Analysis of Snowmelt and Autumn Storm Events Along a Newfoundland and Labrador Boreal Ecosystem Longitudinal Transect

Kenneth Britton
Advisor: Karen Prestegaard
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I. ABSTRACT

Water flux in the boreal forest of Newfoundland and Labrador varies by location and has been changing throughout time. This paper serves to outline characteristics of water flux in the boreal forest of Newfoundland and Labrador based on timing and magnitude of events across a longitudinal transect and with respect to time. Detailing changes in hydrological responses for this region can guide future research in understanding how dissolved organic carbon (DOC) is mobilized. Specifically, water flux occurring during prime DOC mobilization timing is examined. Changes in snowmelt characteristics and autumn peak discharges are statistically analyzed. Snowmelt demonstrated an earlier occurrence annually for the majority of sites across latitudes. Snowmelt peak discharge demonstrated a negative correlation (decrease) with respect to time for all but one of the sites examined. Autumn discharge expressed a positive correlation (increase) in the southern and central regions and insignificant change in the northern region. When evaluating north-south differences in snowmelt and autumn peak discharge, the southern sites experienced higher discharges than the northern sites in both categories. Approximately half of the sites tested for statistical significance when looking for increases and decreases in timing and magnitude of water flux. This research suggests hydrological changes with respect to time, as well as variation among location along a longitudinal transect.

II. INTRODUCTION AND BACKGROUND

Boreal forests are a major storage reservoir of the world's carbon. The boreal ecosystem accounts for 17% of the earth's continental surface and contains more than 30% of the terrestrial carbon (Kasischke, 2000). Of this carbon, most of it is stored in the upper layers of soil as partly decomposed organic matter (Prokushkin et al., 2009). Water passed through these soils can generate dissolved organic carbon (DOC). The DOC contained in runoff can be absorbed by growing vegetation if the runoff occurs during a season where there is plant evapotranspiration (ET). Normally, the DOC contained in runoff can be infiltrated into the soil when occurring during a season where there is plant evapotranspiration. However, if water fluxes occur outside of the growing season and therefore outside of ET timing, runoff rates are increased and the associated DOC can be transported to groundwater or to stream waters and respired as carbon dioxide or lost to the ocean. A past study of the boreal forest found that when calculating DOC flux as a product of DOC concentration and runoff discharge, maximum DOC flux occurred when both DOC and runoff were variable. This condition is most likely to occur during early autumn as ET rates decrease (Bowering et al., 2019). The same study also found that for equal volumes of water, autumn DOC concentrations were higher than during snowmelt. Figure 1. from the Bowering et

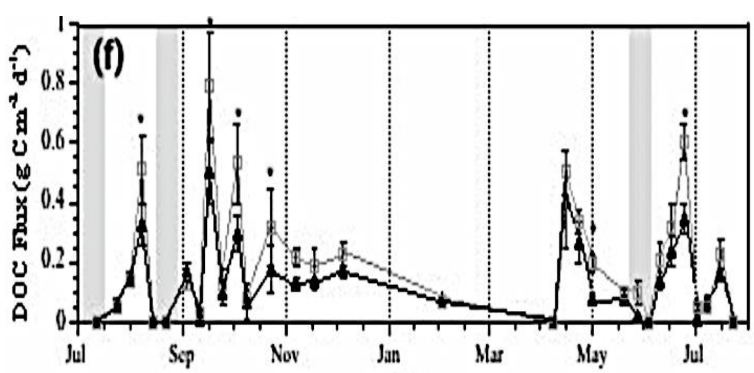

Figure 1. DOC flux (Bowering et al., 2019). Black line represents data collected from forested sites and the gray line represents data collected from harvested sites. Estimates were determined using passive pan lysimeter collections underneath O horizons. Error bars show standard error of the mean.

al. (2019) study shows a significant flux of DOC from September to November. That flux is occurring after ET shutdown. An earlier expression of annual snowmelt can also be a likely condition to flux more water and DOC if occurring before ET starts for the year. In snowmelt-dominated regions of Colorado, DOC levels are shown to spike during initial snowmelt, peak before maximum discharge, and decrease rapidly thereafter (Boyer et al., 2000). This is concerning as DOC contained in the runoff cannot be absorbed and stored by growing vegetation.

The production of DOC can be influenced by temperature. Increases in temperature can lead to faster decomposition rates of organic matter in soils, which when processed by microbial life, produces more DOC (Christ & David, 1996). Global air surface temperatures for northern regions are projected to increase from 1-4°C in the 21st century (IPCC, 2013). Increases in temperature in the boreal forest can influence earlier snowmelt timing. Warmer ocean waters near coastal Newfoundland and Labrador (NL) may have an effect on the frequency of autumn storm events. Both instances can increase water flux for this region during critical times. An analysis of snowmelt timing and autumn water flux can guide further research in hydrological and biogeochemical processes, specifically the flux of DOC, in the boreal forest of Newfoundland and Labrador.

Most previous studies of changes in snowmelt have been conducted in regions with seasonal precipitation, such as the Rocky Mountain regions of the United States and Canada. These studies suggest that as climate warms and the melting of winter snow occurs earlier in spring, there is a decrease in the annual proportion of snowfall to rainfall (Berghuijs et al., 2014). These changes in snowfall and the timing of snowmelt can lead to a decline in streamflow during the summer and autumn months. The maritime climate of NL does not have a seasonal low-precipitation season. Periods of low streamflow are driven by evapotranspiration, not the lack of precipitation. Therefore, changes in the length of the growing season, precipitation in the non-growing season, and changes in timing and amount of snowmelt may all affect streamflow. Warming of the Atlantic Ocean could lead to increases in precipitation in late summer and autumn, perhaps after ET shutdown. Thus, the Canadian Maritime Provinces may experience significantly different runoff changes than other snow-dominated runoff systems.

III. OBJECTIVES OF RESEARCH AND BROADER IMPLICATIONS

For the Maritime provinces, the effects that warming is having on hydrological and biogeochemical processes are not fully understood. A warming climate may be influencing changes within these processes, requiring a detailed understanding of water fluxing events along a climate transect. This research is specifically designed to examine differences along a north-south transect. A space for time analysis of melt and storm events along a longitudinal transect can be used as a proxy for climate warming, considering the sites range across a mean annual temperature gradient of 5.6°C.

To analyze these differences, two types of data can be evaluated: 1) differences in runoff amount and timing as a function of location (latitude); and 2) changes in runoff with respect to time at each location. For the latitudinal transects, the warmer, wetter climates of the southern sites can be expected to yield an earlier onset of snowmelt, a larger snowmelt peak discharge value, and a larger autumn peak discharge value than the cooler, drier climates of the northern sites.

H1: a.) Snowmelt peak discharge and b.) autumn peak discharge increase in magnitude from north to south along the latitudinal gradient.
Null hypothesis: Snowmelt peak discharge and autumn peak discharge have similar magnitudes (after normalization for basin area) along the latitudinal gradient.

H2: a.) The start dates (onset) of snowmelt and b.) the date of peak snowmelt discharge occur earlier annually for all sites.
Null hypothesis: There is no significant change in the timing of snowmelt onset and peak discharge.

H3: Snowmelt peak discharge is decreasing in magnitude at all sites with respect to time.
Null Hypothesis: There is no change in the magnitude of peak snowmelt discharge.

H4: The peak discharge or autumn water flux after autumn ET shutdown (to include September and October) is increasing for all sites.
Null: There is no change in peak autumn discharge or autumn water flux.

The ultimate goal of this research is to identify hydrological changes that can guide further research in hydrological and biogeochemical processes, specifically processes that influence the flux of DOC from the boreal forest soils of Newfoundland and Labrador.

IV. EXPERIMENTAL DESIGN

The Maritime Provinces are found along the Atlantic Coast of Canada. Previous studies in this region have established research sites (NL-BELT study) along a longitudinal trend from SW Newfoundland to NE Labrador (Ziegler et al., 2017). The NL-BELT study includes streamflow measurements in 3 main regions (Figure 2). The NL-BELT study was designed to include catchment data for 3 sites from the northernmost latitude, 3 sites from the central latitude, and 3 sites from the southernmost latitude. The NL-BELT catchment data are for small streams with basin areas 20 km^2 or less; these are low order mountain streams. Therefore, these small streams document the timing and amount of water that is transferred from hillslopes to stream channels. The NL-BELT study as of 2019 has only three years of data making it infeasible to detect trends over time and conduct a comparison across regions. For the analysis in this paper, the source of data is from Environment Canada (EC) and represents the historical streamflow records (21-59 years) collected by the Canadian government. EC data are publicly accessible on their website (Environment Canada, 2019). EC data are primarily on streams larger than 300 km^2 in basin area. The Environment Canada data localities

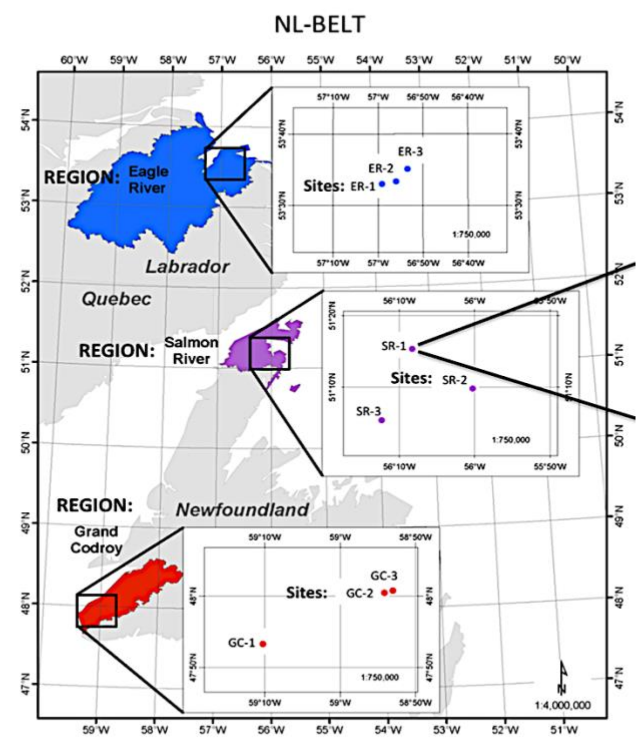

Figure 2. NL-BELT site locations (Ziegler et al., 2017)

will be selected to provide 3 sites from each latitudinal range as the NL-BELT data. Selected gauges are within 1° latitude of NL-BELT sites (Figure 3).

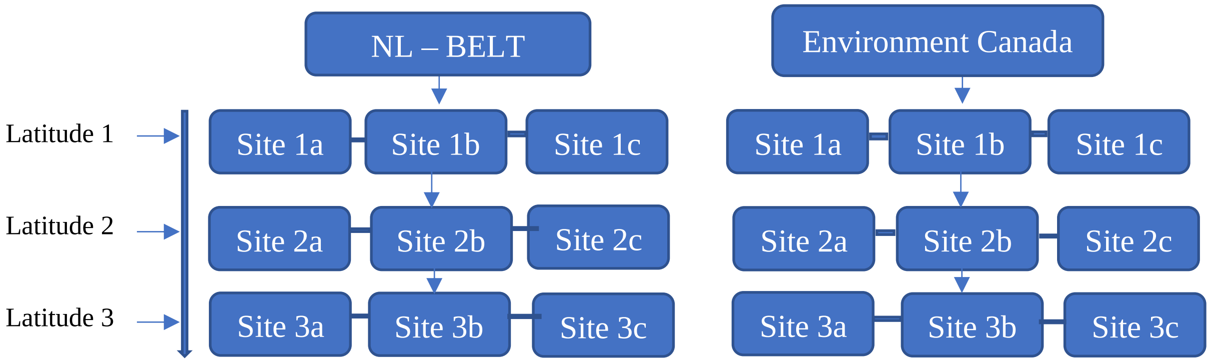

Figure 3. Site distribution

Stream hydrographs (e.g. Figure 4) are a graphical representation of discharge versus time, or when timing alone is important, gauge height versus time. For this research, time series data of daily average discharge were primarily used. From the annual hydrograph, the following parameters can be determined: maximum discharge of snowmelt, the maximum gauge height of snowmelt, the date of maximum snowmelt discharge, the date of snowmelt onset, the discharge of the maximum autumn event and gauge height values, and the date at which they occur.

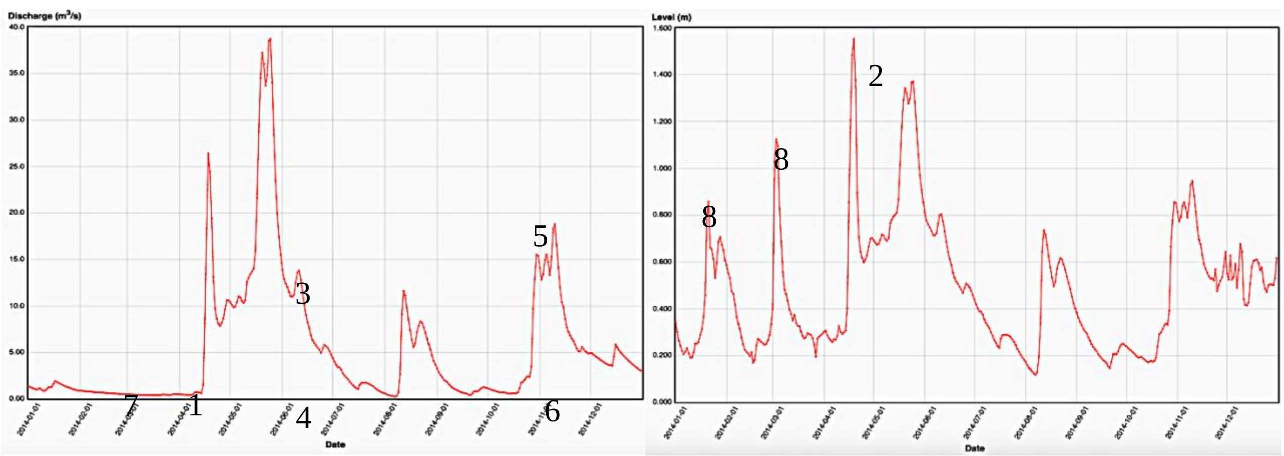

Figure 4. Northeast Brook site 2a. Discharge (left) and level (right). (1) Start date of snowmelt, (2) Maximum gauge height of melt period, (3) Maximum discharge of melt period, (4) Date of maximum snowmelt, (5) Autumn maximum discharge, (6) Date of autumn maximum, (7) Winter base flow, (8) Occurrence of possible ice jamming.

V. METHOD OF ANALYSIS:

The peak discharge data along with the timing of peak discharge events, snowmelt onset, and the number of winter peak events will be obtained from the time series data. Data will be analyzed to compare among regions and to determine whether there are trends in the time series data for each EC station.

Comparison among regions*:* The following will be calculated for each set of data: mean, standard deviation, and coefficient of variance of discharge values, and mean standard deviation (in days) of the timing of discharge events. Due to the differences in drainage basin size, peak discharge data will be normalized by dividing by basin area (Q/km_2). The mean and standard deviation of both normalized discharge and the timing of events will be calculated for each site and region (3 stations) and compared among the three regions. These comparisons will be used to test the hypotheses that discharge magnitude and timing vary with latitude.

Trend analysis of data for each gauging station: To evaluate whether hydrograph parameters are changing with time, this study examines whether time series are stationary or whether there are significant trends in the data with respect to time. Stationarity of the time series can be evaluated with the method outlined in a Spearman rank correlation coefficient analysis of variables plotted against time. This includes snowmelt onset timing, peak discharge of snowmelt, timing of peak snowmelt discharge and autumn peak discharge value. This statistical method is used to summarize the strength and direction (positive or negative) of a relationship between two variables. Relationships between trends with time are then tested for statistical significance.

Error analysis: In this study, the timing and magnitude (discharge) of streamflow events are analyzed. Timing of snowmelt onset and peak events are recorded directly as gauge height events. Peak discharge values, however, require conversion from gauge height to discharge using a rating curve. Rating curves are established and maintained by Environment Canada. Gauge height, however, can be perturbed by ice jams and related processes during winter periods, which affects the discharge-gauge height relationship. For this reason, discharge values are only acquired for autumn peak and snowmelt peak events, which tend to occur outside of the period of ice jams. In general, rating curve relationships provide total uncertainty of 5-7%. However, EC began using acoustic doppler velocimeter in 2006, reducing total uncertainty to 3-5% (Huhta & Sloat, 2007; Water Survey of Canada, 2019). This is not true for gauges with unstable rating curves. Sites with stable or well-characterized rating curves can be used to compare discharge data across regions and for trend analysis within regions. Timing of discharge events will be ± 1 day, because data are recorded at 15- or 30-minute intervals, which can confuse the date of an event if it is near midnight.

VI. PRESENTATION OF DATA AND RESULTS

As a first order evaluation, plotting the variables as a time series will visually display any trends the data may be experiencing. The plots below demonstrate each time series variable for Eagle River, a northern site. An index of all plots for all sites can be found in the figures index. Plots 1, 2, 3 and 4 describe the trends observed in the snowmelt peak discharge data, snowmelt peak discharge date data, autumn peak discharge data and onset of snowmelt timing data respectively for the northern site 1a.

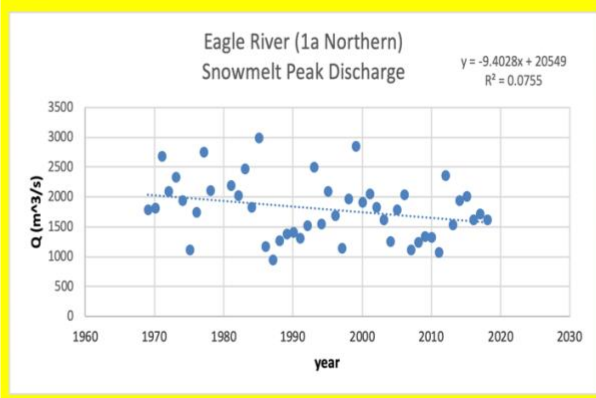

Figure 5. Eagle River (site 1a, northern), basin area = 10900km^2, mean = 1739m^3/s, standard deviation = 499m^3/s

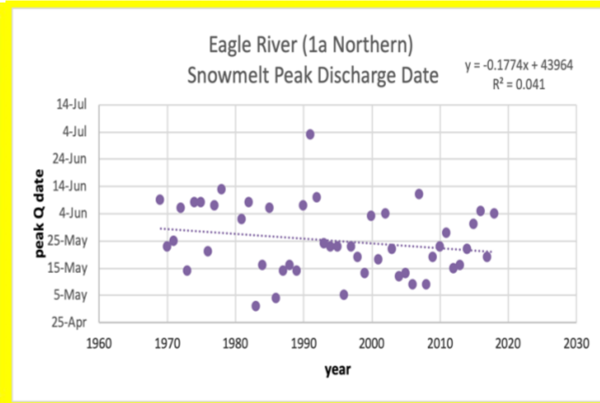

Figure 6. Eagle River (site 1a, northern), basin area = 10900km^2, mean = 25-May, standard deviation = 12.8days

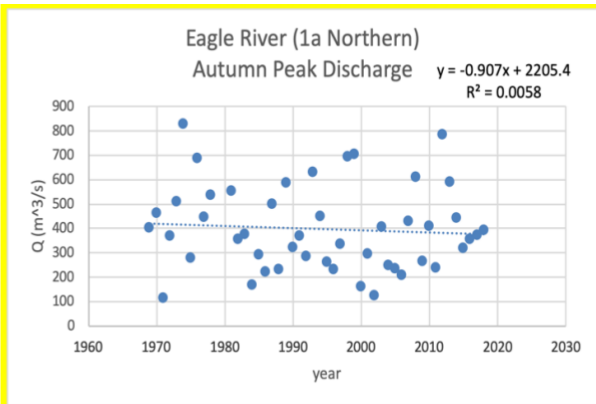

Figure 7. Eagle River (site 1a, northern), basin area = 10900km^2, mean = 397m^3/s, standard deviation = 173m^3/s

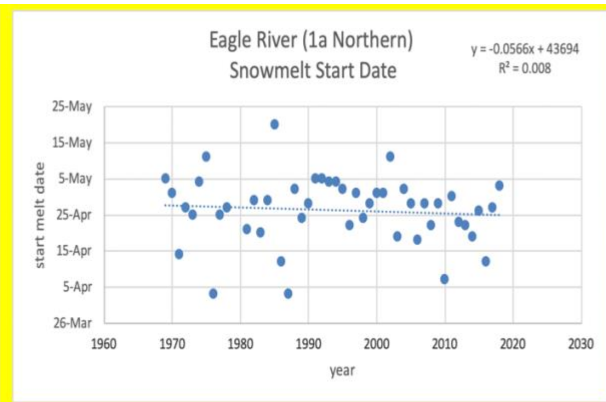

Figure 8. Eagle River (site 1a, northern), basin area = 10900km^2, mean = 24-April, standard deviation = 9.2days

Region	Mean snowmelt peak discharge (Q/BA)	Snowmelt peak discharge standard deviation	Mean date of snowmelt peak discharge	Date of snowmelt peak discharge standard deviation (days)
Northern 1a	0.16	0.05	5/25	12.8
Northern 1b	0.15	0.04	5/19	7.2
Northern 1c	0.08	0.01	6/3	8.3
Central 2a	0.20	0.04	5/13	14.7
Central 2b	0.28	0.10	5/18	15.3
Southern 3a	0.62	0.29	5/7	19.8
Southern 3b	0.63	0.32	4/29	17.7
Southern 3c	0.36	0.16	4/22	16.3

Table 1. Summary of mean snowmelt peak discharge, snowmelt peak discharge standard deviation, mean date of snowmelt peak discharge and date of snowmelt peak discharge, where Q = discharge, BA = basin area.

Region	Mean autumn peak discharge (Q/BA)	Autumn peak discharge standard deviation	Mean date of snowmelt onset	Date of snowmelt onset standard deviation (days)
Northern 1a	0.04	0.016	4/24	9.2
Northern 1b	0.03	0.013	4/25	12.7
Northern 1c	0.03	0.006	4/30	7.0
Central 2a	0.06	0.033	4/9	9.4
Central 2b	0.10	0.046	4/15	12.4
Southern 3a	0.42	0.17	4/2	10.3
Southern 3b	0.50	0.18	4/4	8.1
Southern 3c	0.24	0.15	3/29	6.6

Table 2. Summary of mean autumn peak discharge, autumn peak discharge standard deviation, mean date of snowmelt onset and date of snowmelt onset standard deviation, where Q = discharge, BA = basin area.

To determine significance, Spearman's rank correlation coefficient is used to analyze the trend data. Using the equation:

$$\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}} \quad \text{(eq1.)}$$

for paired ranks, the correlation coefficient (rho) can be determined. Rho can be between -1 and 1. Negative one indicates perfect negative correlation between the two variables, and positive one indicates perfect positive correlation. The rho value is reported with its p-value which is a level of its significance where 'p' is the probability of accepting the null of no difference. A p-value of or less than 0.05 is accepted as statistically significant.

H2: Snowmelt onset demonstrated an earlier occurrence annually for five of eight sites. Four of eight sites tested statistically significant. Of the four significant sites, three sites showed an earlier occurrence of snowmelt onset. These sites were 1c (northern) with a rho value of -0.36, 2b (central) with a rho value of -0.39 and 3a (southern) with a rho value of -0.32. The site that tested significant for a later snowmelt onset was 3c (southern) at a rho value of 0.27. The four sites that tested for significance reject the null hypothesis of no difference. Sites 1a, 1b, 2a and 3b can neither accept nor reject the null hypothesis.

Snowmelt peak discharge timing demonstrated an earlier occurrence for seven of eight sites where only site 2b (central) tested for significance. Site 2b gave a rho value of -0.38. The hypothesis that snowmelt peak discharge timing is occurring earlier annually is accepted for site 2b. For the remaining sites, the null hypothesis can neither be accepted or rejected.

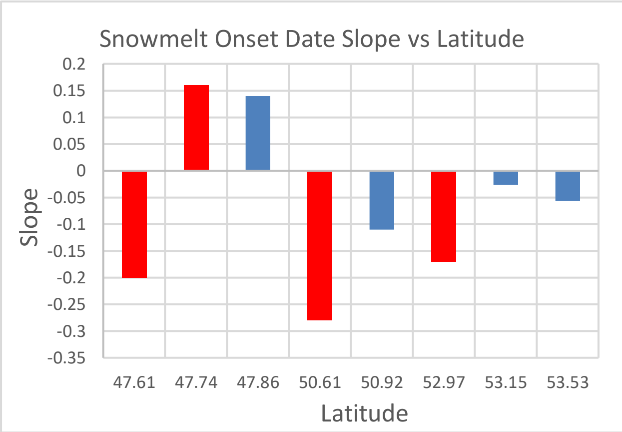

Figure 9. Summary plot of results: snowmelt onset date slope vs latitude. Red indicates slopes that are significant.

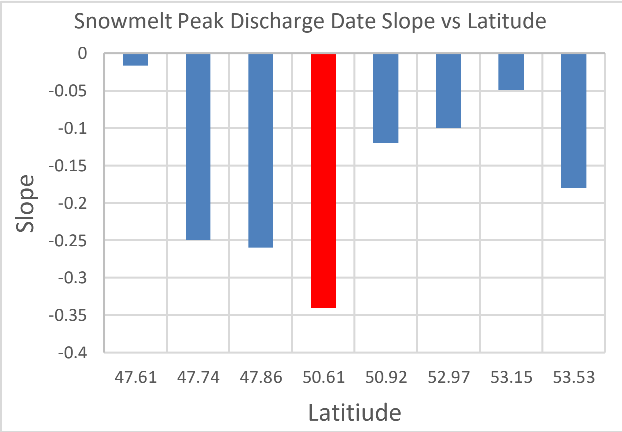

Figure 10. Summary plot of results: snowmelt peak discharge date slope vs latitude. Red indicates slopes that are significant.

H3: Snowmelt peak discharge demonstrated a decrease in seven of the eight sites. Of the eight sites, four tested statistically significant. All four sites showed a decrease in snowmelt peak discharge. Site 1a (northern) gave a rho value of -0.27, site 1c (northern) gave a rho value of -0.66, site 2b (central) gave a rho value of -0.31 and site 3b (southern) gave a rho value of -0.33. The four sites significant sites accept the hypothesis that snowmelt peak discharge is decreasing annually, while the sites that did not test for significance cannot accept or reject the hypothesis.

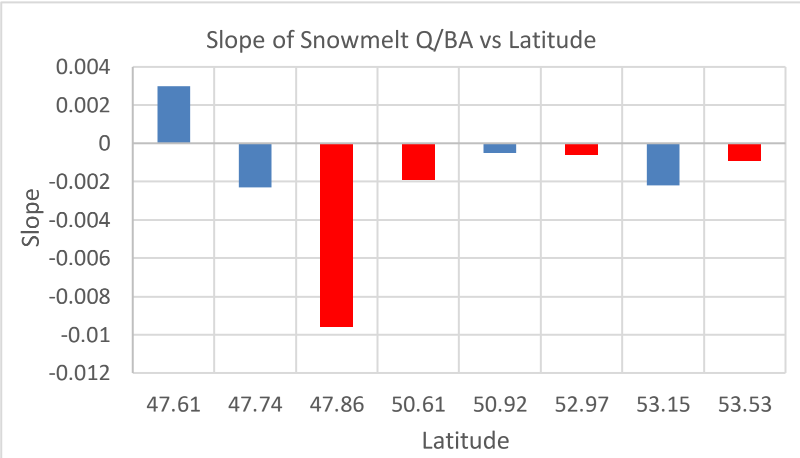

Figure 11. Summary plot of results: slope of snowmelt discharge vs latitude. Red indicates slopes that are significant.

H4: Autumn peak discharge demonstrated that six of eight sites expressed an increase. Four of the eight sites tested for statistical significance. All significant sites showed an increase in autumn peak discharge. These sites were 2a (central) with a rho value of 0.27, 2b (central) with a rho value of 0.24, 3b (southern) with a rho value of 0.38 and 3c (southern) with a rho value of 0.43. The four significant sites accept the hypothesis that autumn peak discharge is increasing annually. The four sites that did not test for significance cannot accept or reject the hypothesis.

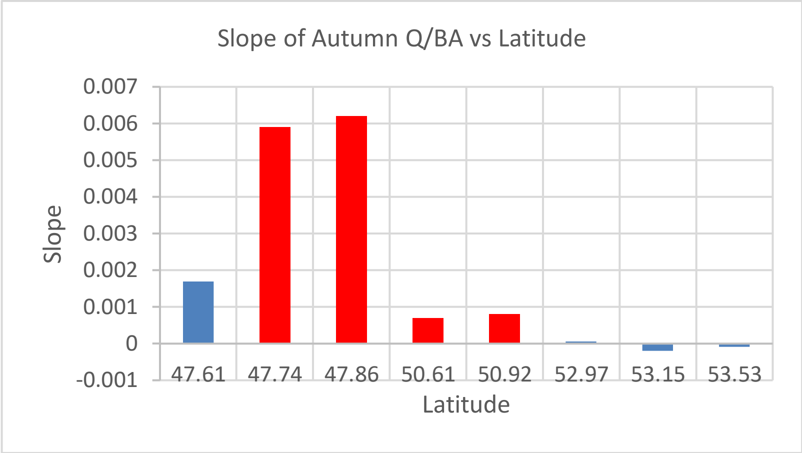

Figure 12. Summary plot of results: slope of autumn discharge vs latitude. Red indicates slopes that are significant.

Region	Snowmelt onset timing	Snowmelt peak discharge timing	Snowmelt peak discharge	Autumn peak discharge
Northern 1a	-0.09	-0.20	-0.27	-0.08
Northern 1b	0.01	0.04	-0.31	-0.10
Northern 1c	-0.36	-0.18	-0.66	0.02
Central 2a	-0.13	-0.10	-0.13	0.27
Central 2b	-0.39	-0.38	-0.31	0.24
Southern 3a	-0.32	-0.01	0.17	0.16
Southern 3b	0.19	-0.16	-0.33	0.38
Southern 3c	0.27	-0.17	-0.17	0.43

Table 3. Summary of results for the Spearman Rank Correlation Coefficient Rho. Red boxes indicate p-values that are statistically significant at the p=0.05 level.

Region	Snowmelt onset timing	Snowmelt peak discharge timing	Snowmelt peak discharge	Autumn peak discharge
Northern 1a	0.27	0.09	0.03	0.29
Northern 1b	0.48	0.43	0.09	0.33
Northern 1c	0.03	0.18	0.0	0.45
Central 2a	0.21	0.28	0.21	0.05
Central 2b	0.0	0.02	0.01	0.03
Southern 3a	0.01	0.47	0.11	0.11
Southern 3b	0.14	0.18	0.02	0.01
Southern 3c	0.05	0.15	0.15	0.004

Table 4. Summary of p-value results. P-value demonstrates the level of significance. A p-value less than 0.05 is considered statistically significant, e.g. p=0.27 indicates we would reject the null hypothesis of no difference with 27% confidence. Red boxes indicate p-values that are statistically significant at the p=0.05 level.

H1: An independent samples t-test was used to evaluate north and south differences. A two tail test with alpha values of 0.05 for snowmelt discharge differences gave a t-stat of -13.3 with a critical value of ±1.97 resulting in the acceptance that the southern sites experienced a significantly higher discharge with less than 5% probability of occurring by chance. A two tail t-test for a larger autumn peak discharge in the southern sites versus the northern sites gave a t-stat of -16.1 and a critical value of ±1.97 resulting in the acceptance that the southern sites have a larger autumn discharge peak value than the northern sites with less than 5% probability of occurring by chance.

Snowmelt Discharge North vs. South	*Northern*	*Southern*
Mean	0.138	0.544
Variance	0.0029	0.085
Observations	94	131
Hypothesized Mean Difference	0	
df	223	
t Stat	-13.3	
P(T<=t) two-tail	3.26E-30	
t Critical two-tail	1.97	

Table 5. Summary of results: Two tailed t-test on snowmelt discharge north vs. south.

Autumn Discharge North vs. South	*Northern*	*Southern*
Mean	0.0326	0.391
Variance	0.0002	0.038
Observations	94	131
Hypothesized Mean Difference	0	
df	223	
t Stat	-17.9	
P(T<=t) two-tail	5.34E-45	
t Critical two-tail	1.97	

Table 6. Summary of results: two tailed t-test on autumn discharge north vs. south.

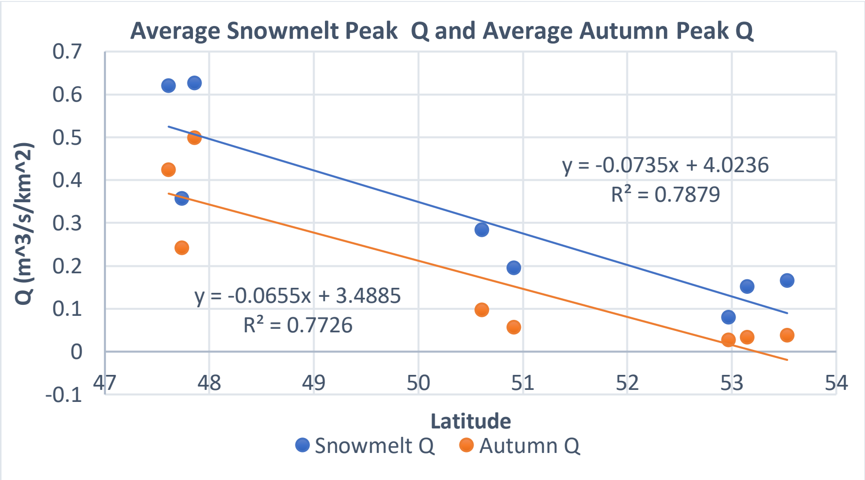

Figure 13. Summary plot of average snowmelt and autumn peak discharges as a function of latitude.

VII. DISCUSSION

The strong trends discovered within this study regarding the hydrological changes occurring in the boreal forest of Newfoundland and Labrador may prove useful to ongoing research and understanding of carbon flux for this region. As previously outlined, carbon flux is sensitive to shifts in timing and magnitude of water flux. This study found a significant amount of data lending support to the hypotheses that snowmelt onset timing is occurring earlier annually for the majority of sites, as well as snowmelt peak discharge occurring earlier annually for all sites. For most sites, specifically the southernmost, autumn peak discharge is increasing annually as snowmelt peak discharge is decreasing as warming occurs, most noticeably at lower latitudes. Autumn peak discharge was found to be higher at lower latitudes. When comparing north vs south for average peak discharges for snowmelt and autumn flux, it was discovered that the southern sites move much more water than the northern sites, meaning it is possible that the south will affect carbon flux more significantly.

VIII. FUTURE WORK

When exploring the relationship between drainage basin area and discharge, an attenuation value was discovered. Plot 10. shows the average maximum discharges for ten sites within the same hydrogeomorphic region as a function of basin area. The exponential on the equation of the line determines the attenuation value. Attenuation is the loss in magnitude of discharge with increasing basin area. Attenuation will have an effect on the normalized discharge values for each site when dividing their discharges by their respective basin areas. Future work that can outline different hydrogeomorphic regions in Newfoundland and Labrador and their attenuation values will be valuable when comparing discharges across sites of different basin areas.

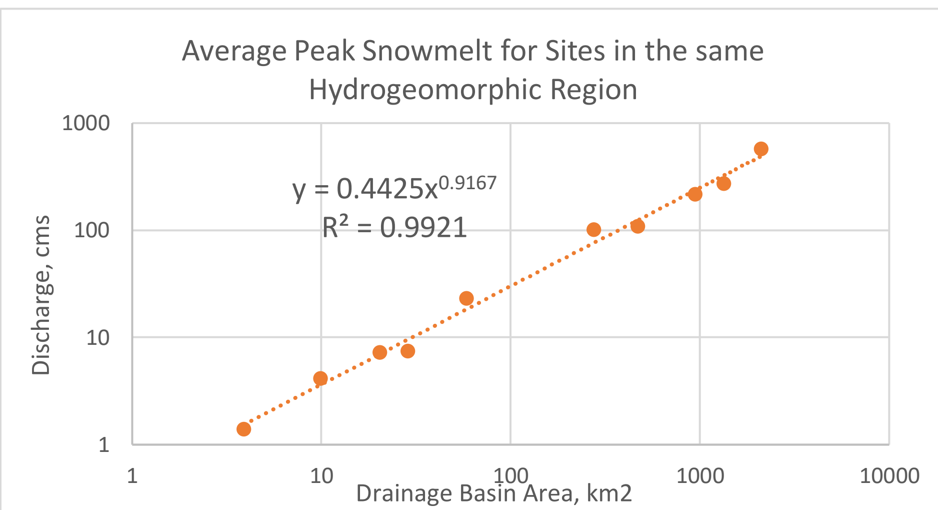

Figure 14. Discharge as a function of drainage area for ten sites within a hydrogeomorphic region.

More data in years to follow from Memorial University's NL-BELT sites will be critical for the comparison of large and small catchment behavior. This study is limited to large catchments. Small catchments could express different results, or further support the results found in this study.

IX. CONCLUSIONS AND BROADER IMPLICATIONS

A warming climate may be influencing hydrological changes in the boreal forest of Canada, requiring a detailed understanding of water fluxing events along a climate gradient transect. Identifying changes in water flux timing can guide further research about the flux of DOC in these forests. In this study, using statistical analyses, significant trends with respect to time and event magnitude at each station were tested. Differences among locations along a climate gradient transect were also tested. For this, snowmelt onset timing, peak timing, and maximum discharge as well as autumn peak discharge and timing were examined. Significant trends and variations were discovered for many sites. The magnitude of snowmelt and autumn discharge is higher at lower latitudes (H1); snowmelt discharge peaks are decreasing as warming occurs, most noticeable at lower latitudes (H3); and autumn peaks tend to be increasing (H4). All sites, with the exception of two, experienced earlier start dates of snowmelt as well as earlier dates of maximum snowmelt discharge (H2). This is one of the first studies observing change that occurs to autumn peaks, finding that southernmost autumn peak discharge is significantly increasing. This will be a major constituent for understanding the changing hydrological system for this region that previously has not been largely considered. The goal of this research is to identify hydrological changes that can guide further research in hydrological and biogeochemical processes, specifically the flux of DOC, in the boreal forest of Newfoundland and Labrador.

VIII. Citations:

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X. Figures Index:

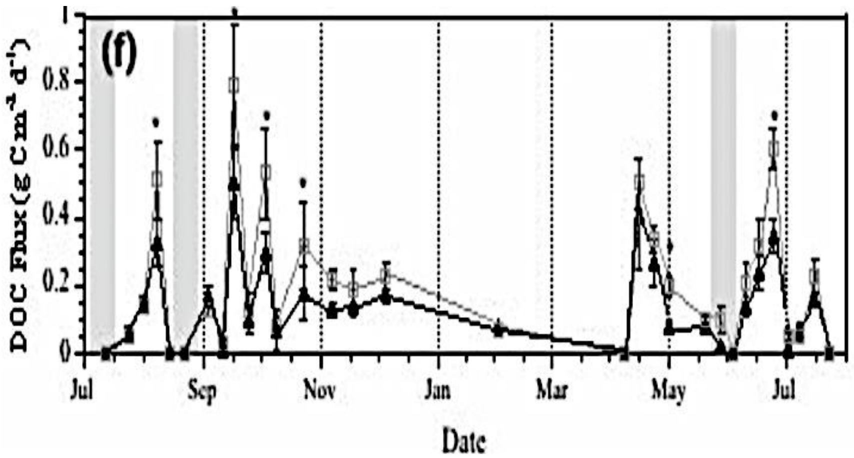


Figure 3. DOC flux (Bowering et al., 2019). Black line represents data collected from forested sites and the gray line represents data collected from harvested sites. Estimates were determine using passive pan lysimeter collections underneath O horizons. Error bars show standard error of the mean.

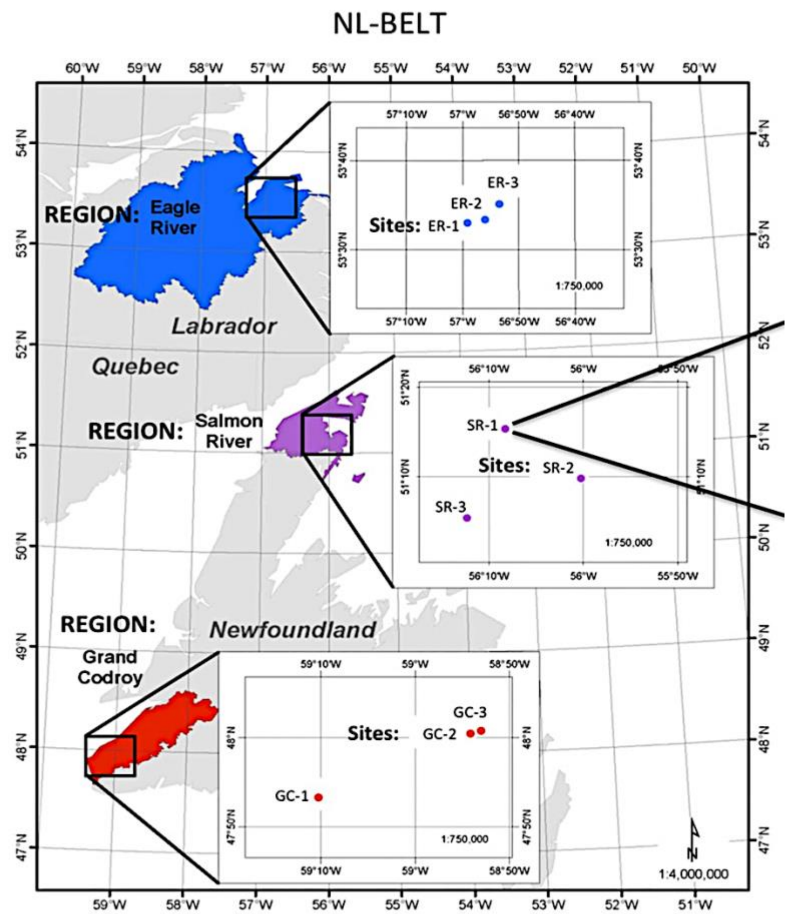


Figure 4. NL-BELT site locations (Ziegler et al., 2017)

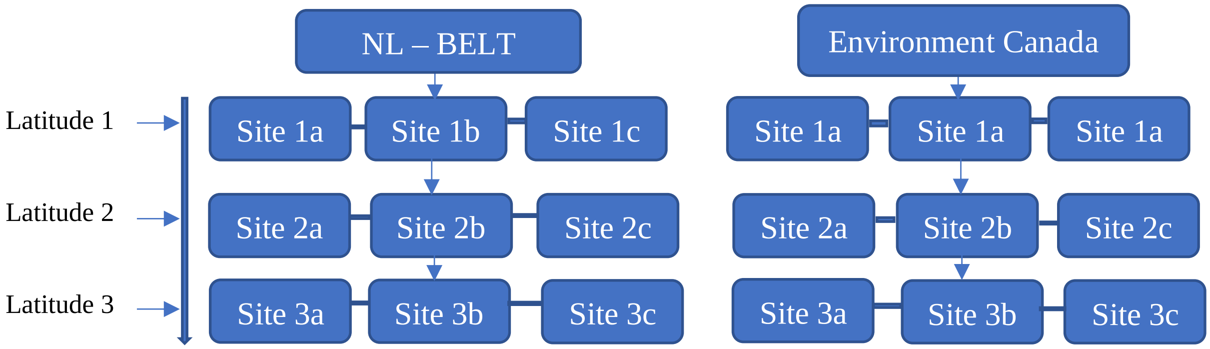


Figure 3. Site distribution.

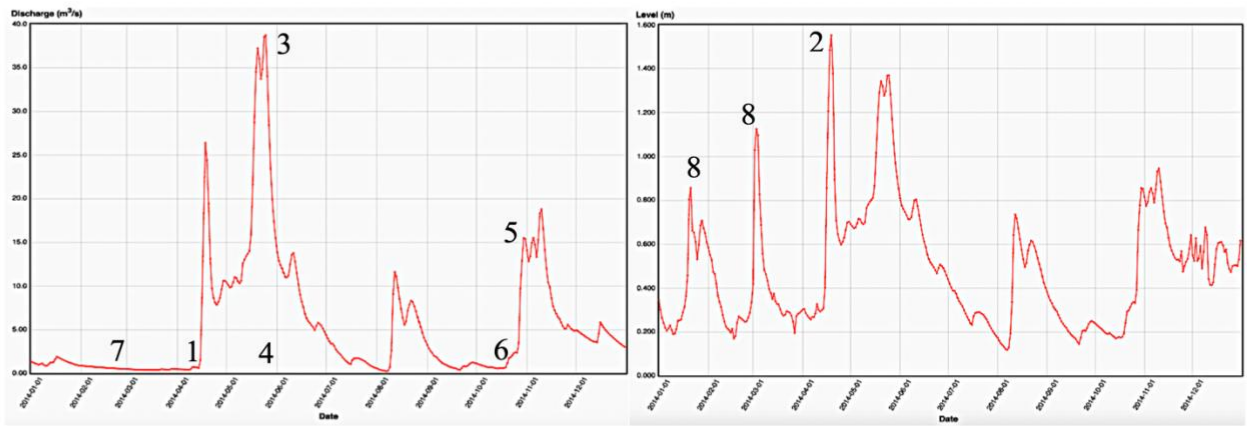


Figure 4. Northeast Brook site 2a. Discharge (left) and level (right). (1) Start date of snowmelt, (2) Maximum gage height of melt period, (3) Maximum discharge of melt period, (4) date of maximum snowmelt, (5) Autumn maximum discharge, (6) Date of autumn maximum, (7) Winter base flow, (8) occurrence of possible ice jamming.

Region	Mean snowmelt peak discharge (Q/BA)	Snowmelt peak discharge standard deviation	Mean date of snowmelt peak discharge	Date of snowmelt peak discharge standard deviation (days)
Northern 1a	0.16	0.05	5/25	12.8
Northern 1b	0.15	0.04	5/19	7.2
Northern 1c	0.08	0.01	6/3	8.3
Central 2a	0.20	0.04	5/13	14.7
Central 2b	0.28	0.10	5/18	15.3
Southern 3a	0.62	0.29	5/7	19.8
Southern 3b	0.63	0.32	4/29	17.7
Southern 3c	0.36	0.16	4/22	16.3

Table 1. Summary of mean snowmelt peak discharge, snowmelt peak discharge standard deviation, mean date of snowmelt peak discharge and date of snowmelt peak discharge, where Q = discharge, BA = basin area.

Region	Mean autumn peak discharge (Q/BA)	Autumn peak discharge standard deviation	Mean date of snowmelt onset	Date of snowmelt onset standard deviation (days)
Northern 1a	0.04	0.016	4/24	9.2
Northern 1b	0.03	0.013	4/25	12.7
Northern 1c	0.03	0.006	4/30	7.0
Central 2a	0.06	0.033	4/9	9.4
Central 2b	0.10	0.046	4/15	12.4
Southern 3a	0.42	0.17	4/2	10.3
Southern 3b	0.50	0.18	4/4	8.1
Southern 3c	0.24	0.15	3/29	6.6

Table 2. Summary of mean autumn peak discharge, autumn peak discharge standard deviation, mean date of snowmelt onset and date of snowmelt onset standard deviation, where Q = discharge, BA = basin area.

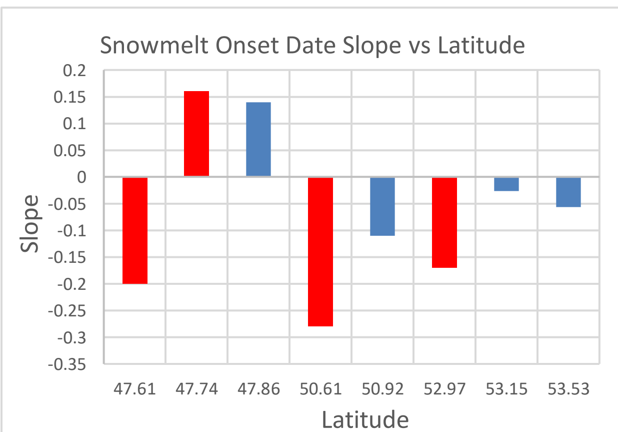


Figure 9. Summary plot of results: snowmelt onset date slope vs latitude. Red indicates slopes that are significant.

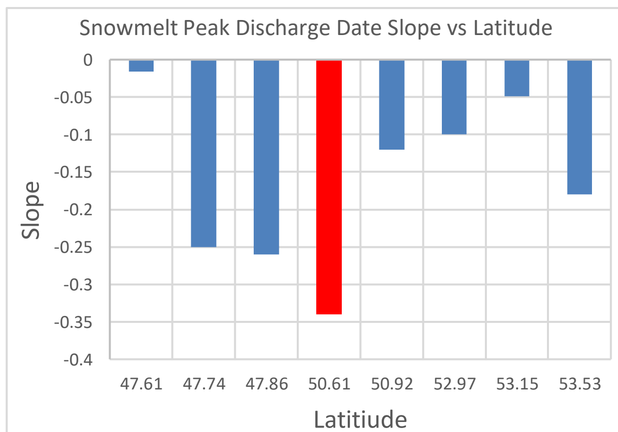


Figure 10. Summary plot of results: snowmelt peak discharge date slope vs latitude. Red indicates slopes that are significant.

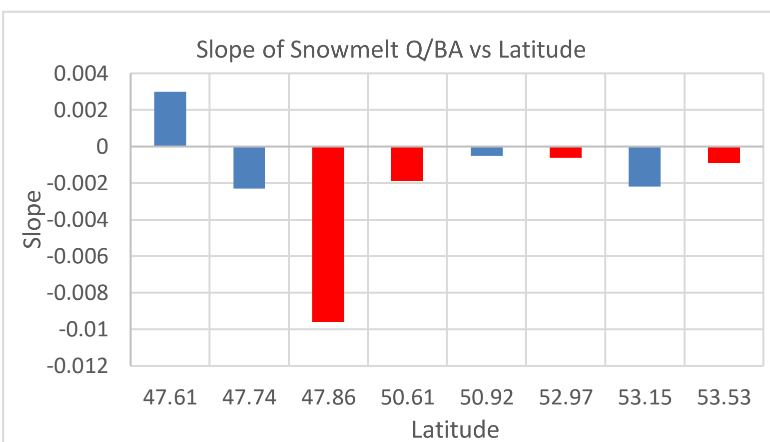


Figure 11. Summary plot of results: slope of snowmelt discharge vs latitude. Red indicates slopes that are significant.

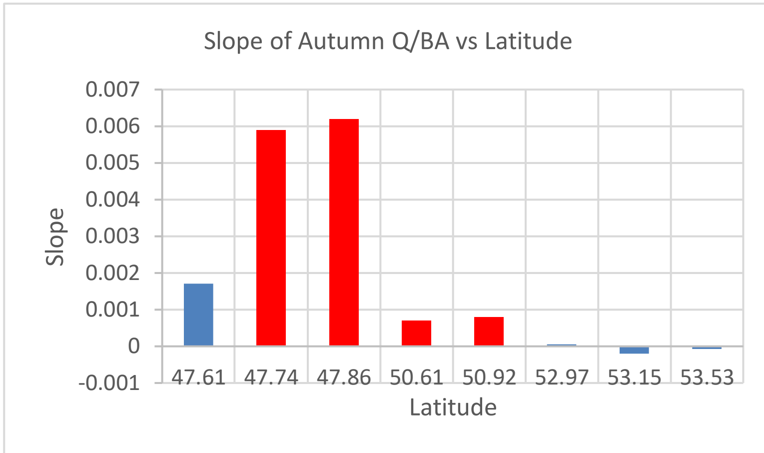


Figure 12. Summary plot of results: slope of autumn discharge vs latitude. Red indicates slopes that are significant.

Region	Snowmelt onset timing	Snowmelt peak discharge timing	Snowmelt peak discharge	Autumn peak discharge
Northern 1a	-0.09	-0.20	-0.27	-0.08
Northern 1b	0.01	0.04	-0.31	-0.10
Northern 1c	-0.36	-0.18	-0.66	0.02
Central 2a	-0.13	-0.10	-0.13	0.27
Central 2b	-0.39	-0.38	-0.31	0.24
Southern 3a	-0.32	-0.01	0.17	0.16
Southern 3b	0.19	-0.16	-0.33	0.38
Southern 3c	0.27	-0.17	-0.17	0.43

Table 3. Summary of results for the Spearman Rank Correlation Coefficient Rho. Red boxes indicate p-values that are statistically significant at the p=0.05 level.

Region	Snowmelt onset timing	Snowmelt peak discharge timing	Snowmelt peak discharge	Autumn peak discharge
Northern 1a	0.27	0.09	0.03	0.29
Northern 1b	0.48	0.43	0.09	0.33
Northern 1c	0.03	0.18	0.0	0.45
Central 2a	0.21	0.28	0.21	0.05
Central 2b	0.0	0.02	0.01	0.03
Southern 3a	0.01	0.47	0.11	0.11
Southern 3b	0.14	0.18	0.02	0.01
Southern 3c	0.05	0.15	0.15	0.004

Table 4. Summary of p-value results. P-value demonstrates the level of significance. A p-value less than 0.05 is considered statistically significant, e.g. p=0.27 indicates we would reject the null hypothesis of no difference with 27% confidence. Red boxes indicate p-values that are statistically significant at the p=0.05 level.

Snowmelt discharge North vs. South	*Northern*	*Southern*
Mean	0.138	0.544
Variance	0.0029	0.085
Observations	94	131
Hypothesized Mean Difference	0	
df	223	
t Stat	-13.3	
P(T<=t) two-tail	3.26E-30	
t Critical two-tail	1.97	

Table 5. Summary of results: Two tailed t-test on snowmelt discharge north vs. south.

Autumn discharge North vs. South	*Northern*	*Southern*
Mean	0.0326	0.391
Variance	0.0002	0.038
Observations	94	131
Hypothesized Mean Difference	0	
df	223	
t Stat	-17.9	
P(T<=t) two-tail	5.34E-45	
t Critical two-tail	1.97	

Table 6. Summary of results: two tailed t-test on autumn discharge north vs. south.

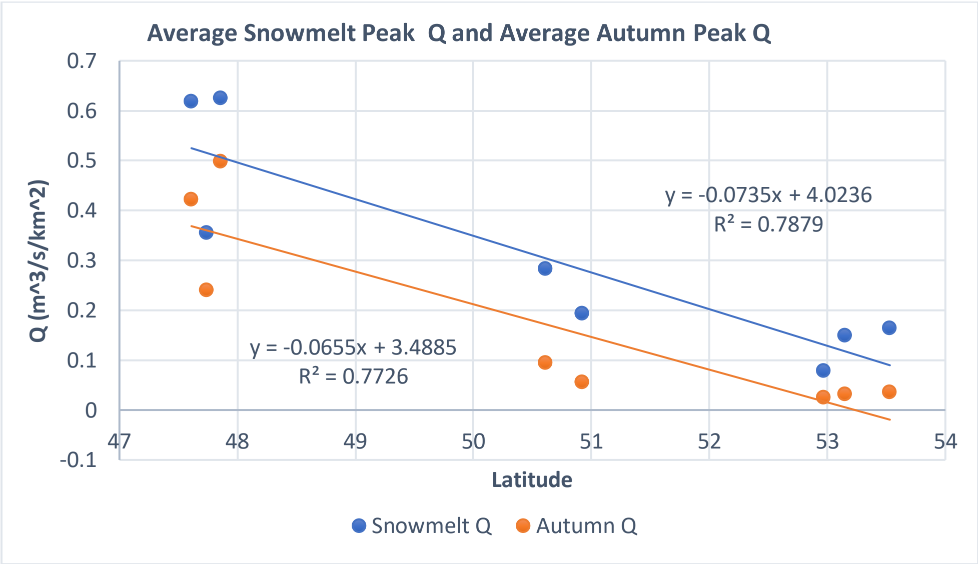


Figure 13. Summary plot of average snowmelt and autumn peak discharges as a function of latitude.

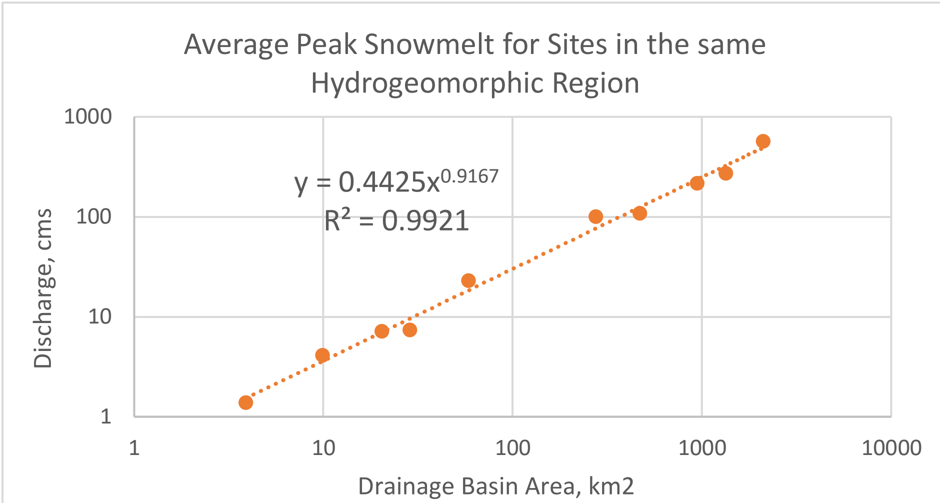


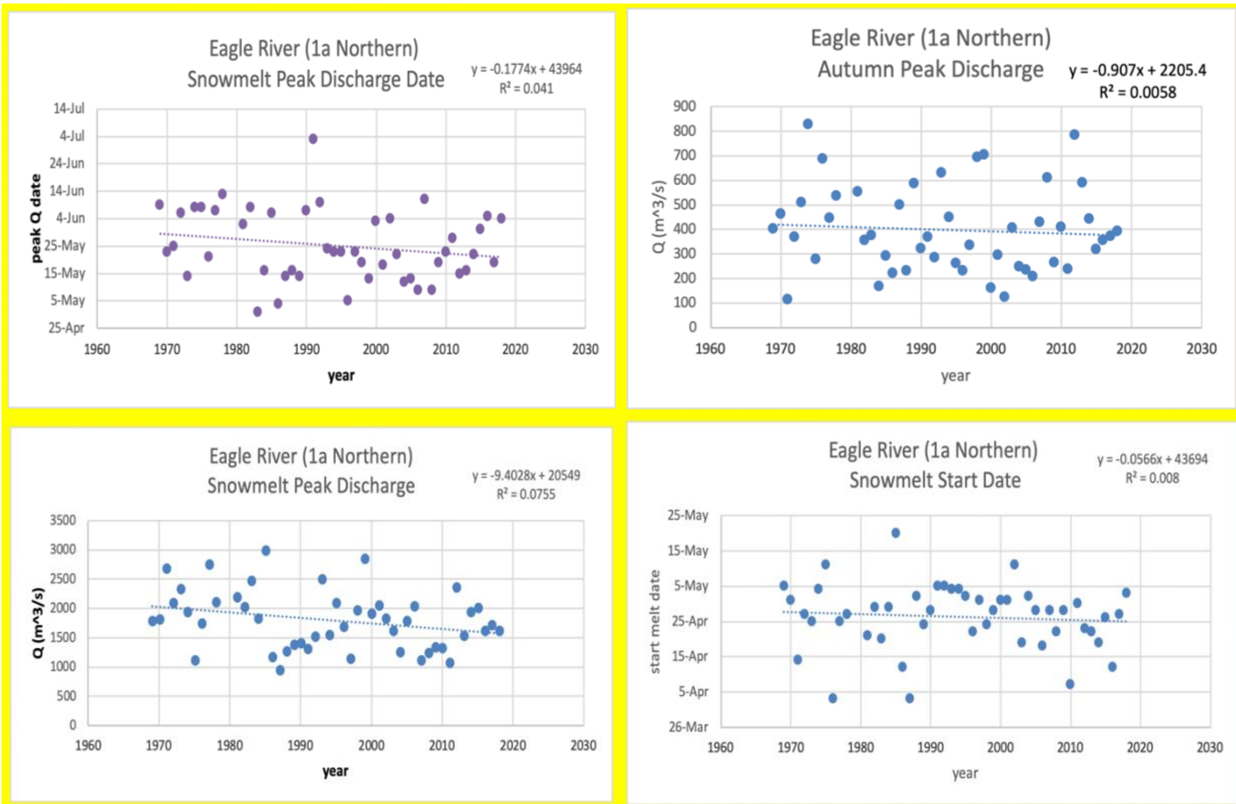
Figure 14. Discharge as a function of drainage area for ten sites within a hydrogeomorphic region.

NL-BELT SITE	LATITUDE		
1	53°33'1.08"N		
2	51°15'21.28"N		
3	48° 0'28.25"N		
EC SITE	NAME	LAT	SITE ID
site 1a	EAGLE RIVER ABOVE FALLS	53° 32' 03" N	03QC001
site 1b	PINUS RIVER	53° 08' 50" N	03OE011
site 1c	ATIKONAK RIVER ABOVE PANCHIA LAKE	52° 58' 06" N	03OC003
site 2a	NORTHEAST BROOK NEAR RODDICKTON	50° 55' 27" N	02YD002
site 2b	TORRENT RIVER AT BRISTOL'S POOL	50° 36' 26" N	02YC001
site 3a	ISLE AUX MORTS RIVER BELOW HIGHWAY BRIDGE	47° 36' 48" N	02ZB001
site 3b	GRANDY BROOK BELOW TOP POND BROOK	47° 51' 21" N	02ZC002
site 3c	GREY RIVER NEAR GREY RIVER	47° 44' 35" N	02ZD002

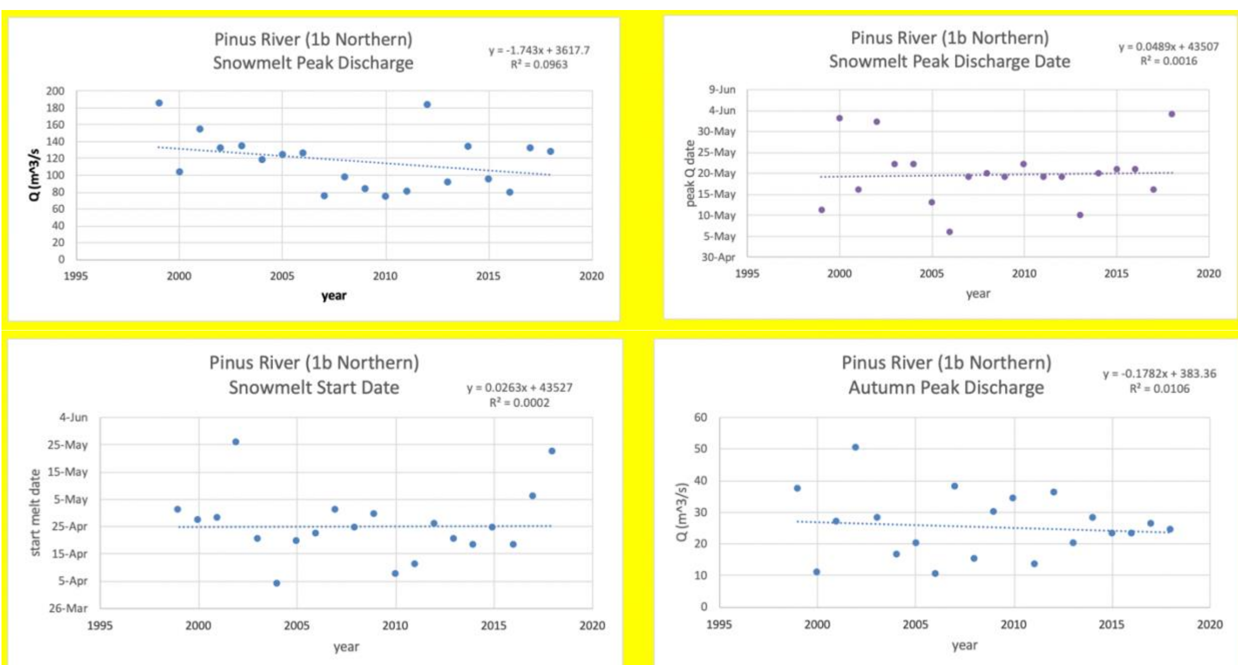
Figure 4. Top table lists latitudes of the NL-BELT sites. Lower table lists all EC sites by name, latitude and site ID.

SUMMARY	basin area (km^2)	peroid of record (yrs)
site 1a	10900	48
site 1b	780	21
site 1c	15100	27
site 2a	200	39
site 2b	624	59
site 3a	205	56
site 3b	230	37
site 3c	1340	38

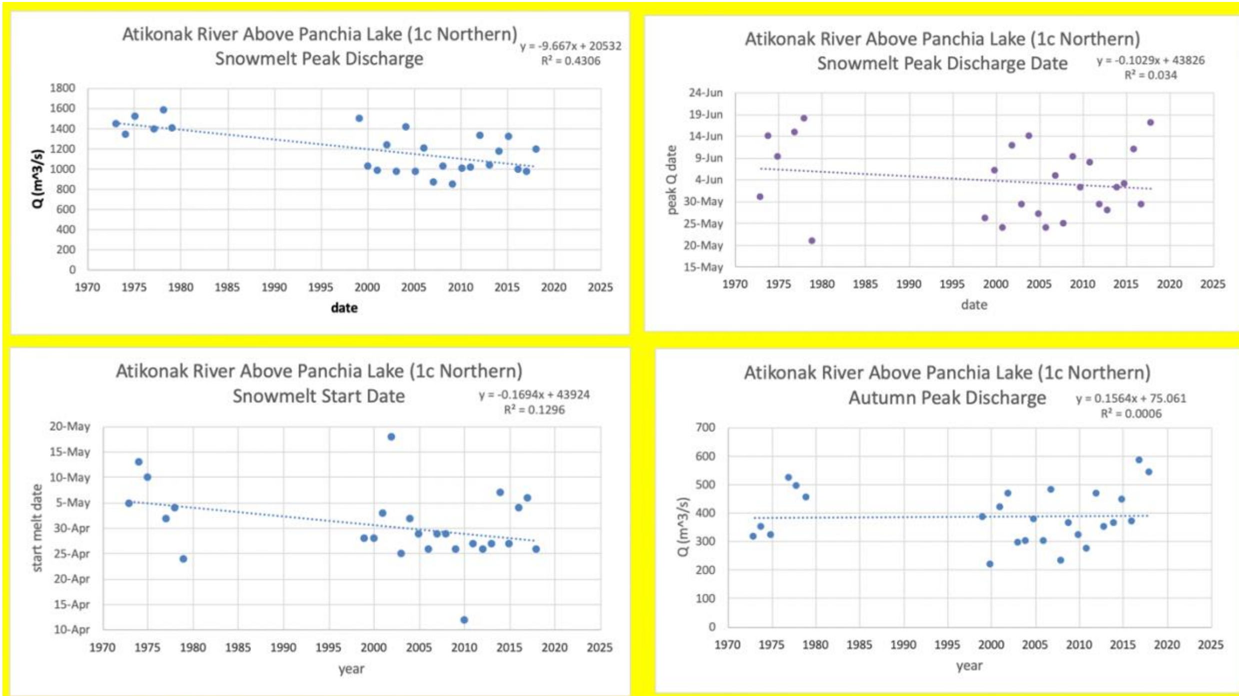
Figure 5. Summary table of basin areas and periods of record.



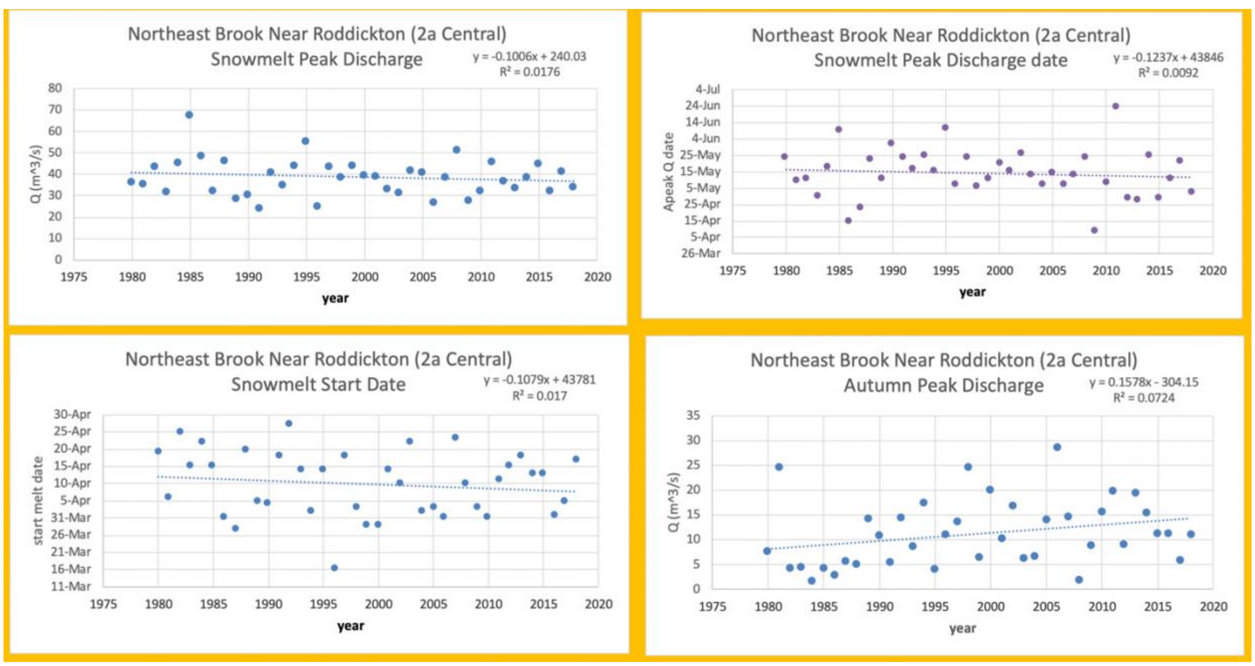
Figures 5,6,7,8. Time series for Eagle River (1a northern) of snowmelt peak discharge date, autumn peak discharge, snowmelt peak discharge and snowmelt start date.



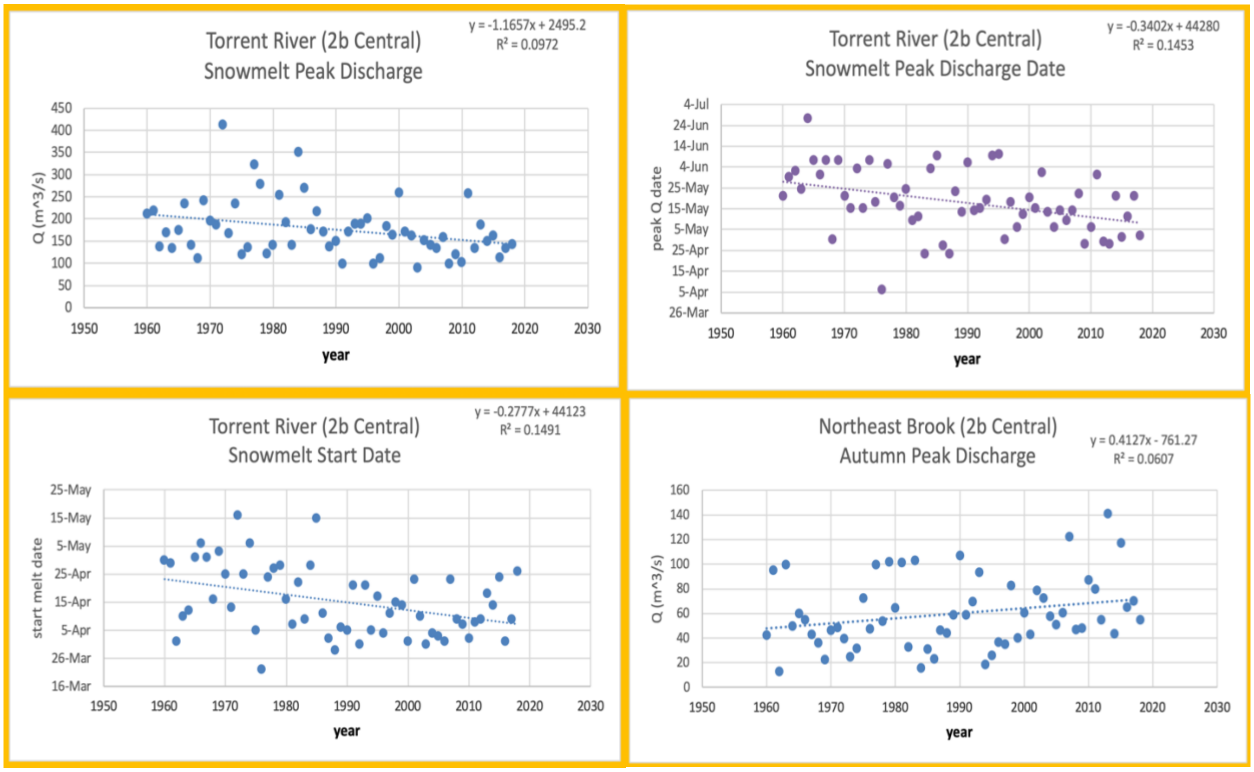
Figures 15, 16, 17, 18. Time series for Pinus River (1b northern) of snowmelt peak discharge date, autumn peak discharge, snowmelt peak discharge and snowmelt start date.



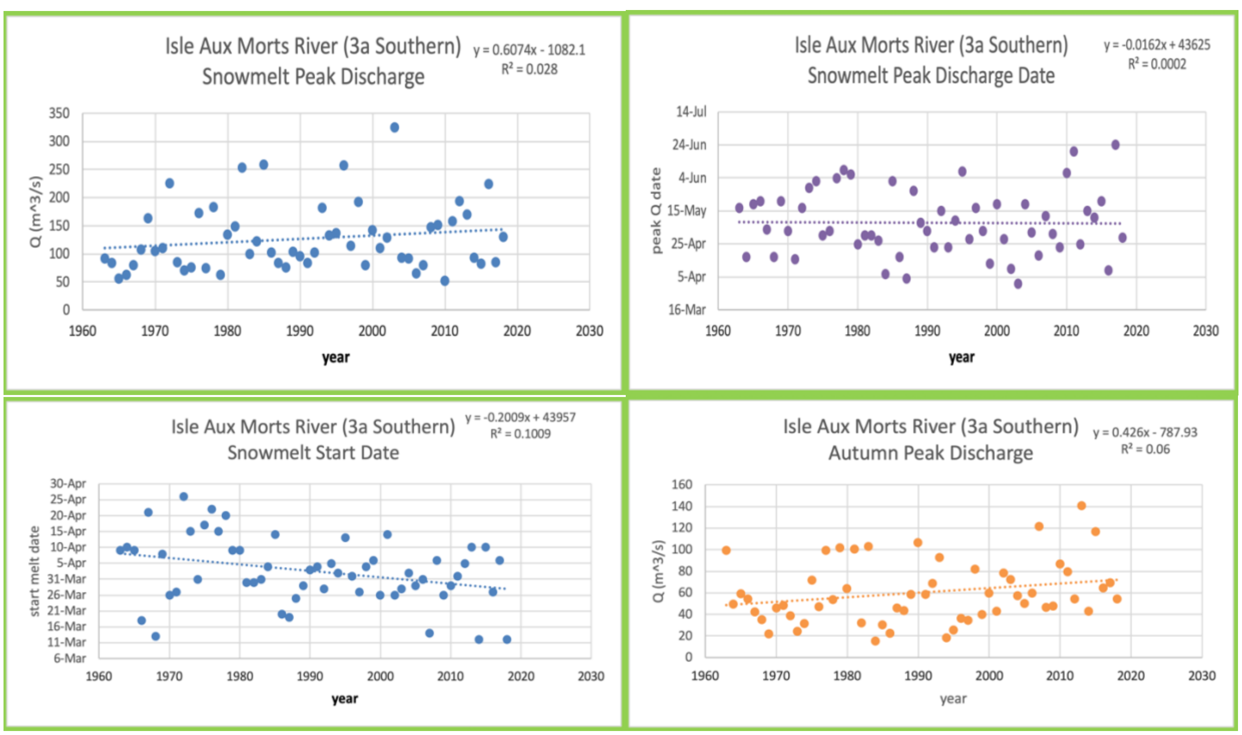
Figures 19, 20, 21, 22. Time series for Atikonak River Above Panchia Lake (1c northern) of snowmelt peak discharge date, autumn peak discharge, snowmelt peak discharge and snowmelt start date.



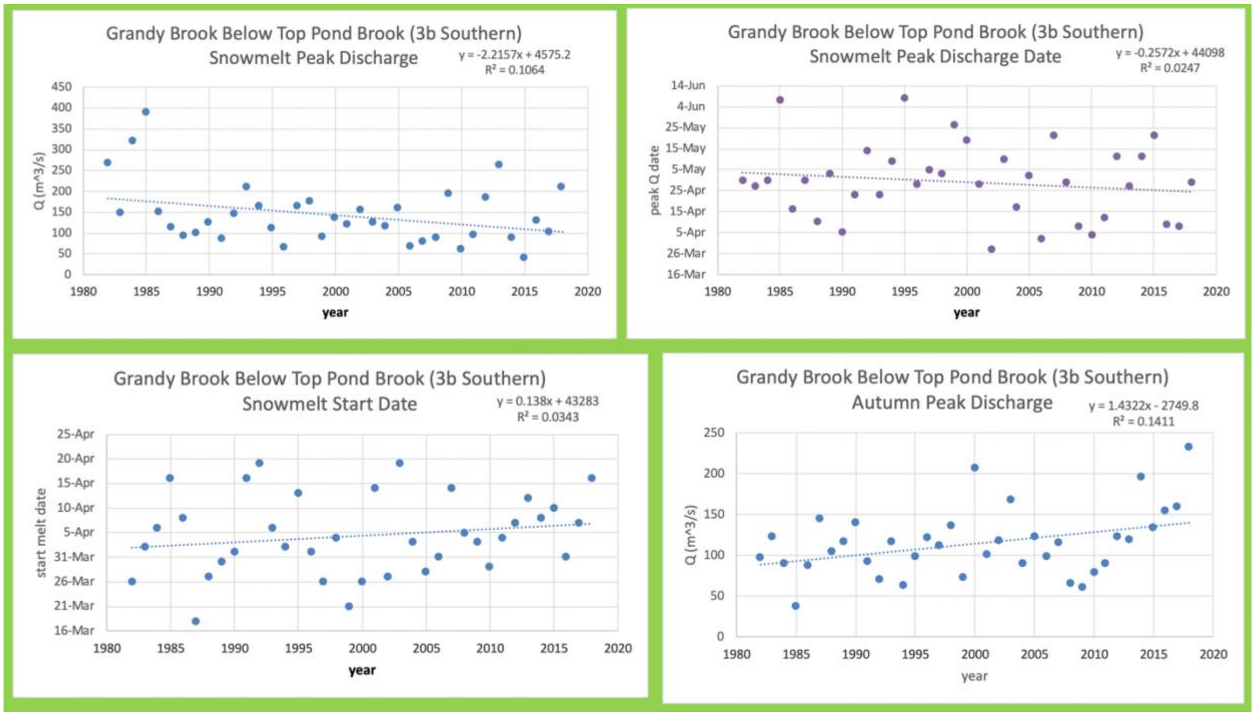
Figures 23, 24, 25, 26. Time series for Northeast Brook Near Roddickton (2a central) of snowmelt peak discharge date, autumn peak discharge, snowmelt peak discharge and snowmelt start date.



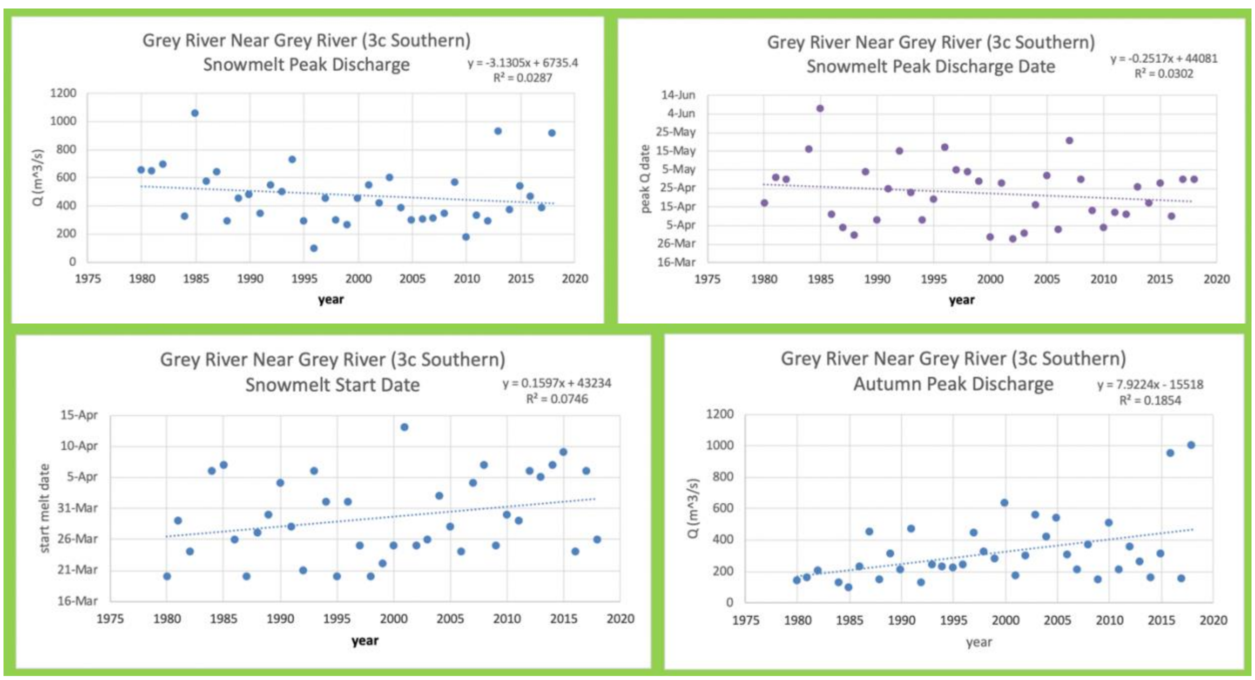
Figures 27, 28, 29, 30. Time series for Torrent River (2b Central) of snowmelt peak discharge date, autumn peak discharge, snowmelt peak discharge and snowmelt start date.



Figures 31, 32, 33, 34. Time series for Isle Aux Morts River (3a southern) of snowmelt peak discharge date, autumn peak discharge, snowmelt peak discharge and snowmelt start date.



Figures 35, 36, 37, 38. Time series for Grandy Brook Top Pond Brook (3b southern) of snowmelt peak discharge date, autumn peak discharge, snowmelt peak discharge and snowmelt start date.



Figures 39, 40, 41, 42. Time series for Grey River Near Grey River (3c southern) of snowmelt peak discharge date, autumn peak discharge, snowmelt peak discharge and snowmelt start date.