Coal Lake Outlet Freeze-up, Containment of Winter Inflows and Estimates of Related Outburst Flood on Wolf Creek, Yukon Territory

by
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Abstract
Spring snowmelt is generally the dominant annual peak flow generating mechanism in subarctic regions, though smaller basins may occasionally experience peak flow events due to summer rain storms. An unusual lake outburst flood event was observed at Wolf Creek, a small tributary of the Yukon River. The event was focused at the outlet of Coal Lake the only major storage element in the basin.

During the unusually cold January of 1996 ice growth at the outlet of Coal Lake created an ice dam which progressively grew through aufies formation as the lake levels increased. The ice dam failed in late April approximately 9 days after the onset of mean daily positive temperatures sending a significant flood wave downstream. This event was in excess of 1996 freshet flows which occurred more than one month later.

There are three hydrometric stations on Wolf Creek however these were not activated until the recession of the outburst event. A water balance was carried out to reconstruct this flood event using observed lake levels for the containment period, the recorded recession limbs of hydrographs at the Coal Lake hydrometric station and a downstream hydrometric station, winter recession flows at an upstream hydrometric station and personal observation.

The analyses indicated that the outburst event was greater in magnitude than the subsequent freshet event. In addition to facilitating the reconstruction of the annual hydrograph, the analyses provides valuable information on a little known streamflow generation mechanism in small subarctic basins with lake storage.

Introduction

The Coal Lake outlet hydrometric station has been in operation since September, 1994. Open water discharge is calculated using a stage discharge relationship. Stage data is collected using a water level recorder and an instream stilling well. Winter flows are calculated using a winter recession equation to interpolate between measurements. Spring snowmelt is generally the dominant annual peak flow generating mechanism in subarctic streams while occasionally peak flows on smaller streams may occur due to summer rain storms (Church, 1974). Low flows occur in March and April in response to minimum groundwater contributions (Janowicz, 1996). During the first two winters of operation the outlet of Coal Lake remained open with only bank ice as shown in figure 2. This allowed open water measurements to be made throughout the winter period. Lower than normal temperatures were recorded by Environment Canada at Whitehorse during January, 1996, with the period January 12-19 having mean daily temperatures below minus 40° C.

An open water measurement was made on January 3, 1996. A February 8 survey found the outlet frozen as shown in figure 3. The ice cover was drilled in the normal metering section at approximately 0.3 metre spacing in an effort to find flow. It was found that the ice extended to the streambed with no flow evident in any of the holes. The station was visited February 12 and March 3 with similar results. During these visits it was noted that aufeis was forming across the surface of the ice cover. This aufeis formation had the effect of thickening the ice blockage as the water level in the lake increased. Figure 1 shows the progression of the ice blockage.

The ice level was observed to be 0.55 metres and 0.73 metres on February 8 and March 12 respectively.

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The lake outlet blockage created a storage situation in Coal Lake. Surface runoff and groundwater entering the lake was trapped until the release of the ice dam. The hydrometric station was visited on April 24 to install the summer stage recording equipment. At that time the channel was found to be ice free except for bank ice that was approx. 0.3 metres above the water level. The discharge was measured at 0.965 c.m.s. which is the highest measurement within the three year station record. Stage dropped from this point until the onset of spring freshet one month later.

Study objectives included estimating the rate and timing of discharge of the outburst event.

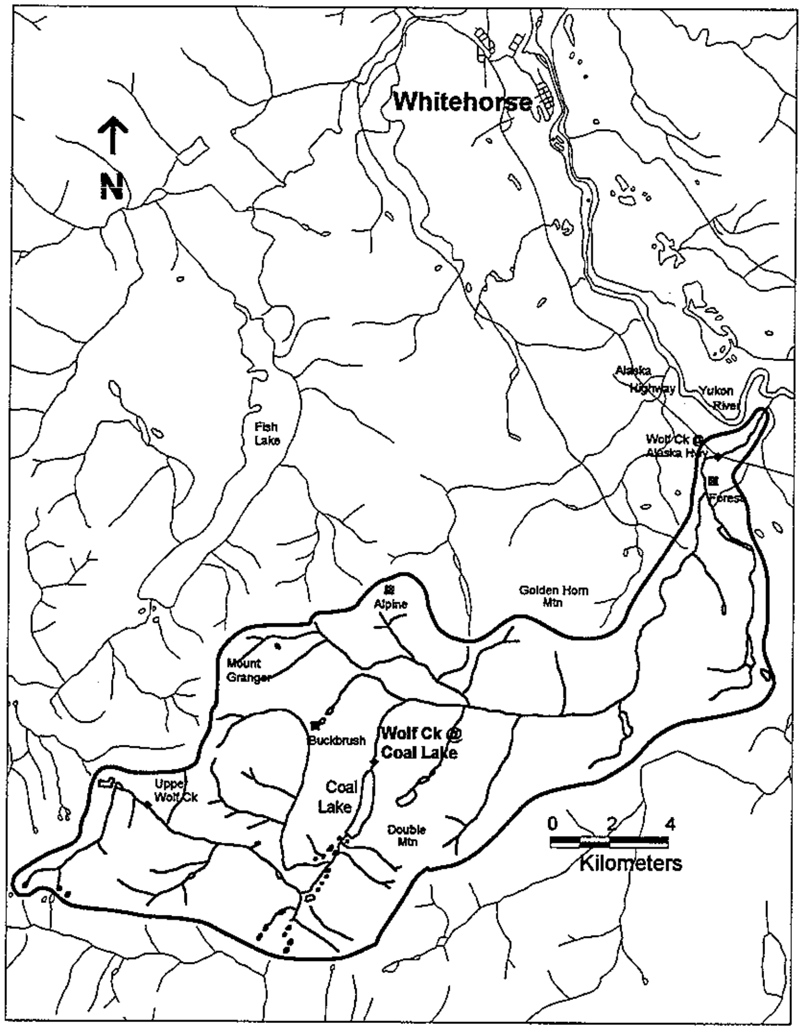

Figure 1: Wolf Creek Basin

Study Area

The Wolf Creek Research Basin project was initiated in 1992 to provide a dedicated site to carry out applied research in the Yukon subarctic (DIAND, 1995). The study area is located 15 kilometres south of Whitehorse, Yukon (Figure 1). The 195 square kilometre basin is quite mountainous with elevations ranging from 2250 metres to 800 metres where it flows into the Yukon River (DIAND, 1995). The climate is subartic continental which is characterized by a large variation in temperature, low relative humidity and relatively low precipitation (Wahl et al.,1987). Coal Lake, with a surface area of 1 square kilometre is the only major lake in the basin (DIAND, 1995). Instrumentation was installed as part of the Wolf Creek Research Basin project. These include three hydrometric stations, three meteorological stations and a remote access snow pillow station. The hydrometric stations are located in the basin at three locations. The "Wolf Creek at the Alaska Highway" site (elevation 750 metres) is near the bottom of the basin with a drainage area of 187 km. sq.. The "Coal Lake Outlet" site (elevation 1200 metres) is approx. 30 metres downstream of the outlet of Coal Lake with a drainage area of 71 km. sq. The "Wolf Creek Upper" site (elevation 1310 metres) near the top of the basin has a drainage area of 14.5 km. sq. Summer flows are measured using standard open water techniques. Winter flows are estimated between measurements using a standard base flow recession equation for exponential decrease (Bruce and Clark 1966).

Requisite Conditions

Meteorological conditions which led to the ice dam formation at the Coal Lake Outlet site included lower than normal temperatures. The Whitehorse Airport weather station, with records dating back to 1943, was used for this study. Temperature data is available from the Wolf Creek snow pillow but has only been collected for three years. During the 1996 event 8 consecutive days of mean daily temperatures below -40° C were recorded at Whitehorse. This represents the second longest such event since records have been kept.

In order to determine threshold temperature requirements to freeze the lake outlet, other events since winter flows have been measured at this site were reviewed. Records at Whitehorse in December 1995 indicated the month was cold with 6 consecutive days when the mean daily temperature ranged from -31° C. to -41° C. During the coldest period 111°C days of frost were accumulated within 72 hours. This was not enough to freeze the outlet to the bed as indicated by a visit on January 3. It was deduced from this that it would take at least -120°C days of frost within 72 hours (3 consecutive days of -40°C mean daily temperatures) to create an ice dam at this location. This assumption was verified in January 1997 when 124°C degree days of frost within 72 hours again formed an ice blockage at the lake outlet.

A review of the historical Whitehorse Airport data since winter 1943 indicated that this condition has been met on 18 occasions (see Figure 3) This suggests that the outlet of Coal Lake freezes to the bottom once in three years. No attempt was made to factor snowpack or streamflow into this condition. A deeper snowpack would have an insulating affect, while a lower discharge would require less degree days of frost to completely freeze the outlet.

It should be noted that a significant inversion exists during these cold temperatures and the actual temperatures at the Coal Lake outlet site would be warmer than the Whitehorse values. During periods of very cold temperatures, the Wolf Creek snow pillow station which is close to the Coal Lake station in both location and elevation, was on average 14° C. warmer than Whitehorse (Figure 6). This would indicate a requirement of 78°C degree days of frost at the Coal Lake site to cause this blockage.

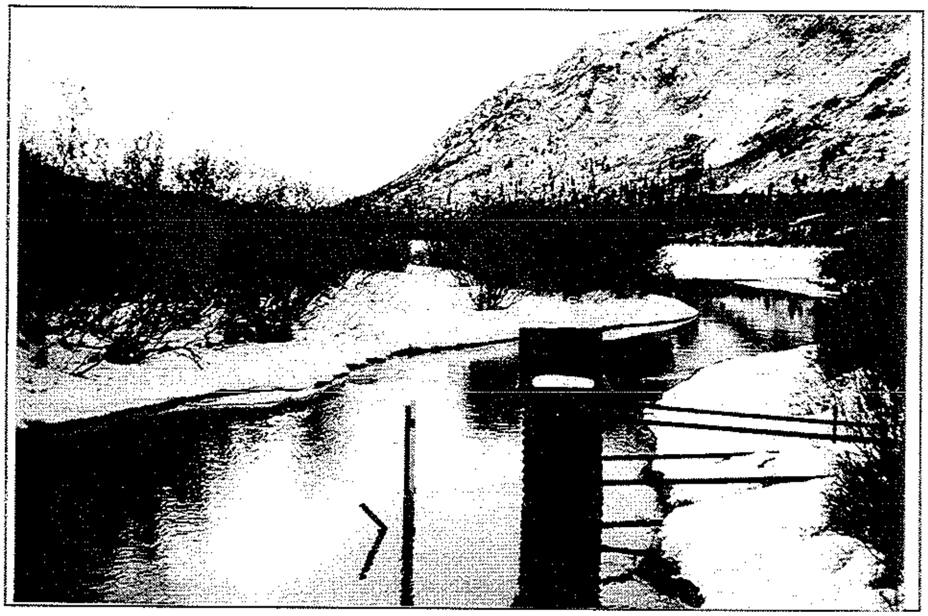

Figure 2: Wolf Creek at Coal Lake Outlet, open water.

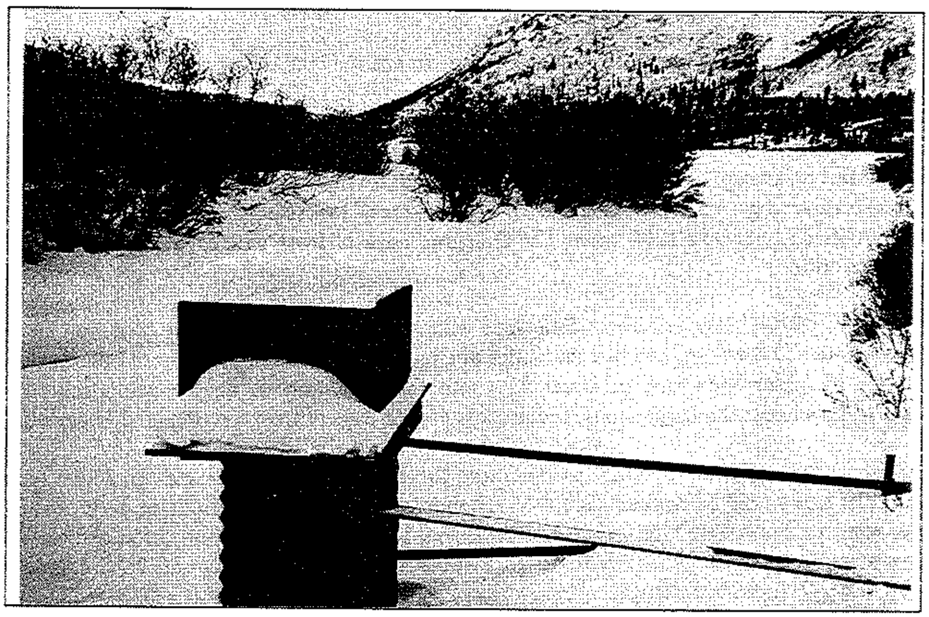

Figure 3: Wolf Creek at Coal Lake Outlet, frozen to bottom.

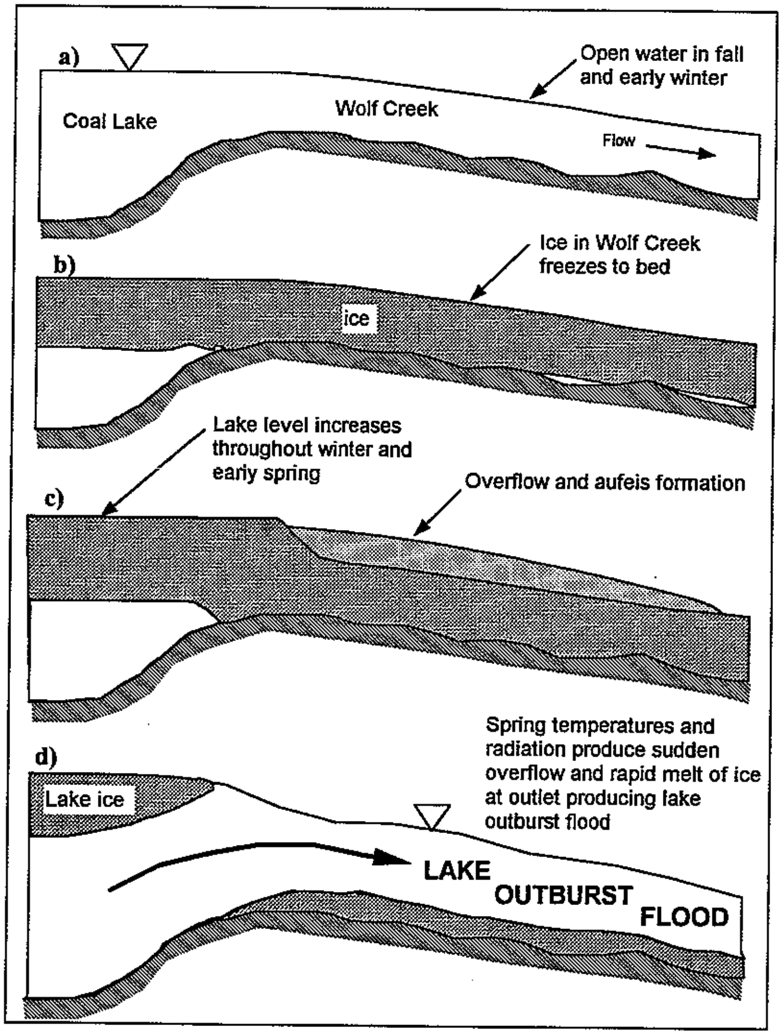

Figure 4: Conditions leading to a lake outburst flood in Wolf Creek.

Lake Storage through Winter

On February 4, 1996, when the frozen lake outlet was first observed, a level survey was carried out to determine the difference between the water level in the lake and the ice level at the gauge. A subsequent March 12 survey showed that the ice level was increasing and formed the basis for estimating the maximum storage level. Surveys carried out on a more frequent basis during the blockage of winter 1997 have confirmed the estimated 1996 levels.

Upper Wolf Creek remained open during the cold period in January, 1996. This is likely a result of the predominance of warmer groundwater contributions at this station together with an insulating snow cover. Reasonable results were obtained using a winter flow recession equation to interpolate between winter measurements at this site (Figure 8). Unit discharge at this site was used to forecast inflows to Coal Lake during the period of impoundment. This however, did not account for all of the water required to fill the lake to the forecast level. Groundwater inputs would be required to make up the difference. This assumption is supported by a review of the discharge records from these two stations. Based on a unit discharge from the Upper Wolf site during the winter months there is less inflow to Coal Lake than outflow. This trend reverses itself in the summer months as shown in figure 7.

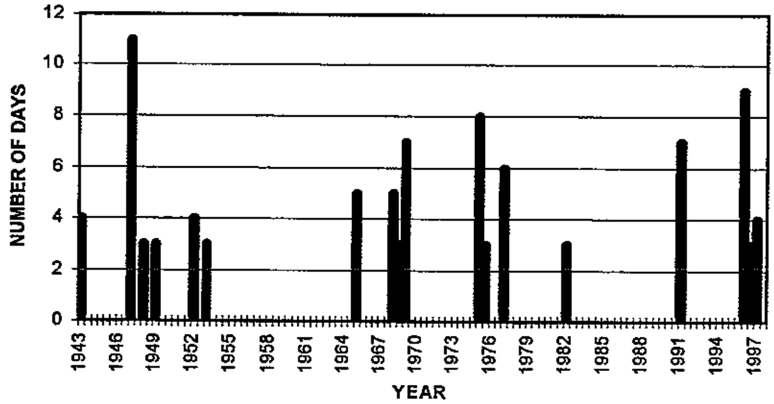

Figure. 5: Historical Events of > -120^0 C Days in 72 Hrs.

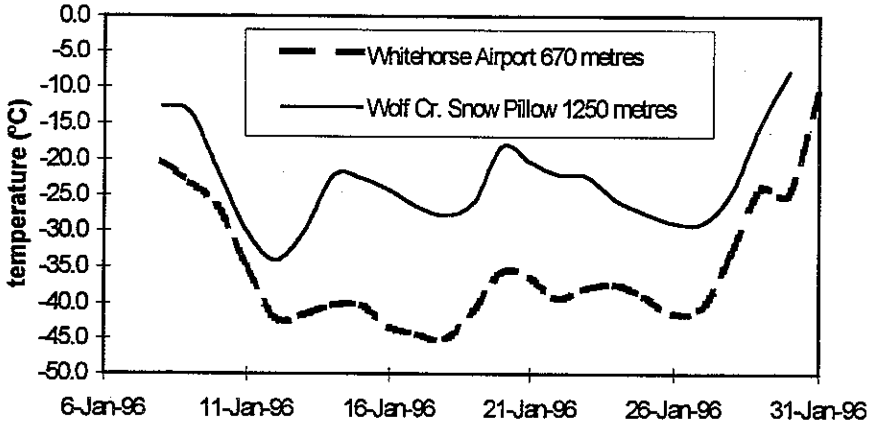

Figure. 6: Temperature Inversion

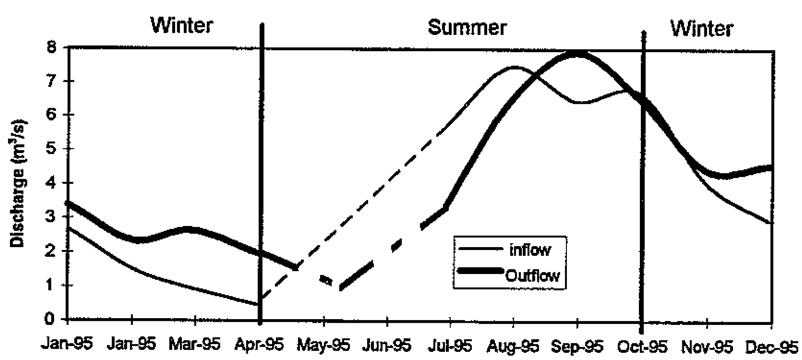

Figure 7: Coal Lake Inflow and Outflow 1995

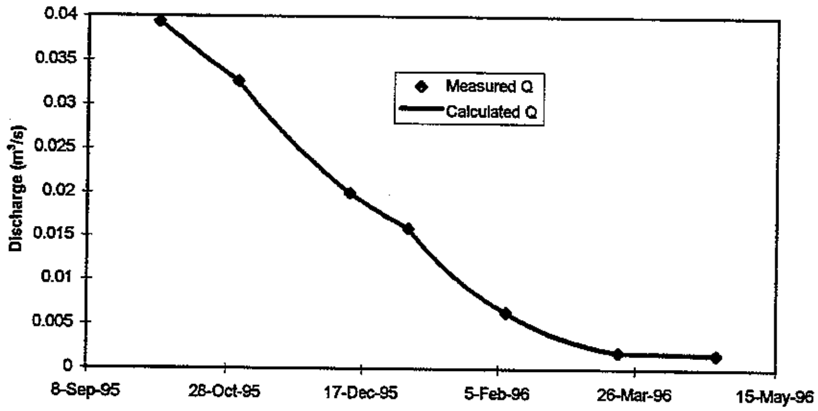

Figure 8: Upper Wolf Creek Winter Flows 1995-96

Outburst Event

The storage situation continued until April 21 1996 when after 8 degree days of thaw at the Wolf Creek snow pillow station, the ice dam released sending a significant flood wave downstream. The event was observed and documented 4 kilometers downstream of the lake outlet. Stream flow on the ice was observed to commence at 12:00 PM on April 21 and reached flood stage at 4:00 PM on the same day (Figures 9 and 10). The water level continued to rise until the afternoon of April 22 when it began to decline. This information provides the basis for the reconstruction of the Coal Lake outlet hydrograph (Figure 12).

The graph of water level in Coal Lake (Figure 11) shows the increase in levels over the winter period. The water level then drops to the point where the gauge is established for the open water season and levels are measured. The hydrograph was adjusted to allow the calculated lake level to meet the measured lake level (Figure 11). The measured value at noon on April 24 was used as the mean daily flow for the day. Estimates of channel shape and velocity based on observation also helped estimate the April 21 flow (Figure 10).

The 1996 annual hydrograph for Wolf Creek at the outlet of Coal Lake shows this outburst flood was considerably greater in magnitude than the freshet flood or any other event during the year (Figure 13).

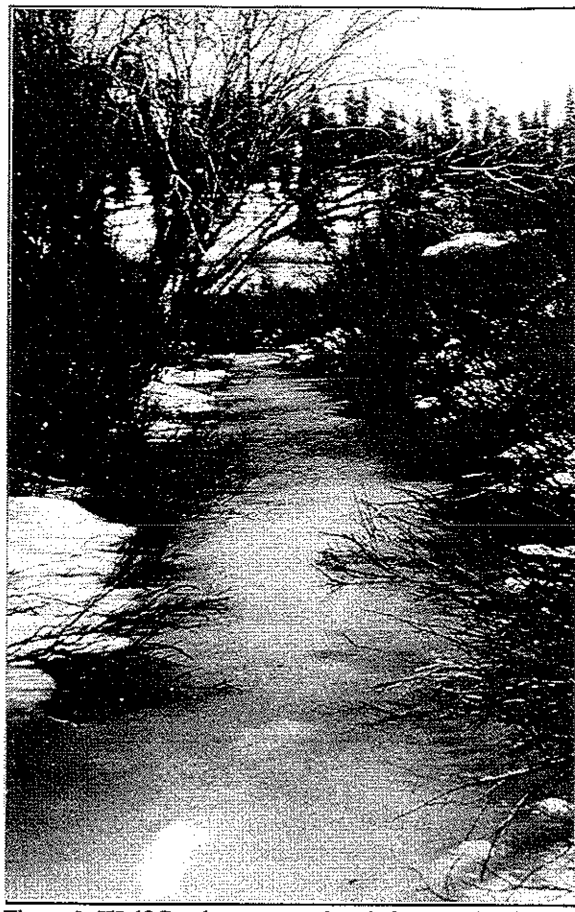

Figure 9: Wolf Creek approx. 4 km. below Coal Lake
April 22, 1996 12:00PM

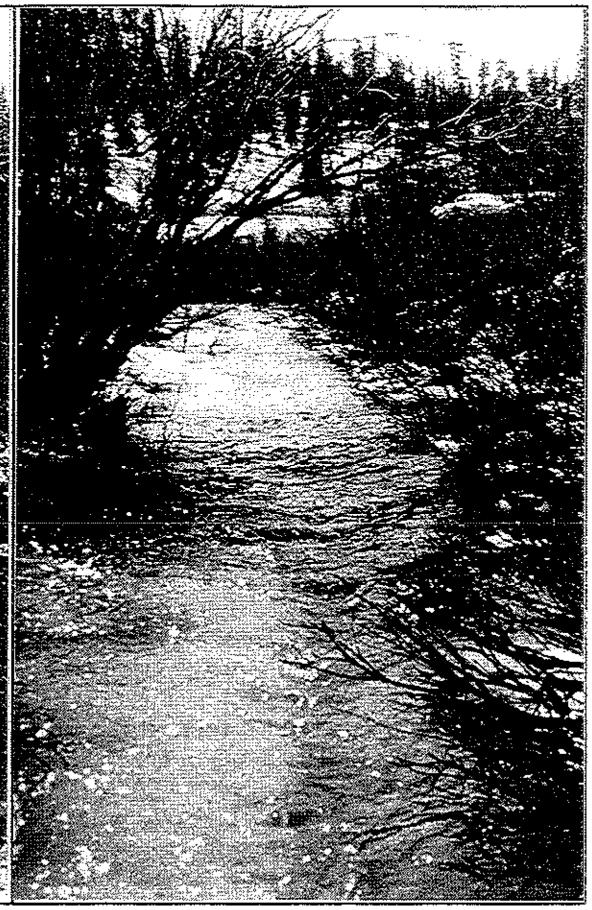

Figure 10: Wolf Creek approx. 4 km. below Coal Lake
April 22,1996, 4:00 PM

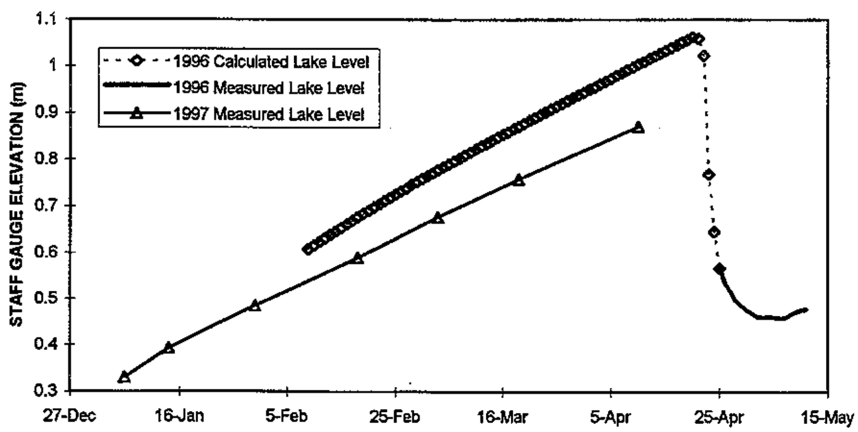

Figure 11: Coal Lake Levels Winter 1995-96 and 1996-97

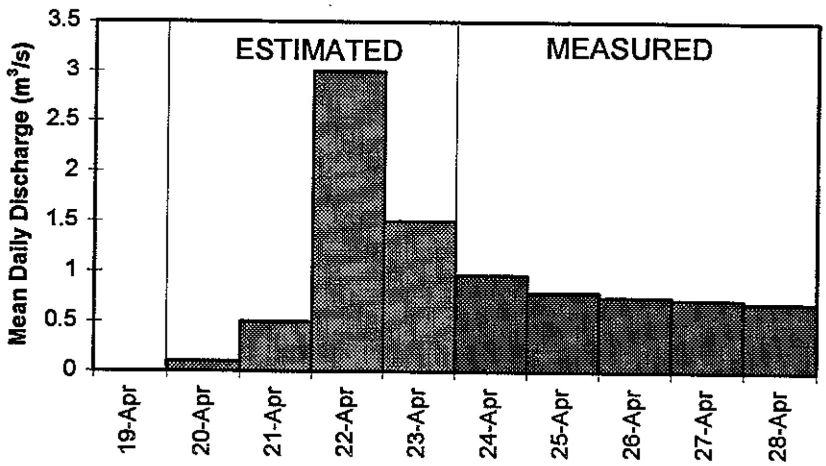

Figure 12: Mean Daily Discharge Wolf Creek at Coal Lake Outlet, Spring 1996

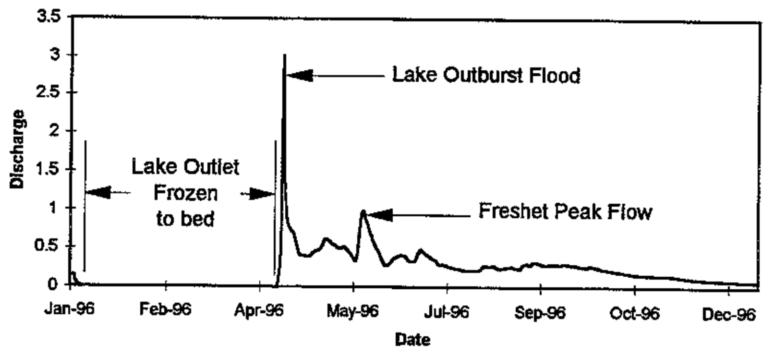

Figure 13: 1996 Annual Hydrograph Wolf Creek at Coal Lake Outlet

Conclusions

Lower than normal temperatures have been observed to freeze the outlet of Coal Lake restricting stream discharge and creating a winter storage situation. During the winter of 1995-96 this situation resulted in the highest stages of the year in Coal Lake during the period of lowest inflow. Above freezing temperatures in the spring allowed the breaching of this ice dam causing a significant flood wave to move downstream. Analysis of available information indicated that this event produced the highest flows of the year preceding the spring freshet by approximately one month. This event produced a much sharper spike than a typical snowmelt or rainfall driven peak at the outlet of Coal Lake. Based on estimates of temperature requirements for this type of event and a review of Whitehorse temperature records it is believed that the Coal Lake outlet freezes approximately once every three years.

Supporting information was obtained during the winter of 1997 which was again colder than normal and produced a similar event. This has allowed an opportunity to collect more information on this type of event. The 1997 levels are lower than the surveyed and estimated 1996 levels and the lake levels do not rise at the same rate. This is consistent with available data which shows Coal Lake levels lower in fall 1996 than in fall 1995 and Upper Wolf Creek winter flows less in winter 1996-97 than in winter 1995-96. The shape and magnitude of the hydrograph can hopefully be confirmed by conducting discharge measurements during the outflow event in spring 1997.

Acknowledgments
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