Yukon University

Enhancing Yukon trade corridor resilience to northern geohazards

Overview of winter hydrology geohazards and icing mitigation strategies |Overview Report| August 2024

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Summary of winter observations and recommendations for glaciation mitigation

<u>Dempster Highway</u>

Between km 16 and km 36, creeks of moderate and large sizes do not seem to cause significant hydrological issues during winter months. However, ephemeral creeks and groundwater seepage may represent a major concern. This seepage is probably the result of the road design (road embankment choking groundwater pathways or forcing groundwater to surface upslope). However, it could also be attributed to a network of trails and dirt roads on the hills above the Highway, and this warrants further investigation. Wet summer and fall conditions may exacerbate groundwater seepage and cause intense aufeis (glaciation) development, as observed during the fall of 2022. Current mitigation options often involve ice excavation, which does not represent an efficient or sustainable response to overflow and icing on the road surface.

Heat tape seems to represent an adequate mitigation approach at several stream sites between km 32.6 and km 195. However, the authors recommend 1. Considering solar energy as a heat source when site characteristics (e.g., sun exposure, hill shade) are adequate and 2. Operating heat tapes for an optimal period, potentially using timers or remotely controlled power sources.

The replacement of large culverts by a single or double-span bridge could be considered at a few large creek crossings (e.g., East Blackstone River). Snow management strategies could also help prevent or delay the development of impactful aufeis at several vulnerable locations.

Detailed, site-specific assessments and mitigation options are presented in Section 4.1.

<u>Silver Trail</u>

At several sites between km 3.9 and km 60.1, steam pipe systems could be replaced by heat tapes connected to the grid and operated as needed during winter. This system (e.g., km 107) would reduce maintenance costs and prevent damage caused by aufeis and overflow (e.g., km 23.1, 2024).

Between km 80 and km 109, overflow and aufeis development is potentially caused by the road design itself (chocking groundwater pathways and forcing groundwater to surface) or by historical and current upslope mining activities. This needs to be confirmed through further analyses. Most culvert heads (and sometimes outlets) have been damaged by excavators during ice removal interventions. The installation of graduated rods should be considered, as a minimum, at all affected crossings to prevent further damage to the infrastructure when machinery is deployed near culverts.

Improved snow management and installing auxiliary culverts made of plastic are also recommended for several aufeis-affected sites along the Silver Trail.

Detailed, site-specific assessments are presented in Section 4.2.

<u>Klondike Highway</u>

Aufeis (glaciation) challenges along this corridor are diverse regarding water sources, process intensity, and process frequency. Site-specific assessments and mitigation strategies are explored in Section 4.3.

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At all the locations where aufeis has been observed in recent years, the systematic reporting of overflow and icing events by highway crews during winter can support mitigation planning and, therefore, reduce maintenance and repair costs. Damaged or decommissioned heating systems should also be methodically removed from creek channels and ditches as they tend to exacerbate aufeis development and to affect mitigation efficiency.

TABLE OF CONTENT

1 INTRODUCTION

In partnership with the Yukon Government's Department of Highways and Public Works (HPW), the YukonU Research Centre (YRC) was awarded a research grant from Transport Canada's National Trade Corridors Fund. The research project extends from 2022to 2026 and aims at enhancing Yukon trade corridors resilience to northern geohazards. Part of this research project is designed to identify and mitigate geohazards specifically related to water and ice along the Dempster Highway, Silver Trail, and Klondike Highway. This document emphasizes aufeis (glaciation) processes and summarizes some of the research conducted by the Climate Change Research (CCR) Group - hydrology team over the first two years of the project, including the identification and description of problematic sites, monitoring strategies, as well as existing and proposed mitigation approaches. It is meant to guide further collaboration between YRC-CCR, HPW, and other stakeholders in order to maximize practical outcomes that will be produced from this research. This involves improving aufeis mitigation, which will ultimately reduce operational costs and improve the safety of Yukon Highways during and after the cold season.

This research is mainly taking place in the right of way of roads and highways. Nonetheless, the authors would like to acknowledge that their research activities in the field at taking place on the Traditional Territories of various First Nations, mainly Tr'ondëk Hwëtch'in and Na-Cho Nyäk Dun.

2 MONITORING METHODS

YRC-CCR first surveyed the Dempster, Silver Trail, and Klondike Highways in spring 2021 to confirm locations with hydrology-related geohazards and have continued regular surveys since. From these observations, we identified a collection of road segments and stream crossings that include some of the most problematic sites but also represent the variety of winter hydrology-related geohazards along these corridors. For each field site, a custom monitoring program was designed to resolve specific details about the processes controlling aufeis development so that information necessary to design and test effective and efficient mitigation strategies could be collected. To date, field methods have included some combination of the following instruments:

Water level sensors: To measure water pressure (level), we deploy either Solinst Leveloggers 5 or Hobo Onset U20 loggers mounted to a custom steel plate and housing. We anchor these plates to the streambed (Figure 1) at strategic locations to avoid freezing, sedimentation, or erosion. We deploy a barometric pressure sensor nearby so that we can compensate the datasets for variations in atmospheric pressure.

Figure 1. A pair of anchored plates at the bed of a stream to which the aquatic sensors are attached.

Water temperature sensors: Both the Solinst Levelogger 5 and the Hobo Onset U20 logger described above also measure water temperature, with an accuracy of ±0.05°C and ±0.44°C respectively. If additional accuracy is required, we deploy an RBR Solo^3 T water temperature probe, with an accuracy of ±0.002°C.

Water conductivity: Similar to the water pressure and temperature sensors, we deploy either Solinst Leveloggers 5 LTC or Hobo Conductivity sensors in anchor plates, as described in Figure 1.

Ice buildup and thermal profile (SIMBA): The SIMBA unit consists in a 4 m-long cable with temperature sensors positioned every 2cm along its length. We mount this cable vertically using a wooden tripod and install a logger and power supply at the top (Figure 2). We collect temperature measurements along the chain every 6 hours and can use these data to monitor the growth of aufeis and its internal temperature over an entire winter season.

Figure 2. Wood tripod with SIMBA unit installed at the top.

Air temperature: We use Solinst Barologgers, SIMBA units, and/or timelapse cameras to measure air temperature.

Timelapse cameras: We use either Reconyx or Boly game cameras, or custom-built DSLR timelapse cameras, to collect images of streams and highway ditches at least once per day.

Other: During specific field campaigns, we collect additional measurements at our study sites, including ice thickness, water pressure, surface runoff, groundwater seepage or aufeis extent, using manual techniques, GPS equipment, or by collecting optical/thermal imagery using a drone.

Field observations: We make several trips to each field site during fall (to install equipment), winter (to maintain equipment), and spring/summer (to recover/download equipment), and during each field campaign, we document our observations and conduct experiments. Experiments include, for example, drilling holes in the ice cover to depressurize the under-ice water or routing spring runoff, and we monitor the effects of these activities.

3 MITIGATION

3.1 Current strategies

Aufeis (glaciation) commonly occurs at consistent locations each winter, allowing maintenance crews to preemptively prepare sites for mitigation. Though strategies are sometimes adapted to site-specific processes, maintenance crews on the Dempster, Silver Trail, and Klondike highways generally use one or many of the following techniques to mitigate aufeis impacts:

Heat tape: Heat tapes are used widely along the Dempster Highways to mitigate aufeis formation and promote drainage. Typically, 170 m-long (550 ft) cables with a maximum capacity of 2300 Watts are tied to trees or poles on either side of a culvert. Wheel-mounted diesel generators power these cables for several hours to days during the winter or before spring snowmelt. When heated, the tape will quickly melt a tunnel within the aufeis body, temporarily or sustainably restoring some of the culvert's functionality.

Steaming: Steampipes, made of metal, are operated at a majority of aufeis-affected culverts on the Silver Trail. Truck-mounted boilers that produce steam are either connected to portable lances (hoses) or, more commonly, to permanent pipes installed close to the top and across the entire length of culverts. Though this technique requires that pipes be regularly inspected and maintained, it is specifically adapted to small or mid-size culverts mostly or entirely blocked by aufeis. Similar to the heat generated by the heat tape, the steam melts a linear cavity through the ice around the pipe, and groundwater or runoff water follows this pathway across the culvert. The melt of a Y-shaped cavity at the upstream end of culverts using a T-shaped portable hose is common, especially on the Silver Trail. While winter interventions often need to be repeated, in part because permanent pipes promote ice formation through heat loss, spring interventions can produce lasting results.

Excavation/grading: Excavators, often operated by contractors, are commonly deployed along the studied highways to mechanically remove ice in order to increase storage capacity in ditches and stream beds (by piling the excavated ice locally or moving it to the downslope side of the road), and to trench drainage pathways in aufeis affected streams. Graders, operated by HPW crews, are used to restore safe driving conditions when icing occurs on the road surface. It is important to note that this machinery cannot restore the evacuation capacity of culverts (it often damages them, which frequently occurs, particularly on the Silver Trail).

3.2 Proposed strategies (Partial list)

Though the current strategies employed by HPW maintenance crews are, in some cases, effective at mitigating aufeis formation or restoring drainage capacity, they are generally not energy efficient and occasionally counterproductive. It is not uncommon to see HPW crews steaming culverts more than ten times at the same location during a single winter. We have identified alternative and complementary approaches that, if successful, could prove to be more efficient, effective, sustainable and/or environmentally friendly. The following list is partial and represents simple and accessible solutions:

Removal of debris: Maintenance crews could more systematically remove debris from drainage pathways, both upstream, downstream and within culverts or ditches, to facilitate drainage and minimize the occurrence of aufeis-prone hydraulic conditions during winter.

Blocked culvert: In cases where multiple culverts drain a stream but commonly become entirely blocked by aufeis during winter, intentionally blocking the head of one of the culverts in early winter could prevent the aufeis formation in that culvert. When the blockage is removed, before the onset of spring freshet, that culvert would have full capacity to drain the bulk of the spring runoff, thereby reducing the risk of flooding. This technique could be tested by blocking the culvert head with plywood (as long as it could be removed in spring), a large inflatable device (that could be deflated), or by the formation of a (snow-made) ice barrier (that can be drilled or removed).

Non-metal culvert: Aufeis commonly form in culverts, partly because metal has high thermal conductivity, and can rapidly remove heat from flowing water. In theory, non-metal culverts (e.g., high-density polyethylene (HDPE)) with lower thermal conductivity can reduce icing problems. Moreover, ice overpressure is known to cause the failure of metal culverts, so exploring the properties of other, deformable materials may also yield structural and capital benefits.

Optimal heat tape usage: Heat tapes are placed along the length of culverts and are used to melt drainage pathways through an ice body. They are often operated until a large gallery (or open channel) is formed in aufeis (upstream and downstream of culverts). In some cases, only a small ratio of this ice would need to be melted to carry winter flows. Since ice and snow cover can provide effective insulation from the cold, ambient air, we propose a more strategic use of heat tapes with careful monitoring (or a capacity to turn off the energy source remotely) to ensure a drainage cavity is formed, but the overlying snow/ice cover remains intact.

Solar panel power supply: At locations where overflow is mostly problematic in the spring when sunlight is abundant, wheel-mounted solar panels could replace diesel generators to reduce carbon emissions and operating costs of heat tapes.

Real-time monitoring: Aufeis commonly form on the ice cover of streams and rivers when the underlying water column becomes pressurized. This condition can occur during mid-winter and early spring warm spells when runoff increases while the ice cover remains thick and strong. The over-pressure phenomenon is widespread at culverts where the flow is constricted, whereas the ice cover thickens fast. The pressure is eventually released through cracks in the overlying ice cover in the riparian zone (or induced through drilling, Figure 3), causing overflow and aufeis development. Real-time monitoring systems could detect over-pressure events before overflow occurs. This could support the planning of timely risk-reduction interventions.

Figure 3. Pressure-driven overflow through an augered hole at km 72 on the Dempster highway on Apr 4, 2024.

Spring augering: The late-winter/spring perforation of an aufeis body comprising unfrozen or porous layers may help direct spring runoff from the ice surface back to the stream bed and through a culvert. Once drainage through these small holes is established, the runoff can further melt and erode the holes, developing well-established sub-surface drainage pathways in the following weeks and attenuating the flood potential upstream of culverts (**Error! Reference source not found.**).

Figure 4. location of an augered hole at km 32.6 on the Dempster highway in March 2023 (top) and the expansion of this drainage hole by early May 2023 (bottom).

Surface darkening: Spreading a thin layer of dark material (e.g., sand/dirt/organic matter) onto an ice surface in the spring will enhance the absorption of solar radiation by up to 9 times, promoting rapid deterioration of an ice body. If the material is placed strategically, it could create a canal and direct surface drainage to culverts or away from vulnerable sites.

Snow management: Snow has been observed to directly cause or exacerbate the formation of aufeis at various stream crossings by blocking overflow or depressing the newly formed stream ice cover. In turn, it seems that the absence of snow on the ground or a newly formed ice cover can also cause overflow by heat loss (the insulating snow layer is not present, and the ice cover thickens faster). Therefore, installing snow fences, creating snow dams, or promoting snow insulation could represent affordable and environmentally friendly approaches to control aufeis at specific sites. As specified above, snow could be placed to block the upstream end of culverts at multi-culvert sites until the spring snowmelt period.

4 FIELD SITES

4.1 Dempster Highway

Our research on the Dempster Highway extends from the Dempster Highway-Klondike Highway corner at km 0 to the Ogilvie River at km 195 (Figure 5). Along this section of the highway, we have documented drainage infrastructure and winter hydrological processes in ditches, creeks, and rivers for water and ice-related geohazards. These hazards are related to the formation of aufeis in ditches, culverts, and shallow rivers, which cause winter overflow and road icing (glaciation) or spring overflow and potential erosion damage to the road infrastructure. Aufeis is predominantly fed by surface water (creeks and shallow rivers), though at some locations, it is fed directly by groundwater. The following subsections present different problematic sites.

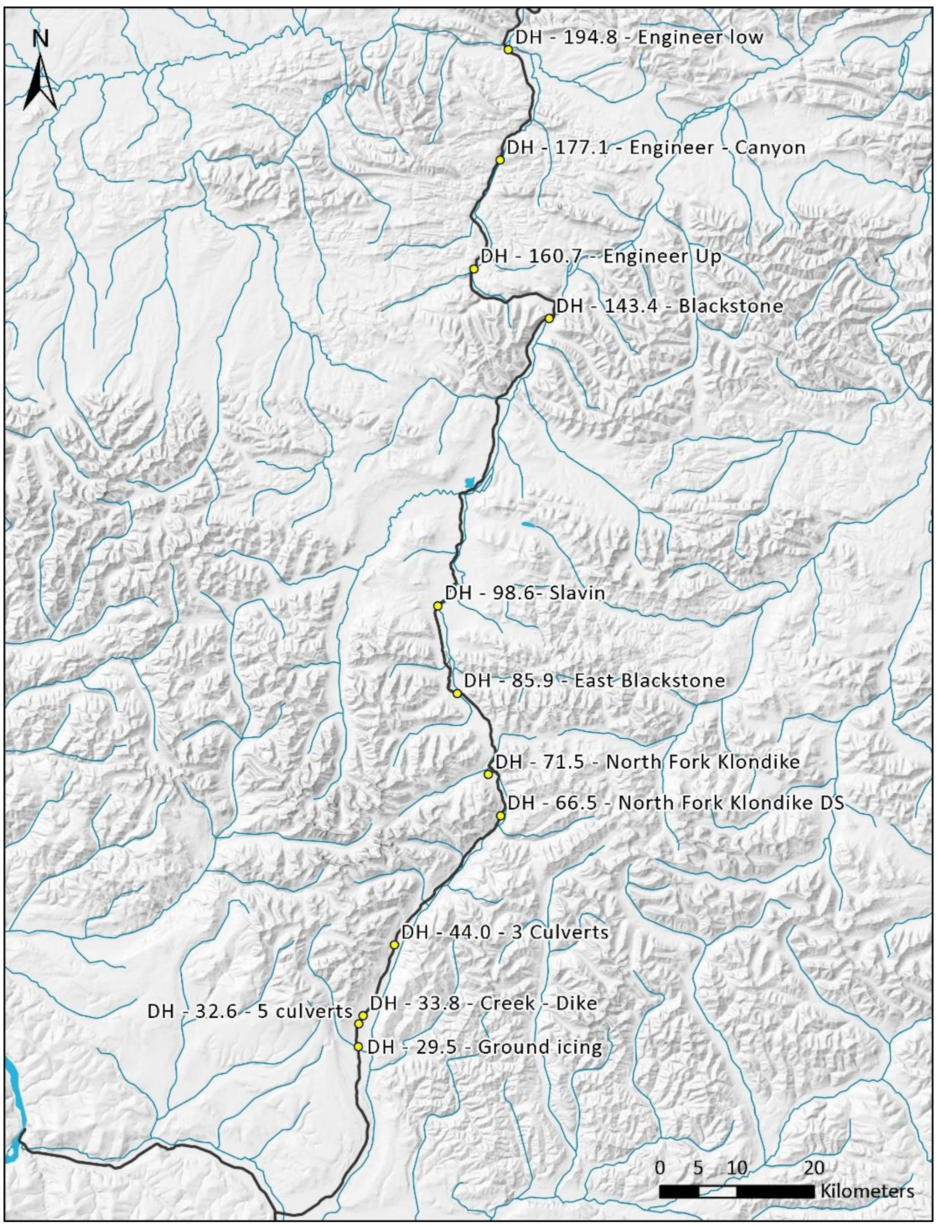

Figure 5. Research sites (observation, monitoring, mitigation) along the Dempster Highway.

4.1.1 Groundwater seeps (km 16-32 and km 34-36)

Figure 6. Groundwater-induced icing near km 29 on October 28, 2022.

Figure 7. Water ponding on the upslope of the Dempster Highway near km 29 on May 9, 2023.

Site Description

The lower section of the Dempster Highway passes across the southern foot of the Ogilvie Mountains. There is active groundwater discharge within this region, potentially because of surface and subsurface disturbances on the hillside above the highway (with permafrost's possible and unconfirmed presence).

In years where groundwater discharge remains high throughout the winter (i.e., after a wet fall), extensive icing occurs, originating from the highway's left or west side (upslope). In most cases, this discharge seeps into the ditch, causing icing along hundreds of metres along the road. Seven discrete areas of icing were observed in winter 2022-2023 between Km 16 to 32 for a total of 1.8 km of affected highway, but the most intense groundwater seepage site is located close to km 29. Culverts within these active icing zones quickly become plugged with ice, causing drainage problems in the spring, if not before.

Monitoring Program

- Field observations/mapping

Current Mitigation Strategy

- Excavation (as required)
- Aufeis fences made of black tarps
- Pumping ponded water across the road in the spring
- Culvert steaming using portable hoses.

Proposed Mitigation Strategy

- Blockage of targeted culverts in the fall
- *Investigation of historical upslope groundwater disturbance*
- *Frost belts upslope of highway
- *Thermosyphons upslope of highway
- *Groundwater drainage or dewatering

* Experimental solutions to further discuss

4.1.2 Unnamed Creek (km 32.6)

Figure 8. Unnamed Creek (km 32.6) wetland on September 23, 2022.

Figure 9. Unnamed Creek (km 32.6) wetland on March 24, 2022.

Table 1. Unnamed Creek (Km 32.6) highway crossing(s).

Number of crossings	1
Location	Km 32.6
Drainage structure	5 Culverts (metal)
Culvert #1	Ø 1.2m
Culvert #2	Ø 0.4m
Culvert #3	Ø 1.2m
Culvert #4	Ø 2.3m
Auxiliary culvert #5	Ø 1.2m

Site Description

The Dempster Highway crosses a wetland area and several headwater creeks at km 32.5-32.7. Five culverts are installed at this location to drain water from the west side to the east side of the highway. Aufeis consistently develops at this site throughout the winter and is fed by creek and groundwater sources. Overflow and aufeis thickening occur in response to cold or rising winter temperatures as well as snow accumulation. The aufeis reaches several meters thick and have overtopped the road surface in recent years (e.g. 2022; Figure 9).

Monitoring Program

- Ice buildup and thermal profile (SIMBA)
- Air temperature
- Timelapse cameras
- Staff Gauges
- Water temperature (upstream and groundwater)
- Water level (upstream and groundwater)
- Stream conductivity (upstream)
- Field observations

Current Mitigation Strategy

- Boiler fed steam pipe (culverts #1 - #2)
- Generator fed heat tape (culverts #2 - #3)
- Excavation (as required)
- Auxiliary culverts

Proposed Mitigation Strategy

- Removal of decommissioned steam pipes and heat tapes
- Blockage of culvert #3 with inflatable device
- Snow damming of auxiliary culvert #5
- Reduction of generator operation time
- Solar panel energy source for heat tape
- Spring drilling in front of main culvert #4
- Snow management (protect culvert outlet against snow accumulation)

4.1.3 Unnamed Creek (km 33.8)

Figure 10. Unnamed Creek (km 33.8) culvert head and ditch on August 23, 2022.

Figure 11. Unnamed Creek (km 33.8) culvert head and ditch on Dec 9, 2022.

Table 2. Unnamed Creek (Km 33.8) highway crossing(s).

Number of crossings	1
Location	Km 33.8
Drainage structure	2 Culverts (metal)
Culvert #1	Ø 0.9m
Culvert #2	Ø 0.9m

Site Description

A stream drains a wetland complex that lies north of the highway. The stream reaches the highway at km 33.8 at an angle through an artificial ditch. During winter, the ditch fills with aufeis, and a depression in the berm enables overflow to reach a secondary culvert at km 33.9. A heat tape is installed at that secondary location (the culvert is damaged and needs to be replaced) to guide overflow to the culvert. Unfortunately, this mitigation is only partially successful.

Monitoring Program

- Timelapse camera
- Field observations

Current Mitigation Strategy

- Steam pipe (main culvert)
- Heat tape (auxiliary culvert)
- Road grading (as required)
- Berm and secondary culvert

Proposed Mitigation Strategy

- Addition of an auxiliary culvert made of plastic (currently being considered with HPW-TMB)
- Reduction of generator operation time
- Solar panel energy source for heat tape
- Improvement of surface drainage to auxiliary culvert
- Snow management

4.1.4 Yin Yang Creek (km 44.0)

Figure 12. Yin Yang Creek (km 44) culvert heads on August 23, 2022.

Figure 13. Yin Tang Creek culvert heads on May 8, 2022.

Table 3. Yin Yang Creek (km 44) highway crossing(s).

Number of crossings	1
Location(s)	km 44
Drainage structure	3 Culverts (metal)
Culvert #1	Ø 1.8 m
Culvert #2	Ø 1.8 m
Culvert #3	Ø 1.8 m

Site Description

The creek drains an alpine valley west of the highway and reaches the highway on a steep, forested alluvial fan where three large (1.8 m) culverts have been installed. Aufeis form within or at the upstream end of the culverts. It seems that the culverts, through heat extraction (cold metal), are responsible for their own blockage, but snowbanks and snowdrifts probably exacerbate the problem. In these situations, drifted snow acts like a sponge by absorbing water that freezes in situ to create a impermeable barrier to subsequent overflow.

Monitoring Program

- Timelapse camera (operated by McMaster University)
- Field observations

Current Mitigation Strategy

- Two heat tapes

Proposed Mitigation Strategy

- Removal of decommissioned steam pipes and heat tapes
- Blockage of upstream end of central culvert (#2) with inflatable device or with a snow dam
- Snow management (protect culvert outlets against snow accumulation)
- Reduction of generator operation time
- Solar panel energy source for heat tape
- *Vertical wood posts upstream of culverts to provide structural support to a newly formed ice cover.

* Low cost experimental solution to further discuss

4.1.5 North Klondike River (km 66.5 - km 71.4)

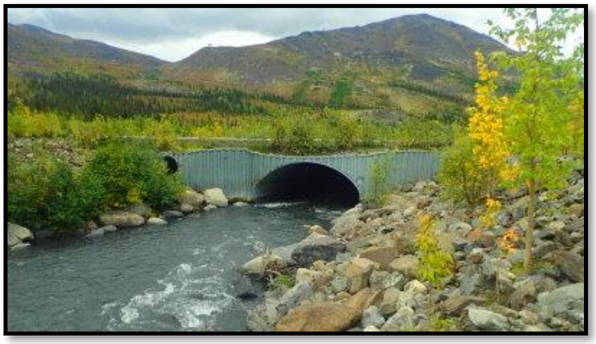

Figure 14. North Klondike River at km 66.5 on August 23, 2022.

Figure 15. North Klondike River from lookout at km 74 on August 23, 2022.

Figure 16. North Klondike River from lookout at km 74 on May 4, 2021.

Table 4. North Klondike River highway crossing(s).

Number of crossings	1
Location	km 66.5
Drainage structure	Arch culvert
Two auxiliary culverts	Ø 1.8 m

Site Description

The North Klondike River drains a portion of the Ogilvie Mountains. Specifically, the valley is leading to Tombstone Mountain. It flows south past the Tombstone Campground and information center and then parallels the lower portion of the Dempster Highway, crossing from the west to the east side of the highway at km 66.5. The river comprises a 400-m wide braided section 1.5 km upstream of the campground where aufeis up to 3 m thick form each winter (
Figure 15 /Figure 16). This aufeis stores significant water and does not fully melt until late June at the earliest. The river becomes channelized as it flows past the campground, then passes through a wetland with abundant beaver activity. Zero flow events (channel frozen to the bed) have been reported, but ice processes do not seem to impact the highway. However, the presence of auxiliary culverts at km 66.5 suggests that this site has historically been impacted by high water or ice levels.

Monitoring Program

- Water temperature/pressure
  - ✓ top of braided section
  - ✓ mid- braided section
  - ✓ Information center (km 71)
  - ✓ Upstream of bridge (km 66.5)
- Timelapse cameras
  - ✓ Bottom of braided section
  - ✓ km 73
- Field observations

Current Mitigation Strategy

- Auxiliary culverts

Proposed Mitigation Strategy

- Targeted monitoring and documentation of aufeis processes

4.1.6 East Blackstone River (km 85.9)

Figure 17. Timelapse photo of East Blackstone River culvert head on Oct 29, 2023.

Figure 18. Timelapse photo of East Blackstone River culvert head on Apr 18, 2024.

Table 5. East Blackstone River highway crossing(s).

Number of crossings	1
Location	km 85.9
Drainage structure	2 Culverts (metal)
Culvert #1	Ø 4.5 m
Culvert #2	Ø 4.5 m
Auxiliary culvert #3	Ø 1.0 m

Site Description

The East Blackstone River headwaters lie in the Ogilvie Mountains. The river drains several alpine valleys through a permafrost-rich lowland that parallels the Dempster Highway from ~km 80 – km 85.9, where it crosses the road through two large (Ø 4.5 m) structural culverts. The East Blackstone River continues to parallel the highway downstream of the crossing until it reaches the Blackstone River near km 115. Aufeis routinely forms upstream and downstream (down to km 88) of the culverts (Figure 17/Figure 18), causing drainage concerns across the road before and during snowmelt. Aufeis also forms on the river surface at other locations along the East Blackstone River. However, it only seems to represent an immediate road infrastructure or safety hazard between km 85.9 and km 87.5. High winds and wind-blown snow play a role in forming this aufeis.

Monitoring Program

- Ice buildup and thermal profile (SIMBA)
- Air temperature
- Timelapse cameras
- Water temperature and level (km 84, 86, and 88)
- Laser measuring ice surface elevation
- Field observations

Current Mitigation Strategy

- Canal excavation (km 85.9-km 87.5)
- Auxiliary culvert

Proposed Mitigation Strategy

- Snow management (removal from culverts, snow dams upstream of culverts during mid-winter period)
- Late-winter ice surface darkening
- Heat sources fed by solar panels
- Replace culverts by a bridge or move crossing to another location

4.1.7 Slavin Creek (km 98.6)

Figure 19. Slavin Creek (km 98.6) timelapse photo of culvert head on September 21, 2021 (Photo provided by McMaster University, Sean Carey's research team).

Figure 20. Slavin Creek (km 98.6) timelapse photo of culvert head buried by aufeis on March 29, 2021 (Photo provided by McMaster University, Sean Carey's research team).

Table 6. Slavin Creek highway crossing(s).

Number of crossings	1
Location	km 98.6
Drainage structure	1 Culvert (metal)
Culvert #1	Ø 1.5m

Site Description

A groundwater-fed creek drains through permafrost-rich tundra west of the highway at km 98.6. The creek crosses the highway through a single culvert which downstream end is hanging above a relatively deep pool. Aufeis plugs the culvert at this site each winter, affecting a large area immediately upstream of the culvert during the spring. The permanent steaming pipe has apparently been damaged and has not been replaced. Blockage begins during the first cold nights and usually reaches 100% before the end of winter. The thickness of this aufeis is likely limited to 2 m, either because of low winter water supply or by the porous nature of the lower road embankment. However, the spring overflow can be many meters deep.

Monitoring Program by McMaster University

- Water temperature/level
  - ✓ Upstream of culvert
  - ✓ Groundwater
- Water chemistry (dissolved oxygen, conductivity, pH)
- Weather station
- Field observations
- Cameras

Current Mitigation Strategy

- Steaming in the spring using a portal hose

Proposed Mitigation Strategy

- Early observation and assessment of ice conditions
- Solar panel energy source and new heat tape
- *Ice drilling from downstream end of culvert
- Installation of an auxiliary culvert at higher elevation to carry snowmelt runoff

* Experimental solution to further discuss

4.1.8 Blackstone River (km 142.3 - km 143.7)

Figure 21. Timelapse photo of Blackstone River at km 143.7 on October 12, 2022.

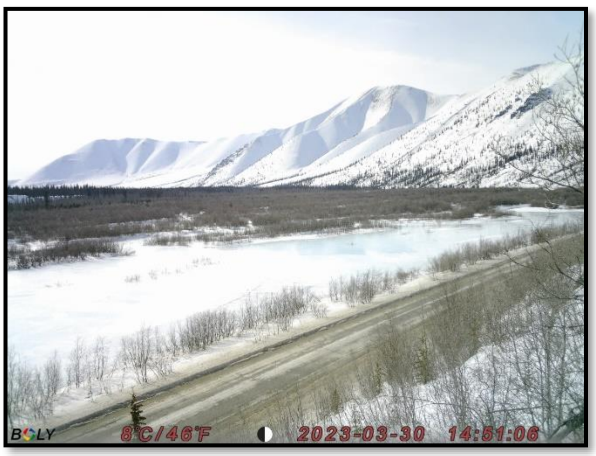

Figure 22. Timelapse photo of Blackstone River at km 143.7 on March 30, 2023.

Site Description

The Blackstone River flows parallel and generally some distance from the highway until km 145.6, where the highway turns west into Windy Pass. Between km 142 and 144, riprap has been installed to protect the road against erosion. The Blackstone River develops aufeis on its surface at many locations, including along that segment. Aufeis commonly achieve a thickness of more than 2 m near km 143, and this probably represents a higher flood risk than high open water flow conditions. This aufeis can damage riparian vegetation and rip rap. Ice blisters have been observed in recent winters, confirming that winter flow conditions can be pressurized.

Monitoring Program

- Timelapse cameras (km 143.7, 142.5)
- Water level/temperature sensors (km 143.7)
- Field observations

Current Mitigation Strategy

- N/A

Proposed Mitigation Strategy

- Targeted monitoring and documentation of aufeis processes
- Late-winter ice surface darkening
- Late-winter canal excavation towards southeast bank, when needed
- *Snow management, when needed (e.g., diagonal snow berms oriented downstream towards the southeast bank)

* Experimental solution to consider in the future

4.1.9 Engineer Creek (km 160.6- km 195)

Figure 23. Engineer Creek at km 160.6 on April 3, 2024.

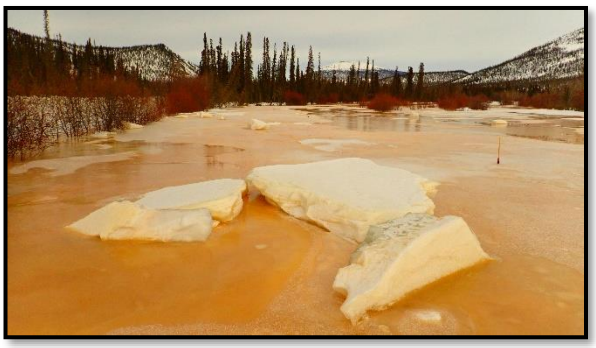

Figure 24. New (colored) overflow and aufeis along Engineer Creek near km 173 on April 3, 2024.

Table 7. Engineer Creek highway crossing(s).

No. of crossings	2	
Locations	km 160.6	km 194
Drainage structure	7 culverts (metal)	Bridge
Culvert #1	5.5 m	
Culvert #2	5.5 m	
Culvert #3	5.5 m	
Auxiliary Culvert #4	1.0 m	
Sec. Culvert #5	1.8 m	
Sec. Culvert #6	1.8 m	
Sec. Culvert #7	1.8 m	

Site Description

Engineer Creek is a sediment-rich and iron-rich (orange) creek that drains from the south and reaches the Dempster Highway at km 160.6. It crosses the highway at this location and then flows parallel to the highway until km 195. Engineer Creek is highly streams susceptible to erosion processes but also experiences river aufeis (Figure 24) and flooding, just like several other streams such as Red Creek (km 168.2) that cross the Dempster Highway in that area. Engineer Creek flows immediately beside the road embankment at many locations, exposing it to water-related hazards in all seasons. Stream crossings at km 160.6 (Engineer Creek, Figure 23) and km 168.2 (Red Creek) comprise large culverts that seem to initiate and promote aufeis development.

Monitoring Program

- Permanent, real-time water level station at km 160.6
- Water level/temperature sensors (km 178, 194)
- Field observations

Current Mitigation Strategy (km 160.6)

- Steam pipes
- Berms, side channel and secondary crossing (culverts #5 to #7)

Proposed Mitigation Strategy

- Monitoring and early-observation of aufeis development at stream crossings (e.g., km 168.2)
- Solar panel energy source and new heat tape (km 160.7, km 168.2)
- Snow management (removal from culverts, snow dams upstream of culverts at km 168.2)
- Replacement of culverts by a bridge (km 160.7)

4.2 Silver Trail

Our research on the Silver Trail extends from the North Klondike Highway and Silver Trail intersection to near Keno at km 110 (Figure 25). Along this section of the highway, we have documented drainage infrastructure such as ditches and culverts, including creek segments located upstream and downstream of the road, emphasizing winter hydrology-related geohazards. Most of the upper Silver Trail (past Mayo) is on a north-facing hillside. The area includes extensive mining and exploration activities, with an assumed significant surface and subsurface modification of drainage pathways upslope of the road. Though many creeks are flowing down the hillside and crossing the highway, abundant groundwater seeps on the south side of the road remain active throughout winter.

Consequently, overflow and aufeis formation events are prevalent and often lead to water and icing across the road, especially between km 80 and km 109. Overflow events seem to occur under a wide range of weather conditions and compromise the safety and integrity of the highway. The slight but continuous groundwater seepage from cut slopes and streamflow in creeks and through culverts represents serious management challenges for maintenance crews every winter.

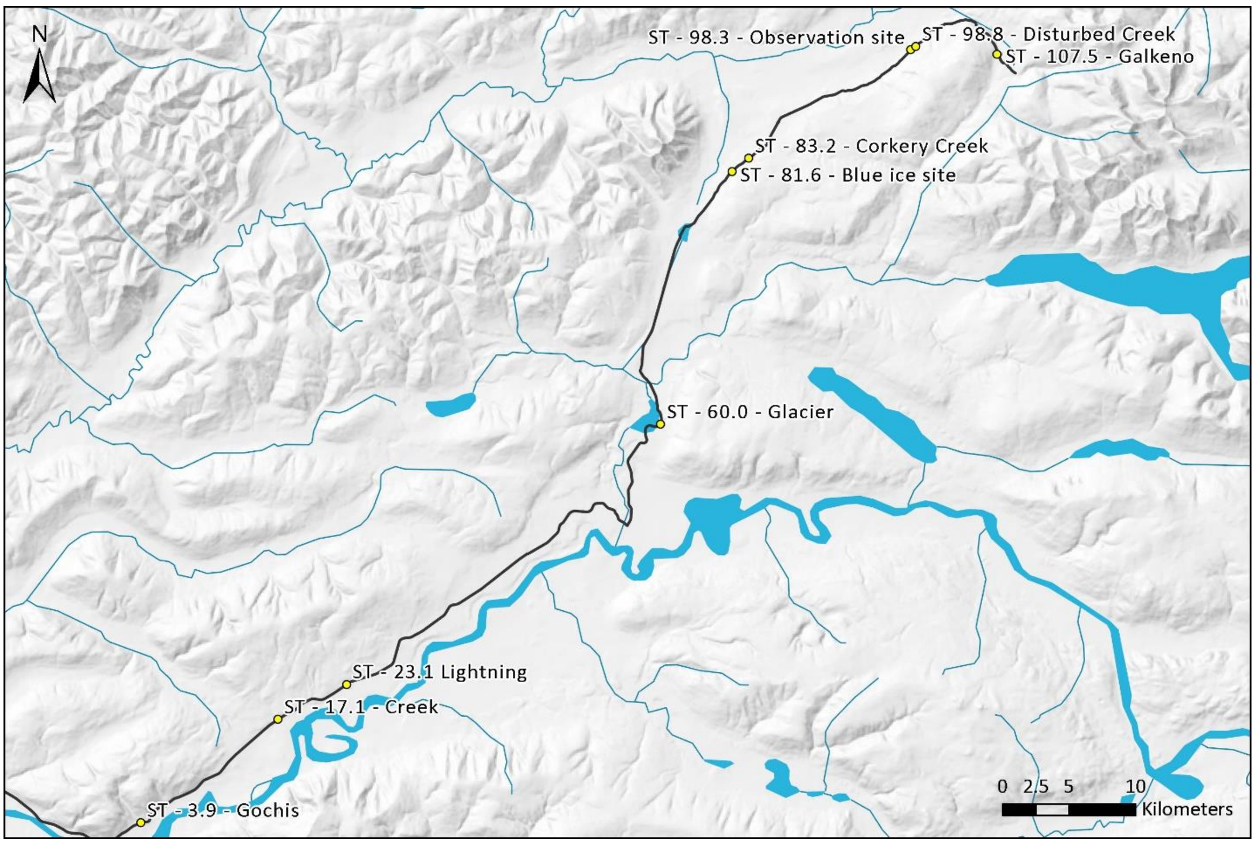

Figure 25. Research sites (observation, monitoring, mitigation) along the Silver Trail.

4.2.1 Gochis Creek (km 3.9)

Figure 26. Gochis Creek upstream of Silver Trail, October 2021.

Figure 27. Gochis Creek after the partial melt of a 1.5 m-thick aufeis in May 2022.

Table 8. Gochis Creek highway crossing(s).

Number of crossings	1
Location	km 3.9
Drainage structure	3 Culverts (metal)
Culvert #1	Ø 0.9 m
Culvert #2	Ø 0.75 m
Auxiliary culvert #3	Ø 0.6 m

Site Description

Gochis Creek drains north to south into the Stewart River, intercepting the Silver Trail at km 3.9. Stream aufeis develops upstream of the Trail and can entirely plug one of the culverts, as observed during winters 2021-2022 and 2023-2024. The steam pipes at the culvert heads contribute to intercepting debris, preventing optimal drainage and potentially promoting a complete blockage by ice. In most years, the creek may carry enough groundwater heat to continue flowing under an ice cover without causing overflow events. However, this condition is only achieved under specific winter weather sequences and could be supported by accessible, low-energy interventions. Aufeis at this location may be initiated downstream of the culvert, which influences mitigation strategies.

Monitoring program

- Timelapse camera (winter 2022-2023)
- Field observations

Current mitigation

- Steam pipes
- Auxiliary culvert

Proposed mitigation

- Removal of debris at the culvert head
- Removal of steam pipes (to prevent debris blockages)
- Installation of heat tape connected to the grid and operated as needed
- *Addition of insulating snow on the ice cover after operating the heat tape
- *Rising the water depth upstream and downstream of the culvert to promote the early formation of an ice cover

* Experimental solutions to further discuss

4.2.2 Unnamed Creek (km 17.1)

Figure 28. Timelapse camera photo of Unnamed Creek (km 17.1) on Oct 12, 2023.

Figure 29. Timelapse camera photo of Unnamed Creek (km 17.1) on Jan 29, 2024.

Table 9. Unnamed Creek (km 17.1) highway crossing(s).

Number of crossings	1
Location	Km 17.1
Drainage structure	2 Culverts (metal)
Culvert #1	Ø 0.9 m
Auxiliary culvert #2	Ø 0.4 m

Site Description

An unnamed creek drains from the northwest and intercepts the Silver Trail in a relatively deep canyon at km 17.1, where it drains through a damaged (capacity reduction of about 20%) primary culvert. Though stream-fed aufeis filled the lower part of this canyon in winter 2021-2022, no significant aufeis developed in winter 2022-2023 or 2023-2024. As stated for km 3.9, and as high-resolution data revealed, the creek carries enough heat to maintain an under-ice flow throughout the cold season without producing overflow events and aufeis under most early and mid-winter weather scenarios. However, in years where overflow would occur, simple mitigation measures could resolve the issue.

Monitoring program

- Timelapse camera
- Water pressure/temperature

Current mitigation

- Heat tape in steam pipe, but electric connector might be too low to use heat tape when aufeis thickness is significant.
- Auxiliary culvert

Proposed mitigation

- Removal of debris at the culvert head
- Connection of heat tape to the grid and only operate it for a few hours every winter
- Cutting hanging extension of auxiliary culvert (it cannot carry water during winter if it is exposed to cold air)
- *Rising the water depth upstream of the culvert to promote the early formation of an ice cover

* Experimental solution to further discuss

4.2.3 Lightning Creek (km 23.1)

Figure 30. Timelapse camera photo of Lightning Creek culvert heads on Oct 14, 2022.

Figure 31. Photo of Lightning Creek with massive overflow on April 2, 2024.

Table 10. Lightning Creek highway crossing(s).

Number of crossings	1
Location	km 23.1
Drainage structure	2 Culverts (metal)
Culvert #1	Ø 0.9 m
Auxiliary culvert #2	Ø 0.9 m

Site Description

Lightning Creek drains from the north and crosses the Silver Trail at km 23.1 through damaged (capacity reduction of about 20%) culverts before reaching farmland and, ultimately, the Stewart River. The creek was affected by aufeis formation upstream of the culverts during the winters of 2022-23 and 2023-24 (this is the opposite of what was observed at km 17.1). Both culverts were submerged by ice, suggesting that the staggered culvert mitigation strategy does not work efficiently. It seems that this creek may carry less heat than those located at km 3.9 and 17.1. At the end of winter 2023-2024, the high backwater on the upstream side of the Trail drowned the steam pipe heads and caused significant damage to the road embankment (closed lane for several weeks).

Monitoring program

- Timelapse camera
- Field observations

Current mitigation

- 1 heat tape
- 2 steaming pipes
- Auxiliary culvert

Proposed mitigation

- Removal of debris at the culvert head
- Removal of steam pipe system (it may extract heat and initiate icing events)
- Installation of heat tape connected to the grid and operated as needed
- *Addition of an auxiliary culvert made of plastic at a higher elevation (2024?)
- *Addition of insulating snow on the ice cover after operating the heat tape
- *Rising the water depth upstream of the culvert to promote the early formation of an ice cover

* Experimental solution to further discuss

4.2.4 Glacier Hill Creek (km 60.1)

Figure 32. Timelapse photo of Glacier Hill Creek (km 60.1) culvert heads on Oct 12, 2023.

Figure 33. Timelapse photo of Glacier Hill Creek (km 60.1) culvert heads on Jan 1, 2024.

Table 11. Glacier Hill Creek (km 60) highway crossing(s).

Number of crossings	1
Location	Km 60
Drainage structure	1 Culverts (metal)
Culvert #1	Ø 0.9 m

Site Description

Glacier Hill Creek drains from the east in an area referred to as "glacier hill," reaching the Silver Trail at km 60.1. The site, a low-gradient wetland, has developed significant aufeis in the past (as stated by HPW personnel), including during the winters of 2022-23 and 2023-24. The culvert seems to be responsible for this situation. Additional overflow soon compromises road safety, requiring frequent ice removal and steaming. Repairs to the road embankment along the culvert have also been required. In the spring of 2023, snowmelt overflow was carried by the east ditch to km 61.4, flooding segments of the eastbound lane. Fine sedimentation also seems to represent a challenge to mitigate.

Monitoring program

- Timelapse camera (2023-2024)
- Field observations

Current mitigation

- 2 steam pipes
- Steaming using a portable hose
- Ice excavation from the ditch and building of ice berms to contain overflow (this measure has proven to not be efficient)

Proposed mitigation

- Installation of a short heat tape operated as needed
- *Snow insulation was proposed by HPW personnel, and this could be tested. If not successful, a snow berm could be built to temporarily control overflow.
- Installation of heat tape connected to the grid or to solar panels (in the spring) and operated as needed
- *Heat tape and wood posts in the ditch from km 60 to km 60.3
- *Replacement of culvert by a small bridge and restoration of the Creek channel

* Experimental solutions to further discuss

4.2.5 Unnamed Creek (km 81.6)

Figure 34. Timelapse camera photo of Unnamed Creek culvert head on Oct 12, 2023.

Figure 35. Timelapse camera photo of Unnamed Creek culvert head on Jan 25, 2024.

Figure 36. Overflow and glaciation on the Silver Trail at km 81.6 on Feb. 13, 2023.

Table 12. Unnamed Creek (km 81.6) highway crossing(s).

Number of crossings	1
Location	km 81.6
Drainage structure	1 Culverts (metal)
Culvert #1	Ø 0.75 m

Site Description

A very shallow creek drains from the east, intercepting the Silver Trail at km 81.6. Many broken steam pipes encumber this site in the upstream ditch, and an excavator has damaged the culvert head. Significant stream-fed aufeis formed at this site during the last three winters of observation, resulting in a flooded and damaged road embankment (Figure 36). The culvert seems to be initiating and causing some of the aufeis. During the winter of 2023-2024, groundwater seepage from the right slope (when looking upstream) contributed to the development of a massive icing mount.

Monitoring program

- Timelapse camera
- Field observations

Current mitigation

- 2 steam pipes
- Ice excavation to restore aufeis storage capacity and road grading to remove ice accumulation

Proposed mitigation

- Removal of all existing steam pipes as they probably contribute to aufeis development in the culvert
- Installation of a short heat tape operated as needed
- Installation of a vertical graded rod or pole at the head of the culvert
- *Rising the water depth upstream of the culvert and install wood posts to promote the early formation of an ice cover
- *Replacement of metal culvert by two plastic culverts, one to be entirely blocked at its upstream end each fall

* Experimental solutions to further discuss

4.2.6 Corkery Creek (km 83.2)

Figure 37. Photo of Corkery Creek at high flow on October 11, 2023.

Figure 38. Photo of Corkery Creek with about 5 m of backwater on March 22, 2022.

Table 13. Corkery Creek highway crossing(s).

Number of crossings	1
Location	km 83.2
Drainage structure	1 Culverts (metal)
Culvert #1	Ø 1.9 m

Site Description

Corkery Creek drains east in a deep and steep canyon, intercepting the Silver Trail at km 83.2. In winters 2021-2022 and 2023-2024, stream-fed aufeis blocked the culvert, resulting in a multimeter backwater that could have impacted the road infrastructure. It cannot be excluded that snow plowing initiated the culvert blockage. During the spring of 2022, the collapse of this aufeis broke trees as high as 5 m above the creek bed. Though aufeis formed in winter 2022-2023, the culvert was not entirely blocked (Figure 38). The culvert is clearly responsible for the aufeis development and consequent backwater.

Monitoring program

- Timelapse camera
- Water level/temperature sensor
- Field observations

Current mitigation

- 1 heat tape in a steam pipe (apparently not used)

Proposed mitigation

- Improvement of snow management (reduce velocity of snowplows so that the snow does not block the culvert inlet)
- Extension of heat tape connector to improve accessibility from the road
- Connect heat tape to a generator or a solar panel (during later winter), as needed, when backwater is first observed
- Consider removing heat tape from steam pipe to reduce heat loss
- *Addition of an auxiliary culvert made of plastic at higher elevation
- *Prevent cold air from entering downstream end of culvert

* Experimental solution to further discuss

4.2.7 Unnamed Creek (km 98.3)

Figure 39. Timelapse camera photo of Unnamed Creek (km 98.3) on Oct 14, 2022.

Figure 40. Timelapse camera photo of Unnamed Creek (km 98.3) on Mar 14, 2023.

Table 14. Unnamed Creek (km 98.3) highway crossing(s).

Number of crossings	1
Location	km 98.3
Drainage structure	1 Culverts (metal)
Culvert #1	Ø 0.25 m

Site Description

An unnamed creek drains down a steep hill from the southeast, intercepting the Silver Trail at km 98.3. This creek is fed by groundwater seeps, is poorly channelized and is potentially intermittent. In winter 2021-2022 and 2023-2024, this site experienced late-winter aufeis development that required multiple steaming interventions (and ice removal). The vertical buffer between the creek bed and the road surface is less than 1 m. This means mitigation interventions may be needed within a few hours following culvert blockage by ice. Overflow can also occur from hillside seepage (see following subsection).

Monitoring program

- Timelapse camera
- Field observations

Current mitigation

- Multiple steam pipes
- Two heat tapes (condition uncertain)
- Excavation of ice in the ditch and grading to remove ice from the road surface

Proposed mitigation

- Removal of all steam pipes (they can initiate and exacerbate ice formation)
- Installation of a single heat tape connected to a generator as needed
- *Improvement of drainage at the mining site located upslope of the Silver Trail
- *Groundwater drainage or dewatering
- *Replacement of metal culvert by two plastic culverts, one to be entirely blocked at its upstream end each fall

* Experimental solutions to further discuss

4.2.8 Groundwater seep (km 98.8)

Figure 41. Timelapse camera photo of Unnamed Creek (km 98.8) on Oct 12, 2023.

Figure 42. Timelapse camera photo of Unnamed Creek (km 98.8) on Jan 1, 2024.

Table 15. Unnamed Creek (km 98.8) highway crossing(s).

Number of crossings	1
Location	km 98.8
Drainage structure	1 Culverts (metal)
Culvert #1	Ø 0.6 m

Site Description

Groundwater surfaces from the hill that lies immediately against the Silver Trail. This represents a typical problematic hydrological process along the upper Silver Trail near Elsa and Keno during winter months, potentially because of the presence of permafrost but also because of upslope mining activity. Aufeis forms in the ditch every winter, including at the km 98.8 culvert. Overflow may occur even if a portion of the seepage water reaches the culvert. The end of the culvert has been damaged by machinery in recent years. During the winter of 2023-2024, steaming interventions were needed more than 10 times at this single location.

Monitoring program

- Timelapse camera (2023-2024)
- Field observations

Current mitigation

- Steam pipes (unknown condition)
- Heat rape (unknown condition)
- Steaming using a portable hose
- Excavation of the aufeis and grading of the road surface to remove ice accumulation

Proposed mitigation

- Removal of all steam pipes (they can initiate and exacerbate ice formation)
- Installation of a single heat tape connected to a generator as needed
- *Improvement of drainage at the mining site located upslope of the Silver Trail
- *Groundwater dewatering using a network of underground pipes
- *Excavation of a frost belt upslope of the Silver Trail

* Experimental solutions to further discuss

4.2.9 Galkeno Creek (km 107.5)

Figure 43. Timelapse camera photo of Christal Creek Oct 14, 2022.

Figure 44. Timelapse camera photo of Christal Creek on February 24, 2023.

Table 16. Christal Creek highway crossing(s).

Number of crossings	2	
Location	km 107.4 (@ access road)	km 107.4 (@ Silver Trail)
Drainage structure	1 Culvert (metal)	1 Culvert (metal)
Culvert #1	Ø 0.6 m	Ø 0.6 m

Site Description

This creek flows in a ditch along the short Galkeno Road, a couple of km before entering Keno. Aufeis has been reported at this site several years in a row. It seems that groundwater reaches this headwater channel during winter, potentially because of mining disturbance upslope. Two culverts carry water from the creek: one across the Silvert Trail (culvert # 5928, the main culvert) and another across Galkeno Road (# 6446), leading the water towards the nearby Christal Creek.

Steam pipes have been installed in both culverts, but, in recent winters, ice excavation has been needed to prevent overflow on the Silvert Trail. It is possible that steam pipes have only been partially operational. Note that heat tapes connected to the grid have been installed downstream in the large Christal Creek culvert. Readings from the power meter suggest that negligeable energy has been used in recent winters, potentially because heat tapes are damaged.

Monitoring program

- Timelapse camera (winter 2022-23)
- Field observations

Current mitigation

- Steam pipes
- Excavation (as required)
- Grading to remove ice from the Silver Trail

Proposed mitigation

- Investigation of winter water source
- Removal of steam pipes
- Heat tape connected to the same grid as the Christal Creek setup
- *Addition of auxiliary plastic culverts
- *Morphological modification of the ditch (alternating deep pools and rock steps)

* Experimental solutions to further discuss

4.3 Klondike Highway

The Klondike Highway is the third transportation corridor of the Yukon that is part of this project. The highway extends from Skagway, Alaska, to Dawson for a total length of 714 km. Given the different geographies along the highway, it is unsurprising that aufeis form at sites presenting different geological and hydrological characteristics. Bear Creek, located at Mount Lorne, just south of Whitehorse, was among the first watercourses where our research team noticed problematic aufeis formation. It seems that mitigation at that site yields positive results, although the Creek carries a significant amount of sediment, so its channel may change over relatively short periods.

Another example where aufeis formation is problematic is at km 338.6, located south of Carmacks. At that site, a diesel generator is operated regularly during winter to prevent overflow from a small creek to reach the highway. A handful of other sites have been included in this report subsection and are presented in Figure 45.

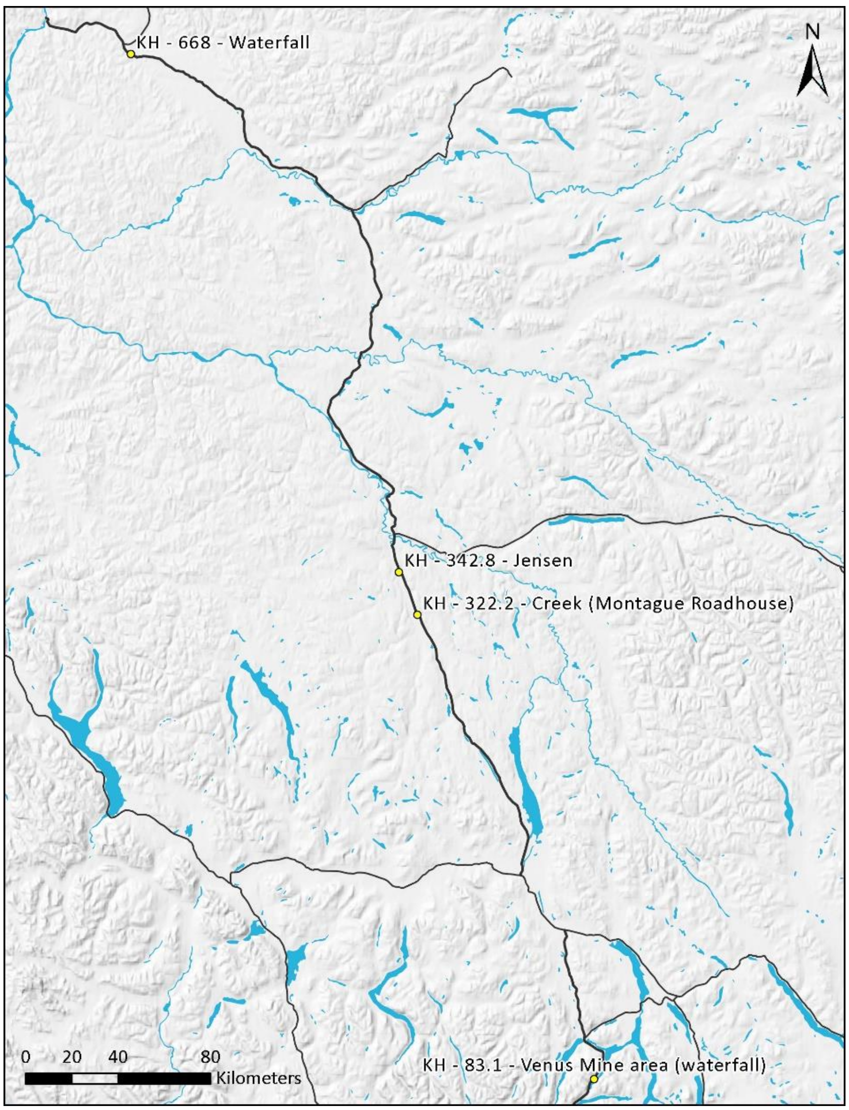

Figure 45. Research sites (observation, monitoring, mitigation) along the Klondike Highway.

4.3.1 Venus Mine area (km 83.1)

Figure 46. Looking south from rock cliff area below Venus Mine, January 7, 2023.

Figure 47. Looking north from rock cliff area below Venus Mine, January 7, 2023.

Table 17. Venus Mine Creek highway crossing(s).

Number of crossings	1 (upslope)
Location	km 83.1
Drainage structure	1 Culverts (metal)
Culvert #1	Ø 1.0 m

Site description

A small amount of water flows from the decommissioned Venus Mine area down the rock face beside the highway. This is also an avalanche and a rockfall area. During winter, the water flow does not stop and creates a frozen waterfall. Unfortunately, the flow soon fills the shallow ditch, and the overflow can affect the highway. The icy surface represents a hazard for the freight traffic from Skagway to Whitehorse, in addition to those travelling towards the White Pass area during the winter months.

The frequency of aufeis formation at that location and the water source have not been confirmed, but groundwater pathways have likely been disturbed by historical mining and road construction at that location, causing aufeis formation every winter.

Monitoring program

- Opportunistic field observations

Current mitigation

- Unknown, but must involve grading the road surface to control ice accumulation.

Proposed mitigation

- Upon investigation of water source, taking advantage of historical mining roads and trails, divert water northeast towards a larger, more defined creek channel and associated culvert (presented in Table 17) located a few hundred meters upslope.
- Installation of a heat tape connected to solar panels, if needed

4.3.2 Unknown Creek (km 322.2)

Figure 48. Head of three culverts in the Montague roadhouse rest area in October 2022 (culverts are mostly blocked by debris).

Figure 49. Same location at in Figure 45, but looking upstream, in May 2022 (creek is full of aufeis, overflow was redirected in dich to the next culvert located 1 km away).

Table 18. Montague Roadhouse rest area stream crossing under North Klondike Highway.

Number of crossings	3
Location	km 322.2
Drainage structure	3 Culverts (metal)
Culvert #1	Ø 1.2 m
Culvert #2	Ø 1.2 m
Culvert #3	Ø 0.6 m

Site description

A creek drains west across the Montague Roadhouse Rest Area parking near km 322. The creek carries a significant amount of sediment and organic material. As a result, all three culverts have been blocked at more than 50% in recent years. It seems that the steam pipes installed in the two larger culverts play a significant role in intercepting woody debris and that sedimentation occurs upstream as a result.

The creek is shallow and must form an ice-shell (fixed and grounded) type of ice cover at the onset of winter. Overflow events are caused by upstream pressurized conditions or culvert blockage by aufeis. In the spring of 2022, snowmelt flow was observed in the parking area and along the highway down to the culvert located at km 321.1.

Monitoring program

- Field observations

Current mitigation

- Two steam pipes (condition unknown)

Proposed mitigation

- Annual removal of woody debris and sediment accumulation (gravel bars) upstream of the culverts
- Removal of steam pipes and replacement by a single heat tape
- Blockage of one culvert during the fall with an inflatable or mechanical (or snow) device and removal of the device at the onset of snowmelt
- *Construction of a small sediment retention structure upstream of the highway and stabilization of the channel near the culverts head.

* Experimental solution to further discuss

4.3.3 Jensen Creek (km 342.8)

Figure 50. Ice excavation in March 2021 upstream of Jensen Creek culvert.

Figure 51. Newly excavated Jensen Creek channel upstream of culvert on Sept 18, 2023.

Table 19. Jensen Creek highway crossing(s).

Number of crossings	1
Location	km 342.8
Drainage structure	1 Culverts (metal)
Arch culvert #1	3.7 m (span)
Auxiliary culvert #2	Ø 1.0 approx.

Site Description

Jensen Creek is a steep watercourse draining southwest towards the highway. Erodible slopes extend over 4 km upstream, and there is an apparent slump 5 km upstream of the highway from where fine sediment could originate. Consequently, Jensen Creek is uniquely turbid, flowing through a braided section that extends both upstream and downstream of the culvert and where high sediment deposition rates occur. Stream-fed aufeis develop each winter at this site and across the culvert. Complete culvert blockage occurs every second winter or so. The aufeis in the arch culvert persists well into the spring freshet, leading to extended flood potential in April and May. An alternated flow path composed of culverts and ditches has been built along the highway to guide overflow to downslope culverts, but this infrastructure is also affected by aufeis formation.

Monitoring program

- Timelapse camera
- Field observations

Current mitigation

- Excavation of aufeis (2021 and 2022)
- Steam line (damaged prior to 2021 and not replaced) or portable steaming hose (at least in 2021 and 2024)
- Local channel geometry modification (2023, Figure 51)

Proposed mitigation

- Further documentation of the creek sediment and ice dynamics
- *Installation of heated drains in the creek bed
- *Construction of a large sediment storage structure upstream of the culvert
- *Replacement of the culvert by a bridge

* Experimental solutions to discuss further

4.3.4 Unknown Creek (km 668)

Figure 52. Small Creek ending with a waterfall just upstream of the North Klondike Highway at km 668 on Sept 18, 2023.

Figure 53. Frozen waterfall and massive aufeis accumulation upstream of North Klondike Highway on May 7, 2021.

Table 20. Creek highway crossing(s).

Number of crossings	1
Location	km 668
Drainage structure	1 Culverts (metal)
Arch culvert #1	Ø 0.8 m

Site Description

This creek drains a steep watershed and ends in a short waterfall before entering a culvert leading immediately to a secondary channel of the Klondike River. It is uncertain whether water remains flowing during the entire winter period in most years, but aufeis development before the spring freshet seems common, if not annual. This represents a particularly challenging site for glaciation mitigation as most of the snowmelt flows reach the site at the surface of the ice. Since the site is mostly in the shade of the mountain, any water reaching the highway crossing flows on a cold, subfreezing surface well into May. In addition, it appears that sediment often accumulates upstream and downstream of the culvert, whose outlet is located in riprap below the highway. Organic material, including woody debris, poses an additional maintenance challenge.

Monitoring program

- Field observations

Current mitigation

- At least one steam pipe (condition unknown)
- At least one heat tape (temporary setup)
- Grading of the ice on the highway surface

Proposed mitigation

- Further documentation of the creek dynamics
- *Complete redesign of the creek outlet, including bank stabilization structures
- Strategic setup and operation of a heat tape (*heat from the Klondike River could be used through a heat pump or directly through hoses and pumps)
- *Drilling of multiple holes in the aufeis upstream of the culvert during snowmelt.

* Experimental solutions

5 REPORT SUMMARY AND STEPS FORWARD

This report presents observations about aufeis (glaciation) development at several sites along three transportation corridors in Yukon: The Dempster Highway, the Silver Trail, and the Klondike Highway. Since 2021, our research team has documented weather and hydrological conditions leading to winter overflow events and aufeis formation at different locations along these Highways. Hydrological processes leading to overflow events have also been described and summarized in a Turcotte et al. (2023a) publication. While it is not currently possible to accurately foresee and forecast the timing and intensity of overflow events and consequent aufeis development episodes at specific sites, some conditions are known to trigger or promote such processes. Our research team is committed to monitoring several stream crossings during a few additional winters to make aufeis development more predictable.

As more knowledge about icing and aufeis is being developed, our team is now ready to test some mitigation measures in collaboration with HPW. Our research team has prepared a review paper (Turcotte et al., 2023b) about risk reduction strategies for aufeis along transportation corridors, considering different hydrological contexts (e.g., groundwater to large creeks, different types of hydraulic structures). Some of the mitigation measures mentioned in Section 4 are relatively easy to deploy or apply and can be tested by our research team starting in the fall of 2024 with a low probability of worsening overflow rates and aufeis thickness. Other, structural or permanent types of interventions are currently being discussed with HPW-TMB. The performance of additional measures could eventually be simulated with numerical models.

The impact of climate change on aufeis development remains uncertain. However, it is known that specific weather patterns, such as wet falls and mid-winter warm spells, could exacerbate the intensity of overflow events in specific hydrological contexts. Therefore, the cost associated with aufeis mitigation along transportation corridors in the North is unlikely to decrease just because winters tend to be warmer. Therefore, the need to adopt effective, energy efficient, and environmentally friendly aufeis mitigation measures along transportation corridors can only remain, if it does not increase.

The YukonU Research Centre, Climate Change Research Group, Hydrology Team, is committed to continue working with partners and collaborators to better understand and reduce the risk associated with icing and aufeis near, against, or under roads and highways of the Yukon.

References

Turcotte B, Dubnick B, McKillop R, Ensom T., 2023a. Icing and aufeis in cold regions I: the origin of overflow. Canadian Journal of Civil Engineering. dx.doi.org/10.1139/cjce-2023-0057

Turcotte B, Dubnick B, McKillop R., 2023b. Icing and aufeis in cold regions II: consequences and mitigation. Canadian Journal of Civil Engineering. dx.doi.org/10.1139/cjce-2023-0119

LIST OF FIGURES

LIST OF TABLES