

A Report to the Giant Mine Team Changing hydrological regimes – Baker Creek: Results, implications and next steps

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Large icing which developed in Baker Creek, winter 2010/2011, Giant Mine, North Slave region, Northwest Territories. Photograph by P. Vescie, May 2011.

Executive Summary

Increases in winter streamflow have been documented across the circumpolar north. This includes published and anecdotal results from the North Slave region. Baker Creek is among the streams exhibiting higher winter streamflow than in the past. This is mainly due to an increase in the frequency of autumn runoff events which raise baseflow during the winter months. These events are related to an increasing trend in September rainfall. This trend has increased the likelihood that rainfall over small basins like Baker Creek will fill storage in wetlands and headwater lakes to generate late fall and winter runoff. The wetter ground conditions in autumn can also slow freezeback of the active layer as more heat must be removed to freeze saturated soils. These changes can increase the duration and total area of soil filled terrain that may conduct water to the stream during the winter months. The wetter ground conditions, more frequent autumn runoff events and higher winter streamflows have implications for on-site water management at the Giant Mine. Icing development, which caused the diversion of Baker Creek streamflow in spring 2011 may also become more common with increased occurrence of winter runoff events. The physical processes that control the location and development of icings in this landscape are not completely understood, but winter streamflow is a prerequisite, and there is a trend towards fewer periods of zero flow during the winter. A study has been initiated to determine the spatial and temporal distribution of icings and to investigate the watershed characteristics and meteorological conditions in the Taiga Shield region that lead to icing development. It is anticipated that a shift in streamflow characteristics, from a predominantly nival regime to a combined nival/pluvial regime, will be associated with changes in predominant runoff pathways. As a greater proportion of the annual streamflow yield is transferred late in the summer rather than early in spring, more water will travel through deeper zones of thawed soils, increasing solute and dissolved organic carbon (DOC) concentrations. Initial results suggest there will be changes in aquatic chemistry in Baker Creek as it approaches the Giant Mine site, particularly in winter. As baseline conditions change, license limits of contaminants may need to be re-evaluated. It is now becoming prudent for water and infrastructure managers to consider persistent streamflow throughout winter, icing development and shifting aquatic chemistry regimes when making planning and management decisions.

Hydrological investigations and study of the spatial and temporal variation in water quality of local lakes and streams, including upstream of Giant Mine will be continued in 2012/2013. These data will provide the baseline streamflow and geochemical conditions and trends relevant to infrastructure management and mine reclamation objectives. Lake sediment coring undertaken in spring 2012 will also contribute to the knowledge base of background water and sediment quality conditions. Regional mapping of icing development is ongoing and will be used to assess antecedent climate and basin conditions conducive to icing development. Finally, this will be complemented by the collection of background information on climate and permafrost data including precipitation, snow and permafrost conditions. Monitoring and research results will be reported annually to the Giant Mine team to support mine reclamation planning and preparation for spring freshet periods.

The changing streamflow regime of Baker Creek

Baker Creek is among many circumpolar streams exhibiting higher winter streamflow than in the past (Figure 1). This is due to an increasing trend in autumn rainfall that results in the more frequent generation of runoff into Baker Creek late in the fall. A critical amount of rainfall is required by September and October to overcome water storage deficits resulting from evaporative losses throughout the summer. The increasing trend in autumn rainfall appears to have crossed a threshold in the mid-1990s and since that time, the frequency of autumn streamflow events has increased. The magnitude of peak flow and the total yield for some of these events has exceeded the previous spring freshet. The occurrence of these events means that creeks in the region now tend to have higher baseflows at the time of freeze up. This change has not manifested as strongly in the larger basins of the North Slave region because relative dominance of different hydrological processes vary with scale. For instance, even though the lake fraction in the Cameron, Baker and Snare catchments is similar, the larger Cameron and Snare watersheds contain at least two lakes that are larger than the entire Baker Creek catchment. The presence of large lakes can attenuate these autumn runoff events and large watersheds may be more resilient to change than the smaller watersheds that are influenced more by hillslope processes. These changing precipitation and hydrological regimes have implications for permafrost stability, stream channel conditions, fish overwintering habitat and water chemistry. This new streamflow regime will continue to be monitored through precipitation and streamflow observations at a network of climate towers and streamflow gauges in the Baker Creek watershed and through the regional Water Survey of Canada hydrometric network. The implications to infrastructure and mine management will be explored through discussions with environmental managers and planners.

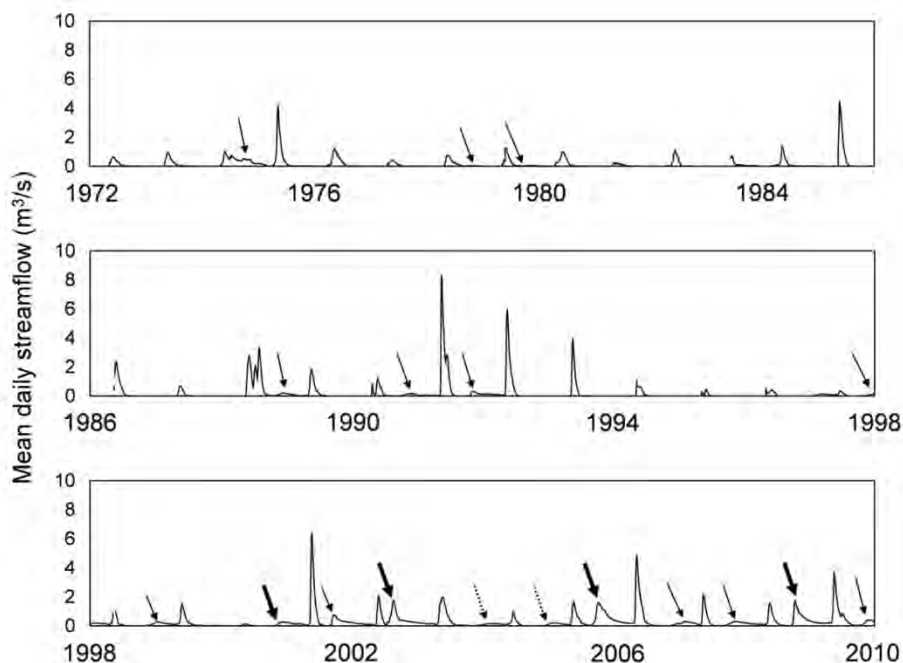


Figure 1: Time series of mean daily streamflow at the Water Survey of Canada station 07SB013 Baker Creek at the outlet of Lower Martin Lake. Arrows denote autumn runoff events. Thick arrows are events during which flow peaked above the previous spring freshet. Dashed lines are autumn runoff events that occurred despite rainfall that did not exceed typical runoff generation thresholds.

Ground temperatures and water movement through the active layer

In areas underlain by permafrost, the thin layer of surface soils that thaw and refreeze annually is referred to as the active layer (Figure 2). The underlying permafrost forms an impermeable layer maintaining a water table close to the ground surface, which promotes the rapid removal of surface water from slopes to streams and lakes. In winter, as the active layer freezes, water can no longer be conveyed from terrestrial environments to lakes and streams and hydrological processes are generally thought to be dormant. Winter baseflow in streams is maintained by storage in lakes or by deep groundwater, and flows typically diminish until the spring freshet (See Figure 1 pre-1997).

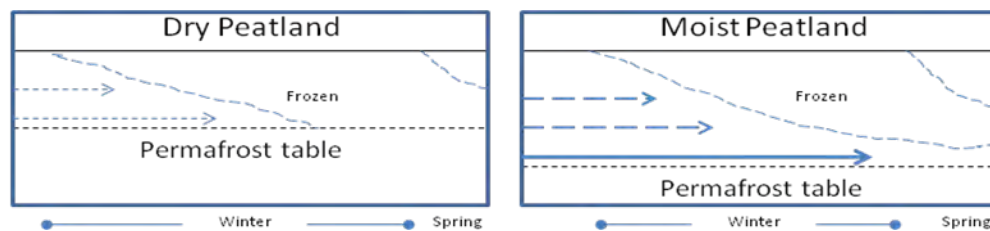


Figure 2. Schematic showing the position of the freezing front (blue dotted line) and magnitude of duration of water flow through soils during autumn, winter and spring. The y-axis represents time and the x-axis represents depth. The arrows indicate the relative depths and magnitudes of soil water movement.

A field experiment near Yellowknife has shown that moisture additions to a peatland soil inhibited the active layer from freezing, whereas drier soils in adjacent areas were completely frozen by the end of January. Therefore, wetter fall soil conditions and warmer winter air temperatures may slow, or inhibit freezeback of the active layer (Figure 2). One result of a prolonged freezeback period is that the landscape may convey water to streams through much of the winter. This further enhances winter baseflows and the transport of soluble materials from the landscape to aquatic systems.

If the active layer does not freeze completely, the permafrost will begin to degrade. With future warming, it can be expected that water movement could persist above a degrading permafrost table throughout the winter. This has important implications for the hydrology of streams and lakes and for the timing and magnitude of solute and nutrient fluxes (ions, metals, DOC and contaminants) from terrestrial to aquatic environments. These changes will be investigated by the instrumentation of slopes across different landscape types and examination of the evolution of water chemistry conditions as the active layer freezes. The presence of unfrozen soils and a perched water table in winter has implications to water management, construction and maintenance operations in areas underlain by permafrost.

Icings

Icings are surface ice accumulations that develop in winter when ground water or streamflow is forced to the soil or ice surface where it freezes (see cover photograph). Icings can accumulate throughout the winter until the water source is exhausted or water flow is impeded. Icings commonly develop in areas where surface or ground water flow is impeded and forced upwards by natural features such as channel constrictions or beaver dams in small streams. Transportation corridors also have a role in promoting icing development, in particular where roads or snowmobile trails run perpendicular to areas of slope drainage or intersect small streams.

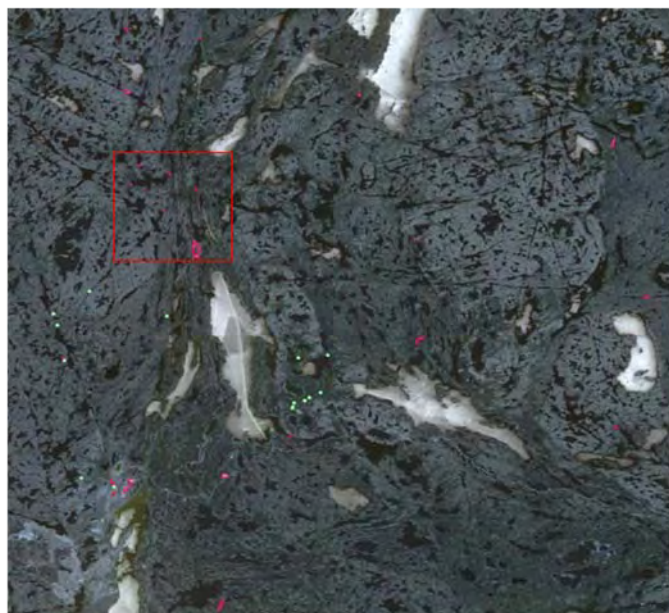
Under certain flow conditions, icings will develop at pinchpoints on small streams where ice becomes bottomfast and runoff is forced upward where the thin layer of water quickly freezes. Persistent water flow through an unfrozen active layer or the re-initiation of runoff into small frozen stream channels can cause icings to build to several meters in thickness. In spring, freshet runoff may occur over top of the icing surface and deviate from the confines of the underlying channel (Figure 3). This can lead to significant water management issues along infrastructure corridors or in sensitive management areas. Several mitigation techniques can be applied to route water appropriately, but the outcomes will be complicated by the size of the icing and the magnitude of the freshet.



Figure 3. The thaw of the Giant Mine icing, May 9 to June 1, 2011. The first two photographs show that initially, spring runoff flowed overtop of the icing and along the Ingraham Trail, several metres above the channel bed and tens of metres to the east of the channel.

In 2010/2011, low summer flow and a late autumn rain on snow event saturated soils and caused runoff thresholds to be exceeded. Streamflow in Baker Creek was initiated in December after a period of zero flow. Ice development in the channels impeded the low but persistent flow, forcing water to the floodplain and causing extensive icing development along several stream reaches throughout the North Slave region (Figure 4), including the Giant Mine site (Figure 3; see cover photograph).

Watershed characteristics and meteorological conditions associated with icing development are being investigated in partnership with the Canadian Centre for Remote Sensing. Since icings persist into early summer, they can be readily mapped using Landsat imagery (Figure 4) which has been archived since the mid-1980s. The historical information on the distribution of icings will facilitate analysis of physical, hydrological and meteorological conditions necessary for icing development. Since winter runoff and streamflow are necessary for icing development, changing hydrological regimes driven by wetter fall conditions and slower active layer freezeback will have implications to the growth and distribution of icings.



- Icings locations provided from Grd truth
- Icings locations from Landsat

Figure 4. Icing locations in the North Slave region (May, 2011). Data from Emily Mahon (IMAG, AANDC) and Joost van der Sanden (TRACS project, NRCan).

Water chemistry regime of Baker Creek

Prior to 1997, 76% of the annual Baker Creek streamflow yield occurred during the spring freshet, but since 1997 this has decreased to an average of 50%. In contrast, the average percentage of annual yield in the winter has increased from 7% to 20%. As more water is released from the basin in late summer and early winter rather than in spring, a larger fraction of runoff must travel to the stream via a deeply thawed active layer, which could increase geochemical flux. This suggests that there will be a change in the aquatic chemistry and total geochemical flux of Baker Creek as it approaches the Giant Mine, particularly in the winter. Field data from 2010 and 2011 suggest that moisture from late fall precipitation events was transmitted through unfrozen soils, resulting in the flush of DOC (Figure 5) and an increase in winter stream solute concentrations. Smaller flow events such as in winter 2010/2011 included a significant proportion of runoff contributions from wetlands adjacent to lakes and along the main creek causing DOC concentrations to be significantly elevated during this event. A more significant winter flow event such as the one in winter 2011/2012 yielded lower DOC concentrations than during the preceding winter due to dilution. It is important to note that in 2011/2012, the autumn streamflow peak was about twofold greater than the preceding spring peak but DOC concentrations still exceeded the concentrations measured during the freshet. These data illustrate that even subtle increases in the proportion of winter flow can have major impacts on the timing and total export of DOC from the catchment. Data have been collected to evaluate if the changing streamflow regime has a similar effect on metal flux but this remains to be evaluated. Comprehensive geochemical surveys will continue throughout the Baker Creek watershed during winter, freshet, summer, autumn and early winter to assist in determining seasonality of water chemistry, changing contributory areas and to develop a baseline to assess the nature of geochemical trends that can be expected in the future.

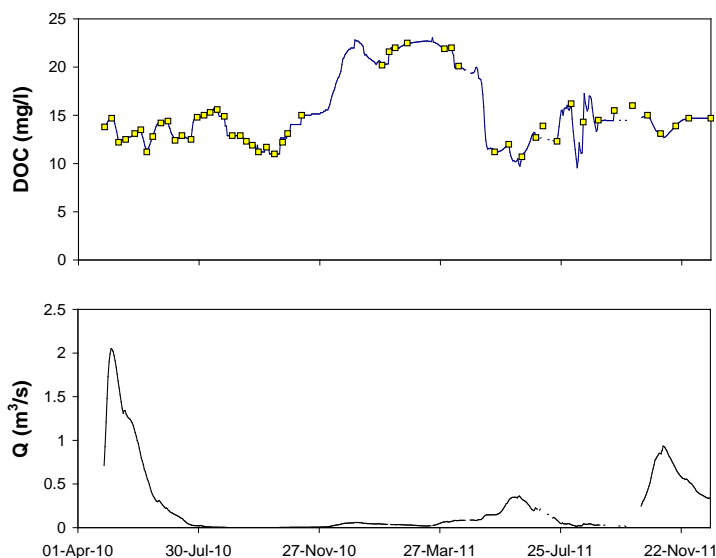


Figure 5: DOC and streamflow in Baker Creek below Lower Martin Lake during two spring freshets, summer base flows, and winter periods. In 2010/2011, there was a small winter streamflow event, but the winter of 2011/2012 was characterized by a runoff event that was larger than the preceding spring freshet. During both winter periods, DOC concentrations exceed those during the preceding freshet, regardless of the magnitude of the flow peaks.

Pre-freshet conditions in Baker Creek Basin

The following table summarizes key hydrological parameters that relate to the magnitude of the spring freshet in Baker Creek (Table 1). The 2011/2012 field measurements are provided relative to the longer term mean values for basin snow water equivalents and antecedent flow conditions. Yellowknife winter precipitation (at the Airport) is also reported relative to the 40-year average (1971-2000) and status of icing conditions at the mine site and upstream locations is recorded, when known.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	Mean (2004- 2011)	Period of record mean
Yellowknife airport November-April precipitation (cm)	129	151	138	197	152	172	121	86	126*	141	121
Baker Creek spring snow water equivalent snowpack (mm)	71.6	108.4		85.5	93.5	114.2	77.8	57.8	81.4	86.275	
Yellowknife airport April and May precipitation (mm)	27.3	22.5	53.9	30.5	15.7	20.8	19	13.8		25.438	30.65
Baker Creek at Lower Martin Lake February 1 streamflow (m3/s)	.15	.192	.3	.31	.17	.241	.213	.04	.2	.202	
Baker Creek at Lower Martin peak spring streamflow (m3/s)	.98	1.67	4.84	2.17	1.62	3.66	2.05	.36		2.169	2.88
Landing Lake portage previous September surface soil moisture (% saturated)					42	100		34	43	58.667	
Icing at footbridge								yes	no		

*Period of record November 1, 2011 – April 23, 2012

Table 1: Key Hydrological Variables, Baker Creek Spring Freshet

The amount of snow received monthly is measured at the Yellowknife airport, the majority of which is received between November and April. Although the average amount of snow fall in this period in recent years has been well above the average recorded between 1971-2000, the value for 2012 is close to the mean.

The Baker Creek snow water equivalent of the snowpack is determined from measurements taken in early April at various sites in the basin. These results are averaged and for 2012, the value of 81 mm is just below the 2004-2011 mean.

Rain received in the basin during spring snowmelt can result in rapid increases in streamflow volumes. Yellowknife airport precipitation received in April and May has therefore been included as a variable that influences peak freshet volume on Baker Creek.

Two variables are included which help to describe antecedent moisture conditions in the basin: Baker Creek flow on February 1 and surface soil moisture at Landing Lake portage in the previous September. Both of these values reflect the volume of moisture in the system prior to the subsequent freshet. Runoff volumes during freshet have the potential to be higher when the basin is saturated as a result of conditions the previous fall.

There are no major icings to report along the main stem of Baker Creek or at the Giant Mine site. Notably there was a significant icing at the outflow of Trail Lake in the upper watershed which did not appear last year when icing development was prolific throughout much of the watershed.

Acknowledgements

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References

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