

Increasing discharge trends in a discontinuous permafrost, fractured bedrock watershed

Abigail R. Baran¹, Élise Devoie¹, Ryan F. Connon² & Stephanie N. Wright¹

¹Department of Civil Engineering – Queen’s University, Kingston, Ontario, Canada

²Department of Environment and Climate Change, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada

Across subarctic and Arctic drainage basins, river discharge has increased in recent years, however the rate and pattern of these changes are not consistent. Winter discharge in large, continental-scale basins (e.g., Mackenzie, Yukon, Lena and Kolyma), has increased 0.4-1.8% per year since 1980, while annual mean discharge shows only weakly increasing trends (Liu et al. 2022). St. Jacques and Sauchyn (2009) evaluated 23 rivers in the Northwest Territories (NWT) and found statistically significant increases in baseflow in 20 rivers and increasing annual discharge in only 9 rivers. Arctic river peak flows have decreased in magnitude and occur earlier (Bennet et al. 2023). Increased discharge and winter baseflow demonstrate changes to the hydrological regime of a watershed, leading to alterations in stream temperature and chemistry and enhanced contaminant pathways (Walvoord et al. 2012).

STUDY SITE

The La Martre River in the central Northwest Territories, flows from Lac La Martre to the Marian River, and ultimately to Great Slave Lake. The gauging station, located below the outlet of Lac La Martre, has a continuous discharge record from 1977 to the present and captures runoff from an area of 13,900 km². Unlike other Arctic and subarctic rivers, the La Martre river has seen profound streamflow increases throughout the year. The watershed is underlain by discontinuous permafrost and fractured dolomite bedrock and the landscape is dominated by wetlands, mixed and coniferous forest, and peatlands. The community of Whatì is located at the outlet of Lac La Martre and is one of three NWT communities using groundwater as their primary source of drinking water. The objective of this study is to understand the nature and timing of changes in streamflow, temperature, and precipitation within the La Martre watershed.

METHODS

Daily discharge records (1977-2023) for the La Martre river (07TA001) are available from the Water Survey of Canada. The ECCC weather station

located at the Whatì airport provides daily temperature records since 1995, and daily precipitation since September 2018. The nearest long-term weather station is in Yellowknife, more than 150 km away. Monthly temperature and precipitation data from four reanalysis products, ERA5-Land (Muñoz Sabater 2019), CMAP, UDEL, and CRU, were compared with the Whatì weather station record and nearby weather stations: Yellowknife, Gameti, and Snare Rapids. ERA5-Land was selected for further analysis as it is available at hourly timescales and performed as well as the other models. ERA5-Land data are generated from monthly observations at meteorological stations where available, interpolated using a general circulation model, and downscaled to 0.1° by 0.1°.

The reanalysis temperature, precipitation, and observed discharge trends were analyzed using the non-parametric Mann-Kendall trend test and Sen slope indicator at annual, seasonal, and monthly timescales. The seasons were divided as follows: Winter (Nov-Apr), Spring (May-Jun), Summer (Jul-Aug), Autumn (Sep-Oct). The annual period was taken as the hydrological year from Nov-Oct, labeled as the year of the final month. The trend in the ratio of baseflow (mean Jan. 1 to Mar. 31 discharge) to total annual discharge was also calculated.

RESULTS

From 1950 to 2022, the average annual temperature in Whatì has increased by 2.24°C. Discharge in the La Martre river showed statistically

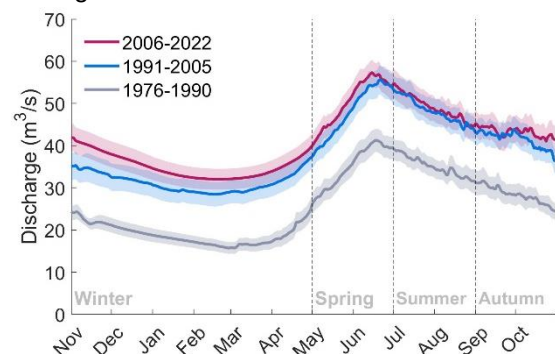


Figure 1. Hydrograph of mean daily discharge in La Martre River in three periods: 1976-1990, 1991-2005, 2006-2022. Shaded area represents the standard error.

significant increases annually and in every season and month from 1977 to 2023 (see Table 1). The greatest increasing trend was in winter discharge. The percent of discharge as baseflow increased significantly from 15% to 21% during the same period. Peak discharge usually occurs in May or June. There was no statistically significant trend in the timing of peak discharge, however in several years since 2010 peak discharge occurred in late summer or autumn. The peak discharge volume also showed a statistically significantly increasing trend.

Increases in annual precipitation from ERA5-Land match or exceed the increase in specific discharge in the La Martre River. Although the reanalysis precipitation does not match the limited observed precipitation data, the increasing trend is similar to the observed trend in Yellowknife. At the 90% confidence level, only summer, July, and August precipitation show statistically significant increases, and October shows a statistically decreasing trend at the 95% confidence level. The reanalysis precipitation magnitudes are much greater than the limited observed precipitation data available in Whatì. This may suggest that recent years have been drier than average, supported by field conditions and discussions with community members. Throughout the recent dry period, discharge has continued to follow the long-term increasing trend.

Table 1. Trends in precipitation and discharge from 1977-2022. Statistical significance at 95% confidence marked as *, 99% confidence as **.

Parameter	Period	Mean	Slope (mm yr ⁻¹)
Total Precipitation	Annual	346 mm	1.02 mm/year **
	Winter	101 mm	-0.82 mm/year
	Spring	62 mm	0.050 mm/year
	Summer	104 mm	0.88 mm/year *
	Autumn	75 mm	-0.035 mm/year
Specific Discharge	Annual	81 mm	1.04 mm/year **
	Winter	33 mm	0.54 mm/year **
	Spring	17 mm	0.15 mm/year **
	Summer	17 mm	0.15 mm/year *
	Autumn	14 mm	0.16 mm/year **

DISCUSSION AND CONCLUSION

The ERA5-Land data suggest that the main driver of the increasing annual discharge in the La Martre River is the rising trend in precipitation. However, more substantial increases in winter discharge and the discrepancy between the season with the greatest upward trend in precipitation (summer) and the season with the highest upward trend in discharge (winter) suggest alterations in the routing mechanisms within the watershed. The

substantial discharge observed throughout the recent dry period, also implies changes to the landscape storage capacity in the watershed. Permafrost thaw may be responsible for increases in winter baseflow through enhanced summer groundwater recharge accompanying a deeper active layer, expanded groundwater flow paths through vertical and lateral taliks, and altered surface water-groundwater connectivity, especially in wetland dominated landscapes (Wright et al. 2022). Further research is needed to determine which processes are responsible for the hydrological regime shift in the La Martre watershed. The next steps in this study include development of a physically based model of the watershed to better understand the changes resulting in increased winter discharge. This will inform our understanding of current and future landscape changes in the watershed and allow for predictions of the quantity and quality of water accessible to the community of Whatì.

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