# A Review and Analysis of the Hydrology of the St. Mary's River, Guysborough County, Nova Scotia.

Sean C. Mitchell, M.Sc., PhD
SMRA Executive Director

March 31, 2009

St. Mary's River Association Technical Report #001

ACKNOWLEDGEMENTS

I would like to thank Dr. Jamie Gibson of Maritimes Region of DFO for the opportunity to compile and analyze all of this information under contract to DFO. This work is in line with the SMRA "*Healthy River, Vibrant Communities*" initiative but the DFO funding allowed us to explore and fully analyze these data and information.

Ms. Megan Myers conducted a preliminary review of the hydrological data upon which this work is built and I thank her for her early work. Ms. Myers was funded through a generous grant from Sage Environmental Program.

# EXECUTIVE SUMMARY

The hydrology of the St. Mary's River has long been an issue of concern. In the 1950s work was done evaluating the feasibility of artificial freshets and constant discharge flow control to augment low summer flows. Experimental dams were built but did not show success for increasing salmon production. In the 1960s, more detailed studies were performed on methods to augment low flows and concluded that dams are not feasible for the St. Mary's River system. Flooding was also a concern in the 1960s but, again, it was found that flow control was not feasible given the small area of flood-prone land. During the 1970s river flow was evaluated as it relates to angling success, hydrological stability (i.e., "flashiness" of streams, and flooding. There was only a single hydrological study involving the St. Mary's in the 1980s; this was a low flow analysis of rivers throughout Nova Scotia. Low flow return periods were calculated for the St. Mary's at Stillwater and Newtown. In the early 1990s the SMRA proposed another river discharge study, which was modified and conducted by DFO. This work in 1991 again concluded that damming and flow augmentation was not feasible in this system. This report also appears to be the first source of a rumour that Governor Lake historically fed into the St. Mary's River; a rumour which was to be promulgated until disproved by the SMRA in 2008. The review of existing information shows clearly there are long-term concerns with flooding and low flow conditions in the St. Mary's River. It equally demonstrates that dams and flow control are not options to be considered and interested parties must move beyond these concepts.

The St. Mary's River drains a large area and is comprised of four large drainage "branches" – the West, East, North and Main branches. Over geological time the course and channels of the St. Mary's have changed significantly, from north flowing to south, and creating new channels. The climate of the area is cool with regular rainfall throughout the year. The greatest (most hydrologically significant) rainfall events are listed from 1873 to present.

This review of hydrology is based primarily on data from the Water Survey of Canada (WSC) hydrometric stations in two areas of the St. Mary's River – at Stillwater (Main Branch) and Newtown (East Branch). A third hydrometric station (Archibald's Brook at Stillwater) is included for completeness.

Long-term mean annual flow of the St. Mary's River is 45.6 $m^3/s$ with peakflows in spring and fall, moderate lows in winter, and lowest water in summer. Flood events bias the mean estimate of flow high relative to the median. Within year variability of flow is quite high (averaging a CV of 123% of daily flow about the mean). There is indication of four "variation regimes" and these coincide approximately with oceanic regime shifts. There is no indication of linear change over time in mean annual flow or variation in flow, nor significant correlations with the North Atlantic Oscillation Index.

Mean annual flow of the East Branch is 9.95 $m^3/s$ and Archibald's Brook (at Stillwater) 1.75 $m^3/s$. Variation for these two data series was similar to that of Stillwater. The year1971 is notable by very high variance in flows, likely due to a February rain-on-snow event and the arrival of Hurricane Beth in August. The East Branch, as measured at Newtown, contributes

approximately 22% of the total flow measured at Stillwater, with this proportion being most variable under low flow conditions and least variable at moderate and high flow conditions.

Bankfull flow is estimated at 443m$^3$/s for Stillwater and 93 m$^3$/s for the East Branch at Newtown. Ninety percent of floods are of magnitude less than 583m$^3$/s. Estimated flood return intervals are 371 (1-in-2 yr), 514 (1-in-5 yr), 569 (1-in-10 yr), 690 (1-in-25 yr), 825 (1-in-50 yr), and 970 m$^3$/s (1-in-100 yr). The most extreme floods have occurred primarily in winter and early spring, which may have profound consequences for incubating salmonid eggs and alevins. On average 0.55 days in a year have flows greater than bankfull. Low flows in the St. Mary's River occur primarily in August and September. Median 1-d low flow is 1.7 m$^3$/s and estimated 1-d low flow return intervals are 1.7 (1-in-2 yr), 0.71 (1-in-5 yr), 0.51 (1-in-10 yr). 0.40 (1-in-20 yr), 0.22 (1-in-50 yr), and 0.15 m$^3$/s (1-in-100 yr). . In most years there are few days less than 1.0 m$^3$/s (mean 4.17 days per year less than this flow).

Climate change is expected to result in lower summer flows and possibly increased (though not necessarily larger) winter floods. These will likely affect the local fish population. Three actions for future work are: (1) a survey to evaluate the inference of Brimley (1986) that the upper reaches are recharge and lower reaches discharge areas, and (2) river gauging of each branch to understand branch-specific hydrology and the hydrological behaviour of the entire system, and (3) assessing the effects of climate change on the fish populations of the St. Mary's River.

## TABLE OF CONTENTS



## LIST OF TABLES

## LIST OF FIGURES

# INTRODUCTION

The St. Mary's River Association (SMRA) has long been interested in the hydrology of the St. Mary's River, and under the SMRA "*Healthy River, Vibrant Communities*" program a comprehensive review of hydrological information was to be conducted. The Department of Fisheries and Oceans also saw benefit to such an analysis and so the following work was conducted under contract to DFO.

This report includes (*i*) a review of historical studies, (*ii*) analysis of hydrology of the St. Mary's River, (*iii*) anticipated climate change, (*iv*) future work, and (*v*) conclusions.

This is the first in a series of Technical Reports to be produced by the St. Mary's River Association.

# 1.0 REVIEW OF HISTORICAL STUDIES

This review includes 14 documents contributing original data or information about the hydrology of the St. Mary's River. An additional three reports were not reviewed here as they could not be accessed. These are: NSDAM (1968), NSDE (1978), and Rudge (1950)

The hydrology of the St. Mary's River has long been identified as an issue for salmon ecology and fisheries. Low flows were identified to be problematic as long ago as 1950. In that year the St. Mary's Branch of the Nova Scotia Fish and Game Association petitioned the government that control dams be built on the river to regulate water flows in times of drought (Dunfield, undated). A survey was conducted in August, 951, the purpose being to assess problems associated with creating artificial freshets to improve angling in the St. Mary's River (Anonymous, 1951). Based on work done with artificial freshets in the LaHave River, a similar approach was evaluated for the St. Mary's. It was concluded that there was insufficient information available to recommend this as an approach to augment low summer water flows to improve angling. Rather, flow control for constant discharge during the summer dry months was seen as more feasible. it was emphasized that storage should be in headwater lakes and that main river dams would have little storage capacity and would be without benefit. One proposed dam site was at the outlet of Two Mile (Lochiel) Lake. The author of this letter-report also suggested a one year trial with flow control to evaluate the efficacy of it.

There is no formal documentation on the construction of experimental structures, but notes (Dunfield, undated) on file at the SMRA state that three dams were built in 1954 at the outlets of McKeen, Lewis and Cameron's lakes on the McKeen Brook system of the East Branch. After two years of trials the contribution of these dams to salmon nursery stock was deemed to be zero, and it was recommended that greater water control should be undertaken (Dunfield, undated). This is in contrast to the recommendation by Anonymous (1951) of a one year pilot project; if not successful the endeavour should be abandoned. In 1961 the Nova Scotia Fish and Game Association again suggested flow control for improvement of fish habitat and fisheries of the St. Mary's River. There is no documentation to show if action was taken on this.

A 1965 social survey (MacDonald and Clare, 1965) reported on the number of landowners indicating (i) flooding of their land, (ii) sediment depositing on their land, (iii) that flooding delayed planting or harvesting, (iv) damage to dwellings, (v) estimated damage due to a 1964 flood, and (vi) that flood control measures would alleviate flooding conditions. A relevant finding from their work, with respect to that reported here, was that they found most flooding reports are accounted for by the communities of Sherbrooke, Stillwater, Glenelg, Caledonia, Aspen, East River and Eden Lake, with the last three representing approximately 50% of flooded acreage involved.

Given the concerns with low flow conditions expressed in the 1950s, a preliminary engineering survey was conducted in 1967 to evaluate the feasibility of flow control on the St. Mary's to improve angling conditions (Jefferson, 1968). That author reported a minimum required discharge of 2.8 $m^3$/s at Stillwater for the protection of juvenile salmon, which Jefferson defined as a minimum 15 cm of water depth in critical juvenile areas. To provide this flow for a 40 day low-flow period would require a water storage volume of 9.9 million $m^3$. To support upstream migration of adult salmon at a discharge of 8.4 $m^3$/s for two months would require storage of around 40 million $m^3$. Jefferson notes that there is very little storage potential, with the principal storage being interflow, baseflow and channel storage. This lack of appropriate storage area for these large volumes of water require reservoirs for storage and these would likely negatively impact on existing salmon rearing habitat. Further, from this study the estimated cost (1968 dollars) was $200,000 for the 9.9 million $m^3$ reservoir. Jefferson concludes that any proposals to dam the river in order to create reservoirs should be discouraged. The author also made several other relevant observations. He maintained that the West Branch contributes 60% of the flow recorded in the Main Branch (though since the West Branch is ungauged, and the East Branch only provided two years of data at the time of this survey, I conclude that he likely simply pro-rated Main Branch drainage by physiographic drainage area to derive this estimate; also see Jansen (1991) below). He also noted that rainfall caused hydrologic peaks in the West Branch which did not appear in the recordings of the East Branch. That is, storms and rain events may have branch-specific effects. This observation may be due to the buffering ability of Eden Lake moderating flows measured at Newtown on the East Branch. Finally, Jefferson suggested a minimum flow of 1.7 $m^3$/s in the West Branch (2.8 $m^3$/s in the Main Branch) to provide sufficient depth in critical areas for the protection of rearing salmon.

Following up on flooding concerns reported by MacDonald and Clare (1965), the Rural Development Branch of the Department of Forestry and Rural Development conducted a study (Anonymous, 1968) to assess flooding and determine methods of alleviating the flooding of agricultural lands during the crop growing season in the St. Mary's River area. They reported that of 137,790 ha of land in the watershed, only 6,958 of these hectares are Class 2 or 3 agricultural land[1], and only 1,813 ha (1.3% of the total land) are flood prone. They estimated providing flood control (headwater control dam and extensive channel improvements) would cost about 1.5 million dollars ($848/ha of flood-prone land) and concluded the expense was not worth the relatively small area of land affected.

Anonymous (1971) reported on another river discharge study, this time evaluating the relationship between stream discharge and salmon angling success in both the Medway and the St. Mary's rivers. The purpose was to determine the potential value of flow control on these two rivers and which one would benefit more from this type of intervention. The authors correlated salmon angling catch with (*i*) rainfall and (*ii*) river discharge, and found the relationships significant with strong correlation coefficients ($r=0.87$ for catch vs rainfall and 0.81-0.94 for catch vs discharge in July and August). That is, angling success is correlated with discharge conditions. They also examined the frequency of low flow[2] (what they termed "drought days"; arbitrarily set at a discharge of 2.8 $m^3/s$ (100 cfs)) and found for the period between 1947 and 1968 that there were between 0 and 51 (mean = 18.8, SD=17.3; n=22) days in the two month period July and August with flows less than this. Years of note from their data (i.e., where number of days <2.8 $m^3/s$ was greater than 31, or >50% of days) were 1957 (51 d), 1960 (47 d), 1950 (45 d), 1955 (38 d), 1966 (36 d), 1947 (34 d), and 1968 (34 d). The authors of this work concluded, that the control of flow in the St. Mary's River to benefit angling would be costly and the benefits uncertain at best, and that the Medway River would be a better selection for flow control to benefit salmon angling.

In 1972 and 1973 MacPhail and Alpert (1975) conducted a survey of various streams in the St. Mary's River watershed looking for suitable sites for streamside egg incubation boxes as part of a salmon enhancement project. They measured discharge (0-22 measurements per site; Figure 1) on 12 streams between June 27 and October 25 (1972) and five streams between June 21 and November 11 (1973). They reported that Indian Man Brook, Cross Brook and South Lake Brook appear to be the most hydrologicaly stable streams, while Archibald's Brook (Glenelg)[3] and

---

[1] Class 2 agricultural land: "*Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices*" Class 3 agricultural lands: "*Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices*" (p5, Anonymous, 1972)

[2] It is shown in the analysis of this report, using a much longer data set, that this definition of low flow does not represent extreme low flows but more of an average, or better-than-average condition.

[3] MacPhail and Alpert (1975) call this brook Archibald's Mill Brook and also Hattie Brook; from their maps it is what we now call Archibald's Brook, near Glenelg.

MacDonald's Brook[4] are "flashy" due to having large influx from surface water. Three streams were also identified as having exceptionally low minimum flows (<0.4 $m^3/s$) – Archibald's Brook (Glenelg), Chisholm Brook[5], and Gorman's Brook.

Three years after MacPhail and Alpert (1975) the concerns around flooding once again became prominent. On January 8, 1978 the St. Mary's suffered a large flood (8th largest on record; see *Flood Flows* below). Following this flood a local committee was struck under the Emergency Measures Organization for St. Mary's Municipality to undertake a study of the problems caused by flooding of the river and the effects on local communities (Anonymous, 1978). This committee identified problem areas within the channel which cause ice jams and force the water to flood the banks. They made recommendations on dealing with these problems, including removal of islands and dredging the channel to deepen it. Also they suggested raising the highway road bed in low areas where flooding regularly inundates the highway. This letter-report was passed on to the Water Planning and Management Branch of Inland Waters Directorate. This government agency then developed a report (IWD, 1979) in which they highlight that a primary cause of flooding is ice jamming combined with the spring thaw, and that flooding also occurs in the summer months due to high runoff. IWD (1979) also lists months and years of the most significant floods in this river (August 1873, January 1956; April 1959 & 1964; February and August, 1971). Four factors are suggested by these two reports that contribute to the flooding:

1. A buildup of silt and gravel on the river bottom causing an ice jam which causes the river to overflow the banks (Glenelg)
2. Islands in the river providing locations for ice to jam (Waternish)
3. Bend in the river resulting in ice-jamming (below Stillwater, near Sherbrooke hospital)
4. Stopper Rock at river mouth causing ice-jamming.

This report did not, however, account for the causes of flooding on the East River and Eden Lake which MacDonald and Clare (1965) had earlier indicated form much of the flooding concern.

---

[4] MacPhail and Alpert (1975) call this brook Duncan MacDonald Brook; from their maps it is what we now call MacDonald Brook, near Indian Man Brook.

[5] MacPhail and Alpert (1975) call this brook Rock Pool Brook; from their maps it is what we now call Chisholm Brook, draining Chisholm Lake from the south on the West Branch.

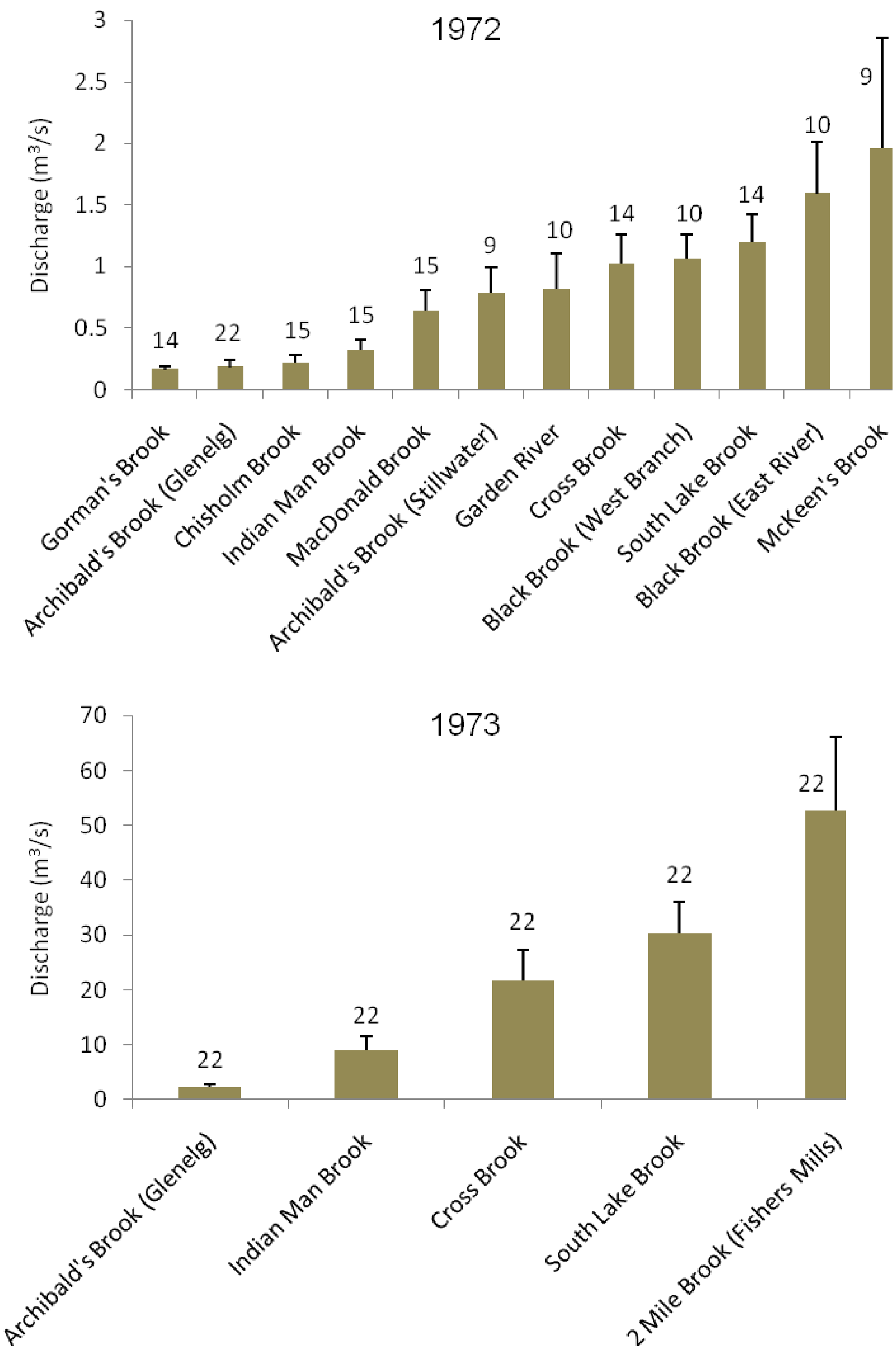



Figure 1: Discharge for brooks measured in 1972 and 1973. Error bars are Standard Error to provide sense of variability. Values above columns indicate number of measurements. Data summarized from MacPhail and Alpert (1975).

Brimley (1986) estimated low flows within the St. Mary's River as part of a Province-wide river low flow analysis. His low flow return periods are presented in Table 1. It may be seen that the arbitrary low flow of 2.8 $m^3/s$ selected by Anonymous (1971) described previously is in reality a 1-in-2 year return interval of 15-d to 30-d low flow period. Thus, it is not a particularly low flow for this river. This 2.8 $m^3/s$ value traces back to Jefferson (1968) who maintained that this was minimal flow to ensure water depth for protection of juvenile salmonids.

Table 1: Low flow discharge ($m^3/s$) return intervals for two areas within the St. Mary's River. Data from Brimley (1986). Estimates for the Stillwater station are based on 69 years of data (1916-1984) and the Newtown station on 13 years (1966-1978).

| Return interval | 1-d | 3-d | 7-d | 15-d | 30-d | 60-d | 120-d |
|---|---|---|---|---|---|---|---|
| **St. Mary's River at Stillwater** | | | | | | | |
| 1-in-2 yr | 1.69 | 1.78 | 2.14 | 2.65 | 3.61 | 6.27 | 11.18 |
| 1-in-5 yr | 0.69 | 0.74 | 0.90 | 1.13 | 1.43 | 2.68 | 5.77 |
| 1-in-10 yr | 0.41 | 0.46 | 0.55 | 0.70 | 0.86 | 1.69 | 4.24 |
| 1-in-20 yr | 0.28 | 0.32 | 0.38 | 0.48 | 0.59 | 1.20 | 3.47 |
| 1-in-50 yr | 0.20 | 0.24 | 0.27 | 0.35 | 0.43 | 0.90 | 3.00 |
| 1-in-100 yr | 0.17 | 0.21 | 0.23 | 0.30 | 0.37 | 0.79 | 2.82 |
| **East River St. Mary's at Newtown** | | | | | | | |
| 1-in-2 yr | 0.21 | 0.22 | 0.26 | 0.36 | 0.54 | 1.10 | 2.83 |
| 1-in-5 yr | 0.062 | 0.069 | 0.081 | 0.11 | 0.14 | 0.29 | 1.30 |
| 1-in-10 yr | 0.035 | 0.040 | 0.047 | 0.054 | 0.073 | 0.13 | 0.89 |
| 1-in-20 yr | 0.025 | 0.029 | 0.034 | 0.032 | 0.049 | 0.066 | 0.70 |
| 1-in-50 yr | 0.020 | 0.024 | 0.028 | 0.020 | 0.039 | 0.036 | 0.58 |
| 1-in-100 yr | 0.019 | 0.023 | 0.026 | 0.017 | 0.037 | 0.027 | 0.54 |

Brimley also suggested that in the St. Mary's (as well as the Cheticamp and Mersey rivers) the upper basins are likely recharge areas and the lower basins discharge areas for groundwater baseflow. There has not been any follow up work to evaluate the accuracy of this suggestion. One would expect a survey of distribution of springs and groundwater inputs would test this inference as it would be expected these should be absent or scarce in the upper basin and prevalent in the lower. This could be addressed by a survey of springs and groundwater influence (see *Future Work*)

In 1990 the St. Mary's River Association (SMRA) presented a draft Terms of Reference to DFO for a proposed water flow study. The SMRA wished to evaluate average summer low water volumes, identify alternatives to increase existing average summer volumes, and list potential water systems that could be utilized to increase this flow (SMRA 1989). The primary objective was to identify ways to increase average low water flow and identify stream systems that could have flood control structures installed on them to accomplish this. The perception of a necessity to increase summer low flows by water control was still alive, despite previous studies having demonstrated it to not be feasible on the St. Mary's.

This proposed SMRA study was approved as an office study of existing material and reported by Jansen (1991). This was a modelling study of the hydrologic feasibility of either (*i*) placing dams on 11 lakes in the watershed (Lochiel, Lochaber, Glenelg, Archibald Mill, Eden, Black Brook, East Loon, West Loon, South Loon, Kelly and McLeod lakes), to act as reservoirs and release flows through summer to increase low flows, or (*ii*) placing dams on only the five largest lakes (Eden, Archibald's Mill, South, Lochiel and Lochaber lakes) for the same purpose. It was concluded that damming the five lakes would not be sufficient to provide significant change in the flow parameters in the lower reaches of the river during extended low flow periods. Construction and operation of 11 dams in the watershed would be a very large project and logistically difficult. Jansen comments that one of the most striking results is that a meter of live storage from South Lake does not provide significant increase in flow parameters in the West River. It would be necessary to construct larger dams to impound greater live storage. He also comments that though Lochaber/Lochiel may at first appeal for damming (going back to Anonymous, 1951), there is actually relatively little salmon habitat downstream of these lakes compared with elsewhere in the watershed and the cottage development on the lakes would make flow control difficult here. Therefore, as with previous studies, it appears that creating reservoirs and controlling river flow is not a feasible solution to the problems of low flows in the St. Mary's River. Jansen assumes that the West Branch contributes 49% of the total flow, the East Branch 35% and the Main Branch 16% (compared with 60% for the West Branch by Jefferson, 1968). There is, however, no discharge data to allow discrimination of flow by branches beyond the East and Main, and so these estimates are based on assumptions of equal hydrological behaviour and response in the various branches. Monitoring of individual branches is required to fully understand hydrological behaviour among the various contributors (see *Future Work*).

There has been a persistent rumour that Governor Lake (near the headwaters of the West Branch) originally flowed into the St. Mary's River but was diverted into East River, Sheet Harbour by Nova Scotia Power. This appears to have first been speculated by Jansen (1991). If this were true than in the past the West Branch may have been fed from a large lake system which would have buffered the extremes of flow, and this source would be a potential for returning to the St. Mary's drainage. This interpretation, however, is based only on a review of maps – not a field survey. In 2006, Murray Anderson of the SMRA Board of Directors submitted a letter-report to the SMRA suggesting, based on historical land surveys, that Governor Lake had not drained into the St. Mary's River in the past and making the very sensible suggestion that a field survey looking for an old channel draining from the lake to the West Branch of the St. Mary's River should be conducted. In 2008 such a survey was conducted and no evidence found that Governor Lake ever did flow into the St. Mary's drainage (report provided in Appendix 1). The rumoured connection between the two watersheds appears to have been initiated by inaccurate map interpretation and promulgated by wishful thinking.

From this review of historical information it is clear that both extreme low flows and flooding have been of concern in the St. Mary's River. These concerns have been sufficient to consider large-scale damming for flow control to prevent flooding and to augment summer low flows in the river. Construction of such dams is not feasible in this system. Further, an alternative to divert water from Governor Lake to the West Branch to augment low flows is not practical. The remainder of this report is an analysis of historical hydrology, it's likely impacts on salmon biology, and anticipated future conditions. Given that the intervention or water control possibilities are very limited it is worthwhile to try and understand the hydrology, its effects, and the future conditions to the greatest extent that we can.

## 2.0 ANALYSIS OF THE HYDROLOGY OF THE ST. MARY'S RIVER

### STUDY AREA

#### *Physiography*

The St. Mary's River drains an area of approximately 1,350 km$^2$ and is composed of four "branches" or major channels: the West Branch (56 km long; drainage area 470 km$^2$), East Branch (27 km long; drainage area 389 km$^2$), North Branch (27 km long; drainage area 82 km$^2$) and Main Branch (19 km long; draining entire watershed) (Hart-Buckland Nicks, 1995). These branches merge at two points. The East and North branches combine at 45$^o$18'23"N, 62$^o$03'49"W near Aspen and the East and West branches at 45$^o$15'20"N, 62$^o$03'48"W, a short distance downstream of Glenelg Lake. Downstream of this latter confluence the river is known as the Main Branch and subsequently flows into the Atlantic Ocean via Northwest Arm at approximately 45$^o$08'00"N, 61$^o$59'01"W. The upstream extent of salt water (i.e., head-of-tide) is approximately the Highway 7 bridge crossing in the town of Sherbrooke, though the location of head-of-tide will vary depending upon tidal conditions and river discharge. There are approximately 130 lakes within the watershed ranging in size from <5ha to 3 km$^2$ (Lochaber Lake). The largest lakes in the watershed are Lochaber, Lochiel, Eden and Archibald's Mills lakes, all on the East and North branches. The West Branch is notable by an absence of large lakes on the mainstem.

The St. Mary's River has not always flowed in the present channels. Roland (1982) describes the likely paleophysiography of the St. Mary's and the following is drawn from that source. It is suspected that prior to the Cretaceous or Tertiary the St. Mary's River flowed north, through the Lochaber-Lochiel Lake chain into what is now the Gulf of St. Lawrence. It is presumed to have reversed course in the Cretaceous or Tertiary as the landscape was changing and tilting in response to crustal movement and orogenies. From that time to present it has flowed south. Prior to the glaciations, the river is thought to have flowed through to Indian Harbour rather than in the present channel from Stillwater to Sherbrooke. There is an abrupt change in channel condition at Stillwater from the wide floodplain to a confined channel, which is consistent with this interpretation. The ancestral St. Mary's River, further, did not possess the length or tributaries it currently has. Over time the West Branch eroded toward the headwaters through the relatively soft (Horton Group) rock. In doing so it increased in length and also its drainage area by stream capture. The river is not likely to have shifted a great deal laterally as it flows within ancient faults (e.g., the West Branch, Moose River, Garden River, North Branch).

### *Climate*

The St. Mary's River watershed is large and encompasses four EcoDistricts within two EcoRegions of the Provincial Ecological Land Classification system[6]. Over such a large area the weather/climate may be expected to vary from place-to-place. The following description is drawn from only one location - the Environment Canada Stillwater weather station[7] - but other relevant stations[8] in the watershed include Trafalgar (operating 1919-1981), and East River St. Mary's (1975-1980). Two other stations, outside of the watershed but sufficiently close to be useful are Copper Lake (1953-1974) and Collegeville (1916-2006).

Based on 1971-2000 climate normals, the average annual temperature at Stillwater is 6.3°C, with the coldest month being January (mean -6.0°C) and warmest August (mean +18.4 °C; Figure 2). The coldest temperature recorded during the period of station operation was -39°C (February 7, 1985) and the warmest +35°C (June 24, 1976). Mean monthly rainfall is 112.1 mm and mean monthly snowfall (during winter) 14.3 cm. The months of greatest rainfall are May and September to November, and snowfall January and February. The greatest recorded rainfall in a

---

[6] The St. Mary's River watershed is composed of two Ecoregions (Eastern Ecoregion and Nova Scotia Uplands Ecoregion). Within the Eastern Ecoregion are the Eastern Interior Ecodistrict and the Governor Lake Ecodististict. Within the Nova Scotia Uplands Ecoregion are the St. Mary's River Ecodistrict and the Pictou Antigonish Highlands Ecodistrict[0].

[7] There are two Stillwater stations over the 90+ years. Stillwater (station ID 8205600; located at 45°10.8'N,62°00.00'W) was in operation 1915-1979. Stillwater Sherbrooke (station ID8205601; located at 45°8.4'N,61°58.8'W) was in operation 1967-2004.

[8] Trafalgar (station ID 8205900; located at 45°16.8'N,62°40.20'W; in operation 1919-1981); East River St. Mary's (station ID 8201690; located at 45°22.8'N,62°10.20'W; in operation 1975-1980); Copper Lake (station ID 8201100; located at 45°22.8'N,61°58.20'W; in operation 1953-1974); Collegeville (station ID 8201000; located at 45°28.8'N,62°01.20'W; in operation 1916-2006).

24 hour period was 142.6 mm (September 14, 1996) and greatest snowfall 38.1 cm (February 26, 1972).

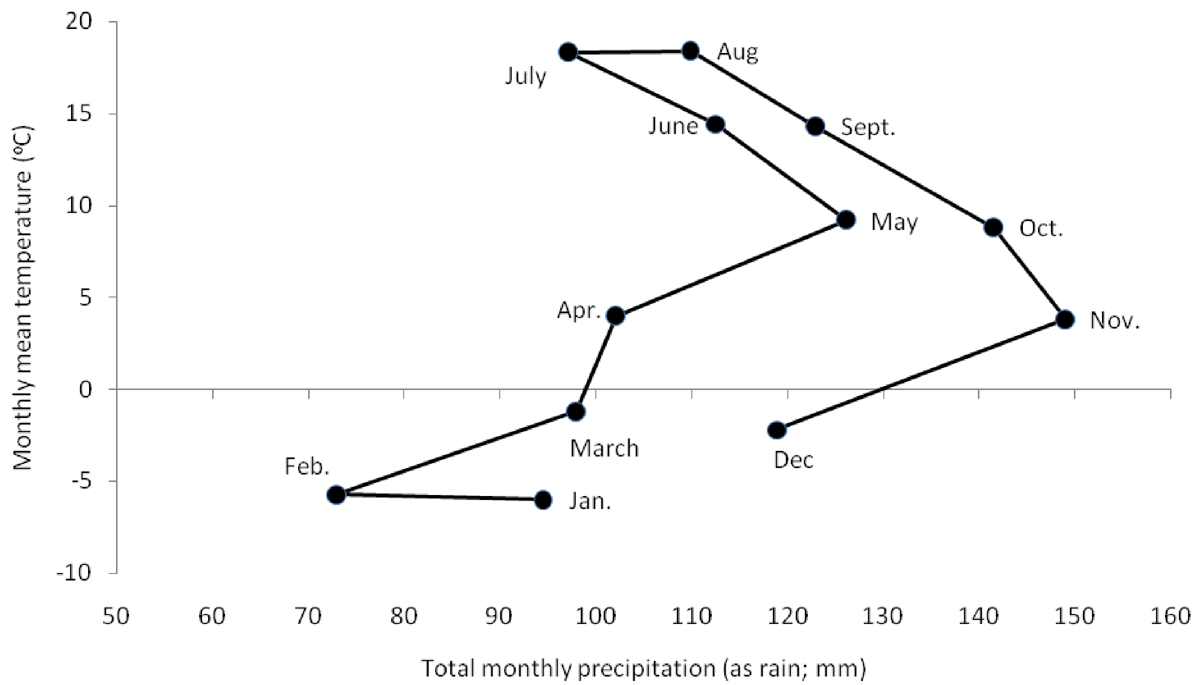



Figure 2: Climograph of St. Mary's River area. Based on 30 year Normals (1971-2000) from Stillwater Sherbrooke climate station. Data from Environment Canada[9].

Nova Scotia is subject to large storms and hurricanes which can have significant hydrological effects in rivers. Of particular note are the following storms (compiled from literature listed in this report, and examining largest flood in St. Mary's river (see Results and Discussion for more on this)).

- August, 1873 Great Nova Scotia Cyclone (500 people killed in Nova Scotia)
- January, 1956 120 mm of rain on January 5$^{th}$ and 6$^{th}$.
- August, 1968 135 mm of rain on August 29$^{th}$ and 30$^{th}$.
- November, 1969 265 mm of rain between November 6$^{th}$ to 10$^{th}$.
- February, 1971 68.9 mm of rain on February 13$^{th}$ and 14$^{th}$.
- August, 1971 236 mm of rain on August 15$^{th}$ and 16$^{th}$ (Hurricane Beth)

[9] http://www.climate.weatheroffice/ec.gc.ca/climate_normals/index_e.html (accessed March 10, 2009).

- January, 1978 124 mm of rain between January 14th to 17th
- March, 1983 65 mm of rain between January 19th to 22nd
- December, 1990 105 mm of rain on December 8th and 9th
- September, 1996 142.6 mm of rain on September 14th (Hurricane Hortense); further 69.4 mm of rain on September 18th.
- February, 1998 72.5 mm of rain between February 24th to 26th.

## METHODS

Archived hydrometric data was downloaded from Water Survey of Canada[10] for three locations in the St. Mary's River watershed (Table 2). Annual hydrology was summarized as Mean Annual Flow (MAF) and relative variation within a year determined using Coefficient of Variation (CV) where CV=SD/mean*100. Data for the winter period (December-January-February) of the North Atlantic Oscillation Index (NAOI) was accessed [11] for correlation with mean annual flow, median annual flow ($Q_{50}$), and variation in mean annual flow. In comparing flows between the East Branch (at Newtown) and the Main Branch (at Stillwater) for the period of 1965-1979 when they were concurrently measured, daily flows at Newtown were divided by corresponding daily flows at Stillwater to provide proportional contribution by East Branch to total flow.

Flood flows were estimated directly from a flood frequency curve, without fitting a distribution to the data. Bankfull flow was estimated as the 67th percentile of these data (i.e., the flow which is exceeded in 2 of 3 years). Low flow was calculated as 1-d, annual low-flow to generate a low flow frequency curve analogous to the flood flows.

Table 2: Description of hydrometric stations in the St. Mary's River watershed used in this analysis.

| Station | Station number | Location | Period of record | Gross drainage area ($km^2$) |
|---|---|---|---|---|
| St. Mary's River at Stillwater | O1EO001 | 45°10'27"N, 61°58'47"W | 1915-2007 (93 years) | 1,350 |
| East River St. Mary's at Newtown | O1EO003 | 45°10'33"N, 61°58'33"W | 1965-1979 (15 years) | 282 |
| Archibald Brook at Stillwater | O1EO002 | 45°21'36"N, 62°08'08"W | 1915-1926 (12 years) | 49.2 |

[10] Water Survey of Canada at http://www.wsc.ec.gc.ca/products/hydat/main_e.cfm?cname=archive_e.cfm (accessed March 1, 2009).
[11] North Atlantic Oscillation Index data downloaded from Climate and Global Dynamics at http://www.cgd.ucar.edu/cas/jhurrell/indices.html (accessed March 1, 2009).

## RESULTS AND DISCUSSION

### *Annual Hydrology*

The hydrology of the St. Mary's River is quite typical of snow-dominated watersheds with a peak flow generally in the spring months (April-May) due to snowmelt and runoff, a period of low flow through summer, and increase in fall due to autumn rains (Figure 3). Mean monthly discharge at Stillwater has ranged between 14.3 (August) and 89.9 $m^3/s$ (April). It may be seen from Figure 3, in which the mean monthly flow is presented with the central 50th percentile of flow ($Q_{50}$), that the mean flow is inflated relative to the median discharge, with the mean approaching and equalling the 75th percentile in the summer months. This inflation of the mean is likely due to flood flows ("rare", high magnitude events) which drive the mean high relative to median flow. It is therefore important to bear in mind when discussing mean annual flow that it overestimates median conditions.

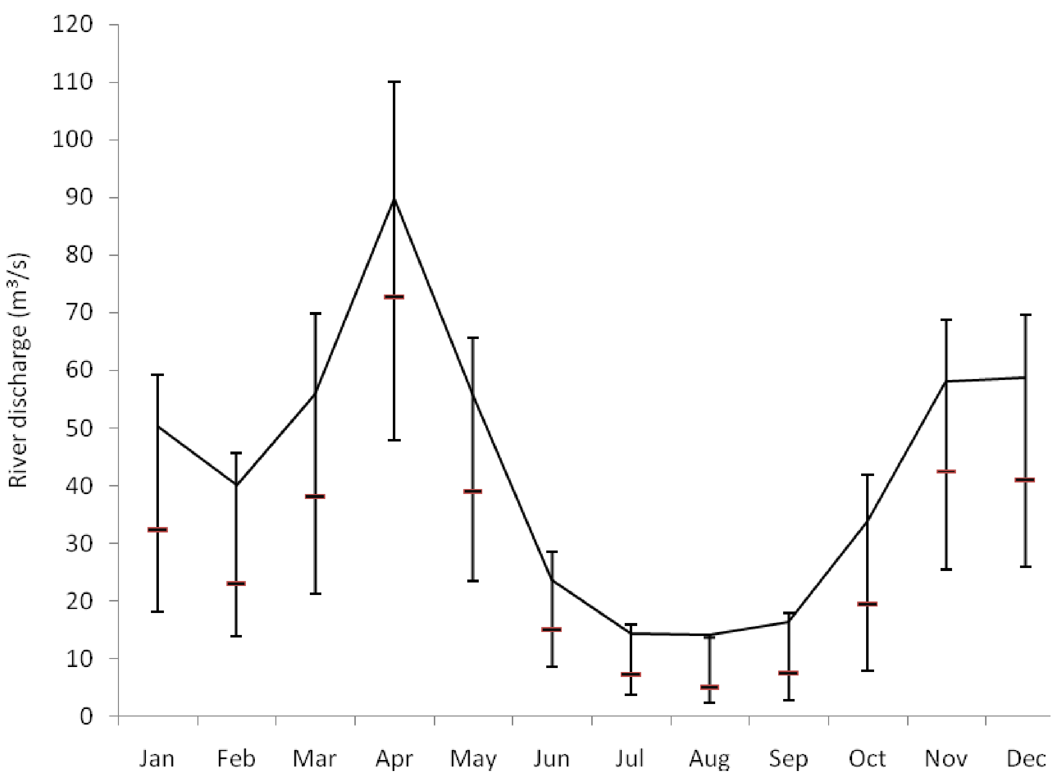



Figure 3: Annual hydrograph of St. Mary's River at Stillwater. Monthly means (solid line) based on daily measurements for each respective month from 1915-2007. Error bars indicate range from 25th to 75th percentiles of flows (i.e., the central 50th percentile of flows); horizontal bar indicates 50th percentile (i.e., $Q_{50}$).

The mean annual flow of the St. Mary's River at Stillwater has ranged among years between 28.2 (1960) and 64.2 (1972) $m^3/s$, with a long-term average of 45.6 $m^3/s$ (±SD 7.2) (Figure 4).

The central 80th percentile of the distribution of mean annual flow (i.e., between 10th and 90th percentiles) range from 34.1-51.1 $m^3/s$ (see Appendix 2 for percentiles). Annual variability of discharge (as measured by CV of daily flow about mean) has ranged from 81% (1977) to 178% (1978), with a long-term mean of 122.4% (±SD 19.2) (Figure 4). The years of greatest variability were 1978 (178%), 1956 (177.7%), 2003 (171%), 1971 (167%), 1950 (160%), 2001 (158%), 1960 (155%), and 1930 (151%). Of these eight years of greatest variation, seven can be linked to rare events of high (1956, 1971, 1978, 2003) or low flows (1950, 1960, 2001) as listed in Table 4 (see *Flood Flows*). This high variability is driven by stochastic flows, in turn driven by storms events and anomalously dry summers. Years of lowest variability were 1977 (81%), 2006 (91%) and 2007 (89%). The central 80th percentile of the distribution of annual flow variation ranged from 100-144%.

Graphically, there is a suggestion of four different "variation regimes" with annual flow in the periods 1915-1949 (mean 119.4%, ±14.4; N=35) and 1979-2000 (mean 118.6%, ±12.1; N=22) having less variation than those periods of 1950-1978 (mean 126.7%, ±25.0; N=29), and 2000-2007 (mean 126.3%, ±29.2; N=8). Beamish et al. (2000) used various atmospheric indices in the North Pacific to discriminate regime shifts occurring in 1925, 1947, 1977 and 1989 and cites other researchers who found similar regime shifts. Compared to the Pacific Ocean, very little work has been done in the North Atlantic on regime shifts, but Weijerman et al. (2005) report regime shifts in the North Sea and Wadden Sea in 1979, 1988 and possibly 1998. The increased inter-annual variability in St. Mary's River discharge between 1950-78 and after 2000, coincide quite well with these noted regime shifts.

There is a common perception that water flows are lower in the summer, floods higher, and river flows more variable than in the past. Therefore, I analyzed mean annual flow, median flow and CV over time to determine if there has been a change overtime consistent with this perception. There is no indication of linear change in mean annual flow, median flow, or annual CV of flow over time based on the Stillwater hydrometric station (Figure 4; Table 3).

Given there is no linear trend, I was interested in assessing river flow against the North Atlantic Oscillation Index (NAOI). The NAOI is a measure of air pressure difference between Iceland and the Azores and represents the westerly atmospheric circulation over the North Atlantic (Burroughs, 2003). The changes in the circulation pattern, signified by extreme NAOI values are accompanied by changes in intensity and number of storms, their paths, and associated westerlies (Hurrell et al., 2002). Positive value of the NAOI are associated with warmer winters in eastern North America and negative values with cooler winters. There is not a significant relationship of mean annual flow, median flow, or variability with the annual North Atlantic Oscillation Index (Figure 5; Table 3). Based on this preliminary, and basic, analysis there is no evidence that hydrological conditions in the St. Mary's River have directionally changed over time or are related strongly to the atmospheric circulation of the North Atlantic.

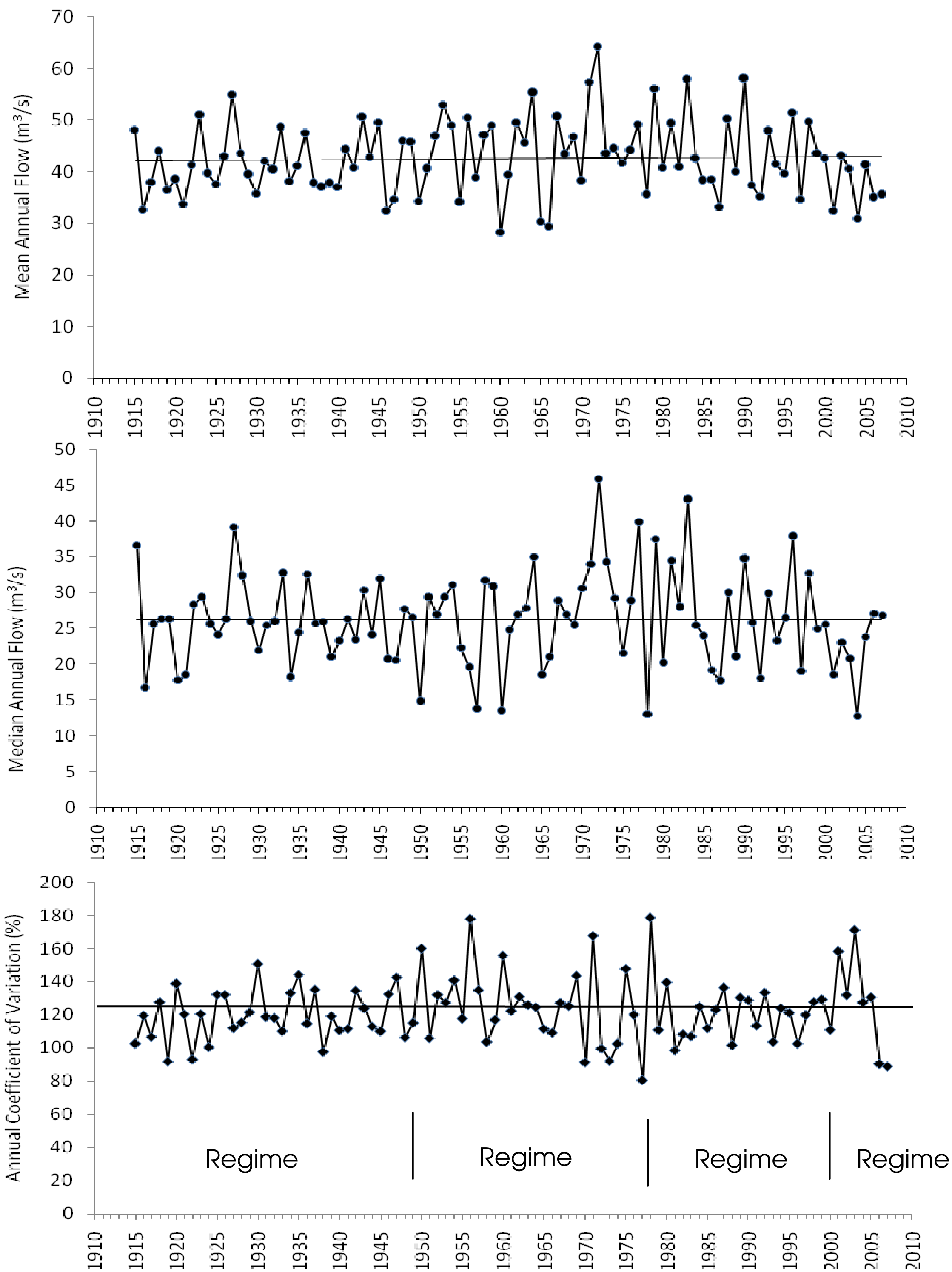



Figure 4: Mean annual flow (upper panel), median flow (middle panel) and within year variation in flow (CV) (lower panel) of St. Mary's River recorded at the Stillwater hydrometric station, 1915-2007. Horizontal lines represent long-term mean annual flow of 45.6 $m^3$/s, mean median flow 26.2 $m^3$/s and annual CV of 122.4%. Four "Variation regimes" also illustrated on lowest panel

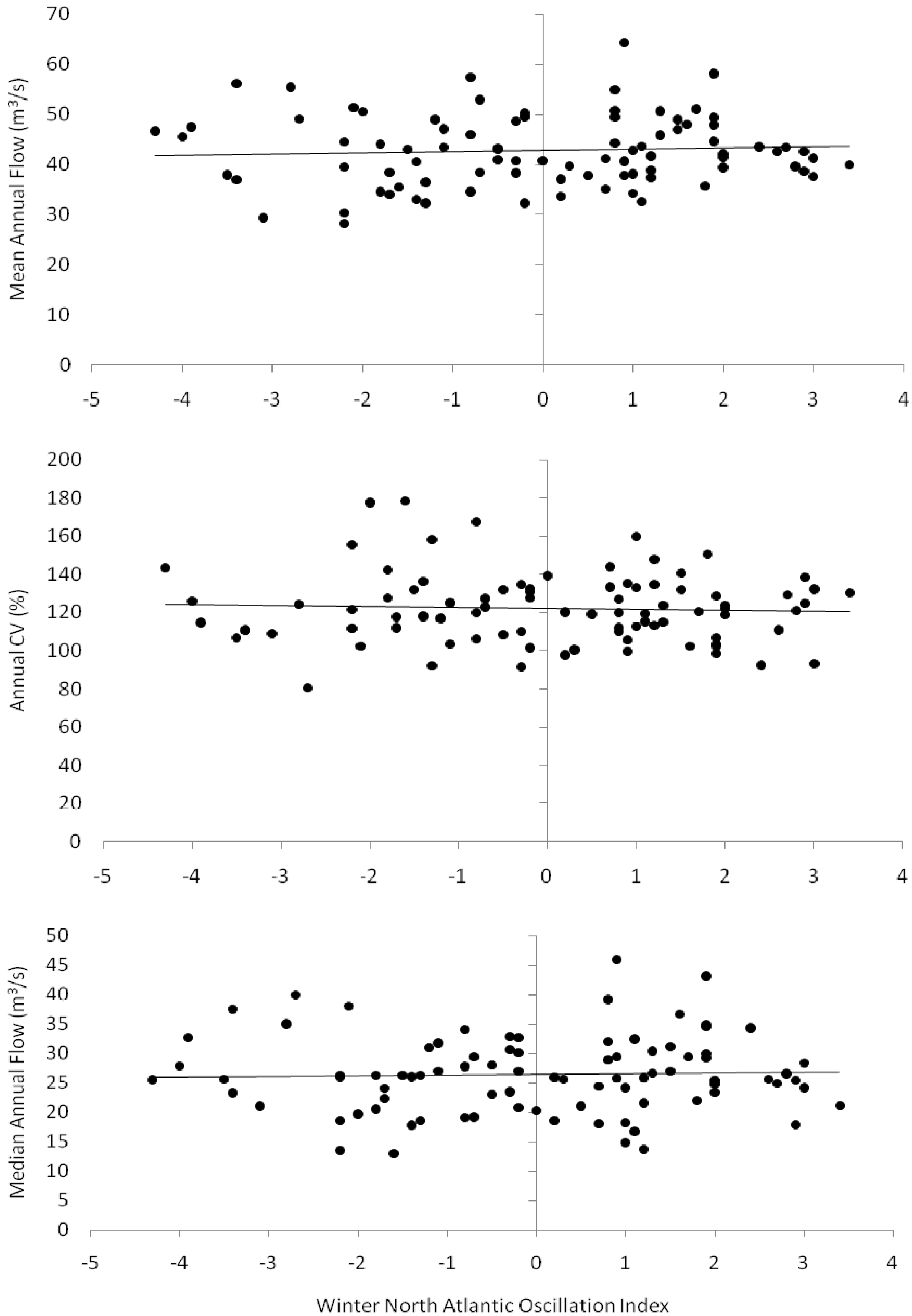



Figure 5: Relationships of mean annual flow, annual variation (CV), and median flow with winter (December-January-February) North Atlantic Oscillation Index, 1915-2002.

Table 3: Results of individual regression analyses of mean annual flow (MAF), $Q_{50}$, and annual flow variation (CV about MAF) over time and against North Atlantic Oscillation Index (NAOI). Plots of these regressions are provided as Figures 4 and 5.

| | Equation | $r^2$ | F | P | N |
|---|---|---|---|---|---|
| MAF over time | $Y = 0.011 * X + 20.96$ | 0.002 | 0.154 | 0.690 | 93 |
| MAF and winter NAOI | $Y = 0.241 * X + 42.89$ | 0.003 | 0.338 | 0.568 | 88 |
| $Q_{50}$ over time | $Y = -0.0005 * X + 27.27$ | 0.000 | 0.0005 | 0.982 | 93 |
| $Q_{50}$ and winter NAOI | $Y = -0.466 * X + 122.19$ | 0.002 | 0.190 | 0.664 | 88 |
| CV over time | $Y = 0.036 * X + 51.14$ | 0.002 | 0.231 | 0.639 | 93 |
| CV and winter NAOI | $Y = 0.102 * X + 26.41$ | <0.001 | 0.074 | 0.787 | 88 |

Mean annual flow of the East Branch St. Mary's at Newtown has ranged between 4.55 (1965) and 15.07 (1972) $m^3/s$, with a long-term average of 9.95 $m^3/s$ (±SD 2.74) (Figure 6). Mean annual flow of Archibald's Brook has ranged between 1.37 (1921) and 2.07 (1919) $m^3/s$, with a long-term average of 1.75 $m^3/s$ (±SD 0.23). Mean within year variation (CV) was 126.7 % (±SD 27.1) and 117.3 % (±SD 20.7) for the East Branch and Archibald's Brook, respectively. The time series for these two hydrometric stations are too short to draw rigorous inferences, but the year 1971 is notable at Newtown for greater variation than other years. Variation at Stillwater in 1971 was also high (i.e., 4$^{th}$ highest CV estimated for that station over period of record). This high variance was due to two separate events. On February 15$^{th}$ a discharge of 767 $m^3/s$ was recorded at Stillwater and 150 $m^3/s$ at Newtown; this followed 51 mm of rain on February 13 and 14. This was likely a major flood in response not only to the rain but the rain induced melting of the snow on the ground as well (rain-on-snow event). On August 15, 1971, Hurricane Beth made landfall on Nova Scotia, dumping ~200 mm of rain at Stillwater between August 14 and 16. The river rose to flood levels of 974 and 940 $m^3/s$ on August 16 and 17, respectively. On the East Branch, discharge on these dates was recorded as 331 and 139 $m^3/s$, respectively.

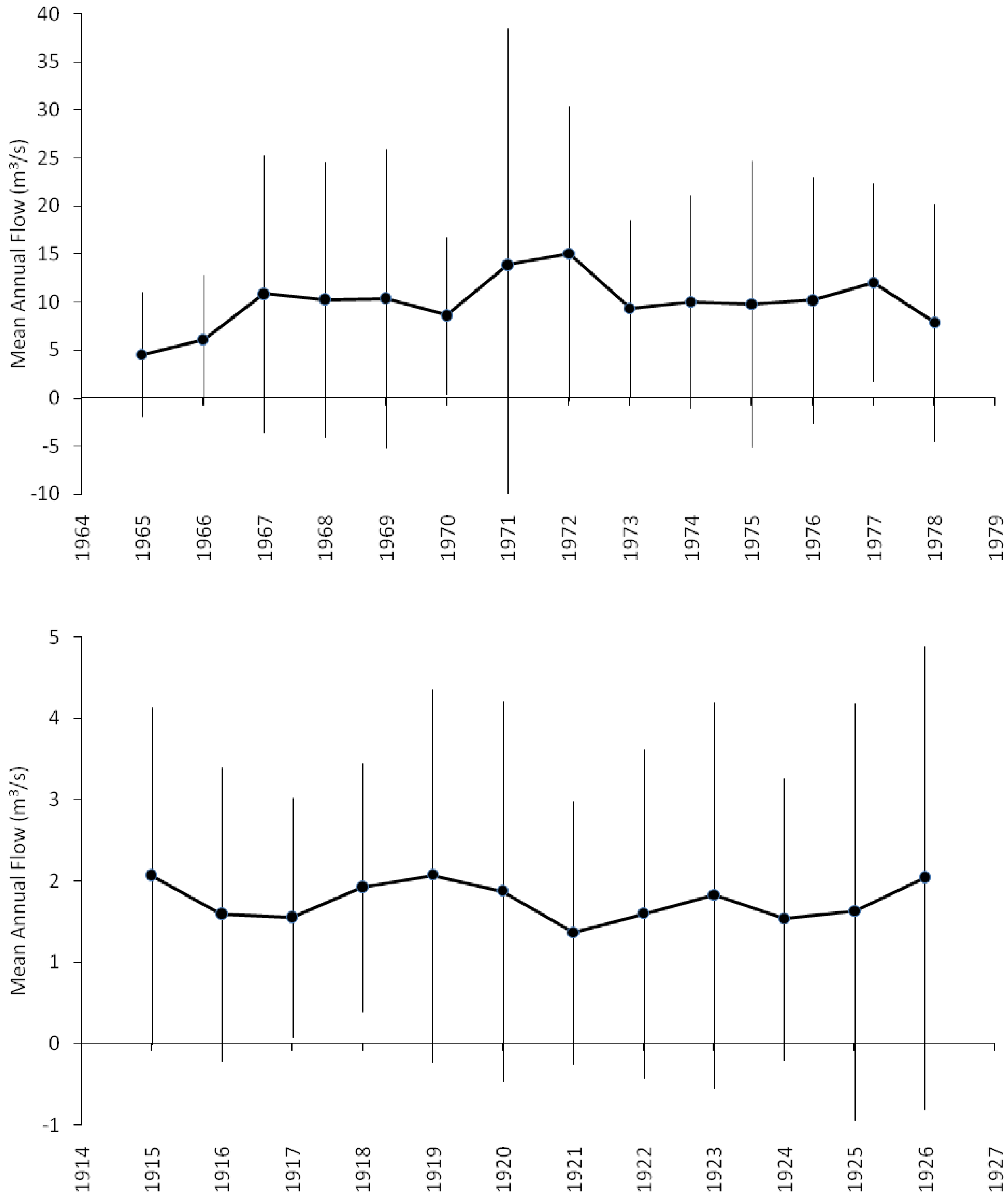



Figure 6: Mean annual flow at the Archibald's Brook (1915-1926, upper panel) and East Branch (Newtown) (1965-1978, lower panel) hydrometric stations.  Error bars are Standard Deviation of flows within the year.

As proportion of discharge measured in the Main Branch at Stillwater, the contribution from the East Branch measured at Newtown averages 22.5%, ranging from 17% in August to 26% in November (Figure 7). Variability in contribution by the East Branch to total flow is greatest among years (i.e., CV>50%) in July, August and September, and least (CV<30%) in December, January, March, April and May. That is, variation is greatest during low flow conditions; during other periods the east Branch provides a more consistent proportion of totalflow. Regression of discharge at Newtown on discharge at Stillwater yields a highly correlated regression (Figure 8; F=30,533; P<0.001) with a slope of 0.22. This suggests that irrespective of flow condition, discharge at Newtown maintains a fairly constant proportion of flow at Stillwater.

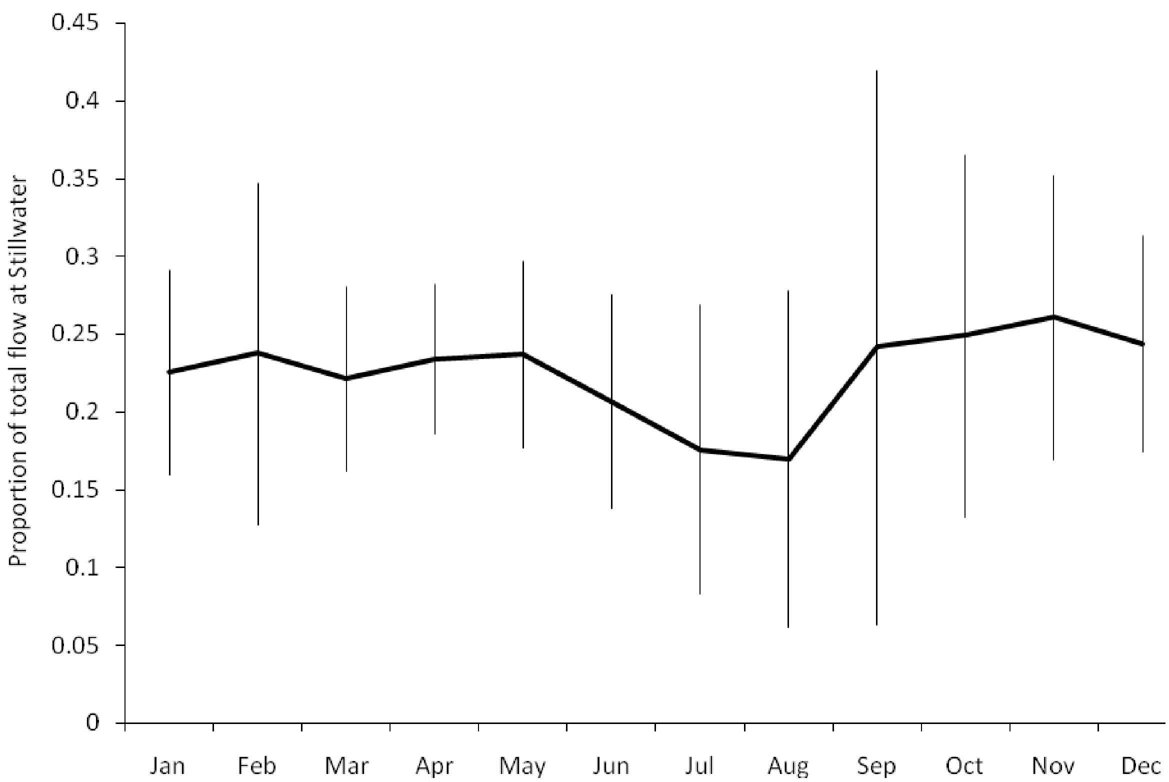



Figure 7: Mean proportion of total St. Mary's River discharge as measured at the Stillwater hydrometric station comprised by flow measured at Newtown for each month. Error bars are Standard Deviation. Data from simultaneous daily estimates of discharge at the two stations between September 1, 1965 and April 9, 1979.

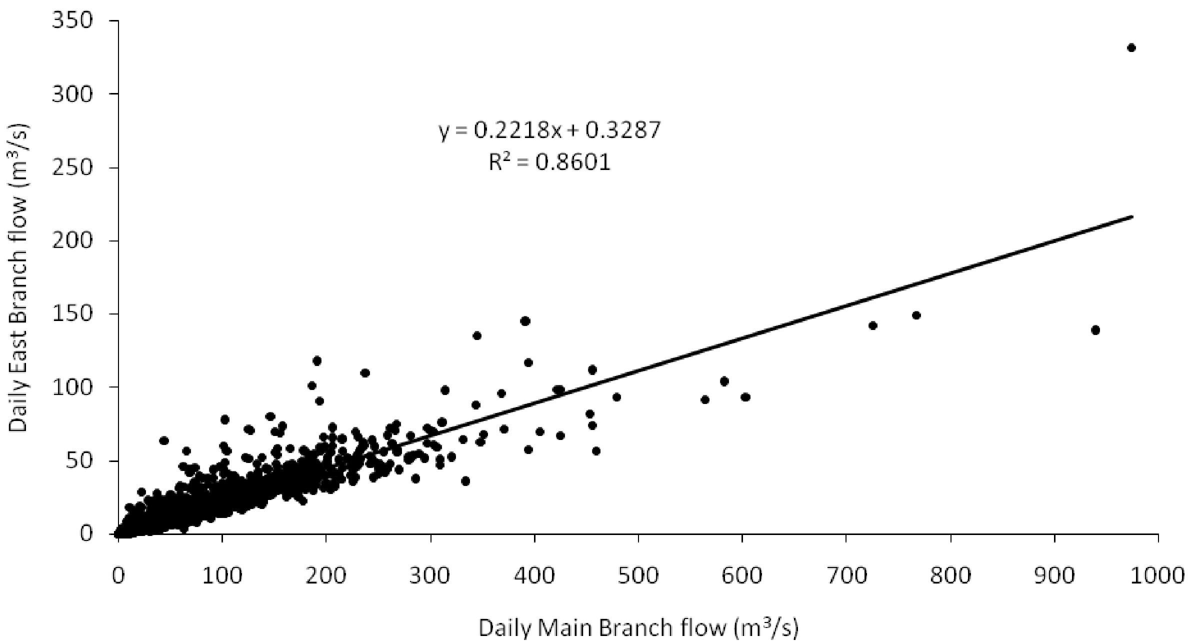



Figure 8: Regression of daily flow at East Branch (Newtown) on simultaneous daily flow at the Main Branch (Stillwater) for the period September 1, 1965 to April 9, 1979. N=4,969.

Jansen (1991) estimated the East Branch contributed 35% of the flow measured at Stillwater. My estimate here is much less, but Newtown is located midway along the East Branch and there are several significant tributaries (Frasers Brook, Archibald's Mill Brook, Big Meadow Brook) downstream of this location. The best approach to determine hydrological behaviour and contribution by the East Branch, or each of the branches, will be by stream gauging (see *Future Work*).

*Flood Flows*

A flood frequency diagram for discharge at Stillwater is presented in Figure 9. Bankfull flow at this location (i.e., the 67$^{th}$ percentile of the flood frequency curve) is estimated at 443 $m^3$/s. Straightforward pro-rating of the drainage areas for the two hydrometric stations suggests that the bankfull flow at Newtown should be approximately 21% that of Stillwater, or approximately 93 $m^3$/s. Ninety percent of the floods in the St. Mary's are estimated to be less than 583 $m^3$/s. Estimated flood return intervals are 371 (1-in-2 yr), 514 (1-in-5 yr), 569 (1-in-10 yr). 690 (1-in-25 yr), 825 (1-in-50 yr), and 970 $m^3$/s (1-in-100 yr).

The ten greatest extreme floods having occurred in the St. Mary's are presented in Table 4. Eight of these extreme floods occurred during periods when salmon eggs were incubating or alevins in the gravel (i.e., November-May) and two occurred in mid-summer (August). The detrimental effect of these sorts of catastrophic floods on fish populations have been repeatedly documented (e.g., Elwood and Waters, 1969; Seegrist and Gard, 1972; Hoopes, 1975; Erman et al., 1988; Jensen and Jonsson, 1999; Weng et al., 2001; Roghair et al., 2002; Carline and McCullough, 2003; Mitchell, 2007). Interestingly, none of the extreme floods occurred in the spring (May-June) when greatest flooding due to snowmelt is expected. These large floods are also well distributed over the decades in the 1950s (1), 1960s (3), 1970s (2), 1980s (1), 1990s (2), and 2000s (1). This observation does not support a notion of increasing flood magnitude over time.

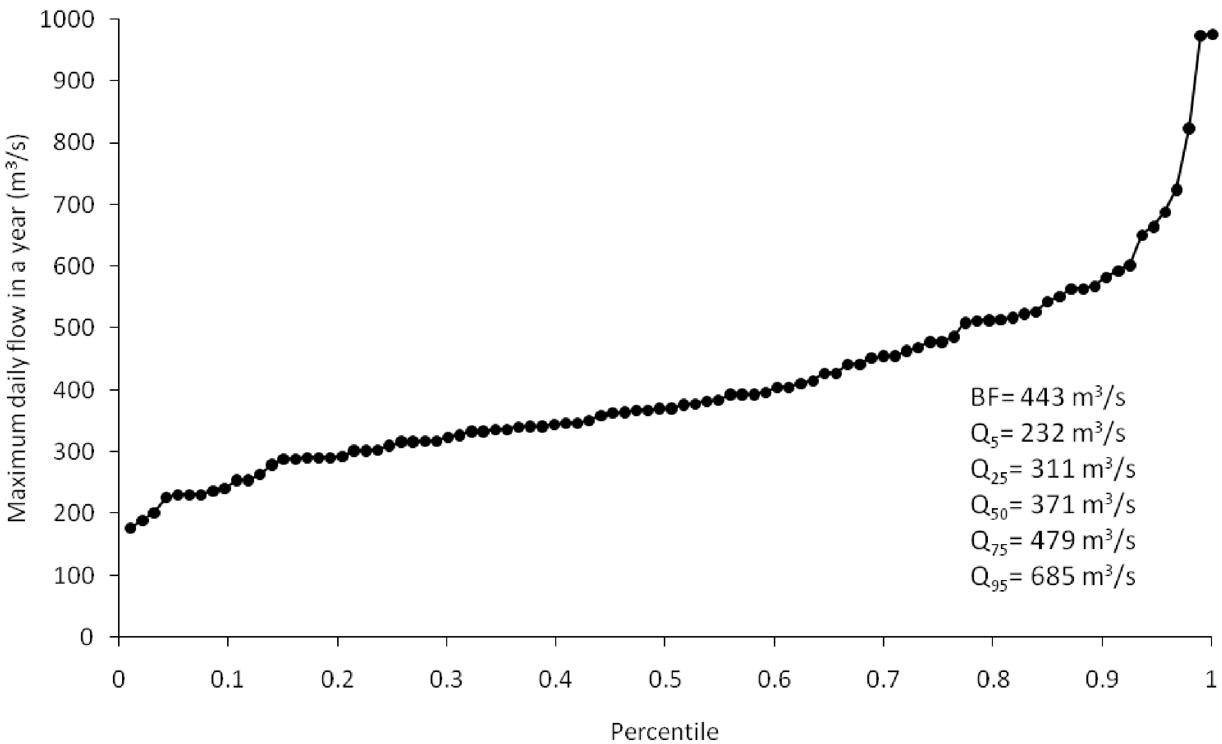



Figure 9: Flood frequency diagram for the St. Mary's River at Stillwater. Period of record 1915-2007, N=93.

There was a mean of 0.55 days (±SD 0.88) in a year with flow greater than bankfull (range 0 to 4 per year). There is no indication of a change in number of bankfull flows per year over time (Figure 10). Of 47 flood events exceeding bankfull on records, 41 (87%) occurred between November 1 and May 31 (i.e., during salmon egg incubation and alevin development) (Figure 11). This is in contrast to the documentation by IWD (1979) who highlight that a primary cause of flooding is ice jamming combined with the spring thaw, and that flooding also occurs in the summer months due to high runoff. Results presented here show summer floods to be relatively infrequent and winter/early spring floods to me the most common.

Table 4: The ten greatest floods (upper half of table) and lowest flows (lower half of table) recorded in the St. Mary's River at the Stillwater hydrometric station, 1915-2007.

| Rank | Daily Discharge ($m^3/s$) | Date | Comments |
|---|---|---|---|
| 1 | 976 | April 1, 2003 | No data at Stillwater or Collegeville climate stations for this month |
| 2 | 974 | August 16, 1971 | 236 mm rain between 15th and 17th (Hurricane Beth) |
| 3 | 824 | January 7, 1956 | 120 mm rain on 5th and 6th |
| 4 | 725 | November 10, 1969 | 265 mm of rain between 6th and 10th |
| 5 | 689 | December 10, 1990 | 95 mm of rain on 8th |
| 6 | 665 | February 26, 1998 | 95 mm of rain on 24th and 25th |
| 7 | 651 | April 17, 1964 | 44 mm of rain on 15th and 16th recorded at Collegeville climate station |
| 8 | 603 | January 16, 1978 | 92 mm of rain on 15th and 16th recorded at Collegeville climate station |
| 9 | 593 | March 23, 1983 | 41 mm rain on 22nd |
| 10 | 583 | August 31, 1968 | 135 mm rain on 29th and 30th |

| Rank | Daily discharge ($m^3/s$) | Date |
|---|---|---|
| 1 | 0.15 | September 9, 1942 |
| 2 | 0.221 | September 12-13, 1960 |
| 3 | 0.238 | August 22, 1975 |
| 4 | 0.308 | September 21, 2001 |
| 5 | 0.405 | October 12, 1950 |
| 6 | 0.42 | August 5, 1975 |
| 7 | 0.453 | September 15-18, 21-24, & 28-29, 1934 |
| 8 | 0.507 | September 1-3, & 5, 1942 |
| 9 | 0.541 | August 28, 1960 |
| 10 | 0.564 | September 8-11, 1937 |

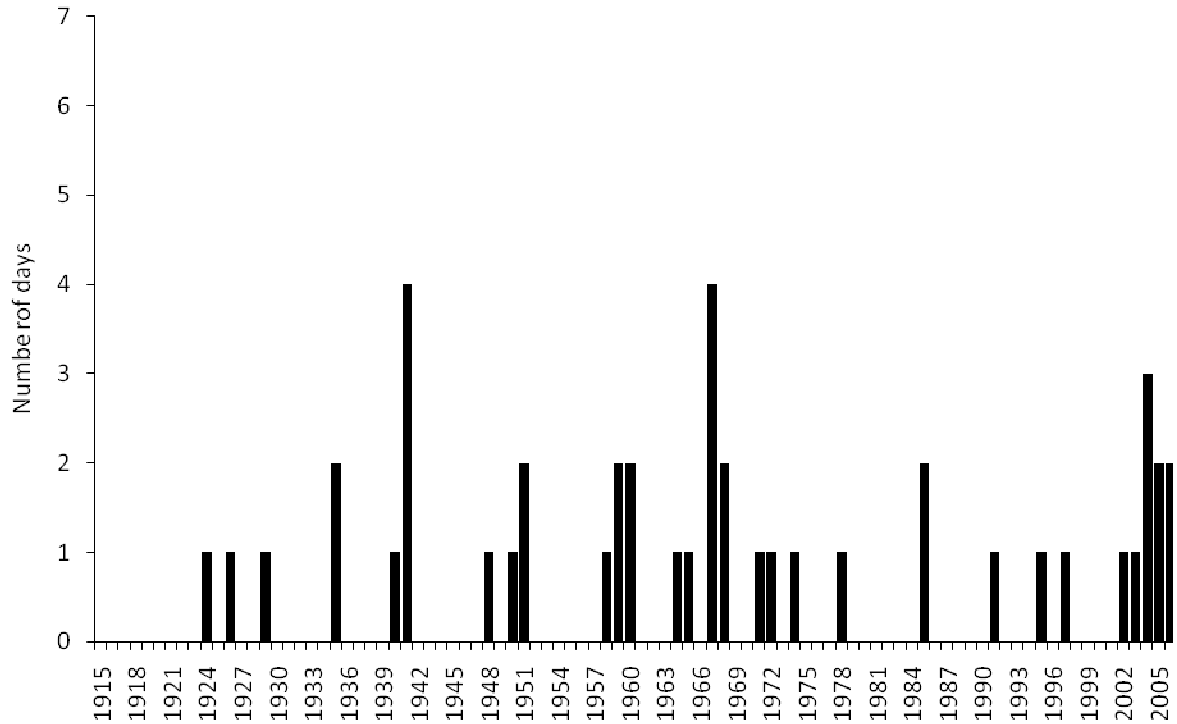



Figure 10: Number of days per year in which St. Mary's River discharge exceeded estimated bankfull flow (443 $m^3/s$) at the Stillwater hydrometric station, 1915-2006.

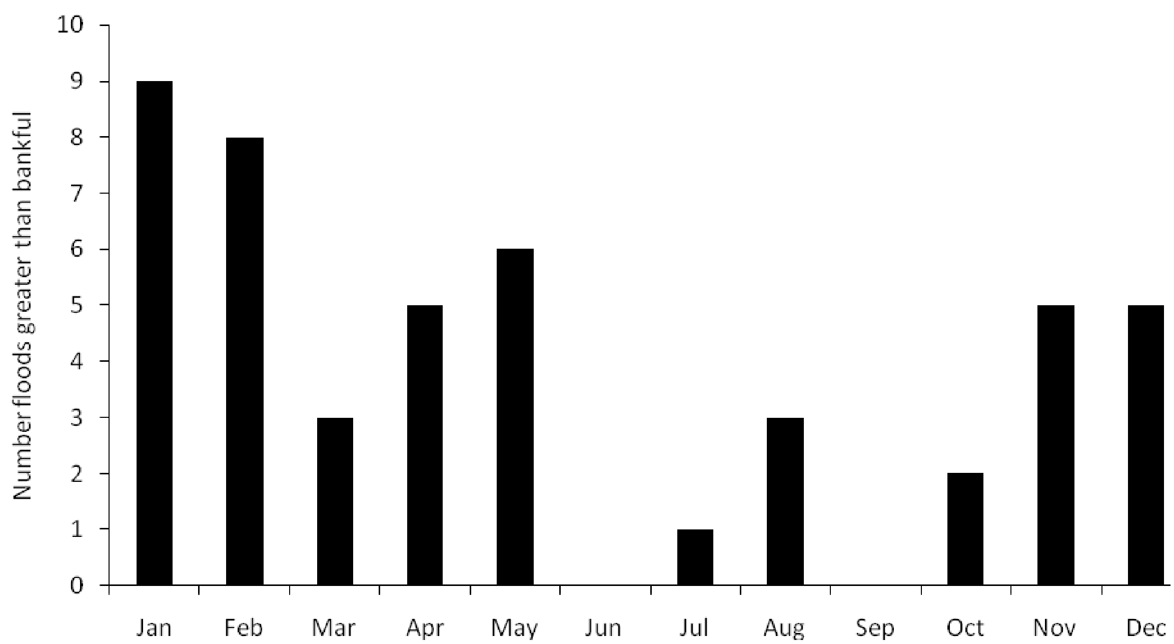



Figure 11: Number of floods exceeding bankfull (443 $m^3/s$) recorded at Stillwater hydrometric station by month for the period 1915-2007.

*Low flows*

A low flow frequency curve is presented in Figure 12. Median daily low flow is 1.7 $m^3$/s, and extreme daily low flows (i.e., lowest 5th percentile) less than 0.41 $m^3$/s. Estimated 1-day low flow return intervals are 1.7 (1-in-2 yr), 0.71 (1-in-5 yr), 0.51 (1-in-10 yr). 0.40 (1-in-20 yr), 0.22 (1-in-50 yr), and 0.15 $m^3$/s (1-in-100 yr). Agreement with estimates of Brimley (1986) is very good (i.e., within 0.02 $m^3$/s) except for the 1-in-10 and 1-in-20 year estimates both of which estimates presented here exceed those of Brimley. I suggest that the larger data set (Brimley had 62 years, here I have used 93 years) has resulted in a "flattening" of the curve. The extremes have remained constant but the mid range (or belly of the curve) have increased over Brimley's estimates. It may be seen that the critical low flow value of 2.8 $m^3$/s by Jefferson (1968) and Anonymous (1971) is likely highly restrictive. In the majority of years (i.e., 75%) 1-d low flows are decreased below this value.

Six of the ten lowest flows on record occurred in September, three in August and one in October (Table 4). As with the extreme flood flows over time, the extreme lows are relatively evenly distributed in time with two in each of the 1930s and 40s, one in 1950s, two in each of the 1960s and 70s and one in the 2000s. The 1980s and 1990s did not see any of these extreme low flows. Using the 67th percentile of flood flows to represent bankfull flow as an analogue, a similar approach may be used to determine a "critical" low flow. This would be the flows which are in the lowest 33% of the distribution (as opposed to the highest 33% for flood flows). For the St. Mary's River at Stillwater this 33rd percentile is equivalent to 1.0 $m^3$/s. The number of days per year with flows less than 1.0 $m^3$/s are shown in Figure 13. The years 1975 and 2001 stand out as having more days than usual of flow below this level; these were unusually dry years. All other years have fewer than 30 days a year less than 1.0 $m^3$/s (mean number days/ year = 4.17; ±SD 4.22). Of a total of 388 days with flows <1.0 $m^3$/s between 1915 and 2007, 28 (7.2%) occurred in July, 177 (45.6%) in August, 175 (45.1%) in September, and 8 (2.1%) in October.

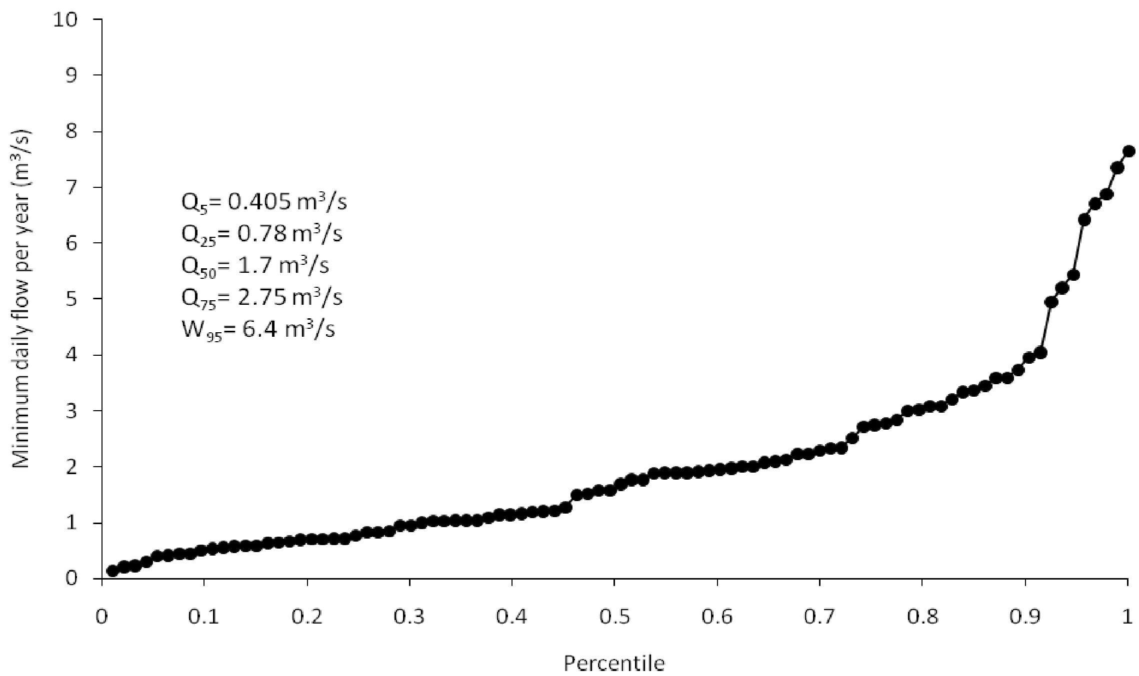



Figure 12: Low flow frequency diagram of the St. Mary's River at Stillwater. Period of record 1915-2007. N=93.

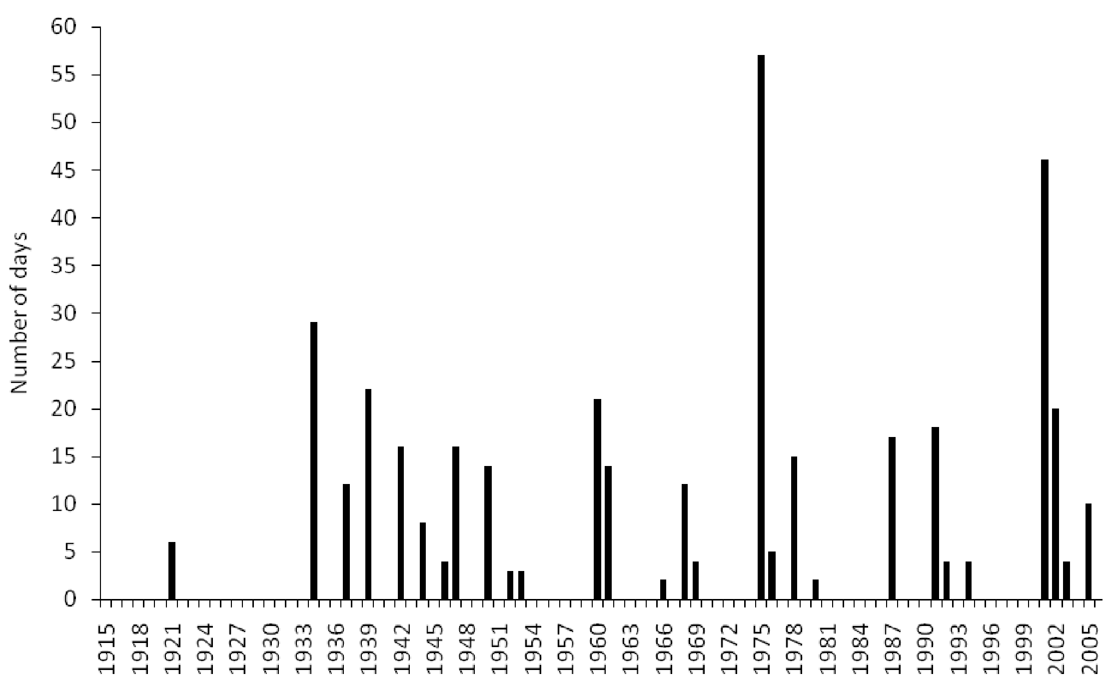



Figure 13: Number of days per year with low flows less than 1.0 $m^3/s$ as measured at the Stillwater hydrometric station, for the period 1915-2007.

## 3.0 Climate Change

Forecast climate change predictions for Canada are provided in Table 5. The increased air temperature, together with only slight increases in precipitation is expected to result in greater evapotranspiration by vegetation, causing declines in water levels (Vasseur and Catto, 2008). Milly et al. (2005) project that flows will increase in Labrador but decrease throughout most of Atlantic Canada. Further, the Maritime Provinces are expected to see more of the precipitation as rain rather than snow in the winter, educing snowpack and groundwater storage (Vasseur and Catto, 2008). So this may exacerbate water availability through summer months. Increased precipitation in winter may increase rain-on-snow events and so winter floods. Climate change projections also include an increase in frequency and intensity of storms. Effects of climate change on river ice formation, distribution and break-up are uncertain.

Thus, in essence, future conditions of hydrology within the St. Mary's River will likely include: decreased summer flows, increased winter floods, and greater variability of storms.

Table 5: Projected air temperature and precipitation increases for Atlantic Canada under climate change conditions for the decades 2020s, 2050s, and 2080s.

| | | |
|---|---|---|
| For periods 2020s to 2080s (from Vasseur and Catto, 2008) | | |
| | Median temperature increase | Median precipitation increase |
| 2020s | ~ 1.5 $^{o}$C | ~ +2% |
| 2050s | ~ 2.2 $^{o}$C | ~ + 4% |
| 2080s | ~ 3.7 $^{o}$C | ~ +8% |
| By 2050s | | |
| Winter | ~ 2.5 $^{o}$C | ~ +5% |
| Spring | ~ 2.0 $^{o}$C | ~ +4% |
| Summer | ~ 2.2 $^{o}$C | ~ + 5% |
| Fall | ~ 2.4 $^{o}$C | ~ +3% |
| By 2080-2099 (from Christenson et al., 2007) | | |
| | Temperature increase | Precipitation increase |
| Annual | + 3 to 3.4 $^{o}$C | + 5% |
| Winter (Dec-Jan-Feb) | + 3.5 to 4.0 $^{o}$C | + 10 to 15% |
| Summer (June-July-Aug) | + 3.0-3.5 $^{o}$C | + 0 to 5% |

Obviously this altered hydrology may gave significant effects on the fish of the St. Mary's River, affecting living space, water quality, and timing of flows as behavioural cues. A review and analysis of these effects is beyond the scope of the work presented here but should be undertaken (see *Future Work*).

## 4.0 FUTURE WORK

This review has identified three avenues of future work with respect to understanding the hydrology of the St. Mary's River:

#1: Following up on the inference of Brimley (1986) that the upper basins are recharge areas and lower basins discharge, a survey of springs and groundwater influences along the lengths of each branch of the river should be conducted. If the inference is correct there should be a greater preponderance of springs in the lower sections of the river. This work could be combined with ongoing cold water refugia mapping work by the SMRA.

#2: Previous authors (e.g., Jefferson, 1968; Jansen, 1991) have attempted to discriminate stream discharge among the various branches of the St. Mary's River. Their approach has been one of modelling based on assuming equivalent hydrological behaviour among branches. In 2009 the SMRA will deploy three Vemco water level data loggers, one in each of the West, East and North branches in order to determine contribution by the various branches to river flow at the WSC gauge at Stillwater. This will, overtime, allow us to evaluate the flow characteristics of each branch and, combined with the Stillwater station, will allow a detailed understanding of branch-specific hydrological behaviour.

#3: This work has defined current conditions and suggested the state the future may exhibit under climate change conditions. A follow-up project recommended to be done is to rigorously define the likely future thermal and hydrological state of the St. Mary's River to properly assess likely impacts on the fish populations. Such an analysis should include thermal and hydrological effects on timing of life histories and behaviour, decreased habitat fr living space, likely bottlenecks to be faced, and effects on the communities. This review could also include a review of how other natural resource managers (e.g., forestry, protected area, commercial marine fisheries) are planning to deal with altered systems under climate change.

## 5.0 CONCLUSIONS

From this analysis it appears that there has long been an interest in the extremes of hydrology (floods and low flows) of the St. Mary's River. The local people have been concerned with flooding of agricultural lands and the anglers concerned with low flow impacting their recreational angling success. It is likely that these extremes are simply the natural behaviour of this river. There is no evidence that floods or low flows are greater or occur more frequently now than in the past, as anecdotal sources have it. The river does suffer from occasional very low summer flows, from occasional catastrophic winter and early spring floods, and the impacts of large summer storms and hurricanes, and all of these likely impact the fish populations in the river. Forecasts for the future under climate change suggest that these conditions will be exacerbated. Given that flow control has been shown repeatedly to not be an option in the St. Mary's mitigation for these impacts, and their possible increasing severity in the future, is likely best approached through comprehensive river restoration work to provide a complex mix of habitats and refuges for the fish and animals to temporarily escape extremes of low and high flow.

Hydrology is only one aspect affecting riverine populations and communities, they are also influenced by other factors (e.g., habitat condition, water chemistry, thermal behaviour, predation, etc.). A similar analysis to that one for the hydrology within the St. Mary's River should also be conducted for these other factors, to truly begin to understand the ecology of the river and anticipate changes in the future.

## 6.0 LITERATURE CITED

Anonymous. 1951. Re: St. Mary's River, Guysborough County, NS. Concerning biological aspects of storage. Letter report on file at St. Mary's River Association.

Anonymous. 1968. Preliminary report. St. Mary's River watershed. Guysborough Co., NS. ARDA 9 & 10 NS. Engineering Section, Rural Development Branch, Department of Forestry and Rural Development, Amherst, NS.

Anonymous. 1971. A study of the effect of river discharge and other factors on angling success in two Nova Scotia rivers (Medway and St. Mary's). Unpublished manuscript report on file at St. Mary's River Association.

Anonymous. 1972. The Canada Land Inventory. Soil capability classification for agriculture. Canada Land Inventory Report 2. Canada Land Inventory, Lands Directorate, Department of the Environment, Ottawa, Ontario.

Anonymous. 1978. Committee to Study Flood Control on St. Mary's River. Letter-report on file at St. Mary's River Association.

Beamish, R.J., G.A. MacFarlane, and J.R. King. 2000. Fisheries climatology: understanding decadal scale processes that naturally regulate British Columbia fish populations. *In:* Harrison, P.J., and T. R. Parsons [eds.]. Fisheries cceanography, an integrative approach to fisheries ecology and management. Blackwell Science. 94-140.

Brimley, W.A.1986. Low flow characteristics of Nova Scotia. IWD-AR-WRB-86-104. Inland Waters Directorate, Environment Canada.

Burroughs, W.J. 2003. Weather cycles, real or imaginary? Second edition. Cambridge University Press. 317 pp.

Carline, R.F., and B.J. McCullough. 2003. Effects of floods on brook trout populations in the Monongahela National Forest, West Virginia. Trans. Am. Fish. Soc. 132:1014-1020.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Dunfield, B. Undated. Notes: *These are notes developed by B. Dunfield but they provide history and data not otherwise available. These notes include history on the watershed going back to 1920s. They include comments for the West Branch, East Branch and St. Mary's as a whole on* *pollution, barriers, spawning and rearing areas, stocking and angling (1958-1963), predatory bird control, physiography, and dams.*

Elwood, J.W., and T.F. Waters. 1969. Effects of floods on food consumption and production rates of a stream brook trout population. Trans. Am. Fish. Soc. 98:253-262.

Erman, D.C., E.D. Andrews, and M. Yoder-Williams. 1988. Effects of winter floods on fishes in the Sierra Nevada. Can. J. Fish. Aquat. Sci. 45:2195-2200.
Hart Buckland Nicks, L. 1995. A community based management plan for the fisheries in the St. Mary's River. Prepared for Working Group St. Mary's River Resource Management Model and St. Mary's River Association. May, 1995.

Hoopes, R.L. 1975. Flooding as a result of Hurricane Agnes, and its effect on a native brook trout population in an infertile headwater stream in central Pennsylvania,. Trans. Am. Fish. Soc. 104:96-99.

Hurrell, J., M.P. Hoerling, and C.K. Folland. 2002. Climatic variability over the North Atlantic. *In:* Pearce, R.P. Meterorology at the millenium. Academic Press. 143-151.

Inland Waters Directorate. 1979. Report on flood risk mapping field reconnaisance in Nova Scotia. May-August, 1978. Water Planning & Management Branch, Inland Waters Directorate, Atlantic Region, Halifax, Nova Scotia.

Jansen, H.1991. Evaluation of the water storage potential of lakes on the St. Mary's River drainage basin and the effect of controlled flow release on flow parameters during low summer flow. Draft report. Freshwater and Anadromous Division, Biological Sciences Branch, Department of Fisheries and Oceans, Halifax, NS.

Jefferson, G.E. 1968. Survey report. St. Mary's River system, Guysborough Co. NS. Unpublished manuscript report on file at St. Mary's River Association.

Jensen, A.J., and B.O. Johnsen. 1999. The functional relationship between peak spring flood and survival and growth of juvenile Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*). Funct. Ecol. 13:778-785,

MacDonald, A.A. and W.B. Clare. 1965. St. Mary's River resource and hydrology survey. Extension Department, St. Francis Xavier University, Antigonish, NS.

MacPhail, D.K., and M Alpert. 1975. Site surveys for semi-natural rearing area and adult holding pond on the St. Mary's River, 1972 and 1973. Internal Report Series No. MAR/I-75-3. Resource Development Branch, Maritimes Region, Fisheries and Marine Service, Department of the Environment.

Mitchell, S.C. 2007. Streamflow and beaver dams: long-term production dynamics of Atlantic salmon (*Salmo salar* Linnaeus) in Catamaran Brook, New Brunswick and Northeast Brook, Trepassey, Newfoundland. PhD Thesis. University of New Brunswick, Frederiction, New Brunswick.

Milly, P.C.D., K.A. Dunne, and A.V. Vecchia. 2005. Global patterns of trends of streamflow and water availability in a changing climate. Nature. 438: 347-350

Nova Scotia Dept. Agriculture and Marketing. 1968. St. Mary's Watershed, Guysborough Co.

Nova Scotia Dept. of Environment report on the flooding problem along the West River St. Mary's. 1978.

Rohair, C.N., C.A. Dolloff, and M.K. Underwood. 2002. Response of a brook trout population and instream habitat to a catastrophic flood and debris flow. Trans. Am. Fish. Soc. 131:718-730.

Roland. A.E. 1982. Geological background and physiography of Nova Scotia. Nova Scotian Institute of Science. Halifax, NS.

Rudge, F.W. 1950. Report on St. Mary's River flowage control, NS. Can. Fish. Serv. Man. Rep. 50-1.

Seegrist, D.W., and R. Gard. 1972. Effects of floods on trout in Sagehen Creek, California. Trans. Am. Fish. Soc. 101:478-482.

SMRA (St. Mary's River Association). 1989. Draft Terms of Reference. Water flow study, St. Mary's River, Guysborough County.

Vassuer, L., and Catto, N. 2008. Atlantic Canada. *In*; From impacts to adaptation. Canada in a changing climate 2007. Lemmen, D.S., F.J. Warren, J. Lacroix, and E. Bush [eds.]. Government of Canada, Ottawa Ontario. 119-170.

Weijerman M., H. Lindeboom, and A.F. Zuur. 2005. Regime shifts in marine ecosystems of the North Sea and Wadden Sea. Mar. Ecol. Prog. Ser. 298:21-39.

Weng, Z., N. Mookerji, and A. Mazumder. 2001. Nutrient dependent recovery of Atlantic salmon streams from a catastrophic flood. Can. J. Fish. Aquat. Sci. 58: 1672-1682.

**Appendix 1**: Report on Field Survey of Governor's Lake, Halifax County October 6, 2008

**Background & Purpose**: There has been a persistent rumour that Governor Lake (near the headwaters of the West Branch) originally flowed into the St. Mary's River but was diverted into East River, Sheet Harbour by Nova Scotia Power. This appears to have first been speculated by Jansen (1991). However. topographic maps do show a drainage from Little Lake (at north end of Governor's Lake) northward into South Brook of the St. Mary's River. In January, 2007, Murray Anderson, a Director with the SMRA file a report doubting the lake historically drained into the St. Mary's, basing this on lack of reference in historical government land surveys to an outlet stream from Little lake draining to the north (see documents in file). Presumably such a stream would have been included in a land description. Mr. Anderson made the point that a field survey should be conducted to establish with some finality the fact or fiction of the rumour.

The purpose of this work was to determine in the field the validity of this rumour to provide information on historic discharge regime and possible future options for the diversion of the lake back to the St. Mary's River if, indeed, it did originally flow to the east.

**Methods**: On October 6th, 2008, Bob Bancroft and Sean Mitchell conducted a field survey of the north end of Little Lake to look for evidence of drainage from this lake northward to the St. Mary's River. Access was by vehicle to the Nova Scotia Power dam at the south end of Governors Lake, and by canoe up to Little Lake. A survey on foot was then conducted in the area where the lake would have drained northward.

**Results**: There does not appear to be convincing evidence that Little Lake historically contributed significant flow to the St. Mary's River. The north end of the lake, at the potential north outflow, has a small swampy area leading a short distance northward. The topography of the land drops off from this swampy area and could conceivably drain the lake northward, but for a very slight rise in the land between the lake surface and the topographic depression (see Appendix Figure 1). The evidence that any drainage northward has been very slight are that there is an old, abandoned, faint channel leading northward and downslope on the north side of the road, but it is very small (i.e., , 20-30 cm across) and very poorly defined. It is consistent with a first order stream collecting runoff water from the surrounding landscape, not consistent with drainage from a lake (even historical drainage). In addition, when we visited Little Lake was at a high water level, as shown by inundation of the roots of shoreline trees and shrubs. This would be due to the water control structure of NSP at the south end of Governors Lake. Presumably, therefore, historical water levels were lower, prior to damming and so the probability of flowing northward is more reduced as the slight topographic rise would have been increased under lower water levels.

It is our conclusion that Little Lake either never flowed northward to the St. Mary's, or did so only under extreme high lake water level conditions. If it did sporadically spill into the St. Mary's drainage, the water discharged was of very low volume as suggested by the very small, indistinct channel. We conclude that the rumour of Governor's Lake being diverted by Nova Scotia Power form the St. Mary's River to Sheet Harbour, is simply that, a rumour.

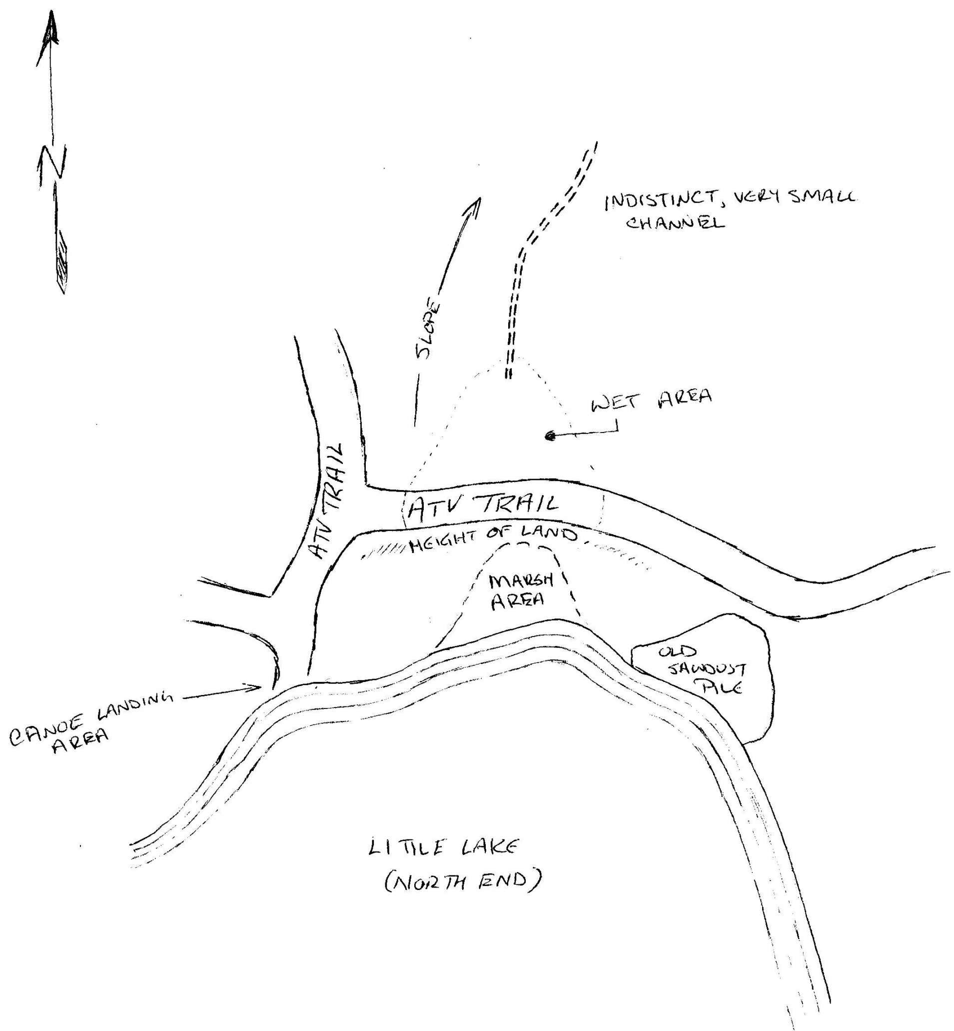
**Other observations**: At the north end of Little Lake is a moderately large old sawdust pile indicating historical sawmill activity in this area. We are uncertain what the power source would have been to run such an operation, unless this was conducted since widespread use of internal combustion engine. Mr. George Ferguson, of the Sackville Rivers Association, told S. Mitchell (personal communication) that there are two good people that know the history of this area: Jack Macdonald and Howard Coady - both from Sheet Harbour – and that Mr. Coady has written a book on the history of this area. This may have information on the sawmilling history of this part of the lake.

At the north end of Little Lake is a well developed trail used byATV's providing access to the lake. We are unaware where the trail originates, but if we were to wish to access this area again it may be worth trying to find out from local ATV users about lake access via this route.

**Field notes**:
Monday, October 6, 2008-10-09 Governor's Lake in headwaters of West Branch
Purpose: Investigate in the field whether Governor's Lake historically flowed into the St. Mary's River.
Personnel: Bob Bancroft, Sean Mitchell
11:30AM: Arrive south end of Governor's Lake at Nova Scotia Power dam. Motor in canoe up to north end. Enter Little Lake at north end of Governor's Lake. Arrive north end of Little Lake. Do walk around
Evidence of a very small channel draining St. Mary's – but very small; would have been inconsequential to flow.
Little Lake water level is high, invading on shoreline trees. This water level controlled byNSP through Governor's Lake dam.
At north end of Little Lake is marshy area with some boulders. ~50 m north of this the very small channel begins an topography drops off to the SMR.
Speculation: Little Lake originally much lower with marsh at north end. May have flowed into St. Mary's under conditions of very high water levels. NSP may have reinforced north end of Little Lake and raised water level. Such reinforcement minimal (no dams or structures) and evidence only that some boulders look out of place.
It des not really matter; If Little Lake flowed into SMR it was probably (1) very little water, and (2) only under conditions of high water.
Conclusion: speculation that Governors Lake used to flow into SMR is only that – speculation. no field evidence to support it.
Note also evidence of industrial use of the area: Old sawdust pile at north end of Little Lake where we investigated potential outflow.
ATV trail (wide and in good conditions) to site. Not sure where it begins but access to site possible by walking in along ATV trail?

Weather: warm, sunny, broken cloud; wind from north ~10 knots, gusting to 20 knots.

FIGURE 2: SKETCH MAP OF NORTH END OF LITTLE LAKE ILLUSTRATING SEPARATION OF LITTLE LAKE FROM INDISTINCT FIRST-ORDER CHANNEL FLOWING NORTH.




Appendix Figure 1: Sketch map of north end of Little Lake illustrating indistinct, first order channel flowing north.

**Appendix 2**: Percentile distribution of the Mean Annual Flow (MAF) and relative annual variation (CV) of St. Mary's River as recorded at the Stillwater hydrometric station, 1915-2007.

| Percentile | MAF ($m^3/s$) | Percentile | CV (%) |
|---|---|---|---|
| 5 | 32.25 | 5 | 92.23 |
| 10 | 34.11 | 10 | 99.87 |
| 15 | 35.07 | 15 | 102.71 |
| 20 | 36.64 | 20 | 106.53 |
| 25 | 37.79 | 25 | 110.24 |
| 30 | 38.34 | 30 | 111.42 |
| 35 | 39.38 | 35 | 113.18 |
| 40 | 40.34 | 40 | 116.72 |
| 45 | 40.80 | 45 | 119.33 |
| 50 | 41.41 | 50 | 120.52 |
| 55 | 42.69 | 55 | 123.54 |
| 60 | 43.46 | 60 | 125.43 |
| 65 | 44.33 | 65 | 127.68 |
| 70 | 46.19 | 70 | 130.51 |
| 75 | 47.88 | 75 | 132.13 |
| 80 | 49.01 | 80 | 134.18 |
| 85 | 49.78 | 85 | 138.91 |
| 90 | 51.08 | 90 | 143.96 |
| 95 | 55.64 | 95 | 158.92 |
| 100 | 64.20 | 100 | 178.46 |