Permafrost Hazard Mapping for Yukon Highways

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Highways and Public Works
Voirie et Travaux publics

- **Presentation by**

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Introduction - Yukon

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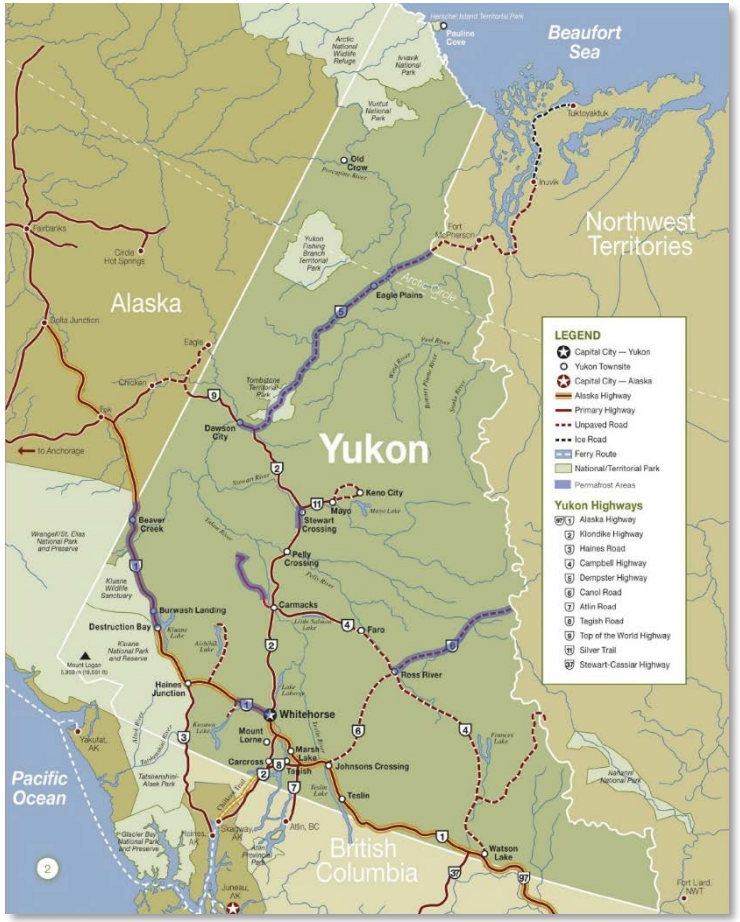
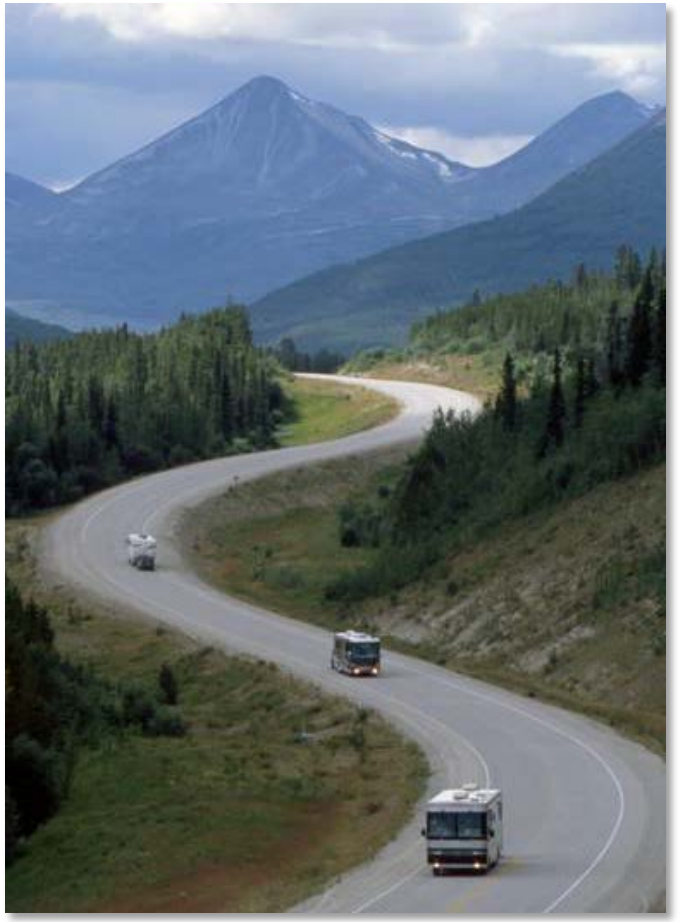
- Area 483,450 km²
- Population ~38,000
- 17 communities
- 4,808 km of maintained highway
  - Asphalt pavement 310 km;
  - BST 1,930 km;
  - Gravel 2,568 km; and
  - 132 bridges.
- ~25% impacted by permafrost degradation





Introduction - Yukon

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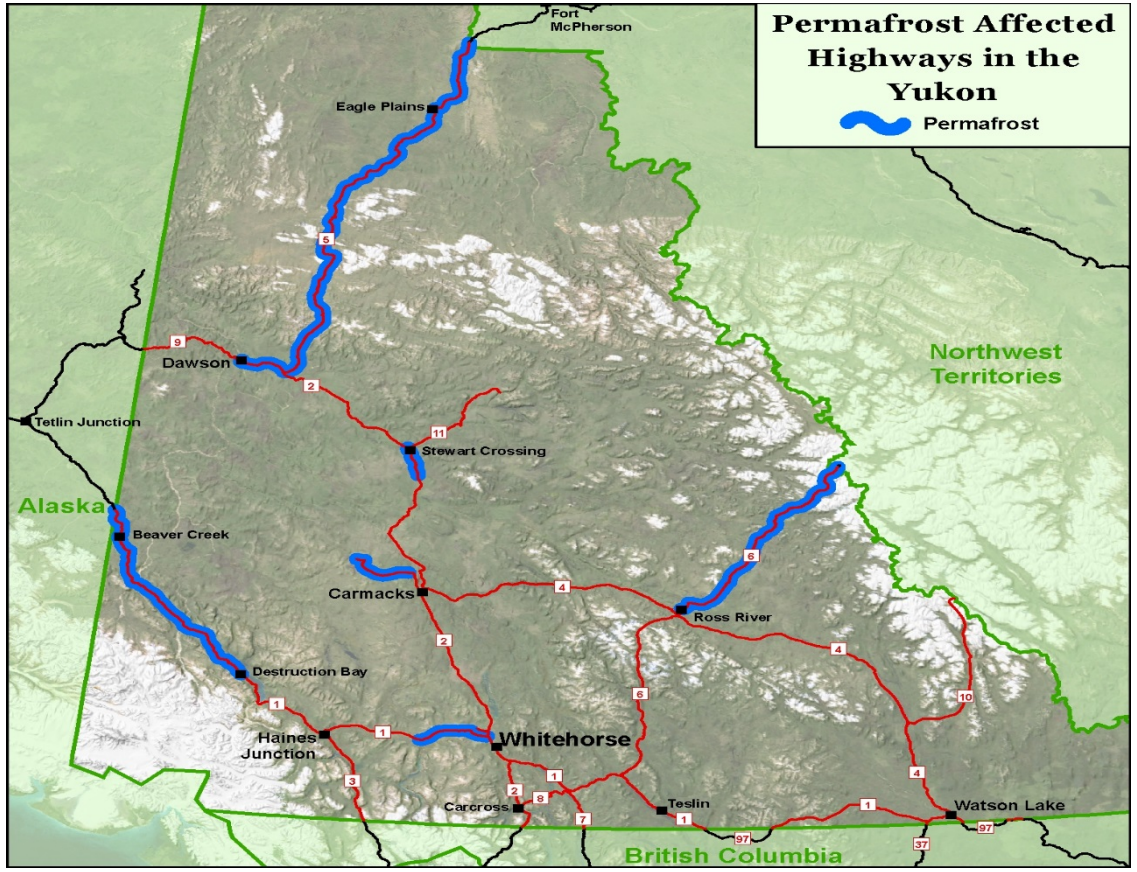

Systematic Approach to mitigate the effects of permafrost thaw

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- Generic Maps and visual observation
- Detailed permafrost maps
- Vulnerability Maps
- Site Selection for mitigation techniques
- Thermal analysis and modelling of potential mitigation techniques
- Selection and detailed design of mitigation technique
- Supply and installation of mitigation technique
- Monitoring

Permafrost General Maps

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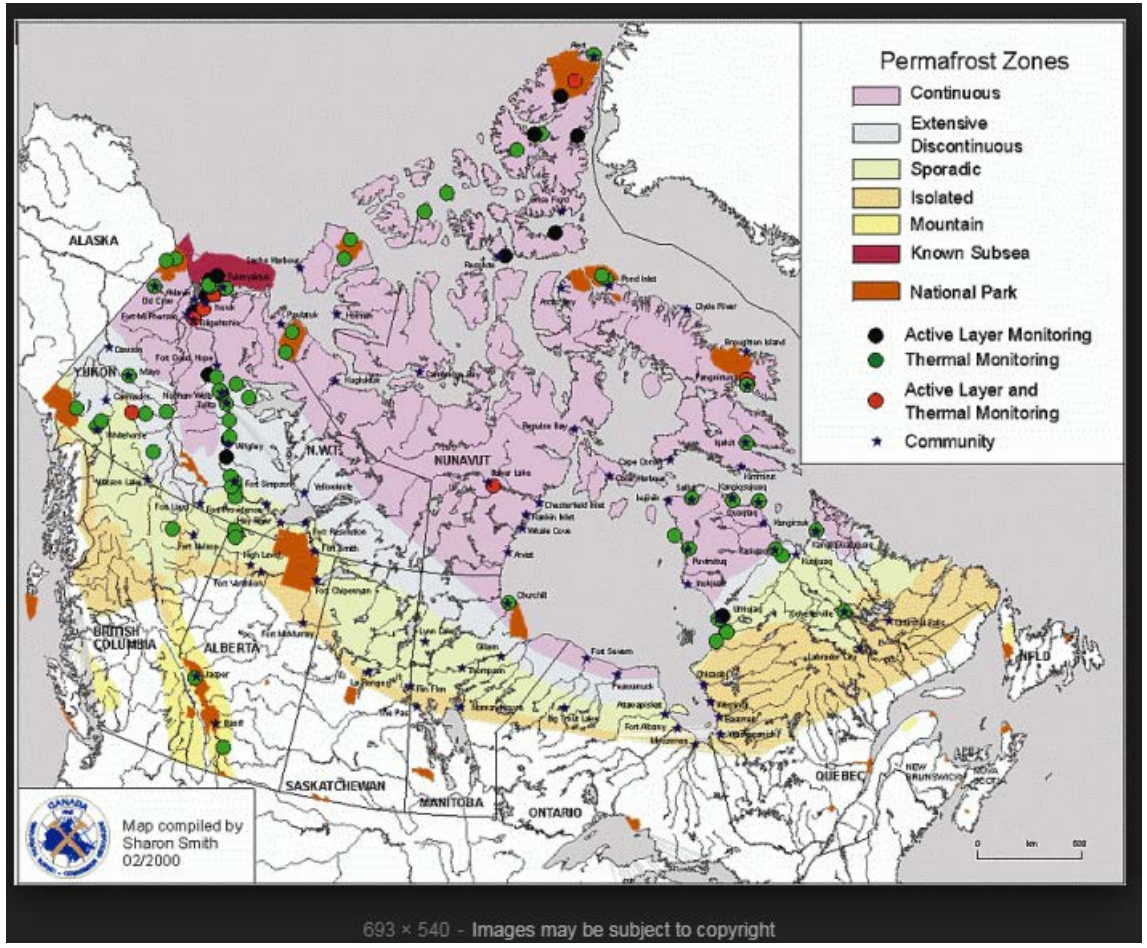
- Generic Maps are good to have better understanding of the permafrost in Canada but are they good for construction of new roads or rehabilitation of existing roads?
- Probably need more detailed maps for alignment of new roads and even rehabilitation of existing roads, like vulnerability maps



Important Factors in Road Design

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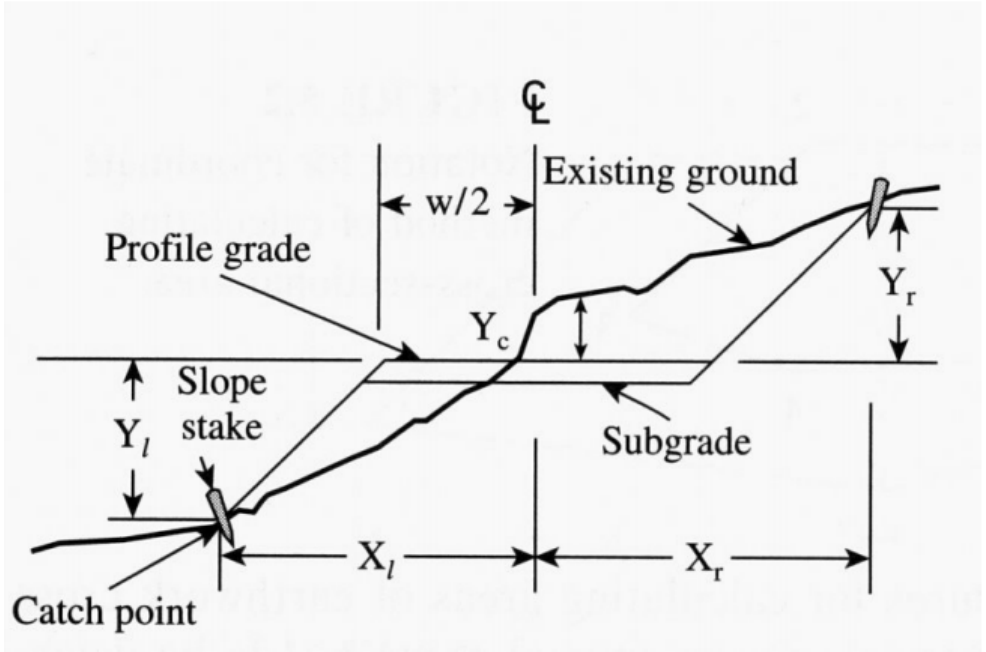
Non Permafrost Areas

- Short distance with detailed Geotechnical information
- Minimum river and creek crossings
- Avoiding significant geo hazards
- Balanced cut and fill

Permafrost affected Areas

- All above factors but no cut
- Avoid ice rich/massive ice bodies
- Alignment in coarse grained soil vs fine grained soil, need extensive geotechnical information

Earthwork Cross-Sections



Vulnerability

https://yukoncollege.yk.ca/downloads/permafrost_report.pdf

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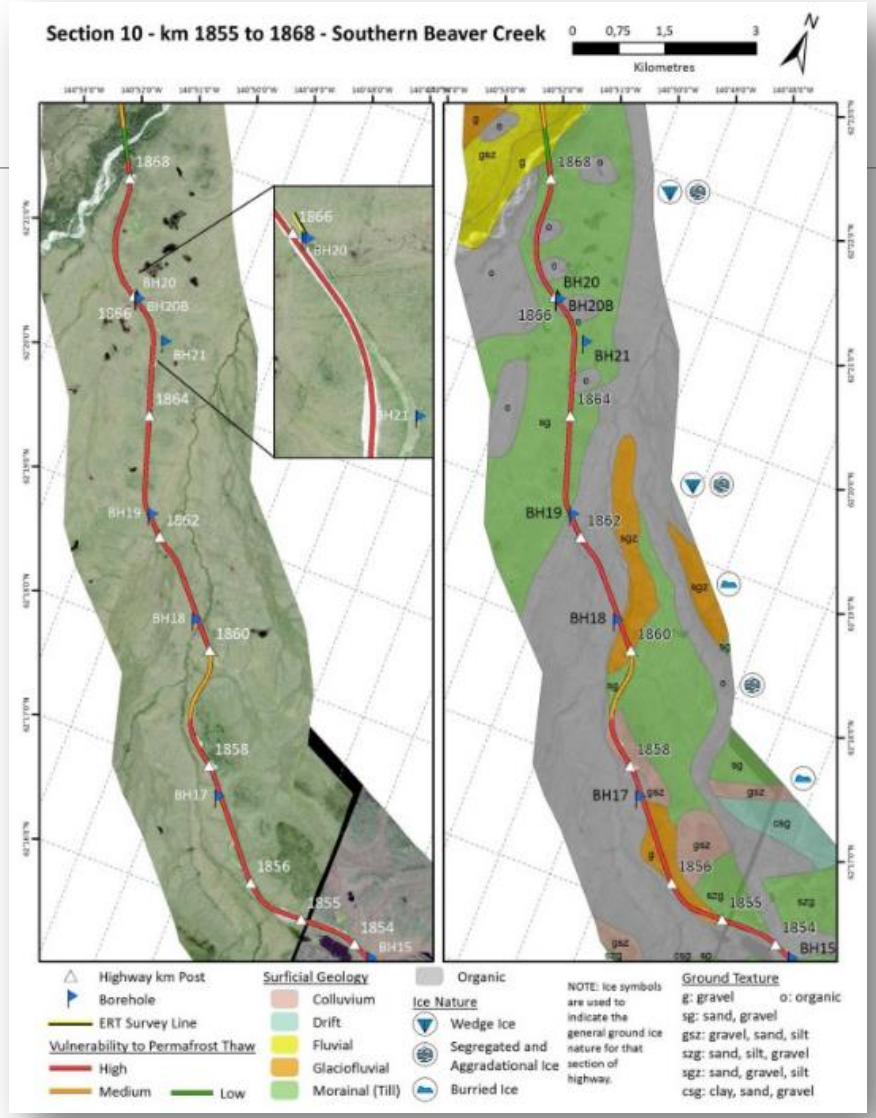

- **Vulnerability of North Alaska Highway km 1700 to km 1902**
- **3 years project with NCE Yukon College, 2012-2015, funded by INAC and Climate Change Secretariat Government of Yukon**

43% highly vulnerable:

- **Intense Subsidence**
- **Long duration**

38% moderately vulnerable:

- **Short Duration**
- **Moderate subsidence**

19% low vulnerability

- **No permafrost**
- **No ground movement**

Vulnerability https://yukoncollege.yk.ca/downloads/permafrost_report.pdf

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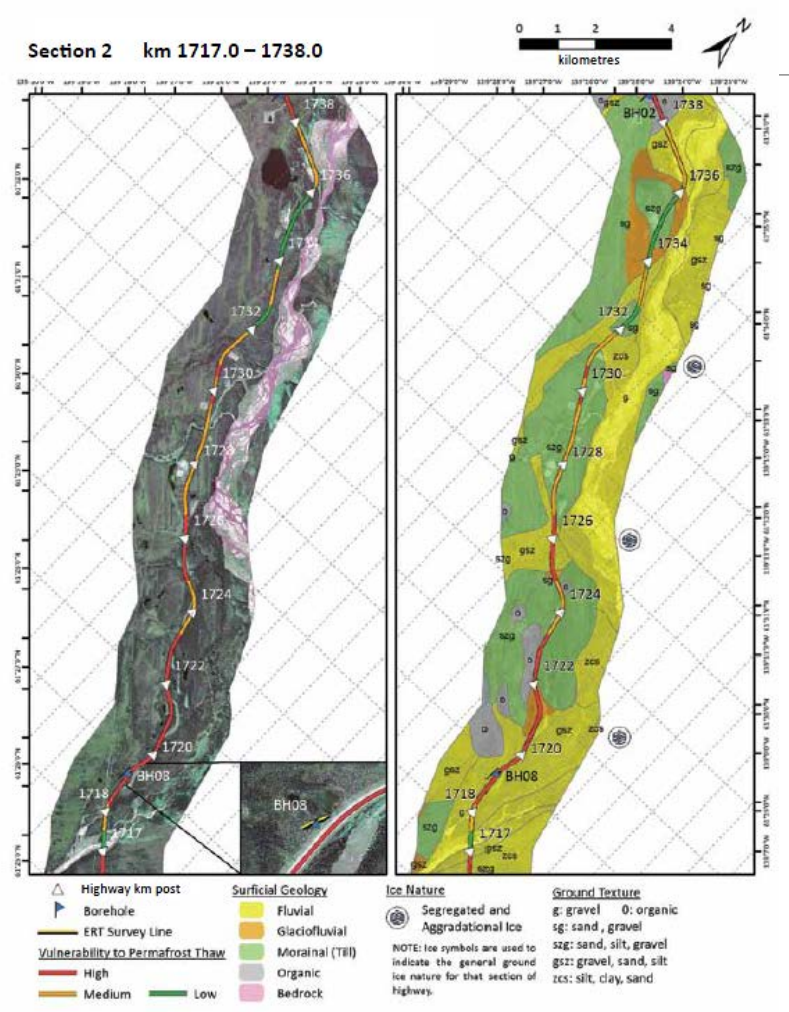

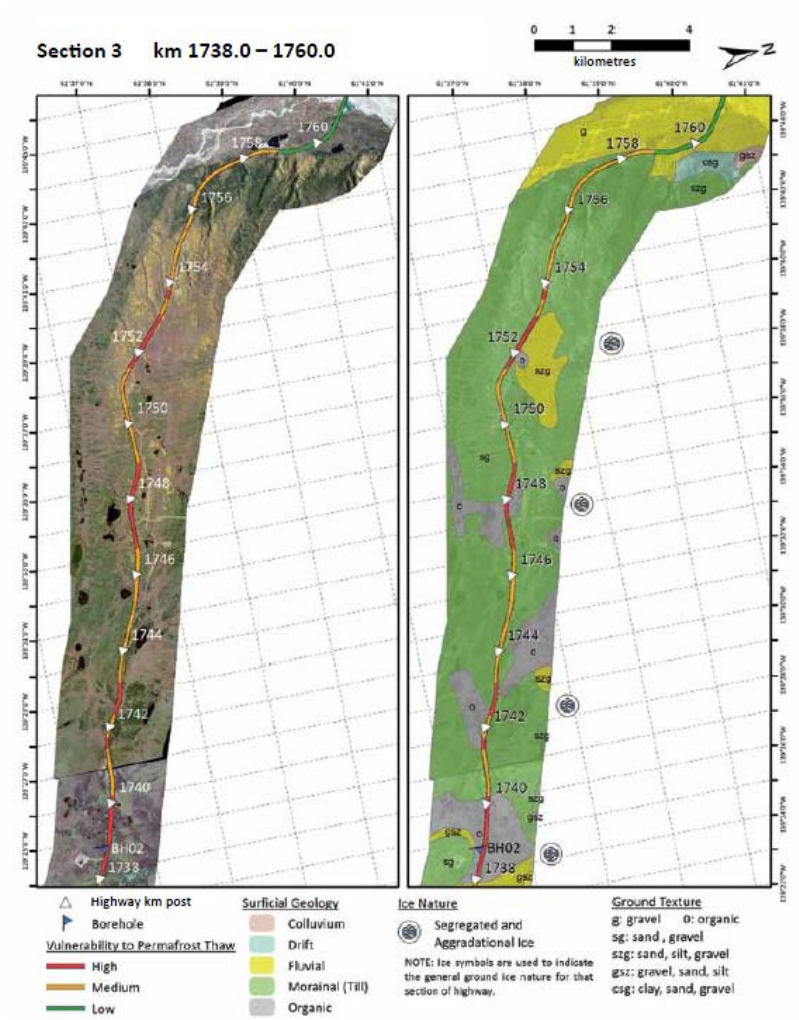

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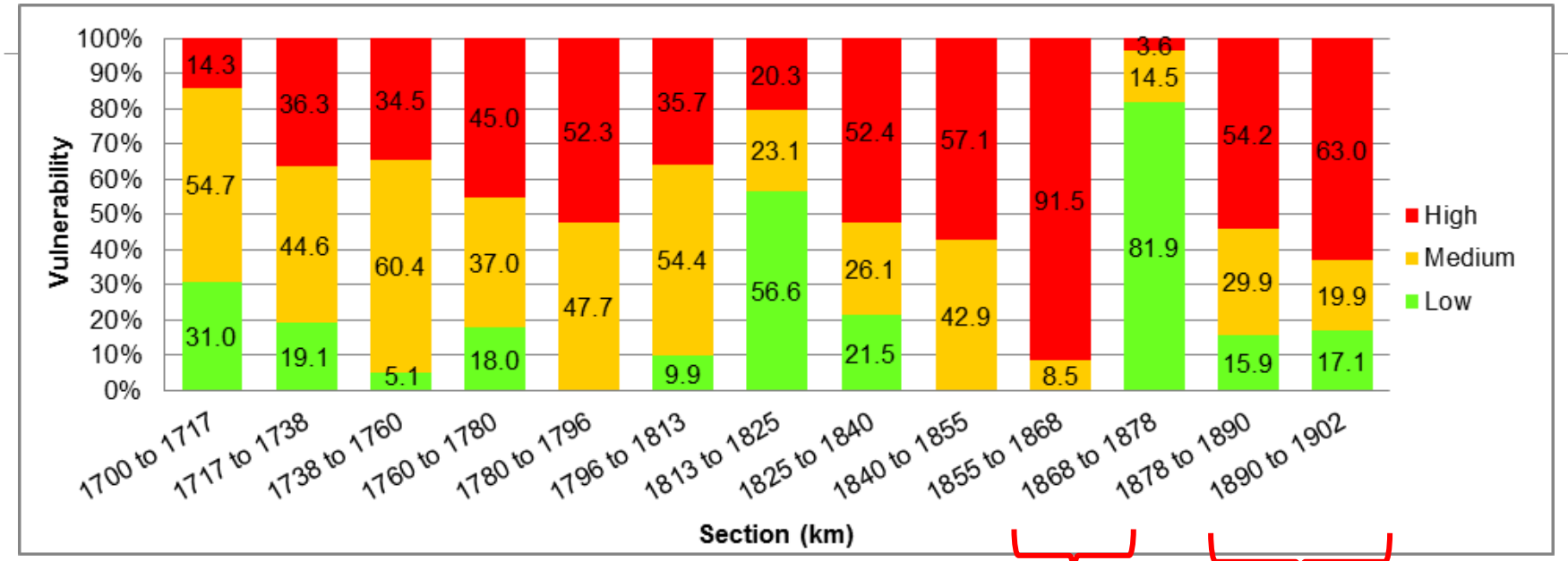

Vulnerability

- ❑ High
- ❑ Moderate
- ❑ Low

Glaciofluvial/massive ice

Unglaciated / wedge ice

Techniques for vulnerability mapping

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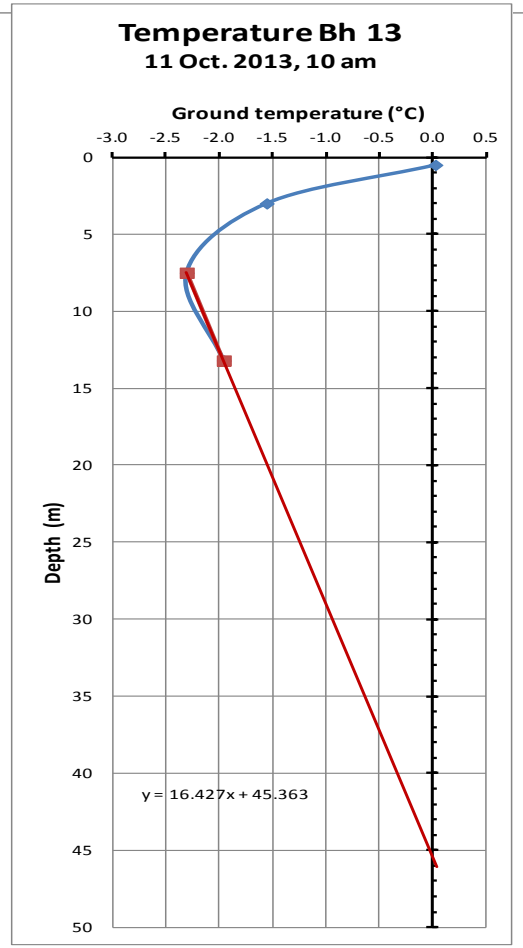
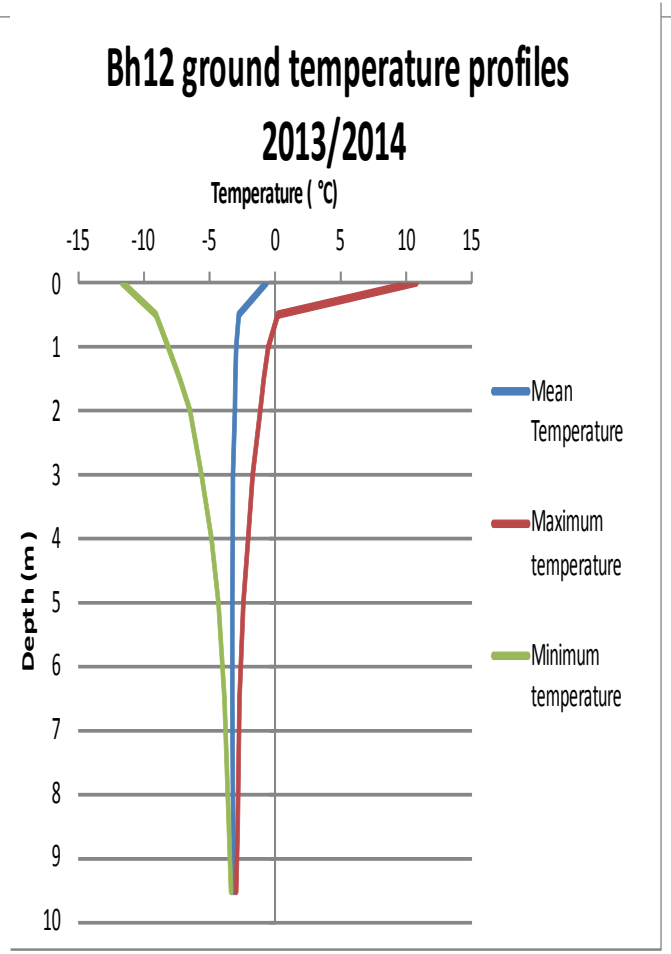
- Geotechnical Investigation (borehole logs), permafrost sample analysis
- Ground Temperature and Climate Monitoring
- Geophysical Techniques (ERT etc)
- Lidar and Imagery data
- Geological Maps





Techniques for vulnerability mapping

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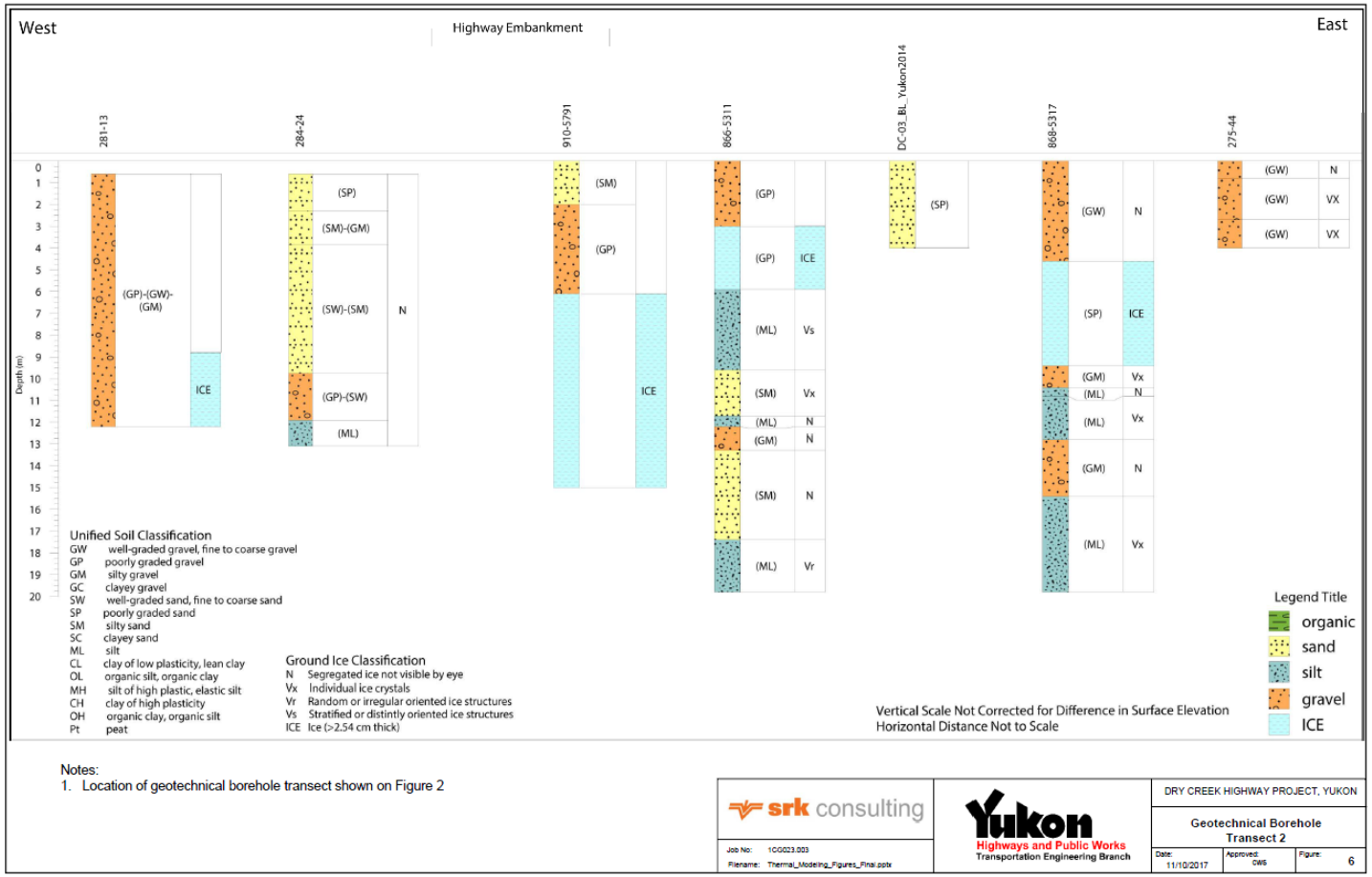

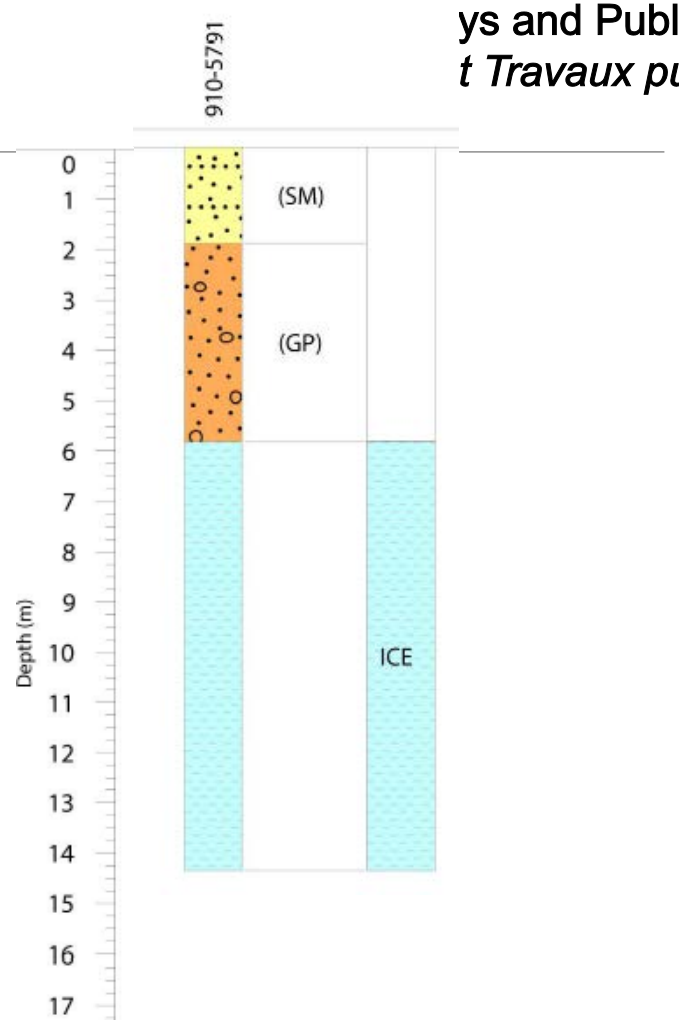

Techniques for vulnerability mapping

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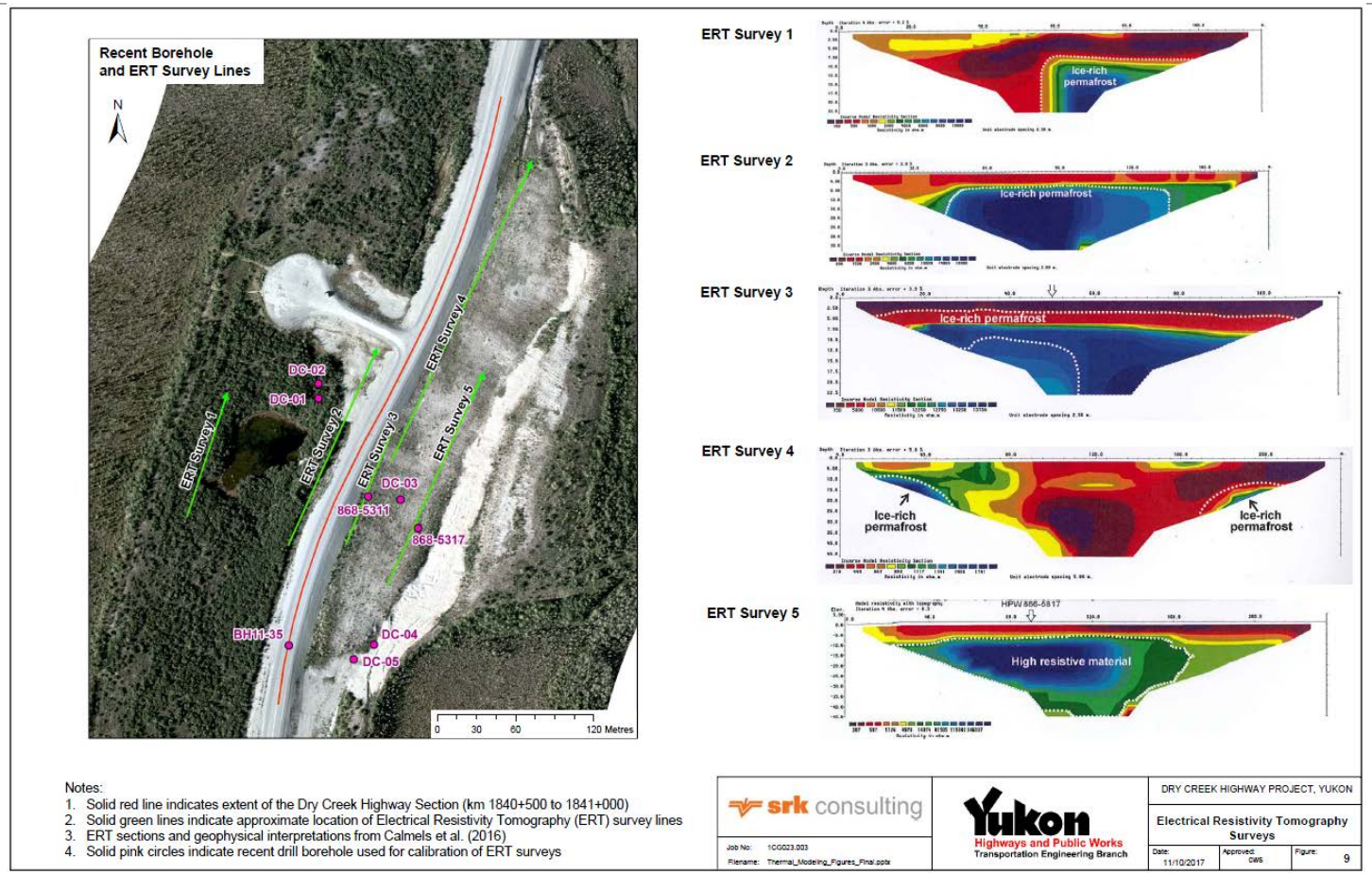

Identification of Sites, Potentially Responsive to Mitigation Techniques, 4th year Extensions

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Description of Site Factors

- Solar Radiation
- Wind
- Precipitation
- Snow Cover
- Embankment Slope and Orientation
- Vegetation Cover
- Drainage
- Soil Types
- Ground Ice Conditions
- Ground Temperature

Mitigation Techniques

- Air Convection Embankment (ACE)
- Heat Drains
- High Albedo Surface
- Insulation
- Thermosyphons

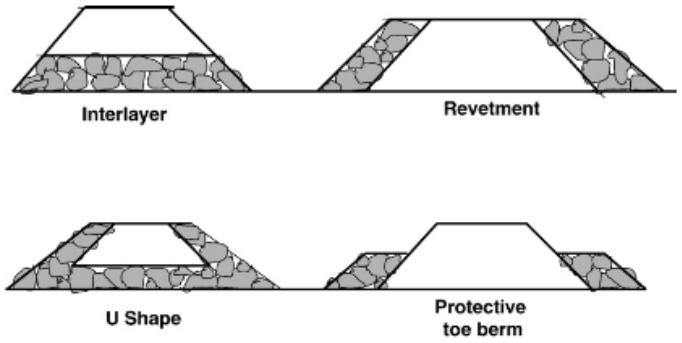

Figure 3.3. Various ACE embankment configurations

Identification of Sites, Potentially Responsive to Mitigation Techniques, 4th year Extensions

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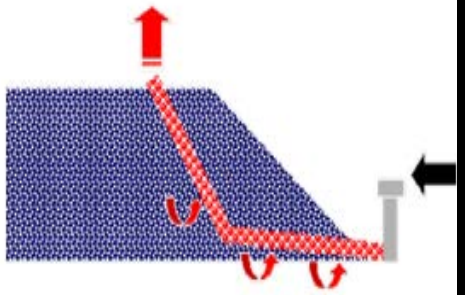
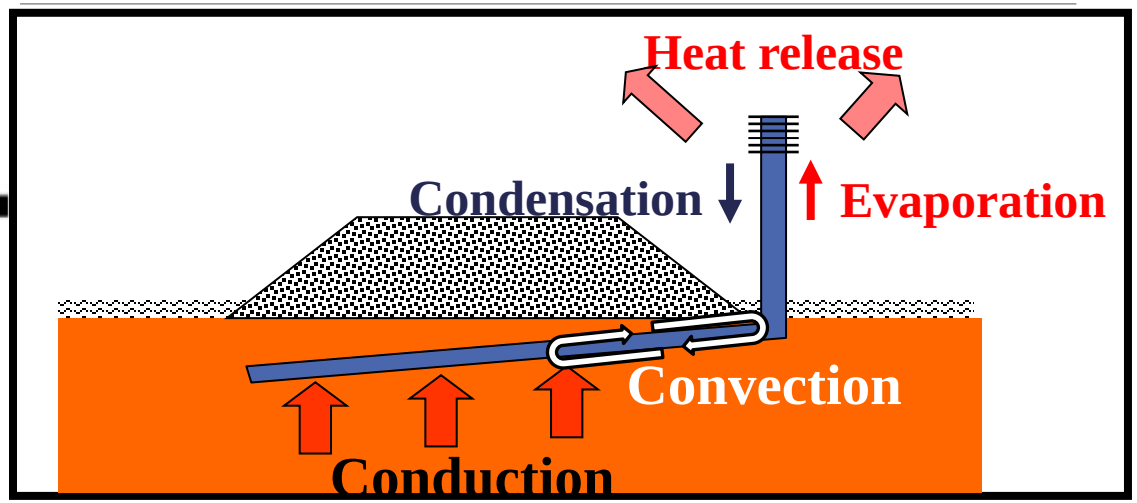
Heat Drains





Thermosyphons

- Extract heat during the winter
  - ➢ Expensive and localised

High Albido Surface

Identification of Sites, Potentially Responsive to Mitigation Techniques, 4th year Extensions

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Table 3.3: Effectiveness, height requirement, implementation and strength/durability considerations

Mitigation Techniques	Effectiveness (based on literature)	Height/Depth Requirement	Implementation Consideration	Strength / Durability Considerations
ACE	Depends on the design. Rising mean annual ground temperature generates more cooling. Measurable rise of permafrost table and decrease of embankment temperature. Less severe settlements and stabilization over time.	Minimum height of embankment ≥ 2.5 m	Uncovered ACE is sensitive to fine soil particles intrusion. Local availability of suitable aggregates may be problematic. Orientation of embankment with respect to intensity of solar radiation and wind direction should be considered when designing ACE.	The high strength of the stones makes it suitable for many conditions such as heavy loads and it also provides very low maintenance. If settlement happens, it will lose efficiency but will keep working.
HD	Measurable rise of permafrost table and decrease of embankment temperature.	Minimum height of embankment ≥ 2.0 m	Labour-intensive (manual installation). Avoid installation during windy day. Need to carefully respect the design.	During installation, a layer of sand must carefully be place on HD for protection. Puncture or compression by heavy equipment must be avoided.
HAS	Measurable decrease of surface temperature.	No specific embankment height requirement	Availability of light-colored aggregate may be problematic. High albedo coatings need to respect specification for northern use.	Durability has a close relationship with the material quality.
Thermosyphons	Measurable rise of permafrost table and decrease of embankment temperature.	No specific embankment height requirement	Angle of inclination, spacing and length must be adjust to the site conditions. Susceptible to damage and vandalism.	If a puncture of the tube occurs, the pressurization is lost and the tube will no longer function correctly.
Insulation	Promote thermal stability and delays thawing. May not reverse warming trend.	Depth of insulation varies from 0.5 m above natural ground surface to 0.8 m below the embankment surface (Zhi, et al., 2005).	Avoid trapping heat in the ground under the insulation layer by implementing in winter/early spring. Relatively easy to construct. Insulation properties may be reduced by the potential for water absorption and compression or breaking of the material. Insulation layer thickness, width, and embedded depth must be adjust to site conditions.	Sensitive to mechanical damage. Insulation material has to be installed deep enough to prevent crushing from cyclic wheel loadings and to reduce the risk of differential icing at the surface of the pavement.

Mitigation Technique at Dry Creek

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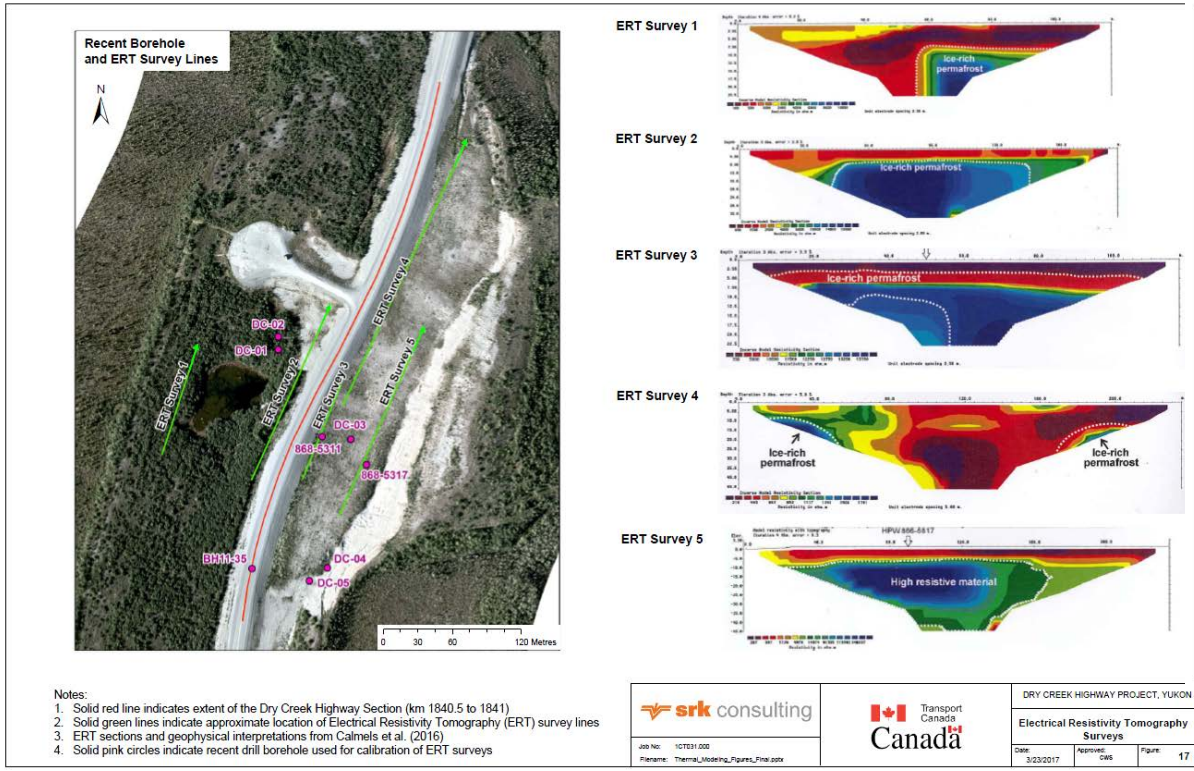

Notes:
1. Solid red line indicates extent of the Dry Creek Highway Section (km 1840.5 to 1841)
2. Solid green lines indicate approximate location of Electrical Resistivity Tomography (ERT) survey lines
3. ERT sections and geophysical interpretations from Calmels et al. (2016)
4. Solid pink circles indicate recent drill borehole used for calibration of ERT surveys

srk consulting | Transport Canada Canada | DRY CREEK HIGHWAY PROJECT, YUKON | Electrical Resistivity Tomography Surveys | Date: 3/23/2017 | Approved: DWS | Figure: 17

Notes:
1. (ICE) indicates ground ice greater than 2.65 cm thick, observed as massive ground ice
2. Individual ice crystals (Vx),
3. Random orientated ice structures (Vr) or stratified ice structures (Vs) in the form of ice lenses
4. Visual description of ground ice not available for all boreholes

srk consulting | Yukon Highways and Public Works Transportation Engineering Branch | DRY CREEK HIGHWAY PROJECT, YUKON | Location of Massive Ground Ice | Date: 11/10/2017 | Approved: DWS | Figure: 4

Thermal Analysis
ACE Embankment vs Thermosyphons at Dry Creek

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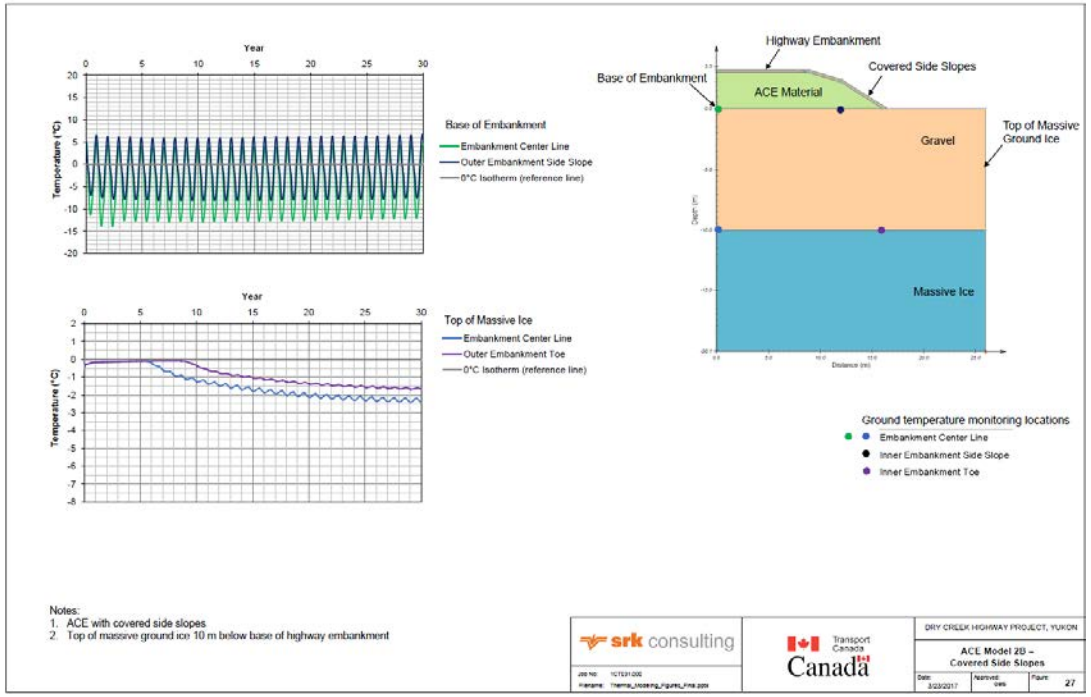

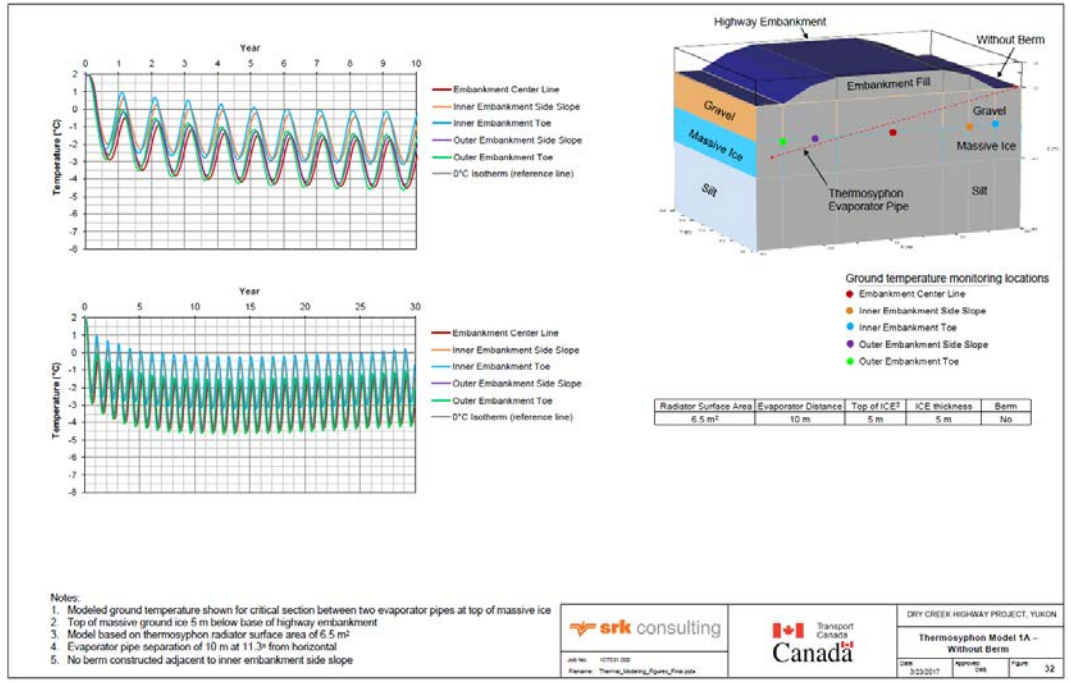

Thermosyphons at Dry Creek, 2018-2021

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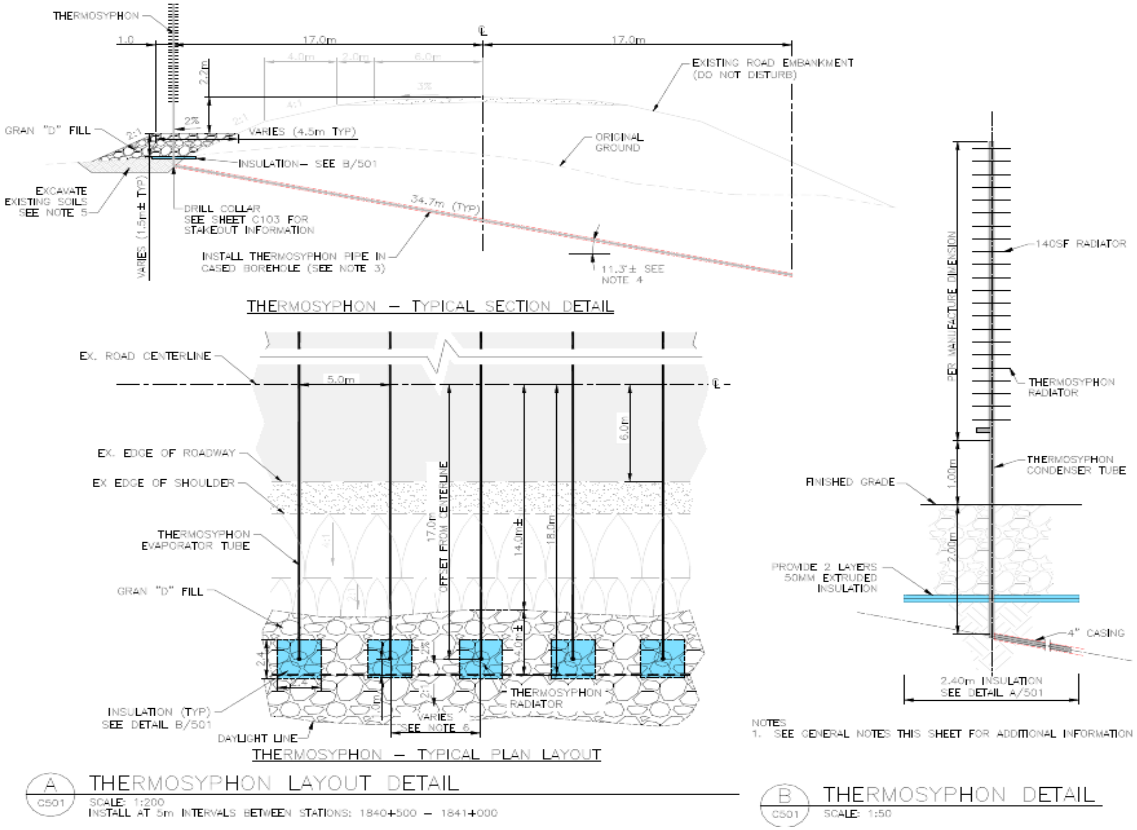

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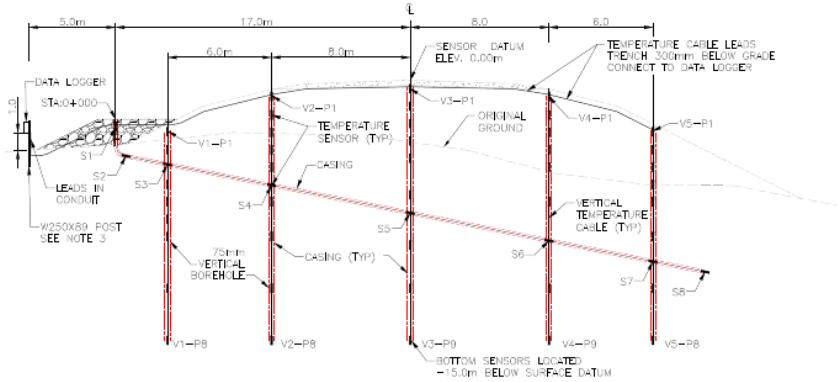

HORIZONTAL TEMPERATURE CABLE SENSOR LOCATIONS	
SENSOR	STATION
S1	0+000.5
S2	0+003.0
S3	0+005.5
S4	0+011.6
S5	0+019.8
S6	0+028.0
S7	0+034.1
S8	0+037.2

VERTICAL TEMPERATURE CABLE SENSOR LOCATIONS					
	ELEVATION DEPARTURE FROM DATUM ELEVATION				
SENSOR POSITION / LEAD LENGTH (m)	V1	V2	V3	V4	V4
	11.00	17.00	25.00	33.00	40.00
P1	–3.0	–1.0	–0.5	–1.0	–3.0
P2	–4.0	–2.0	–1.5	–2.0	–4
P3	–6.0	–3.0	–2.5	–3.0	–5
P4	–7.0	–4.0	–3.5	–4.0	–6
P5	–8.0	–5.0	–4.5	–5.0	–7.0
P6	–9.0	–7.0	–7.0	–7.0	–9.0
P7	–12.0	–9.0	–9.5	–12.0	–12.0
P8	–15.0	–12.0	–12.0	–15.0	–15.0
P9		–15.0	–15.0		

Temperature Monitoring Station - Stakeout Information

Borehole No.	Centerline Information: Station.	Centerline Elev. (CL Elev.)	Offset (m)	Collar Elevation: CL Elev - 4.2m	Collar Position: Northing	Collar Position: Easting	Borehole Azimuth (North Azimuth)	Borehole Dip Degrees
T1	1940+552.50	754.67	17 R	750.47	6892248.8725m	526400.2572m	289° 11' 26.713"	11.3
T2	1940+752.50	750.21	17 R	746.01	6892432.1406m	526575.9191m	289° 11' 13.469"	11.3
T3	1940+952.50	754.50	17 R	750.30	6892617.3017m	526752.7778m	289° 35' 54.027"	11.3

A / C502 GROUND TEMPERATURE MONITORING STATION – DETAIL

SCALE: 1:200
INSTALL AT STATIONS: 1940+552.50, 1940+752.50, 1940+952.50
SEE GENERAL CONSTRUCTION NOTES FOR MORE INFORMATION

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Thank You