ERT and Temperature Monitoring to Assess the Effectiveness of Insulating Culverts on Northern Highways

Northern Climate ExChange
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PROJECT TEAM

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Disclaimer

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EXECUTIVE SUMMARY

Heat transfer into the ground at highway culvert locations can lead to the thawing of permafrost, damaging infrastructure, shortening its lifespan, and increasing maintenance costs. The Dempster Highway in the northern Yukon experiences multiple culvert failures attributed to permafrost thaw. The Yukon Government Department of Highways and Public Works wants to further understand the problem and test potential mitigation methods. A necessary culvert replacement at km 381 provided the opportunity to trial the use of a layer of rigid foam insulation under the new culvert, with the intention of providing an insulating layer between the culvert and the permafrost underneath. Permafrost researchers at the Northern Climate ExChange (NCE) developed an approach to monitor the effectiveness of the insulating layer using a combination of temperature and electrical resistivity monitoring.

MONITORING DESIGN

The NCE-designed monitoring system features two temperature monitoring arrays, and one electrical resistivity tomography (ERT) array below the insulation layer (figure 3.1, pg 10). Sensors and electrodes are evenly spaced along the 23 m culvert. Of the temperature arrays, an 8-sensor array is installed within the bedding material between and parallel to the culvert and the foam insulation layer below the culvert; while a 23-sensor array is installed below and parallel to the foam insulation layer. The system allows for monitoring the difference between ground that is directly influenced by heat-transfer from the culvert, and ground that is protected by the insulting layer. The instrumentation is a series of Onset HOBO UX120-006M analog data loggers, with 16-bit resolution and a capacity for four external sensors for each logger. Logger batteries (two AAA 1.5V alkaline) typically last a year with a logging rate of one minute and sampling interval of 15 seconds or greater. The logger has a 4MB memory which can store up to 1.9 million measurements.

ERT is a geo-physical method which passes current through stainless steel electrodes driven into the ground, and measures the resistivity distribution of the subsurface between the electrode pairs. The resistivity values can then be used to interpret the presence, arrangement, and phase (liquid or frozen) of water within the profile. The NCE-built, custom ERT array features bundled 14-gauge copper electrical wires of increasing lengths (1 m increments), each mechanically attached to a stainless-steel electrode wire with a stainless-steel mesh plate and a stainless-steel perforated plate forming the electrode. Wires are vinyl coated, and connections are coated in liquid plastic. The NCE uses two different electrode configurations (Wenner array, and dipole-dipole array) to investigate the sites; the Wenner array offers better observation of horizontal structures, while the dipole-dipole array offers better observation of vertical structures. Combined, the two configurations offer a comprehensive subsurface profile. The

ERT array at km 381 is installed parallel to and below the insulating foam layer, and allows for monitoring the permafrost conditions below the culvert and foam layer.

Installation of the culvert and monitoring arrays took place September 10-14, 2016. The construction contractor did not bring enough foam for the entire length of the culvert to be insulated as planned, so the finished installation lacked insulating foam for approximately a third of the length of the culvert along the sides (toward the right-hand side of the road), as well as a small portion underneath the end of the culvert on the right-hand side (see fig 3.12, pg 19). In addition to the culvert installation and monitoring arrays, a borehole (DH381 BH1) was drilled in the field at the left-hand side, aligned with the centre of the culvert and the line of the monitoring arrays. The drilling reached 4.55m depth and was lined with PVC piping and instrumented with one 4-channel HOBO logger to record ground temperature at 0. 1.0, 2.0, and 4.55 m depths.

RESULTS

Temperature

Currently, data records cover just under a year. Ground temperature at the deepest borehole sensor (4.55m) was found to be relatively stable throughout the year at -0.2 °C. The the active layer almost reached this depth in August 2017, and, although the permafrost may still be recovering from the disturbance around the culvert and monitoring installations, is is assumed that the ground temperature is warm, close to 0 °C.

Due to unexpected battery drainage, some loggers beneath the culvert did not record data from April 2017 through to June 30th, 2017 when the research team returned to download data. After battery replacement, loggers were re-launched and downloaded again on September 17th, 2017. Temperatures under the culvert can be compared based on available records, and show that temperatures above the foam are cooler than below the foam in Winter (with a mean different of almost 9 °C from January through March), which reverses around the time of freshet in May where temperatures above the foam become warmer than those below the foam for the extent of the summer (with a mean difference of 7 °C from July through September). The foam appears to act as a mitigator of cold surface air temperature in the winter and warm air temperatures in the summer. Winter temperatures below the foam show less variability than above the foam, while in summer, the below-foam temperatures show greater variability than above, suggesting possible penetration of groundwater below the foam. Temperatures both above and below the foam are above 0 °C at times during the summer, however conclusions are cautioned at this time given the short time period recorded, and because the site is likely still recovering from the construction disturbance. The missing foam along the lateral section of the right end of the culvert appears to be influencing the temperatures above the foam.

ERT

ERT surveys indicate two areas of higher resistivity along the length of the culvert. The area on the left side is highly resistive, while the area on the right is more diffuse. They likely represent either more ice-rich ground, or colder areas within the permafrost. The ERT survey taken nine months after the culvert installation shows the ground under the culvert to be less resistive; however, it cannot be determined based on this limited observation whether this is a result of the new culvert installation, or seasonal variation. Resistivity appears to be highest when temperature is lowest, likely due to lower levels of liquid water in colder permafrost.

CONCLUSION

At this time, all interpretations must be regarded with caution because: 1- the site may not have yet reached thermal equilibrium, being still impacted by construction; and 2- the final installation differs from the intended design as about one third of the foam coverage is missing along the culvert.

After one year of monitoring it has been noticed that the insulating foam has been acting like a delayer, i.e. it slows down cooling in winter, as well as warming in summer.

The temperatures are generally colder above than below the foam. This is likely because the foam has prevented the cooling effect of the surface air temperature in the winter, while it did not prevent the warming effect of ground water in summer.

The incomplete foam coverage likely impacts the ERT measurement, yet it appears to show a relationship between resistivity and temperature. With multiple measurements over the course of a year, it should be possible to define a relationship. Modelling the thermal regime based on ERT measurements will require 3D modelling to compensate for the missing foam coverage. As measurements of the installation were made on site during the construction, it is possible to recreate a 3D model of the embankment and foam coverage.

RECOMMENDATIONS

What works

The instrumentation protocol, i.e. multiple arrays cased in ABS tubing, seems to be appropriate as it has survived construction and one year of implementation.

The compaction of the material above the arrays was done with small compactor; once the culvert was set, a roller was used.

The temperature loggers and sensors are relatively economical, yet performed well. The early battery drainage of some loggers is unexplained, but can be prevented with the use of additional battery packs. There is no restriction to the use of another type of instrumentation. The ERT array has proven to be functional, with the electrodes providing a good contact with the ground, and the range of measured resistivity appears to be constant over time, i.e. no increase of resistivity due to loss of contact between ground and electrodes. No welding was used; all connections were made mechanically (nuts and bolts).

What can be improved

The main issue is that the design of the installation was not fully adhered to by the contractor, as insulating foam is missing on roughly one third of the culvert. This affects the thermal regime as well as the ERT survey along the culvert. The original design must be respected and implemented.

Ground water infiltration below the foam might be an issue. A possible solution could be to cover the foam with an impervious membrane, such as a thick polyvinyl sheet, which will also add an additional layer of electrical insulation which is favorable to ERT surveys.

RÉSUMÉ

Les transferts de chaleur dans le sol à partir des ponceaux peuvent mener au dégel du pergélisol sous un remblai, ce qui peut endommager l'infrastructure, réduire sa durée de vie, et augmenter les coûts de maintenance. La route Dempster, nord du Yukon, subit de multiples endommagements de ponceaux résultant du dégel du pergélisol. Le département des routes et travaux publics du gouvernement du Yukon (HPW) désire mieux comprendre ce problème et tester des méthodes potentielles de mitigation. L'installation d'un ponceau au kilomètre 381 a fourni l'opportunité pour HPW de tester l'utilisation d'une couche rigide d'isolant sous le nouveau ponceau, avec l'objectif de créer une barrière thermique entre le ponceau et le pergélisol sous-jacent. Avec pour objectif d'assister HPW d'évaluer la performance de ce système, les chercheurs en pergélisol du Northern Climate ExChange (NCE) ont développé une approche pour contrôler l'effectivité de la couche isolante en utilisant une combinaison de suivi thermique et de résistivité électrique.

CONCEPT DU SUIVI ET APPLICATION

Le système conçu par le NCE comprend deux faisceaux de suivi thermique, et une faisceau tomographique de résistivité électrique. FIG. 3.1, p. 10. Un faisceau comprenant 8 capteurs de température a été installé dans le matériel granulaire entre la couche isolante et le ponceau, et un faisceau de 23 capteurs de température a été installé sous la couche isolante, dans le terrain naturel. Cela permet de faire un suivi de la différence de température entre la couche subissant directement l'effet thermique du ponceau, et la couche protégée par l'isolant. Les détails concernant les capteurs de températures et le système d'enregistrement est disponible en section 3.1 du rapport (p. 9-10)

En complément des faisceaux de température, le NCE a conçu un faisceau ERT maison. L'ERT est une méthode géophysique qui envoi du courant au moyen d'électrodes métalliques enfoncées dans le sol, et mesure la distribution des résistivités dans le sous-sol entre les paires d'électrode. Les valeurs de résistivité peuvent alors être utilisées pour interpréter la présence, la distribution, et la phase (liquide ou gelée) de l'eau dans le profile. Le faisceau construit par le NCE comprend des électrodes reliées à des câbles enfouies à 1 m d'espacement tout au long du ponceau et de l'isolant. Les câbles du faisceau peuvent être attachés à un système Terrameter ABEM pour mesurer la résistivité à n'importe quel moment pour suivi du pergélisol sous le ponceau et l'isolant. Les détails concernant le design et la construction du faisceau maison est disponible en section 3.2.2, les détails concernant la configuration du Terrameter ABEM sont fournis en section 3.2.1.

En addition à l'installation du ponceau et des faisceaux de suivi, un forage (DH381 BH1) a été fait dans le champs au côté gauche, aligné avec l'axe du ponceau et les lignes des faisceaux de suivi. Le forage a atteint 4.55m de profondeur et a été équipé d'un tuyaux PVC, puis instrumenté avec un enregistreur Hobo 4-cannaux pour suivre les températures du sol à 0. 1.0, 2.0, and 4.55 m de profondeur.

L'installation du ponceau et des faisceaux de suivi ont eu lieu du 10 au 14 Septembre 2016. Les contracteurs responsables de la construction n'ont pas apporté suffisamment de mousse isolante pour respecter le design original. En conséquence l'installation finale manque d'isolant sur à peu près un tiers de la longueur de l'installation, sur les côtés du ponceau (en allant vers le côté droit), ainsi qu'une petite portion sous la ligne centrale et à l'extrémité droite du ponceau.

RÉSULTATS

Température

Présentement, un peu moins d'une année d'enregistrement de données est disponible. La température du sol à la profondeur maximale du forage (4.55 m) fut relativement stable durant la période à -0.2 °C. la couche active a presque atteint cette profondeur en août 2017, et bien que le pergélisol puiss toujours être en train de réccupérer de la perturbation induite par le forage à l'eau, il peut être supposé que la température du sol est proche de 0 °C.

Du fait d'un drainage inattendu des batteries, certains enregistreurs sous le ponceau n'ont pas enregistré de données d'avril à juin 2017, quand les chercheurs sont retournés télécharger les données. Après le remplacement des batteries, les enregistreurs furent relancés le 30 juin 2017, puis de nouveau téléchargés le 17 septembre 2017. Les températures sous le ponceau peuvent être comparées pour les périodes enregistrées, et montrent que les températures au-dessus de l'isolant sont plus froides en hiver (avec une différence moyenne de 9°C de janvier à mars), la situation s'inversant au moment du dégel printanier en mai où les températures au-dessus de l'isolant deviennent plus chaudes pour la durée de l'été (avec une différence moyenne de 7°C de juillet à septembre). La mousse rigide semble agir comme un retardateur des températures atmosphériques froides hivernales et chaudes en été. Les températures hivernales sous l'isolant montre moins de variabilité que celles du dessus, suggérant une possible pénétration d'eau sous-terraine sous l'isolant. Les températures au-dessus et au-dessous de l'isolant sons supérieures à 0°C par moment durant l'été. Toutefois, il faut être prudent quant aux conclusions tenant compte du fait de la courte période d'observation, et que le site est toujours sous l'impact des effets perturbants de la construction. La mousse manquante le long des sections latérales de l'extrémité droite du ponceau pourrait avoir une influence sur les températures au-dessus de l'isolant.

ERT

Les levés ERT montrent deux zones de plus grande résistivité le long du ponceau. La zone de gauche est hautement résistive tandis que la zone de droite est plus diffuse. Elles représentent probablement des terrains soit plus riche en glace, soit des zones plus froides du pergélisol. Le levé ERT fait 9 mois après l'installation montre que le sol sous le ponceau est moins résistif; toutefois, dû à la période courte d'observation on ne peut déterminer s'il s'agit du résultat de l'installation du ponceau, ou bien d'une variation saisonnière. La résistivité apparait plus grande lorsque le sol est plus froid, probablement à cause des contenus d'eau liquide moindre en pergélisol froid.

CONCLUSION

À ce moment, toutes interprétations doivent être faîtes avec précaution du fait que : 1- le site pourait ne pas avoir totalement récupéré des effets thermiques de la construction ; et 2- la configuration finale du site diffère du design original du fait des sections de couche d'isolant manquantes le long du ponceau.

Après un an de suivi nous observons que la couche isolante semble ralentir le refroidissement en hiver et le réchauffement en été.

Les températures sont généralement plus froides au-dessus qu'au-dessous de l'isolant. Ceci peut être dû au fait que l'isolant a empêché l'effet refroidissant de la température atmosphérique hivernale, alors qu'il n'a pu prévenir l'effet réchauffant de l'eau sous-terraine estivale.

La couverture incomplète d'isolant a un impact sur les levés ERT, mais néanmoins il apparait une relation entre résistivité et température. Des mesures multiples au courant d'une année pourrait possiblement définir cette relation. La modélisation du régime thermique basée sur les mesures ERT nécessiteront des modèle 3D pour compenser la couverture isolante manquante. Des mesures furent faîtes sur site durant la construction, il est donc possible de recréer un modèle 3D du remblai et de la couverture isolante.

RECOMMANDATIONS

Ce qui fonctionne

Le protocole d'instrumentation, c.à.d. de multiples faisceaux enfermés dans les tuyaux ABS, semble approprié puisqu'il a survécu à la construction et à une année d'implémentation.

La compaction du matériel au-dessus des faisceaux n'a pas endommagé les capteurs. Cela fut fait avec un petit compacteur ; une fois le ponceau installé, un rouleau-compresseur fut utilisé. Les capteurs et enregistreurs de température sont relativement peu couteux et ont bien performé. Le drainage précoce des batteries des certains enregistreur est inexpliqué, mais peut être prévenu avec l'utilisation de batteries additionnelles. Il n'y a pas de contre-indication à l'utilisation d'un autre type d'instrumentation.

Le câble ERT a démontré sa fonctionnalité, les électrodes fournissant un bon contact avec le sol, et l'étendue des valeurs de résistivité mesurée apparait être constante sur la durée, c.à.d. pas d'augmentation de la résistivité au fil du temps due à une perte de contact entre le sol et les électrodes. Aucune soudure n'a été faîte ; toutes les connexions ont été faites manuellement (vis et écrous).

Ce qui peut être amélioré

Le problème principal est que la conception originale du ponceau n'a pas été respectée par le contracteur, comme approximativement un tiers de la couverture isolante est manquante. Cela affecte aussi bien le régime thermique que les levés ERT le long du ponceau. Pour pleinement tester et comprendre l'efficacité d'un design, il faut le respecter et l'implémenter correctement.

L'infiltration d'eau sous-terraine sous la mousse isolante peut être un problème. Un possible solution serait de couvrir la mousse avec une membrane imperméable, telle qu'une bâche épaisse en polyvinyle, qui ajouterait également une couche d'isolation électrique additionnelle favorisant les levé ERT.

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1 INTRODUCTION

The movement of surface water across linear infrastructure (e.g., highways, airstrips. etc.) has always been a challenging issue in permafrost areas. Channeling runoff through culverts is the most common solution to manage surface water. The drawback of this approach is that it creates a “hot spot” at the culvert location whereby water transfers heat to the ground. Where that heat transfer leads to the thawing of surrounding permafrost, localized subsidence may occur causing disruption of the infrastructure, shortening its useful lifespan, and increasing maintenance costs.

Officials at Yukon Government’s department of Highways and Public Works (HPW) are eager to mitigate such issues, especially along the Dempster Highway, where multiple culvert failures have been attributed to permafrost thaw. Repair or replacement of the culverts causes substantial cost. HPW wants to better understand the impact of the culverts on permafrost, and to test the effectiveness of the methods used to maintain permafrost stability. The necessary replacement of a culvert located at km 381 of the Dempster Highway offered the opportunity to trial the use of a layer of synthetic insulation (rigid foam) under the new culvert, with the intent of protecting the surrounding ground and permafrost from heat transfer from the culvert. Permafrost researchers at the Northern Climate ExChange (NCE) developed an approach to monitor the effectiveness of the insulative layer, the thermal impacts of the culvert, and the state of surrounding permafrost using an innovative approach we have pioneered combining temperature and electrical resistivity monitoring.

The project had two main objectives:

1. to monitor the impact of the culvert on underlying permafrost using a combination of temperature monitoring and electrical resistivity tomography (ERT), and

2. to assess the effectiveness of an insulating layer installed below the culvert through temperature monitoring.

The equipment installed as part of this project has allowed for a year of temperature monitoring at the site (reported here), and will allow for continued monitoring and evaluation of the success of the insulation for years to come.

Results presented here show the techniques used are an effective method to monitor temperatures and permafrost conditions under the culvert using a non-invasive and cost-effective approach that can be replicated elsewhere in the highway network. The information provided by this study and the data from future years of monitoring will allow HPW to adjust and perfect their approaches to mitigating heat transfer from culverts, and will be applicable at other permafrost areas in Yukon as well as in elsewhere in the North.

The tasks for this project included:

- General characterization of permafrost at the site of the km 381 culvert using active layer probing, water jet drilling, and electrical resistivity tomography (ERT), as applicable.
- Installation of temperature monitoring sensors and an array of ERT cables directly below the insulation layer buried under the culvert, and temperature sensors buried above the insulation.
- Data retrieval from the site of the culvert and analysis of the data.
- Preparation of this report, documenting:
    - the installation of the above-noted sensors
    - new information about the impact of a culvert on permafrost conditions
    - interpreting the impact, if any, of the insulation layer below the culvert, while insulation is widely used below culverts, it's effectiveness at protecting underlying permafrost has not been tested in this manner
    - describing a protocol for data collection
    - recommendations on the monitoring protocol, and advice for installation of similar systems in other settings, allowing this approach to be re-created elsewhere.

2 SITE OVERVIEW: KM 381, DEMPSTER HIGHWAY

This installation is located at km 381 of the Dempster Highway, Yukon. The physiographic unit is Eagle Plains, which is between km 246 and 405 of the Dempster Highway. The road follows rolling uplands. Surficial material mostly consists of weathered bedrock (Burn et al. 2015).

Burn et al. (2015) mention that the highway route follows the upper surface of Eagle Plains, and avoids many hazards associated with permafrost due to the shallow soils and absence of water courses. The area around km 381 is an exception, with an abundance of water and frost-susceptible floodplain deposits. At this site (Figure 2.1), the field survey consisted of visual observation of permafrost during installation of the new culvert, and the shallow borehole in the field, at the left-hand side of the road. This site was investigated in a recent project to create a function plan for the Dempster Highway. A more detailed description of site conditions can be found in Calmels et al. (2018).

Figure 2.1 Culvert site at km 381.

2.1 GEOLOGY

Based on the surficial geology map from the Yukon Geological Survey, the area where the culvert is located is in a colluvial deposit, a mix of coarse hetero granular material in a fine-grained matrix (Figure 2.2). These types of materials are usually coarse in nature but the fine material content can be significant. The geological map points out the presence of clay within the colluvium, all around the study site.

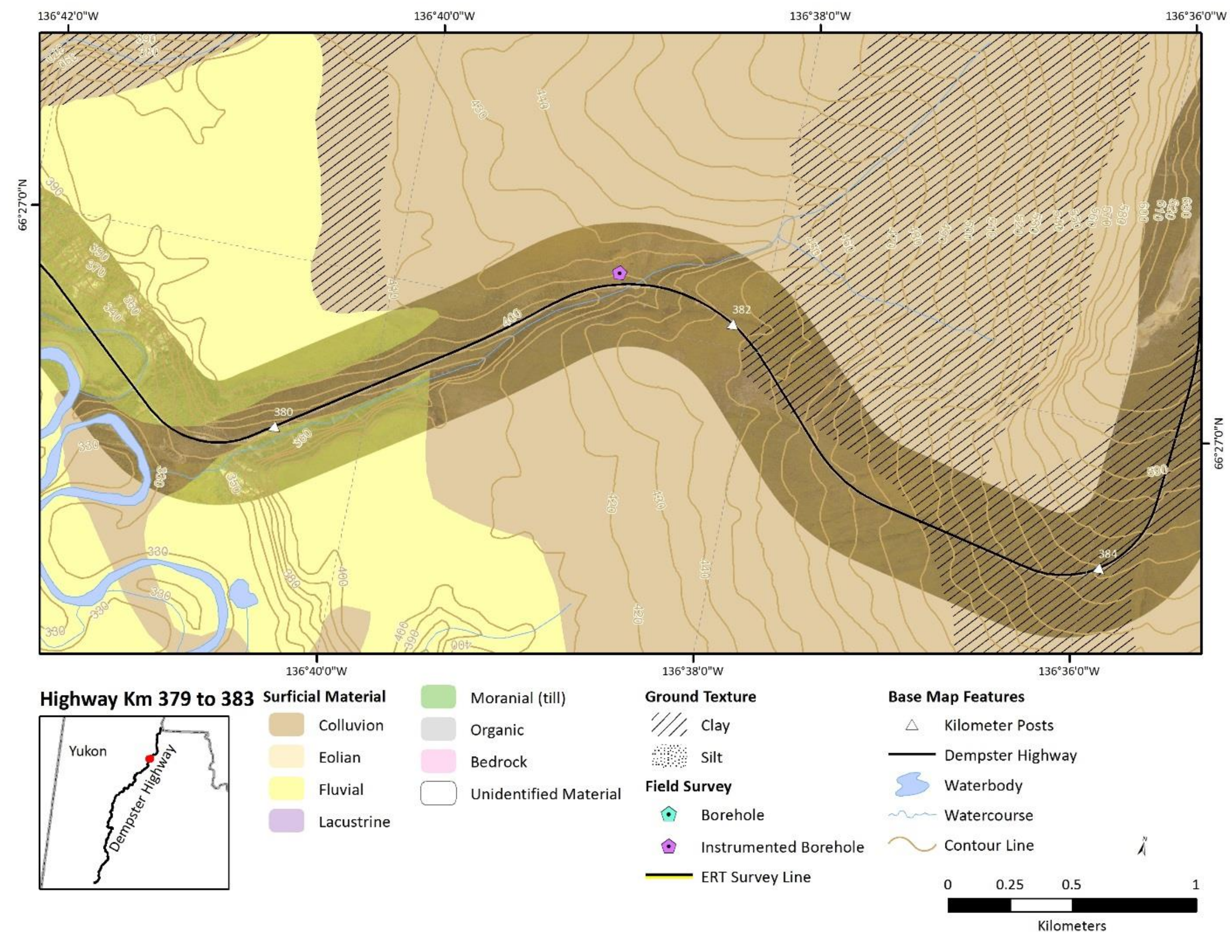


Figure 2.2 Surficial geology map for the Culvert Site at km 381

2.2 AERIAL IMAGERY

The site is located in the lower part of a small valley. Two interesting features providing information about the geomorphic context can be seen in the aerial imagery (Figure 2.3). First are some mud boils (AKA frost boils), which are upwellings of mud that occur through frost heave and cryoturbation in permafrost areas. A group of them is visible about 100 m into the field at the left-hand side of the road. The mud boils are good indicators of a fine-grained, frost-susceptible material, i.e. potentially ice-rich ground. Second, a small slide is visible on the slope about 70-80 m from the road, on the right-hand side.

Permafrost was directly observed during installation of the culvert, when the excavation extended below the road embankment. The ground was fine-grained and ice-rich (Figure 2.4).

Figure 2.3 Aerial view of site km 381.

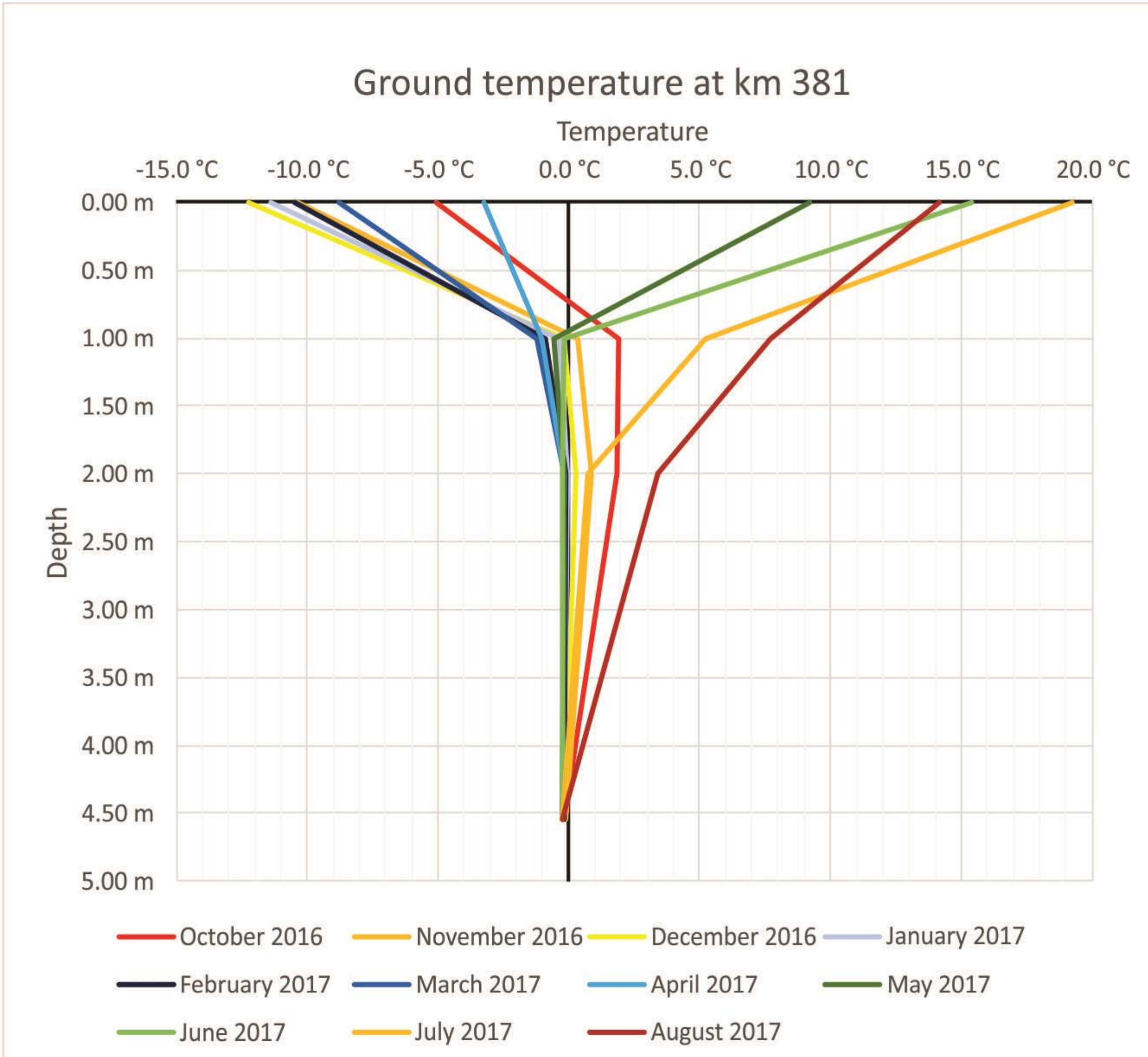
Figure 2.4 Permafrost observed during culvert installation at site km 381. A- ice-rich fine grained soil excavated below the embankment; B- close-up of an ice-rich permafrost sample collected during the excavation works

2.3 BOREHOLE GEOTECHNICAL DATA

A borehole, DH381 BH1, was drilled in the field at the right-hand side using a waterjet drill. Material texture was observed in the field, as the project budget and plan did not allow for collection and lab analysis of the borehole core. The borehole was easy to drill down to the depth of 4.55 m, within fine-grained material. After 4.55m the drilling was unable to continue, likely due to the presence of coarser material.

2.4 GROUND TEMPERATURE

Borehole DH381-BH1 was lined with PVC piping and instrumented with one 4-channel Hobo logger to record ground temperatures at 0, 1.0, 2.0, and 4.55 m depths. Ground temperatures were recorded from September 29th, 2016 to September 17th, 2017, the date of the last downloading (Figure 2.5). Although the records only cover just under a year, the data show that during this period the ground temperature measured at 4.55 m, the deepest sensor depth, remains relatively stable at -0.2 °C. The depth of the active layer almost reached 4.55 m in August 2017. While the permafrost may still be recovering from the drilling process, this is attributable to very warm ground temperature, close to 0 °C.



Depth	2016			2017							
	October	November	December	January	February	March	April	May	June	July	August
0.00 m	-5.1 °C	-10.4 °C	-12.2 °C	-11.4 °C	-10.5 °C	-8.8 °C	-3.3 °C	9.2 °C	15.4 °C	19.2 °C	14.2 °C
1.00 m	1.9 °C	0.4 °C	-0.2 °C	-0.4 °C	-0.9 °C	-1.2 °C	-1.0 °C	-0.6 °C	-0.2 °C	5.2 °C	7.7 °C
2.00 m	1.8 °C	0.9 °C	0.3 °C	0.0 °C	-0.1 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	0.7 °C	3.4 °C
4.55 m	-0.2 °C	-0.1 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C

Figure 2.5 Ground temperature at site km 381, borehole DH381-BH1, based on a record from October 2016 to August 2017.

3 METHODOLOGY

The methodology of this project is based on two techniques: 1) ground temperature measurement with temperature sensors connected to data loggers, and 2) monitoring of electrical resistivity through an electrode array buried below the culvert. Both techniques are described in more detail below. The two ground temperature arrays will allow HPW to continue to measure the effectiveness of the insulation layer between the culvert and underlying permafrost. The ERT array will allow regular monitoring of the condition of the permafrost under the culvert.

3.1 GENERAL DESIGN

This section provides a description for the permafrost and ground temperature monitoring setup for the culvert located at km 381 of the Dempster Highway.

The general design was made on short notice, and altered to accommodate the still on-going design of the culvert installation. For instance, the installation was originally design to monitor the impact of a 20-m long culvert on underlying permafrost. Eventually the length of the culvert was increase to 23 m. Consequently, the number of electrode and temperature sensor had to be increased.

The idea behind the design was to use a combination of temperature monitoring and electrical resistivity tomography (ERT). Two ground temperature arrays allow HPW to measure the effectiveness of the insulation layer between the culvert and underlying permafrost, while the ERT array allows for regular monitoring of the permafrost condition under the culvert by measuring its resistivity.

Initially, the ERT array was to be comprised of two independent wires. One wire would be built by ABEM to interface directly with the ABEM Lund Terrameter system (owned by NCE), and one would be built by NCE and will be able to interface with other ERT systems, such as those owned by the Geological Survey of Canada. The short delay did not allow for obtaining the ABEM cable in time, and therefore, only the custom wire was installed.

The general setup includes the following, and is presented in Figure 3.1:

- 24 composite electrodes (10x10 cm mesh and plates) buried at a depth of 60 cm below the natural ground surface, under the insulation layer at one-meter spacing along the 23-m long culvert. Each electrode is connected to a custom ERT cable made by NCE. Eleven (11) additional wires, without electrode, were added to connect additional electrodes on both sides of the embankment. This string of wires allows for ERT surveys with various systems (**AR** in Figure 3.1).
- 23 temperature sensors connected to a series of four-channel analog Hobo dataloggers to record temperature between the electrodes below the insulation layer, at a depth of 60 cm below the natural ground surface. The purpose of these sensors is to assess the

effect of the insulation layer, by comparing the 8 temperatures recorded by array A with 8 temperatures recorded by array B located at the same longitudinal location. It also allows us to correlate the ground temperature value with the resistivity and assess ground temperature below the ditch based on resistivity (**A** in Figure 3.1).

- 8 temperature sensors connected to a series of four-channel analog Hobo dataloggers to record temperature between the culvert and the insulation layer at a depth of 40 cm below the natural ground surface (**B** in Figure 3.1).

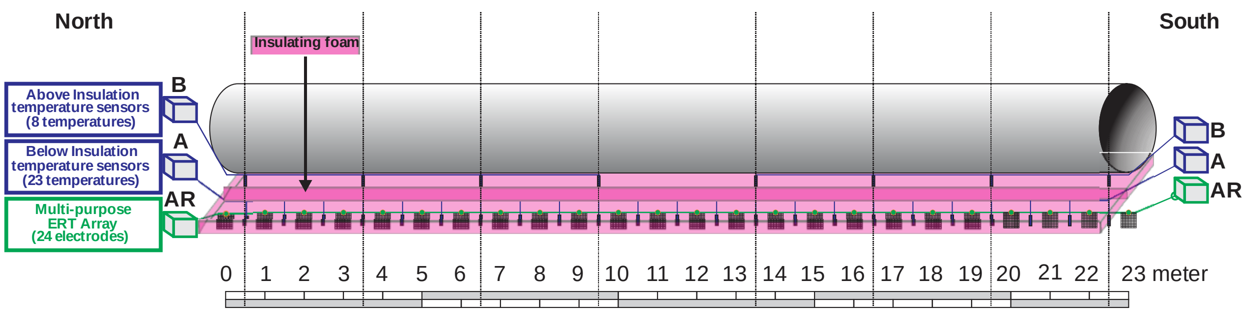


Figure 3.1 Instrument setup of the culvert at km 3xx of the Dempster Highway

AR - 23 electrodes and Multi-purpose ERT Array located below insulation layer;

A- Temperature monitoring below the insulation layer, between each electrode;

B- Temperature monitoring above insulation layer.

3.2 ELECTRICAL RESISTIVITY TOMOGRAPHY

3.2.1 Basics

Electrical resistivity tomography (ERT) is a geophysical method that passes electrical current through stainless steel electrodes driven into the ground surface. A central “station” measures the resistivity distribution of the subsurface between electrode pairs. Resistivity is the mathematical inverse of conductivity and indicates the ability of an electrical current to pass through a material. Mineral materials (except for specific substances such as metallic ores) are mostly non-conductive. Therefore, variation in the resistivity of a soil or rock profile is governed primarily by the amount and resistivity of pore water present in the profile, and the arrangement of the pores. This makes ERT very well suited to permafrost and hydrology applications. Because most water content in frozen ground is in the solid phase and typically has a higher resistivity than unfrozen water content, permafrost distribution can be inferred based on changes in resistivity between frozen and unfrozen ground.

An ERT system consists of an automated imaging unit and a set of wires connected to an electrode array. The system used for the surveys presented in this report is an ABEM Terrameter LS electrical resistivity and tomography system, consisting of a four-channel imaging unit and four electrode cables, each with 21 take-outs at five-metre intervals. To conduct a survey, usually 81 electrodes are driven into the ground along a survey line and connected to the electrode cables (Figure 3.2).

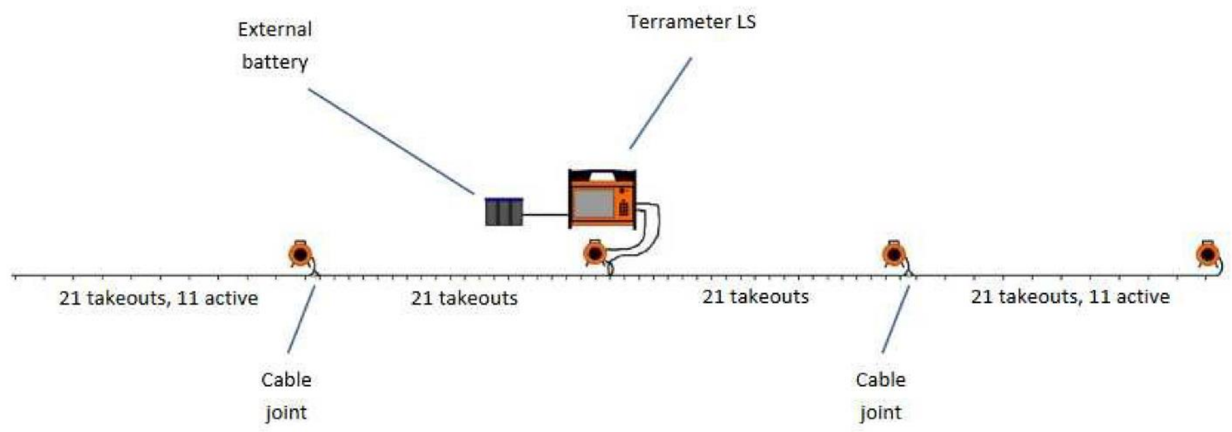


Figure 3.2 Instrument set-up for ERT surveying

Two different types of electrode configurations or arrays were used during the surveys: the “Wenner”, and the “dipole-dipole”. These arrays differ in how they pair current and potential electrodes (Figure 3.3). A direct current electrical pulse is sent from the resistivity meter along the survey line in two current electrodes (C1 and C2), and the measurement is performed by two potential electrodes (P1 and P2). The resulting data consists of a cross-sectional (2D) plot of the ground’s resistivity (ohm·m) versus depth (m) for the length of the survey.

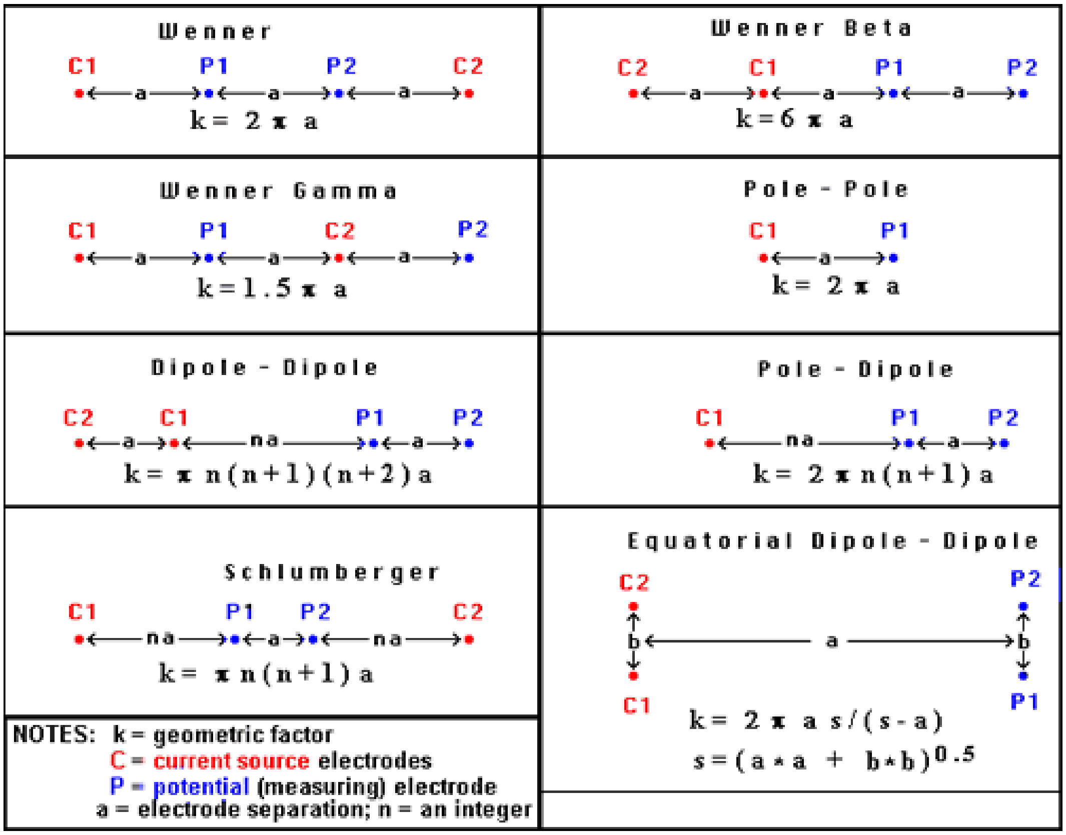


Figure 3.3 Survey configurations or "arrays" for ERT surveying.

In general, the Wenner array is good in resolving vertical changes (i.e. horizontal structures), but relatively poor in detecting horizontal changes (i.e. narrow vertical structures). Compared to other arrays, the Wenner array has a moderate depth of investigation. Among the common arrays, the Wenner array has the strongest signal strength. This can be an important factor if the survey is carried in areas with high background noise. Relatively small current magnitudes are needed to produce measurable potential differences. The disadvantage is that to image deep into the earth, it is necessary to use longer current cables. The Wenner array is also very sensitive to near surface inhomogeneities which may skew deeper electrical responses. One disadvantage of this array for 2-D surveys is the relatively poor horizontal coverage as the electrode spacing is increased, which can be a problem when using a system with a relatively small number of electrodes.

The dipole-dipole array is very sensitive to horizontal changes in resistivity, but relatively insensitive to vertical changes in the resistivity. That means that it is good for mapping vertical structures, such as dykes and cavities, but relatively poor in mapping horizontal structures such as sills or sedimentary layers. This array can have a shallower depth of investigation compared to the Wenner array, but it has better horizontal data coverage than the Wenner, which can be an advantage when the number of nodes available with the multi-electrode system is small. One possible disadvantage can be a very small signal strength. With the proper field equipment and survey techniques, this array has been successfully used in many areas to detect structures such as cavities where the good horizontal resolution of this array is a major advantage.

Usually, ERT surveys are made from the ground surface, the electricity propagating in the soil in all directions (Figure 3.4A). Results of the surveys are post-treated and analyzed using inversion software (Res2DInv 64 and Res3DInv 32, in the case of the NCE's surveys), which solves the geometric calculation and produces a 2D profile of the resistivity, taking the ground surface into account (Figure 3.4B). By burying the ERT cable under an embankment, the geometric factors become much more complicated, as the volume of the embankment will influence the measurement (Figure 3.4C). In the case of this survey, the insulating layer is also an electrical insulator, and constitutes an artificial ground surface, suppressing the influence of the embankment on the measurements. Therefore, 3D modeling is not required to perform the inversion process (Figure 3.4D). In fact, it is the studied object of the survey, the insulating foam, which makes the use of ERT surveying possible. The depth of investigation of the survey without being impacted by the presence of the overlay will be equal to 1/2 of the width of the insulating cover; i.e. a 6 m wide cover will allow a 3 m depth survey.

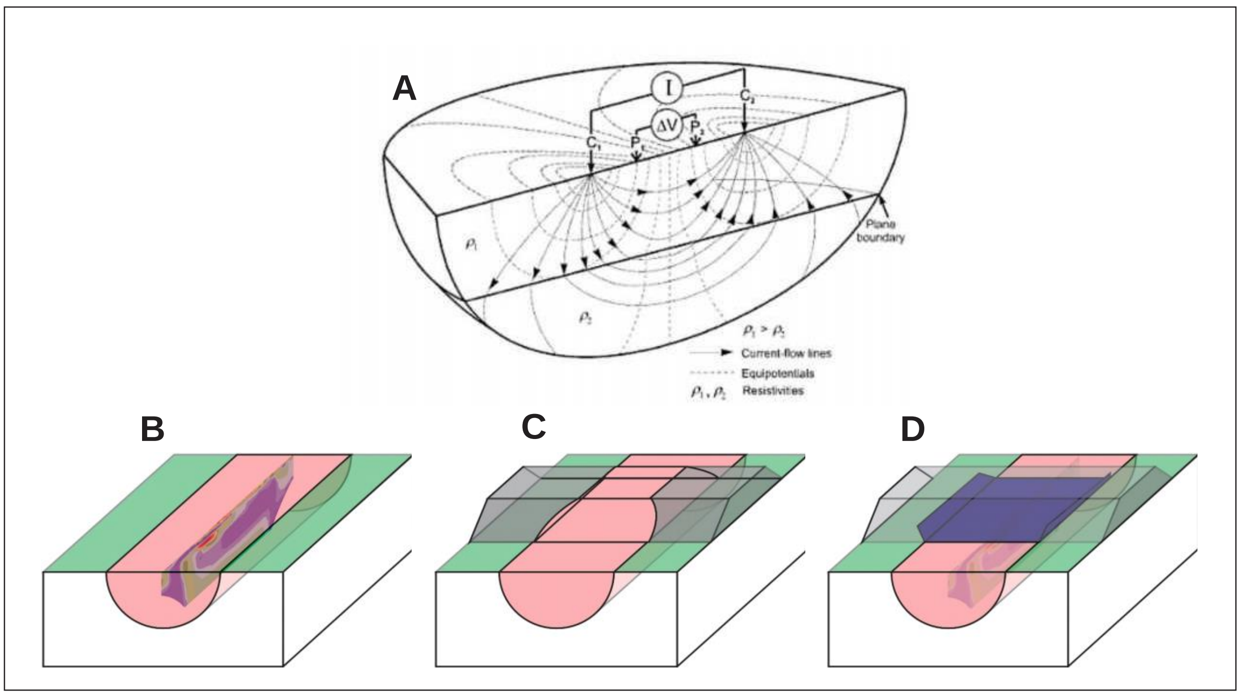


Figure 3.4 Principle of the use of ERT survey under an embankment, with insulating foam providing a barrier to electricity. A: diagram of electrical propagation in the ground; B- standard ERT survey; C- ERT survey under embankment without insulation; and D- ERT survey under embankment with insulation

3.2.2 The NCE-made array

The array consists of a bundle of electrical wires crossing under the culvert from one end to the other. Each wire is connected to an individual electrode buried in contact with permafrost at a specific location. Each electrode is located on a virtual line, aligned with the axis of the culvert (Figure 3.5).

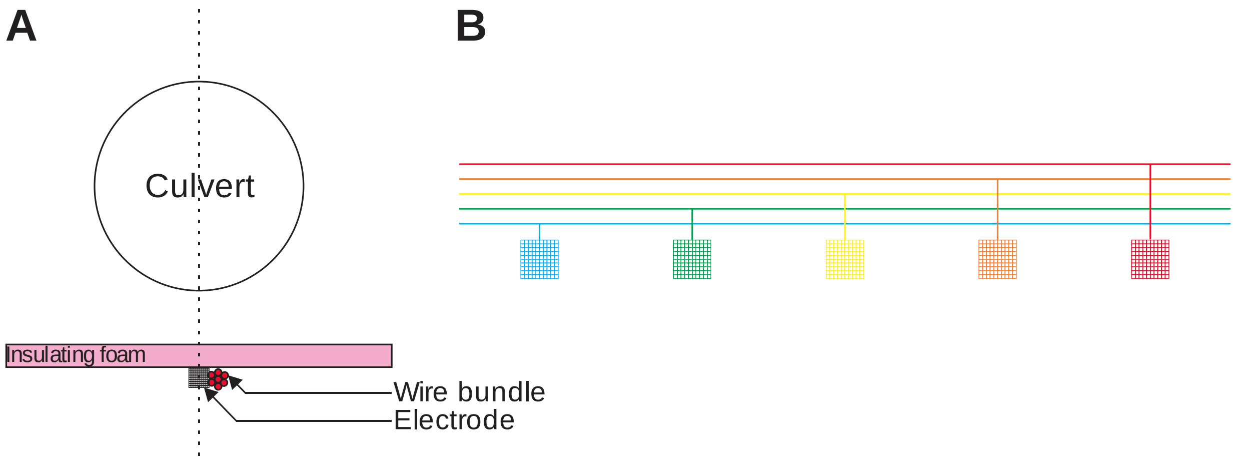


Figure 3.5 electrodes and wires arrangements; A- Location of the electrodes relatively to the culvert axis and insulating foam; B- Connection of each electrode of individual wire on a regular spacing.

The system was assembled in our laboratory. The wire used for the ERT wire bundle is a 14-gauge copper electrical wire. It was mechanically attached to a stainless-steel electrode wire using a brass connector, as copper and steel cannot be welded together (Figure 3.6A). Both wires are coated with vinyl, which insulates them from the ground. The connection between the two wires is coated with liquid plastic to avoid contact with soil and ensure that electricity goes only to the electrode (Figure 3.6B).

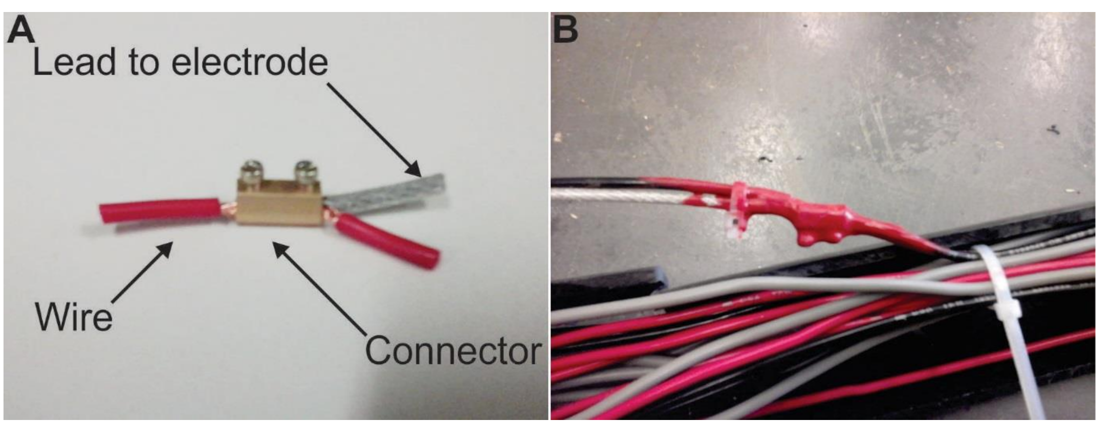


Figure 3.6 ERT wire/electrode wire assembly. A- Connection; B- liquid plastic coating.

The electrode is made of two elements, a stainless-steel mesh plate and a stainless steel perforated plate, attached together at a 90° angle using stainless-steel bolt and washers (Figure 3.7). All the parts, including the electrode wire, are made of stainless-steel to prevent corrosion and ensure good electrical conductivity. Because the electrode cannot have dimensions exceeding 10% of the distance between electrodes, the plates are 10 by 10 cm square with a 1-m spacing. Mesh and perforated plates have been chosen to have maximal surface contact with the ground, therefore favoring a good transfer of the electricity from the electrode to the ground.

Figure 3.7 Stainless-steel mesh and perforated plate electrode.

3.3 TEMPERATURE MONITORING

The instrumentation used to monitor the temperatures below the culvert is made of a series of Onset HOBO UX120-006M Analog Data Logger. It is Onset's highest-accuracy data logger, with 16-bit resolution. It supports up to four external sensors for measuring temperature, and has a LCD display to confirm logger operation and displays near real-time measurement data. This economical stand-alone logger can record data at various intervals and uses a direct USB interface for fast data offload. The logger requires two AAA 1.5 V alkaline batteries, which will typically last one year with a logging rate of 1 minute and a sampling interval of 15 seconds or greater. The logger has a 4 MB memory that can store up to 1.9 million measurements, and allows longer deployments between offloads. For temperature sensors (TMC6-HD to TMC50-HD), this logger notably has a +/–0.15°C accuracy, and a 0.002°C resolution.

To be able to monitor the 23-m length of the culvert, 23 temperature sensors were assembled in a bundle to monitor the temperature within permafrost below the foam insulation, and 8 sensors were used above the foam insulation (Figure 3.2Figure 3.1, Figure 3.8A). The fact that the longest temperature sensor wire is only 15 m long (50 feet – model TMC50-HD) requires the connection of loggers at both ends of the culvert.

To protect ERT and temperature wires during construction, the bundle has been encased in 2-inch black ABS piping. Slots were cut in the piping, and the sensor tip was secured to insure good contact with the soil (Figure 3.8 B and C).

Sensors can accurately record temperatures ranging from –20°C to +70°C, with interchangeability to a tolerance of +/–0.25°C from 0°C to 50°C. They have a resolution of 0.03°C at 20°C.

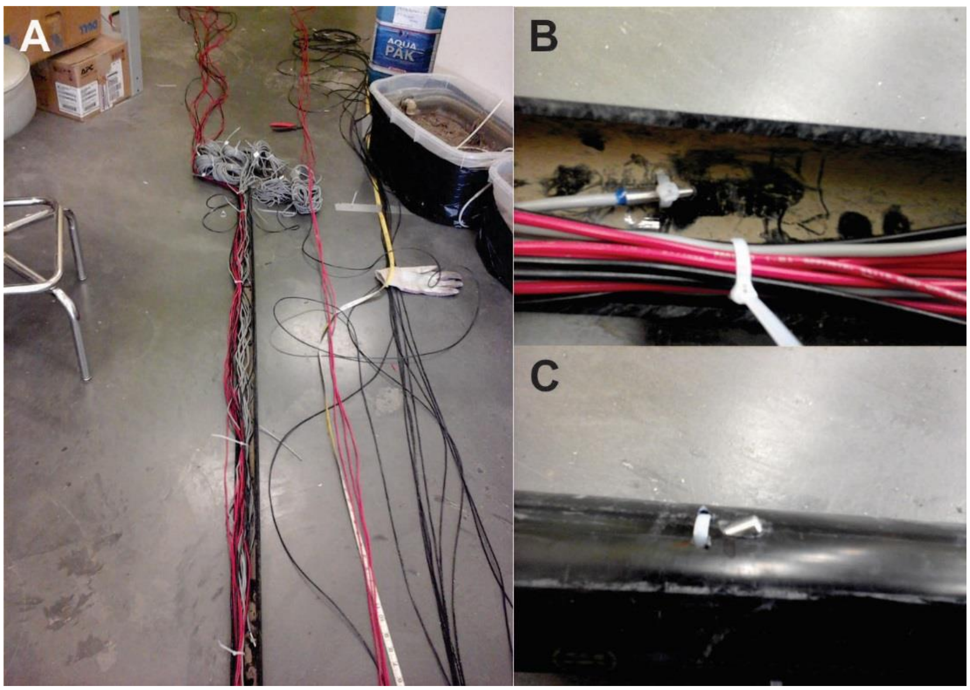


Figure 3.8 ERT and temperature wires bundles. A- ERT and temperature are attached together.; B- internal view of the protective ABS piping; C- external view of the protective ABS piping, allowing contact between sensor and soil.

The temperature array A, located below the foam, measures temperature at each meter from 0.5 to 22.5 m, 0 and 23 m being the location of each end of the culvert. The temperature array B, located between the foam and the culvert, measure temperatures at 8 locations: 0.5, 3.5, 6.5, 9.5, 13.5, 16.5, 19.5, and 22.5 m. Distributed evenly along the culvert, these 8 sensors allow comparison of the temperature below and above the insulating foam.

3.4 INSTALLATION

The Construction took place from September 10th to 14th 2016, starting from the left-hand side, and finishing with the right-hand side. First the road embankment was excavated down to the contact with the natural ground. The natural ground was excavated down to 60 cm below the natural surface. At this time, the first ERT-temperature sensor array was laid at contact with the ground and covered with a thin layer of soil (Figure 3.9A), then the insulating foam was installed above it (Figure 3.9B).

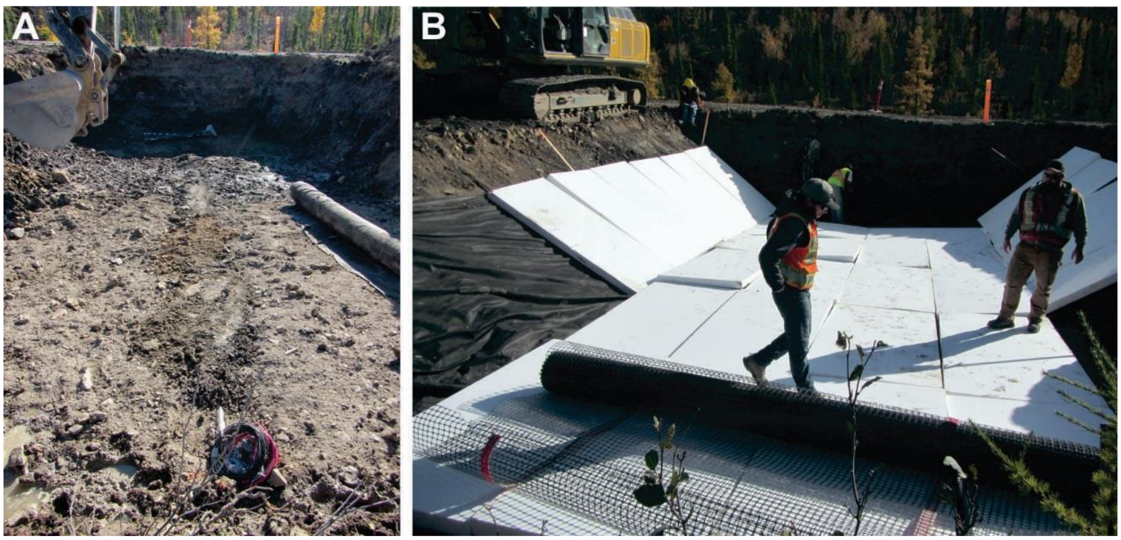


Figure 3.9 Construction of the culvert and installation of the first monitoring array. A- excavation in natural ground; B- installation of the insulating foam.

Gravely material was spread and compacted above the insulating layer and the first array up to 40 cm below the natural ground surface, then geogrid was positioned, and the second monitoring array was installed above it (Figure 3.10A). Another layer of soil was laid on the top of the installation, compacted, and a second layer of geogrid was installed. Finally, the main culvert was positioned, buried under material (Figure 3.10B), then compacted.

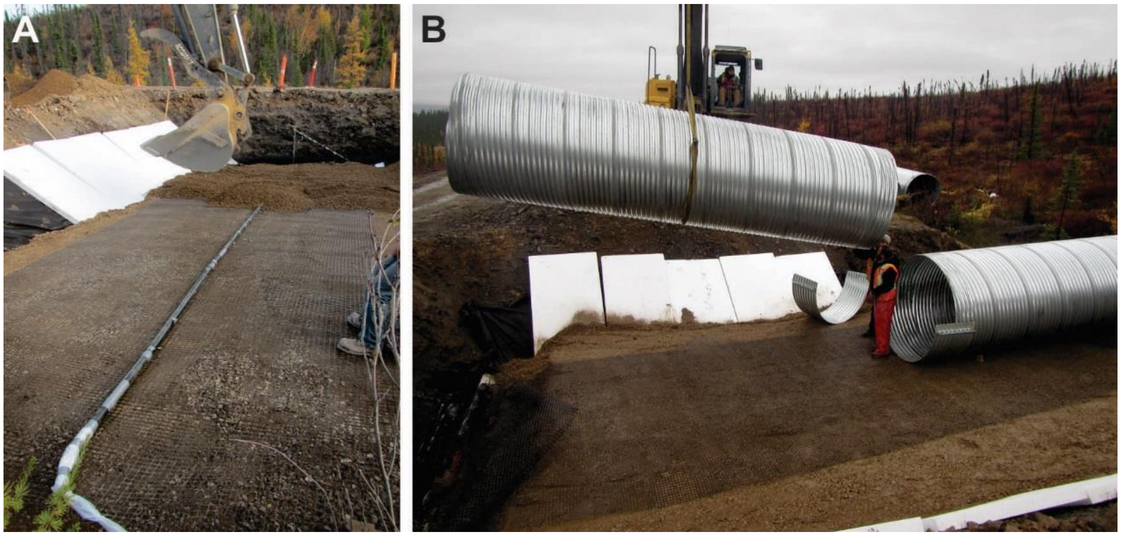


Figure 3.10 Construction of the culvert and installation of the second monitoring array. A- excavation in natural ground; B- installation of the insulating foam.

Additional layers of geogrid were added during the build-up of the embankment, as well as a secondary culvert located downslope at a higher level (Figure 3.11). Because the contractor did not bring enough supply of insulating foam, approximately one third of the total length of the culvert installation lacked insulating foam along the sides of the culvert (toward the right-hand side), as well as at the end underneath the culvert at the right-hand side (Figure 3.12). Measurements were made during construction by NCE team members to exactly record the shape and location of each element of the setup, including the areas missing insulating foam. This should allow for production of an accurate three-dimensional representation to be used in a 3D model, if required.

Figure 3.11 Construction of the culvert at right-hand side of the road. Note the secondary culvert located left of the main culvert. As there was an insufficient supply of foam, some areas remained uninsulated at both sides of the culvert.

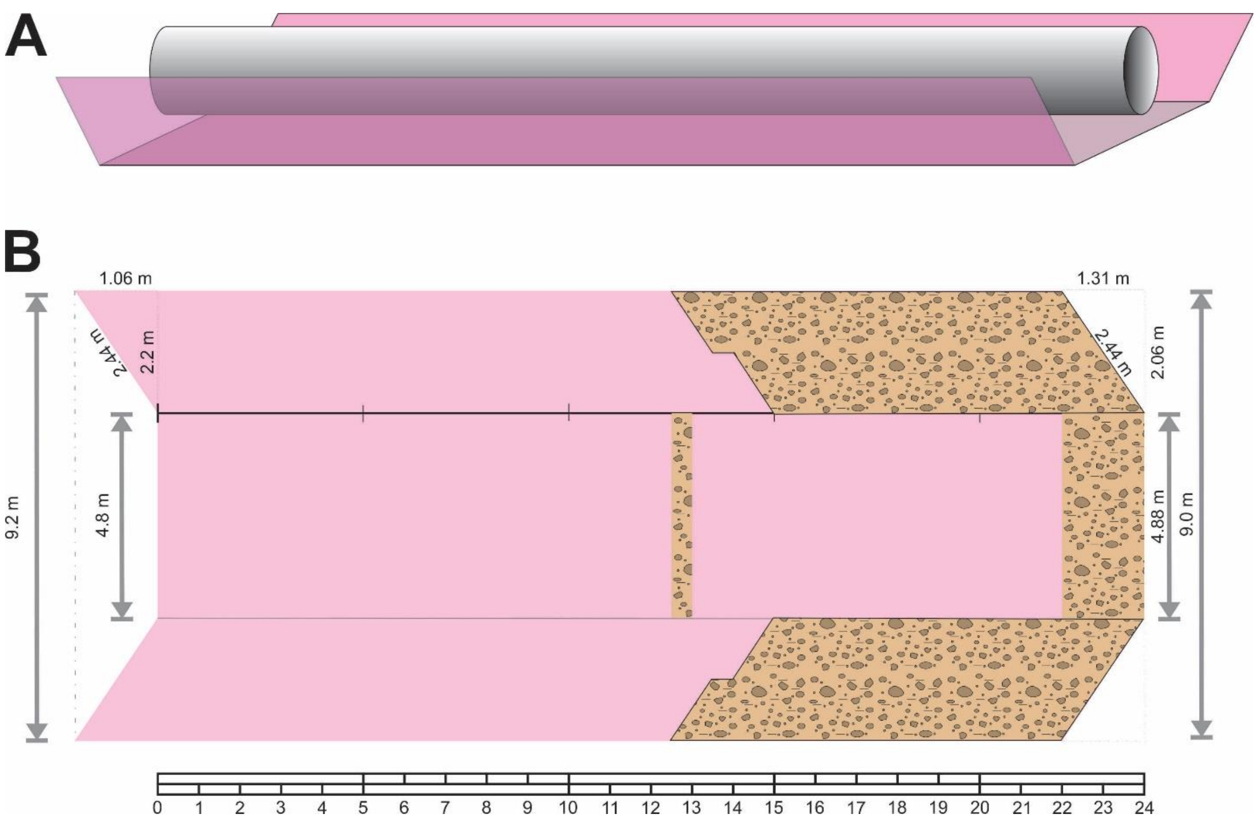


Figure 3.12 Diagram showing foam installation compared to initial design. A- Original U-shape design (3D view); B- final installation with missing insulated areas (brown, gravelly pattern).

Finally, the NCE team came back to the site September 28th and 29th, 2016 to complete the instrumentation of the culvert. A PVC junction box containing the ERT wires, and two steel boxes containing the temperature wires and logger, were fixed on the culvert at either end. The temperature sensors were connected to the 4-channel hobo loggers, and a test was performed on the ERT array using NCE's ABEM ERT system (Figure 3.13). The ERT test proved to be successful, and the temperature sensors were all performing well.

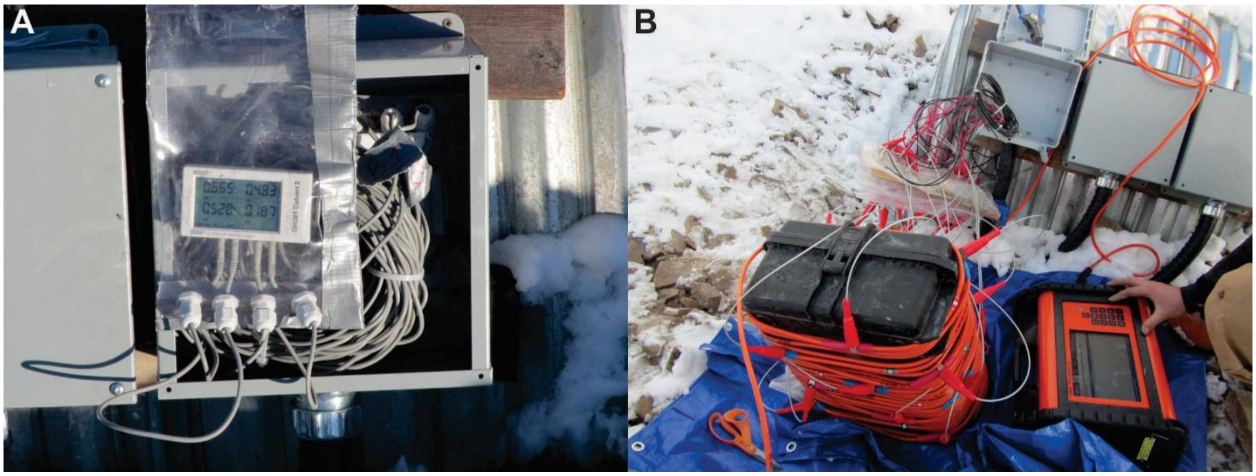


Figure 3.13 Instrumentation such as installed on the main culvert. A- 4-channel Hobo temperature logger in steel case; B- ERT wires connected for a test run on NCE's ABEM ERT system.

In addition, Borehole DH381 BH1 was drilled in the field at the right-hand side using a waterjet drill (i.e. no cores were collected). This borehole was aligned with the center of the culvert, and with the ERT and temperature arrays below the culvert (Figure 3.14). The drilling reached a depth of 4.55 m within fine-grained material. The borehole was lined with PVC piping and instrumented with one 4-channel Hobo logger to record ground temperatures at 0, 1.0, 2.0, and 4.55 m depths. Ground temperature recording started on September 29th, 2016.

Figure 3.14 Borehole DH381 BH1, located in the field, right-hand side, aligned with the center of the culvert and the buried monitoring array lines (location of the station indicated by the yellow arrow).

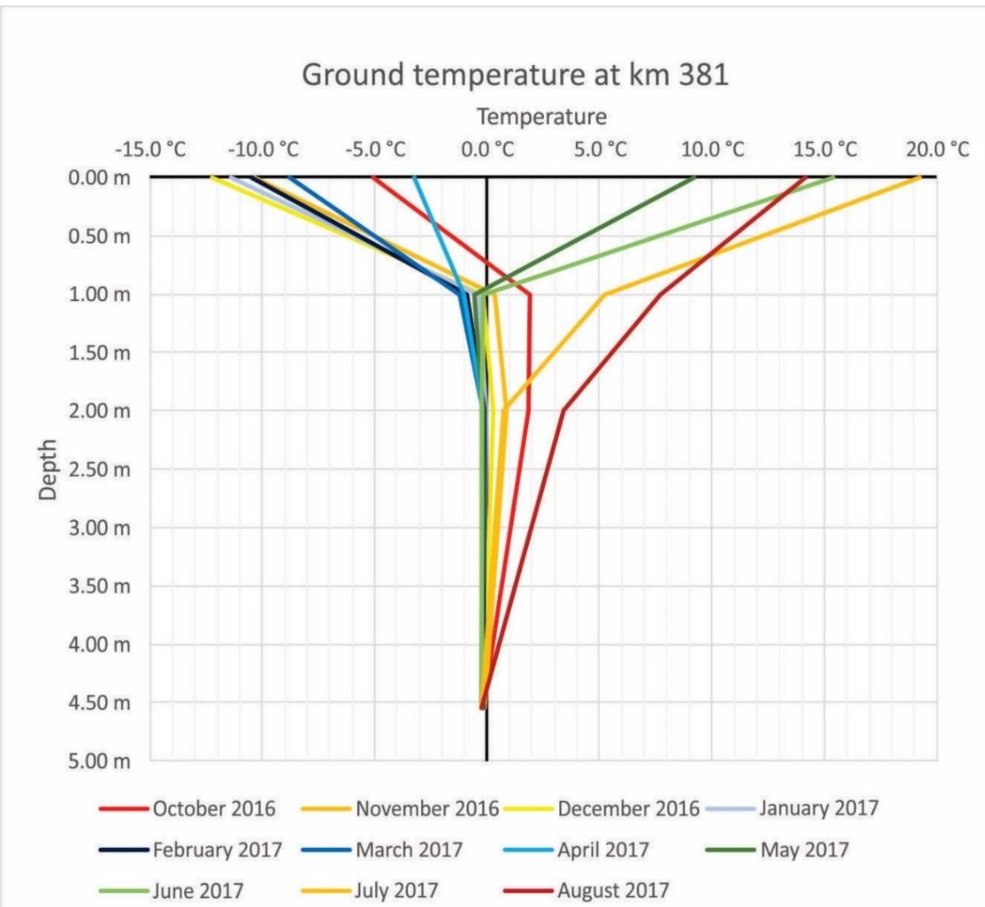
The final configuration of the site is presented in Figure 3.15 (following page).

Figure 3.15 Culvert site at km 381 after construction. A- view from the road on the left-hand side showing the station monitoring the natural ground temperature in the field; B- view from the field showing the left-hand side of the embankment; C- view from the road of the right-hand side; D- general view of the site from up-slope.

4 RESULTS

4.1 FIELD GROUND TEMPERATURE

Ground temperatures were recorded in the field within borehole DH381-BH1 at 0, 1.0, 2.0, and 4.55 m depths, from September 29th, 2016 to September 17th, 2017, the date of the last downloading (Figure 4.1). Although the records only cover just under a year, the data show that during this period the ground temperature measured at 4.55 m, the deepest sensor depth, remains relatively stable at -0.2 °C. The depth of the active layer almost reached 4.55 m in August 2017. While the permafrost may still be recovering from the drilling process, it can be assumed that ground temperature is very warm, close to 0 °C.



Depth	2016			2017							
	October	November	December	January	February	March	April	May	June	July	August
0.00 m	-5.1 °C	-10.4 °C	-12.2 °C	-11.4 °C	-10.5 °C	-8.8 °C	-3.3 °C	9.2 °C	15.4 °C	19.2 °C	14.2 °C
1.00 m	1.9 °C	0.4 °C	-0.2 °C	-0.4 °C	-0.9 °C	-1.2 °C	-1.0 °C	-0.6 °C	-0.2 °C	5.2 °C	7.7 °C
2.00 m	1.8 °C	0.9 °C	0.3 °C	0.0 °C	-0.1 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	0.7 °C	3.4 °C
4.55 m	-0.2 °C	-0.1 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C	-0.2 °C

Figure 4.1 Ground temperature at site DH381, based on a record from October 2016 to August 2017.

4.2 TEMPERATURE UNDER THE CULVERT

The loggers were launched on September 28th, 2016. When the NCE team came back on June 30th, 2017, 4 of the 8 loggers were found to have shut down, their battery having been drained for unknow reasons. All loggers stopped during April 2017. Figure 4.2 indicates the affected loggers and sensors, as well as the period for which the data are missing.

The batteries were replaced in all loggers, and the loggers relaunched on June 30th, 2017. When the data were download again on September 17th, 2017, all loggers were logging and the records were complete. Given their functionality (excepting the battery issues), the loggers and sensors appear to be unaffected by the culvert construction and its aftermath.

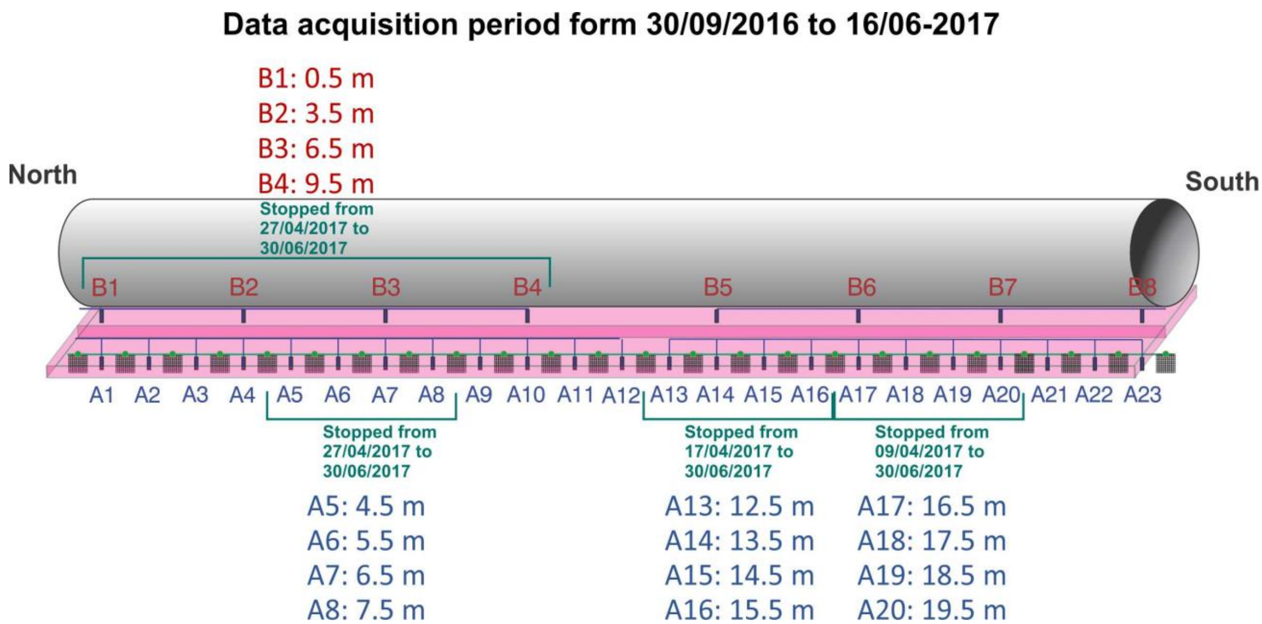


Figure 4.2 Diagram showing what were the loggers and sensors affected by premature shutdown.

Based on the available records, it is possible to compare the temperatures at the 8 locations along the culvert where temperatures where recorded both below and above the insulating foam. This comparison is presented in Figure 4.3. It is seen that temperatures below the foam (blue line) are warmer during the winter than temperatures above the foam (red line). This trend reverses during May (likely during freshet), when temperatures below the foam become colder than temperatures above it. Therefore, in winter, the foam slows the cooling effect of cold air temperature, while in summer, the foam slows the warming effect of the higher air temperature.

In winter, the temperature above the foam layer are more responsive to fluctuation in air temperature, while the temperature curves below the foam are smoother and more stable. Yet in summer, the temperature below the foam shows more variation than during winter; this might be caused by the penetration of ground water below the foam.

It should be noted that at some point during the summer, all sensors, blow and above the foam are showing positive temperature (>0°C). It is hazardous at this time to draw more conclusions based on the existing record given the relatively short time period and considering that the site is likely still recovering from the construction disturbance.

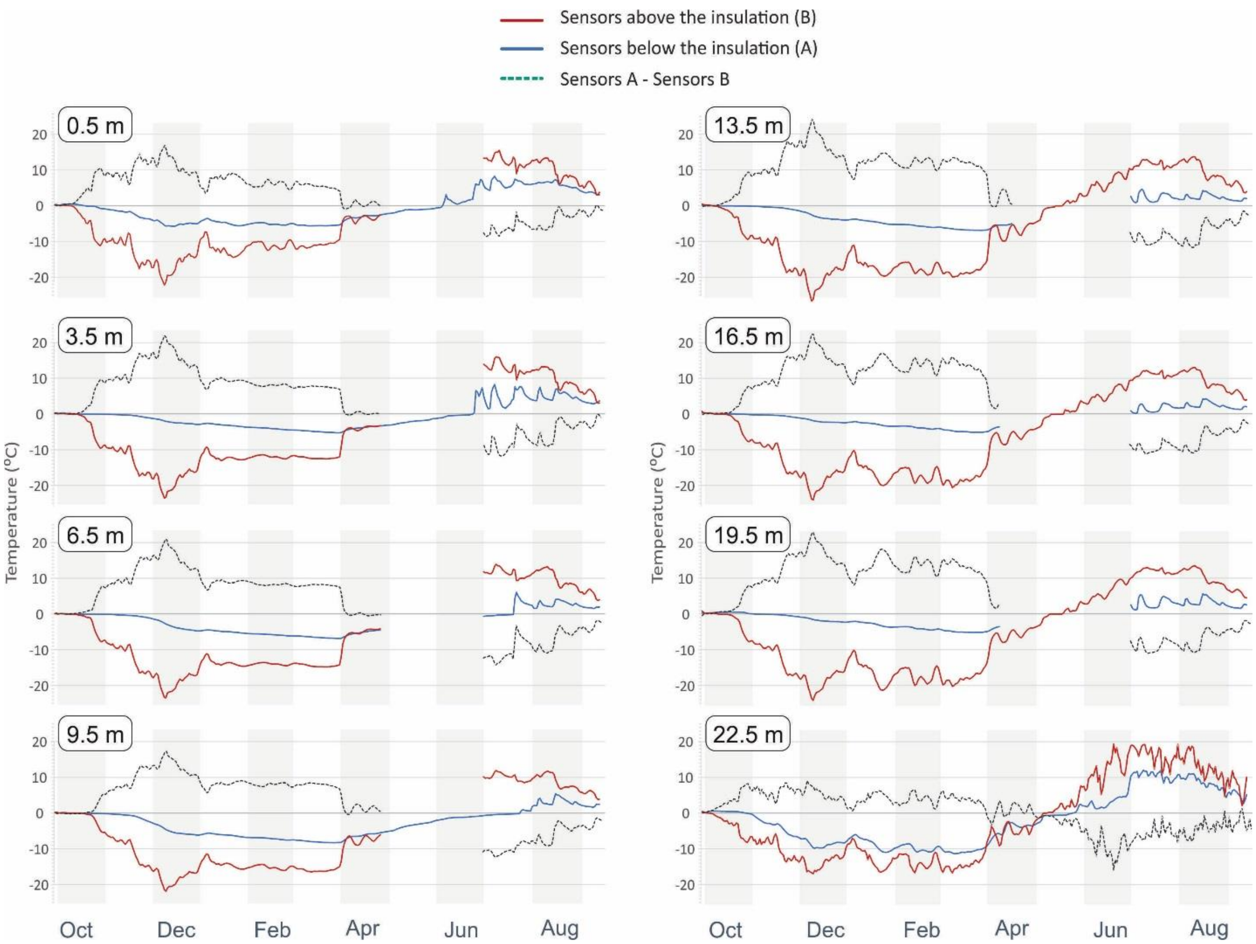


Figure 4.3 Comparison between temperature recorded below and above the foam, at similar locations.

Figure 4.4 shows the evolution of the temperatures recorded all along the culvert during one year, below the foam (Array A) and above the foam (Array B). Produced with Surfer gridding software, it allows for interpolation of the missing temperature data. Similar to what is observed in Figure 4.3 above, temperatures above the foam are much more variable than temperatures below the foam. Also, the right-hand side of the culvert, where the water out-flow is located, shows the warmest temperature during summer, in both arrays.

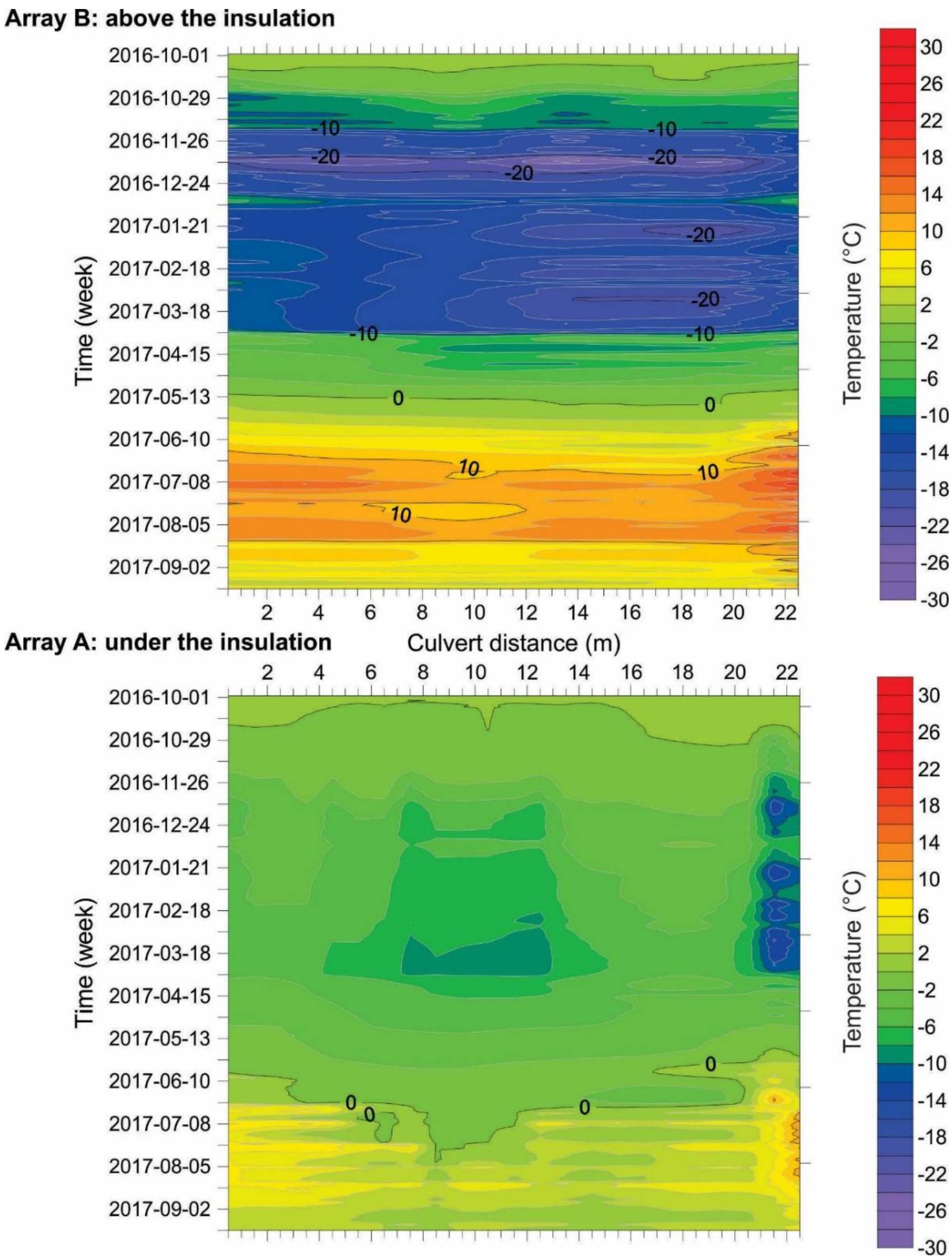


Figure 4.4 Evolution of the temperatures recorded all along the culvert during one year, below and above the foam.

The Figure 4.5 shows the Evolution of the difference of temperatures between array A (below the foam) and array B (above the foam) recorded along the culvert during one year. The figure confirms previous observation that the foam acts as a delaying barrier, with the greatest differences between the two arrays observed early December and mid-July.

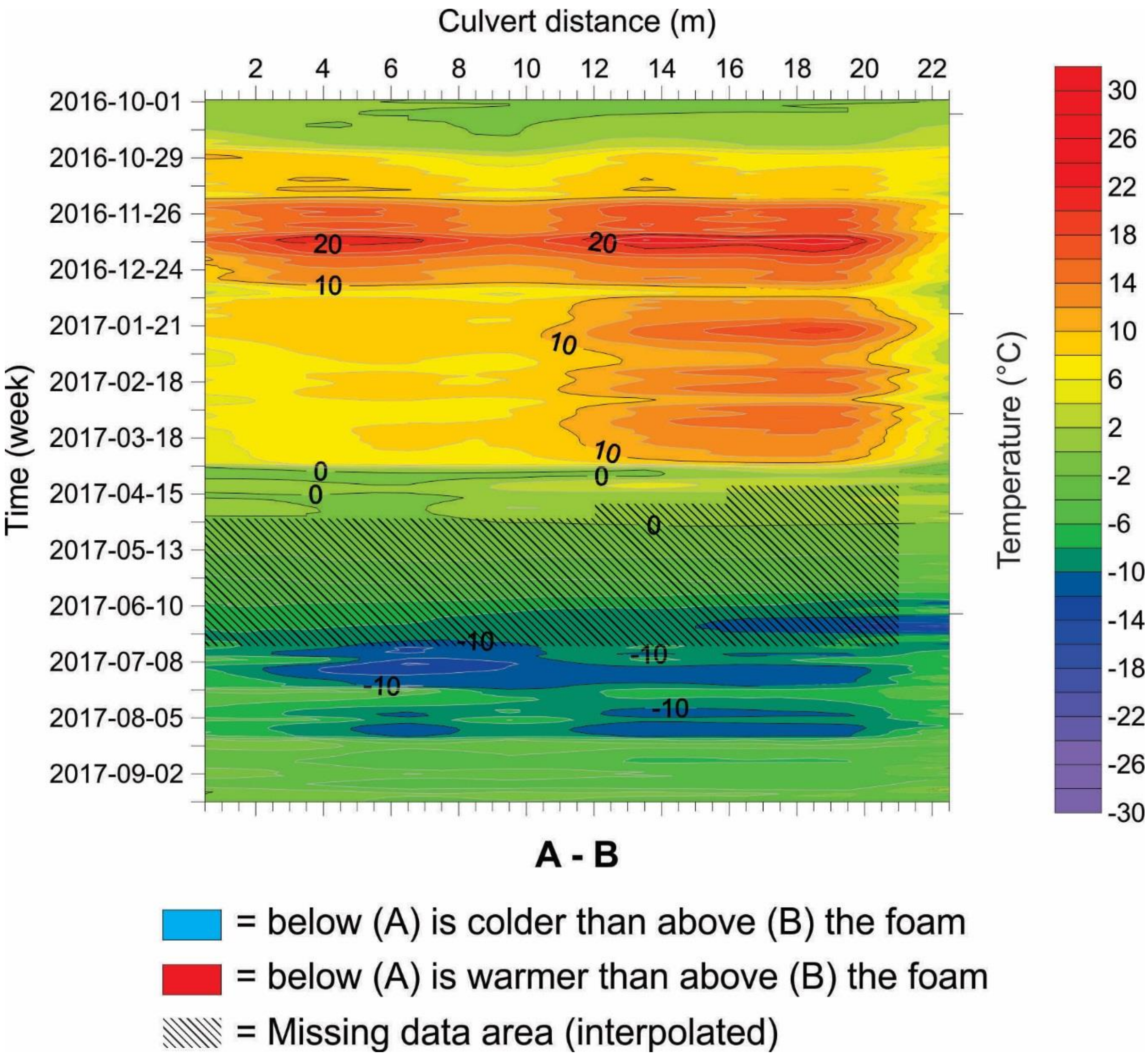


Figure 4.5 Evolution of the difference of temperatures between array A (below the foam) and array B (above the foam) recorded along the culvert during one year. Blueish tones mean that temperature below the foam are colder, below and above the foam. Reddish tones mean that temperature below the foam are warmer.

Table 4.1 shows mean winter (January to March), summer (July to September), and annual temperatures for array A (below foam) and B (above foam). It shows that the winter temperatures below the culvert are warmer by almost 9 °C; while the summer temperature are colder by 7 °C. These periods were not affected by the logger malfunction. Over the whole year, the temperatures beneath the culvert are warmer by 3°C below the foam. As the whole period has been affected by logger malfunction, the results must be considered with caution; but it can be hypothesized that if the foam delays the cooling in winter, the infiltration of ground water in summer under the foam is impairing its insulating action during this period.

To determine the impact of the lack of foam coverage at the right-hand side, the mean annual, winter, and summer temperatures for Array A and B were examined for the left half and right side of the culvert, separately. The general trends are the same as for the whole culvert, with the delaying thermal effect of the foam, and the temperature above the foam colder than below. Yet when regarding each array separately, it appears that the left-hand and right-hand sides of array A (below the foam) show similar mean temperature at all time; while in array B (above the foam) where on the right-hand side some foam coverage is missing, the left-hand side is colder by about 1 °C for the whole year, warmer during winter by about 3 °C, and colder in summer by 1 °C. It is not surprising that array A appears to be unaffected, as the array is located just bellow the horizontal foam layer, which is almost complete along the culvert. Yet it appears that the missing lateral section of the foam layer has an impact on array B.

Table 4.1 Mean Winter, Summer, and annual temperature for Array A and B

Whole culvert	A- Under foam	B – Above foam
Mean annual temperature	-1.8 °C	-4.8 °C
Mean winter temperature	-5.8 °C	-14.7 °C
Mean Summer temperature	3.2 °C	10.2 °C
Left half (entrance, fully insulated)	A- Under foam	B – Above foam
Mean annual temperature	-2 °C	-5.3 °C
Mean winter temperature	-5.8 °C	-13.1 °C
Mean Summer temperature	3.2 °C	9.7 °C
Right half (exit, partly insulated)	A- Under foam	B – Above foam
Mean annual temperature	-1.7 °C	-4.4 °C
Mean winter temperature	-5.3 °C	-16.2 °C
Mean Summer temperature	3.3 °C	10.7 °C

Electrical Resistivity Tomography

The ERT line under the culvert has been surveyed two times, the first September 29th, 2016, shortly after the end of the construction; and the second June 30th, 2017. At each time, Wenner and dipole-dipole surveys where made. Figure 4.6 presents the 4 resulting ERT profiles. While the dipole-dipole survey seems to offer a more detailed profile, Wenner and dipole-dipole profiles show similar general resistivity patterns with similar range of resistivity values. A highly resistive area is observed slightly left of the center line. A second area, more diffuse, is present in the middle of the right half of the profile. Those high resistivity areas may represent either more ice-rich ground or colder areas in permafrost. Another noticeable feature is that 9 months after the construction, the ground appears to be less resistive under the culvert. At this time, it cannot be said if it is a consequence of the installation of the new culvert, of a result of seasonal variation. It must be noted that the impact of the missing sections of foam cannot be quantified at this time.

Resistivity Vs. Temperature

Figure 4.6 shows a comparison between the Wenner ERT surveys performed in September 2016 and June 2017, as well as temperature recorded below the foam, in between the electrode at the time of the survey. In September 2016, it appears to be a relationship between temperature and resistivity, as the lowest temperature recorded matches the highest resistivity values. This is probably due to the fact that in colder permafrost, liquid water content is less important than in warmer permafrost. The lower liquid water content decreases the capacity of the permafrost to conduct electricity, i.e. increases the resistivity.

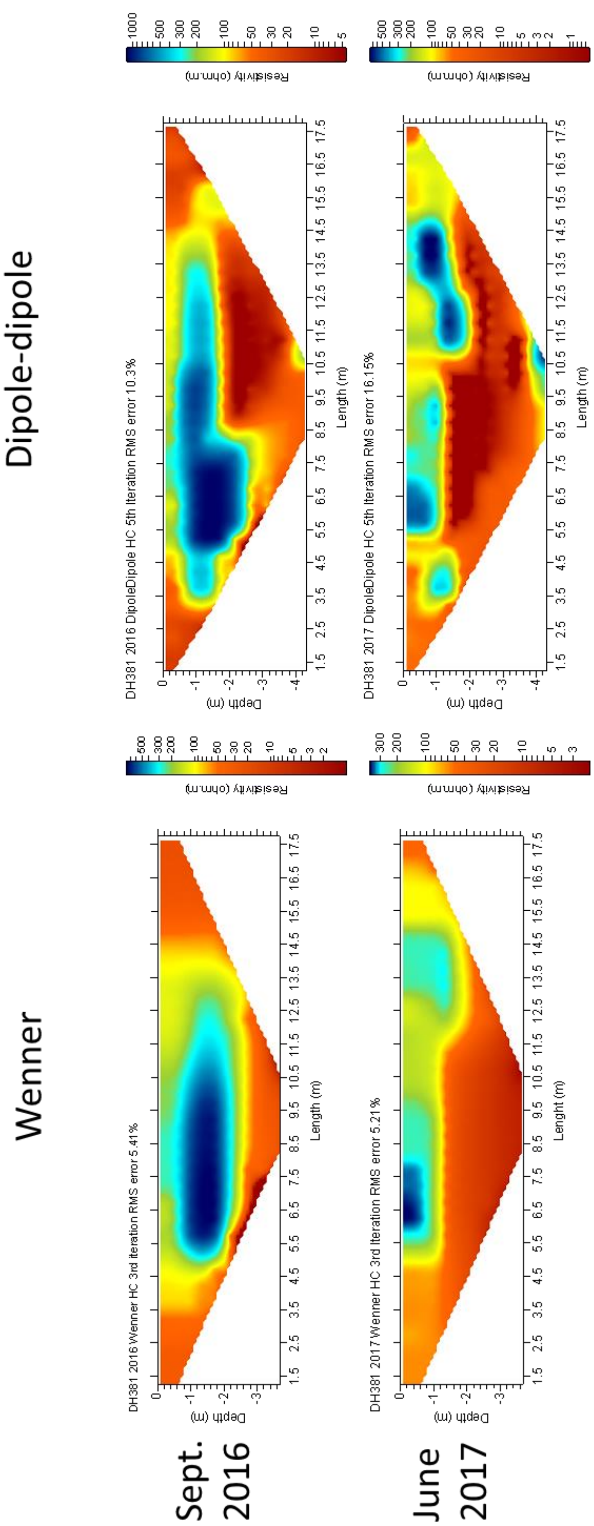


Figure 4.6 ERT surveys performed in September 2016 and July 2017.

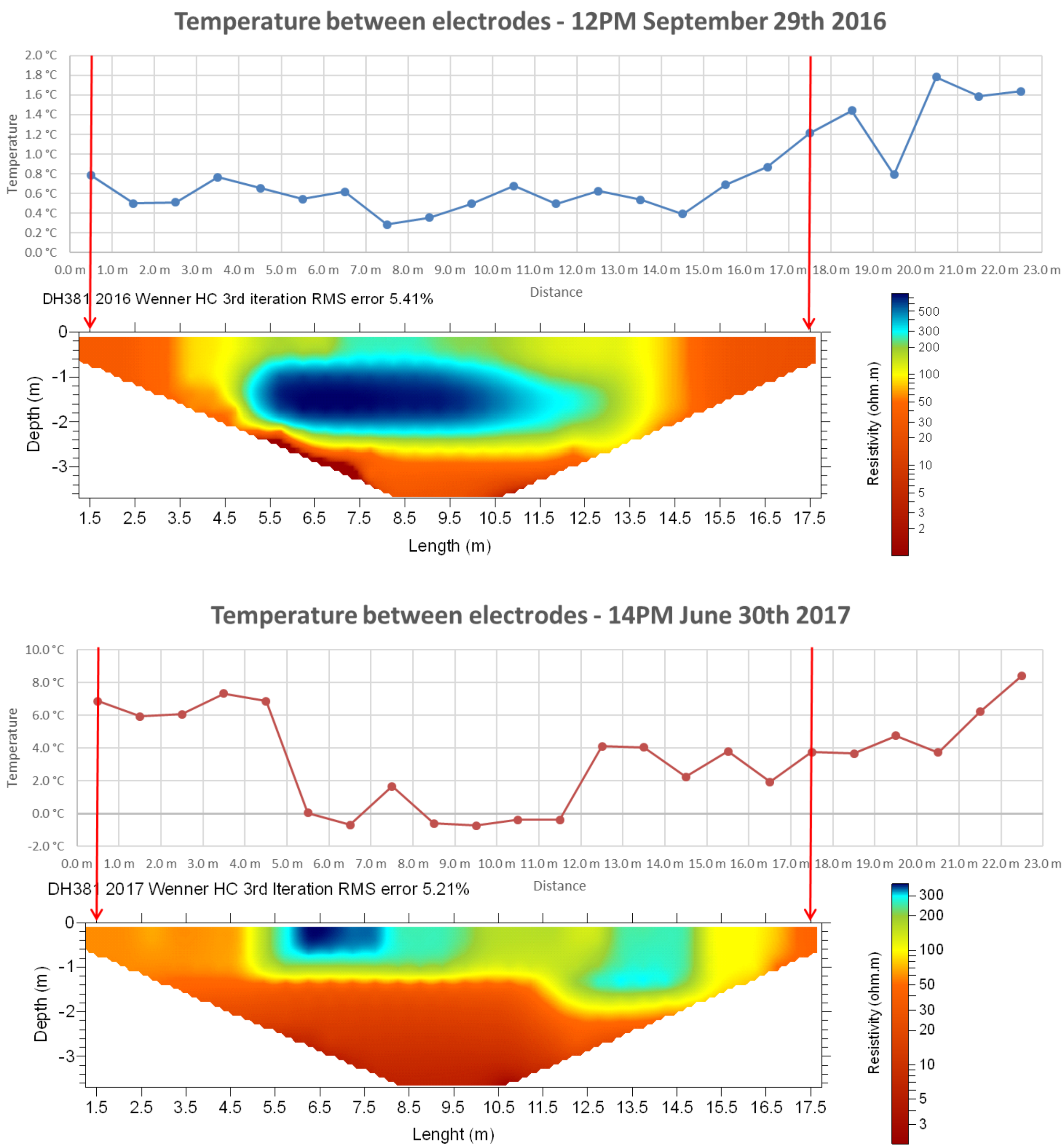


Figure 4.7 Comparison between ERT survey performed in September 2016 and June 2017 and temperature recorded below the foam at the same time.

5 CONCLUSION

5.1 RESULTS SUMMARY

All interpretations must be regarded with caution because: 1- the site may not have yet reached thermal equilibrium, being still impacted by construction; and 2- the final installation differs from the intended design as about one third of the foam coverage is missing along the culvert.

After one year of monitoring it has been noticed that the insulating foam has been acting like a delayer, i.e. it slows down cooling in winter, as well as warming in summer.

The temperatures are generally colder above than below the foam. This is likely because the foam has prevented the cooling effect of the surface air temperature in the winter, while it did not prevent the warming effect of ground water in summer.

The incomplete foam coverage is likely to impact the ERT measurement, yet it appears to show a relationship between resistivity and temperature. With multiple measurements over the course of a year, it should be possible to define a relationship. Modelling the thermal regime based on ERT measurements will require 3D modelling to compensate for the missing foam coverage. As measurements were made on site during the construction, it is possible to recreate a 3D model of the embankment and foam coverage.

5.2 RECOMMENDATION FOR FURTHER IMPLEMENTATION

5.2.1 What works

The instrumentation protocol, i.e. multiple arrays cased in ABS tubing, seems to be appropriate as it has survived construction and one year of implementation.

The compaction of the material above the arrays was done with small compactor; once the culvert was set, a roller was used.

The temperature loggers and sensors are relatively economical, yet performed well. The early battery drainage of some loggers is unexplained, but can be prevented with the use of additional battery packs. There is no restriction to the use of another type of instrumentation.

The ERT array has proven to be functional, with the electrodes providing a good contact with the ground, and the range of measured resistivity appears to be constant over time, i.e. no increase of resistivity due to loss of contact between ground and electrodes. No welding was used; all connections were made mechanically (nuts and bolts).

5.2.2 What can be improved

The main issue is that the design of the installation was not fully adhered to by the contractor, as insulating foam is missing on roughly one third of the culvert. This affects the thermal regime as well as the ERT survey along the culvert. The original design must be respected and implemented.

Ground water infiltration below the foam might be an issue. A possible solution could be to cover the foam with an impervious membrane, such as a thick polyvinyl sheet, which will also add an additional layer of electrical insulation which is favorable to ERT surveys.

6 REFERENCES

Burn, C., Moore, J., O'Neil, B., Hayley, D., Trimble, R., Calmels, F., Orban, S., and Idrees, M. 2015. Permafrost characterization of the Dempster Highway, Yukon and Northwest Territories. GEOQuébec2014: 64th Canadian Geotechnical Conference & 7th Canadian Permafrost Conference, Sept. 20-23, 2015, Québec, Québec. Canadian Geotechnical Society.

Calmels, F., Roy, L.P., Grandmont, K. and Pugh, R. 2018. A Summary of Climate- and Geohazard-Related Vulnerabilities for the Dempster Highway Corridor. Yukon Research Centre, Yukon College, 200 p.

7 APPENDIX A: PRODUCT DESCRIPTION – TERRAFOAM EPS HS-40

Beaver Plastics

Product Name
TERRAFOAM® EPS HS-40
Associated Specification Section
MasterFormat 2011 # 07 21 13
Manufacturer's Name
Beaver Plastics

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PRODUCT DESCRIPTION

PRODUCT FEATURES

- DESCRIPTION
  - Closed cell high density expanded polystyrene (HDEPS) insulation suitable for high load compressive strength applications.
- USES
  - Geotechnical and other below grade applications:
    - Perimeter and under slab insulation.
    - Highway and railroad bed construction.
    - Airport runways, taxiways, and aprons.
    - Large earth structures, ramps, and beams.
    - Isolating bearing pads under heavy process equipment and industrial traffic.
    - Frost protected shallow foundations.
    - Ice arena and snow melt systems.
    - Buoyancy billets.
  - Above grade applications:
    - In conjunction with above grade construction.
    - Masonry and cavity wall construction.
    - Roof insulation, including tapered modules for slope-to-drain.
    - Exterior Insulated Finish Systems (EIFS).
- PRODUCT ATTRIBUTES AND CHARACTERISTICS
  - Excellent resistance to freeze/thaw cycles.
  - Low moisture absorption properties.
  - Breathable, allowing transmission of water vapour.
  - Contains no CFCs, HCFCs, or other refrigerant gases.
  - Biologically inert. Will not support mould, mildew or fungus growth. Not a food source for pests.
  - Contains a chemical additive to inhibit accidental ignition from a small fire source.
  - Non-toxic and hypo-allergenic. Does not off-gas.
  - The insulation value (R-Value) increase as temperature decreases. Does not lose insulation value over time.

Beaver Plastics

Product Name

TERRAFOAM® EPS HS-40

Associated Specification Section

MasterFormat 2011 # 07 21 13

Manufacturer's Name

Beaver Plastics

PRODUCT DESCRIPTION

- SELECTION CRITERIA
  - Suitable for cold climate applications, where soil is prone to heaving.
  - Can be used for buoyancy in sea and fresh water.
  - Available in two standard board sizes, in any thickness up to 610 mm (24 inches).
  - Available in flat sheet form or custom profiles.
  - Minimum and maximum slab thicknesses:
- SUSTAINABILITY CRITERIA
  - Contains recycled content and can contribute to LEED Material and Resources Credit 4 – Recycled Content.
  - Manufactured in Edmonton and Vancouver, Canada and may contribute to LEED Material and Resources Credit 5 – Regional Materials.
  - Contains no CFC or HCFC gasses; does not contribute to ozone depletion.
  - Non-toxic; does not irritate skin on exposure.
  - Biologically inert and will not support mould, mildew or fungus growth or pests.
- APPLICABLE STANDARDS, RELATED REFERENCES
  - ASTM C177 - Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus.
  - ASTM C578 – Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation.
  - ASTM D1621 - Standard Test Method for Compressive Properties of Rigid Cellular Plastics.
  - ASTM D2842 - Standard Test Method for Water Absorption of Rigid Cellular Plastics.
  - ASTM E96 - Standard Test Methods for Water Vapor Transmission of Materials.
  - CAN/ULC-S701 – Standard for Thermal Insulation, Polystyrene, Boards and Pipe Covering.
- QUALITY STATEMENT, TESTS, CERTIFICATIONS, AND APPROVALS
  - Canadian Construction Material Centre (CCMC): CCMC #12982-L.
  - ISO 9001:2000 Registered Company (Quality Certification Bureau #94-41).
  - Performance tests certified by Intertek Testing Services Ltd.
- PACKAGING, HANDLING, PROTECTION, AND DELIVERY INSTRUCTIONS
  - Panels must be protected from damage during transit.
  - Panels must be protected from UV degradation during storage and after erection.

Beaver Plastics

Product Name
TERRAFOAM® EPS HS-40
Associated Specification Section
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Manufacturer's Name
Beaver Plastics

PRODUCT DESCRIPTION

- Do not expose to volatile hydrocarbons, such as fuel oils, gasoline, and alcohols.

- LIMITATIONS
  - Degrades with lengthy exposure to ultra-violet rays.
  - Product will burn when exposed to large continuous flame.
  - Anhydrous acids (such as sulphuric and formic acid) may attack expanded polystyrene.
- SAFETY PRECAUTIONS
  - Normal fire precautions and good housekeeping methods must be followed during storage and application.
- AVAILABILITY
  - Available direct from Beaver Plastics' or appointed distributors.
- COST
  - Varies with substrate condition and configuration, and relative size of building.
  - Consult manufacturer or distributors for specific product costs or relative costs.

PRODUCT PROPERTIES

- MATERIALS, COMPOSITION, PROPERTIES
  - Technical Properties
    - Rigid, closed cell, expanded polystyrene (EPS) board, to ASTM C578 Type XIV, and exceeds CAN/ULC S701 Type 2.

PHYSICAL PROPERTY	METRIC	IMPERIAL
Compressive Strength (ASTM D1621)	276 kPa (min)	40 psi (min)
Thermal Resistance (ASTM C578)	RSI .87 @ -10°C	R-5 @ 15°F
	RSI .75 @ 24°C	R-4.3 @ 75°F
Flexural Strength	414 kPa (min)	60 psi (min)
Water Vapour Permeance (ASTM E96)	143 ng/Pa.s.m^2 (max)	2.5 perm (max)
Water Absorption (ASTM D2842)	1% maximum	1% maximum

Beaver Plastics

Product Name
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Beaver Plastics

PRODUCT DESCRIPTION

Dimensional Stability	1% maximum	1% maximum

- ACCESSORIES
  - Adhesives and/or insulation fasteners.
- DIMENSIONS
  - Thickness: Any thickness up to 610 mm (24 inches).
    - 610 x 1220 mm (2' x 4') panels.
    - 1220 x 2440 mm (4' x 8') panels.
  - Thickness: Any thickness up to 610 mm (24 inches).
  - Profiles: Shiplapped edges, batten slots, and other custom profiles can be produced.

PRODUCT PLACEMENT

- PREPARATION
  - Surfaces must be dry and ready to receive insulation.
- INSTALLATION
  - Install products in accordance with the manufacturer's instructions for each specific application.
  - Cover exposed insulation with a finish acceptable to local building authorities.
- MAINTENANCE INSTRUCTIONS AND PROCEDURES
  - Product should not be exposed to volatile hydrocarbons and anhydrous acids, which may attack the expanded polystyrene.

Corporate Identification

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Beaver Plastics

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PRODUCT DESCRIPTION

Classification and Filing

OmniClass Table 23 - Products

23-20 50 24 11 11 11 Expanded Polystyrene Slab and Board Thermal Insulation

MasterFormat 2011:

07 21 13 – Board Insulation

MasterFormat 1995:

07212 – Board Insulation

END