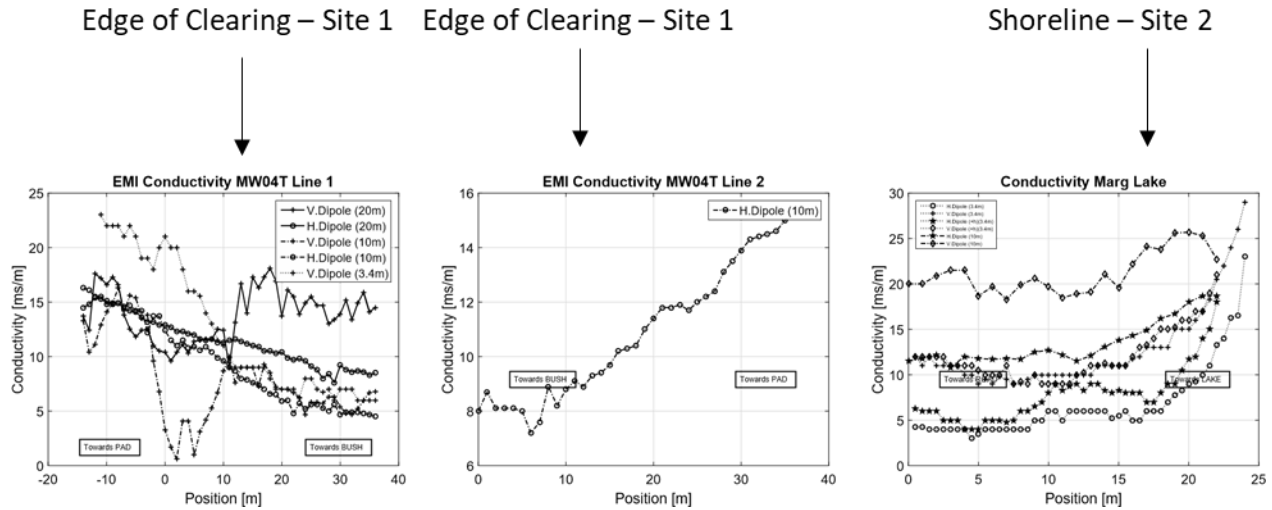


Figure 9. EMI data collected with the EM31 (10 m and 20 m coil separation) and EM 34 (3.4 m coil separation) along survey lines at the clearing site and the lake shore site. (Rudolph, 2019).

The combined results of the terrestrial geophysical surveys illustrate that changes in subsurface occurrence of permafrost can be detected at this field site with electromagnetic methods. This provides confidence that airborne electromagnetic methods would also be successful at mapping permafrost occurrence albeit at a much larger scale. In addition, the terrestrial surveys provided estimates of in situ geophysical parameters that can be used to inform modeling of the airborne geophysical method as presented below.

### Airborne Geophysical Survey for Bogg Creek

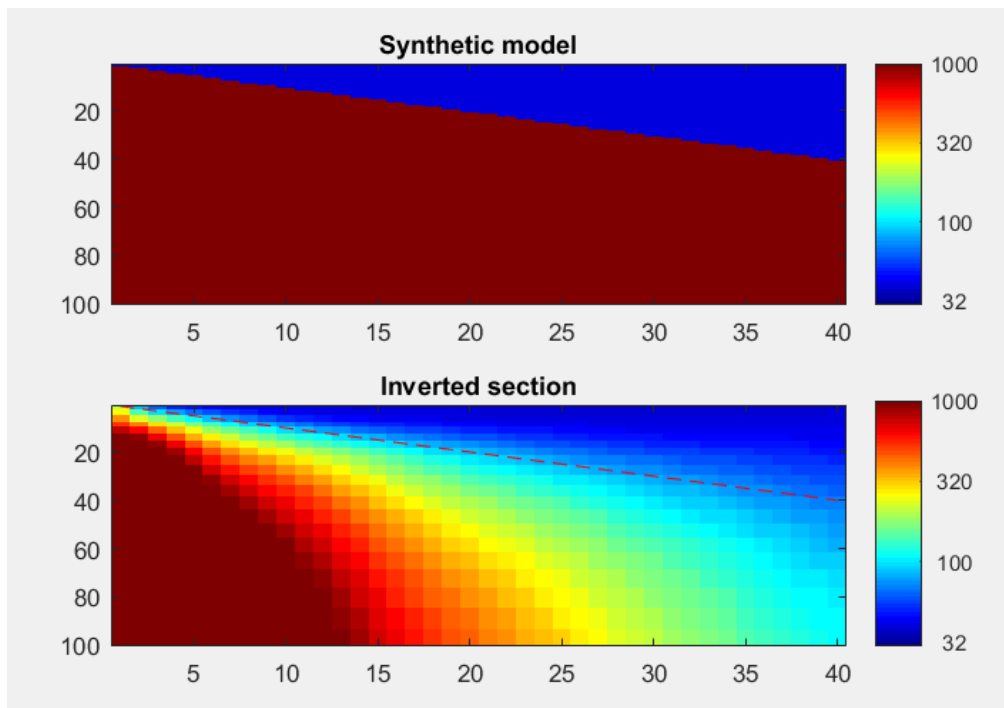
Based on the information available regarding the field conditions within the Bogg Creek watershed, an airborne geophysical survey of specific locations within the watershed region is proposed. The objective of the proposed geophysical survey is to map the thickness and continuity of permafrost in a region of discontinuous permafrost situated within the Bogg Creek watershed using airborne electromagnetic (AEM) techniques. The employed methodology will be expected to be able to map the upper surface of shallow permafrost and the lower boundary of the permafrost at depths of up to 50 m. It is anticipated that the permafrost will be discontinuous and in places absent within the survey area. In order to achieve this scale of subsurface mapping over a regional area, a high precision frequency domain airborne AEM system, which transmits and records with a series of different tuned coil sets is proposed. Xcalibur

Multiphysics offers this type of equipment and can conduct the survey using their Resolve6 system. They have demonstrated experience mapping permafrost continuity within the Yukon Flats, presented earlier in this report, a location which has similar subsurface conditions that are anticipated within the Bogg Creek Watershed area.

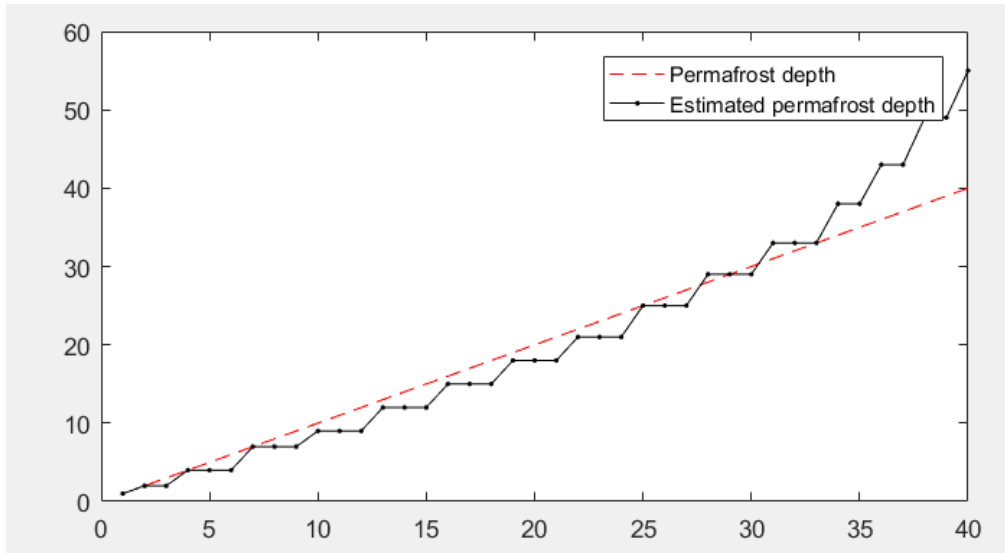
In order to further assess the potential capability of the Resolve6 system to be able to map permafrost occurrence and continuity within the Bogg Creek Watershed, numerical modeling of the subsurface resistivity response expected during the survey under a series of different conditions was conducted.

#### *Initial Resistivity Modeling*

Geophysical specialists from Xcalibur Multiphysics developed a series of DC Resistivity Inversion models to evaluate the ability of the Resolve6 system to delineate the upper and lower boundaries of various permafrost configurations. The modeling work utilized field information from the terrestrial geophysical surveys, geological information and local data on the variability in the depth to the permafrost table collected within the Bogg Creek Watershed. For illustrative purposes, the results from the 1D model were combined to make a 2D image. In Figure 10, a two-layer model with a conductor ( $\sim 20$  ohm-m) over the top of a resistor ( $\sim 3,000$  ohm-m), which represents a thawed active zone over permafrost is simulated. The depth to the permafrost table varies between 0 m and 40 m below ground surface. Figure 10a illustrates the ability of the AEM system to detect the permafrost table as the active zone becomes thicker. Figure 10b shows that the system can accurately detect the permafrost table to depths of approximately 35 m, after which it is difficult to delineate the permafrost table accurately. For most of the conditions that are anticipated within the Bogg Creek Watershed, these results suggest the Resolve6 system will be very successful at mapping the top of the permafrost.



a).



b).

Figure 10. DC Inversion Modeling of simulated resistivity distributions in the subsurface for a two-layer model with a conductor ( $\sim 20$  ohm-m) of varying thickness over the top of a resistor ( $\sim 3,000$  ohm-m). **a)** a 2D image formed by combining together a series of 1D simulation results and **b)** an illustration of the fit between the actual depth to the permafrost table and the estimated depth based on the simulated AEM data. (Xcalibur Multiphysics, 2022).

As the lower boundary of the permafrost is also of interest for this survey, another scenario was evaluated involving a uniform conductive layer ( $\sim 50$  ohm-m) overlying a permafrost body ( $\sim 3,000$  ohm-m) varying in thickness between 0 m and 50 m. This is a reasonable range of permafrost thickness that may be encountered in this discontinuous permafrost environment. The results presented in Figure 11 suggest that the permafrost body can clearly be delineated at thicknesses greater than 8 m with the specified values of layer resistivity. Under conditions where the permafrost is thicker than  $\sim 8$  m both the upper and lower boundaries can be clearly identified.

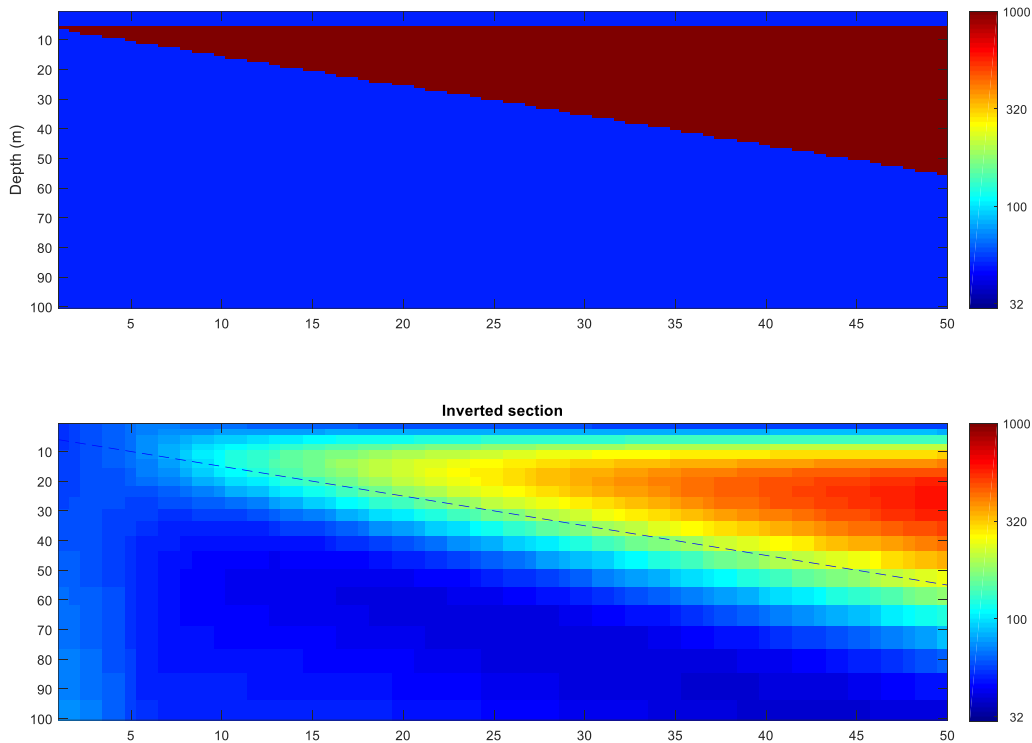


Figure 11. DC Inversion Modeling of simulated resistivity distributions in the subsurface for a two-layer model with a conductor ( $\sim 50$  ohm-m) of uniform thickness over the top of a resistor ( $\sim 3,000$  ohm-m) of variable thickness. The 2D image is formed by combining together a series of 1D simulation results. (Xcalibur Multiphysics, 2022).

Although the field conditions within the Bogg Creek Watershed are anticipated to be variable, the results of the modeling exercises suggest that the Resolve6 system will have the capability of mapping both the existence and continuity of permafrost within a physical setting like Bogg Creek. Based on these results and on the success of the Resolve6 system in the Yukon, a detailed AEM survey is proposed and outlined in the subsequent section.

#### *Proposed Resolve6 Survey for Bogg Creek Watershed*

The land surface and geologic conditions within the Bogg Creek Watershed are highly variable and offer many very interesting geophysical targets to investigate. In order to capture many of these different features, two survey areas are proposed as shown in Figure 12. Within the southeast survey block, the all season access road, a wide range of lake sizes, the Bogg Creek main channel and the Mackenzie River are contained. These are all very interesting features to explore. In the northwest block, a wide range of lake sizes, including a very large lake is found along with areas detected in the past that includes springs and wetlands. Again, these are all features that are anticipated to be influencing the occurrence of permafrost and very interesting to examine with the AEM method.

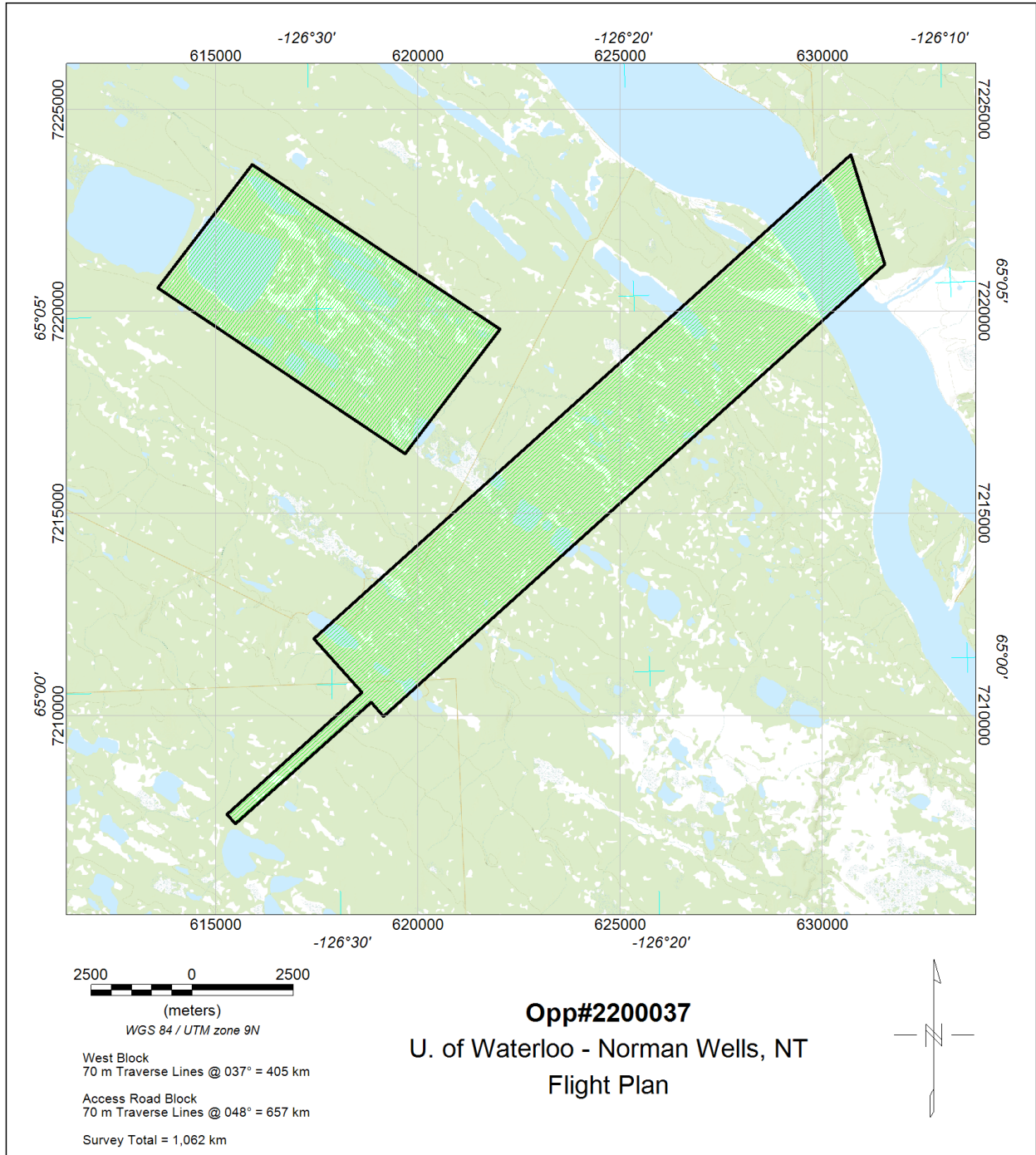


Figure 12. Proposed Resolve6 Airborne Electromagnetic Survey areas. (Xcalibur Multiphysics, 2022).

For both survey areas, it is proposed at a 70 m wide line spacing be selected with the EM instrument flying high averaging 35 m about the ground surface. This will result in a total of 1,062 line kms. Figure 13 provides a photo of the Resolve6 system in flight.



*Figure 13. Resolve6 Airborne Electromagnetic system in flight. (Xcalibur Multiphysics, 2022).*

The raw geophysical data will be processed by the contractor and provided as a series of 2D depth specific maps of resistivity and 3D resistivity volume images of both survey areas. The survey is scheduled to be completed between the months of April and June 2022, will take about a week to complete and is anticipated to cost approximately \$200,000.

### **Conclusion**

The regional mapping of permafrost extent and continuity is critical in understanding water resource availability, hydrologic water balance, influences on infrastructure and impacts on ecosystems, particularly in areas where the permafrost is discontinuous in nature. The warming climatic conditions within the Central Mackenzie Valley (CMV) region of the NWT are anticipated to be accelerating the thaw of permafrost, although this has proven to be difficult to quantify. Newly emerging, remote sensing techniques, such as the airborne electromagnetic systems (AEM) described in this report, promise a rapid and convenient way to map permafrost conditions without the need for costly drilling and land surface disruption.

The detailed field data collection, monitoring and site characterization that has taken place over the last decade or so in the Bogg Creek Watershed within the CMV region, offers a unique and valuable opportunity to apply and evaluate AEM methods to map discontinuous permafrost. The Resolve6 AEM system available through Xcalibur Multiphysics has been shown to be able to successfully map permafrost continuity within the Yukon Flats area, which has similar subsurface characteristics to the Bogg Creek Watershed. This system, supported by initial modeling, has the potential to be able to produce regional scale maps of permafrost in the Bogg Creek area and is proposed to be employed in a focused AEM survey on that site.

The results of the survey will permit an assessment of the utility of the AEM method to map permafrost within this environment and provide insight into the role of a wide range of land surface conditions on the occurrence of permafrost in this setting. It will also provide insight into how this new method could be used for a wide range of applications related to water resource management, impacts of climate change and the impact of permafrost occurrence and thaw on infrastructure like roads, pipelines and structures.

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