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Water temperature characteristics of the Miramichi and Restigouche Rivers

Caractéristiques de la température de l'eau pour les rivières Miramichi et Restigouche

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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ABSTRACT

Water temperature is a key habitat factor in lotic ecosystems and influences many physical, chemical, and biological properties of rivers. Hence a good understanding of the thermal regime of rivers is essential for effective management of water and fisheries resources. This is especially important if fisheries need to be closed at times of high water temperature stress. This study characterizes the thermal regime of the Miramichi and Restigouche rivers. The annual cycle of water temperature was analyzed as well as summer minimum, maximum and mean. Following this analysis, threshold temperatures were analyzed (mainly T_{max} >23°C and T_{min} > 20°C) as they were shown to be important thresholds for Atlantic salmon in terms of physiological stress related to high water temperature events (T_{max}) and their potential recovery from these events (T_{min}). The thermal regime analysis revealed that the Miramichi River experiences warmer conditions than the Restigouche River. This was observed at many levels, including higher summer temperatures, more frequent exceedance of selected thresholds, and more frequent occurrences of low water conditions early in the year. Differences were noted between main river water temperatures and tributary sites, which may be important for management purposes.

RÉSUMÉ

La température de l'eau est un facteur déterminant de l'habitat des écosystèmes lotiques car elle influence de nombreux paramètres physiques, chimiques et biologiques des cours d'eau. Par conséquent, une bonne compréhension du régime thermique des cours d'eau est essentielle pour une gestion efficace des ressources hydriques et halieutiques. Ceci est particulièrement important si des fermetures de pêche doivent avoir lieu dû aux hautes températures de l’eau et causant du stress chez les poissons. Cette étude porte sur la caractérisation du régime thermique de la rivière Miramichi et la rivière Restigouche. Le cycle annuel de la température de l'eau a été analysé ainsi que les températures minimum, maximum et moyennes de l'eau durant l'été. Suivant cette analyse, des températures seuils ont été analysées (principalement T_{max} > 23 °C et T_{min} > 20 °C) car ils ont été repérées comme des températures importantes pour les salmonidés en termes de stress liés aux hautes températures de l'eau (T_{max}) ainsi que pour leur rétablissement durant ces événements (T_{min}). Les résultats de l'analyse du régime thermique démontrent que la rivière Miramichi connaît des conditions plus chaudes que la rivière Restigouche. Ceci a été observé à de nombreux niveaux, y compris pour les températures estivales élevées qui dépassent les seuils choisis plus souvent dans la Miramichi et des conditions de débits faibles plus tôt dans l'année. Des différences ont été notées entre les températures de l'eau des rivières principales et celles des sites affluents, et ces différences peuvent être importantes pour des fins de gestion.

INTRODUCTION

Water temperature has both economic and ecological significance when considering issues such as water quality and biotic conditions in rivers (Caissie 2006). The thermal regime of rivers is influenced by many factors such as atmospheric conditions, topography, riparian vegetation, stream discharge, and streambed thermal fluxes (Poole and Berman 2001; Webb et al. 2008). Knowledge of water temperature characteristics and the thermal regime of rivers is essential to address many water quality and fisheries management issues (e.g., environmental impact). The first step in the overall understanding of the thermal regime of rivers is to characterize natural variations and water temperature dynamics both in space and time.

Stream water temperatures dynamics have been studied for many years (Macan 1958; Raphael 1962; Brown 1969). River water temperature controls the rate of decomposition of organic matter, dissolved oxygen content, and chemical reactions in general. Stream temperatures have also been monitored to evaluate the impact of human activities related to urbanization (Kinouchi et al. 2007; Nelson and Palmer 2007), land-use activities (Nagasaka and Nakamura 1999) as well as to evaluate the impact of flow reduction and flow alteration on the thermal regime (Morin et al. 1994; Sinokrot and Gulliver 2000).

The present study deals with the characterization of the thermal regime of rivers at various sites within the Miramichi and Restigouche rivers of New Brunswick in order to assess potential fishing closures due to high water temperature stress. The specific objectives of this study are: 1) to characterize the thermal regime during summer period, 2) to compare water temperature characteristics among sites, 3) to study threshold events related to high temperature stress in fish (T_{max} > 23°C and T_{min} > 20°C), 4) to study the correlation among sites, and 5) to study the potential impact of river discharge on river water temperature.

MATERIALS AND METHODS

The present study was carried out in the Miramichi and Restigouche River systems. In total, 42 water temperature sites were analyzed (21 sites in Miramichi and 21 sites in Restigouche; Fig. 1). The sites analyzed and their respective locations (latitude and longitude) are identified in Table 1a (Miramichi) and Table 1b (Restigouche). Latitude and longitude coordinates are provided in decimal degree units.

Water temperature was monitored using dataloggers. Data from the Little Southwest Miramichi River, the Doaktown site (Miramichi River) and the Larry’s Gulch site (Restigouche River) were monitored using CR10 dataloggers. These dataloggers were equipped with water temperature sensors, model 107B thermistor probes from Campbell Scientific Canada Corp. The error associated with this type of sensor is typically less than 0.2 °C for the range of -30 °C to +40 °C. For other sites within the Miramichi River, VEMCO™ dataloggers (VEMCO Minilog8-TR) were used for the data collection. These recorders have a typical accuracy of ±0.2°C in the range of -5 to 35°C. In the Restigouche River, VEMCO™ (VEMCO Minilog8-TR) were used from 2002 to 2007 and they were replaced in 2008 with TidBiT v2 Water Temperature Data Logger - UTBI-001 by Onset HOBO™. The accuracy of the TidBit is typically ±0.2°C and they have an operating range of -20°C to 70°C.

Two hydrometric stations operated by Environment Canada were used in the present study (Figure 1a – Miramichi and Figure 1b - Restigouche). The hydrometric station within the Miramichi River was located on the Southwest Miramichi River at Blackville (station 01BO001; 46°44'9"N, 65°49'32"W). This hydrometric station has a drainage area of 5,050 km^2. The mean annual flow for the Southwest Miramichi River is 119 m^3/s and this flow represents a runoff of 744 mm annually. The hydrometric station part of the Restigouche River system was on the main Restigouche River above Rafting Ground Brook (station 01BJ007; 47°54'31"N, 66°56'53"W) and has a drainage area of 7,740 km^2. The mean annual flow of the Restigouche River was 163 m^3/s and this flow represents a runoff of 665 mm annually.

Daily water temperatures were analyzed to characterize the annual cycle of water temperature. The diel cycle (water temperature variability over a 24 hour period) was also analyzed at a selected site (Little Southwest Miramichi River) to show the timing of the minimum and maximum temperatures during the day. Then summer (July and August) river water temperatures were calculated (minimum, maximum and mean), as well as the maximum recorded temperature.

Following the calculations of summer water temperature statistics, an analysis was carried out to determine the level of potential stressful days related to high water temperature events as well as the potential recovery periods for Atlantic salmon. It has been shown that when maximum daily water temperature exceeds 23°C, salmonids will seek cooler water refugia (Breau 2013). As such, this threshold was used in the present study, as a potential upper threshold defining stressful days for Atlantic salmon, and will be referred to as T_{max} > 23°C event. Studies have also shown that when salmonids are subject to stressfully high temperature days, the fish needs cooler water temperature conditions to physiologically recover from high water temperature events (Breau 2013). The temperature threshold of 20°C was used in the present study as a physiological recovery temperature and the number of days where the minimum water temperature exceeds 20°C (T_{min} > 20°C) was calculated for recovery purposes.

A correlation analysis was carried out in both the Miramichi and Restigouche rivers to determine the level of association among sites. Following the correlation analysis, a principle component analysis (PCA) and a cluster analysis were used to explore differences in water temperatures between sites. Only complete and concurrent datasets from the Miramichi River were retained for the analysis which included 13 sites for years 2003 to 2005. To retain the most sites in the analysis, only the month of July was included in the analysis.

RESULTS

The first step in the analysis consisted of calculating the average minimum, maximum and mean daily water temperature throughout the calendar year. The minimum, maximum and mean water temperatures were calculated for each day of year (e.g., June 1 or day 152). Results for the Little Southwest Miramichi River are presented in Figure 2, as an example. This figure shows that river water temperature is generally close to zero in winter, with a departure from zero after day 100 (April 10). The greatest difference in water temperatures (i.e., difference between the minimum and maximum) was observed during the warm part of the summer months, i.e., during the month of July and August (between day 182 and 243). In spring and autumn, all three time series were close together, which is the result of a smaller diel variability and similar thermal regime among years. A similar pattern to the Little Southwest Miramichi River was also observed at other sites within the Miramichi and Restigouche rivers.

To further characterize each water temperature site, summer water temperatures were calculated (i.e., between July 1 and August 31 for minimum, maximum and mean temperatures). Results of this analysis are presented in Table 2a for sites in the Miramichi River and Table 2b for the sites in Restigouche River. The value of *n* in this table represents the number of years of record used in the analysis. For example, the Little Southwest Miramichi River had the longest time series (*n* = 19 years) and the average summer temperature was calculated at 19.6°C. The minimum and maximum water temperatures for this site were 17.4°C and 22.1°C, respectively. Table 2a also shows the maximum recorded temperature during the summer period which was 30.6°C for the Little Southwest Miramichi River. The difference between the mean summer minimum and mean summer maximum was also calculated for each site and the Little Southwest Miramichi River showed a difference of 4.8°C. The difference between the mean summer minimum and the mean summer maximum informs us on the variability (diel variability) for each site. The diel variability over the 24 hour period was also studied for the Little Southwest Miramichi River during high water temperature events in 1995, 1999 and 2010 and the results are presented in Figure 3. This figure shows that the minimum water temperature was generally observed in the morning around 9:00 am (-2.7°C from the mean), the mean water temperature was observed around 1:00 pm whereas the maximum water temperature was observed around 7:00 pm (+2.80°C). The diel variability may differ slightly for different sites; however, the Little Southwest Miramichi River data illustrate the general water temperature pattern over a 24 hour cycle.

Summer water temperature characteristics are presented for all sites in the Miramichi and Restigouche basins (Table 2) and a graphical representation is provided in Figure 4 (mean summer temperature). Figure 5 presents the spatial variability of summer water temperatures in both Miramichi and Restigouche rivers. In the case of the Miramichi River, the coldest site was at Sisters Brook (16.5°C) whereas the warmest site was the Dungarvon River (21.2°C). In the Restigouche River, the coldest site was on Kedgwick River above Forks Pool (14.2°C) whereas the warmest site was on the Restigouche River at Butters Island (18.0°C). Miramichi River sites showed an average water temperature of 19.4°C compared to 16.5°C in the Restigouche River (difference of 2.9°C). Figure 5 also shows that the coldest sites were mainly in tributaries whereas main river sites showed warmer conditions. Figure 4 and Table 2 show the difference between the average summer minimum and average summer maximum water temperatures. The mean difference between the average minimum and the average maximum in the Miramichi River was calculated at 4.5°C compared to 3.3°C in the Restigouche River. This greater difference between the minimum and the maximum in the Miramichi River is most likely related to this river being shallower than the Restigouche River. As such, the Miramichi River experiences greater diel water temperature variability. In the Miramichi River, the maximum water temperatures recorded varied between 25.2°C and 32.9°C (mean of maximum 29.5°C; Summer Max; Table 2) and in the Restigouche River maximum temperature recorded varied between 23.7°C and 27.8°C (mean of maximum 25.4°C; Summer Max; Table 2). These results clearly show that the Miramichi River experiences much warmer maximum water temperatures in the summer than the Restigouche River.

Results of the threshold analysis (T_{max} > 23°C and T_{min} > 20°C) are presented for the Little Southwest Miramichi River in Table 2a and Figure 6a. Table 2a reports the average number of days per year that T_{max} > 23°C. For the Little Southwest Miramichi River, this represented 27.9 days per year. Figure 6a show that T_{max} exceeded 23°C almost every year between 1992 and 2011 and the years with the longest duration were 1999 (62 days), 2001 (52 days) and 2002 (52 days). The distribution of occurrences of high water temperature events is presented in Figure 6b with a total of 531 days between 1992 and 2011. This figure shows that high water temperature events can occur as early as day 140 (May 20); however, most events generally occur between day 160 (June 9) and 260 (Sept 17) with an average of day 207 (July 26). The mean value of 207 (day of year) corresponds well with the annual cycle (Figure 2) where peak summer water temperatures are generally observed around day 211 (July 30; Caissie 2006).

Results of the analysis of stressful days using the T_{max} threshold (T_{max} > 23°C) are presented for other sites in the Miramichi (Table 2a) and the Restigouche (Table 2b). For instance, the mean number of days ranged between 7.8 days per year at Rocky Brook to 42.4 days per year at

Little Southwest Miramichi River at Upper Oxbow. It was noted that the results of the Miramichi River (mean values) were influenced by the length of record, which was quite variable (4 - 19 years). For example, the Little Southwest Miramichi River at the Upper Oxbow site showed a high value of 42.4 days per year; however, no data were available in 2007, 2008 and 2009, which most likely influenced the results. In the case of the Restigouche River, the mean number of high water temperature events per year was low compared to the Miramichi River. Values for the Restigouche River ranged between 0.3 (Kedgwick River above Forks Pool) and 8.3 days per year (Restigouche River at Brandy Brook), with a mean overall of 2.9 days per year (Miramichi overall mean was 26.3 days per year). Occurrences of high water temperature events for both the Miramichi and Restigouche rivers were generally close to July 24-25, day 205-206 (Table 2).

In terms of fish physiological recovery, the 20°C threshold (T_{min} > 20°C) was used for both river systems. When T_{min} > 20°C, there is insufficient cool water temperatures to allow fish to recover physiologically from the high temperature events. The results of this analysis are presented in Figure 7 for the Little Southwest Miramichi River. The years with the most number of days where T_{min} > 20°C were 1999 (26 days) and 2010 (26 days; Figure 7a). A mean value of 9 days per year was calculated for the Little Southwest Miramichi River (Table 2a) whereas the total number of days over the 19 year period was 171. The total number of days for which T_{min} > 20°C was lower than the number of days for which T_{max} > 23°C (531; Figure 6). The distribution or timing of the occurrences of T_{min} > 20°C within the year was very similar to T_{max} with a mean day of 206 (Figure 7b). Results for other sites are presented in Table 2. It is worth nothing that the number of days with T_{min} > 20°C was much lower than for T_{max} > 23°C for all sites in the Miramichi River (26.3 days per year for T_{max} > 23°C compared to 12 days per year for T_{min} > 20°C). In the Restigouche River, results showed low occurrences for both thresholds (2.9 days per year for T_{max} > 23°C and 1.3 days per year for T_{min} > 20°C). Figure 8 shows a summary of high water temperature events (for T_{max} > 23°C and T_{min} > 20°C) for both the Miramichi and Restigouche rivers. This figure clearly shows a marked difference in warm temperature events between these two river systems. For T_{max} > 23°C, the Miramichi River showed many sites with an average number of events per year exceeding 25 days whereas the Restigouche River showed less than 10 days on average per year (Figure 8a). For T_{min} > 20°C, the Miramichi River showed 7 sites where the mean number of days per year was between 15 and 27 days (Figure 8b). For the Restigouche River most sites experienced less than 5 days per year (with the exception of Restigouche River at Butters Island 7.1 days per year).

An analysis of thresholds by year was carried out for selected sites within the Miramichi River, as this river clearly experienced more stressful high water temperature events. For this analysis, a particular emphasis was put on three sites between 2002 and 2011, namely the Little Southwest Miramichi River, the Southwest Miramichi River at Doaktown and the Southwest Miramichi River at Nelson Hollow. The Little Southwest Miramichi River was selected because it has the longest water temperature time series. Accordingly, this time series can inform on long-term water temperature statistics related to temperature stress. The Southwest Miramichi River at Doaktown was selected because this site has real time data which can be accessed and downloaded on a regular basis. This site can provide valuable information for fisheries management purposes. The Southwest Miramichi River at Nelson Hollow was selected because it is very close to the Doaktown site and has data during some years where Doaktown data are not available (i.e., provides supplementary data, 2006-2008).

Figure 9 shows a breakdown of high temperature events, i.e., the number of days with T_{max} > 23°C (Figure 9a) and T_{min} > 20°C (Figure 9b) among years for these three sites. Results showed that the number of days for which T_{max} > 23°C was similar among sites; however, differences were observed during some years (e.g., in 2002 between LSWM and Doaktown and in 2003 between Nelson Hollow and the other two sites). It was also observed that the number of days related to T_{min} > 20°C (Figure 9b) showed a greater variability among sites than T_{max}. For example, the Little Southwest Miramichi River showed fewer days with exceedances per year than the other two sites for many years (e.g., 2002-2005; 2010-2011; Figure 9b). Also, the two sites on the Southwest Miramichi River (Nelson Hollow and Doaktown), despite their proximity, showed some differences in the number of days per year (e.g., 2003, 2010-2011). These differences were noted even though the correlation of mean monthly water temperature among these sites is high (Figure 10). In fact, the correlation between Southwest Miramichi River at Doaktown and the Nelson Hollow site exceeded 0.95 and the correlation between the Southwest Miramichi River at Doaktown and Little Southwest Miramichi River was 0.98. Results of the correlation analysis for other sites in the Miramichi and Restigouche rivers are presented in Table 3. Results of the correlation analysis generally indicated that sites that were in close proximity to other sites and similar in thermal regime showed higher correlations (e.g. sites S3, S4, S5 and S14 which are all part of the Little Southwest Miramichi River; $r^2 > 0.95$; Pearson`s correlation; Table 3a). In contrast, sites that were far apart and different in thermal regime (e.g., tributary vs. main river) showed lower correlation coefficients (e.g. sites S1 vs. S4, S5, S13 and S14 within the Restigouche River; $0.43 < r^2 < 0.60$; Table 3b).

Following the correlation analysis, a principal component analysis (PCA) and a cluster analysis were carried out for the Miramichi sites only (i.e., sites most problematic in terms of high water temperatures). The PCA showed that 83% of the variance was explained by principal components 1 and 2 and 92% of the variance was explained by the first three components (Table 4). The weights of the first principal component were most important for the number of hours in the month of July that exceeded 18°C, 25°C and 26°C. The weights of the second principal component were highest when maximum daily water temperature exceeded 25 and 26°C and the number of days with maximum water temperature exceeded 25°C for one hour. The weights of the second principle component were also highest and negatively correlated to the number of days with water temperature exceeding 18°C for four hours and eight hours.

The Bridge Pool site (a headwater site) on the Northwest Miramichi River was clearly different from all the other sites on the first component irrespective of the year (Figures 11 and 12). The separation of the remaining sites was less pronounced; however, sites lower in the river grouped together on the first principal component. The Moose Landing site was an exception by being higher in the system and grouped with the lower sites. The grouping of sites also varied according to year. The sites all varied in a similar way in a given year with the year 2005 having higher values than 2003 and 2004.

On a geographical scale, the Bridge Pool site formed a separate cluster irrespective of year (Figure 13). Sites lower in the system formed a cluster, except for Moose Landing which is relatively higher in the system but yet behaved like the lower sites. A second group of sites was observed and these included five sites that were between the lower sites and the Bridge Pool site.

River discharge also influences the thermal regime of rivers, particularly during low water conditions, as river water temperature is inversely related to the depth of water (Caissie et al. 2007). Salmonids can be impacted during low water conditions by a reduction in available habitat. As such, low water and warm water conditions can have a combined effect on fishes. Daily river flow was plotted from day 100 (April 10) to 300 (October 27) for both the Miramichi and Restigouche rivers (Figure 14). This period generally corresponds to the open water period (ice free period) where high water temperature events would be encountered and where summer low flows could impact both the thermal regime and the available habitat. Results show a high variability in flows among years for the Miramichi River and a base flow recession curve

(curve of minimum flow represented by a power function) that decreases as the summer progresses (Figure 14a). The base flow recession curve equation Q_B as well as the 2-year and the 50-year low flow (18.7 m^3/s and 11.1 m^3/s, respectively) were also presented in Figure 14a. Based on the low flow recession curve of the Miramichi River, the 2-year low flow is generally not observed before day 203 (July 22). This means that over the period of record (1962-2010), July 22 would generally be the earliest where the 2-year low flow would occur. It is mostly during low flows that high water temperature events would have a combined effect (flow and temperature) and result in added stress on aquatic resources. In the case of the Restigouche River, the 2-year low flow was estimated at 23.2 m^3/s (Figure 14b) and this flow would be reached on day 239 (Aug 27) at the earliest in the season. Not only does the Restigouche River experience fewer high water temperature events, it also reaches low flow conditions later in the year. In the case of the Miramichi River, combined low flows and high water temperature events generally occur after mid-July.

SUMMARY

The present study provided summer water temperature and high temperature events data for the Miramichi and Restigouche rivers. The purpose of this analysis is to help establish and identify thresholds for potential fishing closures within these river systems. The following observations can be made from the present study. First, the annual cycle of water temperature was such that water temperatures reach maximum values (min, max and mean daily) in July and August (highest values between mid-July to mid-August). On a diel period (over a 24 hour period), water temperature tends to reach the minimum early in the morning (8-9am), the mean temperature in early afternoon (1pm), and its maximum in early evening (7pm). Results showed a clear difference in summer water temperatures between the Miramichi and Restigouche rivers where high water temperature events are more prevalent in the Miramichi River. In both river systems, the main rivers generally experienced higher water temperatures than tributary sites and highest water temperatures were generally experienced at the downstream sites. A correlation analysis of monthly summer water temperatures showed that most sites are highly related to each other, especially for sites that are in close proximity and for rivers that are similar in size. Sites that showed the least correlation were small tributaries vs. larger river systems or sites that were far apart. Although water temperature sites showed high correlations, the studied thresholds showed some level of variability among sites. In particular, inter-site variability was higher in the number of days where T_{min} > 20°C than in the number of days with T_{max} > 23°C. High water temperature events are more prevalent from mid-July to mid-August during the high temperature portion of the annual water temperature cycle (reaches its maximum on day 211, July 30). River discharge plays an important role in the river thermal regime as well as in overall habitat conditions. During summer low flows, both water levels and river temperature will have a combined effect on aquatic resources. If the 2-year low flow is used as an index of low flow conditions, then this flow is generally not reached before day 203 (July 22) in the Miramichi River and not reached before day 239 (August 27) in the Restigouche River. The PCA and cluster analysis showed that most sites in the lower part of the Miramichi River behaved similarly, with the exception of Moose Landing and the Bridge Pool sites.

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TABLES

Table 1a. Latitude and longitude (decimal degrees) of study sites in the Miramichi River and its tributaries.

River	Latitude	Longitude
Cains River Camp Admerril	46.65737	65.77362
Dungarvon River at mouth	46.81618	65.90238
Little Southwest Mira above CatBk	46.87937	66.10492
Little Southwest Mira at Clelland	46.89480	66.20238
Little Southwest Mira at Moose Landing	46.96207	66.57128
Little Southwest Mira at Upper Oxbow	46.95457	65.85997
NBr Renous R above Route 108 Bridge	46.79602	66.19842
North Branch Big Sevogle River	47.13488	65.98323
Northwest Mira at Call pool	47.18268	65.89463
Northwest Mira Bridge Pool	47.25680	66.22645
Northwest Mira at Wayerton Bridge	47.13506	65.83270
Renous R below Bailey Bridge	46.80472	65.86867
Rocky Brook at Cold Spring	46.60853	66.63310
Sisters Brook	46.60161	66.64559
Southwest Mira Burntland Brook	46.46059	66.40873
Southwest Mira at Doaktown	46.55250	66.14500
Southwest Mira Nelson Hollow	46.53904	66.18808
Southwest Mira Wades Pool	46.67157	65.77380
Southwest Mira Upper Sisters Pool	46.60099	66.64499
Taxis River	46.42553	66.60532
Tomogonops River	47.23410	65.83588

Table 1b. Latitude and longitude (decimal degrees) of study sites in the Restigouche River and its tributaries.

River	Latitude	Longitude
Kedgwick River above Forks Pool	47.90695	67.90588
Kedgwick River below 1 Mile Bridge	47.67093	67.50933
Patapedia River at 30 Mile	48.07865	67.63383
Patapedia River at 2 Mile	47.86103	67.39397
Main Restigouche River at Junction Pool	47.66465	67.48895
Restigouche River at Larrys Gulch	47.70695	67.44170
Restigouche River above Indian House	47.86905	67.35167
Restigouche River at Two Brooks	47.88548	67.25362
Restigouche River at Brandy Brook	47.93523	67.06143
Restigouche River above mouth of Upsalquitch R.	47.89068	66.96228
Restigouche River below Camp Harmony	47.89328	66.95240
Restigouche River at Moses Island	47.99733	66.81575
Restgouche River at Butters Island	47.98655	66.80265
NW Upsalquitch River at 10 Mile Pool	47.61145	66.81783
SE Upsalquitch above Basket Rock	47.65228	66.59228
Upsalquitch River at Two Brooks	47.73440	66.83712
Upsalquitch River at Crib Pool	47.85430	66.90587
Causapscal River at Barrier	48.46703	67.23223
Matapedia R. below Mouth of Causapscal	48.35280	67.22298
Matapedia R. below Haleys Pool at Village Bridge	47.97440	66.94573
Little Main Restigouche River at Boston Brook	47.52775	67.62218

Table 2a. Summer water temperature statistics for selected sites in the Miramichi River basin.

	Summer Mean (July & August)						Threshold			
	Min	Max	Mean	Difference (Max-Min)	Summer Max	n	T23 (Max)	T20 (Min)	T23 (Day)	T23 (Day)
Cains River Camp Admerril	19.4	22.2	20.7	2.8	29.3	10	24.5	26.6	207	207
Dungarvon River at mouth	19.2	23.6	21.2	4.4	30.6	2	na	na	na	na
Little Southwest Mira above CatBk	17.4	22.1	19.6	4.8	30.6	19	27.9	9	207	206
Little Southwest Mira at Clelland	17.1	21.8	19.3	4.6	29.3	8	24.3	7.5	205	205
Little Southwest Mira at Moose Landing	18.5	21.9	20.1	3.4	28.5	11	25.0	19.2	204	206
Little Southwest Mira at Upper Oxbow	19.1	23.4	21.1	4.3	30.6	9	42.4	23.8	206	208
NBr Renous R above Route 108 Bridge	18.3	23.1	20.5	4.8	30.9	2	na	na	na	na
North Branch Big Sevogle River	16.1	21.8	18.8	5.7	30.0	11	26.0	2.9	208	211
Northwest Mira at Call pool	16.3	21.0	18.5	4.7	29.1	12	19.0	3.8	207	207
Northwest Mira Bridge Pool	14.3	19.8	16.9	5.4	25.2	2	na	na	na	na
Northwest Mira at Wayerton Bridge	17.5	22.6	20.0	5.1	30.2	9	34.8	10.3	207	209
Renous R below Bailey Bridge	18.6	23.0	20.7	4.4	30.4	7	37.3	17.6	206	205
Rocky Brook at Cold Spring	15.0	19.9	17.3	4.9	26.3	4	7.8	0.0	202	na
Sisters Brook	14.7	18.7	16.5	4.0	29.1	4	10.8	2.3	197	202
Southwest Mira Burntland Brook	15.7	21.5	18.4	5.8	30.4	11	24.8	2.4	207	211
Southwest Mira at Doaktown	19.2	22.8	20.8	3.6	29.9	7	32.6	23.0	209	209
Southwest Mira Nelson Hollow	18.6	21.9	20.1	3.3	29.8	11	24.2	20.2	206	208
Southwest Mira Wades Pool	19.2	22.3	20.6	3.1	29.3	11	28.4	25.2	208	209
Southwest Mira Upper Sisters Pool	15.9	20.4	18.0	4.4	28.7	4	17.8	4.3	214	212
Taxis River	16.8	23.1	19.7	6.3	32.9	12	40.3	6.8	207	206
Tomogonops River	16.8	22.2	19.3	5.4	27.6	2	na	na	na	na

n = number of years of record; T23 (Max) = average number of days per year where T_{max} > 23°C; T20 (Min) = average number of day per year where T_{min} > 20°C; T23(Day) = average day of year for the occurrence of T_{max} > 23°C; T20(Day) = average day of year for the occurrence of T_{min} > 20°C; na = not applicable

Table 2b. Summer water temperature statistics for selected sites in the Restigouche River basin.

	Summer Mean (July & August)						Threshold			
	Min	**Max**	**Mean**	**Difference (Max-Min)**	**Summer Max**	**n**	**T23 (Max)**	**T20 (Min)**	**T23 (Day)**	**T20 (Day)**
Kedgwick River above Forks Pool	12.4	16.3	14.2	3.9	23.8	9	0.3	0.0	188	na
Kedgwick River below 1 Mile Bridge	14.2	17.2	15.6	3.0	25.3	9	1.7	0.4	208	212
Patapedia River at 30 Mile	14.0	18.9	16.2	4.8	25.9	9	4.3	0.0	196	na
Patapedia River at 2 Mile	13.5	17.0	15.1	3.5	23.7	9	0.6	0.0	194	na
Main Restigouche River at Junction Pool	14.6	17.5	16.0	2.9	24.5	9	1.3	0.7	206	208
Restigouche River at Larrys Gulch	16.2	19.6	17.8	3.4	24.8	2	5.0	2.0	213	212
Restigouche River above Indian House	15.9	18.9	17.3	3.0	25.6	6	3.8	2.5	204	207
Restigouche River at Two Brooks	15.7	17.9	16.8	2.2	24.5	9	1.3	1.8	202	201
Restigouche River at Brandy Brook	15.8	19.0	17.2	3.2	27.8	9	8.3	2.4	209	207
Restigouche River above mouth of Upsalquitch R	16.4	18.8	17.5	2.4	25.0	4	4.5	2.8	210	213
Restigouche River below Camp Harmony	15.8	19.4	17.5	3.6	27.1	9	6.8	1.2	208	212
Restigouche River at Moses Island	16.3	18.5	17.4	2.2	25.9	9	1.8	3.4	207	208
Restgouche River at Butters Island	17.0	19.1	18.0	2.1	27.1	9	3.6	7.1	207	208
NW Upsalquitch River at 10 Mile Pool	14.3	19.0	16.5	4.6	27.5	9	4.6	0.2	206	201
SE Upsalquitch above Basket Rock	13.6	18.0	15.7	4.4	24.5	9	1.1	0.0	205	na
Upsalquitch River at Two Brooks	15.4	18.2	16.7	2.7	24.5	9	0.7	0.9	208	210
Upsalquitch River at Crib Pool	15.5	18.4	16.9	2.9	25.7	9	2.0	0.9	208	215
Causapscal River at Barrier	13.7	18.4	15.9	4.7	26.8	9	4.4	0.1	203	200
Matapedia River below Mouth of Causapscal	15.5	18.3	16.8	2.8	23.7	8	1.3	0.1	205	199
Matapedia River below Haleys Pool at Village Bridge	15.5	18.4	16.8	2.9	25.9	8	1.6	1.5	212	211
Little Main Restigouche River at Boston Brook	13.0	17.2	14.9	4.2	24.5	9	1.4	0.0	203	na

n = number of years of record; T23 (Max) = average number of days per year where T_{max} > 23°C; T20 (Min) = average number of day per year where T_{min} > 20°C; T23(Day) = average day of year for the occurrence of T_{max} > 23°C; T20(Day) = average day of year for the occurrence of T_{min} > 20°C; na = not applicable

Table 3a. Correlation matrix of mean summer water temperatures for selected sites in the Miramichi River basin (1992-2011).

Sites	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
S1	1.000	0.915	0.776	0.700	0.850	0.910	0.951	0.963	0.945	0.952	0.894	0.815	0.962	0.792
S2	0.915	1.000	0.547	0.954	0.905	0.653	0.773	0.824	0.886	0.901	0.989	0.854	0.798	0.746
S3	0.776	0.547	1.000	0.972	0.985	0.884	0.913	0.809	0.853	0.917	0.434	0.918	0.670	0.982
S4	0.700	0.954	0.972	1.000	0.964	0.707	0.766	0.749	0.968	0.757	0.683	0.873	0.676	0.757
S5	0.850	0.905	0.985	0.964	1.000	0.844	0.963	0.860	0.907	0.934	0.748	0.910	0.788	0.986
S6	0.910	0.653	0.884	0.707	0.844	1.000	0.933	0.946	0.436	0.967	0.391	0.617	0.706	0.851
S7	0.951	0.773	0.913	0.766	0.963	0.933	1.000	0.980	0.960	0.961	0.646	0.897	0.882	0.873
S8	0.963	0.824	0.809	0.749	0.860	0.946	0.980	1.000	0.910	0.888	0.680	0.890	0.924	0.867
S9	0.945	0.886	0.853	0.968	0.907	0.436	0.960	0.910	1.000	0.772	0.899	0.904	0.852	0.912
S10	0.952	0.901	0.917	0.757	0.934	0.967	0.961	0.888	0.772	1.000	0.897	0.906	0.953	0.858
S11	0.894	0.989	0.434	0.683	0.748	0.391	0.646	0.680	0.899	0.897	1.000	0.466	0.775	0.654
S12	0.815	0.854	0.918	0.873	0.910	0.617	0.897	0.890	0.904	0.906	0.466	1.000	0.887	0.595
S13	0.962	0.798	0.670	0.676	0.788	0.706	0.882	0.924	0.852	0.953	0.775	0.887	1.000	0.732
S14	0.792	0.746	0.982	0.757	0.986	0.851	0.873	0.867	0.912	0.858	0.654	0.595	0.732	1.000

Sites

1 Burntland Brook
2 Cains River Camp Admiral
3 LSWM at Clelland
4 LSWM Moose Landing
5 LSWM Upper Oxbow
6 North Branch Big Sevogle River
7 NW Mira at Calls Pool

Sites

8 NW Mira at Wayerton Bridge
9 Renous River below Bailey Bridge
10 SW Mira at Doaktown
11 SW Mira at Wades Pool
12 SW Mira Nelson Hollow
13 Taxis River
14 Little Southwest Miramichi R.

Table 3b. Correlation matrix of mean summer water temperatures for selected sites within the Restigouche River (2003-2011).

Sites	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
S1	1.000	0.906	0.888	0.519	0.591	0.935	0.849	0.944	0.912	0.815	0.836	0.828	0.432	0.543	0.589	0.729	0.606
S2	0.906	1.000	0.975	0.676	0.757	0.951	0.761	0.979	0.990	0.931	0.898	0.932	0.633	0.664	0.731	0.667	0.535
S3	0.888	0.975	1.000	0.661	0.736	0.954	0.825	0.992	0.985	0.946	0.937	0.953	0.672	0.629	0.723	0.724	0.570
S4	0.519	0.676	0.661	1.000	0.991	0.646	0.263	0.826	0.731	0.702	0.801	0.825	0.931	0.940	0.975	0.530	0.215
S5	0.591	0.757	0.736	0.991	1.000	0.712	0.334	0.855	0.799	0.759	0.839	0.869	0.929	0.947	0.985	0.545	0.248
S6	0.935	0.951	0.954	0.646	0.712	1.000	0.774	0.983	0.965	0.956	0.935	0.943	0.596	0.609	0.690	0.797	0.682
S7	0.849	0.761	0.825	0.263	0.334	0.774	1.000	0.798	0.781	0.708	0.739	0.700	0.324	0.217	0.333	0.703	0.669
S8	0.944	0.979	0.992	0.826	0.855	0.983	0.798	1.000	0.990	0.959	0.952	0.965	0.801	0.867	0.859	0.753	0.552
S9	0.912	0.990	0.985	0.731	0.799	0.965	0.781	0.990	1.000	0.950	0.948	0.968	0.699	0.695	0.777	0.736	0.597
S10	0.815	0.931	0.946	0.702	0.759	0.956	0.708	0.959	0.950	1.000	0.954	0.969	0.713	0.593	0.724	0.822	0.755
S11	0.836	0.898	0.937	0.801	0.839	0.935	0.739	0.952	0.948	0.954	1.000	0.991	0.815	0.702	0.824	0.854	0.757
S12	0.828	0.932	0.953	0.825	0.869	0.943	0.700	0.965	0.968	0.969	0.991	1.000	0.822	0.740	0.847	0.798	0.675
S13	0.432	0.633	0.672	0.931	0.929	0.596	0.324	0.801	0.699	0.713	0.815	0.822	1.000	0.820	0.931	0.583	0.315
S14	0.543	0.664	0.629	0.940	0.947	0.609	0.217	0.867	0.695	0.593	0.702	0.740	0.820	1.000	0.961	0.362	-0.093
S15	0.589	0.731	0.723	0.975	0.985	0.690	0.333	0.859	0.777	0.724	0.824	0.847	0.931	0.961	1.000	0.551	0.197
S16	0.729	0.667	0.724	0.530	0.545	0.797	0.703	0.753	0.736	0.822	0.854	0.798	0.583	0.362	0.551	1.000	0.972
S17	0.606	0.535	0.570	0.215	0.248	0.682	0.669	0.552	0.597	0.755	0.757	0.675	0.315	-0.093	0.197	0.972	1.000
S18	0.836	0.830	0.894	0.714	0.751	0.913	0.792	0.919	0.892	0.912	0.977	0.942	0.749	0.600	0.743	0.910	0.864
S19	0.792	0.929	0.979	0.660	0.733	0.885	0.791	0.972	0.942	0.908	0.909	0.929	0.722	0.621	0.721	0.648	0.465

Sites

1 Kedgwick River above Forks Pool
2 Kedgwick River below 1 Mile Bridge
3 Main Restigouche River at Junction Pool
4 Upsalquitch River at Crib Pool
5 Restigouche River below Camp Harmony
6 Patapedia River at 2 Mile
7 Patapedia River at 30 Mile
8 Restigouche River above Indian House
9 Restigouche River at Two Brooks
10 Restigouche River at Brandy Brook

Sites

11 Restigouche River at Moses Island
12 Restgouche River at Butters Island
13 NW Upsalquitch River at 10 Mile Pool
14 SE Upsalquitch above Basket Rock
15 Upsalquitch River at Two Brooks
16 Causapscal River at Barrier
17 Matapedia River below Mouth of Causapscal
18 Matapedia River below Haleys Pool at Village Bridge
19 Little Main Restigouche River at Boston Brook

Table 4. Summary of the principal component analysis for 27 water temperature characteristics from 13 sites in the Miramichi River (July water temperature; 2003-2005).

Number	Eigenvalue	Proportion	Cumulative
1	19.6985657	0.7296	0.7296
2	2.7524232	0.1019	0.8315
3	2.2570036	0.0836	0.9151
4	0.9477009	0.0351	0.9502
5	0.364071	0.0135	0.9637

Weight of variables by eigenvectors	Eigenvectors		
	1	2	3
No. hours >18°C	0.194781	-0.285668	0.059835
No. hours >24°C	0.210152	0.201622	-0.01247
No. hours >25°C	0.200327	0.269222	-0.01609
No. hours >26°C	0.188332	0.309956	0.022006
No. days with T >18°C for 4h	0.18679	-0.276629	-0.1001
No. days with T >25°C for 1h	0.168925	0.272953	-0.27652
No. days with T >18°C for 8h	0.183903	-0.27926	0.139975
No. days with T >20°C for 8h	0.182544	-0.233436	0.215345

FIGURES

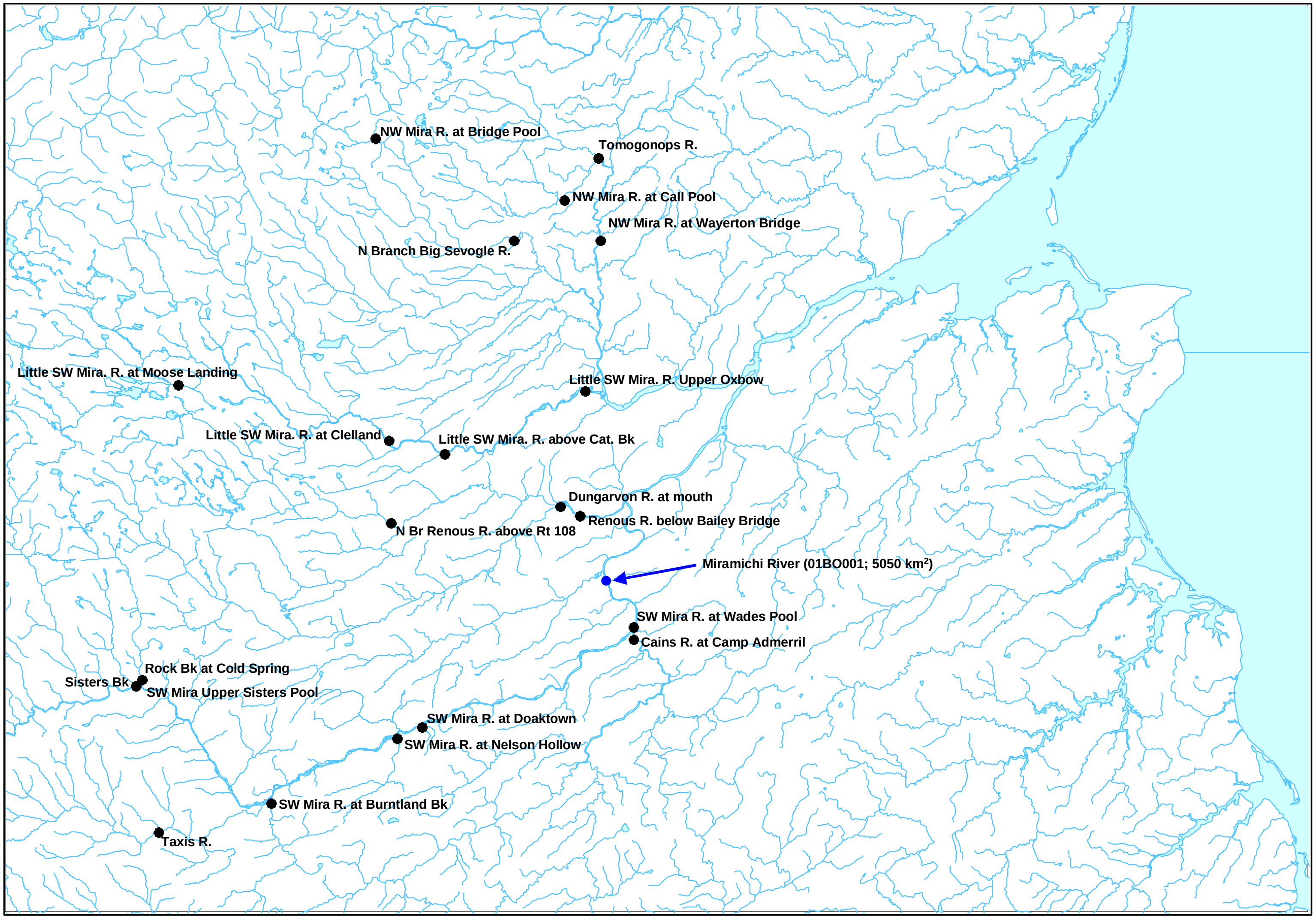


Figure 1a. Location of the water temperature sites and the hydrometric station within the Miramichi River watershed. Blue arrow indicates the location of the hydrometric station.

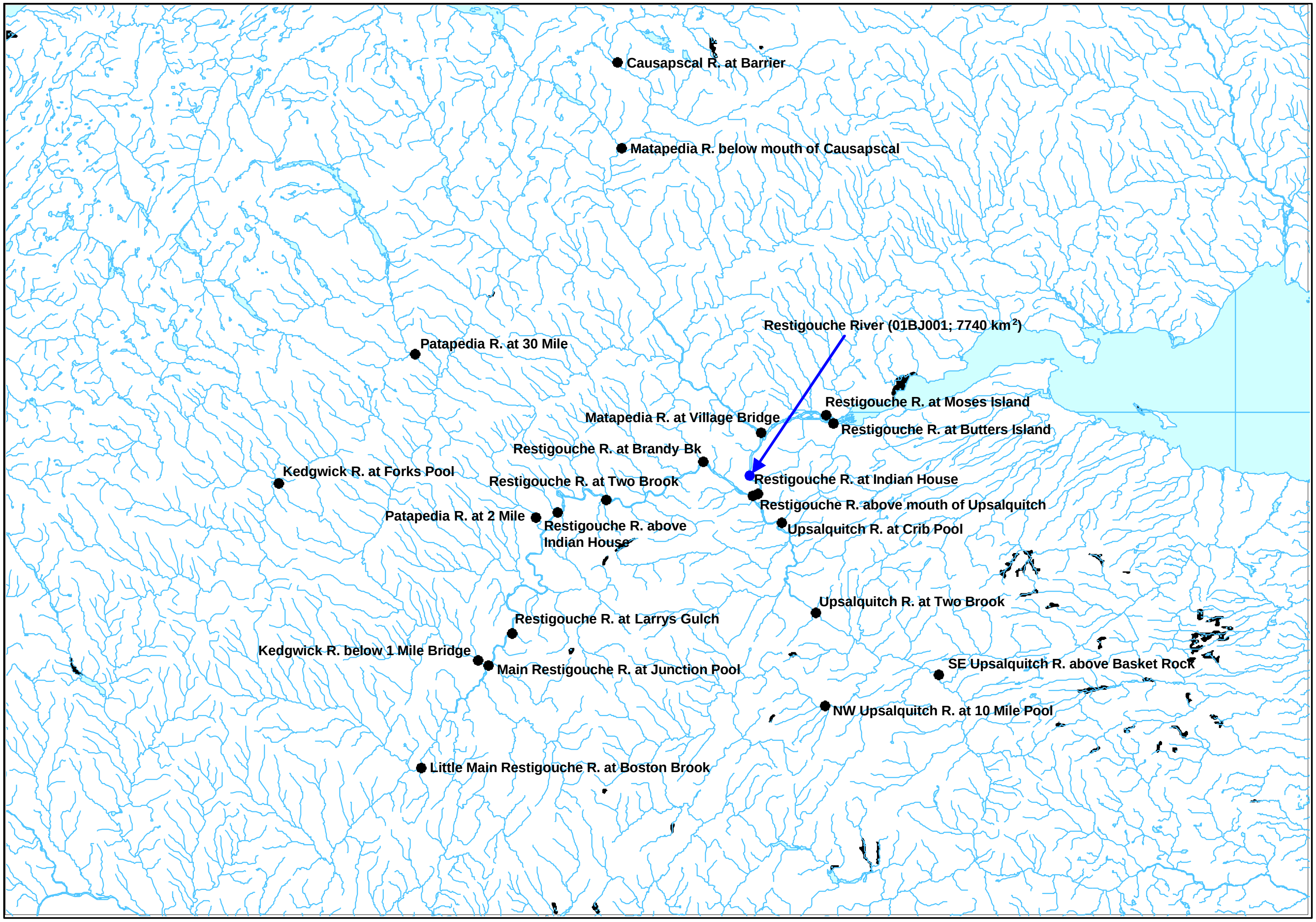


Figure 1b. Location of the water temperature sites and the hydrometric station within the Restigouche River watershed. Blue arrow indicates the location of the hydrometric station.

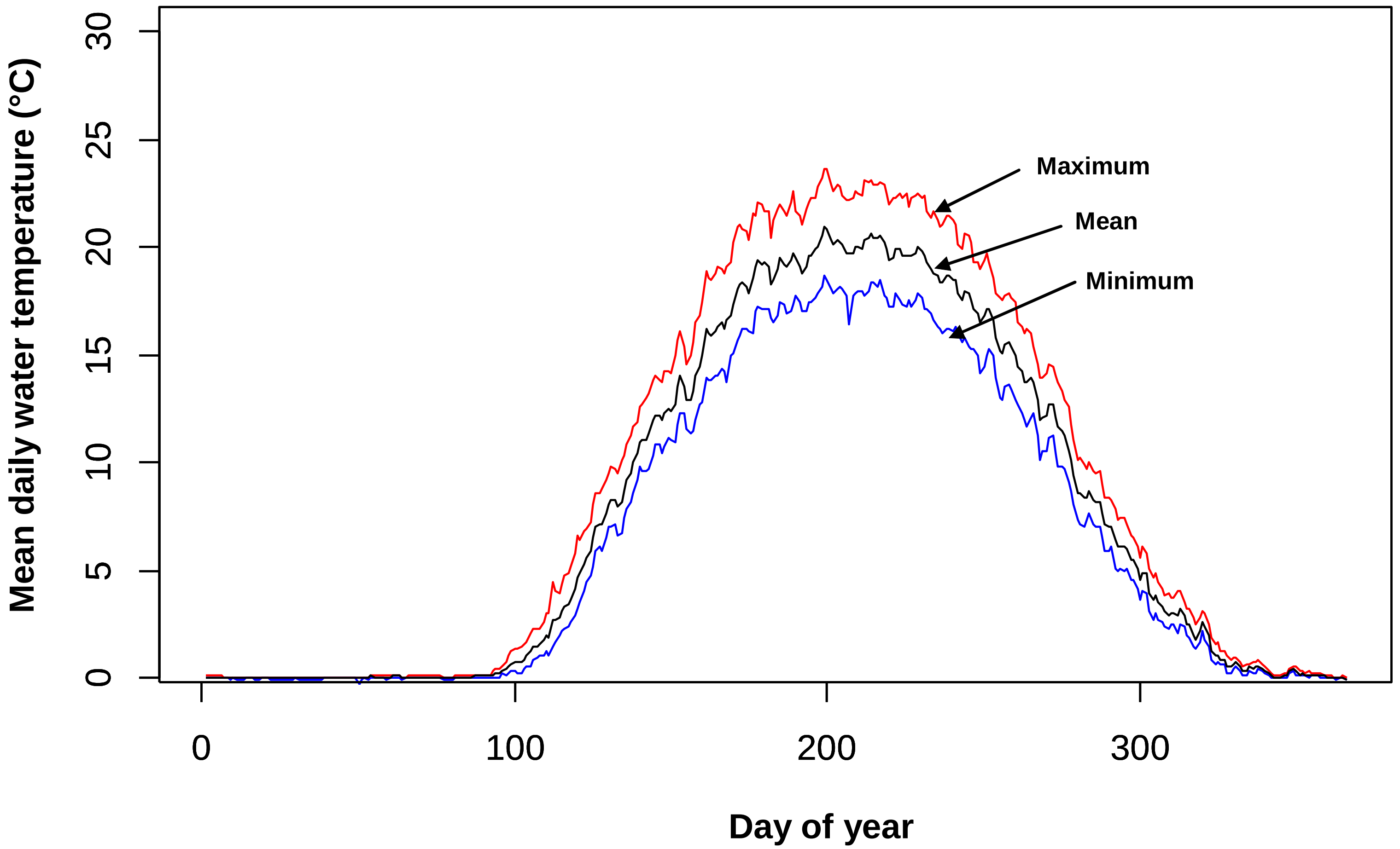


Figure 2. Mean daily water temperature (min, max, and mean for each day of year) for the Little Southwest Miramichi River, 1992 to 2011.

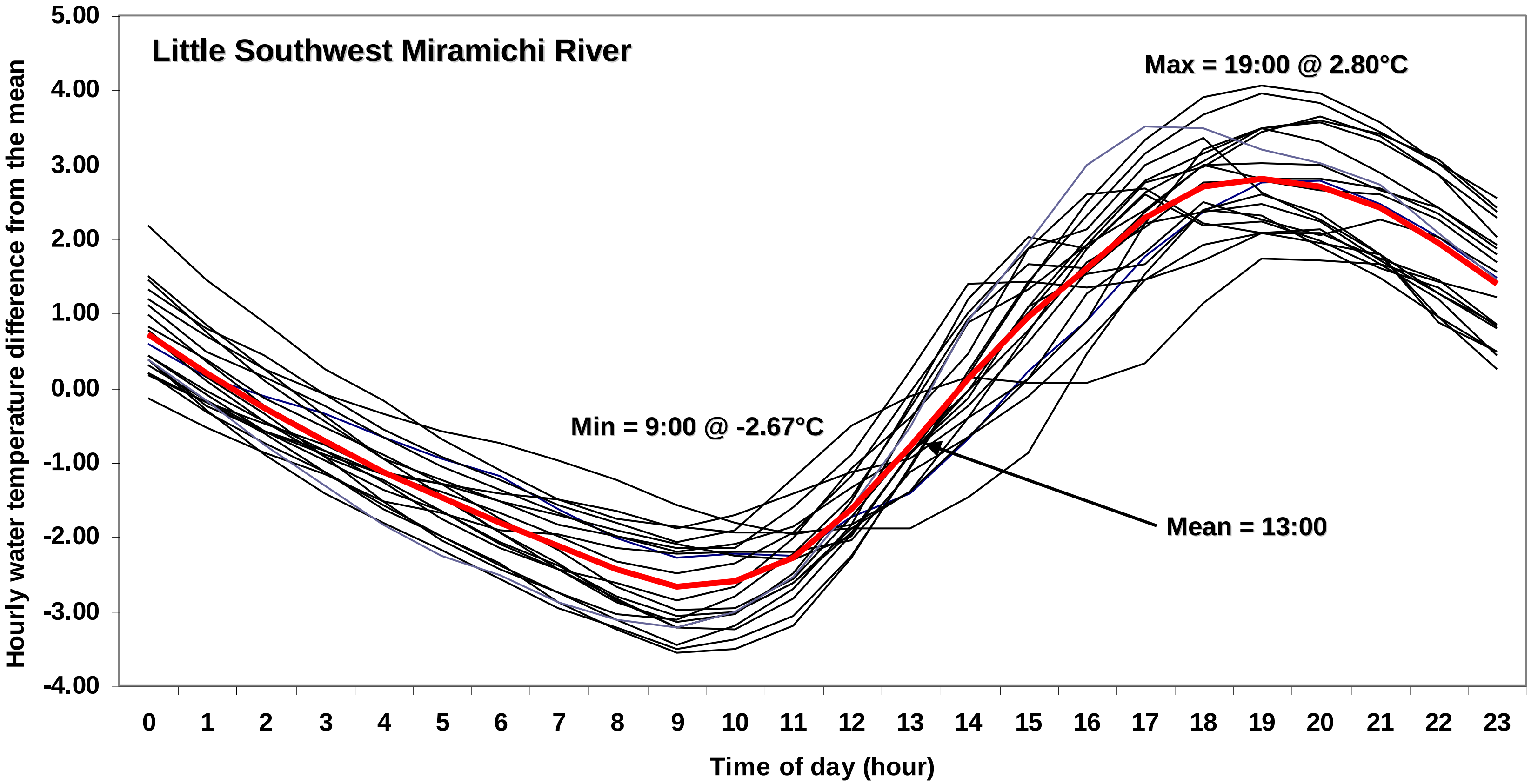


Figure 3. Diel water temperature variability for the Little Southwest Miramichi River, mean of 116 days (1995, 1999, and 2010). Data are specific to summer high water temperature events.

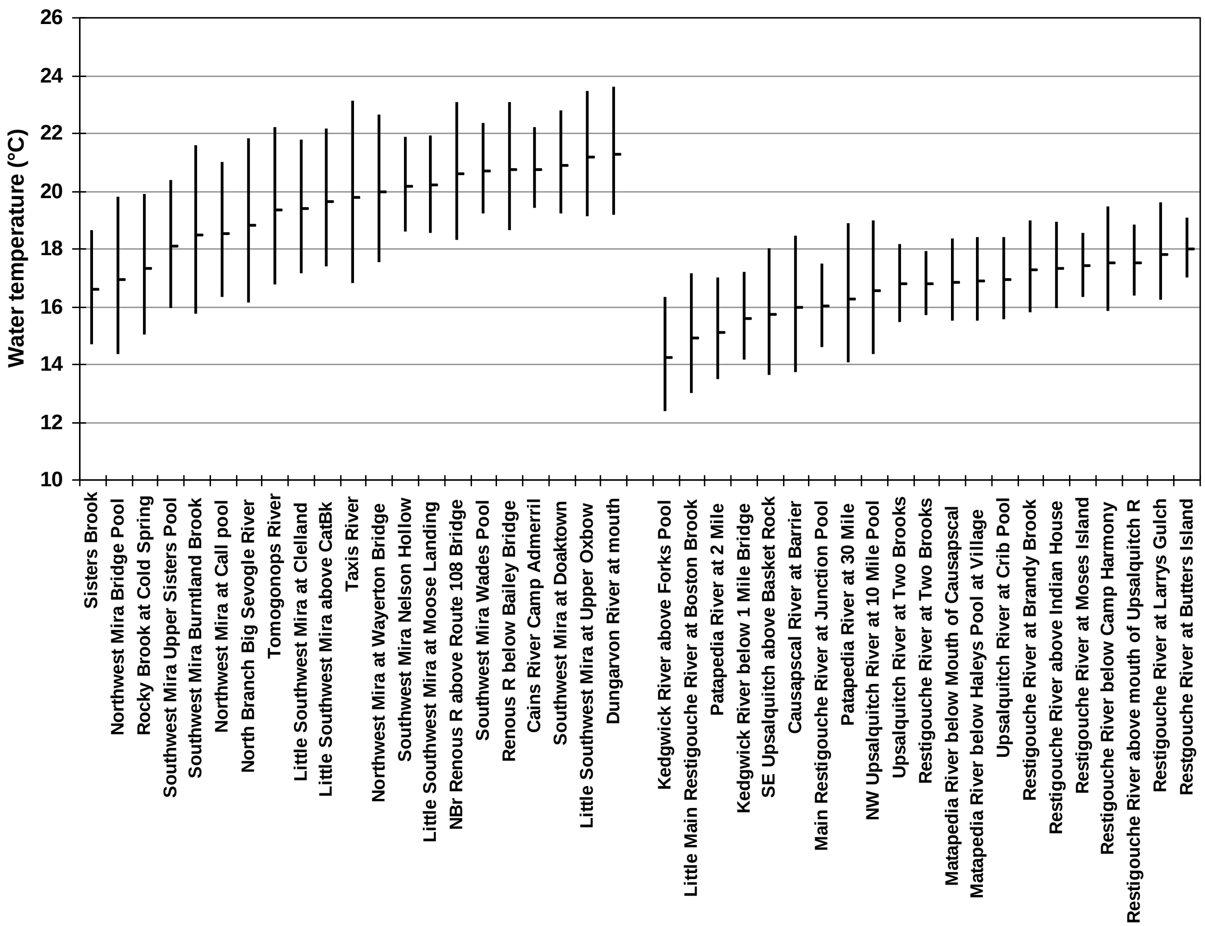


Figure 4. Mean summer (July and August) water temperatures of individual sites in the Miramichi and Restigouche rivers.

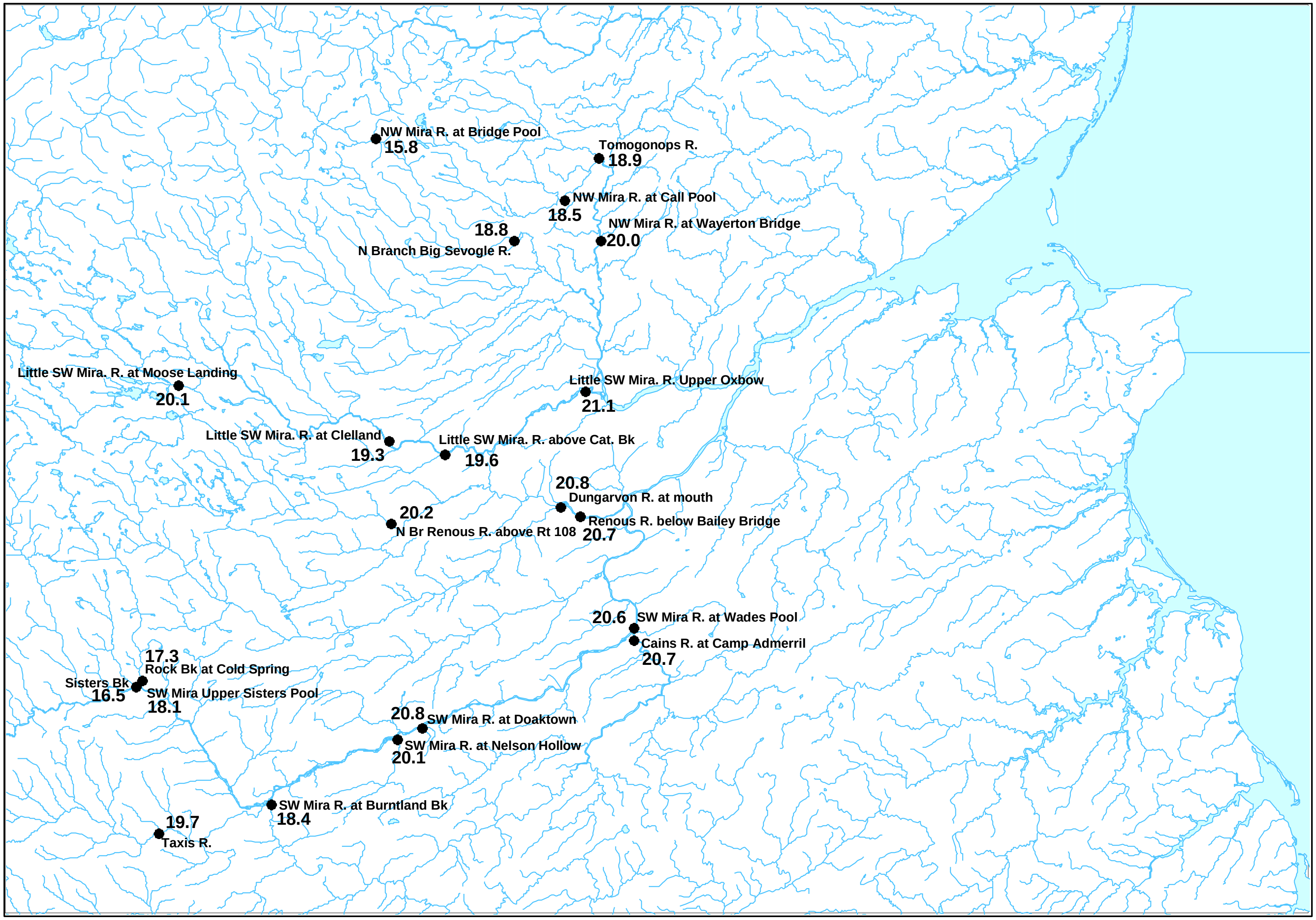


Figure 5a. Mean summer water temperatures (ºC) at selected sites in the Miramichi River basin.

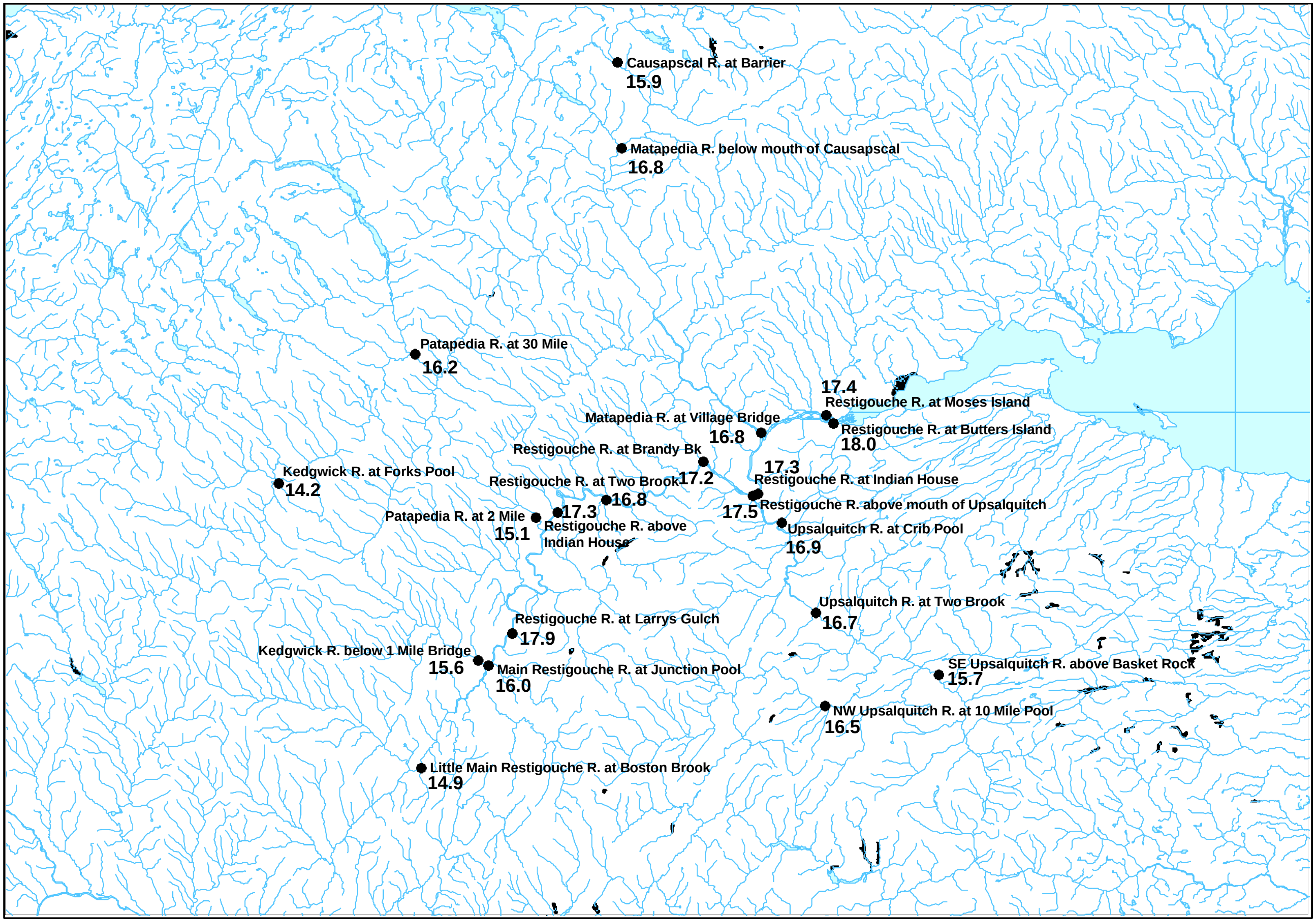


Figure 5b. Mean summer water temperatures (ºC) at selected sites in the Restigouche River basin.

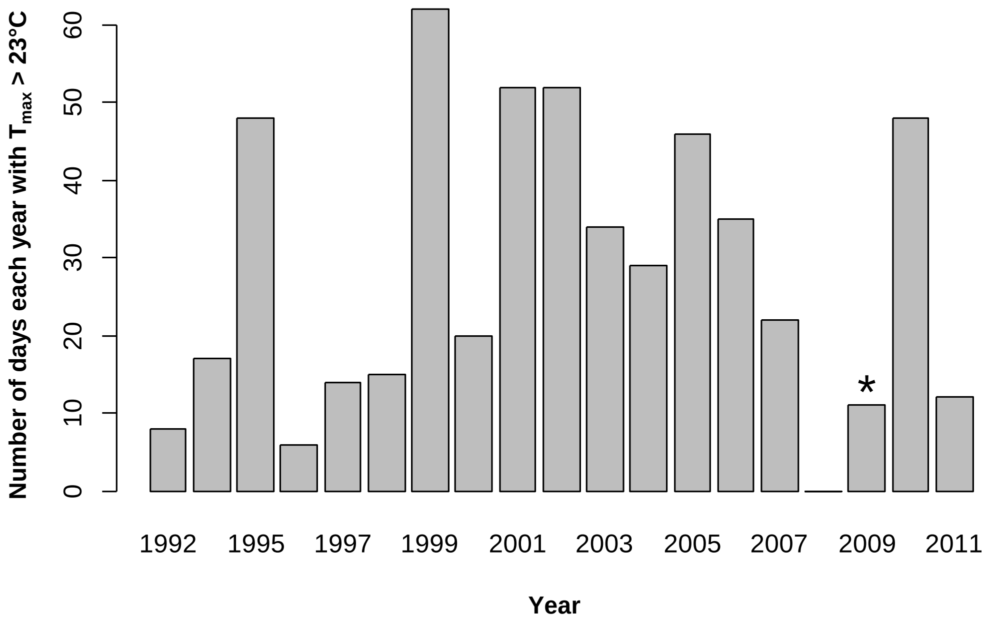


Figure 6a. Number of days each year where the daily maximum water temperature (T_{max}) exceeded 23ºC in the Little Southwest Miramichi River (1992-2011) (= incomplete year).*

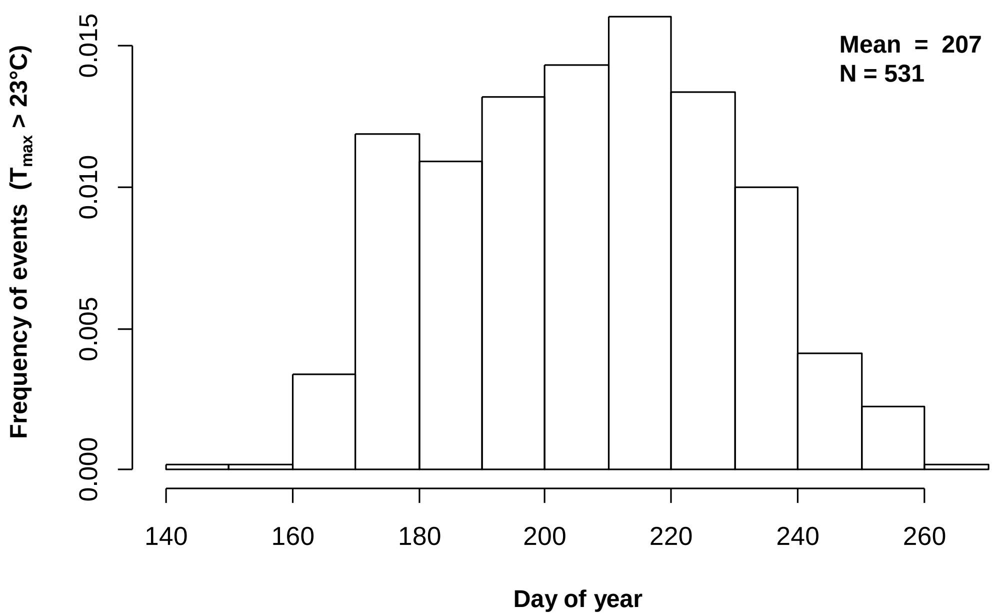


Figure 6b. Number of days each year where the daily maximum water temperature (T_{max}) exceeded 23ºC in the Little Southwest Miramichi River (1992-2011) (= incomplete year).*

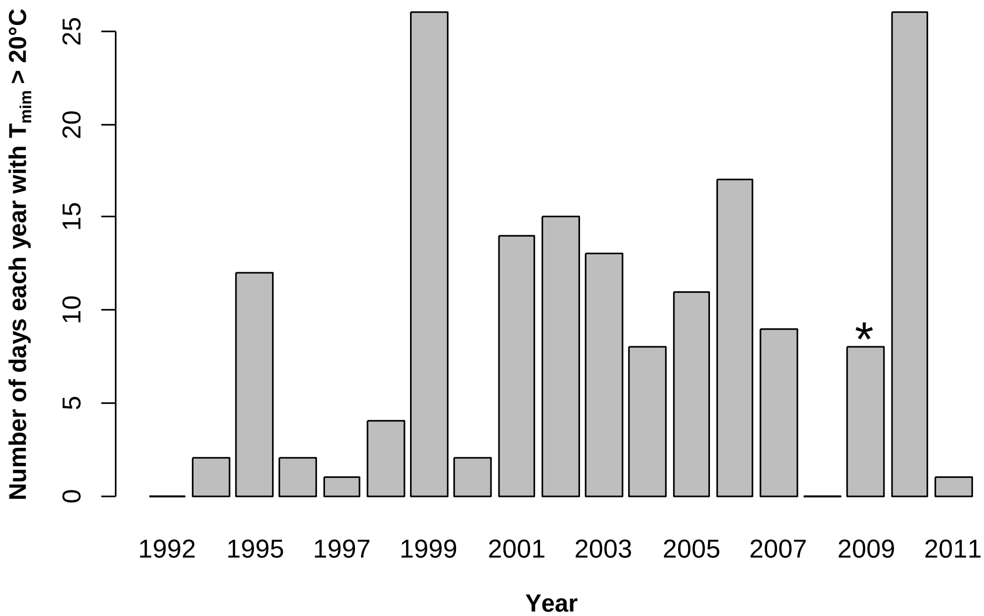


Figure 7a. Number of days each year where the daily minimum water temperature (T_{min}) exceeded 20ºC or the Little Southwest Miramichi River (1992-2011) (= incomplete year).*

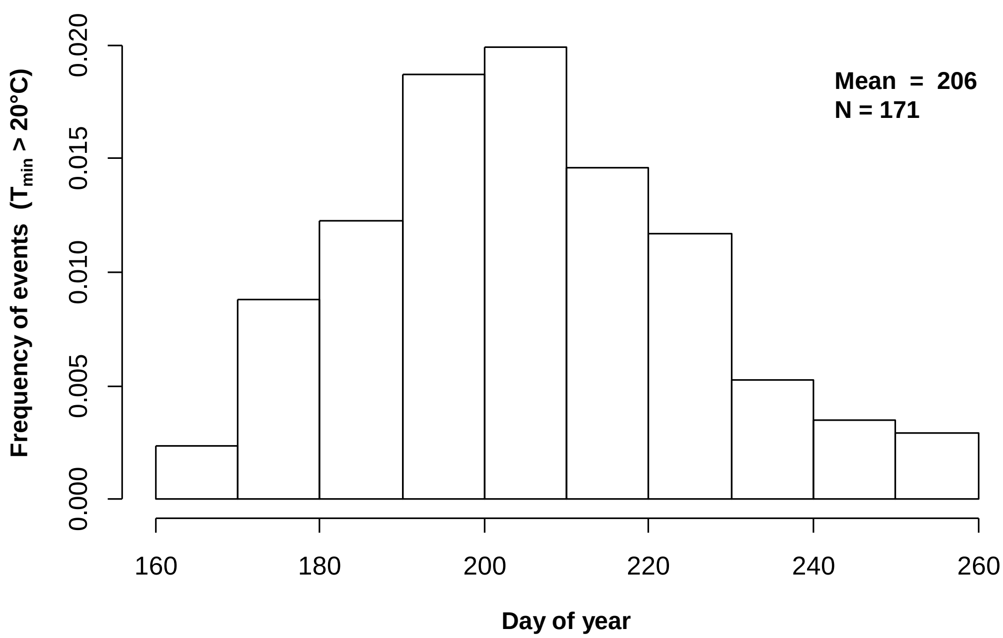
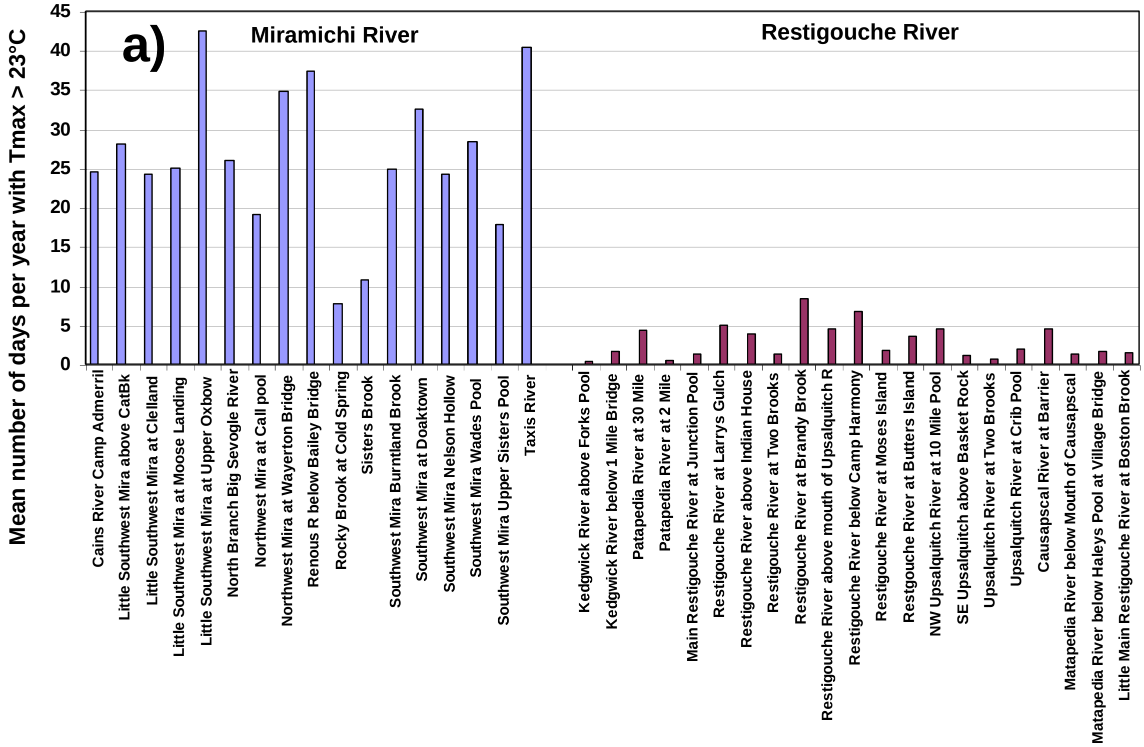


Figure 7b. Frequency of events (T_{min} > 20ºC) as a function of day of year for the Little Southwest Miramichi River (1992-2011).



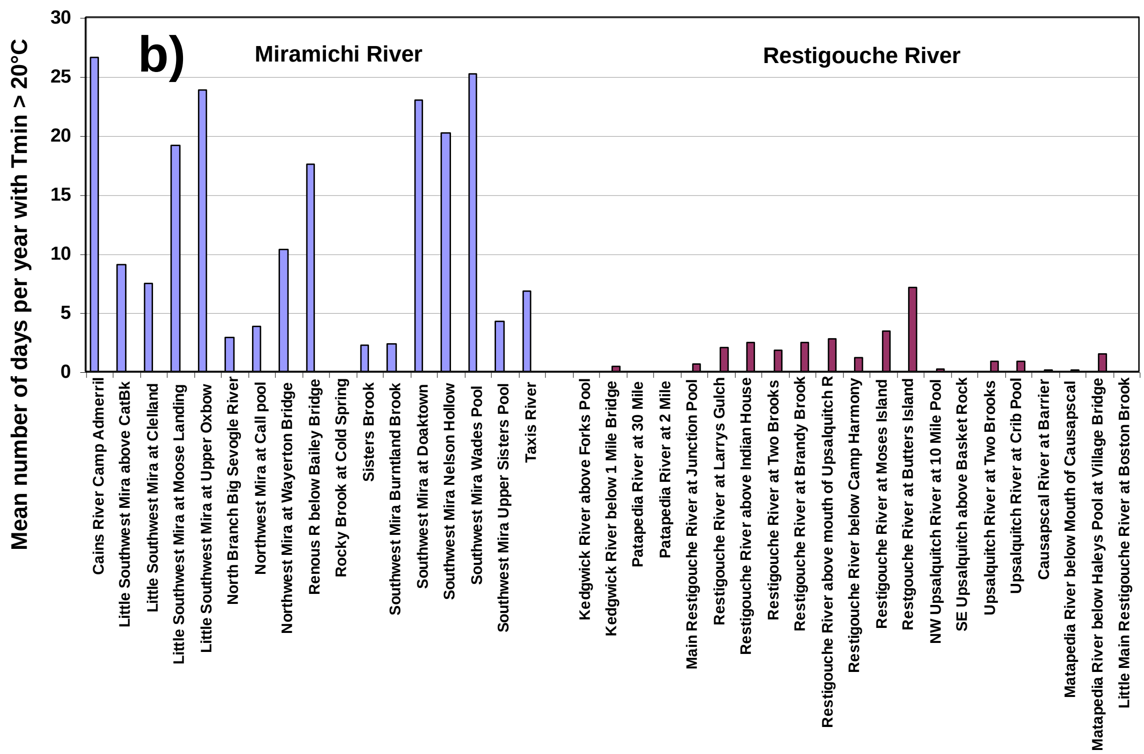


Figure 8. Mean number of days per year by site within the Miramichi and Restigouche rivers with a) T_{max} > 23ºC and b) T_{min} > 20ºC.

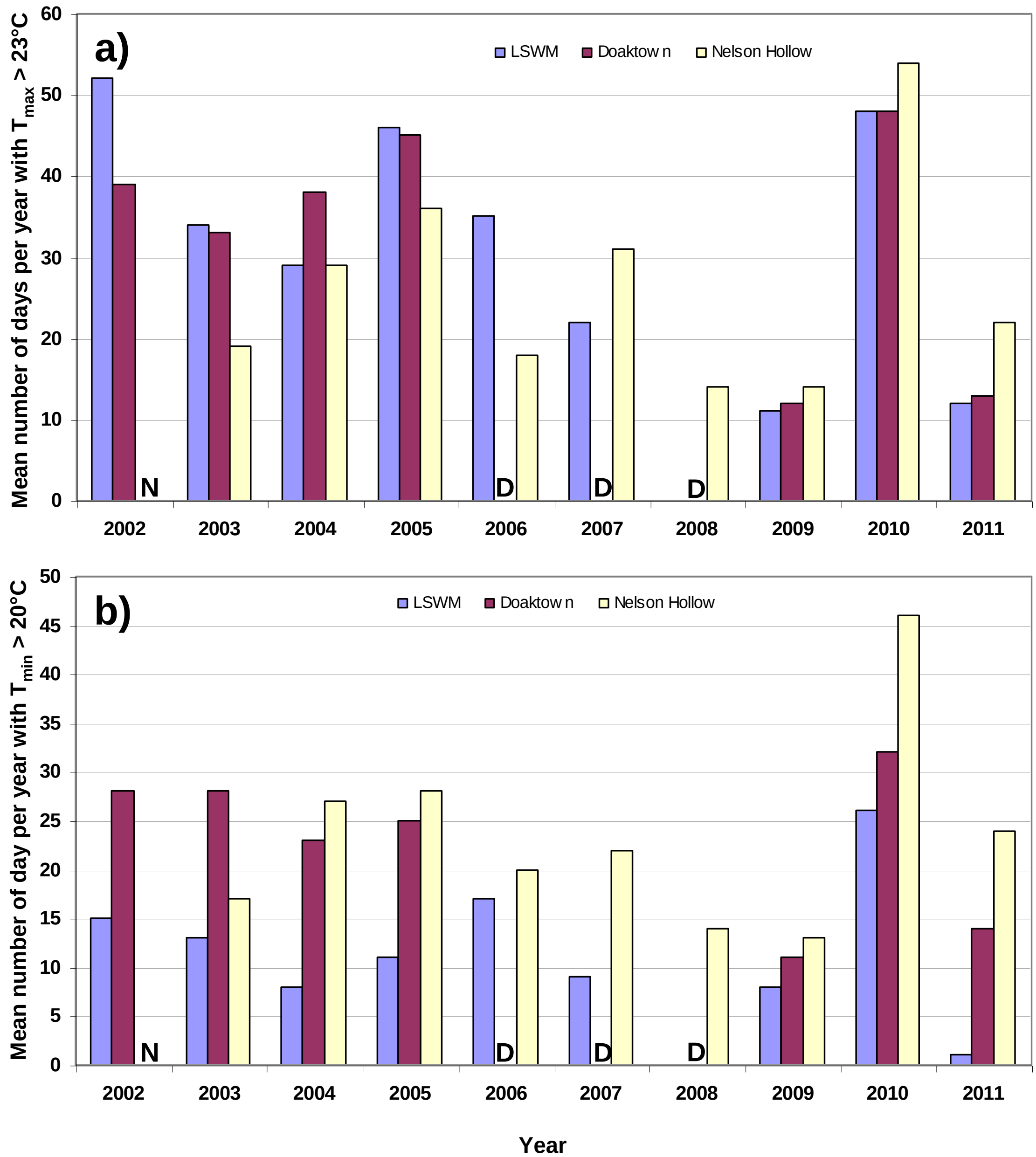


Figure 9. Mean number of days per year for selected sites within the Miramichi River (2002-2011) with a) T_{max} > 23ºC and b) T_{min} > 20ºC. N indicates missing data at the Nelson Hollow site and D missing data at the Doaktown site.

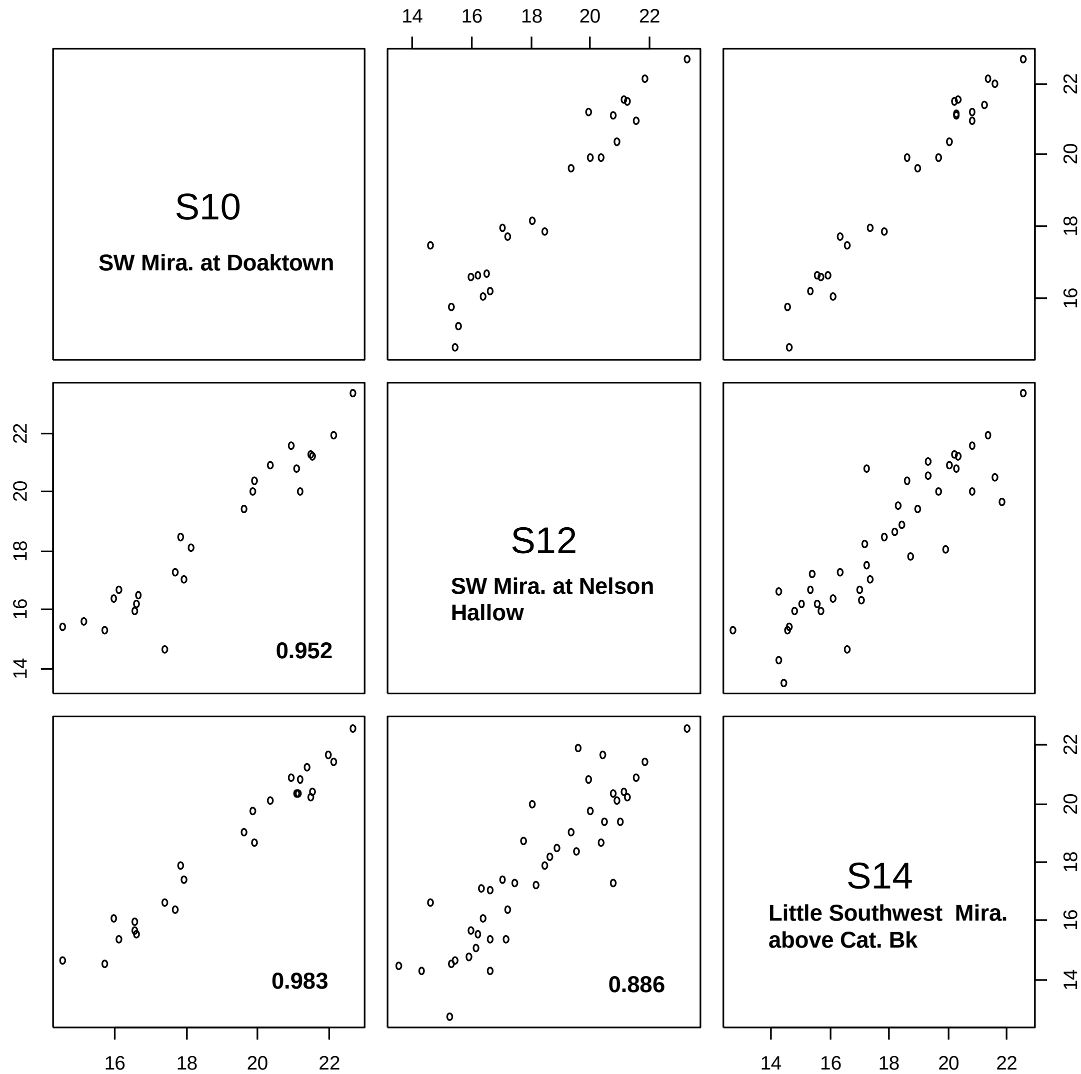


Figure 10. Scatterplots and correlation coefficients between monthly mean summer water temperatures (June to September) for the Southwest Miramichi at Doaktown (S10), Southwest Miramichi at Nelson Hollow (S12) and Little Southwest Miramichi above Catamaran Brook (S14). Data from 1997 to 2011.

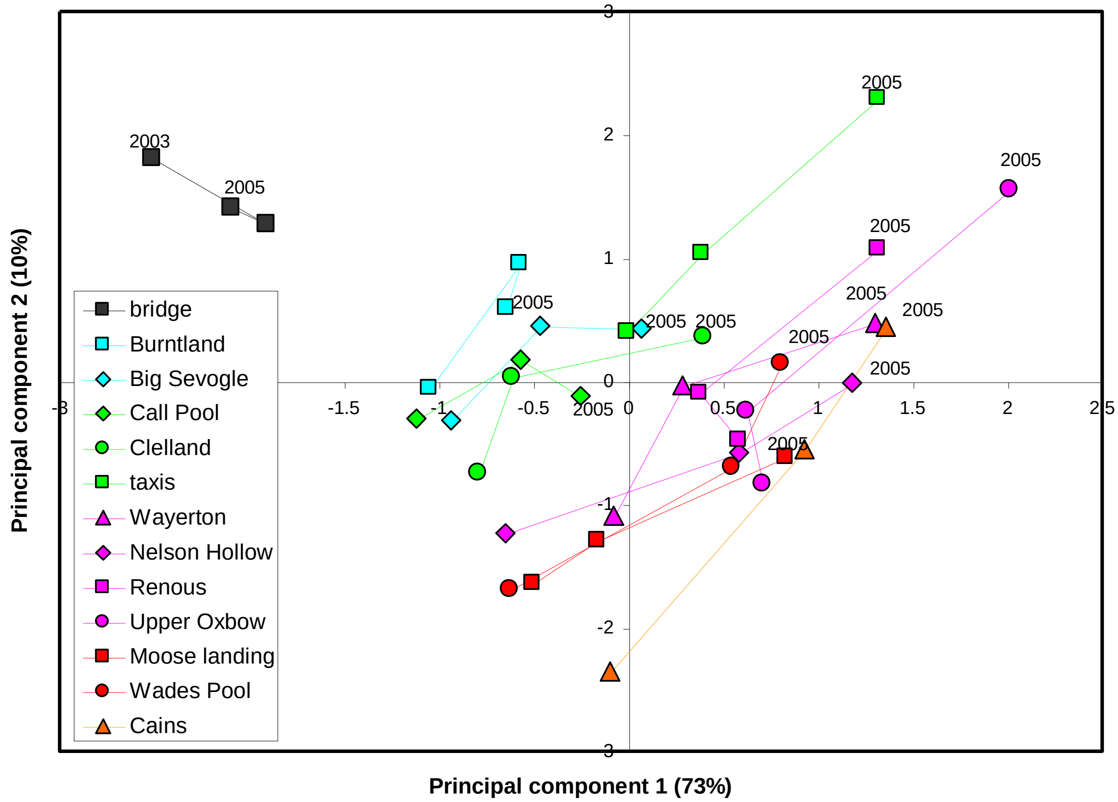


Figure 11. Locations of the 13 sites from the Miramichi River on the first and second principal components for water temperature characteristics. Data used were from the month of July only.

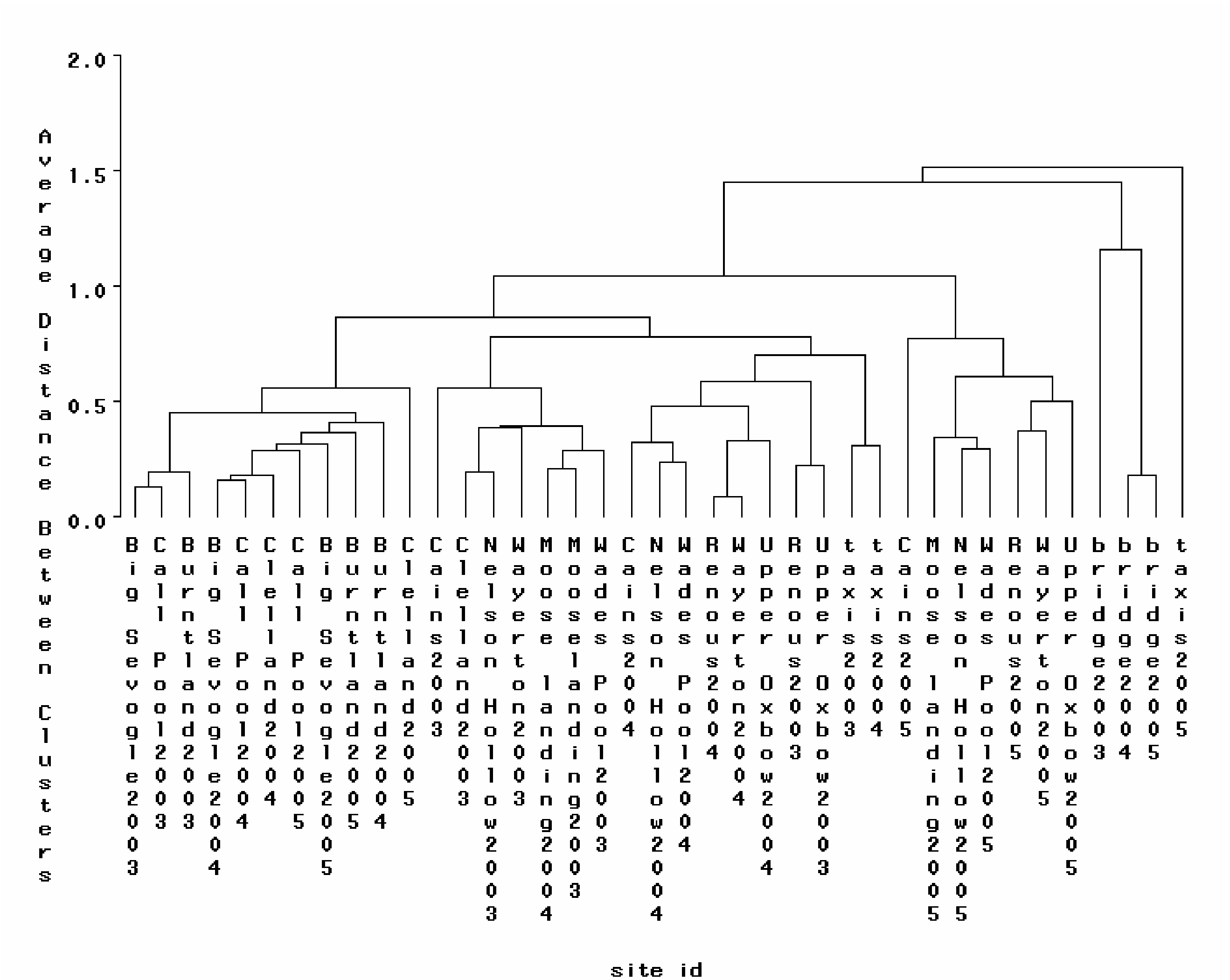


Figure 12. Tree diagram of the clustering for 13 sites in the Miramichi River based on water temperature characteristics.

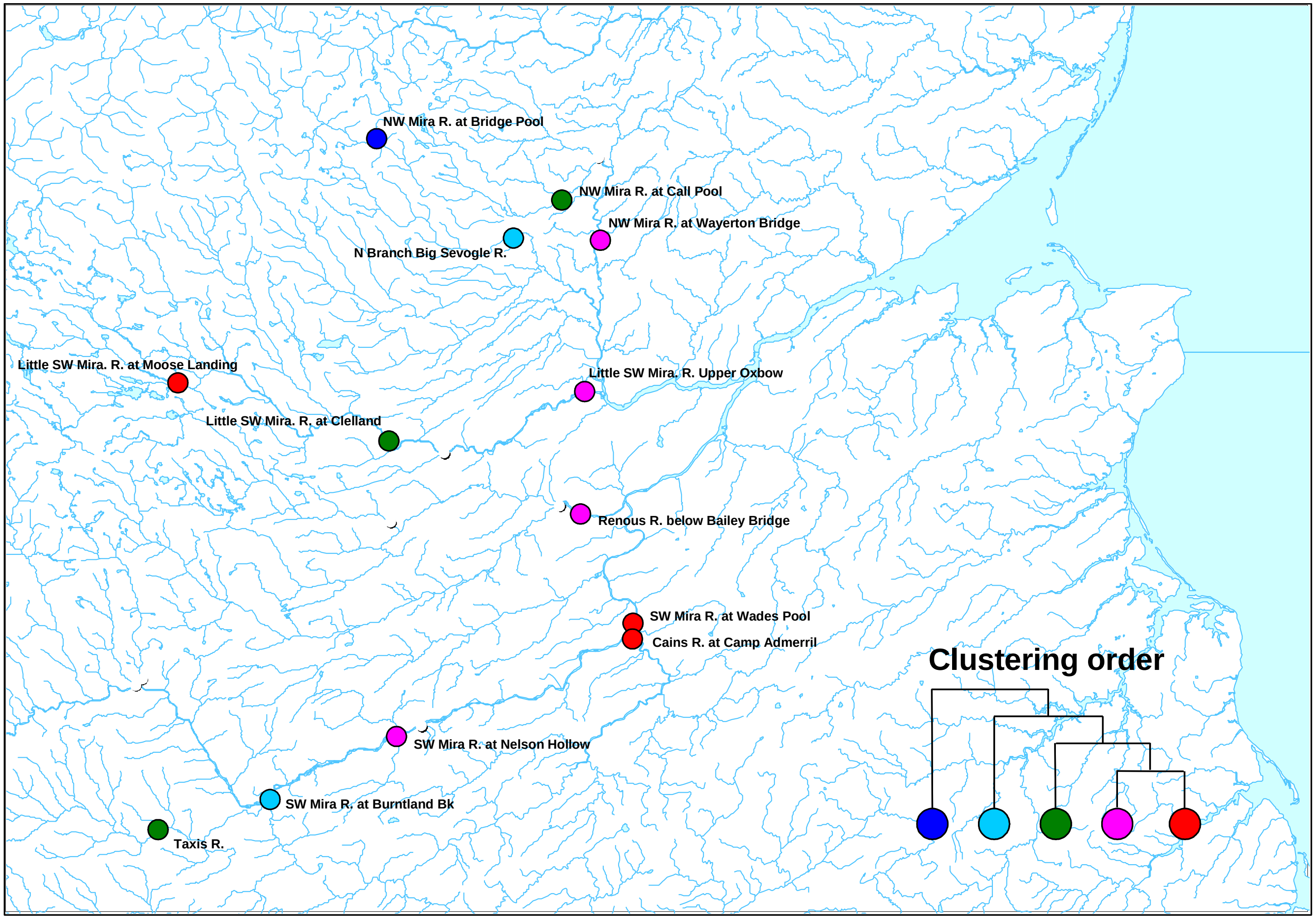


Figure 13. Geographical distribution of site clusters based on water temperature characteristics.

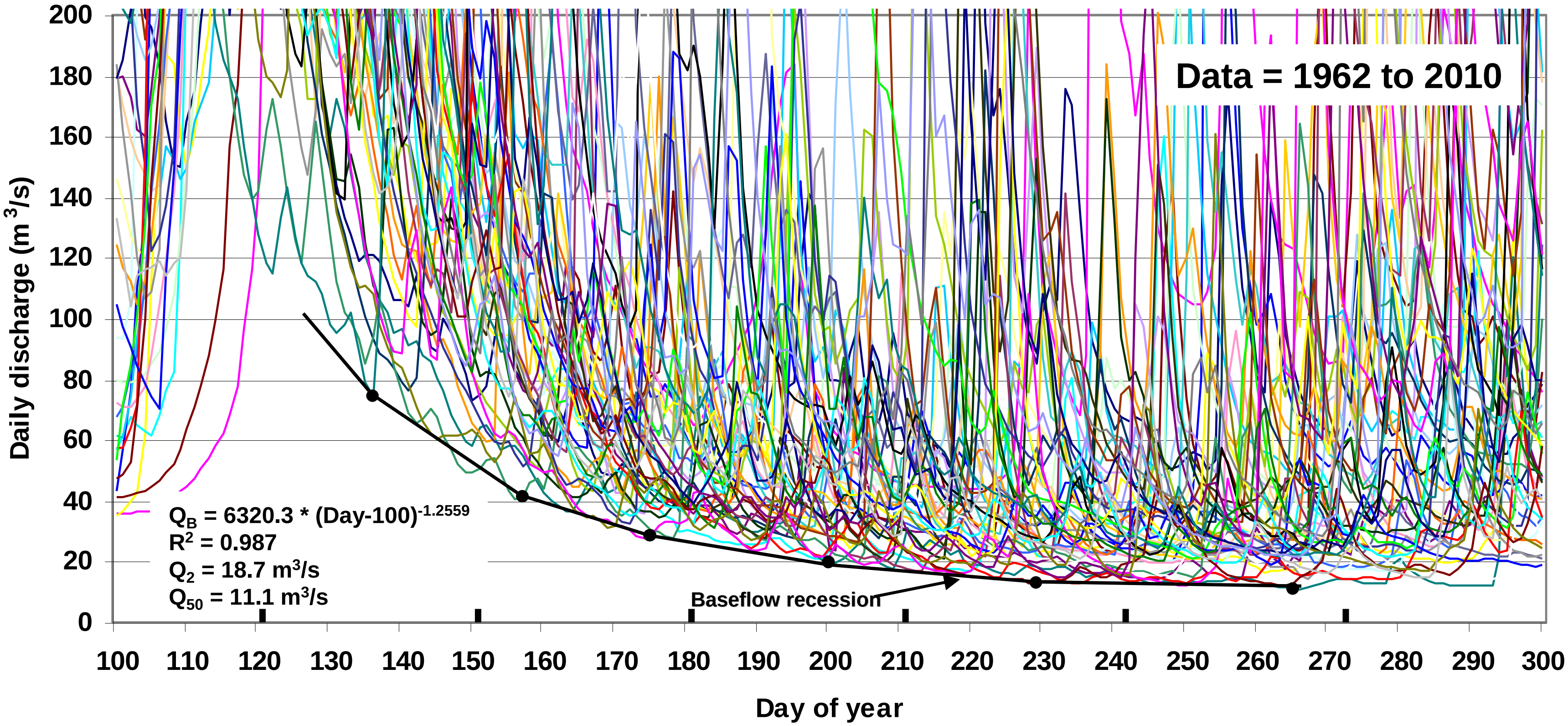


Figure 14a. River discharge for the Southwest Miramichi River (1962-2010) and associated baseflow recession curve showing summer low flows.

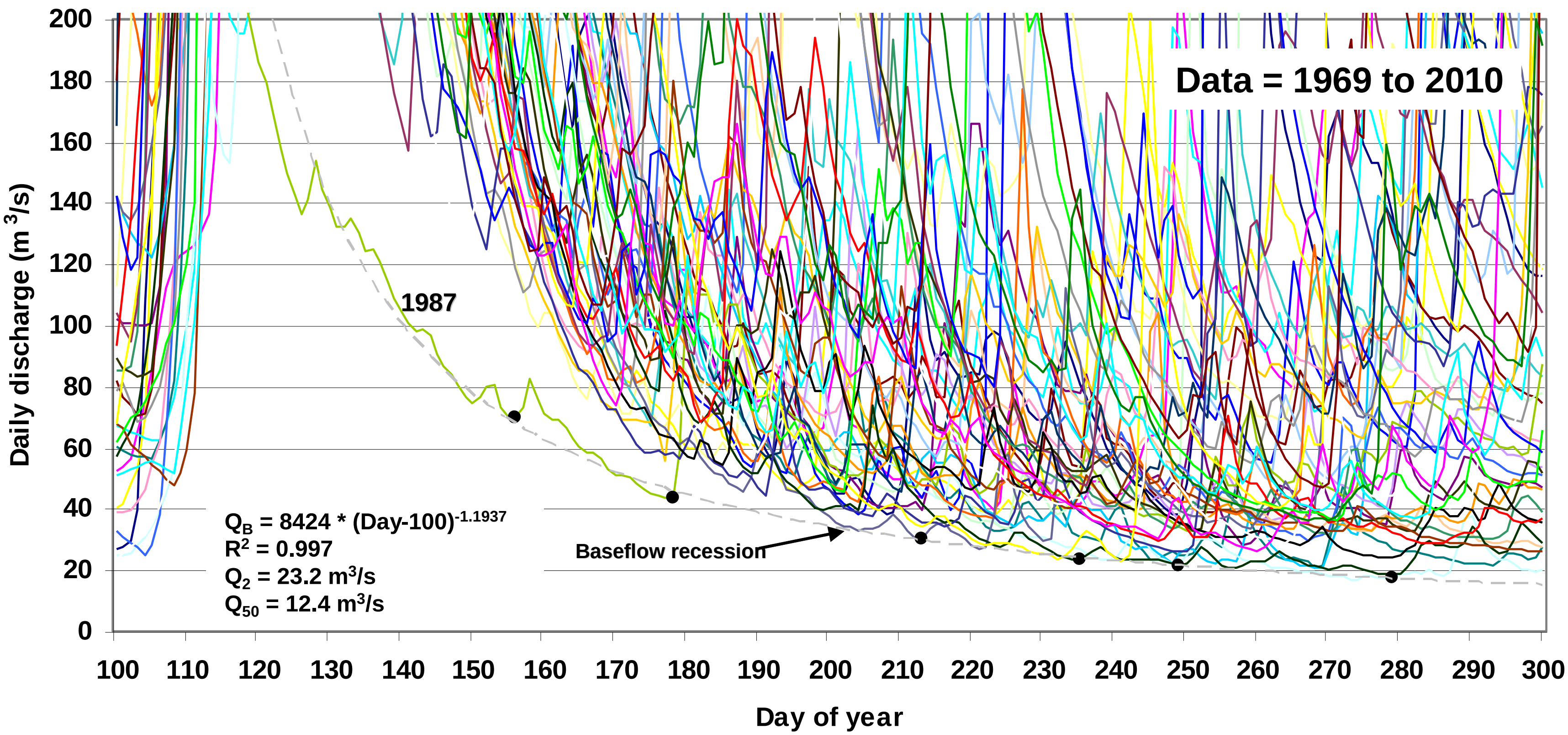


Figure 14b. River discharge for the Restigouche River (1969-2010) and associated baseflow recession curve showing summer low flows.