

# **A Bumpy Road: Highways and Thawing Permafrost**

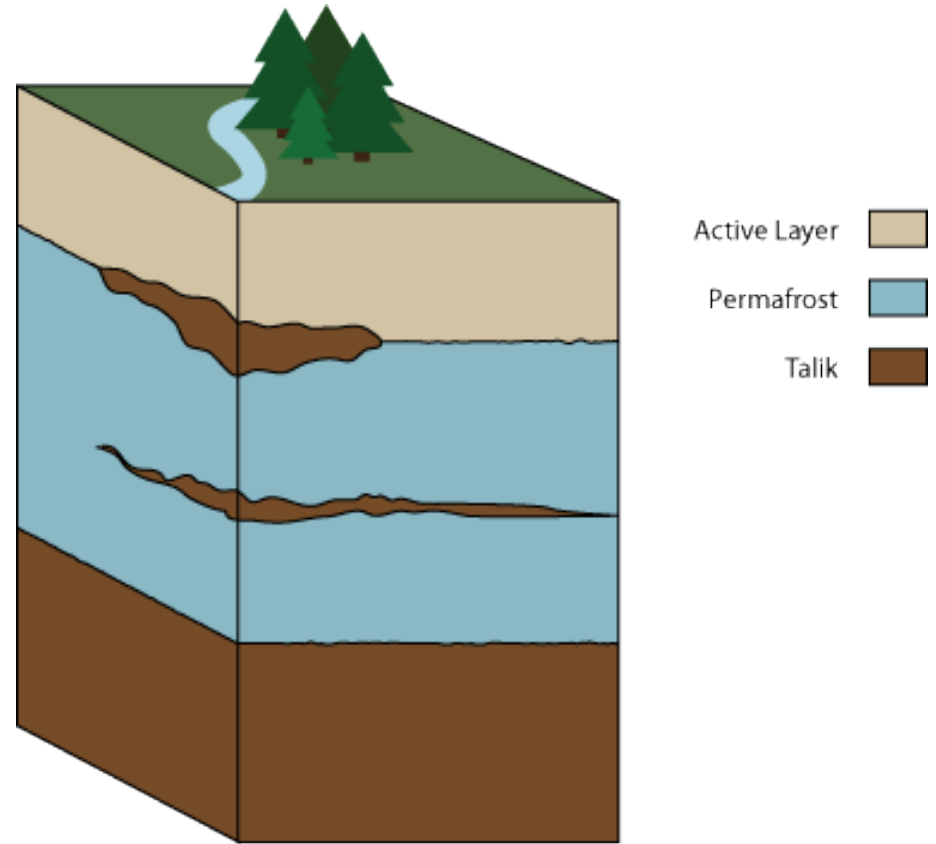
Paul Murchison, P.Eng.

# Outline

- Background
- Transportation infrastructure construction
- Transportation infrastructure deterioration
- Financial implications
- Climate change
- Transportation infrastructure permafrost research
  - Permafrost test site near Beaver Creek on the Alaska Highway
  - Pigmented asphalt in Dawson
  - Alaska Highway vulnerability study
- Transportation infrastructure over permafrost in China

# Permafrost

- Ground, soil or rock, that is continuously below  $0^{\circ}\text{C}$  for a period of 2 or more years.
- Varies from a few metres thick to in excess of 700 m.



<http://classic.wunderground.com/climate/permafrost.asp>

# Permafrost

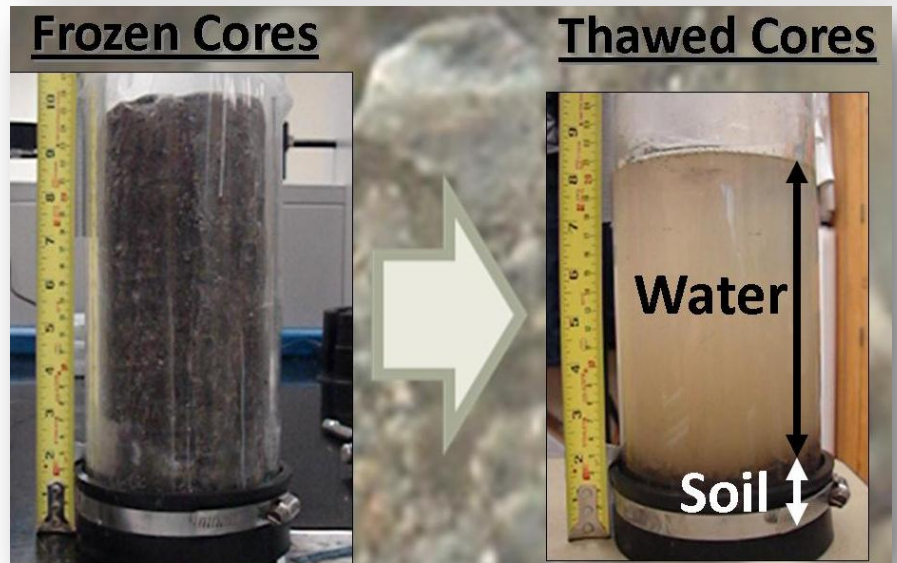
- Discontinuous
- Ice Rich
  - Excess ice

*Volume Ice > Pore Volume Unfrozen Soil*

- Thaw Sensitive

*Thawing = Settlement + Loss of Strength*

- Warm
  - Above  $-1^{\circ}\text{C}$



# Permafrost



# Yukon Background



## General

- Area 483,450 km<sup>2</sup>
- Population ~35,000
- 17 communities
- Transportation is primarily focused on road and air

## Highways

- 4,808 km of maintained highway
- ~25% is impacted by permafrost

**Yukon**  
Highways and Public Works  
*Voirie et Travaux publics*

# Yukon Background



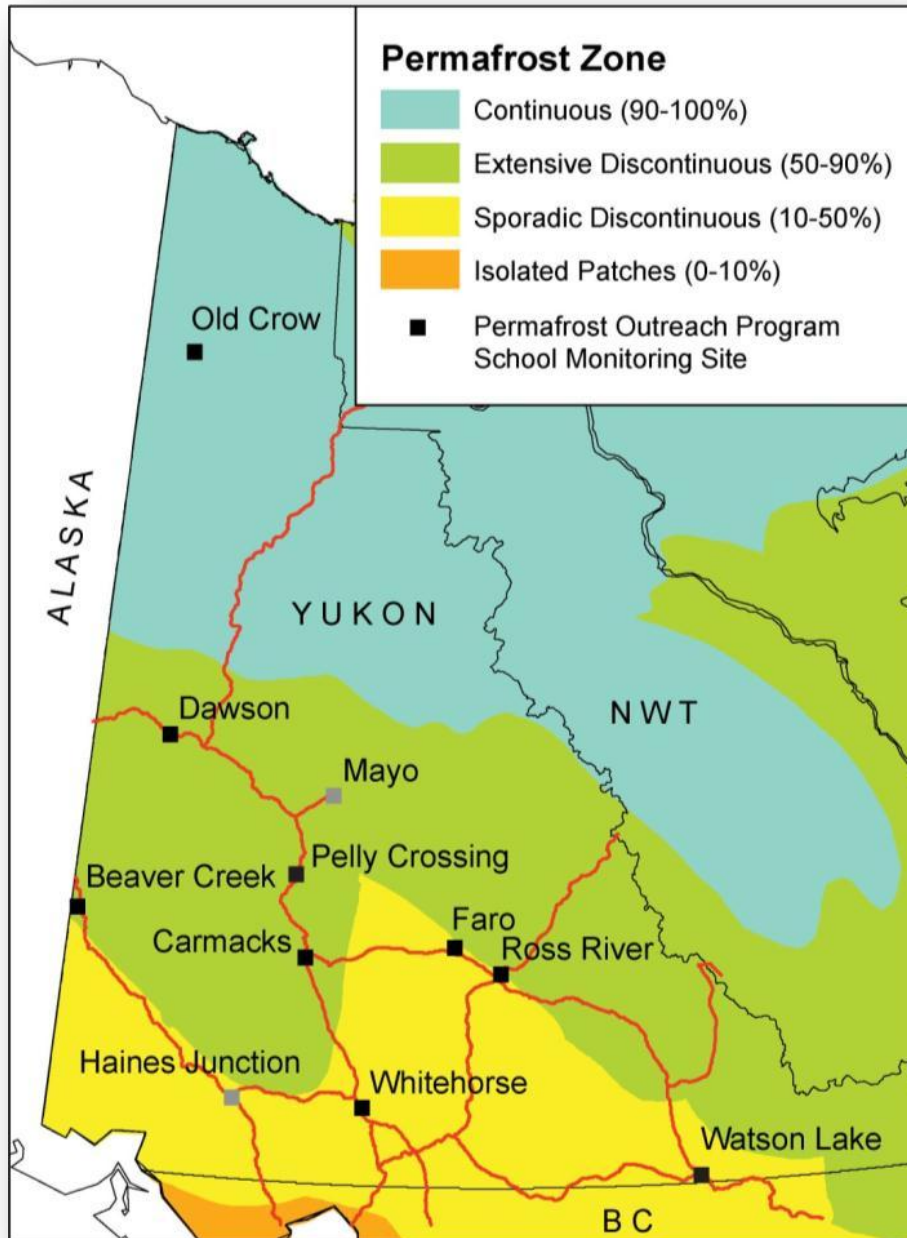
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# Construction Challenges



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- Construction practices to preserve permafrost
  - Winter construction
  - Minimize ground disturbance
    - No grubbing
    - No burning
    - No cuts
  - Manage water

# Infrastructure Deterioration



# Infrastructure Deterioration



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# Infrastructure Deterioration



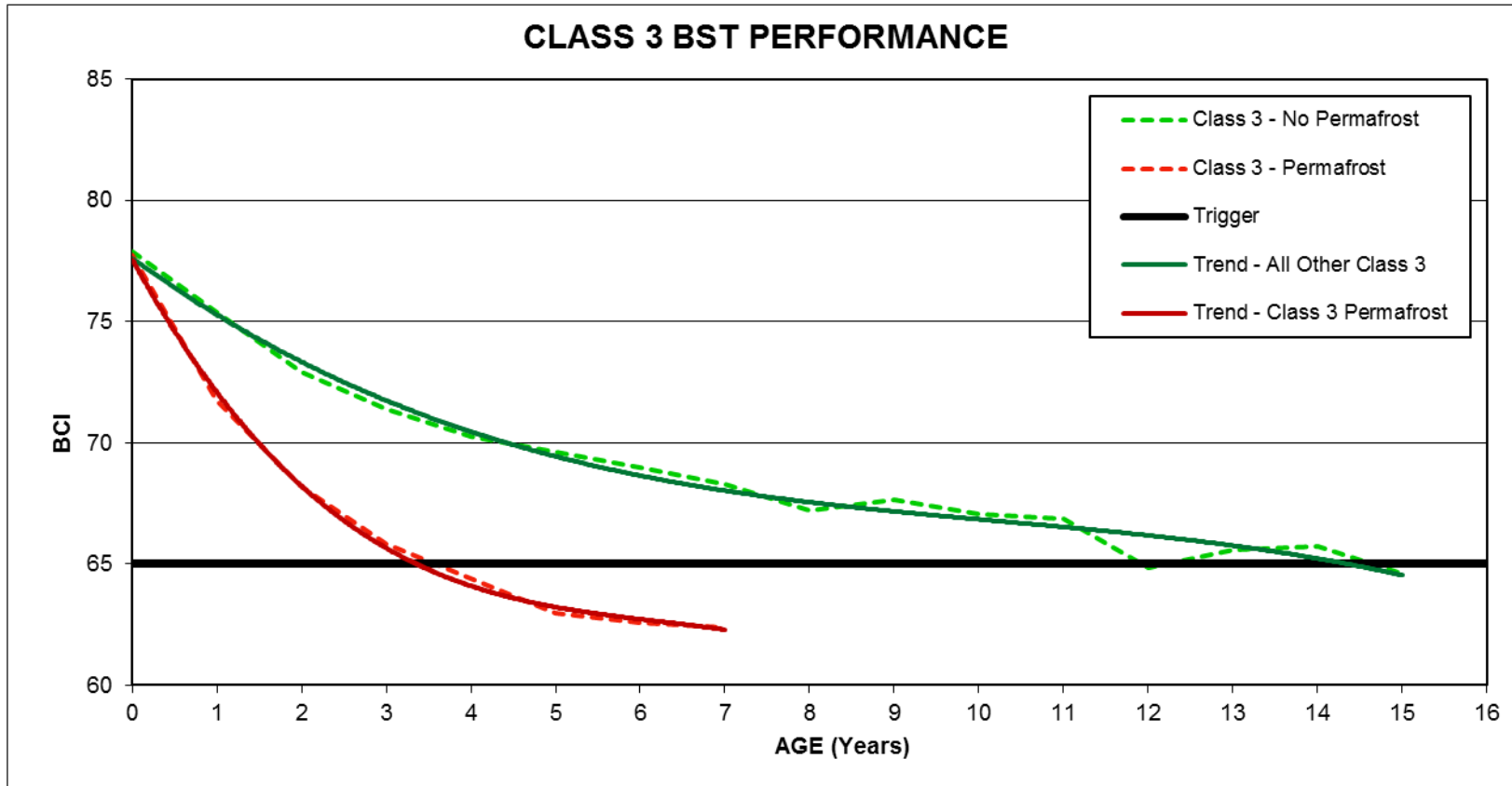
# Infrastructure Deterioration



# Infrastructure Deterioration



# Performance and Cost



- Additional maintenance / rehabilitation cost in the permafrost sections is up to \$22,000 to \$36,000 / km / year
- Maintenance / rehabilitation costs in permafrost sections are up to 10 times as much as non-permafrost sections

# Financial Resources

- Yukon

- Population ~ 35,000
- 4,800 km of highway
- 7 people per km of Highway

- Quebec

- Population ~ 7,600,000
- 30,000 km of highway
- 260 people per km of Highway

# Yukon Climate Trends

## Dawson City Climate Trends

## Rate of Change

Mean Daily Minimum in Winter (°C)

0.62 °C/ decade

Mean Daily Maximum in Summer (°C)

0.38 °C/ decade

Mean Annual Temperature (°C)

0.24 °C/ decade

Days Below -40°C

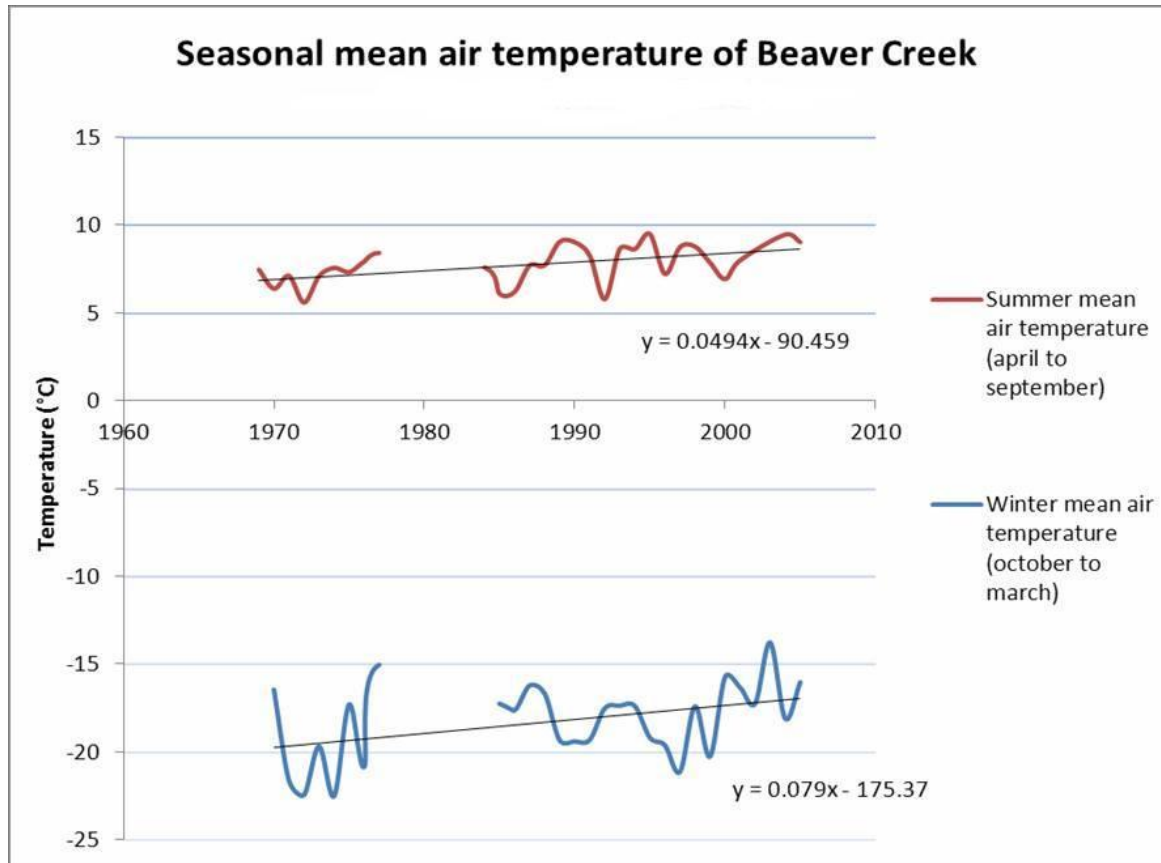
-3.9 days/decade

Frost Free Days

7.4 days/decade

Data Source: Environment Canada

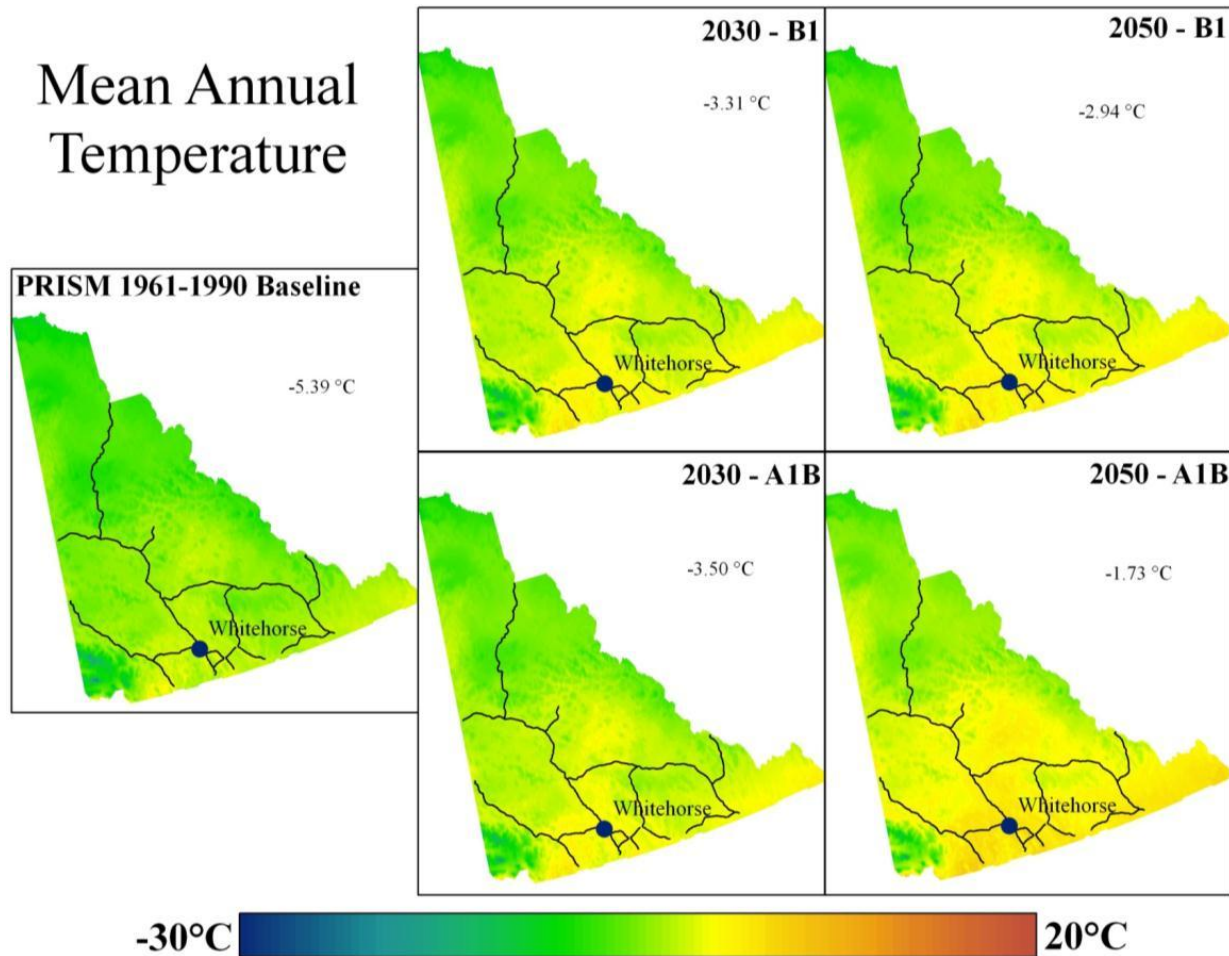
# Yukon Climate Trends



Data Source: Environment Canada

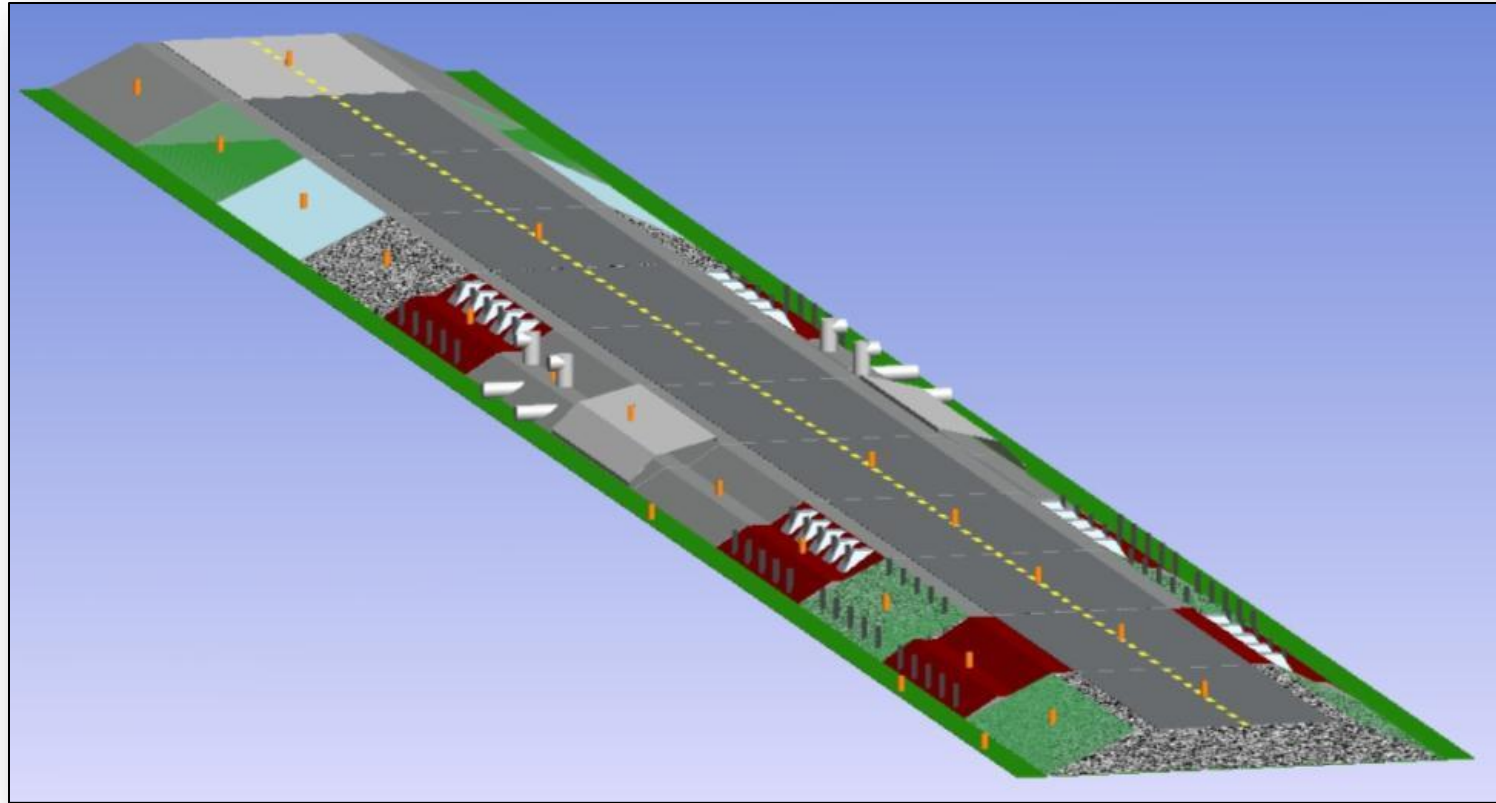
- Observed mean winter air temperatures rate of change is 1.6 times greater than mean summer air temperatures.
- Mean annual air temperatures increasing at  $0.6^{\circ}\text{C}$  per decade (1969 and 2006).

# Yukon Climate Scenarios



Possible destabilization of currently stable sections of highway in the future due to climate changes

# Permafrost Test Site – Beaver Creek



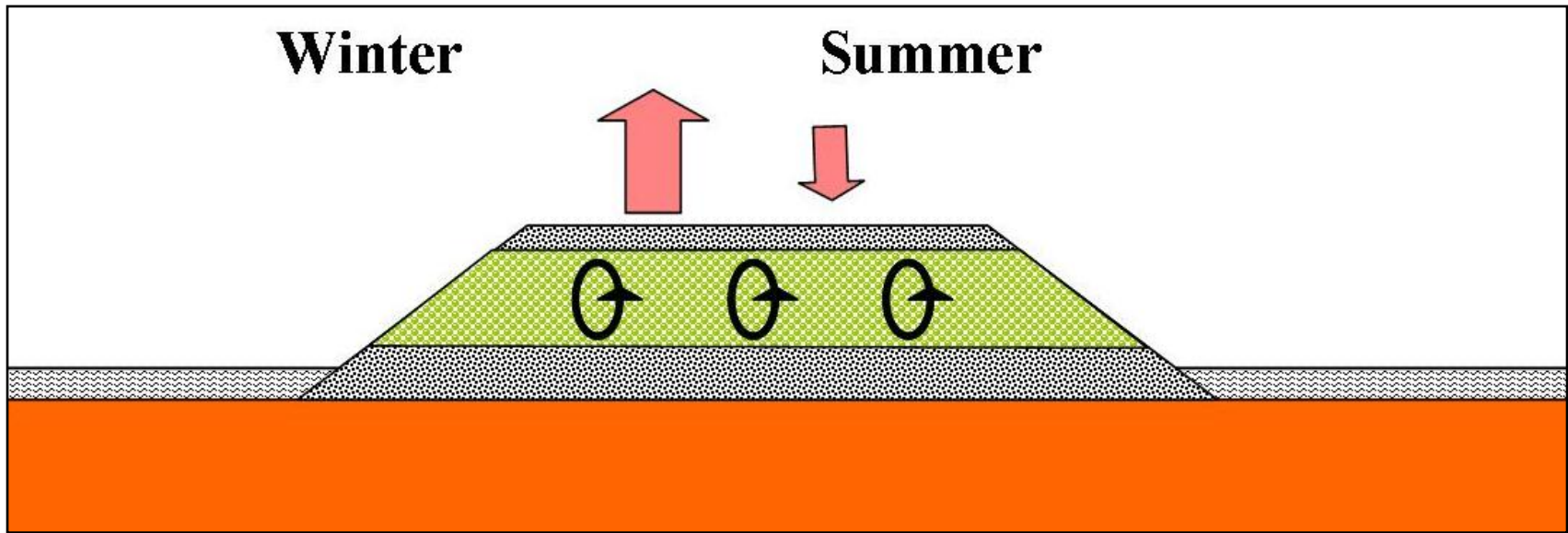
- Twelve instrumented test sections
- Constructed in 2008
- Heavily instrumented 300 thermistors, 150 surface temperature loggers, groundwater sensors and weather monitoring equipment
- Data transmitted by satellite to SCADA (Supervisory Control and Data Acquisition) server in Whitehorse

## Mitigation Methods

- Two general approaches at the test site
  - Activation of heat extraction during winter
  - Reduction of heat intake during summer

# Permafrost Test Site – Test Sections

## Air Convection Embankment (ACE)



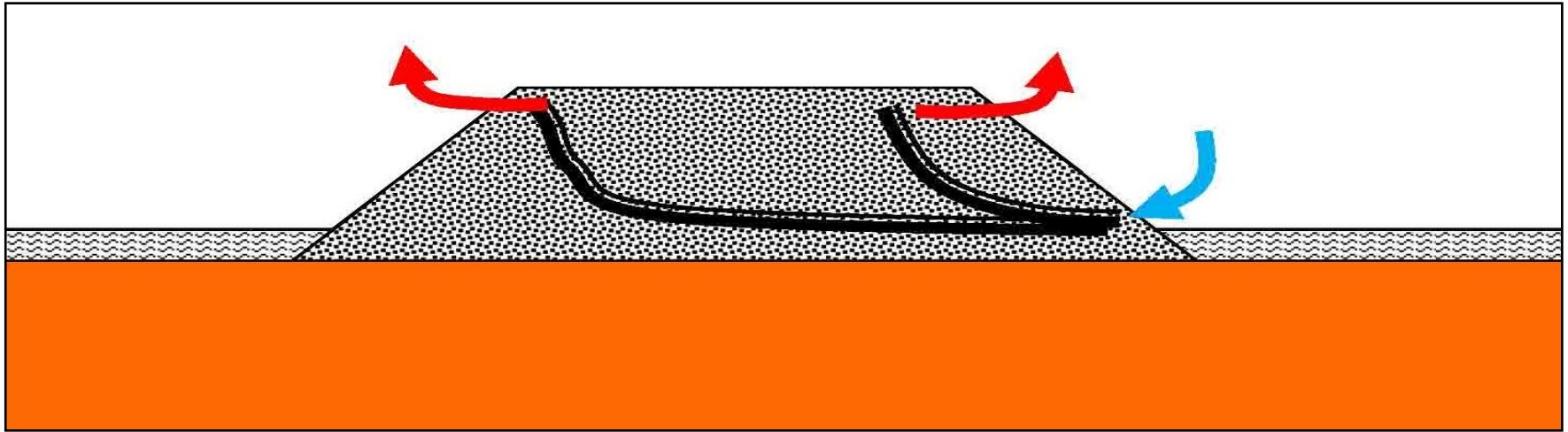
- Constructed using 150 mm to 300 mm, crushed, rock to form interconnected, convective cells in the embankment.
  - Winter, air cooled in the upper voids travels down into the embankment displacing warm air which rises and exits from the embankment.
  - Summer, the rock insulates the ground and reduces warming by keeping warm air near the surface and cool air at the base of the ACE.

# Permafrost Test Site – Test Sections



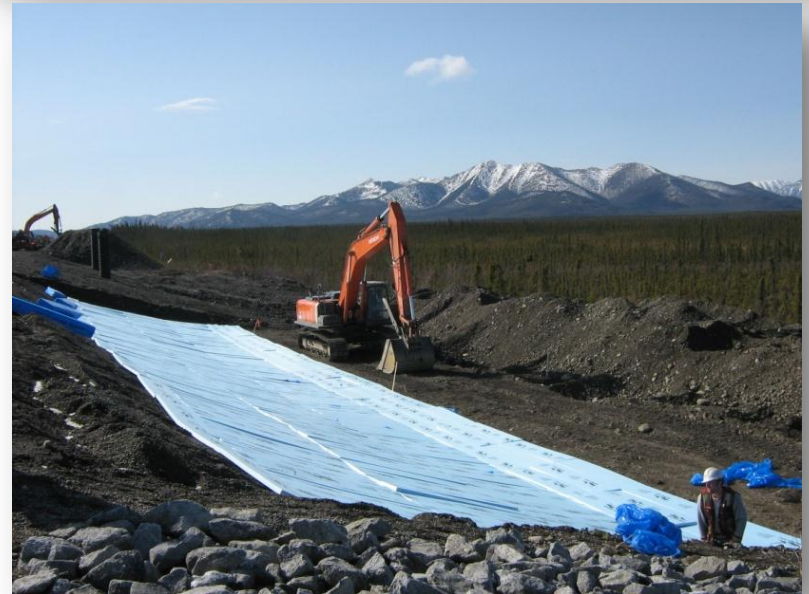
# Permafrost Test Site – Test Sections

## Heat Drains



- Heat extraction by natural convection induced in a geocomposite layer
- Applied in embankment shoulder and across full width of embankment

# Permafrost Test Site – Test Sections

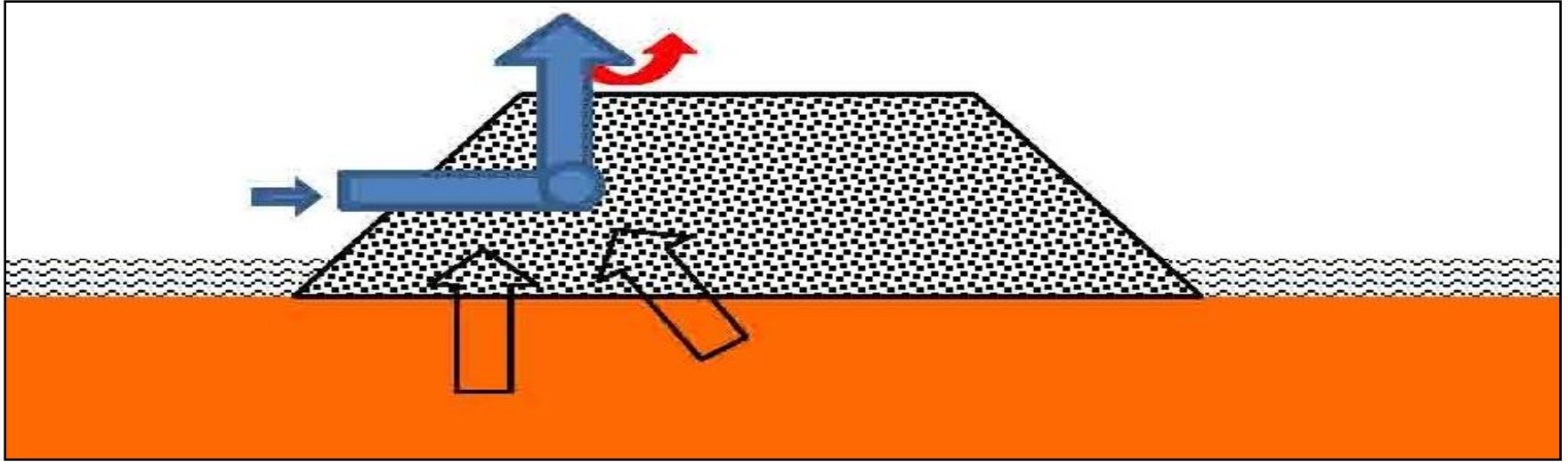


# Permafrost Test Site – Test Sections



# Permafrost Test Site – Test Sections

## Longitudinal Culverts



- Heat extraction by natural convection
  - Winter, cold air is drawn into the embankment at the inlet and warmed air exits at the outlet.
  - Summer, inlet and outlet are blocked to minimize warm air input.

# Permafrost Test Site – Test Sections

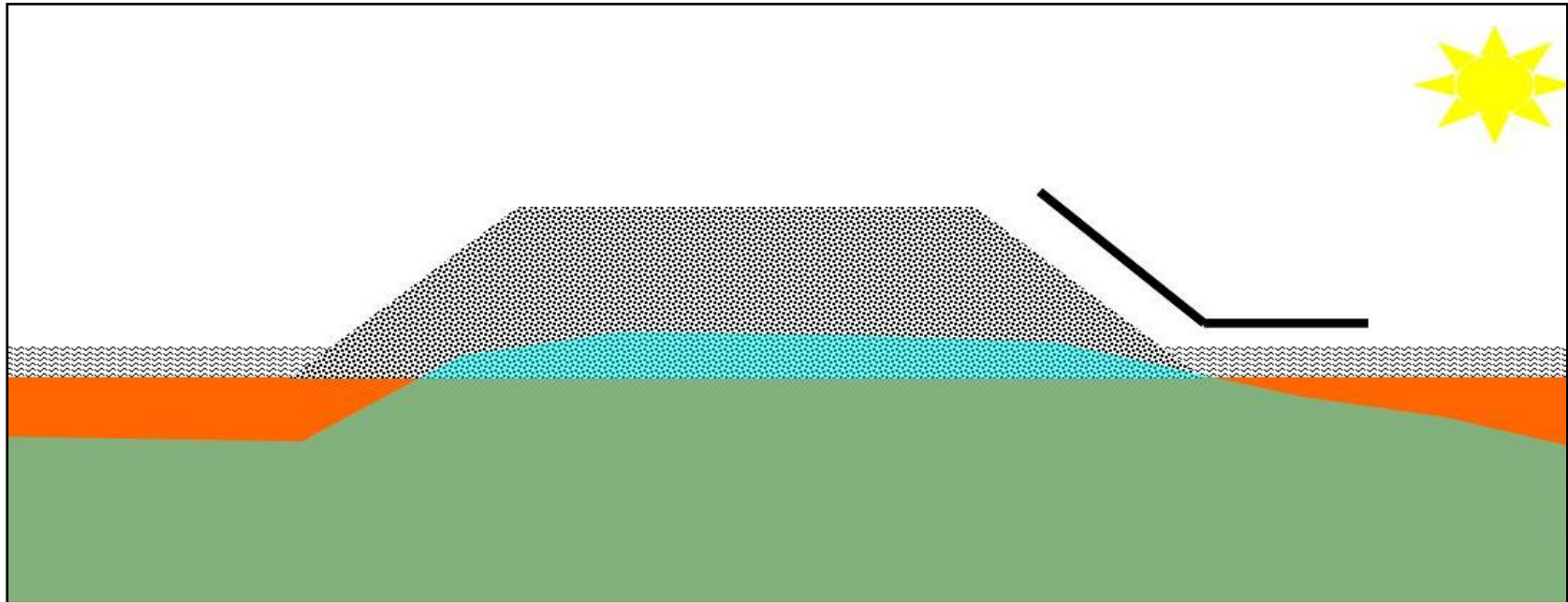


Outlet

Inlet

# Permafrost Test Site – Test Sections

## Sun/Snow Shed



- Technique used to protect the slopes of the embankment.
  - Winter – promote air circulation and protect embankment slopes from snow insulation.
  - Summer – Reflects solar radiation and drastically reduces the effect on exposed slopes

# Permafrost Test Site – Test Sections



# Permafrost Test Site – Test Sections

## High Albedo Surfacing

- Light-coloured aggregate BST reflects solar radiation resulting decreasing heat transfer into the embankment.



# Permafrost Test Site – Test Sections

## Snow Clearing

Clearing the snow from the side slopes during winter to minimize the insulating effect



## Grass Covered Embankment

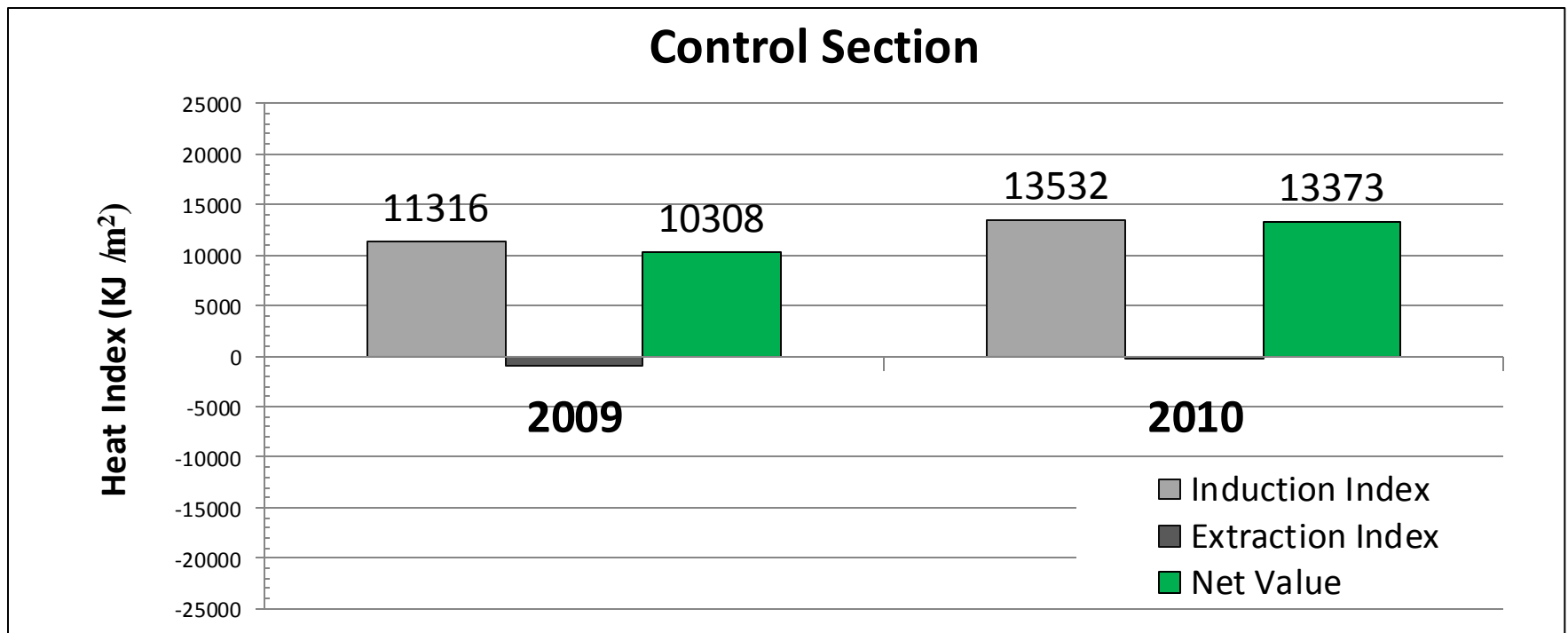
Determine the impact revegetation has on underlying permafrost



# Permafrost Test Site – Analysis

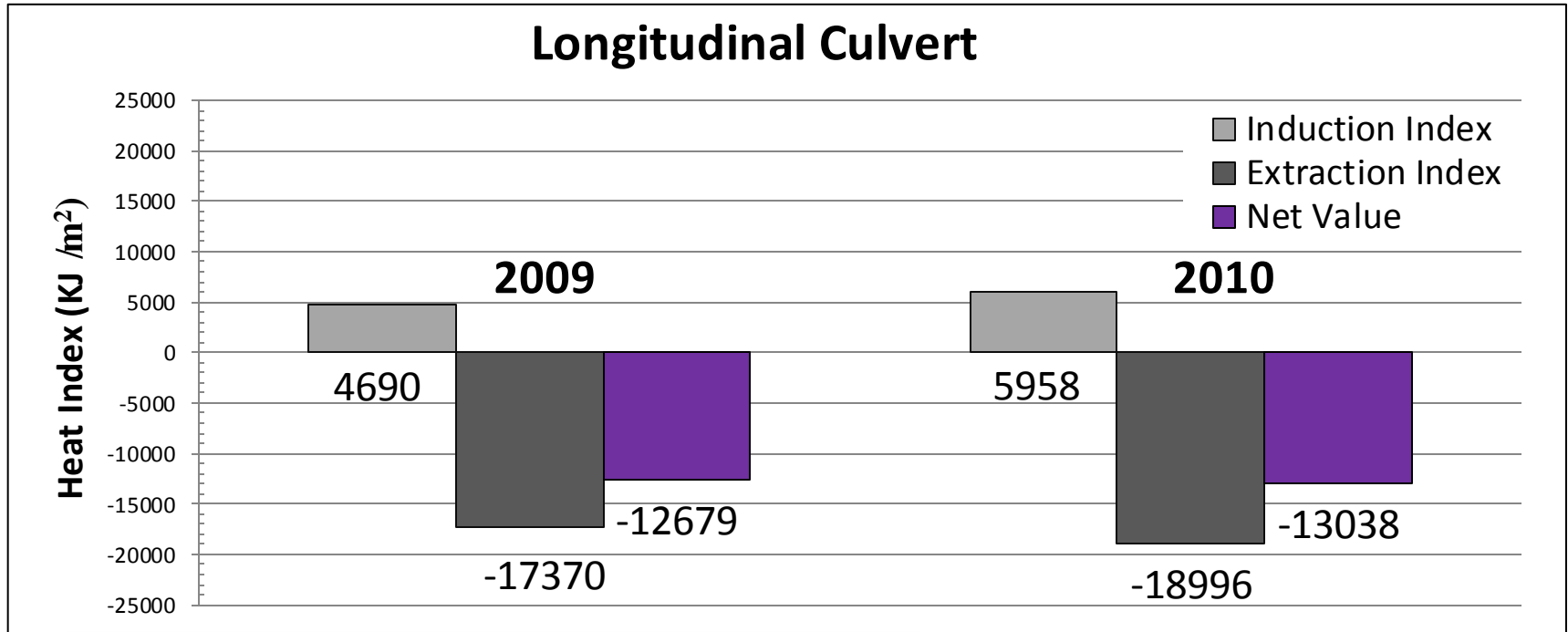
*Thermal Performance of the Permafrost Protection Techniques at Beaver Creek Experimental Road Site, Yukon, Canada*

Heat Index = heat induction index + heat extraction index

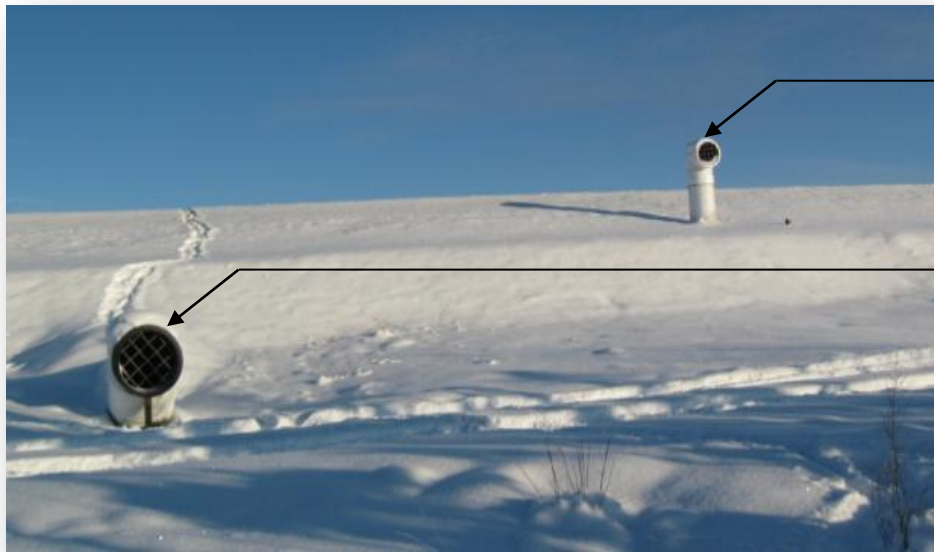


(M.Lapage 2011)

# Permafrost Test Site – Analysis



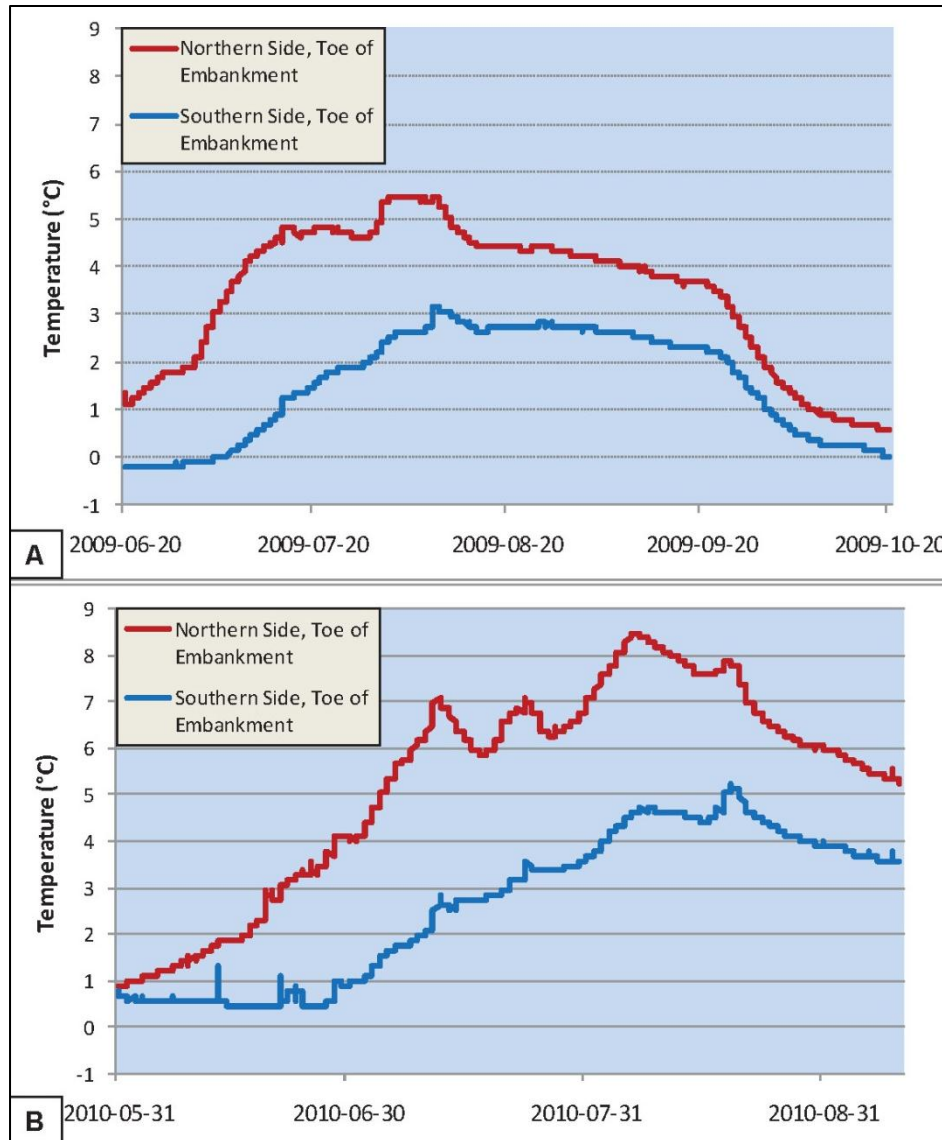
(M.Lapage 2011)



Outlet

Inlet

# Permafrost Test Site – Analysis



*Climate changes and the dynamics of permafrost degradation under transportation infrastructure*

- Findings

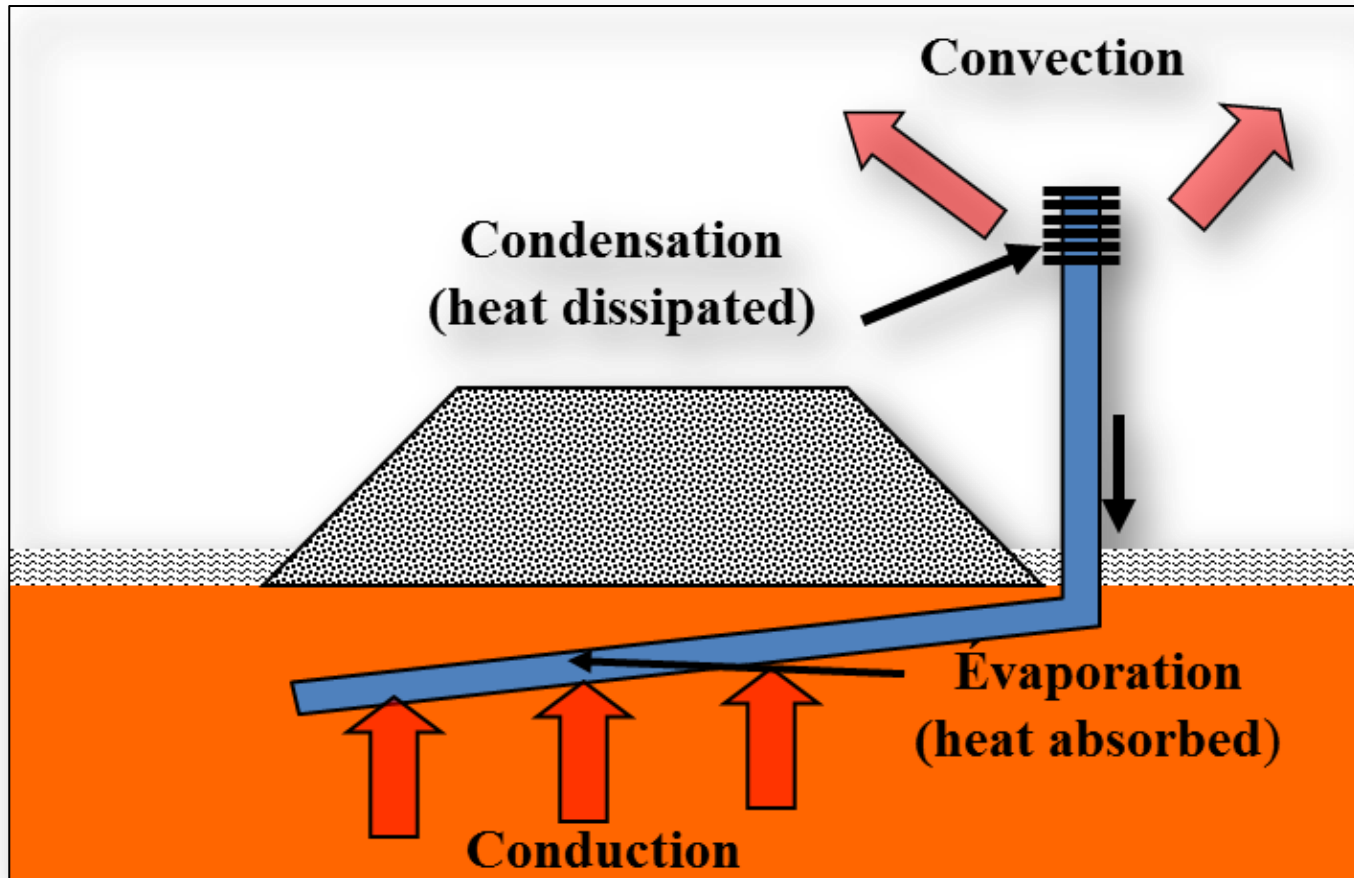
- Groundwater temperatures were cooler by 2°C to 4°C downgradient between June and October
- Road settlements were in the order of 30 cm per year

- Conclusion

- Heat transferred from the groundwater to the permafrost underlying the highway leads to permafrost degradation and highway deformation.

(Fortier 2011)

# Permafrost Stabilization - Thermosyphons



- passive heat exchange based on natural convection
- carbon dioxide or ammonia
- expensive

# Permafrost Stabilization - Thermosyphons



# Pigmented Asphalt Dawson City

Standard black, asphalt cement not an option due to warm, ice rich permafrost

Thermal modelling indicated that a light coloured pavement would have a similar impact on permafrost as the traditional gravel surface

Developed a pigmented, synthetic binder formula to match the colour of the roadway surfacing gravel used in Dawson City

Work completed October 2009



75 mm thick, bottom lift, standard black, asphalt cement



25 mm thick, top lift, pigmented asphalt

# Pigmented Asphalt Dawson City

## Monitoring

Instrumentation installation was completed in partnership with the Yukon Cold Climate Innovation Centre (YCCIC)

Installed to monitor the permafrost over time

Thermistors and DC resistivity arrays were installed



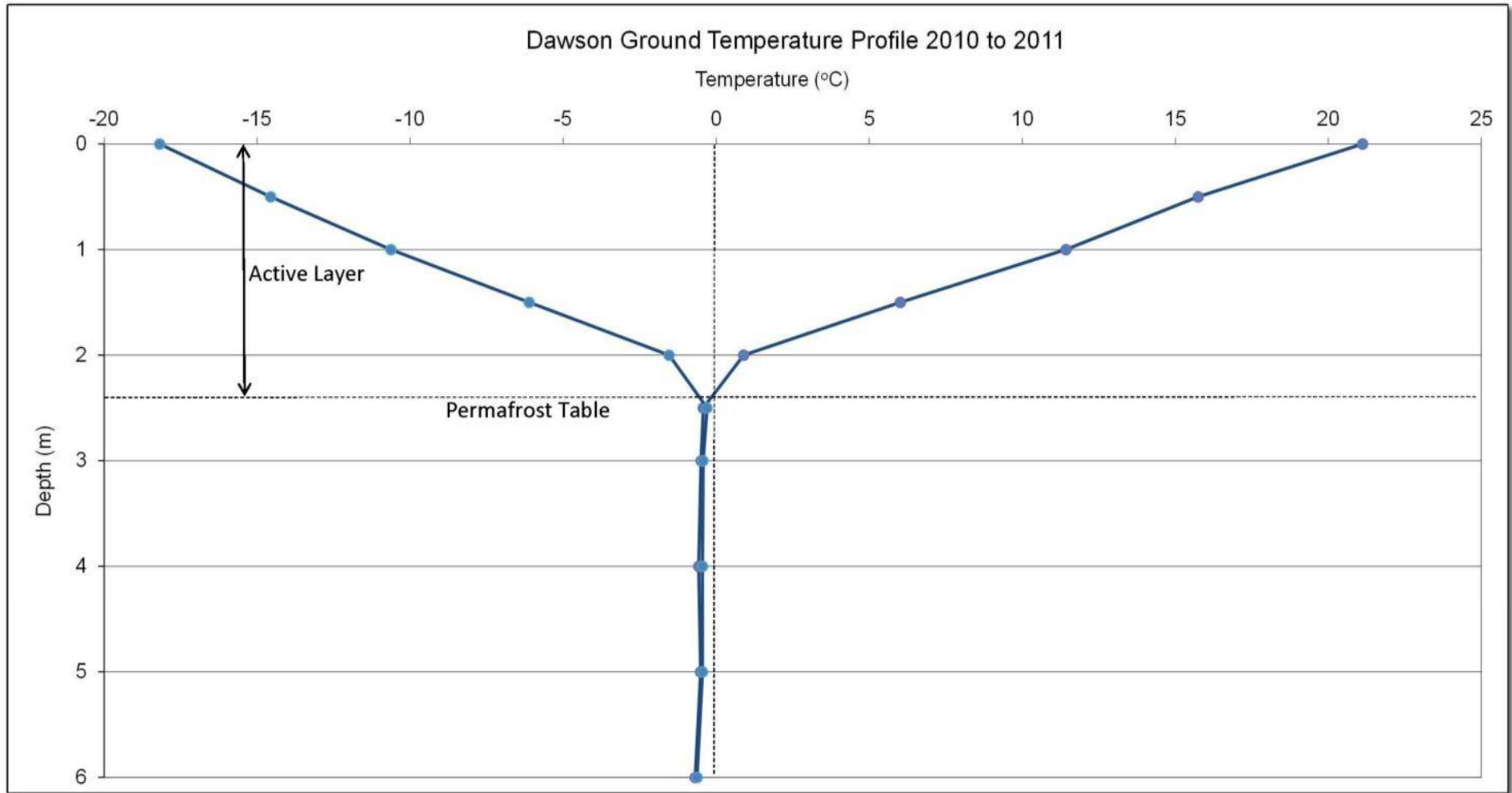
Thermistor Installation



DC Resistivity Array Installation

# Pigmented Asphalt Dawson City

## Monitoring



# Pigmented Asphalt Dawson City

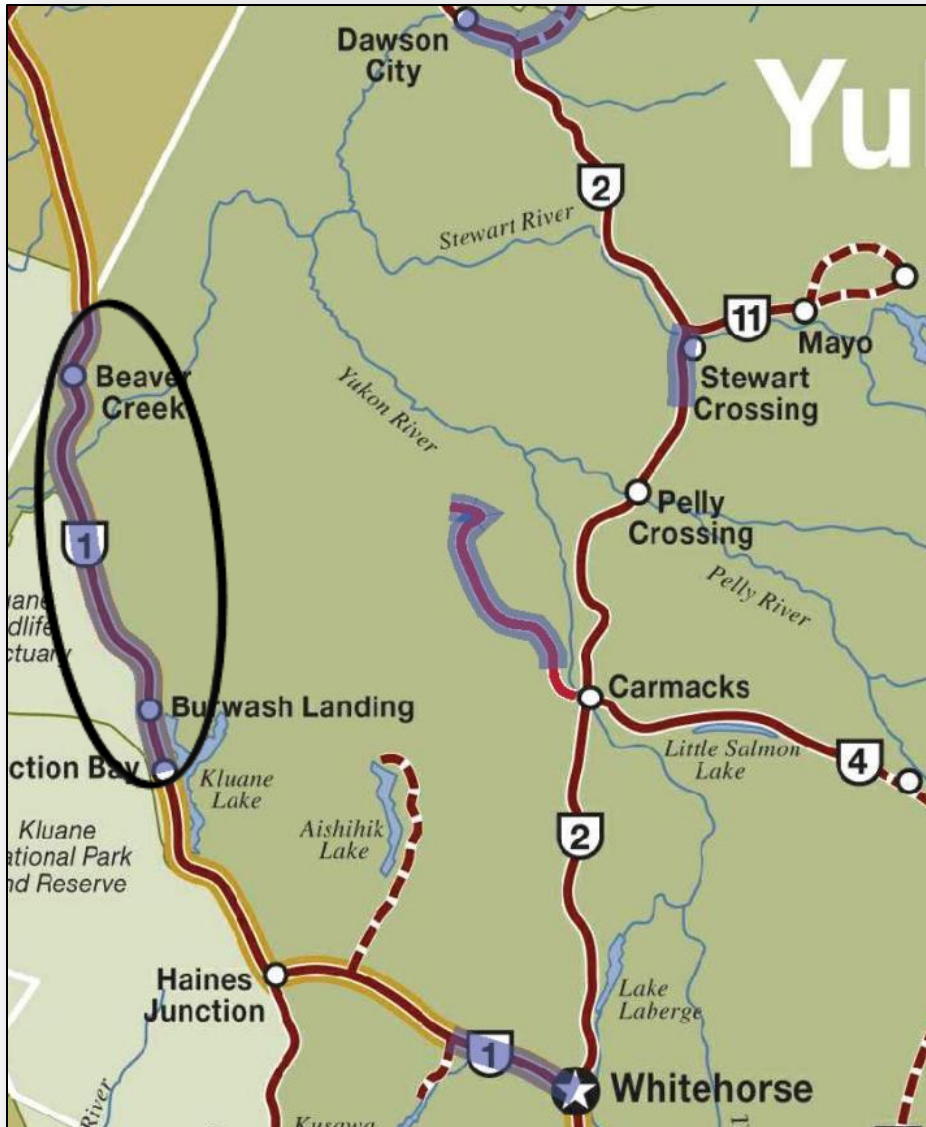
Front Street c. 1898



Front Street 2009

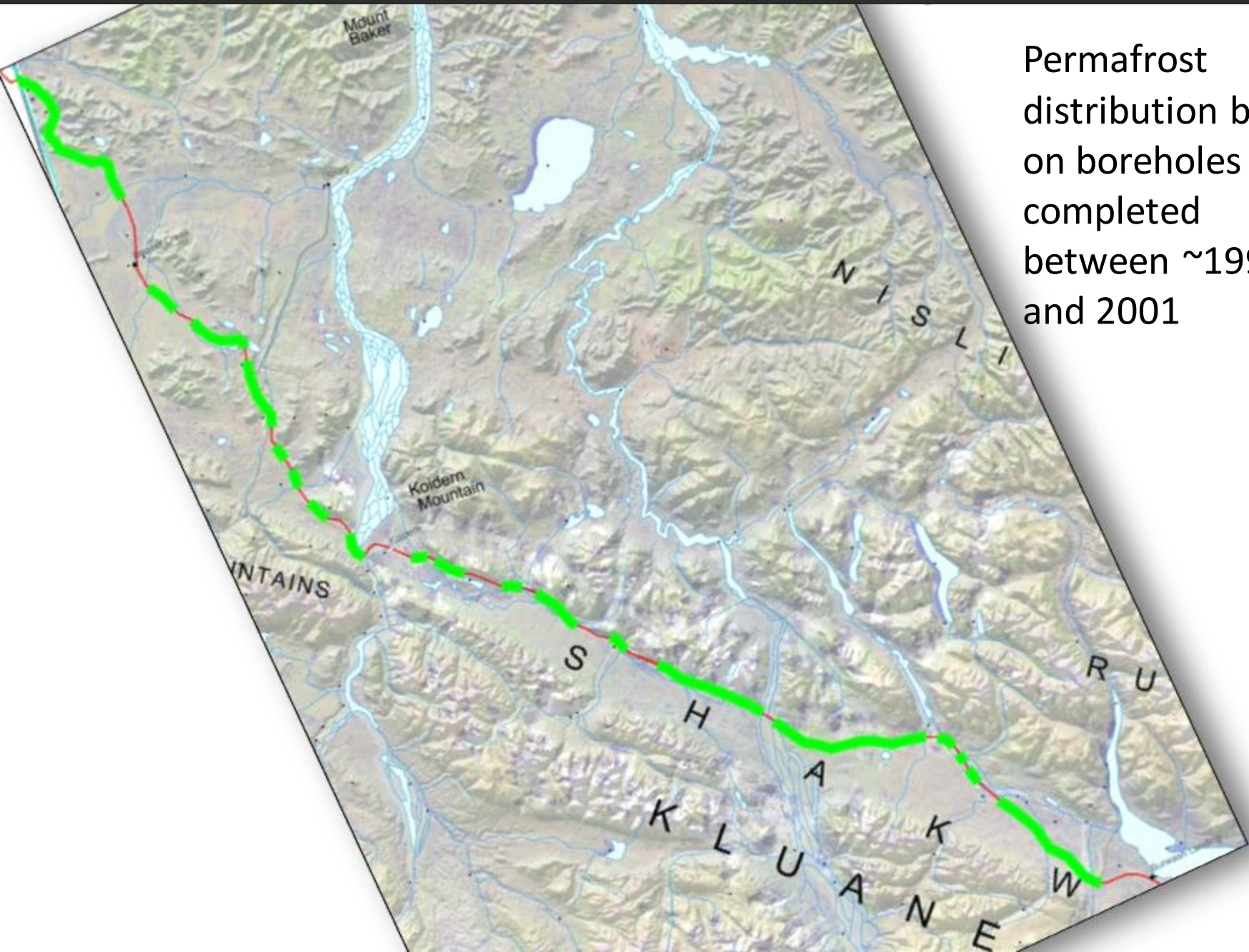


# Vulnerability to Climate Change



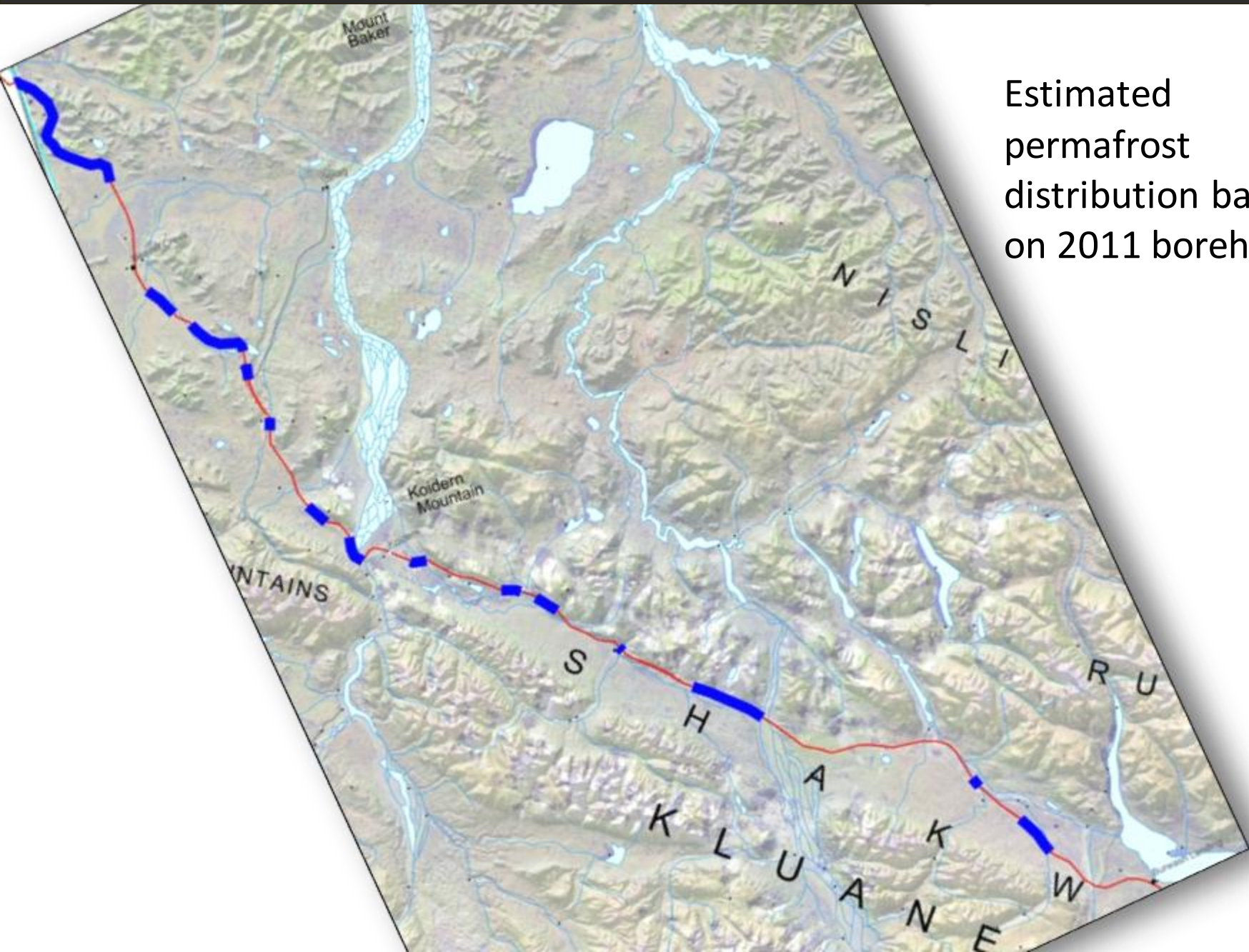
- Detailed characterization of permafrost
- Develop permafrost thaw vulnerability map
- Work includes
  - Review data
  - Geophysical study
  - Drilling investigations
  - Install instrumentation
- Partnered with YRC
- Significant funding from AANDC

# Vulnerability to Climate Change



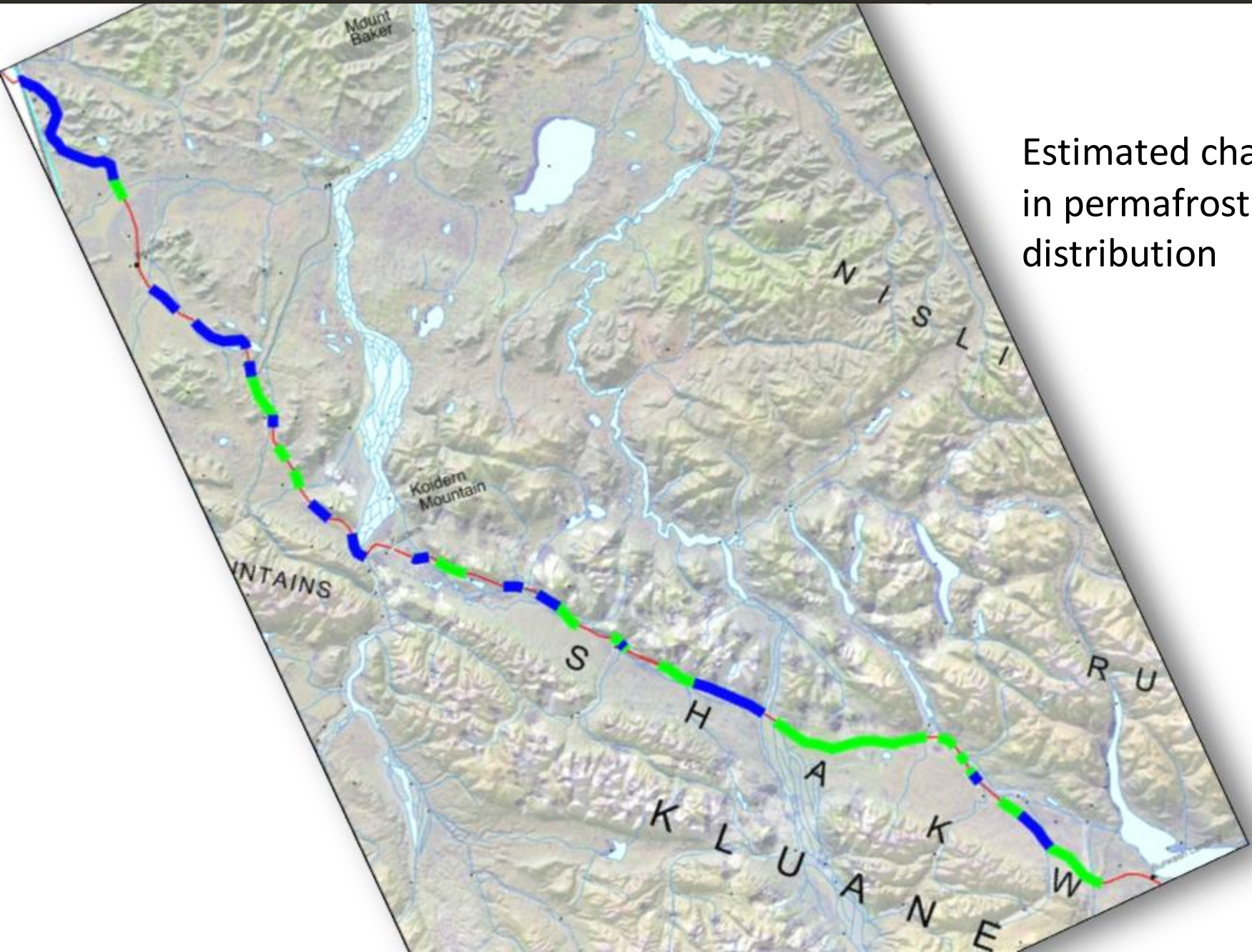
Permafrost  
distribution based  
on boreholes  
completed  
between ~1990  
and 2001

# Vulnerability to Climate Change



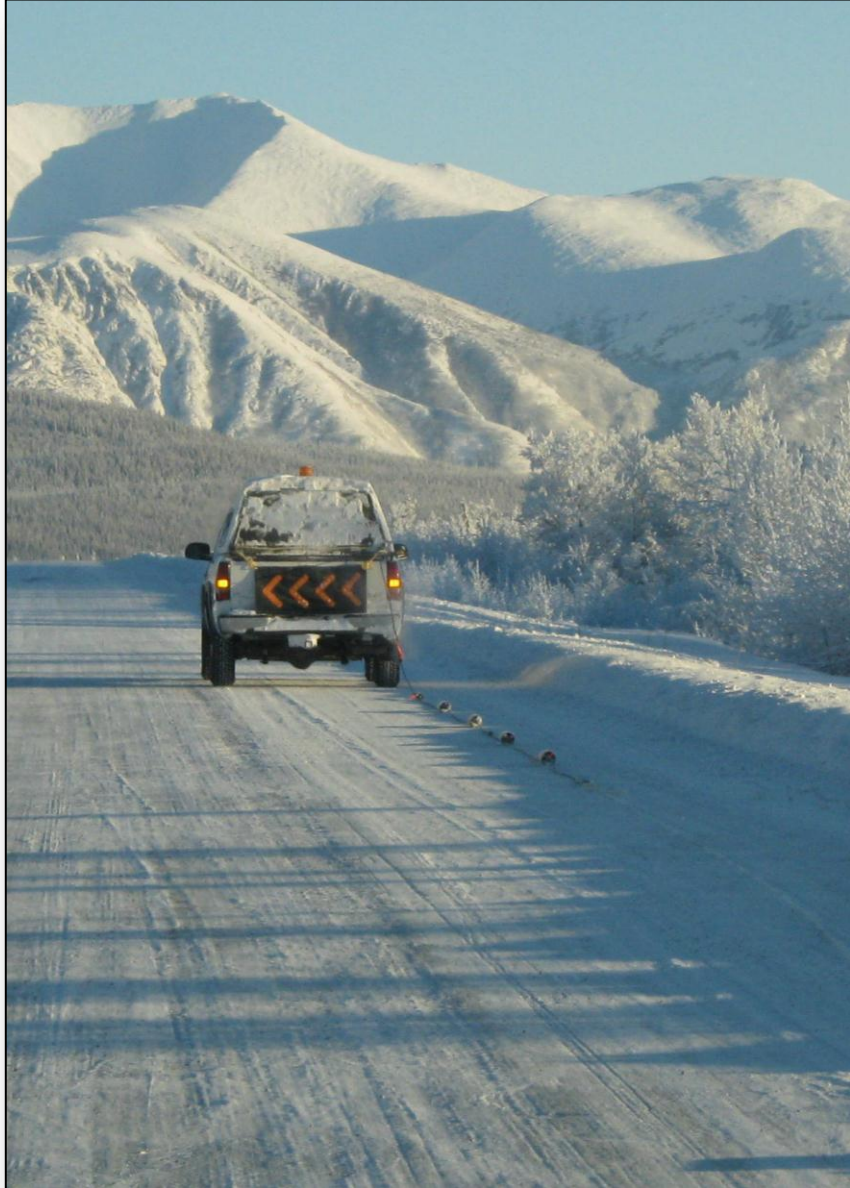
Estimated  
permafrost  
distribution based  
on 2011 boreholes

# Vulnerability to Climate Change



Estimated change  
in permafrost  
distribution

# Vulnerability to Climate Change



- Develop **site specific** strategies for adapting to climate change
- Select regions where permafrost stabilization measures are/are not applicable
- Identify future priority maintenance areas
- Monitor permafrost changes

# Canada – China International Symposium

## 中加寒区道路运营技术国际研讨会

Canada-China International Symposium on Road Operation Technology in Cold Region



支持单位：交通运输部科技司

Supporters: Science and Technology Department, Ministry of Transport, China

主 办：吉林省交通运输厅

Organizer: Department of Transport, Jilin Province

加拿大交通部运输、技术与创新司

Transportation, Technology and Innovation Directorate, Transport Canada

承 办：吉林省交通科学研究所

Undertaker: Jilin Provincial Transport Scientific Research Institute

中国·吉林 2012年3月  
Jilin·China March 2012

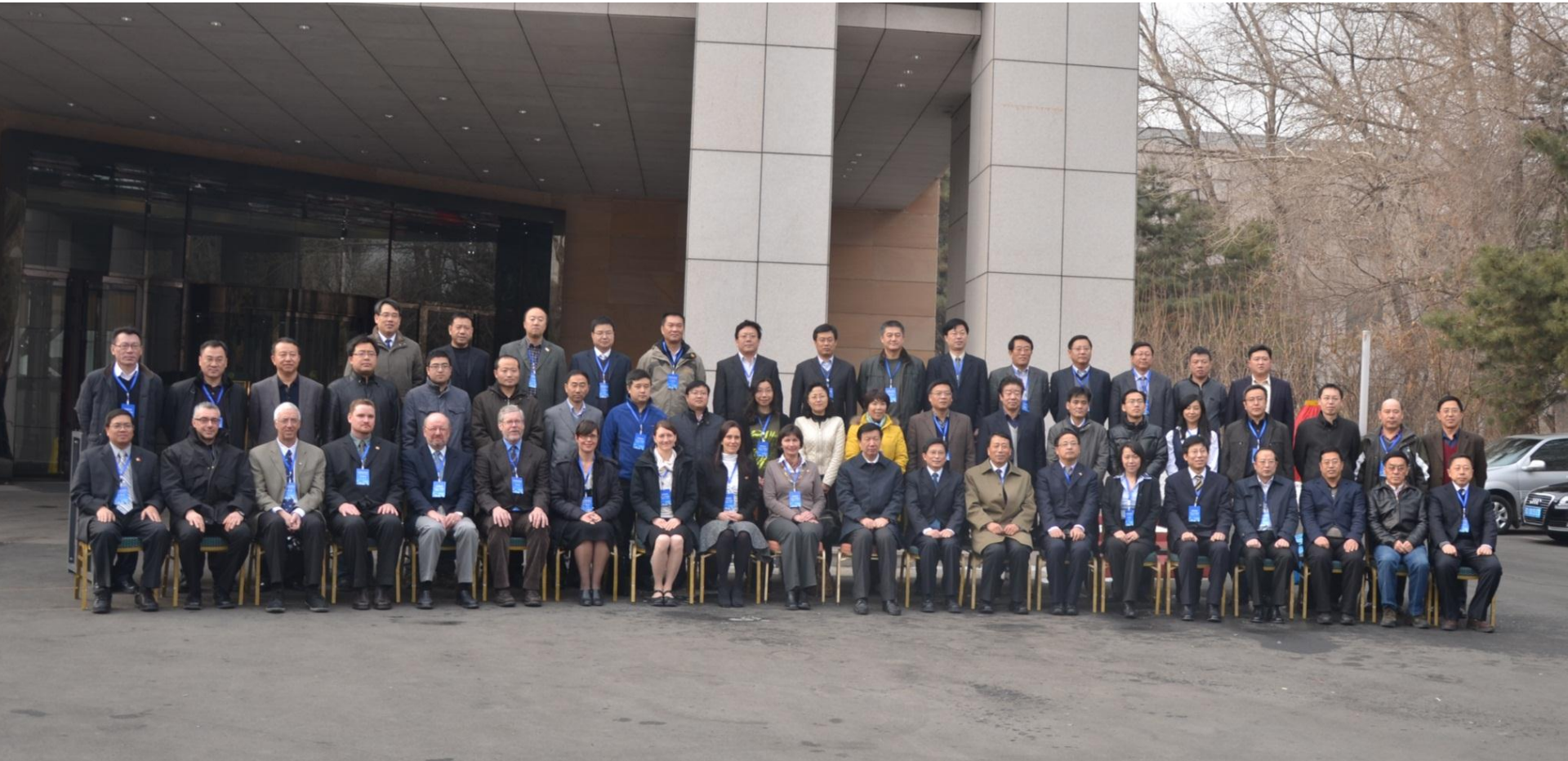
# Canada – China International Symposium

## Canadian Participants

- Jutta Paczulla
- Janice Festa
- Jayleen Robertson
- Greg Cousineau
- Wally Hiding
- Paul Murchison
- Anne-Marie LeBlanc
- Guy Doré
- Daniel Fortier
- Marolo Alfaro



# Canada – China International Symposium



# Canada – China International Symposium





# Chinese Permafrost Research

- Highway Construction, Maintenance and Monitoring Technical Solutions in Permafrost Regions
  - Permafrost monitoring system suffers from out-dated facilities, poor and irregular observation methods.
  - Expanding research and are in the process of moving permafrost research to a national level



# Chinese Permafrost Research



- Qing Hai Research and Observation base, Key Laboratory of Highway Construction & Maintenance Technology in Permafrost Regions (proposed)

# Chinese Permafrost Research

- Current permafrost test sites include sites testing and measuring
  - High albedo surfaces
  - Heat absorption on embankment slopes
  - Air convection embankments with and without ventilation (testing various particle sizes)
  - Embankment creep and settlement
  - Pile foundations in permafrost (soil temperature, strain at points on the pile and whole pile, and pile displacements)
  - Impacts of freeze thaw and highway maintenance on the physical properties of asphalt insitu
  - Monitoring permafrost and seasonal frost in rock at tunnel locations
- Also proposing to improve permafrost baseline data by constructing more sites to monitor permafrost in the region

# Construction/Maintenance in Permafrost Terrain

- Highway and rail infrastructure in permafrost regions has experienced:
  - Embankment settlements
  - Embankment cracking
  - Water ponding and settlement at the toe of the embankment
  - Deformation at bridge piers
  - “Risk water and heat environment”
- Highway and rail construction has included many measures to limit or prevent permafrost degradation

# Construction/Maintenance in Permafrost Terrain



# Construction/Maintenance in Permafrost Terrain



# Construction/Maintenance in Permafrost Terrain



# Construction/Maintenance in Permafrost Terrain



# Mitigation Techniques in Permafrost Terrain



# Mitigation Techniques in Permafrost Terrain



# Mitigation Techniques in Permafrost Terrain



# Mitigation Techniques in Permafrost Terrain



# Construction in Permafrost Terrain

## Mega Projects in High Elevation Permafrost Terrain

- Highway Construction in Permafrost Regions
  - Qinghai-Tibetan Highway >750 km of permafrost
  - Qinghai-Kangding Highway >200 km permafrost
  - Xinjiang-Tibetan Highway 380 km of permafrost
  - Highways have tunnels with icing and concrete issues due to permafrost and seasonal frost

# Qinghai-Kangding Highway

- Total length 635 km
  - 227 km of permafrost terrain
  - Site visit included travelling approximately 450 km of the highway
  - Observed approximately 300 km of continuous construction
- Construction of a 4 lane expressway from a low standard road:
  - 25 million m<sup>3</sup> of dirt
  - 25 km of medium to long bridges (77 bridges with a maximum length of 1.2 km)
  - 1.2 km of short bridges (73 bridges)
  - 1,152 culverts
  - 31 km of tunnels (9 tunnels)
- Highway construction techniques include permafrost stabilization measures
- High elevation with many sections of the highway over 4,500 m (average elevation on the plateau is 4,100 m)

# Qinghai-Kangding Highway

**CHINA**

0 km 200 400 600 km

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- National Capital (11,510,000 in 2000)
- over 10,000,000
- over 6,000,000
- over 2,500,000
- over 1,000,000
- other main city
- other city
- Capital of autonomous region



# Qinghai-Kangding Highway



# Qinghai-Kangding Highway (ACE)



# Qinghai-Kangding Highway (ACE)



# Qinghai-Kangding Highway – Test Sites



# Qinghai-Kangding Highway – Test Sites



# Qinghai-Kangding Highway – Test Sites

## Permafrost and Weather Monitoring Station



# Qinghai-Kangding Highway – Test Sites



# Qinghai-Kangding Highway – Test Sites



# Qinghai-Kangding Highway – Tunnels



# Qinghai-Kangding Highway – Tunnels



# Qinghai-Kangding Highway – Tunnels



# Qinghai-Kangding Highway – Tunnels



# Qinghai-Kangding Highway – Tunnels



# Qinghai-Kangding Highway – Bridges



# Qinghai-Kangding Highway – Bridges



# Qinghai-Kangding Highway



# Thank You



[Paul.Murchison@gov.yk.ca](mailto:Paul.Murchison@gov.yk.ca)

867.633.7977



# References

- Environment Canada. (2010), Climate data Beaver Creek , Yukon, National Data Base on Climatic Data, Available online <http://climate.weatheroffice.gc.ca>.
- Fortier, D. (2011), *Climate changes and dynamics of permafrost degradation under transportation infrastructure, Volume 1: Groundwater flow and permafrost degradation*. Cold Regions Geomorphology and Geotechnical Laboratory, 65
- M-Lapage, J. (2011), *Thermal Performance of the Permafrost Protection Techniques at Beaver Creek Experimental Road Site, Yukon, Canada*. Personal correspondence with author.
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