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Yukon Highways & Public Works

Front Street Paving Project, Dawson City, Yukon: Adapting to Climate Change in a National Historic District

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Introduction

Dawson City is known around the world on account of the 1898 Klondike Gold Rush. The Klondike is a highly valued part of Canada's heritage and much work has been done by Parks Canada and the community to maintain the buildings and streetscapes in keeping with Dawson's gold rush history.

Front Street is Dawson's main thoroughfare, leading highway and local traffic to and from the Yukon River ferry crossing (Figure 1). Because of its importance to Yukon's arterial highway system, Front Street is operated and maintained by the Yukon Department of Highways & Public Works. All the other streets in Dawson come under the jurisdiction of the municipal government.

Front Street is the only paved street in the community having had a Bituminous Surface Treatment (BST) since the 1980s. Over the years the BST has been the source of many complaints from the community due to its inadequate performance under tour bus and RV traffic (Figure 2). The dust and tracking of oil associated with BST rehabilitation was extremely unpopular with the tourist businesses on Front Street.

In 2008 the Yukon Government decided to have an asphalt concrete pavement placed on Front Street. This decision was applauded by the business community but was vociferously opposed by the Dawson Historical Society and the municipal planning board as being a solution incompatible with the community's heritage. The decision to pave also presented an engineering challenge due to the presence of ice-rich permafrost underlying a significant portion of Front Street and a concern that making the surface dark would cause de-stabilization of the permafrost.

Environmental Significance

The "environment" is where we live, everything in our surroundings. In Dawson City the surroundings include a challenging physical environment and a unique built environment assertively protected by residents and governments. The combination of a wilderness setting and a heritage built environment supports a major component of the local and territorial economy.

Any improvement in transportation service levels could only be considered a success if the final product was stable in a difficult permafrost setting while respecting the heritage values derived from Dawson's rich and unique history.

Heritage Values – The discovery of gold in the Klondike Valley in 1896 led to the establishment of a tiny community where the Klondike River flows into the Yukon River. By the summer of 1898, Dawson City was the largest city in Canada west of Winnipeg, with a population of 40,000 in the immediate area. Within months, Dawson boasted telephones, running water, steamed heat, steamboat services, and a wide arrange of elaborate hotels, theatres and dance halls. Dawson City was a gold rush boomtown. Some knew it a Paris of the North.

Dawson City, now less than 2000 residents, is inscribed as the Dawson Historical Complex National Historic Site by the Heritage Sites and Monuments Board of Canada (HSMBC). Preservation of buildings and historic areas, an assortment of activities related to the Klondike Gold Rush, and other tourism initiatives draw some 60,000 visitors each year. The tourism potential of the Dawson City area is expected to continue to grow.

World Heritage Status is bestowed on sites of international significance by the United Nations Educational, Scientific and Cultural Organization (UNESCO). The Klondike is on Canada's nomination list for World Heritage Status.

The heritage value of Dawson City is embodied in five character-defining elements and includes the: "Streetscapes of historical buildings that contribute to the overall sense of place, e.g. the frontier character of structures**, unpaved streets,** boardwalks, collection of boomtown facades, permanent government structures, and a mix of vernacular construction techniques" (HSMBC)

The character-defining elements are protected by development controls and changes may affect the heritage values, tourism potential and the economy of Dawson and Yukon. Black Asphalt would conflict with the heritage character of unpaved streets (Figure 3) and had previously resulted in resistance to re-surfacing Front Street. The use of a pavement matching the colour of the unpaved streets of Dawson gained the support of the community because it preserved the character of Dawson and improved service.

Climate Warming – The permafrost underlying Front Street is considered warm, with temperatures ranging from -1.0 to -0.1ºC and ice contents as high as 200%. This makes it vulnerable to thaw if there is any increase in surface temperature. A good example of this is seen in an 1898 photograph of Front Street (Figure 4) which shows the result of disturbing the permafrost regime by the road infrastructure development of the day.

The regional climate in north-western Canada has been warming for the last 60 years and is projected to increase rapidly in the next half century. The climate is warming faster near the poles with Dawson experiencing one of the highest rates of change. Climate change projections by Environment Canada project a 3.0-4.0°C warming over the next 30 -70 years in the central Yukon, including the Dawson City area (NRCAN, 2008). International Panel on Climate Change models project that within 70 years, 100% of summer average temperatures in the Arctic regions of North America will exceed the 1980-1999 maximum summer average temperature (IPCC 2009).

These warming values, as well as geotechnical and thermal data from Dawson City boreholes were input into a computer modeling program to calculate the impacts of climate change on the permafrost beneath Front Street. A warming rate of 0.10°C/year was used in this climate change model. It was run for twenty years and produced the data displayed in Figure 5 which summarizes thaw that may be expected due to climatic warming. Thaw depth increases of up to 0.2 m could occur by 2018, and 0.9 m by 2028. This could lead to up to 0.5 m in surface subsidence due to the liquefaction of ground ice formerly frozen in permafrost. The high ice contents of the frozen soils could cause significant instability once water is released by thaw.

Mitigation and Innovation

Thermal Modelling – Geothermal modeling was conducted using a thermal finite element computer model developed by the Alaska State Department of Transportation. The modeling was designed to determine the maximum depths of thaw under the current Front Street surfacing of light-coloured chipseal and gravel (estimated to be similar to a light coloured pavement), a standard asphalt paved surface, and an asphalt surface with light coloured rock chips pressed into the surface. The critical difference in the various surfacing materials is the albedo, or percentage of incoming solar radiation reflected by the material. Darker materials such a black asphalt absorb much more solar energy than lighter materials such as a light coloured gravel.

The model took into account air temperature, ground surface temperature, thermal conductivities of various soil materials, thermal effects of climate change and latent heats of fusion within the soils. The simulation was started in 2008 and ran until 2028, producing maximum depths of thaw for each year.

Modeling of a combination of natural and artificially-induced thaw was not attempted due to complexities which were beyond the scope of the project. Figure 6 summarizes differential thaw depth increases that may occur as a result of different surfacing techniques. The gravel and chipseal techniques result in a stable permafrost table, while the use of dark-coloured asphalt results in dramatic permafrost thaw.

The results of the modeling indicated that paving using a black bitumous surfacing on Front Street would have a much greater and immediate impact on underlying permafrost than the gradual warming due to climate change. The use of a light-coloured pavement would be likely to absorb much less solar energy and have a greatly reduced impact.

Pavement Options – Based on the results of the thermal modelling, several options were considered to accomplish a light coloured pavement.

<u>Chip Seals:</u> Using appropriate emulsified asphalts and carefully designed aggregate gradation, combined with skilful application techniques, it is possible to construct a good quality chip seal with a well bonded surface and very little free asphalt or bleeding. A well constructed chip seal would essentially be the colour of the aggregate and could provide an effective light coloured surface. However the use of chip seal is normally avoided in an urban like setting where there are closely spaced intersections and parking lanes, as the shear stress from numerous vehicle turning movements and snow removal may lead to a significant level of chip loss and maintenance difficulties.

<u>Sprinkle Treatment:</u> Embedding chips in the surface of freshly laid asphalt concrete during the laydown operation has been used in some countries to increase road surface friction. A similar process using light coloured chips is used in road tunnels to achieve a light coloured roadway surface with improved reflectance. However the potential for snow plows to remove the embedded chips weighed against pursuing this option.

<u>Coloured Pavement:</u> Coloured pavements are successfully used in Europe to designate transit and bicycle lanes as well as for aesthetic purposes. There has been limited use of this pavement technology in North America. Construction is essentially the same as standard asphalt paving except that the binder is synthetic and the pavement can be coloured by the addition of mineral pigment. This option offered several opportunities for the Front Street project namely:

- Performance similar to asphalt concrete
- The possibility of a high surface albedo
- The ability to match the pavement colour to Dawson City's historic gravel streets.

While coloured pavement had the highest initial cost of the options investigated, it was felt to have the best chance of success in meeting the project objectives and providing better in-service performance and longevity.

Community Outreach and Public Relations – This was a high profile project in the community and the project risk assessment identified that community outreach was a necessity. Several mitigative measures were undertaken as a proactive means of reducing the potential risk associated with poor community support or unresolved community concerns. Two examples of this are the development of a communication strategy as well as a traffic management plan.

The communication strategy detailed methods to effectively communicate to the community with emphasis on critical timing for key messages. A traffic management plan was developed with a view to maintaining safe conditions for the traveling public, cyclists, pedestrians and workers. Each of the documents enhances and compliments the other.

In terms of community communication, prior to the paving project, Highways and Public Works conducted an open house to ensure the community was aware of the scope of the project and to collect input on how to best deliver the project. Based on the information received from the community, the construction schedule was developed to avoid specific tourist events including the Summer Solstice, Dawson City Music Festival and Discovery Days.

The plan for pedestrian and business access was communicated to individual businesses. The day prior to construction, the traffic coordinator visited each business being affected and dropped off a 'one day notice'. There were several public notices to communicate information at critical stages in the project.

The traffic management plan detailed alternative routes used to conduct traffic to and from the ferry landing and maintain good access to the downtown area. To mitigate the impact on businesses, signage was placed at either end of the immediate work area informing people that stores were open for regular business hours and providing direction for pedestrian access. Also, with cooperation from businesses, alternative parking was established off Front Street.

Some quick decisions were made to minimize the impact to the community and this came about from talking with the businesses that were most affected. In one example, discussions with Front Street store owners brought about a change in construction shifts for the grade work. The work planned in front of the blocks containing the majority of the stores was carried out during night shifts, from 1900 to 0700. The almost 24 hours of daylight made night construction feasible. Effective public relations on the project lead to good cooperation amongst all the stakeholders.

Contracting Arrangements – Early in the project planning it became obvious that the traditional public tender process would cause a layer of uncertainty for the project. While researching light coloured pavement, Highways and Public Works contacted potential material suppliers and all expressed concern at the aspect of undertaking the necessary research and development to produce a product suitable for the Dawson City environment without a guarantee of a contract. Also, material suppliers expressed concern at the uncertainty around undertaking a special and novel project without a solid working relationship with the construction company, which they emphasized as a key factor to achieving a successful project. Based on these factors the Department obtained approval to sole source the work to local paving contractor Skookum Asphalt since its parent company ColasCanada had extensive European experience in the manufacture of synthetic binders and construction of coloured pavements. Essentially, the contacting mechanism was selected to reduce project risk.

The special requirements of the project necessitated an early and reliable partnering between primary parties. Early in the project, the owner and the contractor committed to working together on problem solving and innovation. The project logistics were particularly challenging since the synthetic binder, Bituclair, was manufactured in Vitrolles, France and was shipped by ocean via Marseilles through the Panama Canal to Vancouver in specially purchased bitutainers sourced from China, which were then trucked to Dawson City. The seven week delivery schedule was a significant challenge given the short construction season in the central Yukon.

The risk management tasks were shared with the contractor and many of the mitigative tasks were prescribed to Skookum Asphalt employees. The partnerning approach allowed the parties to establish common goals and guidelines, build rapport and allowed for quick communication between key project personnel during planning and construction stages.

Design of Pavement Materials – Traffic volumes on Front Street are relatively low and a paved surface thickness of 100 mm was deemed adequate. Early in the design stage of the project it was decided to place the surface in two lifts using a thin hot mix surfacing system for the top lift to minimize the amount of synthetic binder and pigment required to produce the light colour surface. The base layer consisted of 75 mm of asphalt concrete while the top layer of light coloured pavement was to be placed at a thickness of 25 mm. Dense graded type mixtures were selected for both the base layer and the surfacing layer with the particularity that the maximum nominal aggregate size of the surface layer was 6.0 mm to facilitate placement and compaction.

The production of the appropriate aggregates to produce a viable 6.0 mm dense graded mixture presented certain challenges. The initial intention was to produce the mixture using 2/6 mm chippings, 0/2 mm crushed sand and natural clean sand. The equipment needed to produce such aggregate was not available within the time table of the project. Nevertheless, three aggregates were used to produce the mixture: 0/6 mm sand, 0/4 mm sand and natural sand.

The synthetic binder was formulated specifically for the Dawson City environment. The main focus of the formulation was to obtain a binder that would perform well at low temperature. The performance at high temperature was also important, but not as the main selection factor given the relatively low traffic volumes. Several formulations were tested and the selected formulation rated 54°C for the high temperature and -39°C for the low temperature. It did not meet the initial PG 58-40 target, but it was considered adequate for the Front Street application.

The development of the mix-design was carried out using the method described in the Asphalt Institute MS-2 manual. Early in the development of the mix-design, the necessity of using titanium dioxide as a pigment was identified to obtain a light colour material that would meet both the desired reflectivity and a colour that blended with the historical gravel streets.

The usage of a high performance tack-coat was recognized as critical to ensure complete bonding of the thin light coloured overlay with the base course. A polymer-modified emulsion applied at a residual rate of 300 g/m^2 was selected for this application.

Construction Operations - Dawson City is built on a flood plain and in order to protect the city's infrastructure from periodic flooding of the Yukon River, a dyke was built along the river front. The storm water system includes catch-basins at the intersections along Front Street and it terminates with one way valves on the river side of the dyke. Essentially, the city has little natural positive drainage and the constructed dyke impedes any surface drainage which is not captured in the existing storm water system. The grading and drainage portion of work was undertaken with a view to utilize as much of the existing drainage structures as possible to avoid disturbing parent ground.

The base preparation work included raising the grade an average of 100mm for the entire length. Also, a 2% cross fall was built into the cross section to ensure water is shed from the road surface (Figure 7). Careful and tedious work was carried out to ensure all areas of the road were draining into existing and new catch basins and ensuring that water will not pond on the pavement surface. On satisfactory completion of grading, the 75 mm first lift of asphalt concrete was placed (Figure 8).

Early in the work planning stage, it was recognized that manufacturing and placement of the light colour surfacing system required detailed attention. Accordingly, a quality plan was developed to ensure that key elements that would influence the outcome of the work were identified and that measures were taken to address any potential difficulties. The quality plan was focused on best practices in manufacturing and placement, but also on operations such as cleaning the plant and paving equipment and retrofitting the plant to accommodate the injection of the titanium dioxide. All were viewed as critical tasks in ensuring a uniformly light coloured surface layer. Furthermore, extensive efforts were deployed to raise awareness of potential difficulties in manufacturing and paving with the workforce. The level of detail included ensuring that the paving crew had clean tools and each worker had new boots.

The implementation of the quality plan greatly supported the manufacturing of the light coloured pavement, but many adjustments were still required during production. The aggregate production in such a remote location was challenging, which influenced the mix-design development. The injection of the titanium dioxide was not as precise and efficient as intended due to high humidity and as a precautionary measure the rate of injection was set such that variation would not affect the colour significantly. On the other hand, no black contamination was noticed indicating that the cleaning operation was adequate and that the plant burner was well adjusted. Unburned fuel from the plant can contaminate the mixture the same as residual black HMA material. The quality control results also indicated that the calibration of the plant was adequate and that the production of the mixture remained under control during the entire production.

The placement of the binder rich tack-coat and the placement of the light coloured mixture were carried out without any major difficulties. The polymer-modified bitumen emulsion tack-coat was applied using a conventional distributor. A verification of the calibration of the distributor was carried out at the start of the job. Traffic was closely controlled to minimize soiling from adjacent roads or tracking of tack-coat. It was also found that the heavy polymer-modified tack-coat greatly facilitated the placement of the thin top layer as it anchored the mix to the underlying substrate helping the smoothing of the mixture (Figure 9). Compaction was carried out using a double drum vibratory roller set at low amplitude and high frequency. Compaction was monitored using a nuclear gauge and no difficulties were encountered to reach target density.

Costs - The cost of providing paved streets in remote northern communities is typically much higher than in major centres due to factors such as high mobilization costs, lack of an established marketplace for paving, and high risks for contractors. Because of the high cost, achieving a successful outcome becomes even more critical. Success on Front Street depended on minimizing the impacts on permafrost; meeting the community desire for a high level of pavement performance; and delivering a finished product that was in keeping with Dawson City's gold rush heritage (Figure 10).

Compared to a standard asphalt pavement an additional premium was felt to be justified in order to accomplish the project objectives. The premium in this case was primarily the high cost of the synthetic binder which at approximately $6,000 / tonne was over five times as expensive as standard asphalt cement ($1,120 delivered to Dawson City). The quantity of synthetic binder required was 120 tonnes for an additional cost of about $586,000 or 14% of the overall project budget.

Monitoring - Monitoring the state of permafrost beneath Front Street is being conducted using traditional thermal sensors installed in boreholes beneath the street as well as the experimental use of permanently installed DC electrical resistivity arrays.

Thermal acquisition cables and dataloggers were installed in four boreholes along Front Street. These cables have thermal sensing nodes spaced at 0.5 m intervals from the surface to 5.0 m below grade. Temperatures are taken at all nodes every hour and stored on the attached dataloggers. Two of the boreholes are directly beneath the resistivity arrays, allowing resistivity images to be compared to thermal results.

A permafrost monitoring Smart Surface DC Resistivity Array was installed prior to paving during the summer of 2009 (Figure 11). Three arrays were constructed, each array having 28.0 evenly spaced electrodes. Two arrays were built with 1.0 m electrode spacing (28.0 m total length) and one had 6.0 m electrode spacing (168.0 m total length). Depths of investigation were 5.0 m for the 1.0 m spaced arrays, and 25.0 m for the 6.0 m spaced array. An Advanced Geosciences Supersting R1/IP ground resistivity instrument, 28 electrode switchbox and EarthImager 2D software was used to power the arrays and interpret the data (Figure 12). DC resistivity surveys have been made on a monthly basis since installation. This is one of the first uses of a permanently installed DC resistivity array to monitor permafrost beneath infrastructure.

In addition to monitoring the state of the permafrost underlying Front Street, a careful evaluation will be made of the performance of the light coloured pavement including monitoring for typical pavement distresses such as cracking, ravelling etc. Maintenance costs will be recorded including costs related to specialized maintenance to match the pavement colour if patching or crack filling is required.

Conclusions / Applicability to Transportation

Climate warming is already evident in Northern Canada and this poses new risks for infrastructure constructed on permafrost. Failure to manage these risks could seriously threaten both the environment and the economy. As development of the north advances, northern communities will demand higher infrastructure standards including paved highways and streets. Adapting infrastructure designs to meet the challenges of a warming climate while providing a high level of service to businesses, residents and road users is important. The Front Street project will contribute to a better understanding of the potential for light coloured pavements to help address the challenge of maintaining sustainable communities in the north.

The success of the Front Street project in supporting the heritage values of Dawson City can provide valuable information for other heritage sites with similar challenges relating to road infrastructure, service levels and aesthetics.

Furthermore, on a broader scale, there is potential for the application of coloured pavement technology elsewhere in Canada in urban situations related to special traffic lane designations.

Finally high albedo pavements are of interest in large urban centres in warmer climates as a means to reduce the heat island effect of traditional asphalt paved streets and parking lots.

Appendix 1

Figures

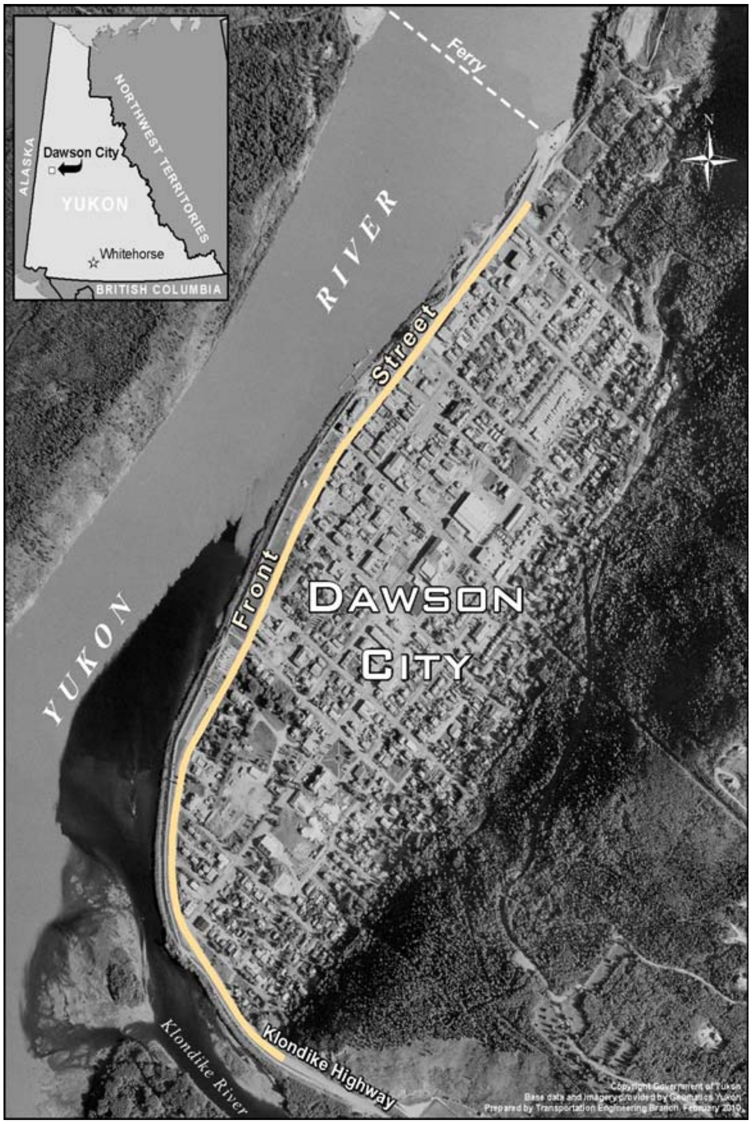

Figure 1 – Project Location

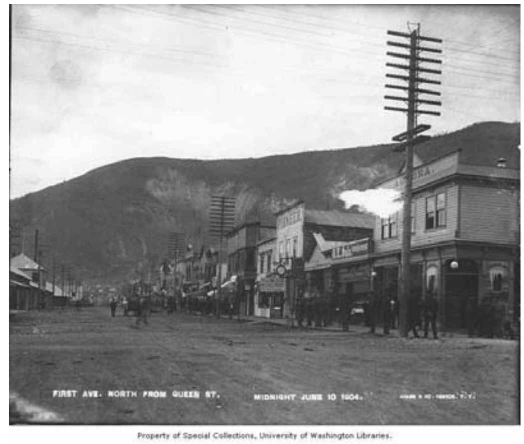

Figure 3 - Front Street at midnight during the summer of 1904

Figure 4 – Lumber cart stuck on Front Street in 1898 – likely a consequence of melting permafrost

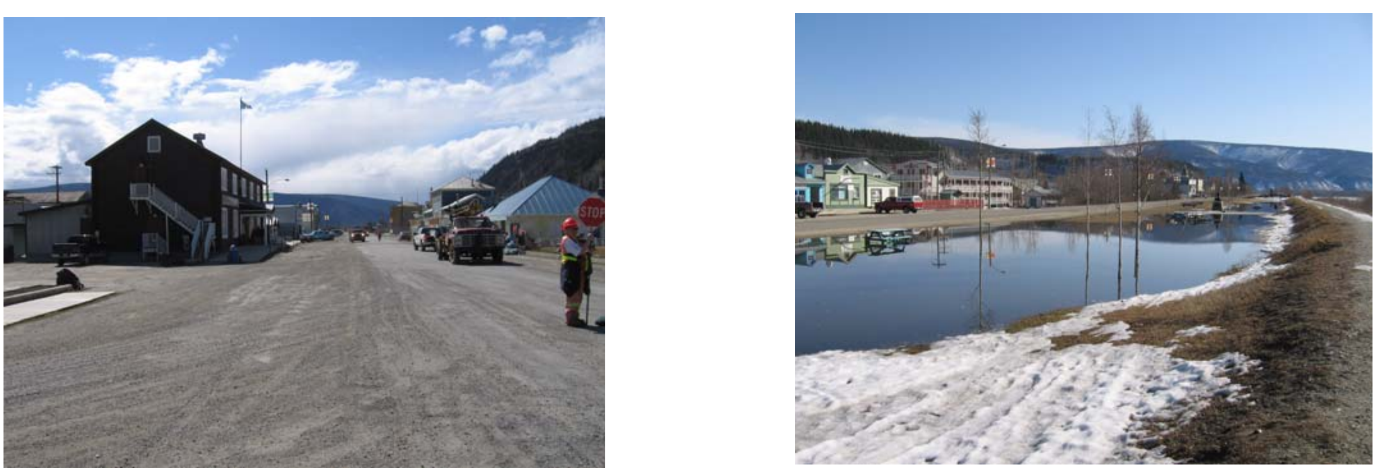

Figure 2 - Spring 2009, typical drainage problems and surface distresses along Front Street were a cause of community dissatisfaction

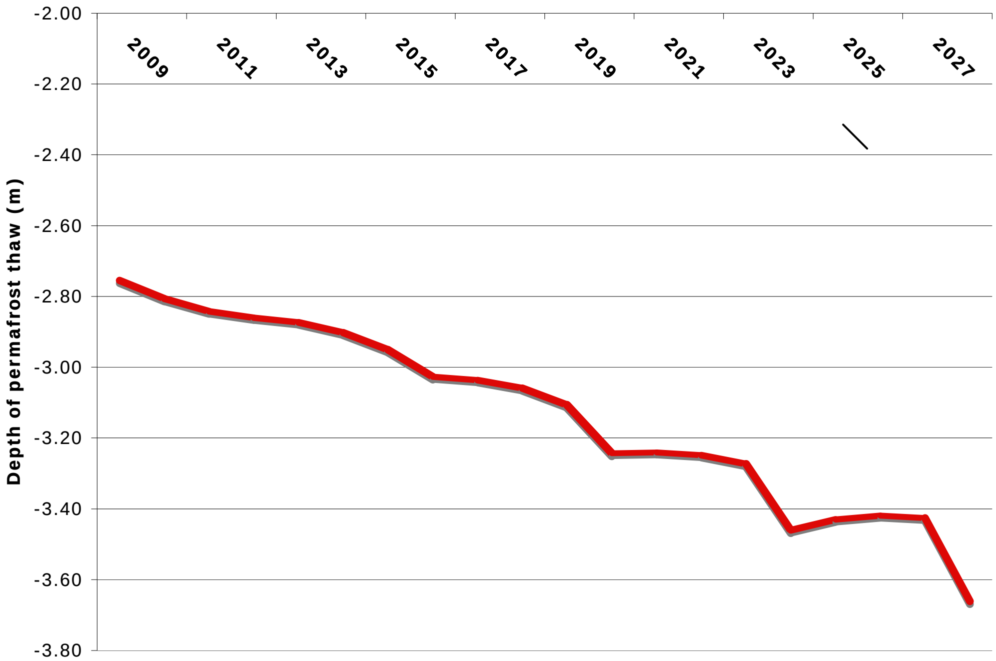

Figure 5. Modeled thaw depth as a result of climate warming (+0.1°C/year)

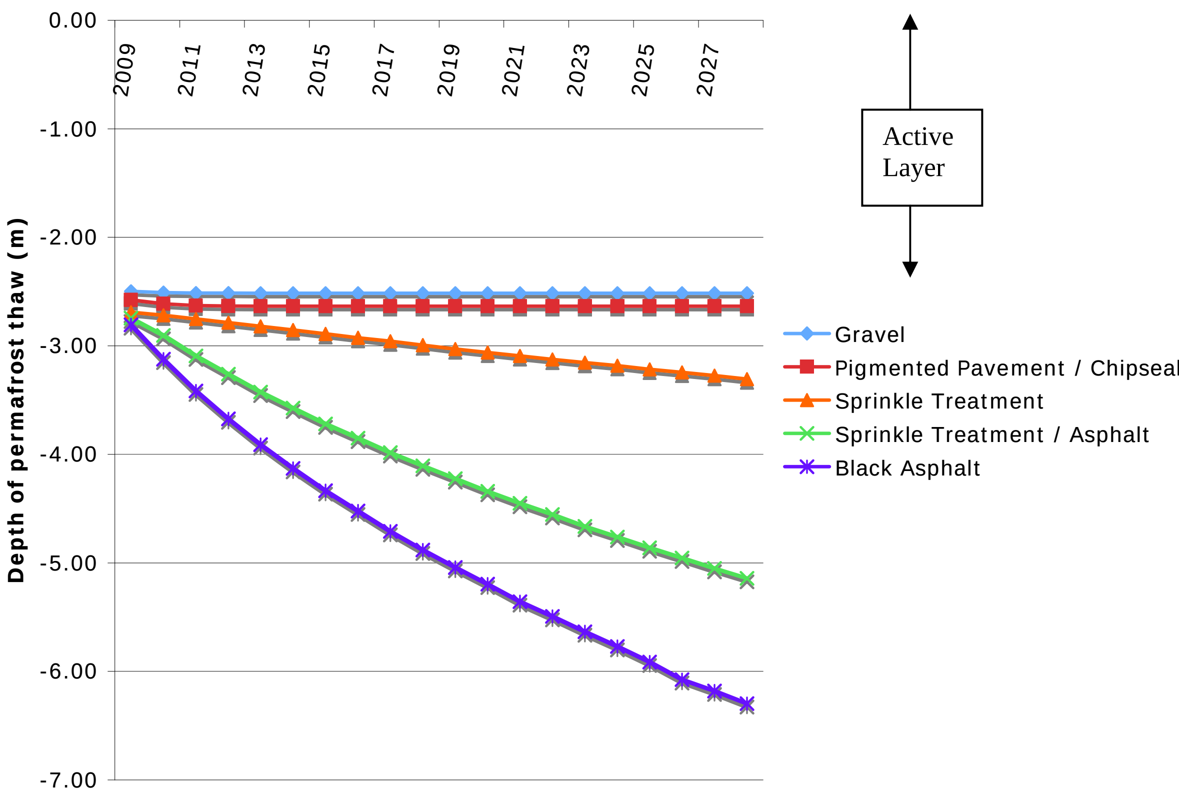

Figure 6. Modeled maximum annual thaw depths beneath various paving materials as projected by MUT1D finite element thermal modeling (does not include projected climate change impact)

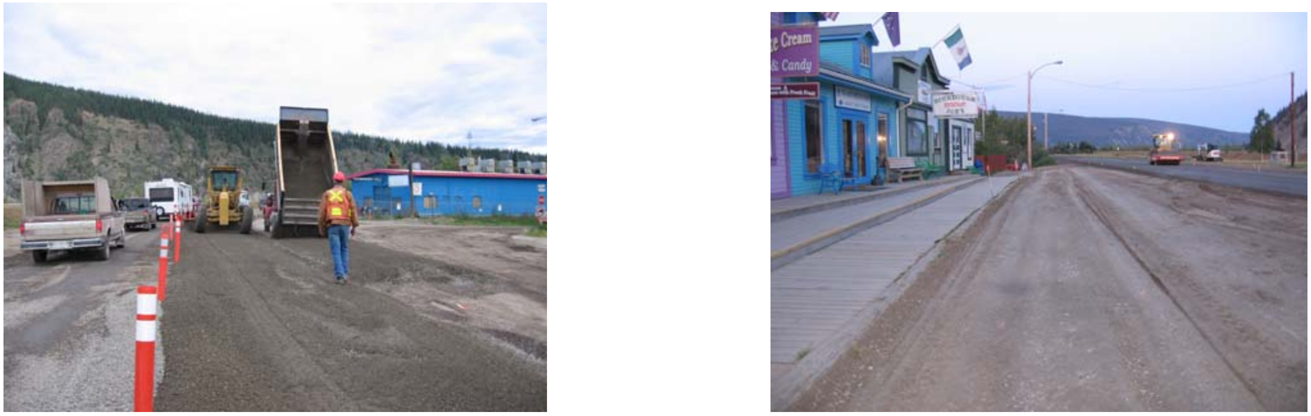

Figure 7 - Base-course preparation

Figure 8 - Base layer of conventional asphalt concrete pavement

Figure 9 - Top layer of light coloured pavement

Figure 10 - Finished pavement, note gravel streets in background

Figure 11. Installing DC Restivity Array

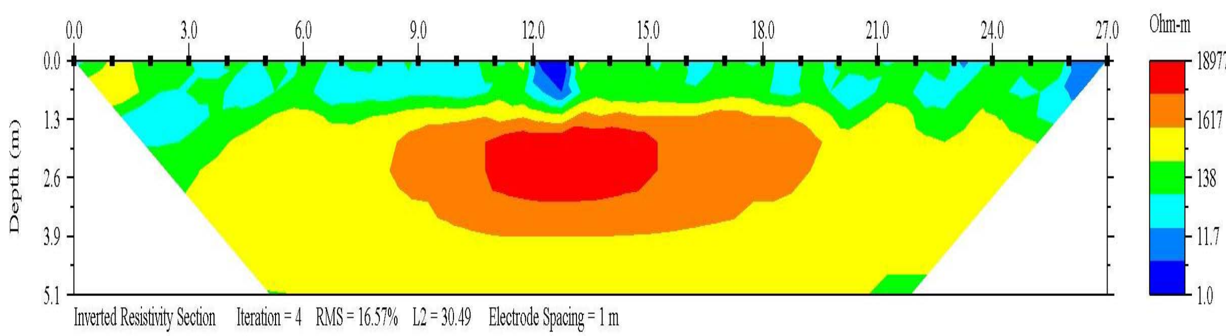

Figure 12. Resistivity image transverse across Front Street. 0.0 m horizontal is the edge of the street, 27.0 m is beneath the boardwalk sidewalk. Yellow, orange and red indicate high resistivity regions associated with frozen ground. Blue and green regions are lower resistivity thawed areas.

Appendix 2

References

Directory of Designations of National Historic Significance: Commemorating Canada's History
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Proceedings of the National Symposium held on the Occasion of the 75th Anniversary of the Historic Sites and Monuments Board of Canada
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