INCREASING WINTER BASEFLOW CONDITIONS APPARENT IN PERMAFROST REGIONS OF NORTHWEST CANADA

J Richard Janowicz,

Water Resources, Department of Environment, Box 2703, Whitehorse, YT,CANADA
e-mail: richard.janowicz@gov.yk.ca

ABSTRACT
Yukon air temperature trends have been observed to change over the last several decades. Summer and winter air temperatures have increased in most regions except southeastern Yukon. The greatest changes have occurred in western, mountainous regions where both summer and winter temperatures have increased significantly. Hydrologic response was generally found to be characterized with higher year round flows. Mountainous streams were found to have the timing of the freshet advanced, with a progressive decrease in this peak flows moving from south to north.
An assessment of winter low flow conditions was carried out to determine if recent changes were apparent in response to the observed temperature changes. Winter low flows are represented by the mean 7 day low flow. Winter low flows have experienced apparent changes over the last three decades. The greatest changes in winter streamflow appear to be occurring within the continuous permafrost zone, where flows from the majority of sampled streams have increased. Winter low flows trends in streams within the discontinuous permafrost zone generally exhibit positive trends, but are more variable. Winter streamflow trends within the sporadic permafrost zone are not consistent. Increasing winter streamflow trends have occurred from some mountainous regions of alpine permafrost. Other streams exhibit no discernable change, while one stream exhibits a negative change.

KEYWORDS
Continuous, discontinuous, sporadic permafrost, 7-day low flow, trend analysis, Mann-Kendall

1. INTRODUCTION

Yukon temperature and precipitation trends have been observed to change over the last several decades (Janowicz 2001). Summer and winter temperatures have increased in most regions except southeastern Yukon. Summer precipitation has been observed to increase in all regions, while winter precipitation has decreased in all regions with the exception of western Yukon. The greatest changes occurred in western, mountainous regions where both summer and winter temperatures and winter precipitation increased significantly. These observed trends support projections developed by a Canadian Climate Centre GCM (GCMII) (Taylor 1997), which is based on a 100 percent increase of CO_2 in the atmosphere.
While there have been numerous studies carried out in western Canada on the impact of climate change on hydrologic response (Kite, 1993; Burn, 1994; Loukas and Quick, 1996; 1999; Leith and Whitfield, 1998; Whitfield and Taylor, 1998), there has been only limited work to date on the impact of climate change on Yukon hydrology. Janowicz and Ford (1994) used the CCC GCM temperature and precipitation projections, and a correlation approach to assess the impacts of climate change on the water supply to the upper Yukon River. More recently Whitfield and Cannon (2000) and Whitfield (2001) assessed climatic and hydrologic variations between two decades (1976-1985; 1986-1995) for stations in British Columbia and Yukon. They found temperatures to be consistently higher, summer precipitation to be lower and winter precipitation to be higher in the second decade. Hydrologic response was generally found to be characterised with higher year round flows. Mountainous streams were found to have the timing of the freshet advanced, followed by lower summer and fall discharge. Janowicz (2001) carried out an analysis of streamflow to assess the response of the observed temperature and precipitation changes on peak flows, which normally occur as a result of spring

snowmelt. The assessment revealed that there has been a dramatic change in mean annual flood (MAF) in some regions of Yukon over the last 20 years, with a progressive decrease in the parameter moving from south to north. The greatest increases in MAF were observed to occur within the sporadic permafrost zone, from predominantly glacierized systems in western Yukon. Smaller increases were noted in southeastern Yukon. These increases correspond to the observed increase in both summer temperatures and winter and summer precipitation. Peak flows from central and eastern Yukon, within the discontinuous permafrost zone, exhibit very little change. Within the continuous permafrost zone, peak flows were observed to decrease progressively moving northward to the Arctic coast.
This paper summarizes the results of a study carried out to assess trends of minimum winter low flows in northwestern Canada over the last few decades.

2. SETTING AND METHODOLOGY

The analyses was carried out using data from Yukon Territory and the western Northwest Territory west of the 125th parallel of longitude, an area covering approximately 920,000 km^2. This region consists of three permafrost zones: continuous, discontinuous and sporadic (figure 1). Data from all active and recently discontinued (< 5 years) stations, on unregulated streams, with at least 25 years of record were used in the analyses. Because of numerous station discontinuations in the mid-1990s, only 21 stations were available for analyses. These were equally distributed between the three permafrost classes. The 7-day average minimum annual low flow, which normally occurs in late winter or early spring, was assessed in the present study. The 7-day average low flow parameter is a commonly used minimum flow measure which reduces the variability over a single value.

2.1. Trend Analysis

The Mann-Kendall trend test was used to assess trends in the 7-day minimum annual low flow parameter. The Mann-Kendall test is a non-parametric test used for the assessment of trends in time series. It is a simple, robust tool which can readily handle missing values. The standard normal variate value (Z) is calculated which is associated with a specific level of significance. The significance level provides an indication of the strength of the trend. A significance level of 0.001 indicates a very strong trend, 0.01 indicates a strong trend, 0.05 indicates a moderate trend, and 0.1 indicates a weak trend. A level of significance of less than 0.1 indicates there is no discernable trend.

3. RESULTS AND DISCUSSION

Table 1 provides a summary of the trend analyses. The greatest positive trends in winter low flows appear to have occurred in the continuous permafrost zone. It is not possible to statistically validate all trends, since some of the study streams have had predominately "zero" winter flows in past decades, with increasing occurrences of measurable winter low flows in recent years. As with many statistical techniques, the Mann-Kendall tests are not able to handle "zero" flows. Winter baseflows are generally directly related to drainage area. In cold regions the relationship is more pronounced, with smaller drainages having less groundwater inputs to baseflow; therefore, smaller winter flows. In regions of continuous permafrost many streams have "zero" flows. Figure 2 provides an illustration of the positive winter low flow trend for the Arctic Red River (10LA002), with a drainage area of 18,600 km^2. Figure 3 provides an illustration of low flow trends for a smaller stream, Rengleng River (10LC003) with a drainage area of 1310 km^2. Winter low flows in past decades have been nonexistent, while measurable flow during recent winter periods has been observed. The winter flow regime for Caribou Creek (10ND002), with a drainage area of 68.3 km^2, has remained unchanged, with "zero" flows throughout the entire 29 year monitoring period.

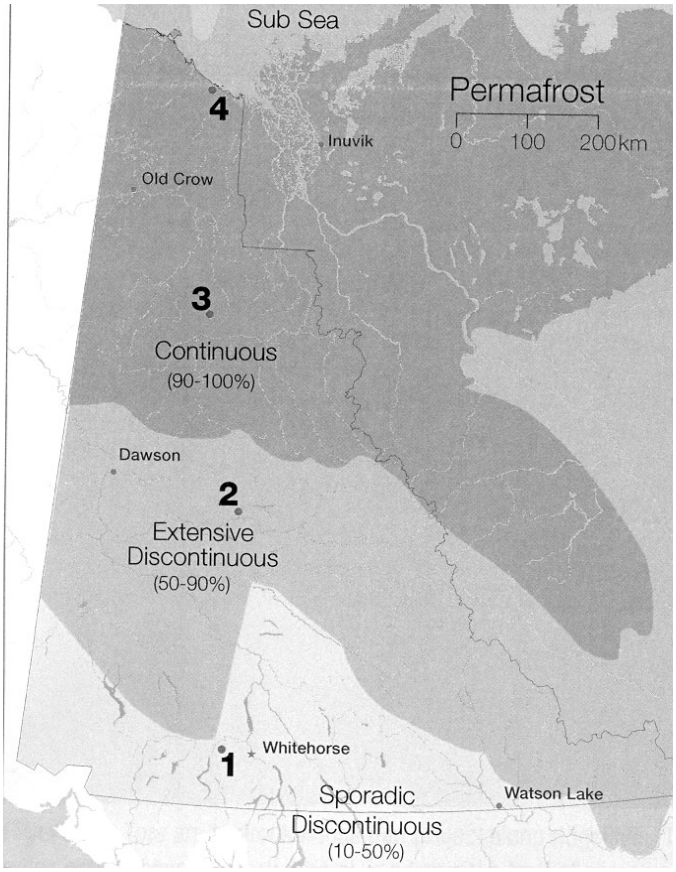

Figure 1. Study Area and Permafrost Zones

Table 1. Mann-Kendall Trend Statistics

Permafrost Class	Station #	Drainage Area (km^2)	Record Period	n	Z Statistic	Significance Level
Continuous	09FC001	13900	1977-05	27	0.83	< 0.1
	09FD002	59800	1962-05	40	1.81	0.1
	10LA002	18600	1969-06	37	4.89	0.001
	10LC003	1310	1973-05	32		
	10LC007	625	1975-06	31		
	10MC002	70600	1975-06	31	3.65	0.001
	10ND002	68.3	1977-06	29		
Discontinuous	09BA001	7250	1961-05	44	1.42	< 0.1
	09BC001	49000	1953-05	52	2.12	0.1
	09BC004	22100	1973-05	33	2.43	0.1
	09DD003	51000	1964-05	42	1.23	< 0.1
	09EA003	7800	1966-05	40	3.44	0.001
	10EA003	8560	1961-06	39	0.94	< 0.1
	10EB001	14600	1964-06	42	2.3	0.1
Sporadic	08AA003	8500	1953-05	53	2.95	0.01
	08AA009	194	1981-05	25	0.82	< 0.1
	08AB001	16200	1975-05	31	0.29	< 0.1
	09AA012	875	1958-05	44	-0.67	< 0.1
	09AC001	6930	1949-05	56	1.49	< 0.1
	09CB001	6240	1975-05	30	2.43	0.5
	10AA001	33400	1961-05	45	0.73	< 0.1

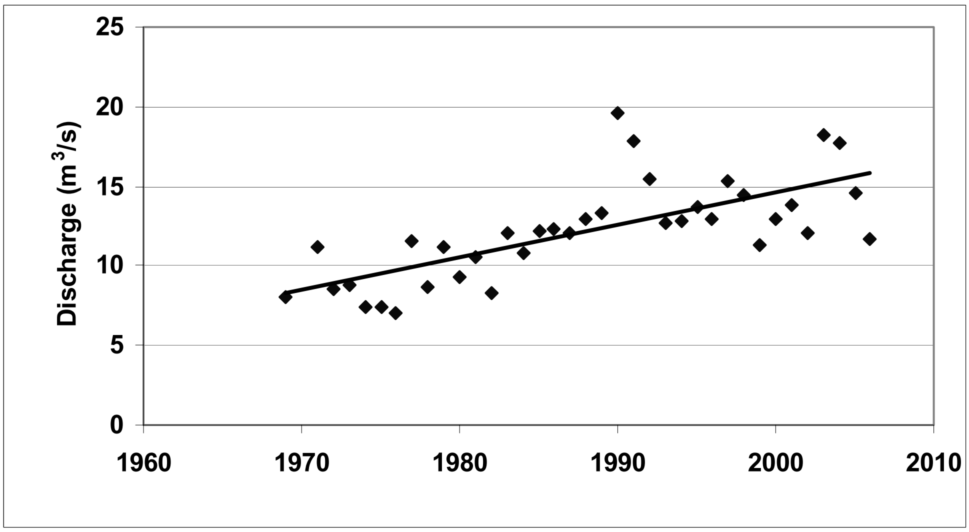

Figure 1. 7-Day Average Minimum Low Flow - Arctic Red River near Mouth

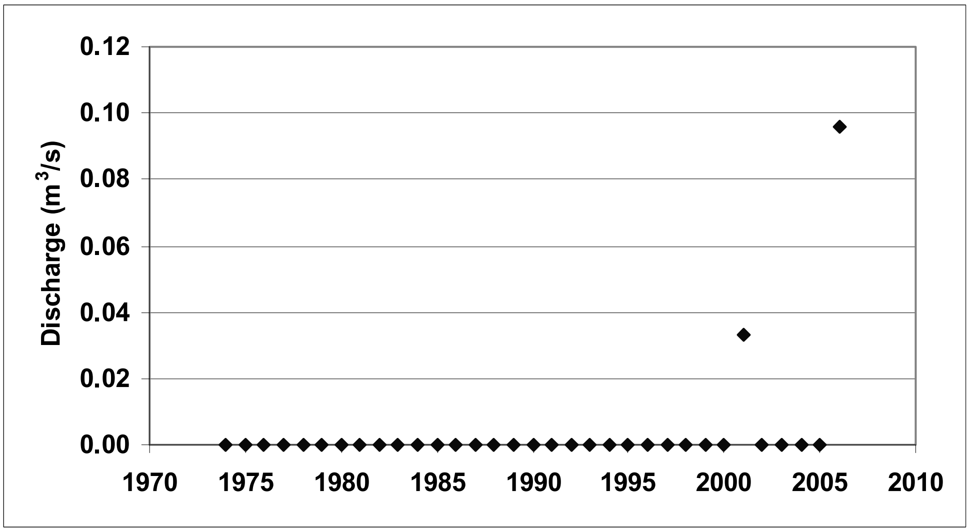

Figure 2. 7-Day Average Minimum Low Flow – Rengleng River at Dempster Highway

Trends of winter low flow regimes, with increasing flows are generally exhibited by streams within the discontinuous permafrost zone. Four of the seven assessed streams have statistically significant positive winter low flow trends. Figure 4 illustrates the increasing trend for Klondike River (09FA003). Even the smallest streams within the discontinuous permafrost zone normally have winter flows, so drainage area is not as strong a factor in influencing winter streamflow, as in the continuous permafrost zone.

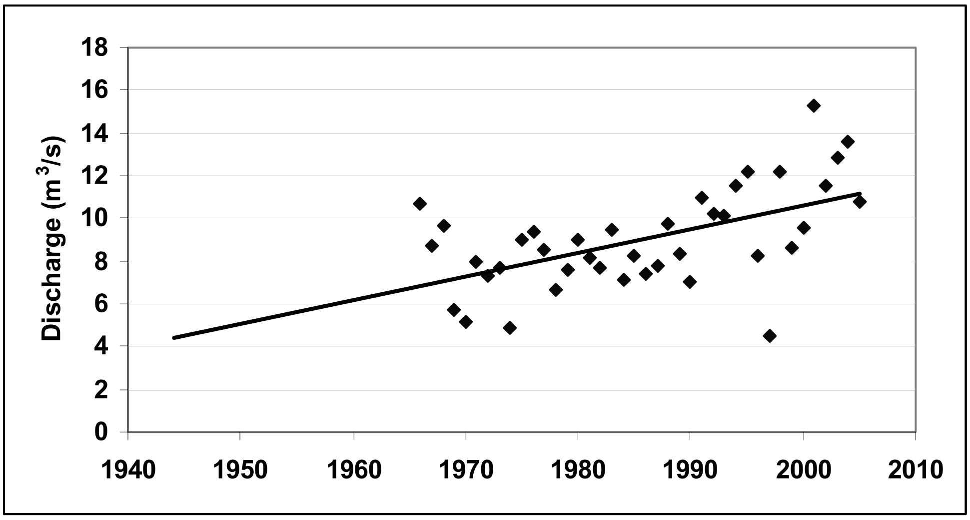

Figure 3. 7-Day Average Minimum Low Flow - Klondike River above Bonanza Creek

Trends of increasing winter low flows are not generally strong within the sporadic permafrost zone. Two of the seven represented streams have statistically significant positive trends. Both of these streams are transitional with the discontinuous permafrost zone, and one of these drains a mountainous region with significant alpine permafrost. Other streams exhibit no discernable change, while one stream exhibits a negative change.

4. CONCLUSIONS

An assessment of winter low flow conditions was carried out to determine if recent changes were apparent in response to the observed temperature changes. Winter low flows are represented by the mean 7 day low flow. The Mann-Kendall test was used to statistically validate observed trends. Winter low flows have experienced apparent changes over the last three decades. The greatest changes in winter low flows appear to be occurring within the continuous permafrost zone, where flows from the majority of sampled streams have increased. Winter low flows trends in streams within the discontinuous permafrost zone generally exhibit positive trends, but are more variable. Winter streamflow trends within the sporadic permafrost zone are not consistent. Increasing winter streamflow trends have occurred from some mountainous regions of alpine permafrost. Other streams exhibit no discernable change, while one stream exhibits a negative change.

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