CGU HS Committee on River Ice Processes and the Environment
21st Workshop on the Hydraulics of Ice Covered Rivers
Saskatoon, Saskatchewan, Canada, August 29-September 1, 2021

Recent Trends in Ice Conditions in Rivers in Ontario, Canada

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In a changing climate, weather parameters that directly and indirectly influence ice and hydrological processes are being altered, thus affecting the frequency and intensity of dynamic ice processes in rivers. This paper reports on the calculation of river ice variables at nine Water Survey of Canada stations located in Ontario and on the corresponding observed trends during recent years. It is part of a national effort to better understand the impact of climate change on many aspects of river ice sciences and engineering.

The evaluation of those variables (ice influenced daily flows and water levels, time of their occurrence and number of days with ice-influenced conditions, referred to as “B-days”) revealed no universally applicable strong trends. However, some findings of interest include:

- Decreasing trend in the number of B-days in southern and central Ontario, but undefined trend in northern Ontario.
- Neutral or increasing trend in the maximum flows during ~~in~~ B-days, which was a strong trend for two of the nine stations.
- Consistent trend towards earlier occurrence of maximum flow on B-days, except for one station in which the trend was undefined.
- Undefined trend for the maximum water levels observed on B-days, for which the results were almost evenly split between increasing and decreasing trends.

The paper highlights areas recommended for further investigation.

1. Introduction

As they gradually manifest, the changes in weather patterns caused by climate change and their effects on ecosystems, are at best partially understood. This is true for many natural processes, and, especially, for winter related phenomena, such as river ice conditions. These changes affect in many ways our lives and the environment where we live: from the occurrence and magnitude of ice-related flooding of riverine communities, to the sustainability of our interaction with hydrologic resources and their availability for present and future generations. Recognizing those changes will have an effect in infrastructure and land use planning and design, and in our ability to promote a healthy natural environment.

In an effort to understand how these processes are being affected by climate change, this paper examines data collected at Water Survey of Canada (WSC) hydrometric stations in the Province of Ontario, Canada, to investigate trends in river-ice affected conditions.

Since the early 1900's, the WSC has been the national authority responsible for collection, interpretation and dissemination of standardized water resource data and information in Canada. This data is of widespread use by researchers and engineers, and constitutes the basis of this investigation. The WSC operates, often in cooperation with other agencies, over 2100 active hydrometric stations across the country. The stations that have been used for this study are located in northern, central and southern Ontario.

This research is part of an initiative by members of the river ice research community (through CRIPE's climate change sub-committee), to better understand the impact of climate change on river ice processes. It intends to contribute to the knowledge on this impact by collecting data, from selected WSC stations, on variables that represent the initiation, duration and magnitude of ice affected processes and calculating corresponding trends over time. The expectation is that this contribution can be expanded later by comparing with findings from other Canadian regions and by further exploring its findings.

No attempt is made herein to cite and assess a variety of preceding works (e.g. Chen and She 2020) on trends in river-ice variables from Canadian and International rivers. A comprehensive review of related studies is presented by Burrell et al (2021).

2. Methodology

The WSC collects and provides data on water levels and flows for hydrometric stations across Canada on a regular basis. In some cases, it collects, environmental data, such as water temperature, sediment data and even ice thicknesses, for some specific locations. Daily data is generally available to be downloaded from the WSC website. Sub-hourly values are also available on the website, for a limited number of record years, and can be obtained by request for longer periods of record. The daily flows reported by WSC are typically accompanied by data symbols that indicate data collection completeness, availability, data quality or level of review applied. One such symbol is the code "B", which indicates that the reported values are considered affected by backwater effects, caused by the presence of an ice cover either at the location of the hydrometric station or downstream of it.

The WSC stations from which data was used in this investigation are listed in Table 1, and their location is shown in Figure 1. Geographically, they can be divided into three groups, one for each of the following regions:

- Southern Ontario (Stations 02GE003, 02GE004 and 02GB001).
- Central Ontario (Stations 02FC001 and 02EC002).
- Northern Ontario (Stations 04LJ001, 04LM001, 04HA001 and 04FC001).

The years of record available from the WSC database, differ among these stations. Not all years available could be used for the analysis, since in some cases the data was incomplete or evidenced quality problems that prompted dismissal of some record values.

Table 1. WSC Stations Investigated

Station No	**Description**	**Latitude**	**Longitude**	**Gross Drainage Area (km^2)**
02GE003	Thames River At Thamesville	42°32'41"	81°58'02"	4,370
02GE004	Thames River At Chatham	42°24'51"	82°10'46"	4,610
02GB001	Grand River At Brantford	43°07'57"	80°16'02"	5,200
02FC001	Saugeen River Near Port Elgin	44°27'23"	81°19'35"	3,950
02EC002	Black River Near Washago	44°42'49"	79°16'53"	1,510
04LJ001	Missinaibi River At Mattice	49°36'39"	83°16'04"	8,570
04LM001	Missinaibi River Below Waboose River	50°35'07"	82°05'27"	22,900
04HA001	Albany River Near Hat Island	51°19'50"	83°50'00"	118000
04FC001	Attawapiskat River Below Muketei River	53°05'28"	85°04'20"	36,000

The methodology applied in this study consisted of identifying the period in which the daily flow values reported at these WSC Stations included a B-code, which was considered representative of days in which there was presence of an ice cover or ice jam in the river reach through the stations or at a nearby downstream location. The data was reviewed to exclude periods of apparent malfunction of the gauges that could affect the analysis.

Environment and Climate Change Canada has compiled pertinent information in the Canadian River Ice Database (CRID) (de Rham et al. 2019). This database is very valuable for a research of this type. However, upon review, a direct match was not evident between the multiple values that are provided in CRID for the variables investigated and the singular values derived with the methodology applied in this study. The authors, therefore, decided to maintain the consistent approach of finding the B-code directly from the WSC daily flow records and coupling it with corresponding records of water levels. For some of the stations selected for this study, with which the authors had familiarity from previous analyses, this was the only approach available, since the stations were not included in the CRID database. Using the vast amount of data organized in CRID is a potential expansion to the investigation presented in this paper.

Figure 1. Location of WSC Stations Investigated

The available flow data was queried to identify for each winter season on record, the first and last day in which the values were accompanied by the B-code (referred to in this paper as "B-days"). In some years, typically for the stations in southern Ontario, the records showed occasional interruptions of the backwater effects (application of the B-code was interrupted for some days) revealing instances of mid-winter ice cover breakup and clearance events. For each winter season on record, the total number of B-days were counted, and the maximum daily water level and flow reported among those days was identified, as well as the days in which they occurred.

An analysis was then performed, for each WSC station, to investigate if there was a discernible trend on the corresponding time series. When possible, the analysis was done for at least 30 years of record; but in some cases, the reliable data available was limited to the most recent 20 years. The trend analysis was performed for the following seven variables, when data was available:

- First day of ice affected water levels (First B-day)
- Last B-day
- Number of B-days
- Maximum daily mean water level within B-days
- B-day of maximum water level
- Maximum daily mean flow within B-days
- B-day of maximum flow

To facilitate the numerical analysis for the first and last B-days, December 31st of each winter season was assigned a Julian-day value of zero, and the days were counted increasingly from then (e.g. January 1st was day number one). Days preceding December 31st were counted in decreasing order (e.g. December 30th was day number minus one).

The trend analysis was carried out applying the Mann-Kendall test. Unlike the more familiar linear regression that can be conveniently performed in Excel, to assess trend in time series of hydrological and other variables, the Mann-Kendall, or M-K, test is non parametric. This means that M-K does not assume that a time series obeys any particular functional form or that it is normally distributed (Kendall 1938, Mann 1945, Hirsch et al. 1968). Therefore, M-K is suitable for any dataset, regardless of functional form. It is widely used in hydrological and meteorological studies; but it requires that there should be no autocorrelation within the data series.

The data was checked for autocorrelation, and a preliminary test indicated that autocorrelation did not impact the results here presented. However, this is an area in which further evaluation is recommended. Autocorrelation within the data can be removed by "prewhitening" (Bayazit 2007).

The various equations used in M-K to arrive at the P-value, i.e. the probability of the null hypothesis (a series has no trend) can be found in a variety of publications, e.g. Hirsch et al (1982).

To quantify the trend associated with the M-K test, a non-parametric estimate of the data series slope has been developed by Sen (1968), which is more robust than the slope estimate obtained with linear, least squares, regression. For a set of pairs (i, x_i) where x_i is a time series, **Sen's slope** is defined as:

$$Sen's\ slope = Median\left\{\frac{x_j - x_i}{j - i} : i < j\right\} \quad [1]$$

In this paper, Sen's slope is used to estimate overall change of any one variable over the period of studied record. For completeness, the linear regression slope is also presented in summary tables, so that readers can compare it to Sen's slope.

3. Findings

The findings, for each of the WSC stations investigated, are presented hereby.

3.1. Thames River at Chatham (02GE004)

The City of Chatham occasionally experiences major floods caused by ice jams that form on the Thames River, most recently in February of 2019. A relatively large river in Southwestern Ontario, the Thames runs through the city and empties into Lake St. Clair, some 30 river km below Chatham. The Thames River is moderately regulated, primarily for flood control and water supply and is gauged by WSC at several locations, including at Chatham (WSC Station 02GE004). The daily mean gauge height at the Chatham station is available online, while usable (for the present purpose) data covers the period 1975-2020. Gauge height can be converted to geodetic elevation by adding 173.736 m. The WSC "… estimates that Geodetic Survey of Canada Datum refers to CGVD28, however cannot confirm the epoch, age or accuracy of the conversion".

The Chatham station does not report flow, therefore presence or absence of ice-related backwater was decided on the basis of flow datasets (which come with a B-code) at the Thamesville gauge (WSC Station 02GE003), which is located ~36 km upriver. Peak breakup water level was defined as the maximum (daily mean) gauge height that occurred within anyone season, during the time when a B-code was indicated at Thamesville and up to three days past the day of the last B at Thamesville. The 3-day lag is partly subjective and based on the third author's observational experience of local ice processes (1980-1987). On anyone season, ice effects on the Chatham stage end later than at Thamesville, owing to: (a) the general downstream progression of the breakup event; and (b) the nearly-zero slope of the Thames River below Chatham (Beltaos 1987), which means that backwater effects from an ice cover or an ice jam, located well below Chatham can extend for long distances upstream. Therefore, the end-of-backwater at Chatham likely coincides with ice clearance of the entire reach between Chatham and Lake St. Clair. Though there is reasonable confidence in the 3-day lag, a scenario in which Chatham backwater effects end one day later than at Thamesville was also examined, to assess whether the lower lag value significantly alters the results of the analysis.

There were three years for which relevant data were missing (1987, 1993, 1995) while no ice at all (no B-code) appears to have formed at Thamesville during the 2011-12 season. Because ice forms more readily over relatively quiescent water, it is possible that some ice may have formed at and below Chatham in that season, but the lack of B-code precludes interpretation of the local gauge record.

Slight, not statistically significant, decreasing trends were found for the peak breakup water level at Chatham using both 3-day and 1-day ice "clearance" lags. A summary of results for the 3-day lag is presented in Table 2. A strong, statistically significant, trend towards earlier occurrence of the peak breakup water level was detected, again using both 3-day and 1-day ice clearance lags. Peak breakup water levels tend to occur on average ~4 weeks earlier nowadays than they did in the 1970s. Trend analysis has been based on the non-parametric Mann-Kendall test (Hirsch et al. 1982) and the Sen's slope equation (Sen 1968). Slope values were also calculated using the more familiar linear regression for comparison, even though there is no assurance that various time series vary linearly over time.

Table 2. Regression Analysis Results for the Thames River at Chatham. Bolded text indicates significance at the 0.05 level.

Variable	**Sen's slope**	**Regression Slope**	**Mann-Kendall P-value**	**Change in 45 years based on Sen's slope**
Maximum Water Level on "B Days"	-0.022 m/yr	-0.020 m/yr	0.26	-1.0 m
Day of Maximum Water Level	**-0.64 days/yr**	**-0.54 days/yr**	**0.036**	**-29 days**

3.2. Thames River at Thamesville (02GE003)

The first gauge upstream from Chatham is located at Thamesville (WSC Statiom 02GE003), some 36 river km away. This gauge reports both water level and flow, the latter obtained via frequent discharge measurements and flow rating curves that relate flow to water level. The usable (for the present purpose) dataset extends from 1956 to 2020 and primarily contains values of daily mean flow, accompanied by a B-code when applicable. "Suspect" data for 1964 (flows are far too small) were ignored; there was no B-code at all for the 2011-12 fall-winter season, from which it was inferred that an ice cover never formed near Thamesville in that season. The downloaded dataset also contains values of daily mean gauge height for the years 2002 to 2020, which was deemed too brief a period for trend analysis.

For the analyzed variables, the following trends were detected (see also Table 3):

-First B-day: slight, not statistically significant, decreasing trend
-Last B-day: slight, not statistically significant, decreasing trend
-Total number of B-days: strong, statistically significant, decreasing trend
-Peak ice-influenced flow: no or slight decreasing trend, not statistically significant
-Day of peak ice-influenced flow: strong, statistically significant, decreasing trend

During the analysis of the Thamesville dataset, it was noticed that B-day sequences often contained gaps, meaning that ice cover presence is generally episodic during anyone fall-winter season. The number of episodes and the B-day gaps between them appeared to increase over time. This would explain the strong decrease in total B days, despite insignificant changes in the first and last B days.

Table 3. Trend Analysis Results for Thames River at Thamesville. Bolded text indicates significance at the 0.05 level.

Variable	**Sen's slope**	**Regression Slope**	**Mann-Kendall P-value**	**Change in 64 years based on Sen's slope**
First "B Day"	-0.041 days/yr	-0.052 days/yr	0.68	-3 days
Last "B Day"	-0.14 days/yr	-0.23 days/yr	0.18	-9 days
Number of "B Days"	**-0.53 days/yr**	**-0.52 days/yr**	**0.001**	**-34 days**
Maximum Water Level on "B Days"	NA	NA	NA	NA
Day of Maximum Flow on "B days"	**-0.41 days/yr**	**-0.41 days/yr**	**0.019**	**-26 days**
Maximum Flow on "B Days"	0 $m^3/s/yr$	-0.71$m^3/s/yr$	1.0	no change

3.3 Grand River At Brantford (02GB001)

The Grand River is the largest river in southern Ontario. It runs 280 km from the Dufferin Highlands to its mouth in Lake Erie, at Port Maitland. Its watershed has an area of approximately 6,800 km^2 and is home to close to one million people, including a number of towns, villages, the cities of Brantford, Cambridge, Guelph, Kitchener and Waterloo and two First Nations territories (GRCA 2018). The WSC Station 02GB001 is located on the Grand River at the City of Brantford. Approximately 40% of the watershed at this location is regulated with seven reservoirs, established between 1942 and 1976, which are operated for flood control and flow augmentation. The Grand River Conservation Authority's website indicates that operation of the reservoirs can reduce peak flows at urban centres, including Brantford, by up to 50%.

There is a long history of ice jamming, causing flooding, at the Grand River at Brantford, including the events of February of 2018 (Curi et al. 2019), which forced evacuations when the river overtopped the flood defenses, and in 1996, which resulted in water levels that were within one metre of the record ice jam value of 2018.

The data obtained for WSC Station 02GB001 included daily flow values from 1913 to 2019, daily water levels from 2002 to 2019 and sub-hourly water levels from 1969 to 2018. The latter were used to develop average water levels, which were then added to the daily values to complete a series of winter water levels from 1969 to 2018. A review of the data revealed some quality concerns with data during the initial years, so that the period used to evaluate presence of backwater effects starts in the 1950's and the water levels used in the analysis in the mid 1970's.

For the analyzed variables, the following trends were detected (see also Table 4):
- First B-day: slight, not statistically significant, decreasing trend

- Last B-day: no or slight, not statistically significant, increasing trend
- Total number of B-days: slight, not statistically significant, decreasing trend
- Peak ice-influenced water level: slight, not statistically significant, increasing trend
- Day of peak ice-influenced water level: slight, not statistically significant, increasing trend
- Peak ice-influenced flow: slight, not statistically significant increasing trend
- Day of peak ice-influenced flow: slight, not statistically significant, decreasing trend

Table 4. Trend Analysis Results for Grand River at Brantford. Bolded text indicates significance at the 0.05 level.

Variable	**Sen's slope**	**Regression Slope**	**Mann-Kendall P-value**	**Change in evaluated period based on Sen's slope** [1]
First "B Day"	-0.083 days/yr	-0.109 days/yr	0.692	-3.4 days
Last "B Day"	0 days/yr	0.068 days/yr	0.963	no change
Number of "B Days"	-0.047 days/yr	-0.071 days/yr	0.88	-1.9 days
Maximum Water Level on "B Days"	0.015 m/yr	0.017 m/yr	0.162	0.8 m
Day of Maximum Water Level on "B days"	0.146 days/yr	0.07 days/yr	0.739	7.7 days
Maximum Flow on "B Days"	1.368 $m^3/s/yr$	1.366 $m^3/s/yr$	0.529	56.1 m^3/s
Day of Maximum Flow on "B days"	-0.174 days/yr	-0.154 days/year	0.701	-7.1 days

3.4 Saugeen River Near Port Elgin (02FC001)

The Saugeen River drains an area of 4,001 square kilometers in southwestern Ontario and empties into Lake Huron. The watershed is dominated by agricultural and swamp land cover and experiences ice related flood issues that impact communities within the floodplains.

The Saugeen River Near Port Elgin (02FC001) gauge is located 16.5 km from the basin outlet and the community of Southampton. The gauge is classified by Water Survey of Canada as a Reference Hydrometric Basin and is therefore suitable for long-term climate analysis. HYDAT flow records and B-code data are available from 1914 to 2019 and water level data are available from 2002 to 2019. Flow prior to 1955 were not used due to data quality issues. Water level quality issues produced a record insufficient for trend analysis.

Slight, not statistically significant, trends towards initiation of freeze-up and no change in the date of occurrence of break-up were found. There was a strong, significant decrease in number of ice

[1] 40 years of data were used for all variables, except for the Maximum Water Level and the Day of Maximum Water Levels, for which 51 years were used

days with a decrease of 37.5 days over the period of record. A slight, not statistically significant increase in peak flow with a trend towards statistically significant earlier peak occurrence of 31.5 days over the period of record was observed (Table 5).

Table 5. Trend Analysis Results for Saugeen River Near Port Elgin. Bolded text indicates significance at the 0.05 level.

Variable	**Sen's slope**	**Regression slope**	**Mann-Kendall P-value**	**Change in evaluated period based on Sen's slope**[2]
First "B Day"	0.016 days/yr	0.008 days/yr	0.651	1.6 days
Last "B Day"	0 days/yr	0.024 days/yr	0.932	0 days
Number of "B Days"	**-0.375 days/yr**	**-0.364 days/yr**	**1.1E-04**	**-37.5 days**
Maximum Water Level on "B Days"	NA	NA	NA	NA
Day of Maximum Water Level on "B days"	NA	NA	NA	NA
Maximum Flow on "B Days"	0.633 $m^3/s/yr$	0.299 $m^3/s/yr$	0.445	41.1 m^3/s
Day of Maximum flow on "B days"	**-0.485 days/yr**	**-0.454 days/yr**	**0.006**	**-31.5 days**

3.5 <u>Black River Near Washago (02EC002)</u>

The Black River is an unregulated tributary of the Severn River, in Central Ontario. It originates in Powderhorn Lake, south of Algonquin Provincial Park and runs south and southwest, through forest and rural areas, for approximately 110 km to flow into the Severn River near its source at Lake Couchiching. The Severn River, in turn, flows into Georgian Bay.

The WSC Station 02EC002 is located approximately 6 km west of the small community of Washago, as the river approaches an area characterized by riverbank cottages and houses. There is no known history of ice jamming at this location, however, the station is listed on the CRID.

Daily flow data available for this station spanned for approximately 100 years and was used to evaluate trends on peak flow on B-days, first, last and number of B-days. However for the peak water level on B-days, only 18 years were available, from the 2001-02 to the 2018-19 winter seasons. The analysis was performed on the latter data, recognizing that the period of record is relatively short, compared with other trend analyses reported in this study.

[2] 100 years of data were used for all variables except for the Maximum Flow and the Day of Maximum Flow, for which 65 years were used

For the analyzed variables, the following trends were detected (see also Table 6):
- First B-day: no or slight, not statistically significant, decreasing trend
- Last B-day: no or slight, not statistically significant, increasing trend
- Total number of B-days: slight, not statistically significant, decreasing trend
- Peak ice-influenced water level: slight, not statistically significant, decreasing trend
- Day of peak ice-influenced water level: slight, not statistically significant, decreasing trend
- Peak ice-influenced flow: slight, not statistically significant, increasing trend
- Day of peak ice-influenced flow: slight, not statistically significant, decreasing trend

Table 6. Trend Analysis Results for Black River Near Washago. Bolded text indicates significance at the 0.05 level.

Variable	**Sen's slope**	**Regression Slope**	**Mann-Kendall P-value**	**Change evaluated period based on Sen's slope**[3]
First "B Day"	0 days/yr	-0.109 days/yr	0.865	0 days
Last "B Day"	0.016 days/yr	-0.002 days/yr	0.663	1.6 days
Number of "B Days"	-0.077 days/yr	-0.095 days/yr	0.337	-7.7 days
Maximum Water Level on "B Days"	-0.022 m/yr	-0.025 m/yr	0.544	-0.418 m
Day of Maximum Water Level on "B days"	-1 days/yr	-2.096 days/yr	0.471	-19 days
Maximum Flow on "B Days"	0.214 $m^3/s/yr$	0.081 $m^3/s/yr$	0.363	21.4 m^3/s
Day of Maximum Flow on "B days"	-0.25 days/yr	-0.289 days/yr	0.416	-25 days

3.6 Missinaibi River At Mattice (04LJ001)

The Missinaibi River is an unregulated river in northern Ontario, which flows northeast from Missinaibi Lake, north of Chapleau and empties into the Moose River, which, in turn, flows into James Bay. The Missinaibi River is a Canadian Heritage River and its full length is part of the Missinaibi Provincial Park. In the fur trade days it was part of the main route between James Bay and Lake Superior. It is a popular destination for canoeing enthusiasts.

The WSC Station 04LJ001 is located at the Township of Mattice-Val Cote, approximately 160 km from the river source at Missinaibi Lake. The station is included in the CRID. Daily flow data available for this station spanned for approximately 96 years and was used to evaluate trends on peak flow on B-days, first, last and number of B-days. However for the peak water level on B-days, only 17 years were available, from the 2001-02 to the 2017-18 winter seasons. This period of record was, nonetheless, used for the trend analysis of that variable, recognizing its relatively short length.

[3] 100 years of data used for all variables, except for Maximum Water Level and Day of Maximum Water Level, for which 18 years of data were used.

For the analyzed variables, the following trends were detected (see also Table 7):
- First B-day: strong, statistically significant, decreasing trend
- Last B-day: slight, not statistically significant, decreasing trend
- Total number of B-days: slight, not statistically significant, increasing trend
- Peak ice-influenced water level: slight, not statistically significant, decreasing trend
- Day of peak ice-influenced water level: slight, not statistically significant, increasing trend
- Peak ice-influenced flow: slight, not statistically significant, increasing trend
- Day of peak ice-influenced flow: slight, not statistically significant, decreasing trend

Table 7. Trend Analysis Results for Missinaibi River at Mattice. Bolded text indicates significance at the 0.05 level.

Variable	**Sen's slope**	**Regression Slope**	**Mann-Kendall P-value**	**Change in evaluated period based on Sen's slope[4]**
First "B Day"	**-0.083 days/yr**	**-0.094 days/yr**	**0.009**	**-8.1 days**
Last "B Day"	-0.026 days/yr	-0.026 days/yr	0.393	-2.5 days
Number of "B Days"	0.026 days/yr	0.029 days/yr	0.557	2.5 days
Maximum Water Level on "B Days"	-0.022 m/yr	-0.017 m/yr	0.621	-0.4 m
Day of Maximum Water Level on "B days"	0.969 days/yr	0.537 days/yr	0.149	17.4 days
Maximum Flow on "B Days"	**2.837 $m^3/s/yr$**	**2.487 $m^3/s/yr$**	**0.013**	**278.0 m^3/s**
Day of Maximum Flow on "B days"	-0.025 days/yr	0.319 days/yr	0.531	-2.5 days

3.7 Missinaibi River Below Waboose River (04LM001)

The WSC Station 04LM001 is located approximately 158 km downstream (north) of the Township of Mattice-Val Cote, and 49 km from the river mouth at the Moose River. The station is included in the CRID. Daily flow data available for this station spanned for approximately 47 years and was used to evaluate trends on peak flow on B-days, first, last and number of B-days. However, for the peak water level on B-days, only 18 years were available, from the 2001-02 to the 2018-19 winter seasons. They were used for analysis despite the short period of record.

For the analyzed variables, the following trends were detected (see also Table 8):
- First B-day: strong, statistically significant, increasing trend
- Last B-day: no or slight, not statistically significant, increasing trend
- Total number of B-days: slight, not statistically significant, decreasing trend

[4] 96 years of data were used for all variables except for the Maximum Water Level and Day of Maximum Water Level, for which 17 years of data were used.

- Peak ice-influenced water level: slight, not statistically significant, increasing trend
- Day of peak ice-influenced water level: slight, not statistically significant, increasing trend
- Peak ice-influenced flow: slight, not statistically significant, increasing trend
- Day of peak ice-influenced flow: slight, not statistically significant, decreasing trend

Table 8. Trend Analysis Results for Missinaibi River Below Waboose River. Bolded text indicates significance at the 0.05 level.

Variable	**Sen's slope**	**Regression Slope**	**Mann-Kendall P-value**	**Change in evaluated period based on Sen's slope[5]**
First "B Day"	**0.2 days/yr**	**0.173 days/yr**	**0.036**	**9.4 days**
Last "B Day"	0.062 days/yr	-0.031 days/yr	0.563	2.9 days
Number of "B Days"	-0.091 days/yr	-0.179 days/yr	0.383	-4.3 days
Maximum Water Level on "B Days"	0.028 m/yr	0.021 m/yr	0.649	0.5 m
Day of Maximum Water Level on "B days"	0.727 days/yr	0.376 days/yr	0.322	13.8 days
Maximum Flow on "B Days"	3.333 $m^3/s/yr$	0.659 $m^3/s/yr$	0.497	156.7 m^3/s
Day of Maximum Flow on "B days"	0 days/year	-0.08 days/yr	0.847	0 days

3.8 Albany River Near Hat Island (04HA001)

The Albany River drains an area of 135,200 square kilometers across northern Ontario and empties into James Bay. The watershed is relatively undisturbed but has three diversions that remove flow from the headwaters. The Albany River is subjected to frequent major, ice-influenced, flooding that affects the remote first nations communities of Fort Albany and Kashechewan situated near the mouth of the river.

The Albany River at Hat Island (04HA001) gauge is critical for monitoring ice breakup and flow. It is located 177 km from the communities and 194 km from the river mouth. WSC flow and B-code data are available from 1964 to 2018 and water level from 1995 to 2018 at this gauge. Manual QA/QC of the data resulted in the removal of level data in mid-90s and early 2000's and removal of flow in 1995 due to erroneous values impacting calculations of trend statistics.

Slight, not statistically significant, trend towards earlier occurrence of freeze-up and break-up with no change in the number of ice days were found. There was a slight, not statistically significant, decrease in peak breakup water level trending towards a later occurrence (not statistically

[5] 47 years of data were used for all variables except for Maximum Water Level and Day of Maximum Water Level, for which 18 years of data were used.

significant). Slight, not statistically significant, increases in peak breakup flow trending towards an earlier occurrence were found (not statistically significant) (Table 9).

Table 9. Trend Analysis Results for Albany River Near Hat Island. Bolded text indicates significance at the 0.05 level.

Variable	**Sen's slope**	**Regression slope**	**Mann-Kendall P-value**	**Change in evaluated period based on Sen's slope[6]**
First "B Day"	-0.094 days/yr	-0.044 days/yr	0.308	-4.8 days
Last "B Day"	-0.034 days/yr	-0.085 days/yr	0.660	-1.7 days
Number of "B Days"	0 days/yr	-0.160 days/yr	0.929	0 days
Maximum Water Level on "B Days"	-0.016 m/yr	-0.011 m/yr	0.837	-0.3 m
Day of Maximum Water Level on "B days"	0.288 days/yr	0.103 days/yr	0.680	4.9 days
Maximum Flow on "B Days"	6.905 m3/s/yr	9.252 m3/s/yr	0.575	359.1 m3/s
Day of Maximum flow on "B days"	-0.066 days/yr	-0.123 days/yr	0.472	-3.4 days

3.9 Attawapiskat River Below Muketei River (04FC001)

The Attawapiskat River is an unregulated river in northwestern Ontario that flows from Attawapiskat Lake to James Bay. The WSC Station 04FC001 is located approximately 260 km from the river source and 200 km from its mouth. The station is included in the CRID. Daily flow data available for this station spanned for approximately 46 years (from 1968 to 2018 but excluding 1994 to 1998) and was used to evaluate trends on peak flow on B-days, first, last and number of B-days. However, for the peak water level on B-days, only 18 years were available, from the 2001-02 to the 2018-19 winter seasons, which were used for the analysis.

For the analyzed variables, the following trends were detected (see also Table 10):
- First B-day: slight, not statistically significant, decreasing trend
- Last B-day: no or slight, not statistically significant, decreasing trend
- Total number of B-days: no or slight, not statistically significant, increasing trend
- Peak ice-influenced water level: slight, not statistically significant, increasing trend
- Day of peak ice-influenced water level: slight, not statistically significant, decreasing trend
- Peak ice-influenced flow: slight, not statistically significant, increasing trend
- Day of peak ice-influenced flow: slight, not statistically significant, decreasing trend

[6] The number of years varied among variables: 51 years were used for the Number of B Days, First B Day and Last B Day; 52 years were used for the Maximum Flow and the Day of Maximum Flow; 18 years were used for the Maximum Water Level and the Day of Maximum Water Level

Table 10. Trend Analysis Results for Attawapiskat River Below Muketei River. Bolded text indicates significance at the 0.05 level.

Variable	**Sen's slope**	**Regression Slope**	**Mann-Kendall P-value**	**Change in evaluated period based on Sen's slope[7]**
First "B Day"	-0.13 days/yr	-0.052 days/yr	0.168	-6.6 days
Last "B Day"	0 days/yr	-0.02 days/yr	0.754	0 days
Number of "B Days"	0.034 days/yr	-0.032 days/yr	0.776	1.7 days
Maximum Water Level on "B Days"	0.0255 m/yr	-0.059 m/yr	0.544	0.5 m
Day of Maximum Water Level on "B days"	-0.167 days/yr	-1.561 days/yr	0.762	-3.2 days
Maximum Flow on "B Days"	6.364 $m^3/s/yr$	0.668 $m^3/s/yr$	0.211	324.6 m^3/s
Day of Maximum Flow on "B days"	-0.075 days/yr	0.284 days/year	0.582	-3.8 days

4. Discussion

Table 11 shows the change per year found in the analysis for each variable and each station evaluated. Since the period of record varied among variables and stations, the changes per year, and to provide a consistent estimate of change in the variables, Table 12 was prepared using the values listed in Table 11 for an assumed period of 30 years. It must be noted, however, that the trends were found to be somewhat dependent on the years used for analysis, as stations have different periods of record and some record years were excluded based on assessment of data quality.

In addition to the tabular data provided, plots of the data used and the trendlines obtained are shown in Appendix A for each of the three regions considered: Northern, Central and Southern Ontario.

In general, a strong common trend was not evident among the stations investigated or even among those corresponding to any of the three regions of the Province: Southern Ontario, Central Ontario, Northern Ontario. Because the trends were generally weak, less defined, it was not uncommon to find contrasting trends, among the variables investigated, within a given region.

[7] 32 years of data were used for all variables, except for Maximum Water Level and Day of Maximum Water Level, for which 18 years of data were used.

Table 11. Average change per Year Obtained from Trend Analysis for all Stations Investigated (Sen's Slope).

Station No.	**Station Name**	**First B Day**	**Last B Day**	**Number of B Days**	**B Day of Max Water Level**	**B Day of Max Flow**	**Max Water Level on B Days**	**Max Flow on B Days**
02GE003	Thames River at Chatham				**-0.64 days**		-0.02 m	
02GE004	Thames River at Thamesville	-0.04 days	-0.14 days	**-0.53 days**		**-0.41 days**		0 m^3/s
02GB001	Grand River at Brantford	-0.08 days	0 days	-0.05 days	0.15 days	-0.17 days	0.02 m	1.37 m^3/s
02FC001	Saugeen River Near Port Elgin	0.02 days	0 days	**-0.38 days**		**-0.49 days**		0.63 m^3/s
02EC002	Black River Near Washago	0 days	0.02 days	-0.08 days	-1.00 days	-0.25 days	-0.02 m	0.21 m^3/s
04LJ001	Missinaibi River at Mattice	**-0.08 days**	-0.03 days	0.03 days	0.97 days	-0.03 days	-0.02 m	**2.83 m^3/s**
04LM001	Missinaibi River Below Waboose River	**0.20 days**	0.06 days	-0.09 days	0.73 days	0 days	0.03 m	3.33 m^3/s
04HA001	Albany River Near Hat Island	-0.09 days	-0.03 days	0 days	0.29 days	-0.07 days	-0.02 m	6.91 m3/s
04FC001	Attawapiskat River Below Muketei River	-0.13 days	0 days	0.03 days	-0.17 days	-0.08 days	0.03 m	6.36 m^3/s

Table 12. Summary of Trend Analysis Results for all Stations Investigated (Change Based on Sen's Slope applied to an assumed period of 30 years).

Station No.	**Station Name**	**First B Day**	**Last B Day**	**Number of B Days**	**B Day of Max Water Level**	**B Day of Max Flow**	**Max Water Level on B Days**	**Max Flow on B Days**
02GE003	Thames River at Chatham				**-19.2 days**		-0.6 m	
02GE004	Thames River at Thamesville	-1.2 days	-4.2 days	**-15.9 days**		**-12.3 days**		0 m^3/s
02GB001	Grand River at Brantford	-2.4 days	0 days	-1.5 days	4.5 days	-5.1 days	0.6 m	41.1 m^3/s
02FC001	Saugeen River Near Port Elgin	0.6 days	0 days	**-11.4 days**		**-14.7 days**		18.9 m^3/s
02EC002	Black River Near Washago	0 days	0.6 days	-2.4 days	-30.0 days	-7.5 days	-0.6 m	6.3 m^3/s
04LJ001	Missinaibi River at Mattice	**-2.4 days**	-0.9 days	0.9 days	29.1 days	-0.9 days	-0.6 m	**84.9 m^3/s**
04LM001	Missinaibi River Below Waboose River	**6.0 days**	1.8 days	-2.7 days	21.9 days	0 days	0.9 m	99.9 m^3/s
04HA001	Albany River Near Hat Island	-2.7 days	-0.9 days	0 days	8.7 days	-2.1 days	-0.6 m	207.3 m^3/s
04FC001	Attawapiskat River Below Muketei River	-3.9 days	0 days	0.9 days	-5.1 days	-2.4 days	0.9 m	190.8 m^3/s

The number of B-days counted within a season showed a decreasing trend in Southern and Central Ontario, which was strong on the Thames River and Saugeen River stations. The data for the Grand River, on the other hand, showed only a weak decreasing trend. It must be noted that this river is subject to rigorous regulation in the winter, to reduce the risk of flooding, and that could have affected the results in that station.

For Northern Ontario, on the other hand, the trends in the number of B-days in a season varied. One of the stations showed a decreasing trend, another one showed a neutral trend and the other two stations showed an increasing trend. Interestingly, the trend in the number of B-days differed between the two stations in the Missinaibi River. At Mattice, an increasing trend was observed, using 96 years of record, from 1920 to present; while further downstream, near the mouth of the Waboose River, the analysis, which was performed with only data for the last 47 years, showed a decreasing trend. This finding highlights how the results were affected by the period used for the analysis.

One possible explanation of the difference in trends for the number of B-days, found between northern regions of Ontario and those located further south, is the difference between these regions in typical ice cover thickness. In the southern regions, the ice cover typically reaches a relatively small thickness (in the order of 0.3 m), compared to the ice covers found in northern Ontario (unpublished data from the third author, from 1961 to 1980, indicates an average value of 0.7 m for the Moose River at Moose River Crossing. Ice covers could be thicker farther north). The thinner ice cover of the southern regions would be more sensitive to temperature increases than that of the northern areas. Nonetheless, this finding merits further evaluation.

With respect to changes in the maximum water levels observed on B-days, the results were almost evenly split among increasing and decreasing trends. No significant trends were found for this variable, suggesting no significant change so far in ice-jam flooding potential.

The day of maximum water level was also found to be trending negative (earlier occurrence) in some stations; but positive (later occurrence) in others. Only the station for the Thames River at Chatham showed a strong trend for this variable, which was in the negative direction.

Maximum flows in B-days consistently showed a neutral or increasing trend, which was significant for two of the stations: Black River near Washago and Missinaibi River at Mattice. In both cases a long record, approximately 100 years, was available for the analysis of flow values.

The day of maximum flow showed a trend towards earlier occurrence in all stations, except at the Missinaibi River below Waboose River, where it was neutral. This trend was strong in two of the stations: Thames River at Thamesville and Saugeen River Near Port Elgin.

A preliminary analysis of climate data showed increasing trends in precipitation and temperatures for two locations: one in northern Ontario and one in southern Ontario. It is recognized that more analysis is required in this front, to allow more conclusive comparisons with the evaluation of data from the WSC stations. The evaluation of climatic variables and their relationship with the hydrometric results is one aspect recommended for further investigation.

The availability and quality of data varied among the stations, which poses difficulties for a consistent analysis. Other similar studies are being carried out concurrently for other Canadian Provinces and Territories. A comparison of the results here presented with those studies is also recommended, to identify similarities, differences and aspects that could be further investigated. It is possible that more trends become evident as data and approaches are shared and compared.

5. Conclusions

The data revealed no universally applicable strong trends, in the variables investigated. Trends were observed to be somewhat dependent on the periods used for the analysis, with different periods, suggesting even contrasting trends on a given river. It was difficult to draw conclusions about the direction of the trends given the weak signal in the data.

In general, a strong common trend was not evident among the stations in Ontario or among those corresponding to any of the three regions of the Province: Southern Ontario, Central Ontario, Northern Ontario. Some specific variables, however, did show strong trends at specific locations, or slight consistent trends. Commonalities observed, included:

- The number of B-days counted within a season showed a decreasing trend in Southern and Central Ontario, which was strong on the Thames River and Saugeen River stations. For Northern Ontario, however, the trends in the number of B-days varied.
- Maximum flows in B-days consistently showed a neutral or increasing trend, which was significant for two of the stations: Black River near Washago and Missinaibi River at Mattice.
- The day of maximum flow was found to consistently trend towards earlier occurrence, except for one station in which it was neutral. This trend was significant for two of the stations: Thames River at Thamesville and Saugeen River Near Port Elgin.
- The maximum water levels observed on B-days, showed almost evenly split results between increasing and decreasing trends. No significant trends were found for this variable.
- No significant trends were found for the maximum water level on B-days, suggesting no significant change so far in ice-jam flooding potential.

Aspects such as autocorrelation checking, and analysis of climate data were only evaluated in a preliminary manner and are proposed to be further investigated. These, as well as comparison with other concurrent studies could reveal useful information in the assessment of climate change effect on river ice processes.

6. Acknowledgments

A part of this study was conducted with funding provided by Environment and Climate Change Canada’s Climate Change adaptation (CCA) program. Assistance provided by Melanie Taylor and Tracy Malakoff (National Hydrological Service of Environment and Climate Change Canada) in obtaining unpublished WSC data is acknowledged with appreciation. Brooke Irving and Kevin Gaylord (KGS Group) kindly assisted with preparation of figures.

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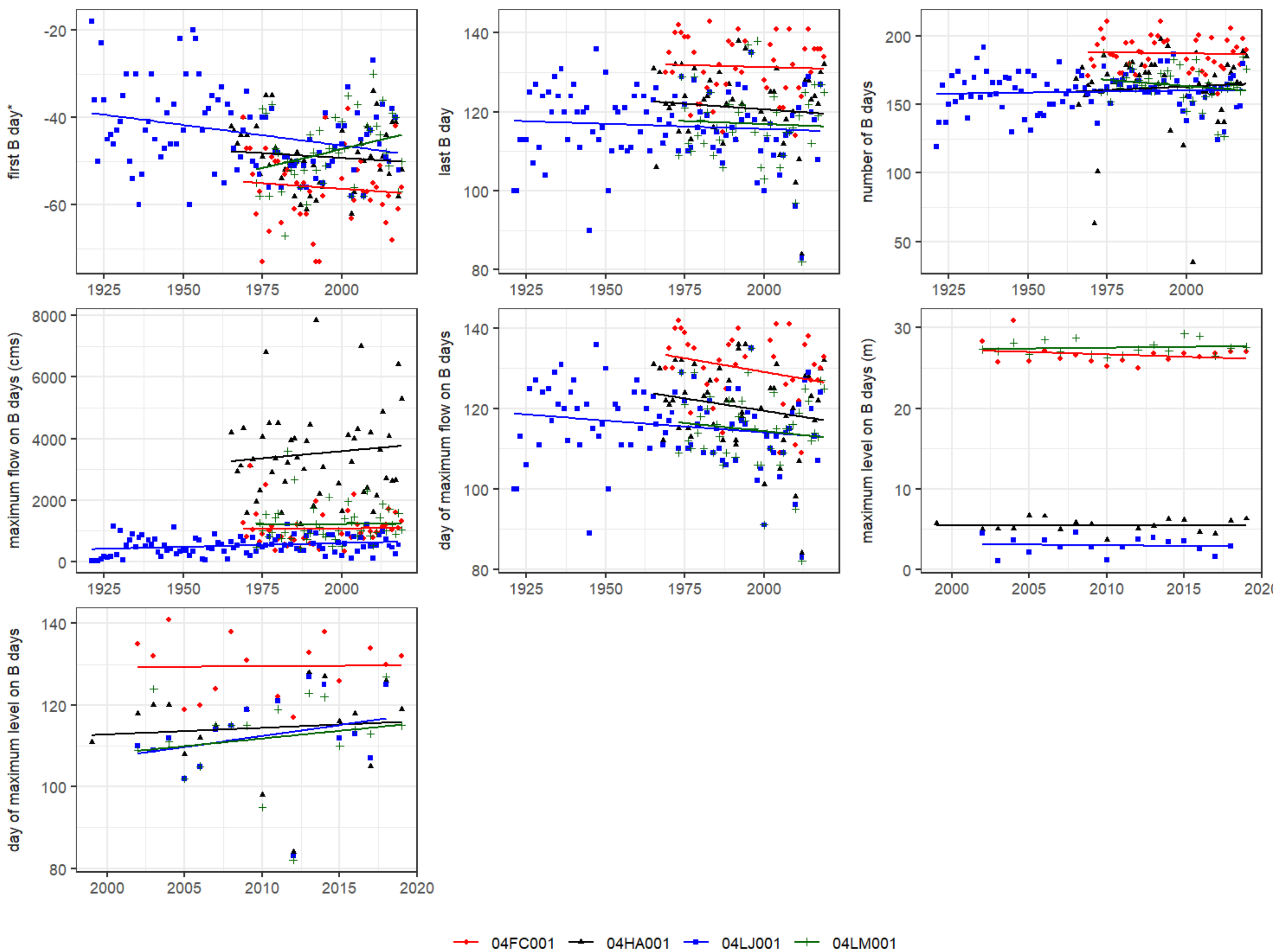
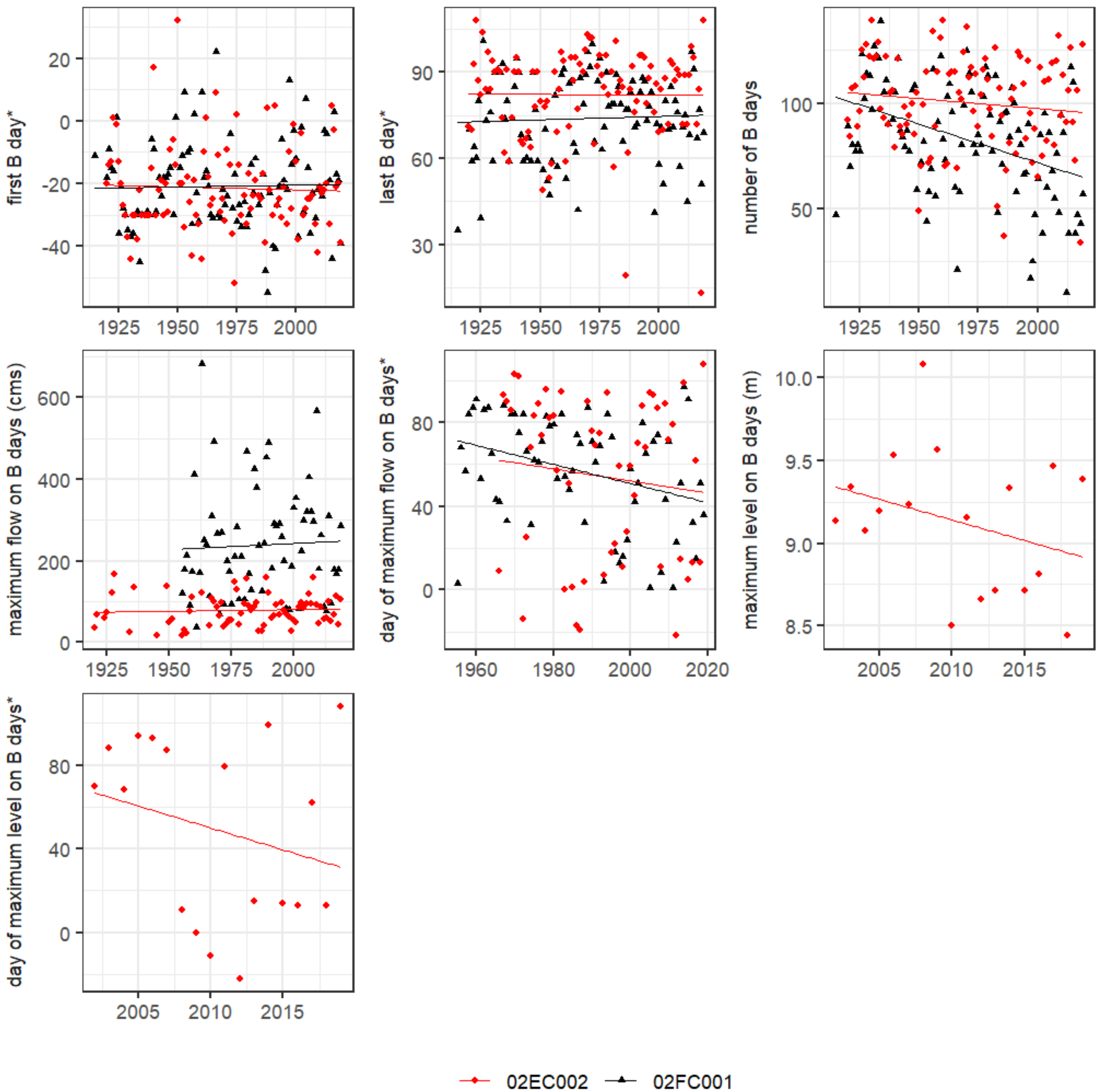


*negative values represent previous year with day 0 assigned to Dec 31st



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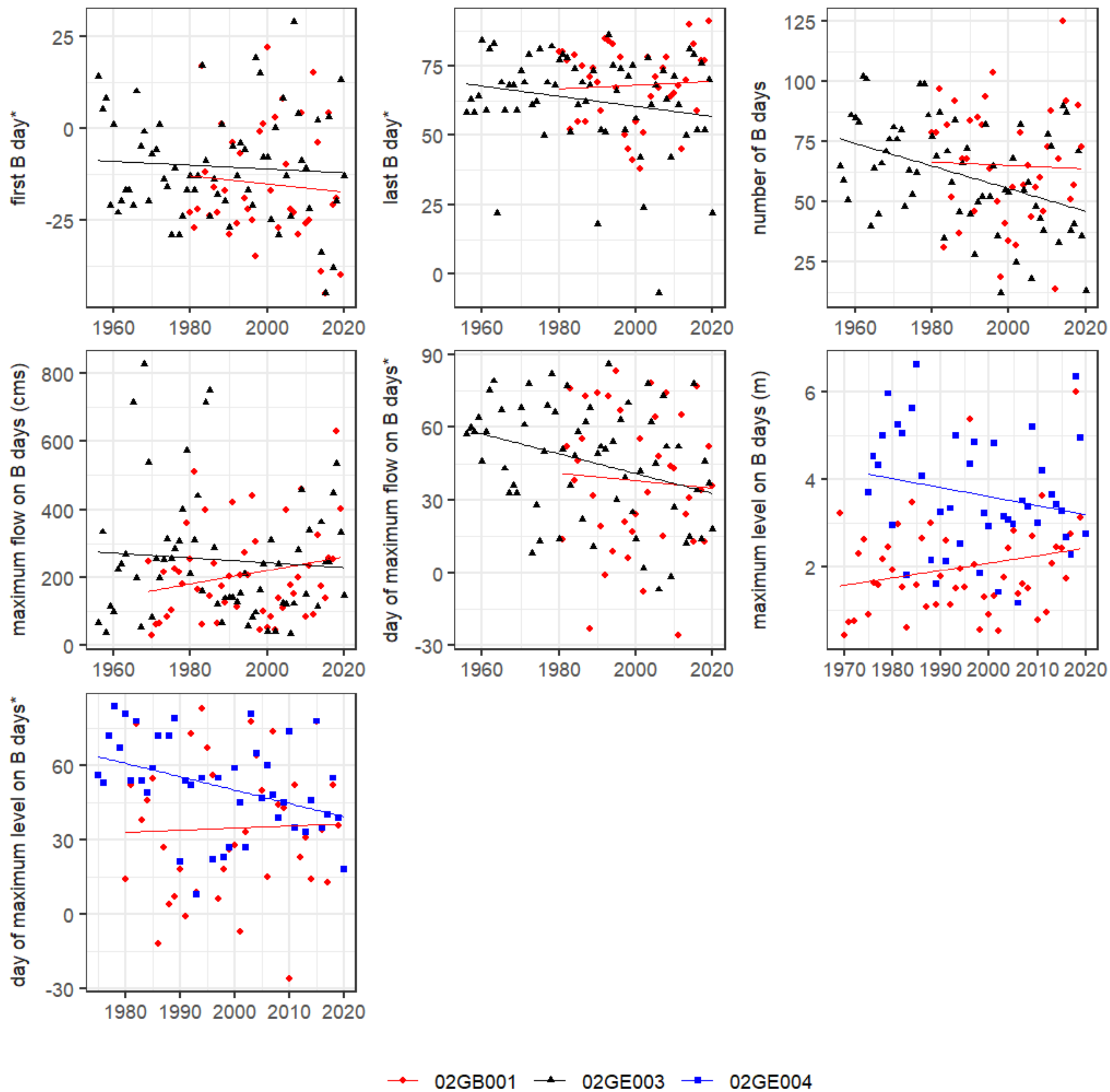

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