Coordination and Completion of Multi-Year Geotechnical Investigation in the Canadian Arctic: Challenges and Lessons Learned

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Challenges from North to South
Des défis du Nord au Sud

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ABSTRACT
The Northwest Territories Department of Transportation is constructing an all-season highway connecting Tuktoyaktuk with Inuvik and the Dempster highway. This development will comprise over 140 km of two-lane, gravel surfaced highway. It will require close to 10 million m^3 of material for construction and operation thus requiring the completion of a borrow source investigation program along the proposed corridor.
The execution of the program required the development of risk management strategies with an emphasis on team roles focusing on the logistical aspects and associated challenges while maintaining technical oversight and quality. As such, significant effort was spent on planning, including identifying areas deemed most probable to contain suitable borrow. This included cooperation between geotechnical staff and terrain staff using new technologies to complete an initial desktop study of the proposed alignment area in order to identify and prioritize investigative areas of interest. Overall, approximately 700 boreholes were drilled in under 80 days, spread over three winter seasons.

RÉSUMÉ
Le ministère des Transports des Territoires du Nord-Ouest a entrepris la construction d'une route en gravier toute saison de 140 km à deux voies qui assurera la connexion entre Tuktoyaktuk et Inuvik. Un programme d'exploration pour sources potentielles de remblai et gravier le long du corridor routier était nécessaire afin de localiser près de 10 millions de m^3 de remblai et gravier.
L'exécution du programme d'exploration a nécessitée l'élaboration de stratégies de gestion des risques mettant l'accent sur les aspects logistiques et les défis associés au projet, tout en maintenant le contrôle technique et la qualité. Un effort important a été consacré à la planification du programme, y compris l'identification des sites jugées les plus probables à contenir des matériaux de qualité. Une collaboration entre ingénieurs géotechniques et géomorphologues s'est développée pour effectuer l'analyse préliminaire de la zone d'étude et a permis de localiser et prioriser les sites les plus propices. Près de 700 forages d'essai ont été forés en moins de 80 jours repartis sur trois périodes hivernales.

1 INTRODUCTION

Inuvik and Tuktoyaktuk are located in the northwestern corner of the Northwest Territories as shown on Figure 1.

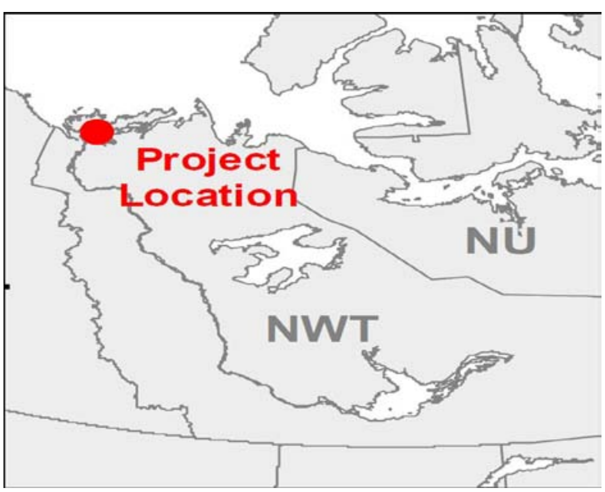

Figure 1. Project Location.

Linking these communities with southern Canada is part of a long-term initiative lead by the territorial and federal governments. Currently, Tuktoyaktuk is accessible by land only via a 187 km winter ice road. The Inuvik to Tuktoyaktuk Highway (ITH) will replace the ice road and will be comprised of an all-weather gravel surfaced road linking the two communities along the alignment shown in Figure 2.

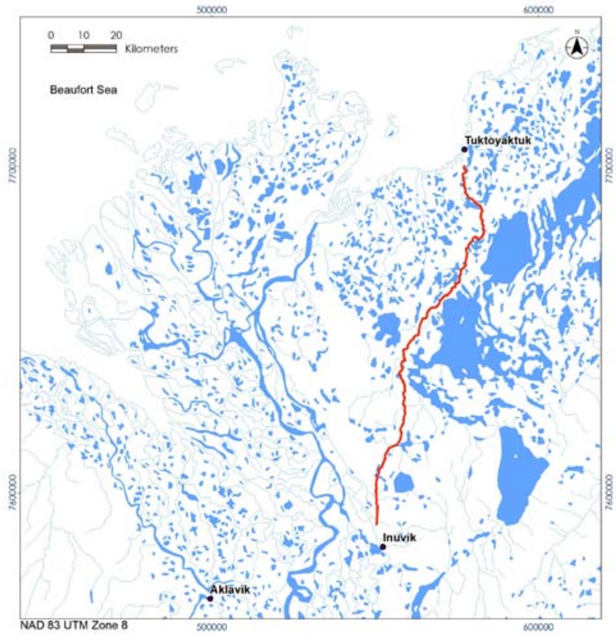

Figure 2. ITH Alignment.

The final stages of planning and designing the ITH project was a collaborative effort between the owner, Northwest Territories Department of Transportation (NWTDOT), the design team and the general contractor. The design team consisted of Stantec Consulting Ltd. and Tetra-Tech EBA both working through their respective aboriginal partnership companies, namely KAVIK-Stantec and Kiggiak-EBA. Kavik-Stantec was responsible for the borrow source investigation, among other design responsibilities.

The borrow source investigation scope of work included a desktop study to identify areas having potential suitable borrow material, a field investigation totaling nearly 700 boreholes, laboratory testing of samples, and estimating borrow material volumes available for use during the 50 year project lifetime.

2 PROJECT DESCIPTION AND HISTORY

The idea of constructing a road linking the communities of Tuktoyaktuk and Inuvik has been discussed between the Territorial and Federal governments since the late 1960's. Initial route surveys took place in 1974 when oil and gas exploration activities were occurring in the Parsons Lake area. Public Works Canada (PWC) identified the initial road alignment. Several preliminary engineering and environmental investigations were completed along this initial route in 1975-1976 and the alignment became known as the 1977 PWC Surveyed Route (Rescan 1999). The first borrow source investigations were completed by PWC, with the results documented in a series of annual reports (PWC 1975, 1976, 1977, 1981a, 1981b). Additional borrow source investigation programs have been completed over the years by the Inuvialuit Lands Administration (ILA), Aboriginal Affairs and Northern Development Canada (AANDC, formerly Indian and Northern Affairs Canada - INAC), Geological Survey of Canada (GSC) and by private firms.

The current ITH project includes upgrades to the existing Navy Road in Inuvik (approximately 6 km), upgrades to an existing access road south from Tuktoyaktuk (approximately 19.5 km long), and construction of approximately 120 km of new highway over ice rich, thaw sensitive terrain. The ITH, when completed, will consist of over 140 km of two lane, gravel surfaced highway. The project will require approximately 10 million cubic metres of granular material for its construction and operation over a 50 year period (NWTDOT – personal communication 2012).

3 BORROW SOURCE INVESTIGATION

Some of the earlier borrow source investigations were "proven" with a geotechnical investigation while others relied on limited field studies. Furthermore, some of these previously identified sources required the construction of lengthy winter access roads. To mitigate costs associated with the construction of access roads leading to some of the borrow sources, the NWTDOT proposed investigating additional supplementary sources of borrow material along the ITH alignment. As a result, the recently completed multi-seasonal borrow source investigation program was developed.

The borrow source investigation program began in the fall of 2011 with a literature review completed to determine the amount of relevant archived information available regarding potential borrow sources located along the proposed ITH alignment. The literature review was supplemented with a brief site reconnaissance completed along the southern most portion of the proposed alignment. From this initial work, an intrusive borrow source investigation program and methodology was developed and launched in the winter of 2012.

The intrusive borrow source investigation program was completed in two parts: (i) a desktop exercise having terrain scientists and geotechnical staff review targeted borrow source areas identified by the NWTDOT in order to plot borehole locations most likely to encounter suitable borrow material; and (ii) complete a field drilling and laboratory testing program to identify and prove borrow material quality and quantity.

The borrow source investigation program comprised of seasonal work completed over three winter periods as outlined in Table 1 below.

Table 1. Summary of the Borrow Source Investigation Program

Year	No. of borrow sources investigated	No. of boreholes executed	Winter Field Program Timeframe
2012	7	350	Mar 15 – Apr 15
2013	14	211	Mar 24 – Apr 21
2014	4	138	Mar 27 – Apr 13
TOTAL	24*	699	78 days

* Some sources were revisited

As the borrow source investigation program was apportioned between several winter field seasons, it allowed the project team to implement lessons learned for each subsequent season. Modifications were made to various aspects of the investigation program with varying degrees of success. Some of the changes included but were not limited to: the type and number of drilling equipment used; the project team roles and responsibilities; the decision matrix to determine whether or not to continue drilling at a particular borrow source; logistics and management of field samples; and reporting of field results.

4 PROJECT RISKS AND PRIORITIES

Significant risks and challenges were attributed to the remote location and winter climate along the ITH alignment. The Health and Safety (H&S) and logistical support of the field investigation team were obviously top priorities.

The following table summarizes the primary risks and challenges faced by the project team along with a brief description of the mitigative action taken.

Table 2. Primary Risks, Challenges, Mitigative Measures

Risk	Mitigative Measure
Health & Safety	H&S plan developed to identify safe working temperature limits, personal protective gear required, communication plan (satellite phone), medical support and emergency evacuation measures.
Remote Location	A self-sustained mobile worker camp towed with a dozer followed the field crew. The camp included a kitchen, sleeping quarters, showers, washrooms and its own power supply.
Sample Processing	A temporary geotechnical laboratory was set-up at the Aurora Research Institute (ARI) in Inuvik. Samples were brought to the ARI lab every other day to allow for early processing and basic index testing of samples.
Schedule	Field work had to be completed within a relative narrow window of time. Field work typically started in March to avoid the coldest winter temperatures, but had to be completed prior to the spring thaw which was also associated with environmental restrictions.

5 PROJECT TEAM

The project team reporting structure was somewhat unconventional compared to typical geotechnical investigations in that it resembled a ‘design-build’ agreement where the Contractor was retained directly by the Owner and Sub-consultants were retained by the Contractor. The reporting structure for the borrow source investigation is presented in Figure 3.

Key roles and responsibilities within the Kavik-Stantec borrow source investigation team are presented in Table 3.

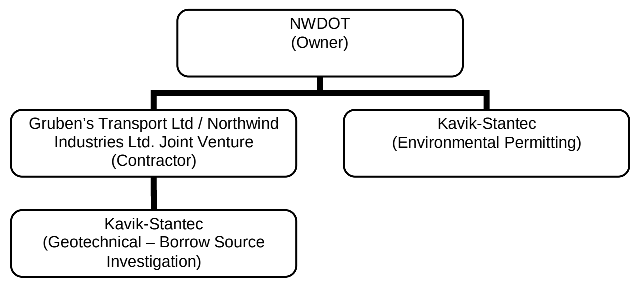

Figure 3: Project Team Structure – Borrow Source Investigation

Table 3: Kavik-Stantec Team (geotechnical) Roles and Responsibilities

Role	Responsibilities
Task Manager	Responsible for all aspects of the Kavik-Stantec team delivery
Terrain Sciences Lead	Responsible for mapping terrain features and identifying areas likely containing suitable borrow material
Geotechnical Lead	Responsible for overseeing technical aspects of the borrow source investigation
Laboratory Lead	Responsible for overseeing all aspects of sample logistics, testing and reporting.
Field Coordinator/ Manager	Responsible for coordinating field related activities
Independent Reviewer	Responsible for providing independent review during the program.

6 TERRAIN MAPPING

As indicated earlier, probable borrow sources along the proposed ITH had been identified through numerous desktop-based mapping studies, geotechnical and geophysical field investigations. From these previous studies, the NWTDOT identified a list of potential borrow sources targeted for additional investigation. As a result, one of the initial tasks consisted of refining the mapping of potential borrow sources identified during past studies.

This mapping exercise was conducted in a digital environmental using the ESRI ArcGIS® 10.1 platform and the Purview software. The mapping was carried out through the interpretation of high resolution stereo-imagery and Light Detection and Ranging (LiDAR) data provided by NWTDOT. The aerial photography used for the mapping exercise consists of digital 1:30,000 scale color photographs acquired in 2004 and 2005 as part of the Mackenzie Valley Airphoto Project (GNWT 2011). The LiDAR data was acquired specifically for the project in the summer of 2011. The LiDAR data was used to create bare-earth hillshade images and one metre interval contour lines.

The purpose of the mapping exercise was two-fold: (i) to confirm the delineation of areas where potential suitable borrow could be found and (ii) to identify terrain features that could impact or limit the results of the drilling program. For example, moderate to steep slopes that could not be accessed by track-mounted drill rigs; areas showing polygonal pattern could likely result in fine grained and ice-rich material; poorly-drained areas would likely contain thick overburden; areas characterized by higher vegetation cover, etc. The identification of these types of terrain features within the potential borrow sources was essential and formed the base of the identification and placement of the boreholes.

As the borrow source investigation program evolved, two types of boreholes were identified for investigation: pioneer boreholes meant to investigate potential borrow areas at a very high level, and proving boreholes which were more closely spaced to prove the deposit. Terrain scientists in conjunction with geotechnical personnel mapped and positioned each borehole type during the seasonal field program planning stage.

7 FIELD INVESTIGATION

Following the terrain mapping exercise, the field program initiation (or pre-program preparation) consisted of an orientation session involving all field staff to review the field program logistics, sample handling and transportation, communication plan and reporting structure, as well as the project health and safety plan. Results from the initial borrow source mapping exercise were clearly communicated to the field staff in order to identify prominent locations where suitable borrow may be encountered. Sample handling, transportation, and processing procedures were outlined so that testing could be completed efficiently and concurrently during the drilling operation.

Investigation of the potential borrow sources consisted of initially drilling pioneer boreholes, which represented less than 20 percent of the planned boreholes for a particular borrow source. If the visual assessment of the samples collected was favorable, then drilling of the proving boreholes using an auger drill rig and a grid spacing of approximately 100 m to 120 m proceeded along with the collection of additional samples for laboratory testing.

Generally, pioneer boreholes were advanced using an air rotary drill rig whereas proving boreholes were advanced using standard 150 mm diameter solid stem augers. Boreholes were advanced to maximum depths varying from 6 m to 10 m or until massive/solid ice was encountered at a shallower depth. All boreholes have been backfilled using a mixture of cuttings and bentonite.

Samples of drill cuttings circulated to the surface from the drill rigs were continuously reviewed and a preliminary visual assessment of the cuttings was performed in the field. Representative samples of drill cuttings were collected and retained for laboratory index testing. A typical sampling frequency at 0.75 m to 1.5 m intervals was followed. All samples were collected in moisture tight containers (5 gal/20L plastic pails with lids) for transportation back to the temporary geotechnical laboratory at ARI in Inuvik. Field borehole records were prepared in the field and included the following information:

- Borehole location (GPS coordinates in latitude longitude format)
- Unified Soil Classification (USC) system for each soil unit encountered
- Depth range of soil changes
- Summary of soil samples obtained including depth of sample and type of sample (grab, bulk, other)
- Soil formation at end of hole (e.g., massive ice)
- Site photographs.

8 DATA ANALYSIS

Soil classification was based on procedures described in the ASTM D2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System); ASTM D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure); and ASTM D4083, Standard Practice for Description of Frozen Soils (Visual-Manual Procedure).

The quality of the material encountered during the field investigation was classified using the criteria from the AANDC Quality Classification of Granular Materials. Material classification was primarily based on the grain size distribution and natural moisture content with select samples chosen for additional testing (Petrographic Number and LA Abrasion).

The AANDC quality classification is comprised of four general classifications: 1-excellent; 2-good; 3-fair; 4-poor. Each sample classification is based on the material general description, technical identification parameters, and suggested uses of the material.

The AANDC Class 2 description allows for materials with an excess of 10% fines content to be classified as Class 2 if the fines in excess of 10% can be removed with a minimum of processing. As minimal processing can be subjective, two criteria were applied to identify this material. First, the material had to have a "good" distribution of sand and gravel sized particles. Second, the initial fines content in the material had to be less than 13% as the removal of 3% fines by screening was considered to be reasonable. As such, the AANDC material classification used for the project was modified to include Class 2 material, as well as Class 2* to account for material which could meet the Class 2 classification with some processing.

Material volumes for each AANDC Class and each general UCS material type (gravel, sand, silt, clay) were estimated based on the data from the pioneer and proving boreholes completed throughout each potential borrow source. LiDAR data was used to establish approximate surface elevations at the borehole locations and the soil stratigraphy from each borehole extended laterally to the mid-point between adjacent boreholes.

9 LESSONS LEARNED

The balance between the cost of having higher quality data, the constraint of the field schedule, and the acceptance of using the best material available against the overall project objectives was constantly being evaluated. Having the borrow source investigation completed over several seasons provided the project team with an opportunity to evaluate the results against the project objectives and adjust the project approach as required.

The following paragraphs present, in no particular order, some of the key lessons learned during the borrow source investigation program.

Field Methodology: Air Rotary Rig vs Auger Rig
One of the concerns and risks brought forward during the planning stages of the field program was the impact of using an air rotary drill rig to collect granular material samples. The specific concern was if the air rotary rig would pulverize the material thus rendering it non-representative of the deposit.

Grain size analysis results of twenty five different samples collected from three different borrow sources using the air rotary drill rig were compared against results from twenty five samples collected using conventional augers. Comparisons were made on samples from adjacent boreholes at similar depths, thus assuming each sample came from the same deposit and was similar in nature.

Results show the percent passing (by weight) for each sieve size was higher in every case for the samples collected using the air rotary drill rig, thus reinforcing the concern regarding the impact of using the air rotary rig on the granular samples. It is premature to bring definitive conclusion that the rig impacted or modified the sample as there are many other variables that could have influenced the results. However, there was a definitive trend showing the air rotary samples were "finer" for each sample tested.

The average, maximum and minimum difference of the percentage of material passing each sieve size between air rotary samples and auger samples is shown in Figure 4.

Field Methodology
A flexible protocol to continue or discontinue borehole drilling at a particular borrow source was developed after the first winter season. The protocol included the terrain scientists identifying the most likely locations in a potential borrow source area to contain suitable borrow and positioning a few pioneer boreholes in these areas. During the field program, the field coordinator/manager, in conjunction with the contractor and owner, discussed the visual assessment of the pioneer borehole samples and decided whether to continue investigating the potential borrow source with additional proving boreholes.

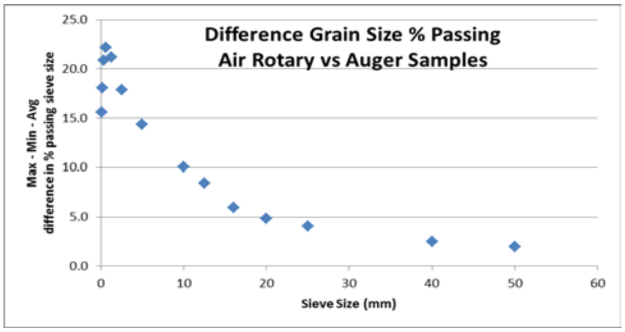

Figure 4: Average difference between Air Rotary samples and Auger samples for material passing each sieve size.

The implications of the new protocol resulted in needing a very flexible logistical support plan for the field program, and also had to be recognized in the contract agreements.

Field Methodology
Maintaining samples frozen while awaiting laboratory testing (i.e. storing them outside the ARI facility in Inuvik) proved to be valuable in that it provided a second opportunity to complete a visual sample classification at the temporary geotechnical laboratory set-up at ARI.

Project Management
Engaging the local workforce through aboriginal partnerships as well as direct hires and using local facilities (such as ARI) proved to be very beneficial to the project. The temporary ARI geotechnical laboratory in

Inuvik helped with immediate processing and index testing of samples, and minimized the weight of samples having to be shipped south.

Project Management
Holding a full-day orientation session with all members of the project team, including the owner, contractor and sub-consultant, proved to be very beneficial in clarifying communication lines, roles, responsibilities, health and safety as well as environmental management plans, and overall expectations. This project orientation was supplemented with a project kick-off meeting internal to Kavik-Stantec in order to review internal roles and responsibilities as well as “calibrate” field personnel with regards to qualitative soil descriptions.

Project Management
Given the volume of samples generated during the relatively short duration period of the field programs, the overall responsibility to track logistics, testing, results, and reporting of each sample was assigned to one individual. Having one point of contact to obtain status and/or test results provided to be very efficient.

Project Management
The environmental regulatory permit application process and resulting ‘project description’ is typically completed well before field crews mobilize to site. However, benefits may be realized by having geotechnical staff involved with and providing input during the regulatory application process so that unnecessary restrictions are not inadvertently imposed on future field work required.

10 ACKNOWLEDGEMENT

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