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Observations aufeis formation in Jarvis Creek, Alaska

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Jarvis Creek originates at the terminus of Jarvis Glacier on the north side of the Alaska Range. It flows northward for 35 miles through a narrow valley before passing onto military lands near Delta Junction, in central Alaska. The gradient of Jarvis Creek then lessens and it becomes a wide, braided channel as it flows across a large glacial outwash fan. The outwash fan deposits are quite permeable and large quantities of the Jarvis Creek flow infiltrates to the groundwater table, resulting in a decrease in discharge in the downstream direction. The wide alluvial creek bed, low flow rates, and very cold air temperatures combine to contribute to the formation of massive aufeis deposits. The aufeis deposits form first each winter in the channel itself. The aufeis then expands into the eastern overbank area and covers a large area outside of Jarvis Creek itself. These aufeis deposits cause overbank flooding during the late winter but especially at the time of the spring freshet. This paper reports on the field data collection program to monitor the aufeis deposit over the winter of 2007-08 and 2008-09. This program included monitoring the aufeis thickness and extent, searching for the water flow paths from Jarvis Creek to the outer edges of the aufeis deposit, and investigating high resolution satellite imagery. The implications of these observations on a model of aufeis formation are described.

1. Introduction

Jarvis Creek originates at the terminus of Jarvis Glacier on the north side of the Alaska Range. Its total length is 58 km and it drains an area of about 640 km^2. It flows northward through a narrow valley before passing onto military lands near Delta Junction, in central Alaska (Figure 1). These military lands contain important training grounds for the US Army. Aufeis formation on Jarvis Creek has long been recognized (Holmes and Benninghoff 1957). In some years, the aufeis formation extends into the east overbank of Jarvis Creek and in severe cases nearly reaches some training facilities. In every year, the aufeis remains in place for a period of time after the spring runoff begins in late April and May. The aufeis blocks the channel and is a major contributor, if not the single cause, of flooding of the training facilities east of the creek.

This report is a brief summary of some of the observations that have been made of aufeis formation in Jarvis Creek. The mechanism of aufeis formation is well known: the freezing of water flowing over the top surface of ice and it has been observed in the field and studied in the laboratory (see for example Carey 1973, Harden et al 1977, Hu and Pollard 1997a, Kane 1981, Schohl and Ettema 1986, 1990). Aufeis can occur under a number of conditions; and it is often associated with springs that convey water to the surface all winter. In the case of Jarvis Creek the aufeis is formed in a braided channel and little is known about aufeis formation in braided channels (Hu and Pollard 1997b). In this report we provide a brief background on the surface geology, climate and hydrology of Jarvis Creek; describe the initial freezeup of Jarvis Creek and the start of the aufeis formation, the channel aufeis, ice blisters, and the overbank aufeis formation.

2. Background

The gradient of Jarvis Creek lessens as it enters the military lands and it becomes a wide, braided channel as it flows across a large glacial outwash fan. In this reach the floodplain consists of broad flat river terraces several meters higher in elevation than the active braided stream channel. The thick deposits of permeable gravel sediments in the alluvial fans and floodplains allow for substantial infiltration of groundwater. Observations (Holmes and Benninghoff 1957) suggest that in its lower reaches Jarvis Creek is *influent*, losing water to the groundwater system. In addition to the permeable gravel sediments, the valley glaciers that extended out from the Alaska Range in the recent geologic past left extensive terminal glacial moraine deposits in specific well-defined areas of the Jarvis Creek floodplain (Harmon et al 2008, Coulter et al 1965). They are characterized by hummocky surfaces and contain depressions, lakes, ponds, and wetlands, and hills and terraces of sediment. The till sediments of the glacial moraines are poorly sorted, ranging from silts to boulders in size. The hydraulic conductivities of the moraine sediments are apparently quite low as evidenced by the lakes, ponds and wetlands that lay in the areas identified as glacial moraines. These can be contrasted with the high hydraulic conductivities of the permeable gravel sediments in the alluvial fans and floodplains which lay immediately adjacent to the glacial moraines. It is interesting to note that the only reach of Jarvis Creek with adjacent mapped glacial moraine on both its east and west banks corresponds to the reach where aufeis is observed. With glacial moraine on both its east and west banks it is easy to image that this reach of Jarvis Creek may actually cross glacial moraine before entering the alluvial fan immediately downstream. The relatively low hydraulic conductivities of the moraine sediments would prevent Jarvis Creek from losing water to the ground water table below and contribute to the formation of aufeis.

The air temperature in the Jarvis Creek watershed is generally frigid in winter (Table 1). Below 0°C temperatures have been recorded in every month except July. The average monthly temperature is below 0°C from October through April, with average monthly temperatures less than -20°C during December, January, and February. Daily extreme cold temperatures of less than -40°C have been recorded in November through March. The average annual precipitation is about 290mm with over half the annual precipitation falling in June through August.

Very few flow measurements have been made in the Jarvis Creek (Holmes and Benninghoff 1957, Wilcox 1980) (Figure 2). Most flow measurements were made at the Richardson Bridge, the only bridge crossing Jarvis Creek, located about 1300 m upstream of its mouth on the Delta River and about 5 km downstream of the study reach. Jarvis Creek enters the Delta River about 10 miles above the mouth of the Delta River on the Tanana River. There is generally no flow observed at this location from November through March, although episodic periods of flow have been observed apparently corresponding with warm periods during these months. The maximum flow recorded at the Richardson Bridge site is about $25m^3s^{-1}$.

Table 1. Climate data for Jarvis Creek (Big Delta Airport (1948-2007))

Month	Monthly Average Temperature °C			Daily Extreme Temperature °C		Monthly Precipitation mm		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
October	-0.1	-7.5	-3.8	23.3	-39.4	15.7	52.6	0.0
November	-10.1	-17.7	-13.8	11.1	-43.9	11.7	71.6	0.5
December	-14.7	-22.6	-18.7	12.8	-52.2	9.1	65.3	0.0
January	-15.7	-23.7	-19.6	8.9	-52.8	8.1	34.3	0.0
February	-10.7	-20.2	-15.5	10.6	-51.1	7.9	63.0	0.0
March	-4.6	-16.7	-10.6	14.4	-45.0	6.4	29.0	0.0
April	4.9	-6.4	-0.7	22.2	-38.3	6.1	50.3	0.0
May	13.9	2.8	8.3	32.2	-18.3	22.4	78.0	0.5
June	19.6	8.6	14.1	33.3	-1.1	57.4	137.7	7.9
July	20.8	10.3	15.6	32.8	0.0	67.1	157.0	14.2
August	18.1	7.7	12.9	32.2	-5.6	50.3	122.2	13.5
September	11.3	1.9	6.6	26.1	-18.9	27.7	76.5	3.6
Annual						289.8		

3. Aufeis Observation

. Observations of aufeis were made on Jarvis Creek during the winters of 2006-07, 2007-08, and 2008-09. In addition a few observations of aufeis formation were recorded during the winter of 1955-56. (Holmes and Benninghoff 1957). Large variability in aufeis formation was observed between winters. Aufeis covered extensive areas of the overbank east of the channel during the winters of 06-07 and 07-08, but little overbank aufeis was observed in the same area during the winter of 08-09. Measurements of the overbank aufeis were made during the winter of 07-08 and are described below. Five surveys of the aufeis area of Jarvis Creek were made during the winter of 08-09 starting in October. The information collected during these surveys and during the previous winters forms the basis for the description below.

Initial Freezeup. The many braided channels of Jarvis Creek were observed to initially freezeup through the accumulation of frazil ice at their surface and with anchor ice covering the channel substrate. The water levels rose in each channel, apparently in response to the formation of the ice covers. Channels with higher water surface elevations spilled out over the gravel bars into channels with lower elevations. In several instances the spillover flow was observed to “ice over” in response to the frigid air temperatures and pressurized conduit type flow between the channels of the braided channels was observed. The pressurized flow was recognized through the upwelling of water through openings in the ice cover at the downstream ends of these conduits. The implication is that pressurized flow is a feature of the ice formation in Jarvis Creek starting from the initial freezeup. The exchange of flow between the braided channels promotes aufeis formation by directing flow to channels with relatively low water surface elevations after the initial ice cover has formed. The braided channels are relatively narrow and the ice cover can apparently resist the water pressure on its underside by bridging across the channel. The net result is that water is likely to spill out over the in-place ice covers, both within channels and between channels, starting very soon after ice formation has been initiated. The frigid air temperatures cause water flowing over the ice to freeze in relatively short distances (Schohl and Ettema 1986, 1990).

Channel Aufeis. The active flow area of Jarvis Creek was observed to be progressively covered with aufeis during the winter of 2008-09. Flow was observed at the surface of the aufeis in two forms: sheet flow (Figure 3) or flow channels (Figure 4). Sheet flow was very shallow {~1cm) and quickly froze. Active flow channels indicated evidence of icing over and eroding and cutting into the underlying ice surface. The conveyance of water to the surface was through fractures likely to have been caused by thermal contraction of the ice (Hu and Pollard 1997b) or other fractures. Often no visible water passageway to the surface could be found in areas where sheet flow was actively occurring. Although conduits of flowing water in the aufeis were not directly detected, the delivery of water to ice blisters (described next) and the surface flow, confirms their existence. The conduit lengths, the aufeis thickness, and the channel slope control the flow regime. This can be seen by noting that the pressure available to drive flow to the surface, P_a, is $P_a = \rho_w g\left(\eta_0 + \bar{L}(t)S\right)$, where $\bar{L}(t)$ = the conduit length (which may be a function of time, t); ρ_w = density of water; g = gravity; S = mean channel slope and η_0 = the aufeis thickness at the upstream end of the conduit (assuming that the conduit connects to the surface). Water will not be able to reach the surface of the aufeis if it is thicker than ($\eta_0 + \bar{L}(t)S$). This is in line with the statement of Hu and Pollard (1997b) “Furthermore, as icing height is increased by overflow events, the elevation of the damming zone will continuously be promoted upstream.”

Observations were made of the aufeis surface elevation along two transects that were made across an active flow area. The measurements were made using a differential GPS unit. The transect locations are shown in Figure 5. The observations were made on 2/12/2009 and 3/20/2009 and the surface elevations are shown in Figure 6. The origin of each transect was its western end and its eastern end extended to the bank of the active flow area. At this location, the aufeis had extended into the overbank section on the eastern side of the channel. It can be seen that on each date, the upstream transect was at a slightly higher elevation overall than the downstream transect. On 2/12/2009 the ice surface of each transect slopes downward away from the channel bank more or less continuously, although the slope is not smooth for either transect. On 3/20/2009 a distinct “hump” or high point had formed in the ice surface about 50m to 100m west of the eastern bank. The aufeis surface sloped downwards in both the east and west direction away from this high point. In addition, the ice surface had increased in elevation roughly 0.75m to 1.0m between 12 February and 20 March.

Ice Blisters. Ice blisters (also known as ice mounds, icing mounds, river-ice mounds, or river blisters) are a common feature of the Arctic regions (Kovacs 1992). Ice blisters in Jarvis Creek were recognized by their general elevation rise (0.2-2m) above the surrounding ice and by the longitudinal crack along their length. Ice blisters were up to 35m wide and up to 60 meters long (Figure 7). Typically, their long axis was parallel to overall flow direction of the channel. They were found at random locations throughout the aufeis covered area. A range of conditions were found when the blisters were either broken or drilled into: dry and hollow, filled with air at a vacuum, filled with pressurized water, or completely frozen. Ice blisters are apparently formed when flow conduits were cut off downstream but still connected by a conduit upstream so that a pressure greater than hydrostatic was created.

Overbank Aufeis. Extensive areas of aufeis were observed during the winters of 2006-07 and 2007-08 but not during the winter of 2008-09. Measurements were made of the overbank aufeis thickness throughout the winter of 2007-08. One relatively small occurrence was observed during the winter of 2008-09, when water was observed flowing into the east overbank of Jarvis Creek in an upstream area on 11 February 2009 (the same location where the transects were made as shown in Figure 6). The surface flow was several centimeters thick on top of aufeis. The liquid flow extended about 50m into the overbank area (Figure 8). This overflow area was revisited the next day, on 12 February 2009. No liquid water was found at time. Evidence of upwelling of water around some tree trunks could be seen. A hole was knocked through the ice cover about 20m into the overbank where the ice had a “hollow” booming sound when walked on, indicating that it may be hollow underneath. The surface ice was approximately 50mm thick. There was a 50-75mm space beneath the ice cover filled with air and ice crystals that appeared to be similar to hoar frost. Liquid water was visible on the ground (Figure 9).

Measurements were made of the aufeis surface elevation and thickness in the overbank area at the locations shown in Figure 10 during the winter of 2007-08. This was an extensive overbank aufeis formation that occurred during the winter of 2006-07 and 2007-08 (Figure 11). The aufeis thicknesses are shown in Figure 12. The aufeis immediately along the Jarvis Creek bank (R01 through R04) was the thickest, with maximum thicknesses reaching 2.5m by early April 2008. It can be seen that the aufeis thickness did not decrease linearly from R01 to R04 but the aufeis surface elevations displayed a smooth linear decrease in the downstream direction (figure 13). The overbank aufeis thickness along the “trail” which runs more-or-less parallel to Jarvis Creek (T01-T05, T08-T11) is shown in Figure 14. It can be seen that the thicknesses varied considerably along the trail but that aufeis surface elevations displayed a relatively smooth decrease in the downstream direction (Figure 15).

6. Summary

Observations were made of the aufeis formation in Jarvis Creek. These observations reveal the complexity of the aufeis formation in the braided channel environment. Aufeis formation, while simple to describe in general terms, is nearly impossible to describe quantitatively. The extent, thickness, porosity, water flow capabilities of aufeis can not be reliably estimated. The general structure of the water flow through the aufeis, combining conduit flow with surface sheet and active flow and ice blisters changes throughout the winter as the ice surface rises and blisters are formed and abandoned. Further, detail observations, combined with a thorough understanding of the physical processes will be necessary before a complete description is developed.

7. References

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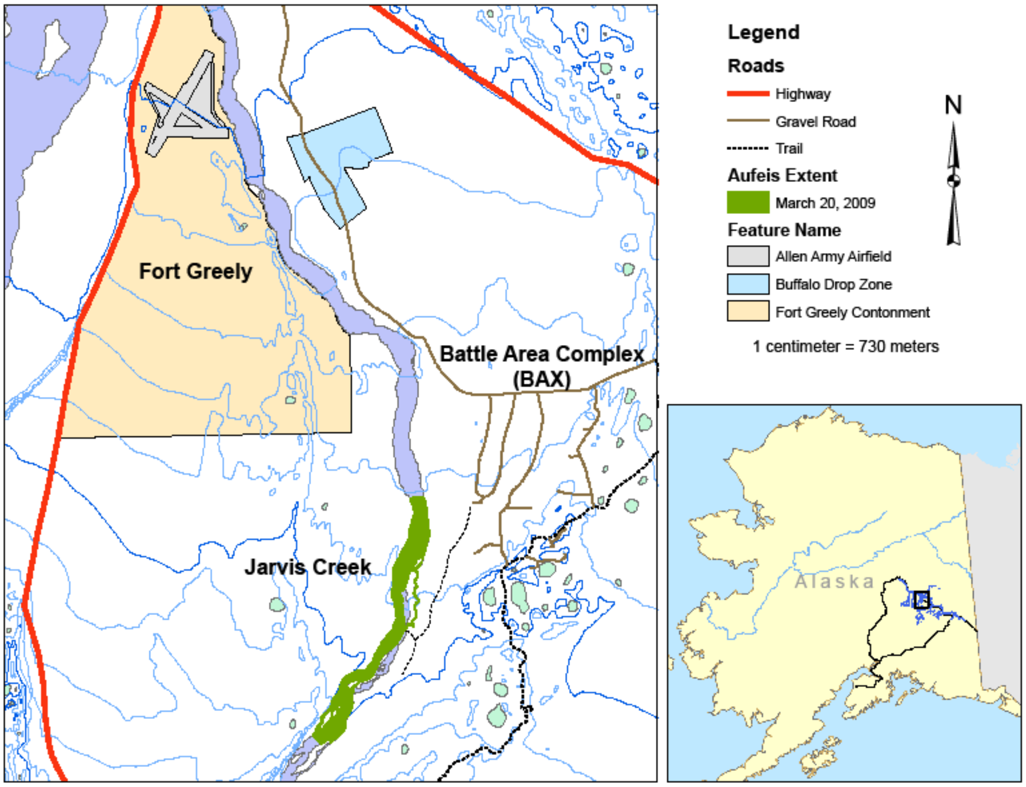

Figure 1. Overview of Jarvis Creek and the reach where aufeis forms. The flow is to the north.

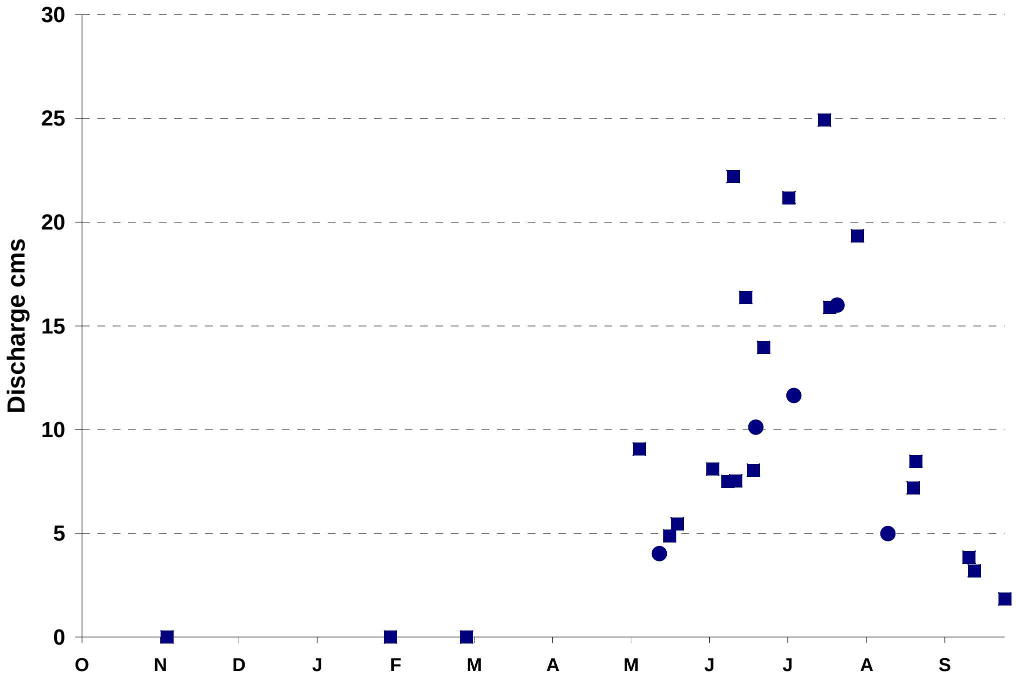

Figure 2. Discharge measurements at the Richardson Bridge. All measurements were by the USGS. Squares are the measurements reported by Wilcox (1980) and circles reported by Holmes and Benninghoff (1957)

Figure 3. Sheet flow on aufeis surface.

Figure 4 Active Flow channel on surface

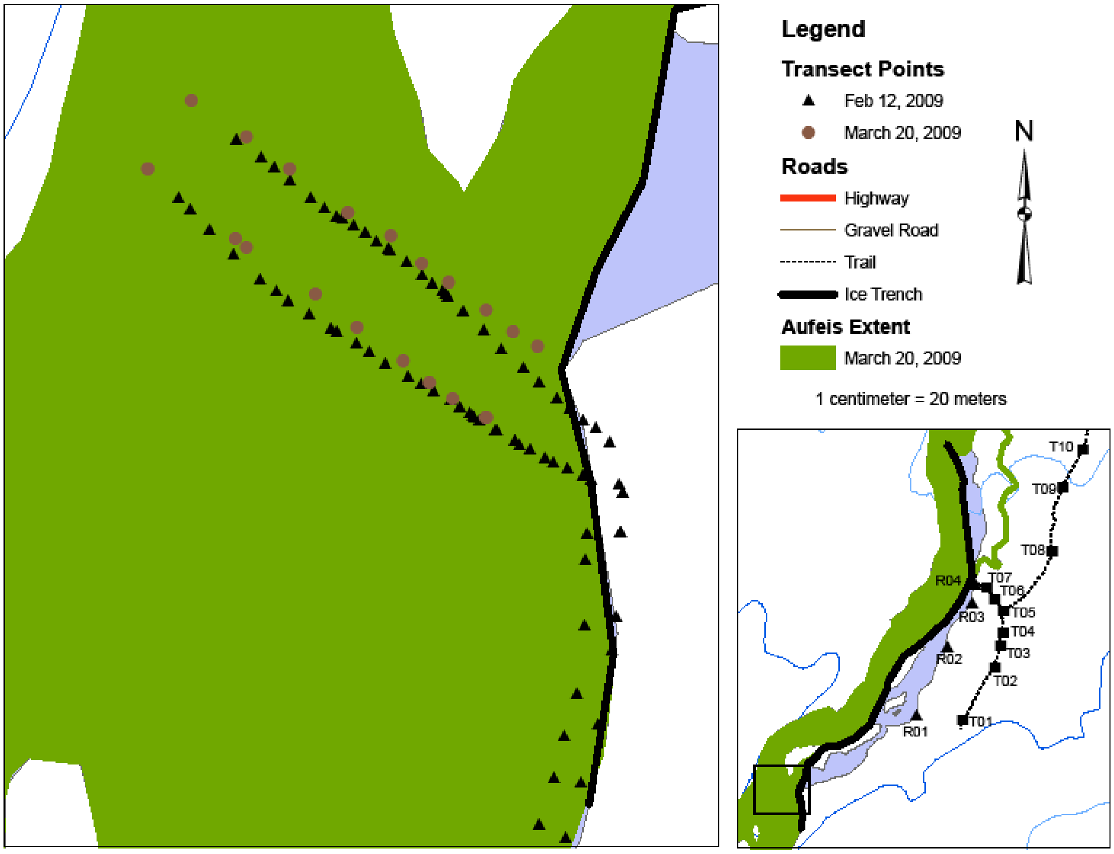

Figure 5. Location of transects.

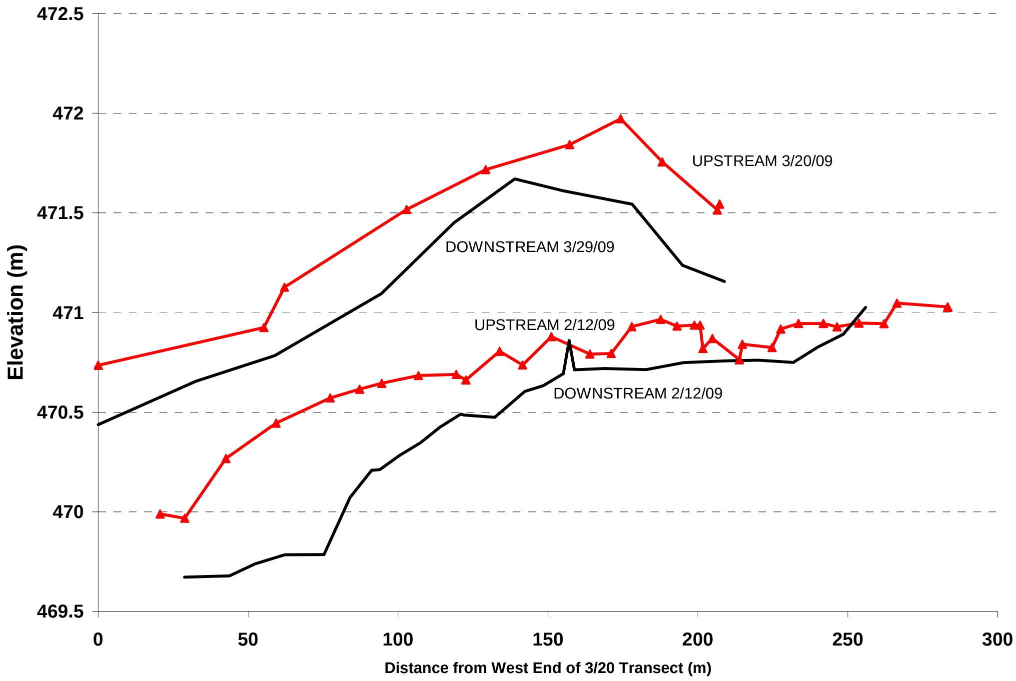

Figure 6. Surface elevations of transects on 2/12/09 and 3/20/09

Figure 7. Ice blister with surveyor.

Figure 8. Active surface flow into the overbank.

Figure 9. Jarvis Creek 12 Feb 2009. Solidified overflow into east bank. a.) Hole broken in aufeis, liquid water visible on bottom; b.) Close up of hole; c.) Hoar-frost like crystals visible under ice; d.) Surface ice layer turned upside down, exposing hoar frost like crystals.

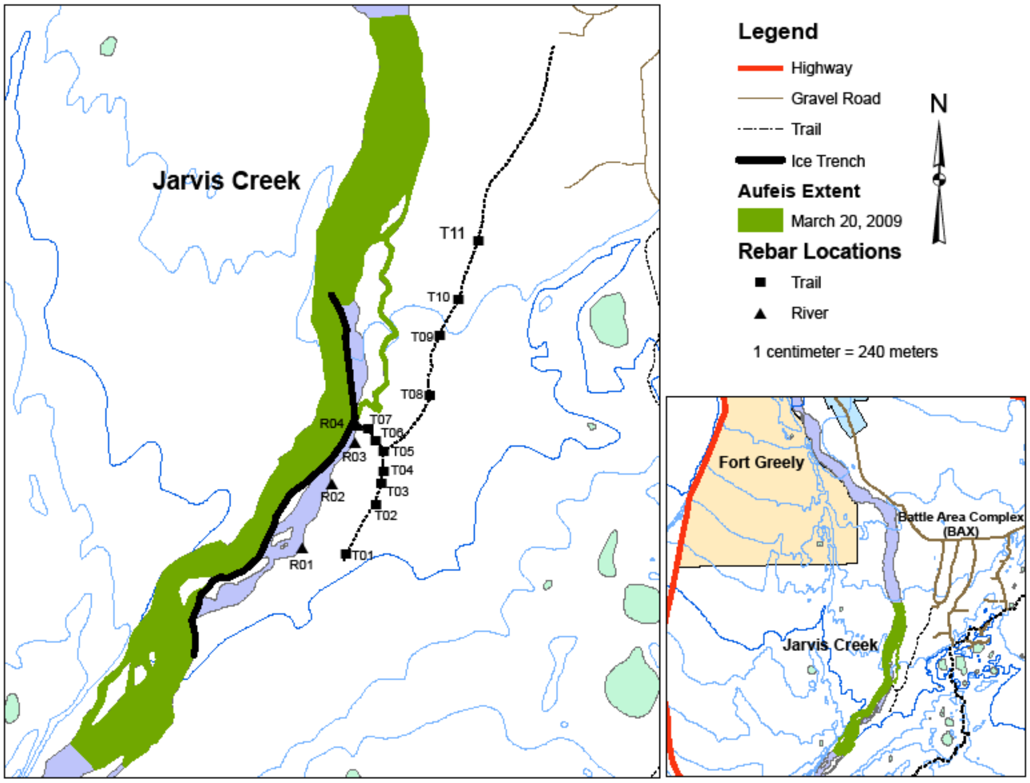

Figure 10. Locations in overbank where aufeis surface elevation and thickness were measured.

Figure 11. Snow has been cleared away to reveal outer edge of overbank aufeis on east bank. Jarvis Creek is several hundred meters ahead.

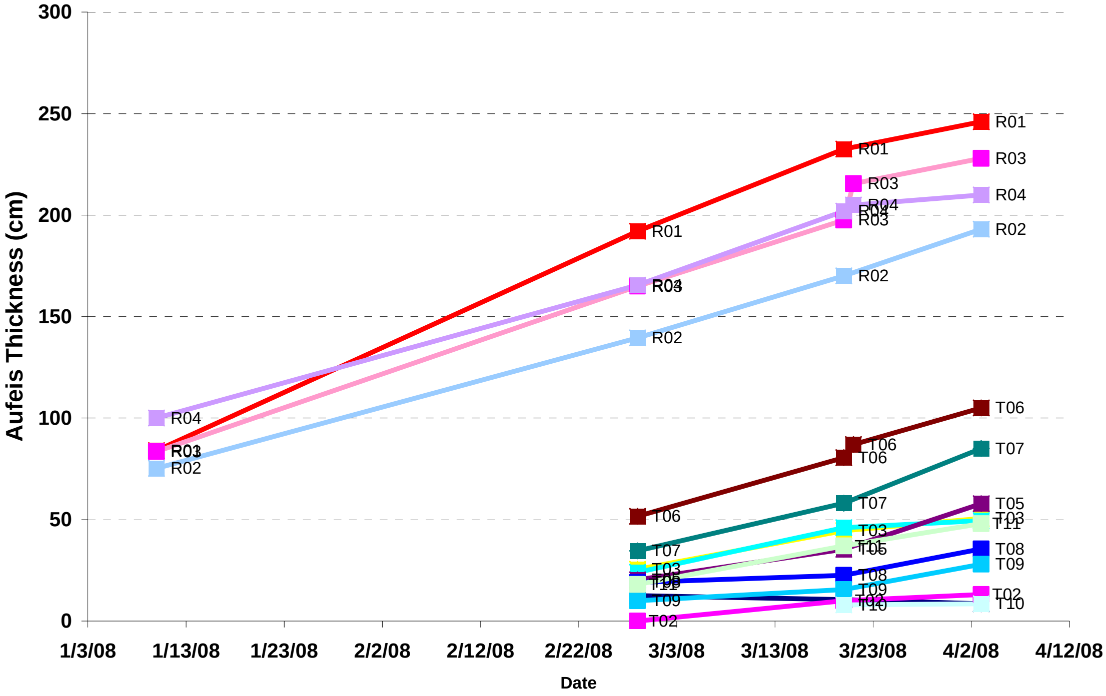

Figure 12. All aufeis thickness observations during the winter of 2007-08. All measurements in meters

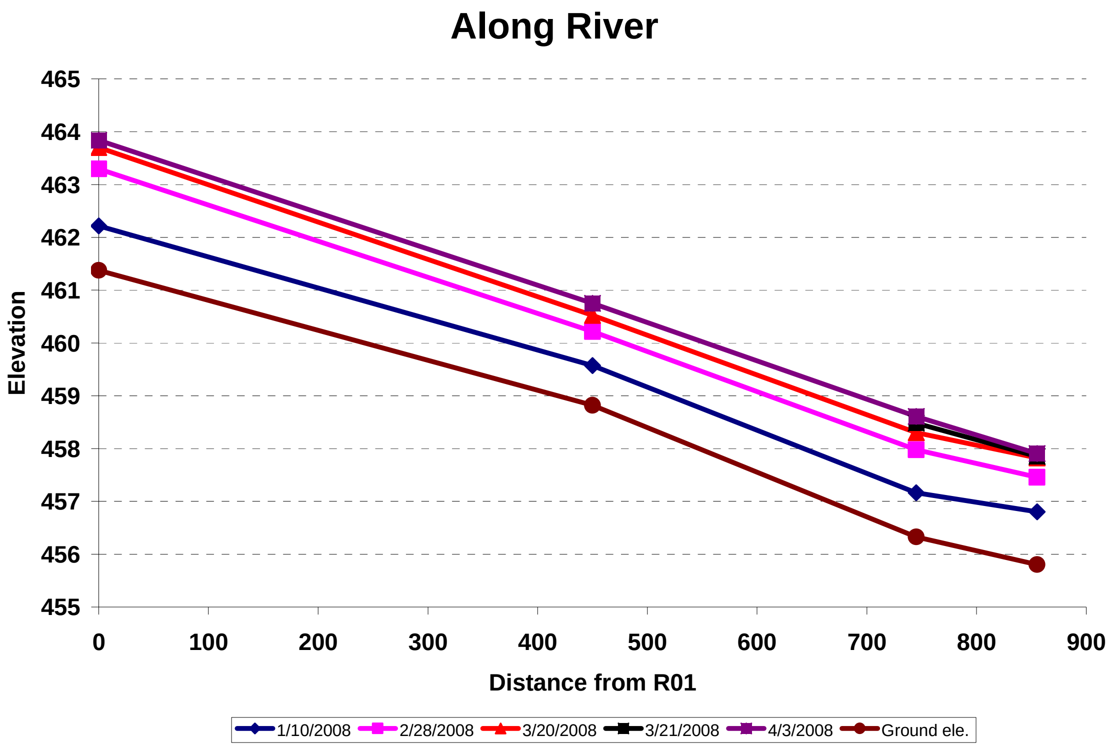

Figure 13. Aufeis surface elevation along river bank (R01-R04). All measurements in meters.

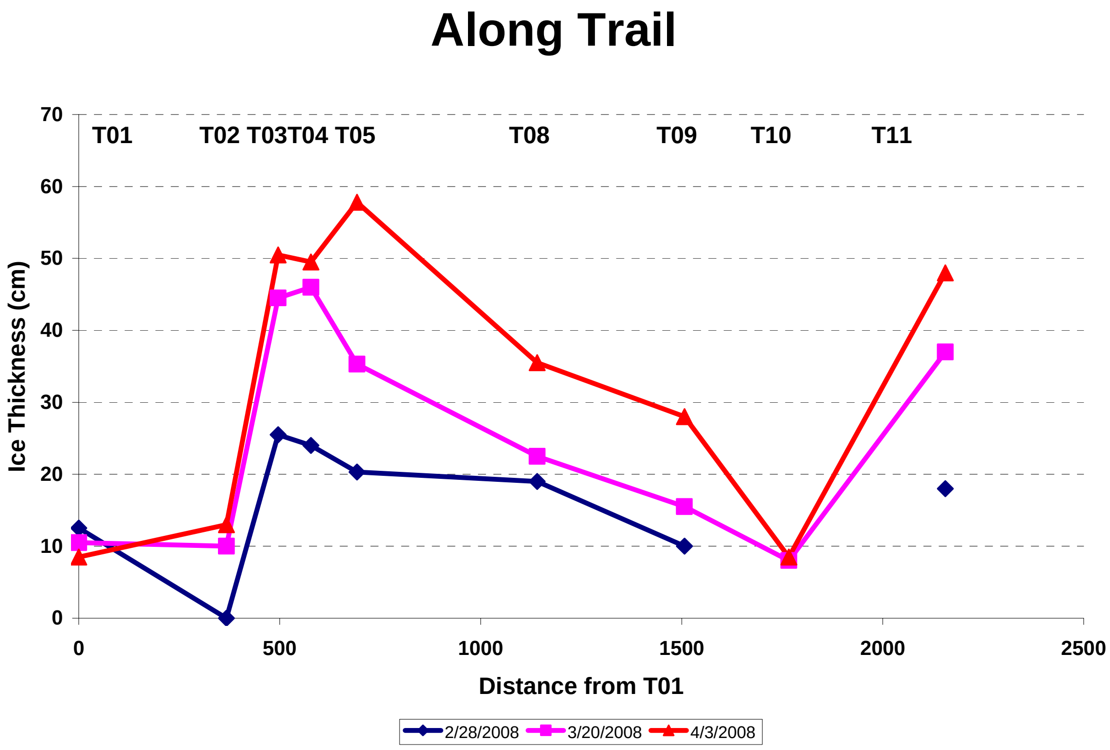

Figure 14. Observed overbank aufeis thickness along trail during the winter 07-08. All measurements in meters.

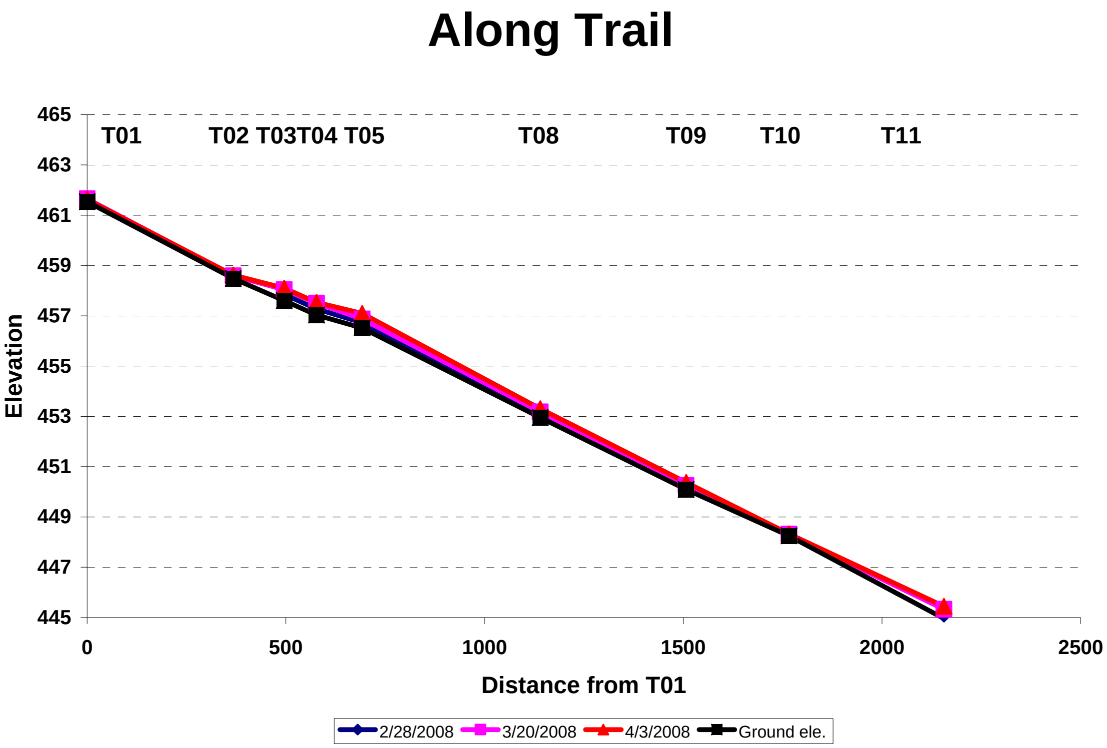

Figure 15. Observed overbank top of aufeis elevation during the winter 07-08. All measurements in meters.