
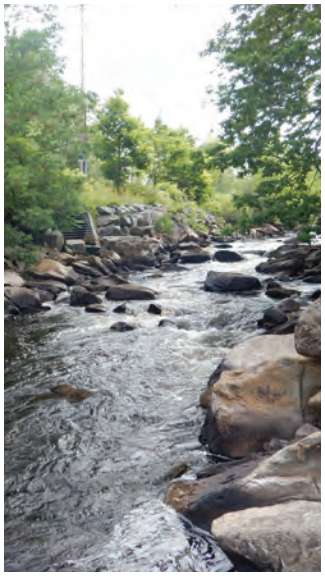

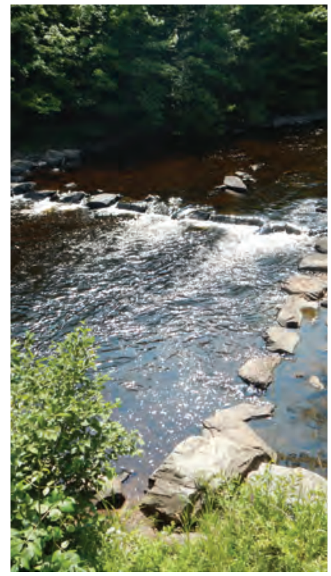

Sackville Rivers Floodplain Study: Phase I

Final Report

Halifax Regional Municipality

45 Akerley Boulevard Dartmouth Nova Scotia B3B 1J7

11102282 | Report No 4 | October 30 2015

October 30, 2015 Reference No. 11102282-4

Mr. Cameron Deacoff
Halifax Regional Municipality
PO Box 1749
Halifax, NS B3J 3A5

Dear Mr. Deacoff:

Re: Sackville Rivers Floodplain Study: Phase I
Final Report

GHD is pleased to provide the Halifax Regional Municipality (HRM) with the attached Final Report for the Sackville Rivers Floodplain Study: Phase I.

This report presents the final results for this study, including: flood and sea level frequency analyses, joint flood and sea level probability analysis, hydraulic modelling, topo-bathymetric survey data collection, and analysis of flooding factors. Data sources, methodology, and results are described in detail. Recommendations for the Phase II Study are also provided.

All of which is respectfully submitted,

GHD

Yours truly,

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Executive Summary

The lower reaches of the Sackville River have been the site of several instances of flooding over the last decade, which has been a significant issue for the Halifax Regional Municipality (HRM). A Hydrotechnical Study of the Sackville River was performed in 1981, and a Hydrotechnical Study of the Little Sackville River delineated the floodplain in 1987. Development policies were adopted by Halifax County Council in 1994. A follow-up study was performed in 1999 to revise the floodplain boundary, but no new policies have been adopted by Halifax Regional Council.

The Sackville River watershed is composed of the Sackville River and the Little Sackville River. The two watersheds have different hydrologic response characteristics: the Sackville River watershed is rural while the Little Sackville River watershed is urban. Downstream from the confluence of the two rivers, the Sackville River has a mild gradient and a number of man-made flow constrictions. The Sackville River discharges into Bedford Basin and is affected by sea level. Further complexity is added by the emerging effects of climate change and sea level rise. Climate change is expected to result in earlier and more frequent snowmelt and decreased snow cover in the winter, and more frequent and extreme precipitation events. The sea level near Halifax has risen steadily over the last century. An understanding of the complex interactions within the watershed is the key to developing accurate and representative floodplain maps.

Due to these challenges, the HRM wishes to update the floodplain maps for the Sackville River, using the most current land use and topographic information available. The study was organized in two Phases. The purpose of Phase I was to collect background information in preparation for Phase II. Phase II will be a detailed hydrologic and hydraulic modelling study to develop the new floodplain maps. This report presents the results of Phase I of the study. Four main tasks were performed:

- Statistical flood and sea level frequency analyses, including flow pro-rating and joint probability analysis.
- High-level hydraulic modelling of the lower Sackville River.
- Topo-bathymetric survey data collection.
- Historical review of flooding factors, including the ten largest precipitation events and the regional rainfall events.

The summary of key results and findings for each task are listed below. This is followed by the recommendations of this study.

Statistical flood and sea level frequency analyses, including flow pro-rating and joint probability analysis.

Single-station flood frequency analysis was performed for the first time for both the Sackville River at Bedford and Little Sackville River at Middle Sackville stations. The flood frequency estimates for the Sackville River at Bedford station were similar to the estimates obtained by the 1981 study, but the flood frequency estimates for the Little Sackville River at Middle Sackville station were lower than the estimates obtained by the 1987 and 1999 studies. Annual maximum flows were found to be increasing in the Sackville River at Bedford. The trend was not statistically significant but is expected to become statistically significant in the future. There was no long-term trend in annual maximum flows at the Little Sackville River at Middle Sackville station.

The flood estimates were pro-rated to develop flood estimates at the confluence of the two rivers. The increase in flow for the Little Sackville River was lower than the increase estimated by the 1987 and 1999 studies. The decrease in flow for the Sackville River was minor, and there are no tributaries in the lower reach of the Sackville River. The flood estimates for the Sackville River above the confluence cannot be added directly to the flood estimates for the Little Sackville River at the confluence due to differences in the timing of floods in the two watersheds.

There was a statistically significant long-term increasing trend in the sea level data measured in the Bedford Basin of approximately 3.8 mm/year, which can be divided into land subsidence (approximately 1.6 mm/year) and actual sea level rise (approximately 2.2 mm/year). The Halifax sea level data are measured relative to land ("relative sea level"), and were used for the high-level hydraulic modelling as both effects increase the flooding potential in coastal areas. The sea level estimates were compared to the estimates developed in the 1981 study. The stationary sea level estimates were similar but slightly higher, which reflected the continuing rise in sea level. The non-stationary sea level estimates were significantly higher than the previous estimates.

The instantaneous annual maximum flow events and the annual maximum sea level events have similar seasonality of occurrence. However, the instantaneous annual maximum flow events and annual maximum sea level events have not occurred at the same time during the overlapping historical period of record. The floods and sea level data were found to be independent and the joint return period of flood and sea level occurring simultaneously was calculated as the product of the individual return periods. The relationship between floods and sea level (if there is one) was masked by other factors (such as the tidal variation). Such a relationship (if it exists) would be unimportant for floodplain modelling considering the magnitude of observed sea level variation.

High-level hydraulic modelling of the lower Sackville River

The purpose of the preliminary hydraulic model was to delineate the survey extent. The hydraulic impact of the sea level was found to be limited to the first 200 m of the river upstream from Bedford Basin. The modelling showed that the simulated water level near the confluence was very high; the interaction between the rivers may further increase flooding potential in this area. Several areas were identified as prone to flooding: Bedford Place Mall parking lot, condominiums on River Lane, Range Park, Department of National Defense gun range, Fish Hatchery Park, residential area east of Union Street near Bedford Place Mall, and Bedford Tower. The Bedford Place Mall entrance #1 and #2 bridges acted as hydraulic "bottle-necks," causing flooding in downtown Bedford.

Topo-bathymetric survey data collection

The hydraulic model cross-sections and the hydraulic structures (bridges) were surveyed. Several cross-sections above the confluence were surveyed to allow for more detailed modelling of the confluence during Phase II. In addition, a number of confirmatory survey points were collected in the floodplain. The confirmatory survey points agreed well with the LiDAR data obtained in 2007.

Historical review of flooding factors, including the ten largest precipitation events and the regional rainfall events

The main flooding factors identified in the Sackville and Little Sackville watersheds were rainfall, antecedent conditions, and snowmelt. The most significant flooding factor was rainfall, but different types of rainfall cause high flow events for each watershed. The rain events that result in high flows for the Sackville River watershed are mostly frontal systems with large accumulations and long durations. The rain events that result in high flows for the Little Sackville River watershed are mostly local convective systems with short durations and higher intensities. Wet antecedent conditions were significant factors for both watersheds, but less important for the Little Sackville River watershed. Snowmelt was a factor in approximately half of the peak flow events. Some bridges have ice jamming potential, but no evidence of historical ice jams causing flooding was found.

The ten largest 24-hour precipitation events were analyzed, and there was wide variation in their characteristics (duration, modality, and intensity). The Chicago distribution was the best-fitting distribution for the majority of the precipitation events, and also for the average of the ten largest precipitation events. Halifax Water also recommends the Chicago distribution, and using this distribution will ensure that the results are consistent with other design standards in use in the area.

Nova Scotia has the largest number of regional rainfall events out of the four Atlantic Provinces. The majority of the regional rainfall events occurred in the July to November period, and 75% of the events were not caused by hurricanes or extra-tropical storms. The Halifax area has a large number of winter storms; peak flow events in the Sackville River also often occurred in the winter. The Shearwater Auto IDF appeared to be the best estimate of the 24-hour, 100-year precipitation.

Recommendations

The non-stationary flood and sea-level frequency results are recommended for Phase II considering the increasing trends found in the time series and the updating frequency of floodplain mapping. It is recommended to periodically update the non-stationary flood and sea-level frequency analyses (every 5 years). The use of flood and sea-level frequency results generated for 2020 or another future year should also be considered. The relative sea level data are recommended for hydraulic floodplain modelling. It is recommended to use the absolute sea level data (removing effect of land subsidence) for other applications, such as investigating climate change impacts on sea level rise.

The discrepancies between the flood frequency results and the1987 and 1999 studies for Little Sackville River at Middle Sackville should be investigated in Phase II. Field work should be performed to determine if there are flow constrictions limiting channel hydraulic capacity. Flows at flow-change locations in the hydraulic model should be determined using combined hydrologic and hydraulic modelling, so that hydraulic routing effects are considered. The flow pro-rating coefficients should be verified with streamflow monitoring. In addition, a better understanding of the hydraulic conditions at the confluence should be developed by investigating the individual behaviour of the two watersheds and the interactions between the two rivers (e.g. timing of peak flows).

The potential for ice jam formation and the occurrence of historical ice jams at each water crossing should be determined. Partial blockage due to ice jams should be considered in Phase II. A scenario for potential future development in the Sackville River watershed should also be included in the Phase II study. Future development in the watershed will likely increase flow rates and volumes in the Sackville River and decrease response time.

The Chicago synthetic design storm is recommended for Phase II modelling. The worst-case ratio for time to peak to storm duration should be investigated in Phase II and backed up by historical observations. Long storm durations (one day or more) should be considered for the Sackville River, while short storm durations (one day or less) should be considered for the Little Sackville River. The historical storms that caused the five largest flow events should be considered for unsteady-state modelling purposes.

The potential to combine IDF curves to obtain a longer time series that is more representative of the precipitation characteristics near the Sackville River watershed should be investigated. Combining the IDF curves may only be feasible for long durations.

A detailed hydraulic model should be developed in Phase II which will utilize the topo-bathymetric survey data collected in this study, including modelling of the confluence. Additional historical high flow events should be used to calibrate the hydraulic model for both rivers.

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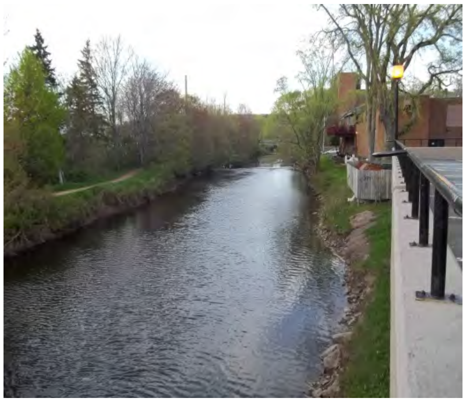
1. Introduction

1.1 Project Background



Historically, flood-related risks within the Halifax Regional Municipality (HRM) have been a significant issue. The lower reaches of the Sackville River have been the site of several instances of flooding over the last decade. In particular, the recent flooding event on December 10-11, 2014, caused severe flooding along Union Street in Bedford. Several hydrotechnical studies have been undertaken for this area (Interprovincial Engineering, 1981; Nolan Davis and Associates, 1987; Porter Dillon, 1999). A Hydrotechnical Study of the Little Sackville River delineated the floodplain in 1987 under the Canada-Nova Scotia Flood Damage Reduction Program (FDRP). Development policies were adopted by Halifax County Council in 1994 to control development in the floodplain. A follow-up study was performed in 1999 to revise the floodplain boundary, but no new policies have been adopted by Halifax Regional Council. The purpose of this study is to update the floodplain mapping for the Sackville Rivers. Accurate floodplain mapping is key to reducing flood damages and ensuring public safety in the Sackville River watershed.

The Little Sackville River watershed is approximately 16 km^2, while the Sackville River watershed is approximately 150 km^2. The two watersheds have been changing through time, with significant urbanization in the last 20 years. The Little Sackville River watershed is developed, but the Sackville River watershed is mainly rural and has a number of lakes. As a result, the two watersheds have different hydrologic response characteristics. The Sackville River system is a complex river system with interactions between the Sackville and Little Sackville rivers. Downstream from the confluence of the Little Sackville and Sackville Rivers, the lower Sackville River has a mild gradient and a number of man-made flow constrictions, which result in increased flooding potential. The majority of the flooding events occur in the October to March period. The major causes of flooding are one or more (as a combination) of: snowmelt, storm surge, convective or cyclonic rainfall, high sea level, and ice jams. The Sackville River discharges into Bedford Basin and sea level hydraulically impacts the lower reaches of the river. The highest sea levels also often occur in the October to March period. An understanding of the complex interactions within the watershed is key to developing accurate and representative floodplain maps.

In addition to the hydrological and hydraulic factors, further complexity in the watershed is added by the emerging effects of climate change. Canada's climate has warmed significantly over the past century. In Atlantic Canada, increases in air temperature are predicted to be most pronounced in winter, and smaller in summer and autumn. This is expected to result in earlier and more frequent snowmelt and decreased snow cover. By the mid-21st century, air temperatures are expected to rise by 2-4°C. Increased concentrations of greenhouse gases (GHGs) will not only increase air temperatures and induce earlier snowmelt, but also increase evaporation, which in turn will enhance the atmospheric moisture content, and consequently, extreme precipitation rates (Trenberth, 1999). According to the Intergovernmental Panel on Climate Change (IPCC, 2013), heavy precipitation events are expected to increase both in frequency and intensity under changing climate conditions. The return period of extreme precipitation events could be reduced by a factor of two or more by the end of this century (Kharin et al., 2007). Climate change has also caused mean sea level to rise globally (IPCC, 2013); and there is a regional "hotspot" for sea level rise along the North American Atlantic Coast (Sallenger, et al., 2012). Each of these effects can affect the flooding characteristics of the Sackville River.

Due to these challenges, the HRM wishes to update the 1999 Hydrotechnical Study. New (updated) land use and detailed 1 meter digital elevation model (DEM) data are now available. This Sackville Rivers floodplain study is focused on the lower reaches of the Sackville River (Figure 1.1). In addition, the study also develops an understanding of the flooding characteristics in the Little Sackville and Sackville Rivers. The flood risks associated with the backwater effect caused by tidal/storm surges in the Bedford Basin and the joint probability of these surges occurring simultaneously with a large flooding event are also investigated.

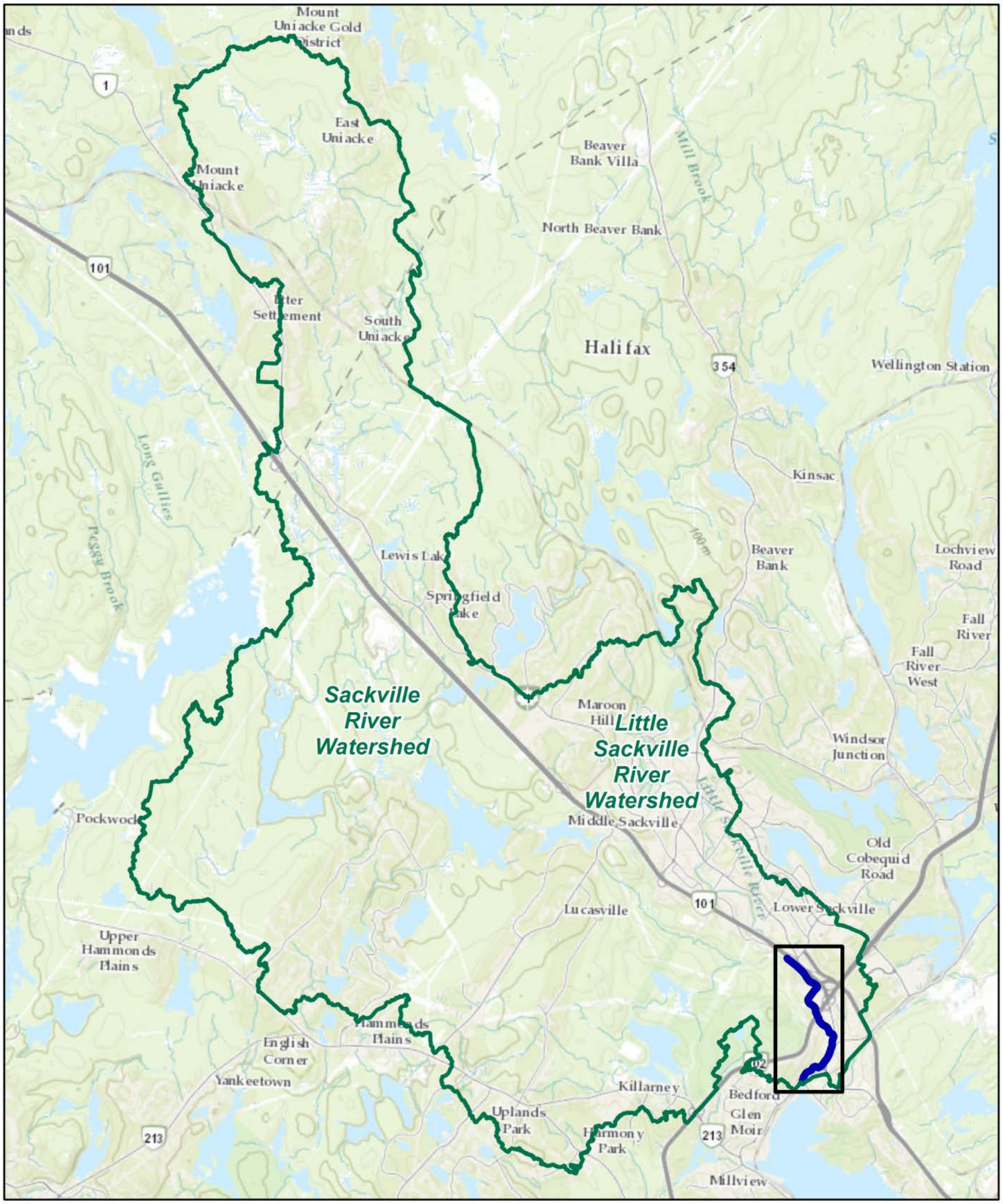
The objectives of this study are:

- Development of improved floodplain mapping for the Sackville Rivers, using the most current land use and topographic information available.
- Development of tools for effective mitigation of risks to people and property associated with flooding within these watersheds.

The study is organized in two Phases. The purpose of Phase I was to collect background information in preparation for Phase II. Phase II is a detailed hydrologic and hydraulic modelling study to generate the updated floodplain maps. This project represents Phase I of the study.

Phase I included several tasks.

- **Statistical flood and sea level frequency analysis**: Single station flood frequency analyses were performed for the Sackville River at Bedford and Little Sackville River at Middle Sackville Water Survey of Canada (WSC) stations. The flood frequency results were pro-rated to obtain the flood frequency estimates at the confluence of the Sackville River and Little Sackville River. A sea level frequency analysis was performed for the Halifax sea level gauge. Finally, the joint probability of floods and high sea level was determined.
- **Hydraulic modelling of the lower Sackville River**: A high-level hydraulic model was developed for the lower Sackville River to conduct a preliminary analysis of flooding extent and identify the required spatial extent for survey data collection.
- **Topo-bathymetric survey data collection**: Topographic and bathymetric survey data were collected for the entire floodplain identified by the high-level hydraulic model. Detailed data were obtained for river cross-sections. Confirmatory survey was performed for the floodplain, where topographic data were already available. In addition, the water crossings were also surveyed.
- **Historical review of flooding factors**: A review of the flooding factors for each of the instantaneous annual maximum flow events was performed for both WSC stations. The review was used to identify the main causes of floods in each of the two watersheds. The ten largest 24-hour precipitation events were also identified, and used to select an appropriate synthetic rainfall distribution. The regional rainfall events in the Atlantic Provinces with precipitation accumulations in the range of the 100-year precipitation event for Halifax were also analyzed.



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HALIFAX REGIONAL MUNICIPALITY
HALIFAX, NOVA SCOTIA
SACKVILLE RIVERS FLOODPLAIN STUDY: PHASE I

11102282-04
Oct 1, 2015

PHASE I STUDY AREA

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Figure 1.1 Phase I Study Area

1.2 Report Organization

The report is organized as follows. Section 2 presents the flood and sea level frequency analyses, including the flow pro-rating and joint flood and sea level probability analyses. The data sources, methodology, and results are described in detail. Section 3 presents the high-level hydraulic modelling analysis. The data sources, model setup and calibration, and results are presented. Section 4 discusses the topo-bathymetric survey data collection results. The survey extent, QA/QC and results are described in detail. Section 5 presents the historical review of flooding factors analysis. The results of the analysis of the flood factors, the ten largest precipitation events, and the regional rainfall events are all presented in detail. Sections 6 and 7 summarize the conclusions and recommendations. The results from each stage of the analysis are summarized, and recommendations for Phase II modelling are provided.

2. Flood and Sea Level Frequency Analysis

2.1 Data Sources

2.1.1 Previous Studies and Documents

HRM provided the following studies and documents to assist with Phase I of the Sackville Rivers Floodplain Study:

- Hydrotechnical Study of the Sackville River, Interprovincial Engineering, 1981
- Hydrotechnical Study of the Little Sackville River Floodplain, Nolan Davis and Associates, 1987
- Hydrotechnical Study of the Little Sackville River Floodplain, Porter Dillon Limited, 1999
- Halifax Harbour Extreme Water Levels in the Context of Climate Change: Scenarios for a 100-year Planning Horizon, Geological Survey of Canada Open File 6346, 2009
- As-built drawings for the water crossings in the lower reach of the Sackville River
- Historical air photos, news articles, and maps of flooding
- Flooding in Nova Scotia an Overview: 1759-1986, Environment Canada 1989
- Flooding Frequencies of Nova Scotia Streams – Technical Bulletin No. 4, Coulson, 1967
- Comparison of 24 hour (from Tipping Bucket Rain Gauge, TBRG) and one day (from daily data) extreme rainfall results for Halifax area stations and notes of two extreme events in 1942 and 1971, Environment Canada, 2014

2.1.2 Water Survey of Canada Streamflow Stations in the Sackville River Watershed

There are two Water Survey of Canada (WSC) gauges on the Little Sackville and Sackville Rivers (Table 2.1 and Figure 2.1). One station is located on the Little Sackville River, approximately 2.5 km upstream of its confluence with the Sackville River. The other station is located on the Sackville River, approximately 0.4 km upstream of its discharge into Bedford Basin.

Table 2.1 Water Survey of Canada Streamflow Stations in the Sackville River Watershed

Station ID	Station Name	Years of Data	Number of Years	Watershed Area
01EJ001	Sackville River at Bedford	1916-2012	43	146 km^2
01EJ004	Little Sackville River at Middle Sackville	1980-2012	32	13.1 km^2

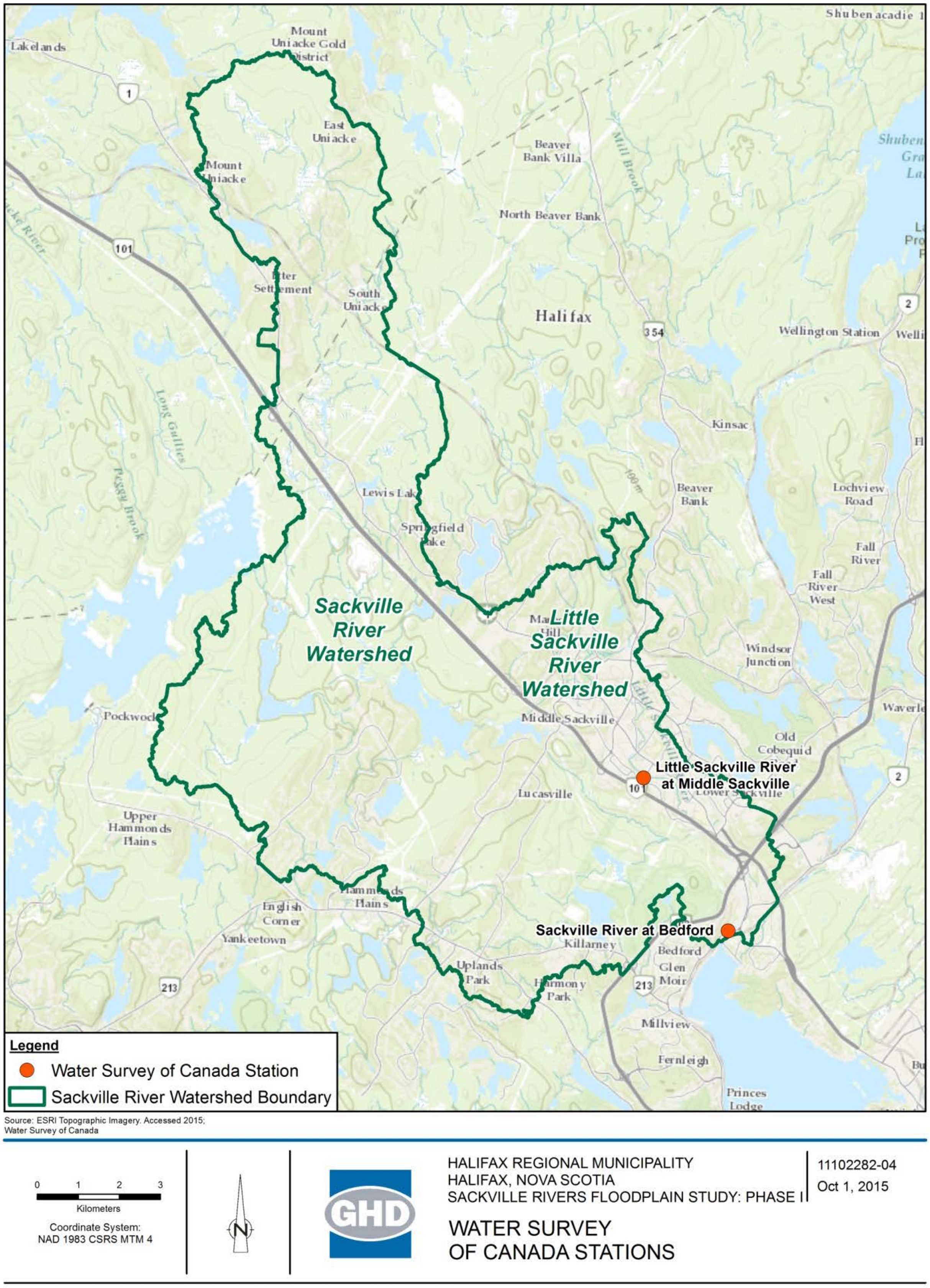


Figure 2.1 Locations of Water Survey of Canada Streamflow Stations in the Sackville River Watershed

It is recommended that there be a minimum of 30 years of data to perform a single-station flood frequency analysis (Environment Canada (EC), 1976). Both stations have more than 30 years of data available, and are therefore suitable for single-station flood frequency analysis.

Watershed changes such as deforestation and urbanization can greatly affect the hydrological response of a watershed. Similarly, climate change may change the hydrologic characteristics of the region. These effects can then be seen as changes in instantaneous annual maximum flow through time. Therefore, the data must be tested for outliers, change points, and trends, as these may have a large effect on the results of a frequency analysis. The instantaneous annual maximum flow rates for both stations are plotted in Figure 2.2. The linear best fit line for the entire data record is also included in the Figure. The Sackville River at Bedford annual maximum flow data were increasing slightly over the period of record but with considerable variation, while the Little Sackville River at Middle Sackville annual maximum flow data were neither increasing nor decreasing. In addition, the recent periods (1995-2012) of data for both stations show an increasing trend, particularly for the Sackville River at Bedford station.

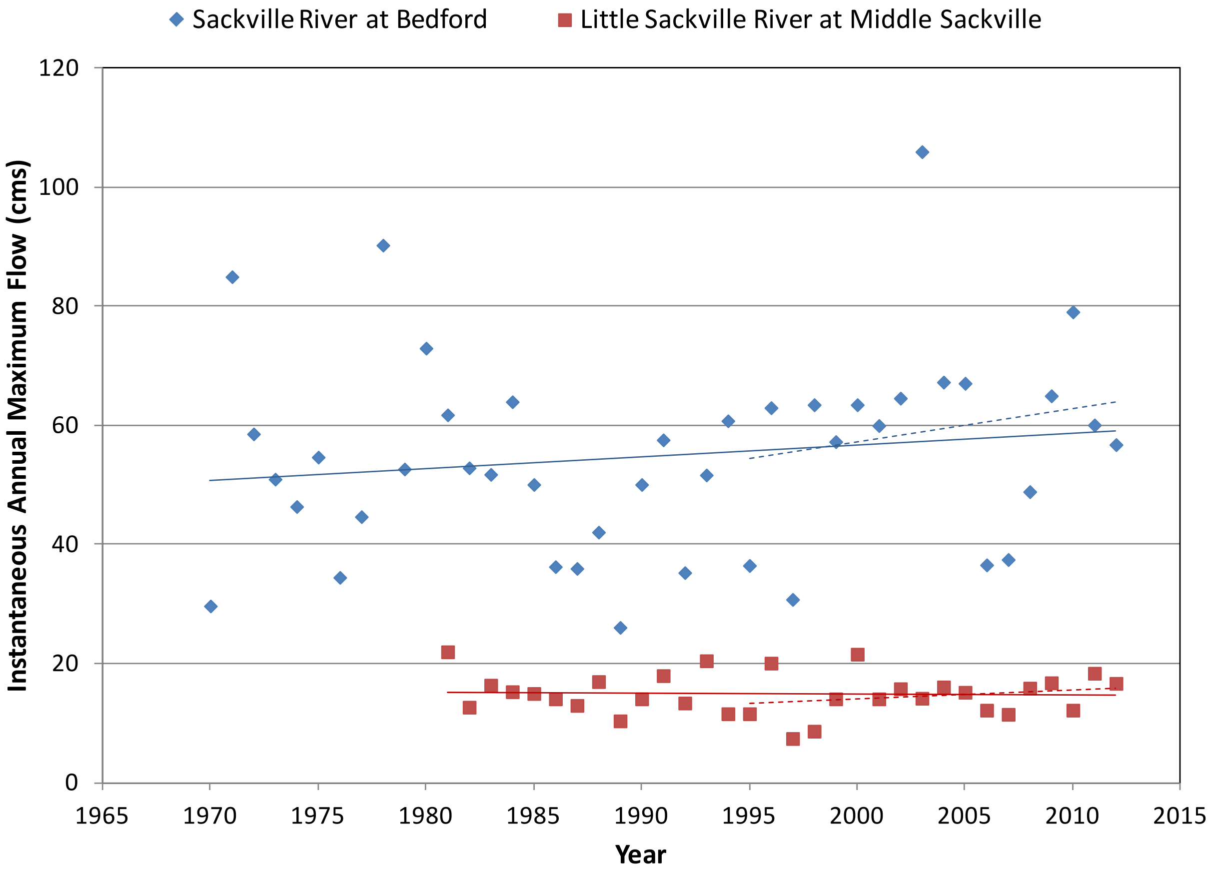


Figure 2.2 Instantaneous Annual Maximum Flow for Sackville River at Bedford and Little Sackville River at Middle Sackville Streamflow Stations

For the joint flood and sea level probability analysis, it was necessary to characterize the relationship between floods and sea level. The time series of daily average flow was used for this characterization, as it was necessary to examine multiple dates (not only the dates of the instantaneous annual maximum flow events).

2.1.3 Water Survey of Canada Streamflow Stations Near the Sackville River Watershed

For Phase I high-level hydraulic modelling of the lower reaches of the Sackville River, only the Sackville River at Bedford data were used in the hydraulic model. The flood frequency estimates at the WSC station were used for the full extent of the lower Sackville River. This was a conservative assumption, to ensure that the largest possible extent was obtained for the survey data collection. The Little Sackville River at Middle Sackville data were not used because the flow for the Little Sackville River is included in the Sackville River at Bedford data. The hydraulic model did not model the Little Sackville River, and hence the Little Sackville River data were not used.

For Phase II modelling, it may be necessary to use flood estimates at the confluence of the Little Sackville and Sackville Rivers, so that the hydraulic behaviour of the confluence of the two rivers may be modelled with greater accuracy. This region was identified during Phase I as critical due to its proximity to Highway 101 and the depth of the water for the 100-year flood. Therefore, the flood estimates at the confluence of the Little Sackville River and Sackville River were developed with a non-linear pro-rating model.

The 5-year, 20-year, and 100-year flood estimates for the Sackville River at Bedford and Little Sackville River at Middle Sackville stations were pro-rated according to watershed area to obtain the flood estimates at the confluence of the Little Sackville River and the Sackville River. The regional non-linear relationships between flood estimates and watershed area were found, using the two Sackville River stations and several nearby WSC stations. To be selected for the regional analysis, the WSC stations must have a minimum record length of 20 years, drain eastwards into the Atlantic Ocean, be geographically close to the Sackville River watershed, and be hydrologically similar to the Sackville River watershed. A 20-year threshold was chosen to ensure that sufficient data existed for reasonable return period estimates, but the threshold was low enough so that a reasonable number of stations would be selected. Table 2.2 and Figure 2.3 show the WSC stations near the Sackville River watershed that were selected to be included in the regional analysis. The instantaneous annual maximum data were used to produce 5-year, 20-year and 100-year flood estimates for each station. The regional flood to watershed area relationship was developed for each return period. The instantaneous annual maximum data for the four stations are plotted in Figures 2.4 to 2.7.

Table 2.2 Water Survey of Canada Streamflow Stations Near the Sackville River Watershed

Station ID	Station Name	Years of Data	Number of Years	Watershed Area (km^2)	Distance to Sackville River at Bedford (km)
01EK001	Musquodoboit River at Crawford Falls	1956-1995	40	650	38.0
01EG002	Gold River at Mosher's Falls	1966-1996	31	370	57.9
01EE001	Medway River at Charleston	1930-1994	65	1390	100.9
01EE002	Medway River at Harmony Mills	1945-1982	36	342	116.3

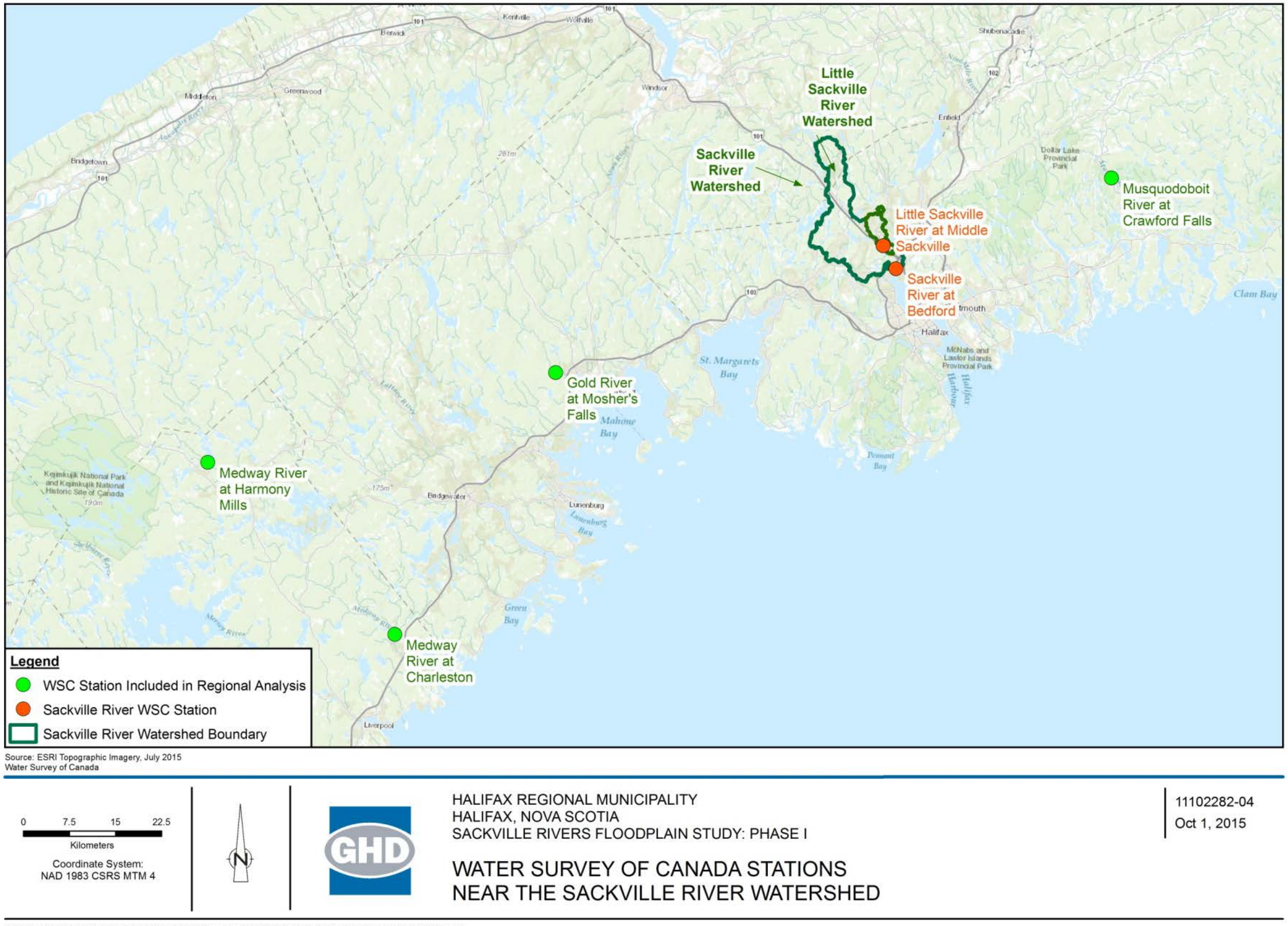


Figure 2.3 Locations of Water Survey of Canada Stations Near the Sackville River Watershed

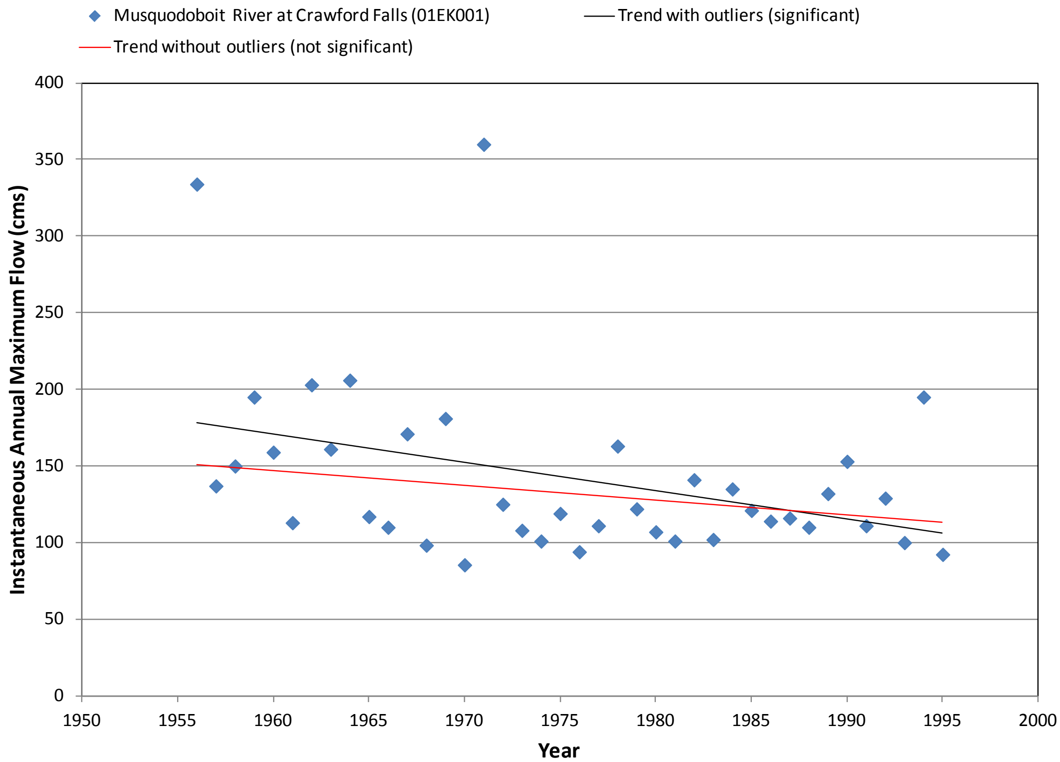


Figure 2.4 Instantaneous Annual Maximum Flow for Musquodoboit River at Crawford Falls (01EK001)

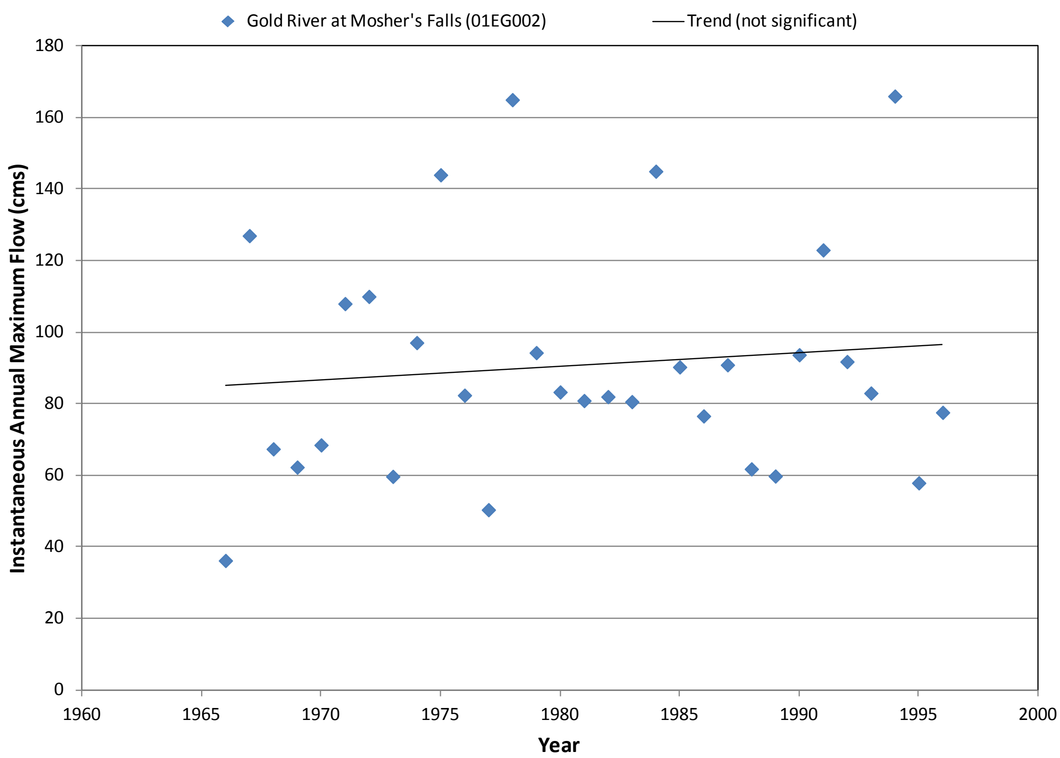


Figure 2.5 Instantaneous Annual Maximum Flow for Gold River at Mosher's Falls (01EG002)

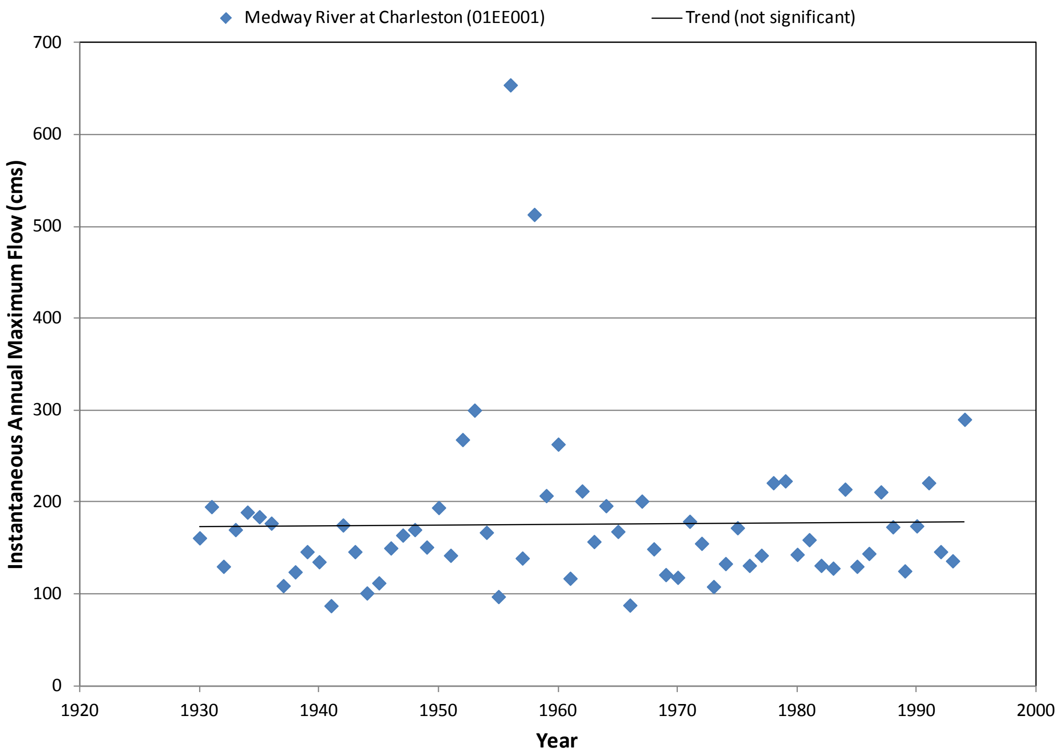


Figure 2.6 Instantaneous Annual Maximum Flow for Medway River at Charleston (01EE001)

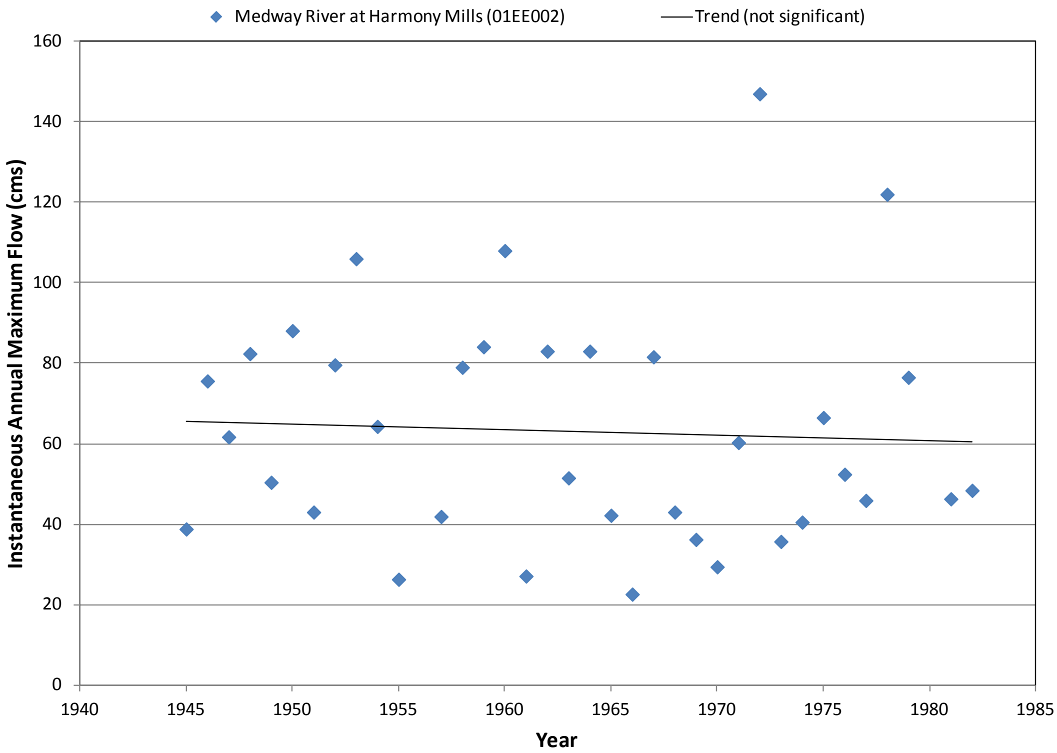


Figure 2.7 Instantaneous Annual Maximum Flow for Medway River at Harmony Mills (01EE002)

2.1.4 Department of Fisheries and Oceans Sea Level Stations

There are two Department of Fisheries and Oceans (DFO) gauges in the Bedford Basin (Table 2.3 and Figure 2.8). The Bedford Institute gauge is located at the southern end of the Bedford Basin. The Halifax gauge is located in the Narrows. Both gauges recorded hourly data in the past, but more recent measurements are recorded at 15-minute or 1-minute intervals.

Table 2.3 Department of Fisheries and Oceans Sea Level Stations

Station ID	Station Name	Years of Data	Number of Years
491	Bedford Institute	1972-2015	21
490	Halifax	1895-2014	102

Sea level data are recorded in the Lower Low Water at Large Tide (LLWLT) chart datum, but the Canadian Geodetic Vertical Datum 1928 (CGVD28) was used for the hydraulic model. The LLWLT chart datum is currently 0.8 m below CGVD28, but prior to 1987 it was 1.09 m below CGVD28. However, the DFO has already corrected the data prior to 1987 for the datum shift, and all data are recorded in the current LLWLT chart datum (DFO, 2015). Accordingly, the sea level data were converted to CGVD28 by subtracting 0.8 m for all years.

The Bedford Institute station is closer to the outlet of the Sackville River than the Halifax station and therefore represents a more accurate downstream boundary condition for the Sackville River hydraulic model. However, the Bedford Institute station time series is shorter than the Halifax station time series and is not suitable for frequency analysis (insufficient data). Therefore, the relationship between the two stations was examined, and the long time series of the Halifax data was adjusted to account for the differences between the stations. The Bedford Institute data were known to have quality issues prior to the rebuilding of the intake structure in 2004 (DFO, 2015). In addition, there have been structural failures at the intake structure for the Halifax gauge, and data after 2012 were also considered to be suspect (DFO, 2015). Therefore, the relationship was established by examining the data for the period 2004-2012. The Bedford Institute and Halifax hourly sea level data are compared in Figure 2.9. The Bedford Institute and Halifax data are similar, but the values at the Bedford Institute gauge are slightly higher. This is likely due to the higher temporal resolution of the Bedford Institute measurements: The Bedford Institute data were measured at a 1 min interval, while the Halifax data were measured at a 15 min interval. The hourly average of the 1 min data was slightly higher than the hourly average of the 15 min data. A best-fit line was used to adjust the annual maxima for Halifax to account for the differences between the gauges.

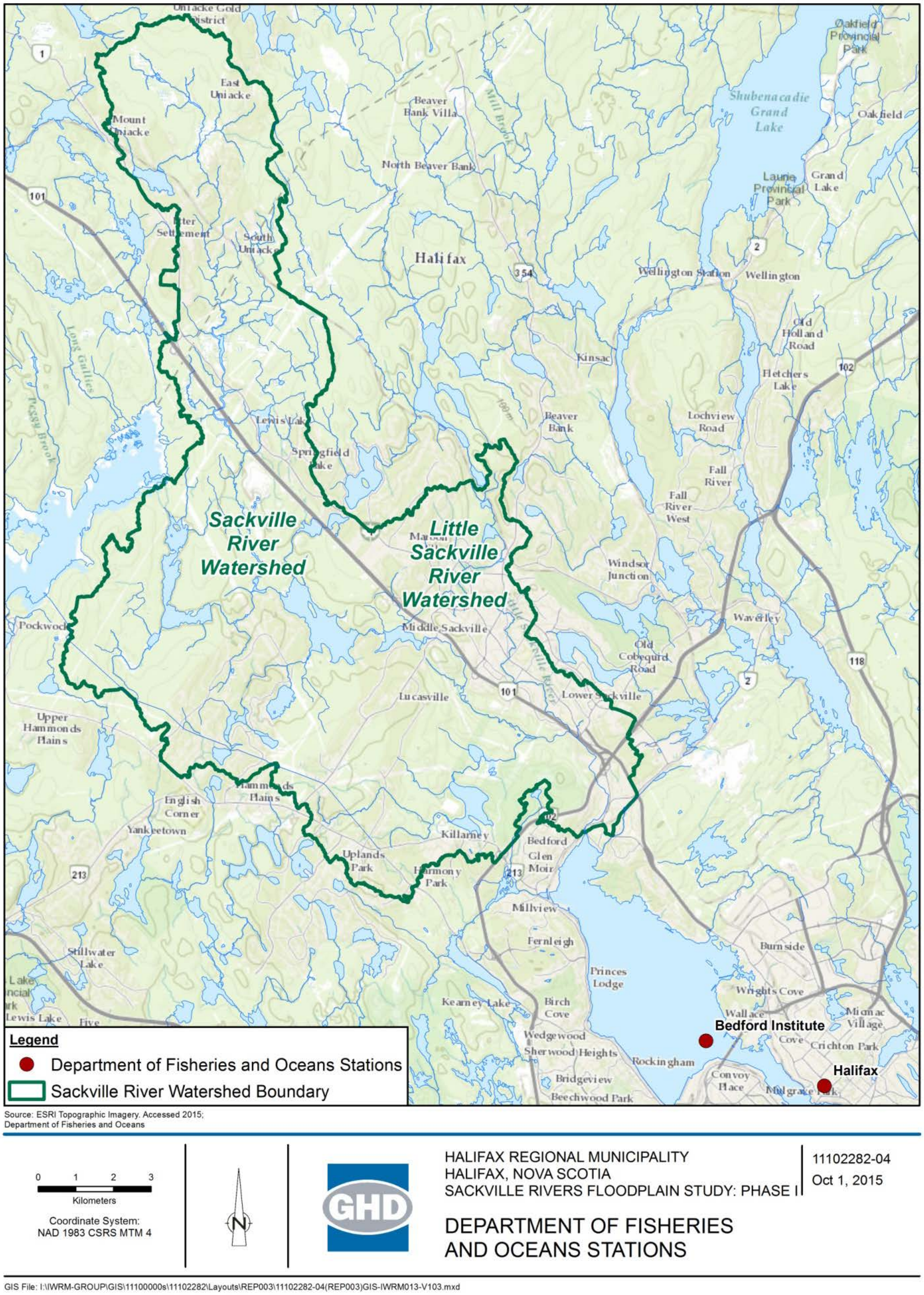


Figure 2.8 Locations of Department of Fisheries and Oceans Sea Level Stations

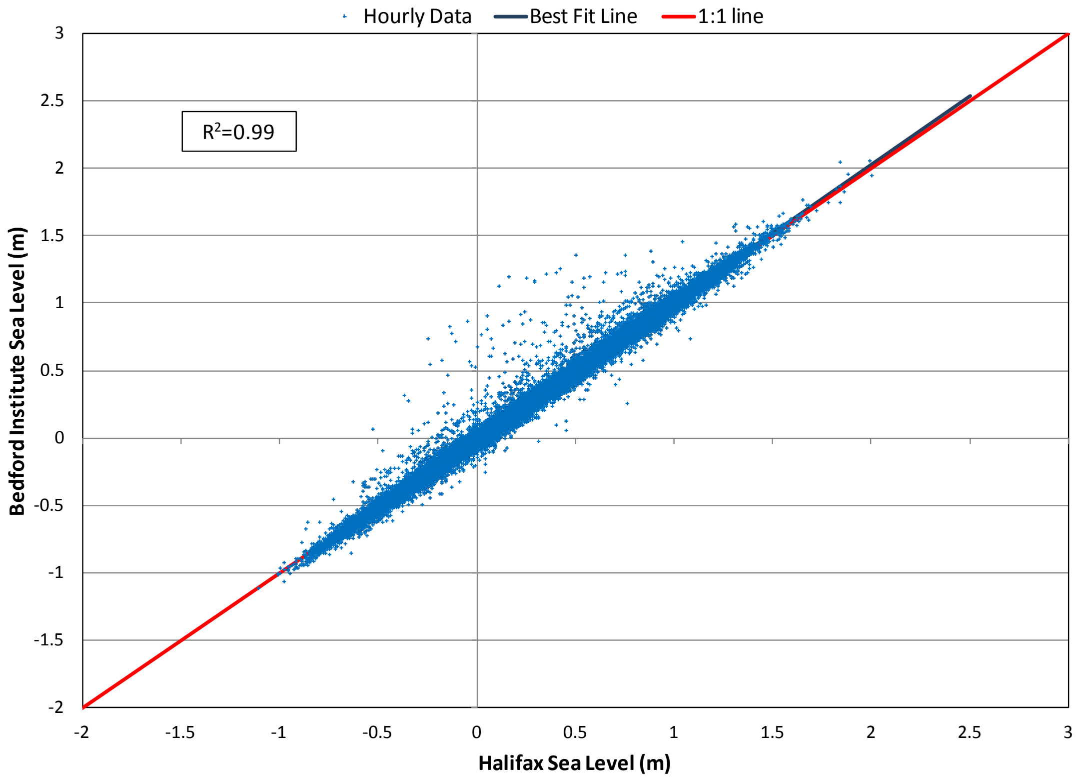


Figure 2.9 Bedford Institute and Halifax Sea Level Data, 2004-2012

The original and adjusted Halifax data are shown in Figure 2.10. The sea level frequency analysis was carried out for both sets of Halifax data. The data show a strong positive trend through time, which is consistent with other sea level stations in Nova Scotia (e.g., North Sydney and Yarmouth). A portion of the trend is due to local land subsidence. A Global Positioning System (GPS) that has been operating continuously at the Bedford Institute of Oceanography since 2002 has measured a subsidence rate of approximately -1.6 mm/year (downwards), based on 6 years of observed data (Forbes, et al., 2009). Several authors (Fader, 2005; Forbes, 2006; Gehrels, et al., 2004) suggested that there were insufficient data to qualify the rate as a long term trend. Gehrels, et al. (2004) predicted a much higher rate of land subsidence: approximately -3 to -4 mm/year with an additional -0.75 to -1.0 mm/year due to increased weight of water from sea level rise. The rate of land subsidence is not constant through time; it is expected to decrease exponentially over the next 2,000 years to zero (Pirazzolli, 1996). For the purpose of this report, the rate of -1.6 mm/year was used, and assumed constant in both time and space. The observed trend is greater than the rate of land subsidence, indicating that some of the trend is due to sea level rise. This is in agreement with observed global long-term sea level rise due to climate change and/or other factors (e.g., IPCC, 2013; Sallenger, et al., 2012).

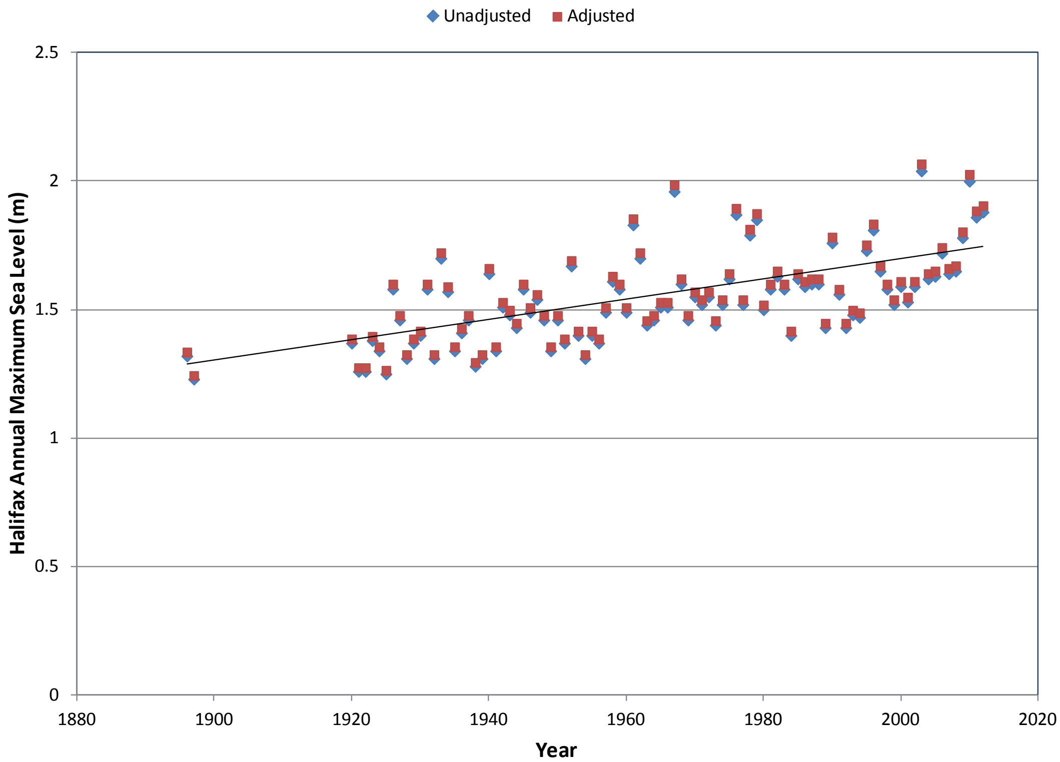


Figure 2.10 Original and Adjusted Halifax Annual Maximum Sea Level Data

For the joint flood and sea level probability analysis, it was necessary to characterize the relationship between floods and sea level. The original Halifax sea level time series data were used for this purpose. Daily data were used because only daily average flow data were available. Therefore, the hourly sea level data were aggregated to the daily resolution. The maximum hourly sea level for each date was used as the daily sea level in the joint flood and sea level probability analysis.

2.2 Methodology

2.2.1 Flood and Sea Level Frequency Analysis

The methodology used for the flood and sea level frequency analyses is illustrated in Figure 2.11. The first three steps of the analysis were used to perform QA/QC on the data. The data QA/QC identified if there were any potential issues with using the data for frequency analysis by checking for outliers, change points, and trends. Outliers may condition a frequency curve, and therefore should be investigated to determine if the outlier is valid data. Change points represent heterogeneity in the time series (the data do not come from the same underlying distribution). Trends represent non-stationarity in the time series (the data are changing through time). Frequency analysis assumes that the data are homogeneous and stationary. If the tests showed that the data contained heterogeneity or were non-stationary, the data and/or the methodology for the frequency analysis were adjusted. For heterogeneity, some of the data were potentially discarded from the analysis. For non-stationarity, non-stationary frequency analysis was performed. The results from the adjusted frequency analysis were compared with the results from the unadjusted frequency analysis (stationary analysis using entire time series). Following the data QA/QC, the candidate distributions were fit to the data, and goodness-of-fit testing was performed.

The best-fitting candidate distribution was used to develop estimates of the 5-year, 20-year, and 100-year events, and their associated confidence limits.

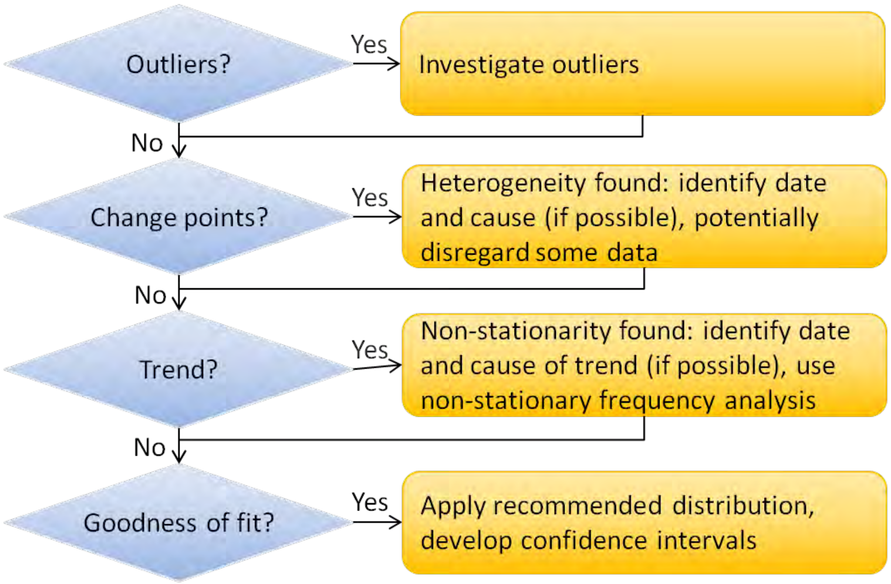


Figure 2.11 Flow Chart for Frequency Analysis

The next three subsections describe the methodology in greater detail. The data QA/QC testing procedure is described in Section 2.2.1.1; the distribution fitting procedure is described in Section 2.2.1.2; and the goodness-of-fit testing procedure is described in Section 2.2.1.3.

2.2.1.1 Data QA/QC Tests

The Grubbs test (Grubbs, 1969; Grubbs and Beck, 1972; also known as Extreme Studentized Deviate or Distance from the Mean) was chosen as the test for outliers. This test assumes that the data are normally distributed. The test statistic is the largest number of standard deviations away from the mean. The normal distribution is used to assign the level of significance of the test statistic. Since the annual maximum flow and sea level data were not normally distributed, the data were transformed using a log transformation to make the data normal prior to performing the test. In addition, as outliers may "mask" other outliers in the data, the single (tests most extreme value only) and double (tests the highest and lowest extreme values) outlier versions of the test were both performed. The test was applied iteratively in the case where there was more than one potential outlier on either the high or low sides. Graphical methods such as box plots and histograms were also applied to confirm the results.

The Pettitt test (Pettitt, 1979) was chosen as the test for change points in the time series. This test is nonparametric and assumes only that each observation is independent of the other observations. It is robust to outliers and non-normality. The Pettitt test calculates a rank-based test statistic, similar to the Mann-Whitney (Mann and Whitney, 1947) test statistic. For each timestep of the data, the data are divided into two groups at that timestep and the test statistic is calculated. The result of the test is the location with the highest test statistic (the most likely change point) and the level of significance of the test statistic. The null hypothesis is that there is no change point. The test statistic is compared to a table of critical values, at the chosen level of significance. If the test statistic is larger than the critical value, the null hypothesis is rejected and the alternate hypothesis (there is a change point) is accepted. Autocorrelation may affect the results of this test. Therefore, the test was performed twice: on the original data and on the pre-whitened data (autocorrelation removed). The pre-whitening method of Wang and Swail (2001) was used.

For the trend testing, the Mann Kendall test (Mann, 1945; Kendall, 1975) was combined with the Theil-Sen (Theil, 1950; Sen, 1968) robust line estimation. The Mann-Kendall test is a nonparametric test that determines if there is a statistically significant monotonic trend in a set of data. The trend can be either increasing or decreasing, and does not have to be linear. The test assumes a null hypothesis: that the data do not have a trend. To calculate the test statistic, the sign of the difference between each two data points is found. The total of all of the signs of the differences is determined. The test statistic is compared to a table of critical values, at the chosen level of significance. If the test statistic is larger than the critical value, the null hypothesis is rejected and the alternate hypothesis (there is a trend in the data) is accepted. The Mann Kendall test is known to falsely identify trends when there is autocorrelation in the data (von Storch and Navarra, 1995). Therefore, the portion of the trend due to autocorrelation was removed from the time series using the Wang and Swail (2001) pre-whitening method. The Theil-Sen robust line estimation is a nonparametric method of determining the linear slope of the trend in a set of data. It is relatively insensitive to outliers (as compared to least squares regression). The slope is defined as the median of the slopes between all pairs of points in the data set.

For this analysis, a 5 percent level of significance was chosen for all statistical tests. The tests were calculated using the "R" statistical analysis package (R Core Team, 2014). The tests returned a "p value", which is the lowest level of significance at which the null hypothesis can be rejected. If the p value was less than 0.05 (5 percent), the test indicated that the null hypothesis should be rejected, and that the alternative hypothesis should be accepted.

2.2.1.2 Distribution Fitting Method

EC (1976) recommended the use of four probability distributions for flood frequency analysis: Generalized Extreme Value Type I (Gumbel), Lognormal, 3-parameter Lognormal, and Log Pearson III (EC, 1976). In addition, the Generalized Extreme Value (GEV) distribution is also frequently used in contemporary hydrology. These five distributions were selected for consideration in this analysis.

The method of L-moments (Hosking and Wallis, 1997) was used to fit the distributions. L-moments are analogous to traditional moments (i.e., the second L-moment is an estimate of the variance in the data just as the second moment is an estimate of variance), and can be used to fit frequency distributions. L-moments are linear functions of the sample values. They avoid the non-linear transformations of data that are used in standard moments (e.g., the second moment squares the deviation from the mean), and which are known to bias the moments when there are extreme data. L-moments are virtually unbiased, have relatively small sampling variance and are less sensitive to outliers than traditional moments. Due to these characteristics, the method of L-moments has become popular for parameter estimation in hydrology. To ensure that the results were reasonable, the L-moment results were compared to the results obtained from the Maximum Likelihood Estimation (MLE) method recommended by EC (1976). However, the L-moments method is preferred over the MLE method for non-stationary frequency analysis because the MLE method searches for the optimal parameter values and does not allow the frequency curve to be adjusted for non-stationary data sets. Therefore, the L-moment results are presented in this report.

If there is a significant trend in the data, non-stationary frequency analysis is recommended. In traditional frequency analysis, it is assumed that the underlying hydrologic/climatologic factors affecting the data do not change through time (i.e., the data are stationary). Therefore, it can also be assumed that the moments do not change through time. This assumption is false when a trend exists in the data. Non-stationary frequency analysis allows one or more moments to vary through time. The mean and/or variance of the data may change over time. For this method, a time-varying function is fit to the data to obtain an equation to predict the mean/variance for any year (e.g., Cunderlik, et al., 2007). For this project, the Theil-Sen robust line estimation method was used to obtain a time-varying function for the mean. The variance was assumed stationary through time.

When using L-moments for first-order non-stationary frequency analysis, the first L-moment (the mean) is adjusted according to the time-varying function described above. This results in a frequency curve that agrees with the results of the trend analysis. However, non-stationary frequency analysis must be recalculated for each time horizon of interest. The results for this analysis were produced for 2015. The L-moments can be calculated on the original data or on the de-trended data. When the trend is removed from the data, the result is a time series that is stationary and suitable for frequency analysis. However, trend removal also results in changes to the variance, skew, etc. (some of the variance, skew, etc. is due to trend). This may result in decreased estimates for the return periods of interest. To be conservative, the analysis was performed on both the original data and the de-trended data, to determine the effect of any de-trending of the data on the results and to ensure that the largest possible flood or sea level estimates are found.

The five candidate distributions were fit to the data using the L-moments method. The best-fitting distribution was chosen according to the goodness-of-fit tests described in Section 2.2.1.3. For the best-fitting distribution, the 95% and 99% confidence limits were also calculated. The confidence limits were calculated using a parameter bootstrap approach. A Monte Carlo simulation was used to develop a large number of sets of data, and the resulting variation in results was used to calculate the confidence limits. The L-moment algorithms from the "R" statistical analysis package were used for this project (R Core Team, 2014).

If frequency estimates for a future year (e.g., 2020) are desired, it is necessary to extrapolate the time-varying function for the mean out to the year of interest. This may be performed, but the estimate assumes that the time-varying function will not change over time. (i.e., the trend in the data will neither increase nor decrease). If there is a change in the trend, the future frequency estimate will be incorrect.

2.2.1.3 Goodness-of-Fit Tests

The goodness-of-fit for each candidate distribution was assessed visually and using statistical tests. For the visual comparison, the quantile-quantile (QQ) and the return period plots were used. Two tests for goodness-of-fit were used: Kolmogorov-Smirnov and Chi-Square.

A quantile-quantile (QQ) plot is a plot of the theoretical quantiles compared to the actual quantiles. The empirical return period of each data point is calculated using the Hazen plotting position function. The empirical return period is used in the theoretical distribution to calculate the theoretical quantile. The theoretical quantile data are plotted on the x-axis, while the original data are plotted on the y-axis. If a distribution fits the data perfectly, the points will line up exactly along the 1:1 line.

A return period plot is a plot of the data against the return period. The empirical return period was calculated using the Hazen plotting position function. The data are plotted as points. The theoretical distribution is plotted as a continuous line. If a distribution fits the data perfectly, the data points will line up exactly along the theoretical distribution line. The return periods were plotted using the Gumbel variate, and therefore the Gumbel distribution was a straight line on the plot. The other four distributions were curved.

The nonparametric Kolmogorov-Smirnov (Kolmogorov, 1933; Smirnov, 1948) test compares two Cumulative Distribution Functions (CDFs). For a goodness-of-fit test, the empirical CDF of the data is compared to the theoretical CDF of the distribution being tested. To calculate the test statistic, the largest difference between the two CDFs (empirical and theoretical) is found. The test statistic is compared to a table of critical values, at the chosen level of significance. The null hypothesis is that the data are from the distribution being tested. If the test statistic is larger than the critical value, the null hypothesis is rejected and the alternate hypothesis (the data do not come from the distribution being tested) is accepted.

The Chi Square goodness-of-fit (Pearson, 1900) test is a discrete parameter test. In order to apply the test, the data must be divided into ranges, and the number of samples in each range must be determined. Most authors recommend that equi-probable bins should be used, and that the expected number of data points in each range should not be less than 5 (e.g., Croarkin and Tobias, 2015). As the test is sensitive to the number of bins chosen, the test was applied three times, using three different numbers of bins as follows:

$$nbins = int\left(\frac{ndata}{5}\right), int\left(\frac{ndata}{5}\right) - 1, or\ int\left(\frac{ndata}{5}\right) + 1$$

Where:

$nbins$ is the number of bins
$int(\cdot)$ is the integer operator
$ndata$ is the number of data points

The result for the majority of the tests was reported. The test assumes a null hypothesis: that the data come from the distribution being tested. The test statistic calculates the squared difference between the actual number of data points in each range and the expected number of data points in each range. The number of degrees of freedom for the test is found as the number of bins minus the number of distribution parameters minus one. The test statistic is compared to a table of critical values, at the chosen level of significance. If the test statistic is larger than the critical value, the null hypothesis is rejected and the alternate hypothesis (the data do not come from the distribution being tested) is accepted.

As for the QA/QC tests, a 5 percent level of significance was used. The tests were calculated using the "R" statistical analysis package (R Core Team, 2014), and the p value was used to accept or reject the null hypothesis.

2.2.2 Flow Pro-rating Analysis

The flow pro-rating methodology is illustrated in Figure 2.12. A regional analysis was performed to develop the flood to watershed area relationship for each return period. Potential stations to include in the analysis were identified and checked for hydrological similarity, as described in Section 2.1.3. The hydrological similarity was tested using the Hosking and Wallis (1997) homogeneity test. Monte Carlo simulation was used to generate a large number of sets of samples using the kappa distribution. For each sample, the regional average L-moment coefficient of variation (L-CV) is calculated (L-CV is equal to the second L-moment divided by the first L-moment). The variation in the L-CV is determined to calculate the test statistic. If the test statistic is less than one, then the region is "acceptably homogeneous". If the test statistic is between one and two, then the region is "possibly heterogeneous". If the test statistic is greater than two, then the region is "definitely heterogeneous". The QA/QC process described in Section 2.2.1.1 was followed for each station, and data quality issues were investigated. A stationary flood frequency analysis using L-moments was performed for each station to develop the 5-, 20-, and 100-year flood estimates, using the frequency distribution selected for Sackville River at Bedford and Little Sackville River at Middle Sackville.

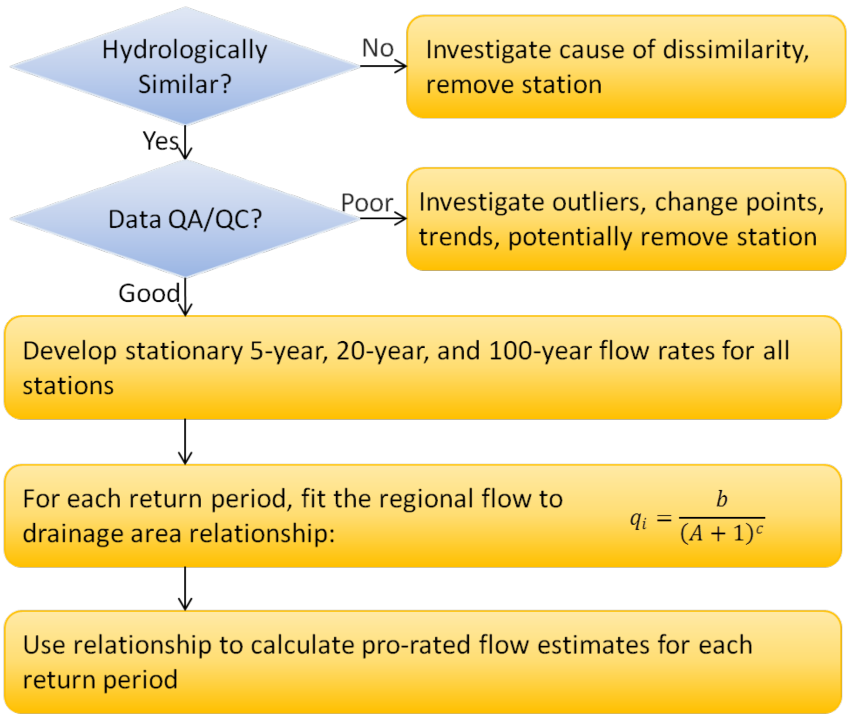


Figure 2.12 Flow Chart for Flow Pro-rating Analysis

For each return period, the regional flood to watershed area relationship was developed. The following equation was used:

$$q_i = \frac{b}{(A+1)^c}$$

Where:

- q_i is the regional specific flood estimate ($m^3/s/km^2$)
- i is the return period of interest (5-, 20-, or 100-year)
- A is the watershed area (km^2)
- b, c are empirical parameters obtained from the best-fit solution for the region.

The relationship was used to pro-rate the flood estimates to the confluence of the Little Sackville and Sackville Rivers, using the watershed areas listed in Table 2.4.

Table 2.4 Watershed Areas for Sackville River Watershed

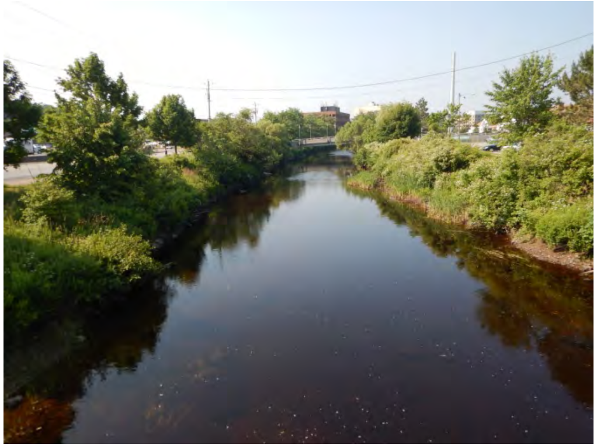
Location	Watershed Area (km^2)
Little Sackville River at Middle Sackville (WSC station)	13.1
Little Sackville River Above Confluence with Sackville River	15.6
Sackville River at Bedford (WSC station)	146.0
Sackville River Above Confluence with Little Sackville River (excludes Little Sackville River watershed area)	124.5
Sackville River Below Confluence with Little Sackville River (includes Little Sackville River watershed area)	140.1

2.2.3 Joint Flood and Sea Level Probability Analysis

Joint flood and sea level probability analysis is required to determine the return period associated with a combination of high river flow and high sea level. The joint flood and sea level probability varies according to the level of dependence between the flood and sea level. If two events are independent, the joint probability is the product of the individual probabilities. If two events are fully dependent, then the probabilities of the two events are always equal to each other and the joint probability is equal to the probability of the events. However, joint probability is not trivial in the case of partial dependence. In this case, a high river flow is expected to be partially correlated with a high sea level. This section describes the method used to determine the level of correlation between floods and sea level, and hence the joint return periods.

2.2.3.1 Determining the Level of Correlation

The methodology for determining the level of correlation is shown in Figure 2.13. It is necessary to determine whether the variables are correlated or independent. As a first check, a seasonal analysis was performed to determine when the annual maxima for flow and sea level occur, so that the behaviour of the annual maxima for both variables could be understood. If the annual maxima for the two variables did not occur in the same part of the year then the variables were considered to be independent. If the annual maxima did occur in the same part of the year, the degree of correlation between the annual maxima was found. If no correlation was found between the annual maxima of both variables, then the correlation between the peaks over threshold (POT) for both variables was examined.



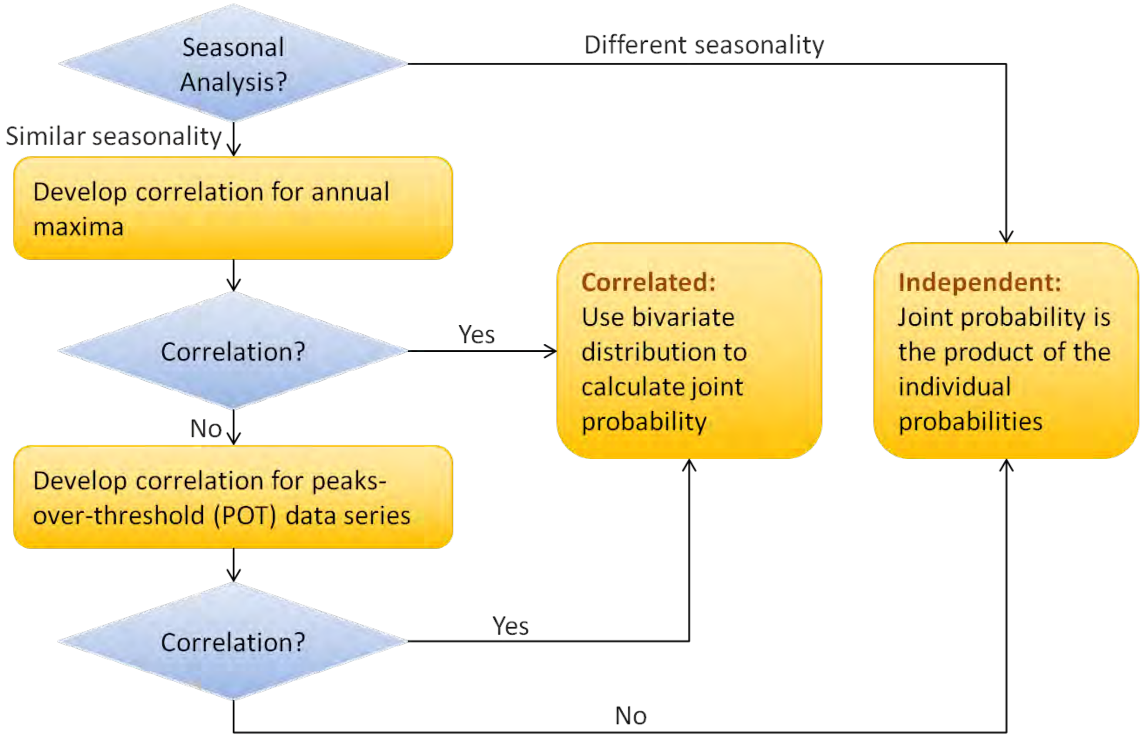


Figure 2.13 Flowchart for Determining Level of Correlation

For the seasonal analysis, a radial (polar) plot of the frequency of occurrence of the annual maxima in each month of the year was used. The plot was used to define the months of the year when the annual maxima have occurred historically. If the annual maxima have not occurred in the same months of the year, then different hydrologic/meteorologic factors cause annual maxima in each variable, and the variables are therefore independent. In this case, the joint flood and sea level probability is the product of the individual probabilities.

Following the seasonal analysis, the correlation coefficient for the annual maxima was determined. Yue (2000a, 2000b, 2001a, 2001b) developed several bivariate frequency distributions to describe correlated variables. The methods used the product moment correlation coefficient between the annual maxima. If the two variables had the same distribution, the product moment correlation coefficient was calculated from the data. If the two variables had different distributions, the two variables were transformed to normal using the Box-Cox transformation and the product moment correlation coefficient was calculated on the transformed data. The Box-Cox transformation is defined as:

$$y_i = \frac{x_i - 1}{\omega} \qquad \omega \neq 0$$

$$y_i = \log x_i \qquad \omega = 0$$

Where:

y_i is the transformed data

x_i is the original data

ω is the transformation parameter to fit the data to a normal distribution, selected by the method of Maximum Likelihood

The product moment correlation coefficient is defined as:

$$\rho = \frac{E\left[(x - \mu_x)(y - \mu_y)\right]}{\sigma_x \sigma_y}$$

Where:

ρ is the product moment correlation coefficient

$E[\cdot]$ is the expected value operator

x, y are the two variables (flow and sea level in this project)

μ_x, μ_y are the means of the two variables

σ_x, σ_y are the standard deviations of the two variables

If the correlation determined from the analysis of the annual maxima was inconclusive, a POT analysis was performed. For instance, an inconclusive result would occur if the annual maxima between flow and sea level have not occurred on the same date in the historical record, but the seasonal analysis indicates that the annual maxima for both variables occur in the same months of the year. Hawkes (2005, 2008) developed the correlation between two variables with a POT approach. To develop the POT data series, it was necessary to define a minimum separation distance between peaks, to ensure that the peaks are independent events. In Hawkes (2005), a minimum separation of one day between peaks was used for waves and tides. However, for flood events, a single day of separation may be insufficient to obtain independent events. A five-day separation was selected. Hawkes (2008) suggested the use of multiple thresholds, but found that the best correlation coefficients were obtained using the top 10% of the data. For this report, various thresholds were used, ranging from the top 5% to the top 15% of the data. Peaks that were below the threshold were not included in the correlation. The threshold should be high enough that low peaks are removed, but also low enough that sufficient peaks remain in the analysis. If too many or too few peaks are used in the analysis, the correlation is affected (i.e. too much noise or insufficient data). The analysis was performed twice; the first analysis required that the flood and sea level peaks occur on the same day, and the second analysis required that the flood and sea level peaks were at most one day apart (three-day search window for peaks). Hawkes (2005, 2008) transformed the data to a normal distribution before calculating the correlation. For this report, the correlation was determined for both the untransformed and the transformed data. The Box-Cox transformation was used.

Hawkes and Svensson (2003) used the ranges shown in Table 2.5 for their dependence mapping between floods, wave heights, and sea levels in the United Kingdom. They obtained correlation coefficients in the range of -0.1 to 0.9. For very low correlation coefficients (≤0.11), they assumed that the two variables were independent. This implies that information about one of the variables (e.g., the flood) cannot be used to predict the value of the other variable (e.g., the sea level). As a result, the joint return period is a product of the individual return periods.

Table 2.5 Level of Dependence for Different Correlation Coefficients

Level of Dependence	Correlation Coefficient Range
Independent	$\rho \le 0.11$
Modest	$0.12 \le \rho \le 0.37$
Well	$0.38 \le \rho \le 0.53$
Strong	$0.54 \le \rho \le 0.70$
Very strong	$\rho > 0.70$

Source: Hawkes and Svensson (2003)

A negative correlation implies that when flow is high, that sea level is likely to be low (and vice-versa). Theoretically, this would result in return periods greater than the product of the individual return periods (i.e. it is highly unlikely for a 100-year flood and a 100-year sea level to occur at the same time, and the joint return period is greater than 10,000 years). However, there is no physical basis for the use of a negative correlation. For instance, the two highest surge events (difference between sea level and tidal prediction) recorded at Halifax did not occur during a high spring tide, but if they had, they would have represented the two highest sea level events in the monitoring period history of the Halifax station (Forbes, et al., 2009). The negative correlation may therefore be due to other effects (such as the timing of the tides relative to the historical flood events) and not due to an actual negative relationship between the variables (i.e., there is correlation but not causation). For this report, it was assumed that negative correlation implied no correlation, regardless of the value of the correlation coefficient. This is a conservative assumption, as it limits the maximum joint return period to the product of the individual return periods.

2.2.3.2 Calculating the Joint Return Period

After the level of correlation was determined, the joint return period was calculated. If the variables were found to be independent, the joint return period was calculated as:

$$T(x,y) = T_x \times T_y$$

Where:

$T(x,y)$ is the joint return period

T_x, T_y are the individual return periods

If the variables were found to be correlated, the joint return period was calculated using an appropriate bivariate frequency distribution. If the variables come from the same distribution, the logistic function can be used to describe the inter-relationship of the variables (e.g., Yue, 2001a). If the variables come from different distributions, the bivariate normal distribution can be used with the transformed variables (e.g., Yue, 2000a; Loganathan, et al., 1987). The joint probability density function of the bivariate normal distribution is:

$$f(x,y) = \frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-\rho^2}} exp\left\{-\frac{1}{2(1-\rho^2)}\left[\left(\frac{x-\mu_x}{\sigma_x}\right)^2 - 2\rho\left(\frac{x-\mu_x}{\sigma_x}\right)\left(\frac{y-\mu_y}{\sigma_y}\right) + \left(\frac{y-\mu_y}{\sigma_y}\right)^2\right]\right\}$$

Where:

$f(x,y)$ is the joint probability density function

x, y are the two variables (transformed to normal)

μ_x, μ_y are the means of the two variables (transformed to normal)

σ_x, σ_y are the standard deviations of the two variables (transformed to normal)

ρ is the product moment correlation coefficient

The joint probability of exceedance is obtained by numerically integrating the joint probability density function for both variables greater than the quantiles of interest. The joint return period is then the inverse of the joint probability of exceedance.

2.3 Results

2.3.1 Flood Frequency Analysis

Box and Whisker plots for both WSC stations are included in Figure 2.14. The "box" part of the plot represents the first, second, and third quartiles of the data; the box extends from the first quartile to the third quartile, and the second quartile is the bold line inside the box. The "whiskers" extend to the furthest data point that is inside 1.5 times the height of the box (the interquartile range). If there are points outside of 1.5 times the interquartile range, they are drawn as data points above/below the whiskers. These data points may represent outliers. The highest flow for Sackville River at Bedford was outside of 1.5 times the interquartile range. As a result, the daily average flow hydrograph for this period was checked for consistency. In addition, nearby stations were examined to determine if they also experienced a high flow on that date. No concerns were identified with the data point, and the outlier test did not identify the point as an outlier after the data were normalized with the log transform. Therefore, the point was retained in the analysis. The data for Sackville River at Bedford were skewed. The data for Little Sackville River at Middle Sackville were not skewed, and there were no data outside of 1.5 times the interquartile range. The QA/QC results are summarized in Table 2.6. There were no statistically significant outliers, change points, or trends in the data. The highest flow for Sackville River at Bedford was not an outlier (at the 5 percent level of significance) after the log transformation was applied. Although the line fit to the Sackville River at Bedford data in Figure 2.2 indicated a small upward trend in the data, the trend was not statistically significant at the 5 percent level of significance and may therefore have arisen by sampling variability. In addition, the larger trend observed in the 1995-2012 part of the time series was also not statistically significant at the five percent level of significance. The positive trend observed in the 1995-2012 part of the time series for Little Sackville River at Middle Sackville was also not statistically significant at the five percent level of significance. Since the trend in annual maximum flow is based on only one flow rate per year, it is possible to "miss" a trend due to multiple peaks and/or a general increase/decrease in flow (e.g. due to more/less precipitation overall). Therefore, the mean annual flows were also calculated for each year for each station. For both stations, the mean annual flow was trending slightly downwards, but the trends were not statistically significant (at the 5% level of significance). The mean annual flows for the period 1995-2012 were also examined. There were upward trends in both stations, but they were not statistically significant (at the 5% level of significance).

Table 2.6 QA/QC Results for Water Survey of Canada Streamflow Data

Station ID	Station Name	Outliers	Change Points	Trend
01EJ004	Little Sackville River at Middle Sackville	None	None	None
01EJ001	Sackville River at Bedford	None	None	None

As no concerns were identified with the data during the QA/QC analysis, a stationary flood frequency analysis using L-moments was performed for both stations. The five candidate distributions were fit to the data, and the goodness-of-fit tests were applied. Figures 2.15 and 2.16 present the QQ and return period plots for Sackville River at Bedford, while Figures 2.17 and 2.18 present the QQ and return period plots for Little Sackville River at Middle Sackville. Table 2.7 summarizes the results of the goodness-of-fit tests for both stations. The 5-, 20-, and 100-year stationary flood frequency estimates for all distributions are included in Appendix A.

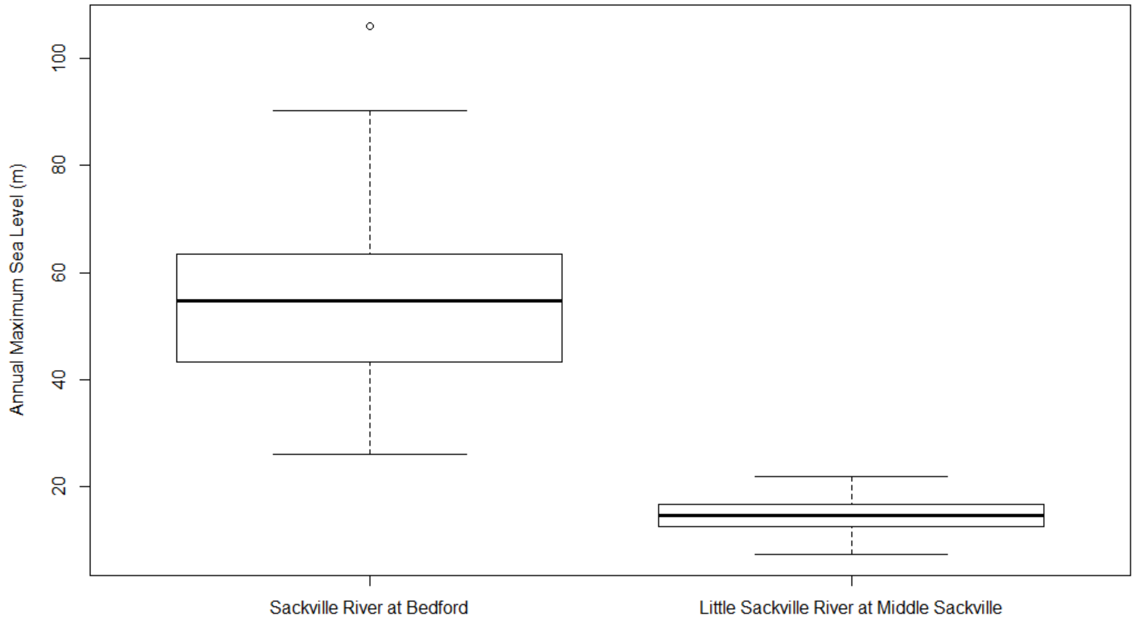


Figure 2.14 Box Plots for Sackville River at Bedford and Little Sackville River at Middle Sackville Streamflow Stations

The Kolmogorov-Smirnov test indicated that all distributions were acceptable for both stations. The Chi-Square test indicated that none of the distributions were acceptable for the Sackville River at Bedford data, and that all of the distributions were acceptable for the Little Sackville River at Middle Sackville. However, the results of the Chi-Square test did not necessarily imply that none of the distributions were acceptable for the Sackville River at Bedford station, because some of the information about the data is lost during the binning process. This is a weakness of the Chi-Square test. Therefore, the fit of the distributions was further checked with the QQ and return period plots. The QQ and return period plots indicated that the Gumbel and Lognormal distributions fit the extreme data for Sackville River at Bedford very well. The Gumbel distribution provided slightly higher estimates. The three parameter distributions fit the extreme data for Little Sackville River at Middle Sackville better than the Gumbel and Lognormal. However, it was desired to choose one distribution for both stations. As the Sackville River at Bedford station is located near the discharge of Sackville River into Bedford Basin, it was considered to be critical for floodplain modelling in the lower reach. The Gumbel distribution provided the best estimates for Sackville River at Bedford, and the highest estimates for Little Sackville River at Middle Sackville. The main differences between the five distributions for the Little Sackville River were noticed for the largest return period, 100-years. The 100-year flood estimates ranged from 23.2 cms (Log Pearson III) to 26.3 cms (Gumbel). These were all considerably lower than previous estimates, as shown in Table 2.9 (Nolan Davis, 1987; Porter Dillon, 1999). Therefore, the highest estimate (Gumbel) was used, as it was closest to the results of previous studies (but still lower). Any potential overestimation of floods at Little Sackville River at Middle Sackville due to the use of the Gumbel distribution was considered to be acceptable as it represented the lowest decrease from previous estimates and was therefore the most conservative for floodplain delineation. Therefore, the Gumbel distribution was chosen as the distribution for Sackville River at Bedford and Little Sackville River at Middle Sackville.

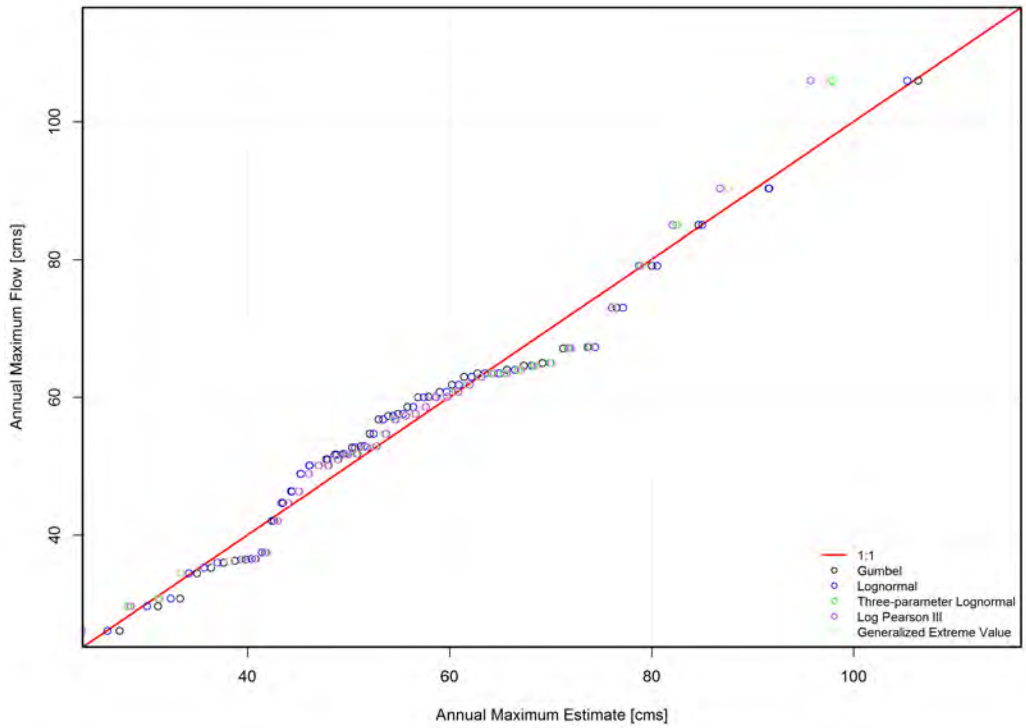


Figure 2.15 Quantile-Quantile Plot for Sackville River at Bedford Streamflow Station

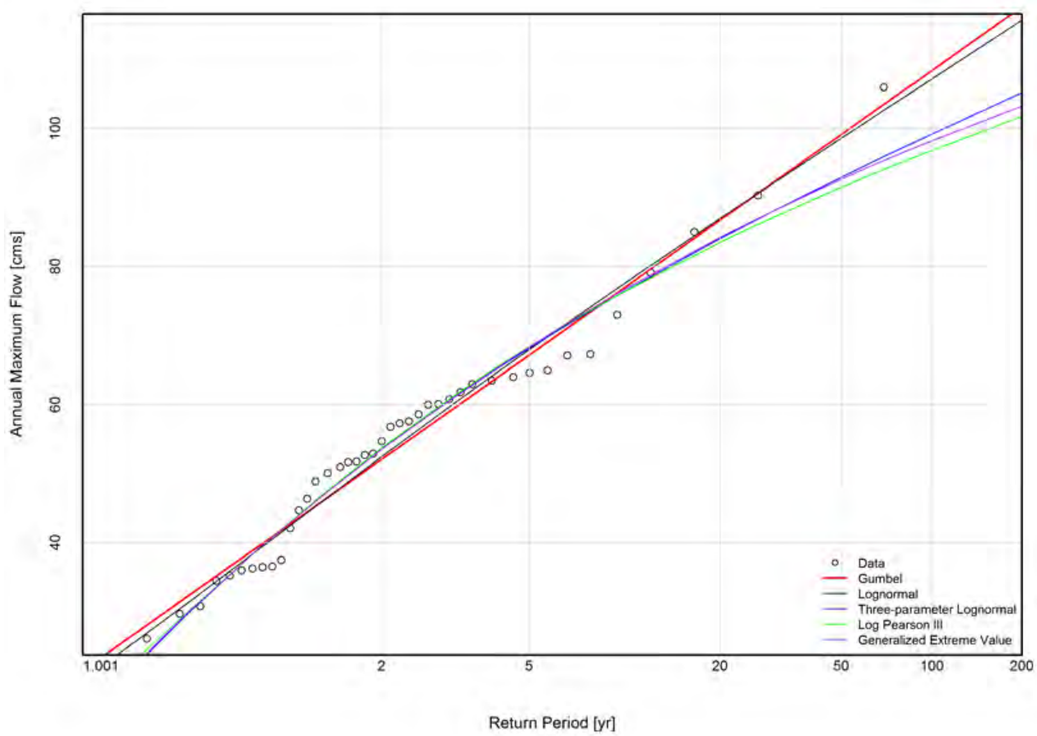


Figure 2.16 Return Period Plot for Sackville River at Bedford Streamflow Station

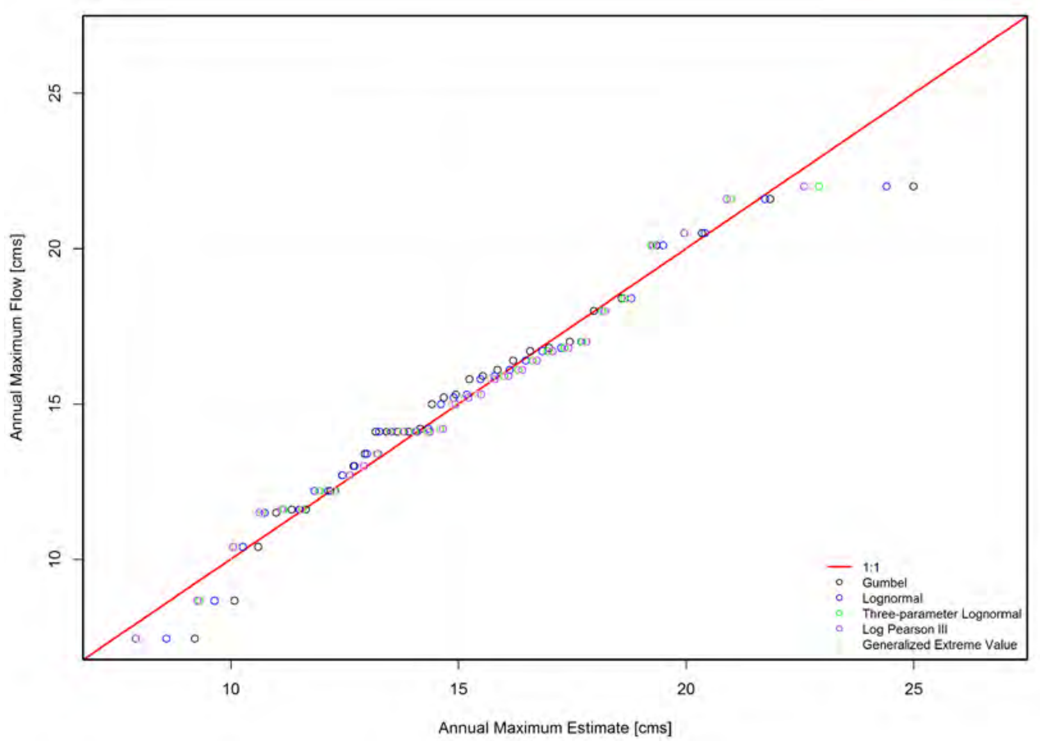


Figure 2.17 Quantile-Quantile Plot for Little Sackville River at Middle Sackville Streamflow Station

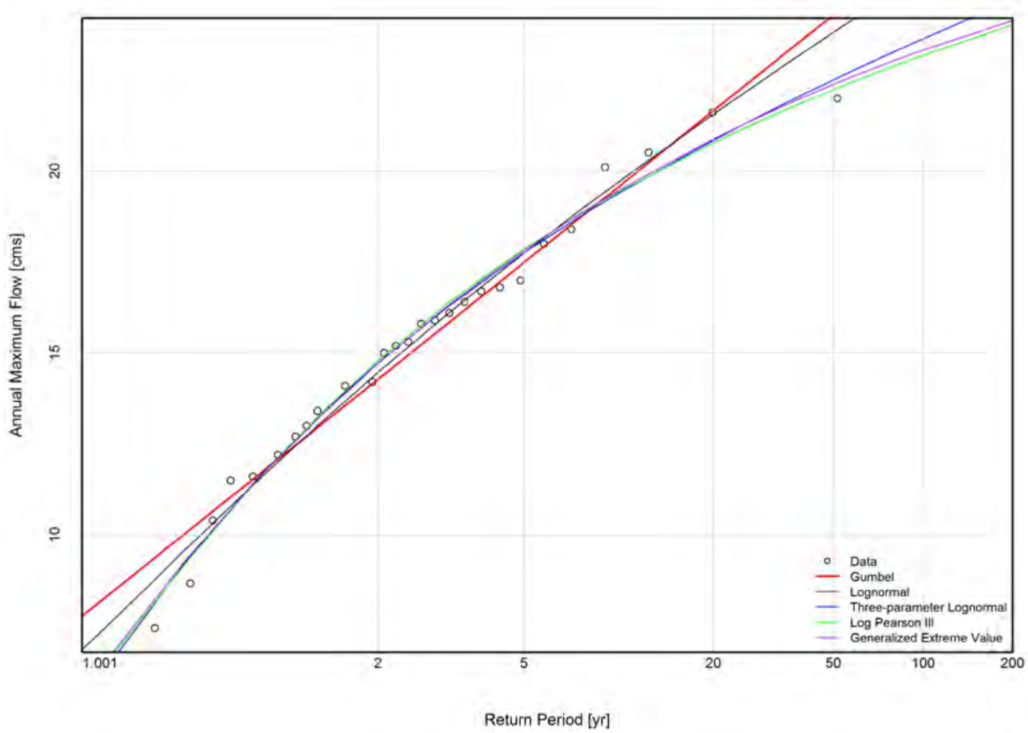


Figure 2.18 Return Period Plot for Little Sackville River at Middle Sackville Streamflow Station

Table 2.7 Goodness-of-Fit Results for Water Survey of Canada Streamflow Data

Distribution Name	Kolmogorov-Smirnov test	Chi-Square test
Sackville River at Bedford		
Gumbel	Accept	Reject
Lognormal	Accept	Reject
3-parameter Lognormal	Accept	Reject
Log Pearson III	Accept	Reject
Generalized Extreme Value	Accept	Reject
Little Sackville River at Middle Sackville		
Gumbel	Accept	Accept
Lognormal	Accept	Accept
3-parameter Lognormal	Accept	Accept
Log Pearson III	Accept	Accept
Generalized Extreme Value	Accept	Accept

The Gumbel distribution was used to obtain flood frequency estimates for the 5-year, 20-year, and 100-year return periods. In addition, a non-stationary flood frequency analysis was performed for Sackville River at Bedford (with de-trending and without de-trending of the data), even though the trend was not statistically significant at the 5 percent level of significance. It is possible that the trend may become statistically significant in the near future and, therefore, the non-stationary analysis was performed in order to ensure that a conservative estimate was used in the hydraulic model for calculating the survey extent. The Theil-Sen line for the instantaneous annual maximum data for Sackville River at Bedford was:

$$Q_Y = -427.07 + 0.2423Y$$

Where:

Q_Y is the mean annual maximum flow estimate in year Y (cms)

Y is the four digit year of the analysis (2015 for this report)

The 2015 mean was therefore 61.2 cms, compared to a long-term mean of 54.9 cms. A future year mean may also be calculated with this equation. However, the use of the equation to estimate a future year mean assumes that the magnitude of the trend will not change over time. The extrapolated 2020 mean was 62.4 cms. This value could then be used with the L-moment analysis to generate frequency estimates extrapolated to 2020.

The results are summarized in Table 2.8, and plotted in Figures 2.19 and 2.20. The worst-case flood estimates for Sackville River at Bedford (highlighted in red) were used for the high-level hydraulic modelling. The purpose of Phase I modelling was to define the extent of the worst-case flooding event so that survey data collection could be performed for the entire floodplain, and therefore the non-stationary results were used. The trend was not statistically significant and there was considerable variation around the trend. As a result, the non-stationary estimates were within the 95% confidence limits of the stationary flood frequency estimates. The results extrapolated to 2020 are also included in the Table 2.8. The flood estimates increased by approximately 1 cms for 2020. This may have an effect on the floodplain mapping throughout the lower Sackville River. The flood estimates for other return periods are included in Appendix A.

Table 2.8 Flood Frequency Analysis Results for Water Survey of Canada Streamflow Data

Return Period	Stationary (cms)	Non-Stationary (2015)		Non-Stationary (2020 Extrapolation)[1]	
		No De-trending (cms)	De-trending (cms)	No De-trending (cms)	De-trending (cms)
Little Sackville River at Middle Sackville					
5-year Estimate (95% Confidence Interval) (99% Confidence Interval)	17.5 (15.8 – 19.4) (15.3 – 20.0)	N/A	N/A	N/A	N/A
20-year Estimate (95% Confidence Interval) (99% Confidence Interval)	21.7 (18.5 – 25.4) (17.6 – 26.5)	N/A	N/A	N/A	N/A
100-year Estimate (95% Confidence Interval) (99% Confidence Interval)	26.3 (19.7 – 34.0) (17.9 – 36.2)	N/A	N/A	N/A	N/A
Sackville River at Bedford					
5-year Estimate (95% Confidence Interval) (99% Confidence Interval)	67.2 (60.4 – 75.0) (58.4 – 77.4)	73.4 (66.7 – 81.2) (64.5 – 83.5)	73.2 (66.5 – 80.7) (64.4 – 83.0)	74.7 67.9 – 82.4 65.7 – 84.7	74.4 67.7 – 81.9 65.6 – 84.2
20-year Estimate (95% Confidence Interval) (99% Confidence Interval)	86.7 (73.8 – 102) (70.7 – 107)	93.0 (79.9 – 108) (76.8 – 113)	92.3 (79.5 – 107) (76.4 – 112)	94.2 81.1 – 110 78.0 – 114	93.5 80.7 – 109 77.6 – 113
100-year Estimate (95% Confidence Interval) (99% Confidence Interval)	108 (81.8 – 140) (74.4 – 151)	115 (87.7 – 146) (80.1 – 156)	113 (87.0 – 144) (79.5 – 154)	116 88.8 - 147 81.2 – 157	115 88.2 – 145 80.6 – 155

Notes:
[1] Extrapolation to 2020 assumes that the existing trend does not change until 2020. Extrapolated estimates are not for design purposes and should be used with caution.

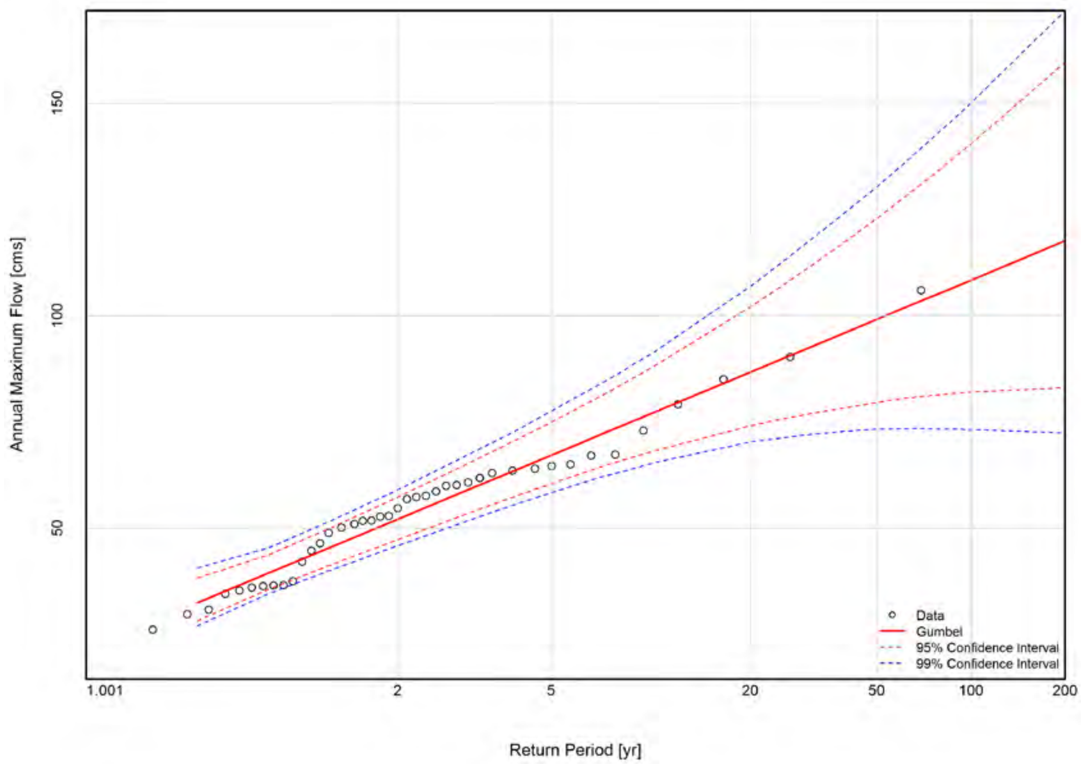


Figure 2.19 Return Period Plot with Confidence Limits for Sackville River at Bedford Streamflow Station

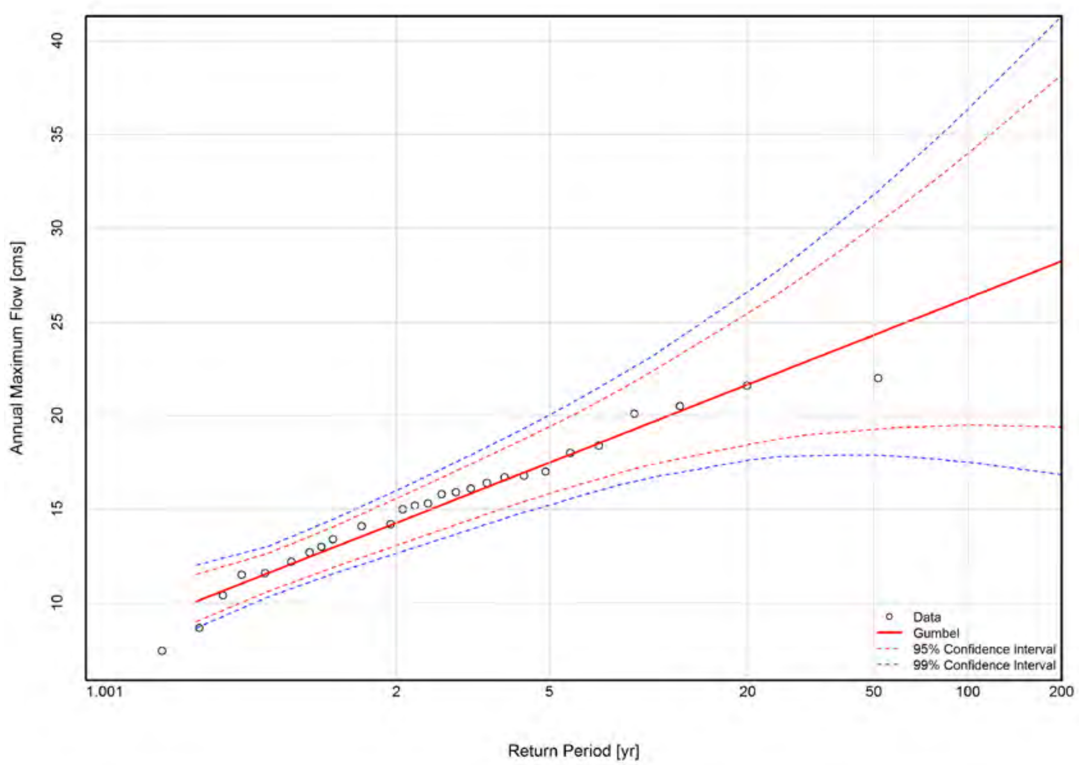


Figure 2.20 Return Period Plot with Confidence Limits for Little Sackville River at Middle Sackville Streamflow Station

The comparison between the stationary single station flood frequency analyses and the previous studies is provided in Table 2.9. This is the first time that there have been sufficient data to perform a single station flood frequency analysis at both stations. The previous flood estimates for the Sackville River at Bedford were derived from a regional flood frequency analysis (Interprovincial Engineering, 1981). The estimates obtained from the single station flood frequency analysis performed in this project were similar to the previous results. For the Little Sackville River at Middle Sackville, the previous flood estimates were derived from an OttHymo model in the Nolan Davis (1987) and Porter Dillon studies (1999). The Porter Dillon (1999) estimates are higher than the Nolan Davis (1987) estimates. The Porter Dillon (1999) report attributes the increase to the increase in the area of the subwatersheds located in the upper reaches of the watershed (due to a review of the stormwater drainage system) and to the increased impervious fraction due to the increased degree of urbanization of the watershed. The five-year flow estimate from the frequency analysis and the Nolan Davis (1987) report were similar, but the flood frequency analysis results are lower than the results from the Nolan Davis (1987) report, and significantly lower than the results from the Porter Dillon (1999) report for the other two return periods. The largest instantaneous annual maximum flow event recorded for Little Sackville River at Middle Sackville was 22.0 cms on July 21, 1981 (32 years of data). This is lower than the 20-year flood estimate from the Nolan Davis (1987) report and considerably lower than the 20-year flood estimate from the Porter Dillon (1999) report. These results indicate that there may be hydraulic flow constrictions near or upstream of the WSC gauge that limit flow and/or that there are other factors limiting the flow. Note also that the use of the Gumbel distribution for Little Sackville River at Middle Sackville represented a potential overestimation of the flood quantiles, indicating that the potential discrepancies between the frequency analysis and the previous studies may be even greater than that indicated in Table 2.9.

Table 2.9 Comparison Between Stationary Flood Frequency Analyses and Previous Studies

Return Period (Years)	Stationary Frequency Analysis Estimate (cms)	1981 Interprovincial Engineering Study (cms)	1987 Nolan Davis Study (cms)[1]	1999 Porter Dillon Study (cms)[1]
Sackville River at Bedford				
5	67.2	Not reported	N/A	N/A
20	86.7	80.5	N/A	N/A
100	108	109.4	N/A	N/A
Little Sackville River at Middle Sackville				
5	17.5	N/A	17.8	Not reported
20	21.7	N/A	24.5	26.9
100	26.3	N/A	32.1	40.9

Notes:
1 Results shown for the midpoint between Hydrologic Reference Points 2 and 3

The flood frequency results are summarized in Table 2.10. The stationary results for Little Sackville River at Middle Sackville and the non-stationary results for Sackville River at Bedford are presented.

Table 2.10 Summary of Flood Frequency Analysis Results

Return Period (Years)	Estimate	95% Confidence Interval (cms)	99% Confidence Interval (cms)
Sackville River at Bedford			
5	73.4	66.7 – 81.2	64.5 – 83.5
20	93.0	79.9 – 108	76.8 – 113
100	115	87.7 – 146	80.1 – 156
Little Sackville River at Middle Sackville			
5	17.5	15.8 – 19.4	15.3 – 20.0
20	21.7	18.5 – 25.4	17.6 – 26.5
100	26.3	19.7 – 34.0	17.9 – 36.2

2.3.2 Flow Pro-rating Analysis

The four stations identified for use in the regional flow pro-rating analysis were combined with the two Sackville River stations. The Hosking and Wallis (1997) regional homogeneity test was applied to the six stations. The test statistic was less than one, indicating that the region was "acceptably homogeneous" and suitable for development of a regional flow pro-rating equation. The QA/QC results for the WSC stations near the Sackville River watershed are summarized in Table 2.11. There were statistically significant outliers at two of the stations, where the two largest flows at each of the stations were both outliers. There were no statistically significant change points or trends at any of the stations.

Table 2.11 QA/QC Results for Water Survey of Canada Streamflow Data near the Sackville River Watershed

Station ID	Station Name	Outliers	Change Points	Trend
01EK001	Musquodoboit River at Crawford Falls	Two largest flows	None	None[1]
01EG002	Gold River at Mosher's Falls	None	None	None
01EE001	Medway River at Charleston	Two largest flows	None	None
01EE002	Medway River at Harmony Mills	None	None	None

Notes:
1 No trend after outliers removed

Outliers may be caused by either measurement error and/or extreme climatic conditions. Therefore, the outliers were examined to determine if there were any issues with the data. The daily average time series of the station was obtained from WSC. For both stations, the peak flow rates for the year 1956 were outliers. The flow data were due to an event on January 9-10, 1956. The hydrographs for both stations were similar to each other, indicating that it was an extreme climatic event and not caused by measurement error. For the Musquodoboit River at Crawford Falls station, the peak flow rate for 1971 was also an outlier. The hydrograph for this event (August 16, 1971) looked reasonable. This event was also measured at the Sackville River at Bedford station (Hurricane Beth) and represented one of the highest recorded flow rates at that location. For the Medway River at Charleston station, the peak flow rate for 1958 was also an outlier. The hydrograph for this event (January 17, 1958) looked reasonable. This event was also measured at several nearby stations. It was the peak flow for 1958 at those stations and represented a relatively large flow. Therefore, although the outliers were statistically significant, there were no valid reasons to discard the data. As a result, the outliers were retained in the analysis.

There were no statistically significant trends at any station. Note that for the Musquodoboit River at Crawford Falls station, the presence of the two large flow events near the beginning of the time series caused an apparent downward trend in the data (see black line on Figure 2.4). However, non-stationarity in a time series is indicated by a long-term trend in the data, not by the presence of outliers. Therefore, the trend test was applied to the remaining data (following removal of the outliers). The remaining data had a small decreasing trend, but it was not statistically significant at the 5% level of significance (red line on Figure 2.4). Therefore, there was no long-term, statistically significant trend in the remaining data and the data at this location were considered to be stationary. Note that the outliers were only removed from the analysis for the purpose of determining if there was a long-term trend in the data. The outliers were retained in the analysis for the purpose of developing the regional flow pro-rating equations.

The method of L-moments was used to fit the Gumbel distribution to each location using a stationary analysis. The goodness-of-fit test results are summarized in Table 2.12. The Gumbel distribution was accepted for all stations with the Kolmogorov-Smirnov test, but was rejected for one station with the Chi-Square test. It is possible that the two outliers at this station caused a poor fit. The 5-, 20-, and 100-year flood estimates for each station were obtained. The 5-, 20-, and 100-year flood estimates were converted to specific flow by dividing by the watershed area. The specific flow rates were plotted against watershed area and used to fit the regional flow to watershed area relationship. Figures 2.21 to 2.23 present the results of the analysis and the relationship equations that were obtained. In each case, the R^2 was 0.97 or higher.

Table 2.12 Goodness-of-Fit Results for Gumbel Distribution for Water Survey of Canada Streamflow Data near the Sackville River Watershed

Station ID	Station Name	Kolmogorov-Smirnov	Chi-Square Test
01EK001	Musquodoboit River at Crawford Falls	Accept	Reject
01EG002	Gold River at Mosher's Falls	Accept	Accept
01EE001	Medway River at Charleston	Accept	Accept
01EE002	Medway River at Harmony Mills	Accept	Accept

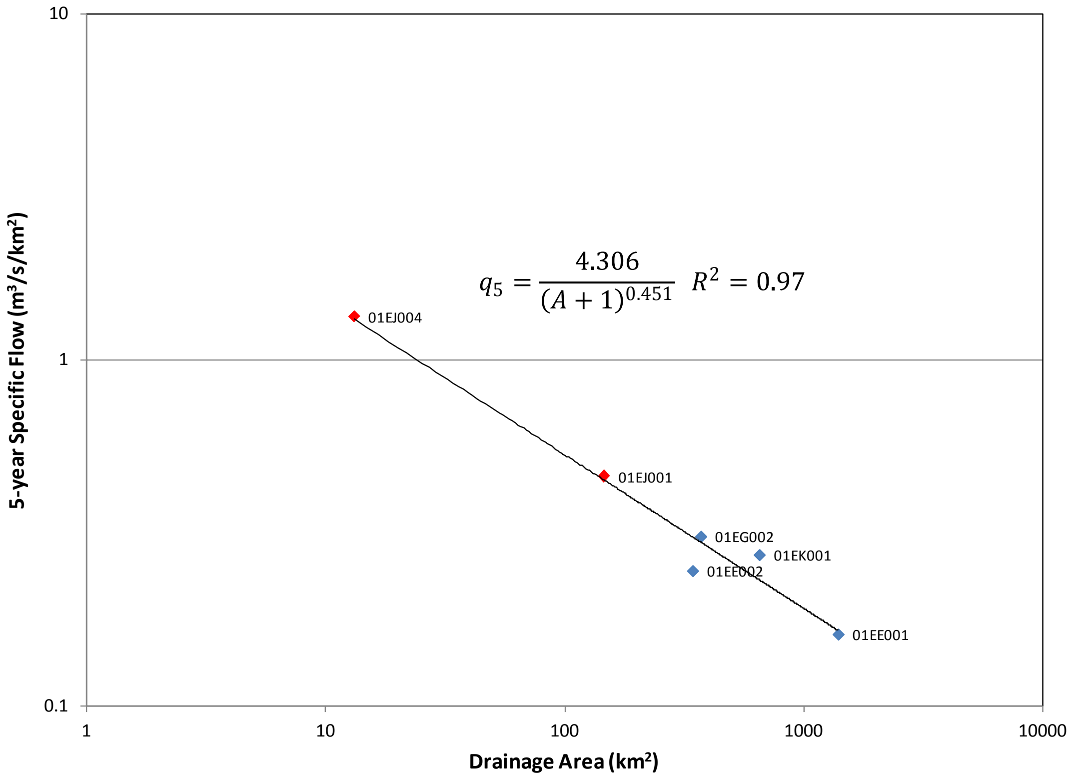


Figure 2.21 Regional Flow to Watershed Area Relationship for 5-Year Flood

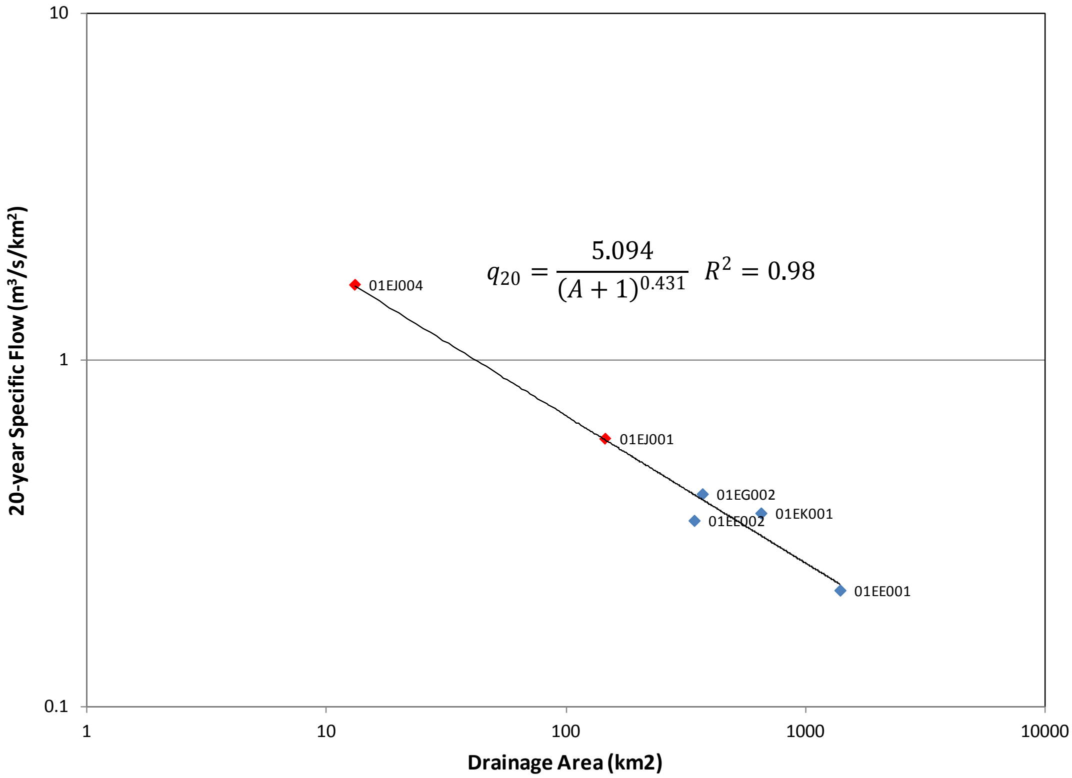


Figure 2.22 Regional Flow to Watershed Area Relationship for 20-Year Flood

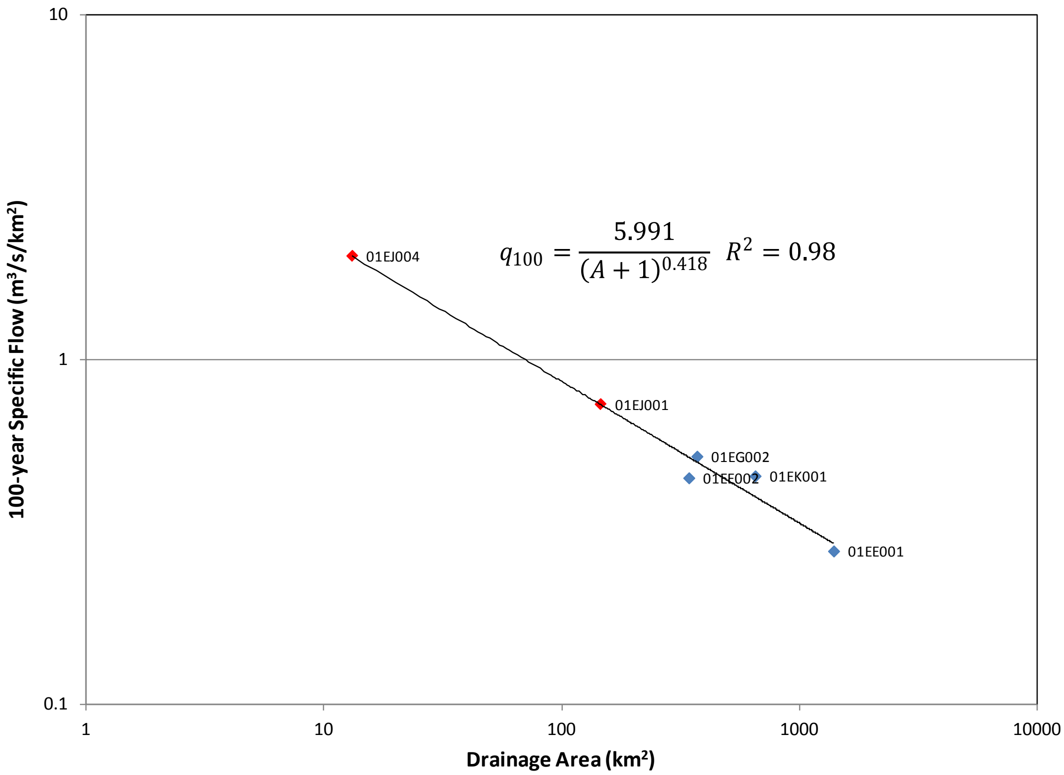


Figure 2.23 Regional Flow to Watershed Area Relationship for 100-Year Flood

Table 2.13 presents the pro-rated flow values for the Little Sackville River and Sackville River watersheds (stationary flood frequency analysis). The differences between the Little Sackville River at Middle Sackville (WSC station) and the entire Little Sackville River watershed were small (e.g., the 100-year flood estimate at the confluence was 110% of the WSC station flood estimate). Much higher ratios were obtained by the Otthymo hydrologic model in the Porter Dillon (1999) and Nolan Davis (1987) studies (124% and 123%, respectively). The differences between the Sackville River at Bedford (WSC station) and the Sackville River at the confluence (including the Little Sackville River watershed area) were also small (e.g. the 100-year flood estimate at the confluence was 98% of the WSC station flood estimate). There are no tributaries in the lower reaches of the Sackville River and therefore the difference in flow is due to local watershed area contributions. Since there are no tributaries in the lower reach of the Sackville River, no flow change locations will be required in the hydraulic model. The Sackville River at the confluence (excluding the Little Sackville River watershed area) was also provided. However, the peak flood events in the two rivers may not occur at the same time. For instance, when the annual maxima for the Sackville River at Bedford and Little Sackville River at Middle Sackville stations occur on the same day, there is a delay of approximately two hours between the stations. If the values in Table 2.13 are used without any adjustment for travel time, it may result in overestimation of the flooding at the confluence.

Table 2.13 Pro-rated Flow Rates for Little Sackville River and Sackville River (Stationary)

Location	Watershed Area (km^2)	5-Year Flood (cms)	20-Year Flood (cms)	100-Year Flood (cms)
Little Sackville River at Middle Sackville (WSC station)	13.1	17.5	21.7	26.3
Little Sackville River Above Confluence with Sackville River	15.6	18.9	23.7	28.9
Sackville River at Bedford (WSC station)	146.0	67.2	86.7	108
Sackville River Above Confluence with Little Sackville River (excludes Little Sackville River watershed area)	124.5	60.6	79.0	99.0
Sackville River Below Confluence with Little Sackville River (includes Little Sackville River watershed area)	140.1	64.7	84.5	106

2.3.3 Sea Level Frequency Analysis

Box and Whisker plots for the original and adjusted Halifax sea level data are included in Figure 2.20. The differences between the original Halifax data and the adjusted Halifax data were small. The three largest sea level measurements were outside of 1.5 times the interquartile range. The hourly time series for each of these points were examined, and no concerns were identified with the data. The QA/QC results are summarized in Table 2.14. The outlier test did not identify that any of the three points were outliers at a significance level of 5%, but a change point and a trend were identified (at the 5 percent level of significance). The Pettitt test may identify a trend as a change point (i.e., there is no actual change point). Therefore, the homogeneity was further tested by applying the Pettitt test to the de-trended data. There were no change points in the de-trended data. The trend is relatively constant through time (Figure 2.6), but the most recent period (1985-2012) may indicate that the trend is increasing in magnitude. As there were no change points in the de-trended data, there is no indication that the change in slope is statistically significant at the 5% level of significance. The QA/QC results indicated that there was non-stationarity in the data.

Table 2.14 QA/QC Results for Department of Fisheries and Oceans Sea Level Data

Station ID	Station Name	Outliers	Change Point	Trend
490	Halifax (original data)	None	None[1]	3.8 mm/yr[2]
490	Halifax (adjusted to Bedford)	None	None[1]	3.9 mm/yr[2]

Notes:
1 No change point after de-trending the data
2 Sen slope estimate of trend in pre-whitened data, entire time series

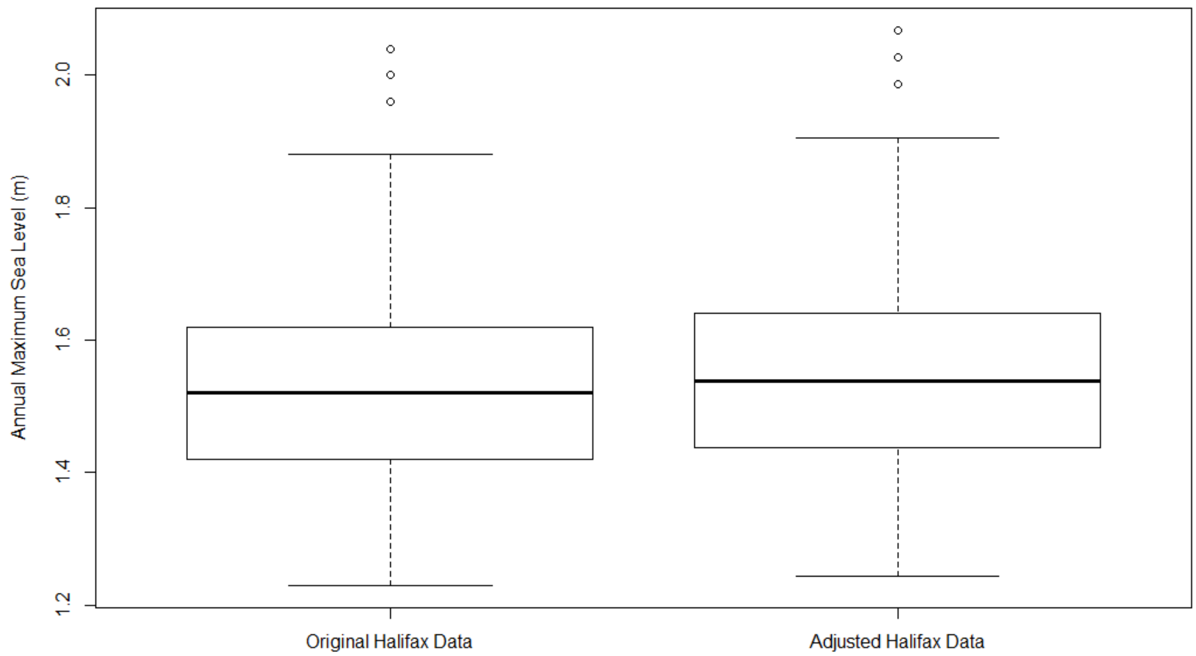


Figure 2.24 Box Plots for Original Halifax and Adjusted Halifax Sea Level Data

Note that the sea level data used in this analysis are referred to as "relative sea level". This implies that the sea level is measured relative to reference point(s) on land. However, the land near Halifax is subsiding at a rate of approximately -1.6 mm/year (Forbes, et al., 2009). To convert the trends listed in Table 2.14 to actual sea level rise, it is necessary to subtract the land subsidence. This results in a sea level rise of approximately 2.2 mm/year for the original Halifax data. Forbes, et al. (2009) reported a relative sea level trend of 3.2 mm/year using data to the end of 2007 (1.6 mm/year land subsidence and 1.6 mm/year sea level rise). The larger sea level rise values obtained in this report are likely due to the apparent increase in the slope of the trend in annual maximum sea levels observed in the most recent data period. The data may indicate that sea level rise is accelerating near Halifax, which may be due either to increased global sea level rise and/or local effects (however, the change in slope is not statistically significant and may therefore have arisen due to the natural variability in sea level).

The sea level rise and land subsidence trends are shown in Figure 2.21. In 1928, the Canadian Geodetic Vertical Datum (CGVD28) was established. As the land subsides, the land elevation in

CGVD28 does not change (e.g. an elevation of 10 meters above sea level (m.a.s.l.) in 1928 is still 10 m.a.s.l. in any other year, even though the land has subsided). The mean sea level was -0.01 m in 1928 and +0.31 m in 2012 (the last year of valid data at the Halifax station), based on the annual average of hourly sea level data at Halifax station. The sea level has appeared to rise by the combination of actual sea level rise and land subsidence (the "relative sea level rise"). The point on land is only 9.69 m above the water in 2012, instead of 10.01 m above the water. If the sea level data were corrected to 1928 to remove the land subsidence component, it would result in increased distance above the water. This would not be conservative. In a report to prepare for extreme sea level over the next 100 years in Halifax, Forbes, et al. (2009) used projected global sea level rise from IPCC and added the land subsidence component to obtain the relative sea level rise for Halifax Harbour, which could then be used for planning purposes. For this study, hydraulic modelling of the Sackville River floodplain, the relative sea level was used, because it represents the sea level that dictates the amount of flooding near Bedford Basin.

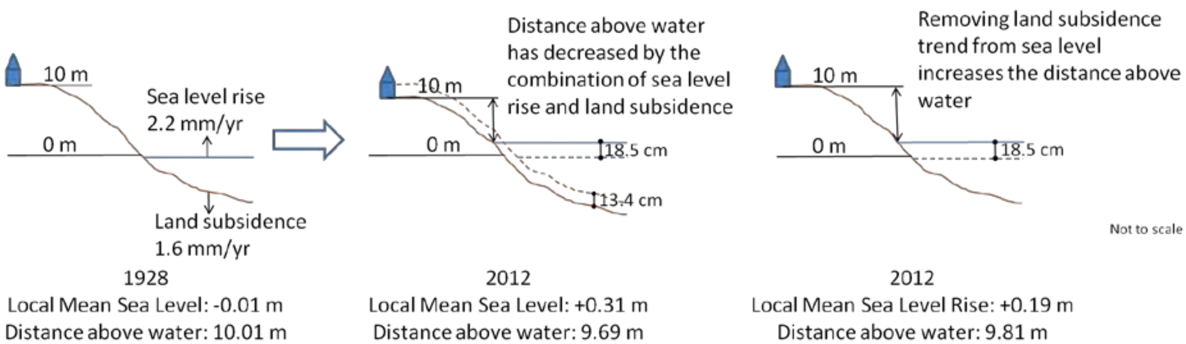


Figure 2.25 Sea Level Rise and Land Subsidence in Halifax

To select an appropriate frequency distribution for the sea level, a stationary frequency analysis was performed for each of the five candidate distributions (non-stationary frequency analysis changes the mean of the frequency curve and cannot be used for fitting a frequency distribution).The goodness-of-fit tests were applied. Figures 2.26 and 2.27 present the QQ and return period plots for the original Halifax data using all data, while Figures 2.28 and 2.29 present the QQ and return period plots for the adjusted Halifax data using all data. Table 2.15 summarizes the results of the goodness-of-fit tests. The 5-, 20-, and 100-year stationary sea level frequency estimates for all distributions are included in Appendix A. All five distributions were acceptable for both sets of data according to the Kolmogorov-Smirnov and Chi-Square tests. According to the plots, the Lognormal distribution underestimated the extreme tail of the distribution slightly, and the other four distributions overestimated the extreme tail of the distribution. The highest sea level estimates were obtained with the Gumbel distribution. To be conservative, the Gumbel distribution was chosen to develop the 5-, 20-, and 100-year sea level estimates. In addition, the use of the same distribution for both flood and sea level has advantages for joint probability analysis.

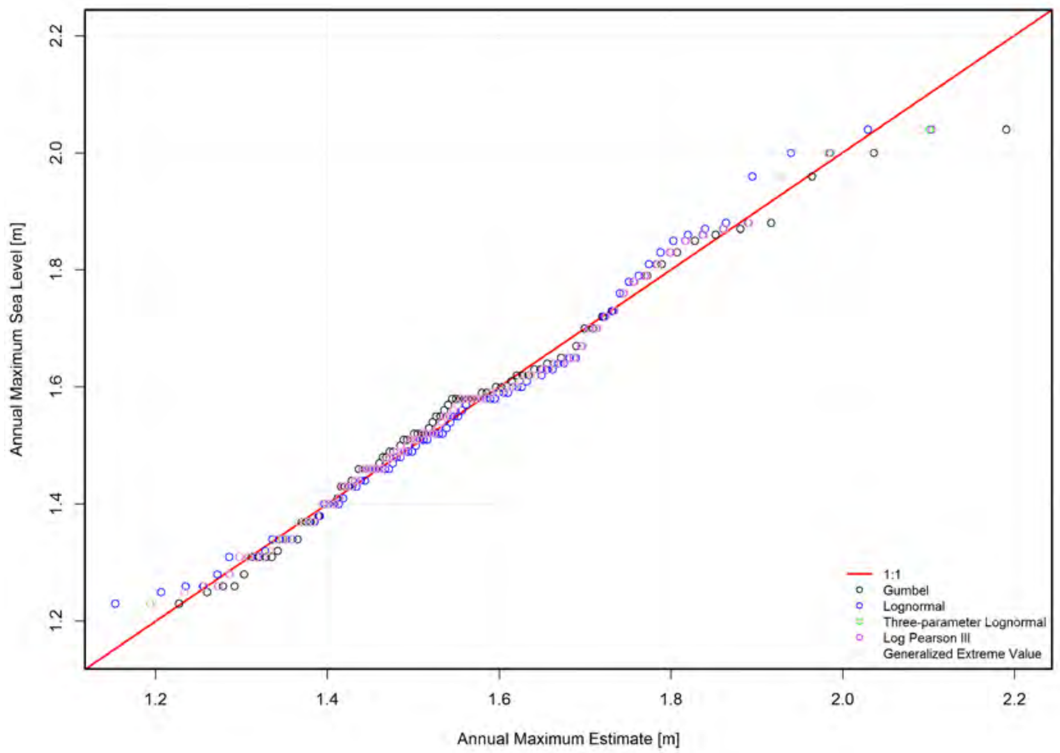


Figure 2.26 Quantile-Quantile Plot for Original Halifax Sea Level Data

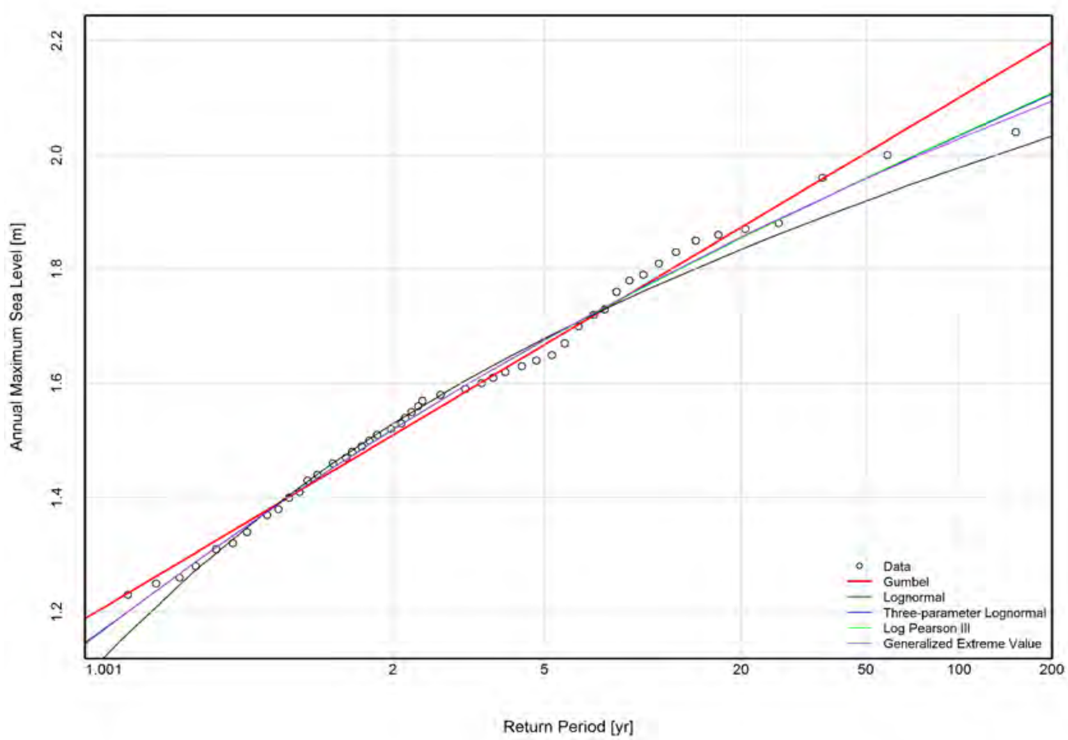


Figure 2.27 Return Period Plot for Original Halifax Sea Level Data

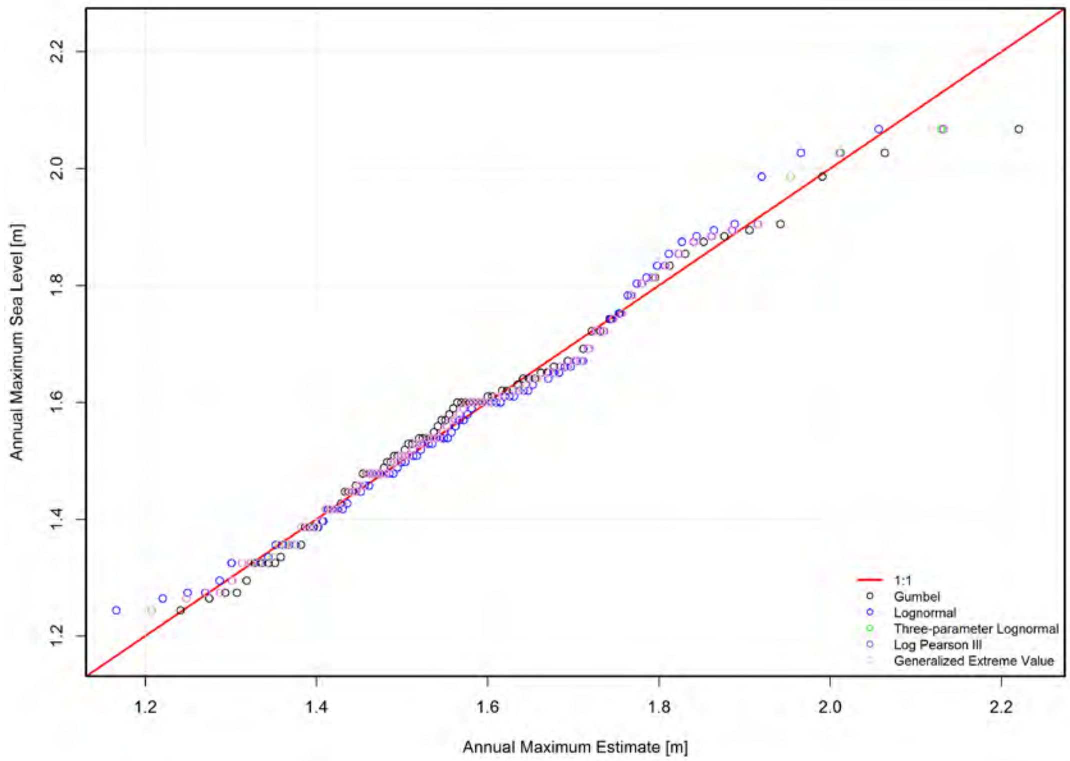


Figure 2.28 Quantile-Quantile Plot for Adjusted Halifax Sea Level Data

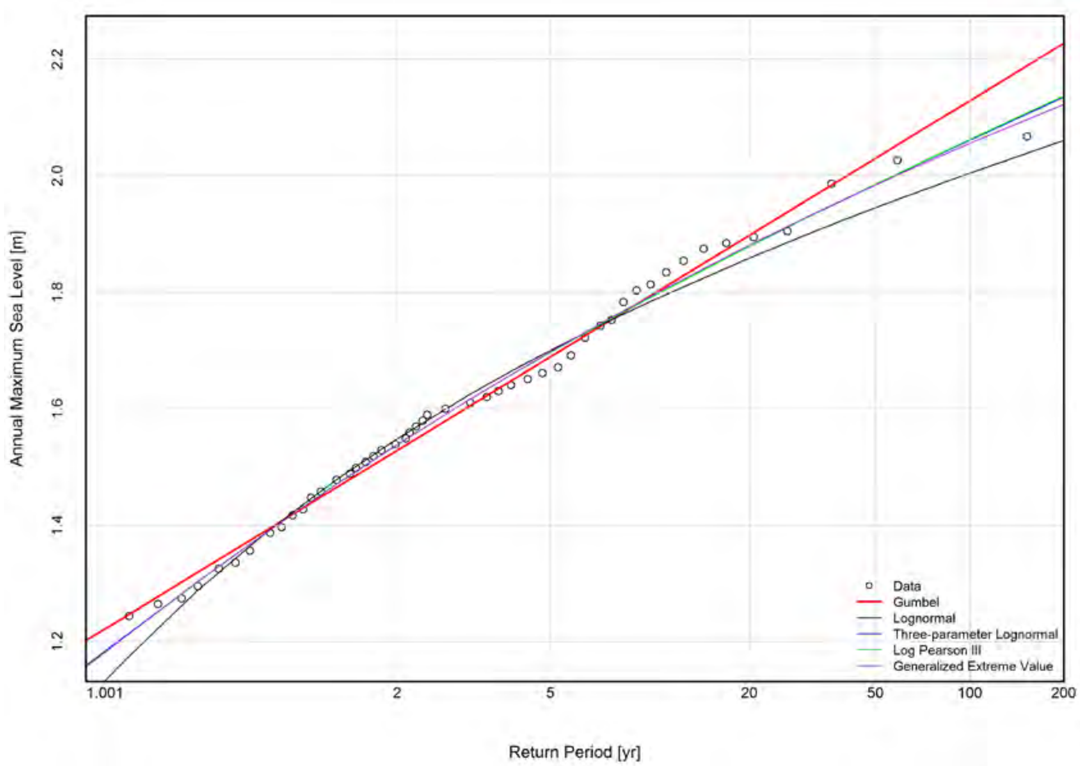


Figure 2.29 Return Period Plot for Adjusted Halifax Sea Level Data

Table 2.15 Goodness-of-Fit Results for Department of Fisheries and Oceans Sea Level Data

Distribution Name	Kolmogorov-Smirnov test	Chi-Square test
Original Halifax Data: All Data		
Gumbel	Accept	Accept
Lognormal	Accept	Accept
3-parameter Lognormal	Accept	Accept
Log Pearson III	Accept	Accept
Generalized Extreme Value	Accept	Accept
Adjusted Halifax Data: All Data		
Gumbel	Accept	Accept
Lognormal	Accept	Accept
3-parameter Lognormal	Accept	Accept
Log Pearson III	Accept	Accept
Generalized Extreme Value	Accept	Accept

The existence of non-stationarity in the data required a non-stationary L-moment analysis. The Theil-Sen lines for the annual maximum sea level data were:

$$SL_Y = -5.887 + 3.766 \times 10^{-3} Y \ (original)$$

$$SL_Y = -5.991 + 3.828 \times 10^{-3} Y \ (adjusted)$$

Where:

SL_Y is the mean annual maximum sea level estimate in year Y (m)

Y is the four digit year of the analysis (2015 for this report)

The 2015 means were therefore 1.70 m (original data) and 1.72 m (adjusted data), compared to long-term means of 1.54 m and 1.56 m respectively. Future year means may also be calculated with these equations. The use of the equations to estimate future year means assumes that the magnitude of the trend will not change over time. However, the sea level trend appears to be accelerating in the most recent period (1985-2012). If this trend continues, the extrapolated means will be underestimated. Using these equations, the extrapolated 2020 means would be 1.72 m (original data) and 1.74 m (adjusted data), respectively. These values could then be used with the L-moment analysis to generate extrapolated 2020 frequency estimates.

Six sets of results are presented in Table 2.16. The worst-case sea level (highlighted in red) was selected for the high-level hydraulic modelling. The de-trended non-stationary estimates were larger than the stationary estimates for the 5-year and 20-year return period, but almost identical for the 100-year return period. In contrast, the non-stationary estimates without de-trending were outside of the 95% confidence limits for the 5- and 20-year return periods and near the upper limit of the 95% confidence limits for the 100-year return period. The confidence limits for the sea level are plotted in Figure 2.26. The results extrapolated to 2020 are also included in the Table 2.16. The sea level estimates increased by approximately 0.02 m for 2020. This may have an effect on coastal flooding. The sea level estimates for other return periods for the worst-case frequency analysis are included in Appendix A.

Table 2.16 Sea Level Frequency Analysis Results for Department of Fisheries and Oceans Sea Level Data

Return Period	Stationary (m CGVD28)	Non-Stationary (2015)		Non-Stationary (2020 Extrapolation)[1]	
		No De-trending (m CGVD28)	De-trending (m CGVD28)	No De-trending (m CGVD28)	De-trending (m CGVD28)
Original Halifax Data					
5-year Estimate	1.67	1.83	1.80	1.85	1.82
(95% Confidence Interval)	(1.62 – 1.72)	(1.78 – 1.88)	(1.76 – 1.84)	1.80 – 1.90	1.78 – 1.86
(99% Confidence Interval)	(1.60 – 1.74)	(1.76 – 1.90)	(1.75 – 1.85)	1.78 – 1.92	1.77 – 1 87
20-year Estimate	1.87	2.03	1.95	2.05	1.97
(95% Confidence Interval)	(1.78 – 1.97)	(1.94 – 2.13)	(1.88 – 2.03)	1.96 – 2.15	1.90 – 2 04
(99% Confidence Interval)	(1.74 – 2.00)	(1.90 – 2.16)	(1.85 – 2.05)	1.92 – 2.18	1.87 – 2 07
100-year Estimate	2.10	2.26	2.13	2.28	2.14
(95% Confidence Interval)	(1.89 – 2.30)	(2.05 – 2.46)	(1.96 – 2.27)	2.07 – 2.49	1.98 – 2 29
(99% Confidence Interval)	(1.81 – 2.36)	(1.97 – 2.52)	(1.90 – 2.32)	1.99 – 2.53	1.92 – 2 33
Adjusted Halifax Data					
5-year Estimate	1.69	1.85	1.82	1.87	1.84
(95% Confidence Interval)	(1.64 – 1.74)	(1.80 – 1.91)	(1.78 – 1.86)	1.82 – 1.92	1.80 – 1.88
(99% Confidence Interval)	(1.62 – 1.76)	(1.78 – 1.92)	(1.77 – 1.87)	1.80 – 1.94	1.79 – 1.89
20-year Estimate	1.90	2.06	1.98	2.08	2.00
(95% Confidence Interval)	(1.80 – 2.00)	(1.96 – 2.16)	(1.90 – 2.06)	1.98 – 2.18	1.92 – 2.07
(99% Confidence Interval)	(1.77 – 2.03)	(1.93 – 2.19)	(1.88 – 2.08)	1.95 – 2.21	1.89 – 2.09
100-year Estimate	2.13	2.29	2.15	2.31	2.17
(95% Confidence Interval)	(1.91 – 2.33)	(2.08 – 2.50)	(1.99 – 2.31)	2.09 – 2.52	2.00 – 2.32
(99% Confidence Interval)	(1.84 – 2.39)	(2.00 – 2.55)	(1.93 – 2.35)	2.02 – 2.57	1.94 – 2.36

Notes:
[1] Extrapolation to 2020 assumes that the existing trend does not change until 2020. Extrapolated estimates are not for design purposes and should be used with caution.

The 1981 Interprovincial Engineering Study used the Weibull plotting position method for the sea level at the Halifax gauge to determine 20-year and 100-year sea level estimates (Table 2.17). The stationary sea level frequency analysis estimates for the original Halifax data were slightly higher than the results obtained by the previous study. The increase was particularly noticeable for the 100-year event. As sea level continues to rise, the sea level estimates for each return period will also continue to rise. This study identified a non-stationary trend in the sea level data, and therefore performed a non-stationary frequency analysis. The data were also corrected for the differences between the Halifax gauge and the Bedford Institute gauge. The resulting estimates were considerably higher than the previous study. The use of higher estimates is more conservative for floodplain delineation.

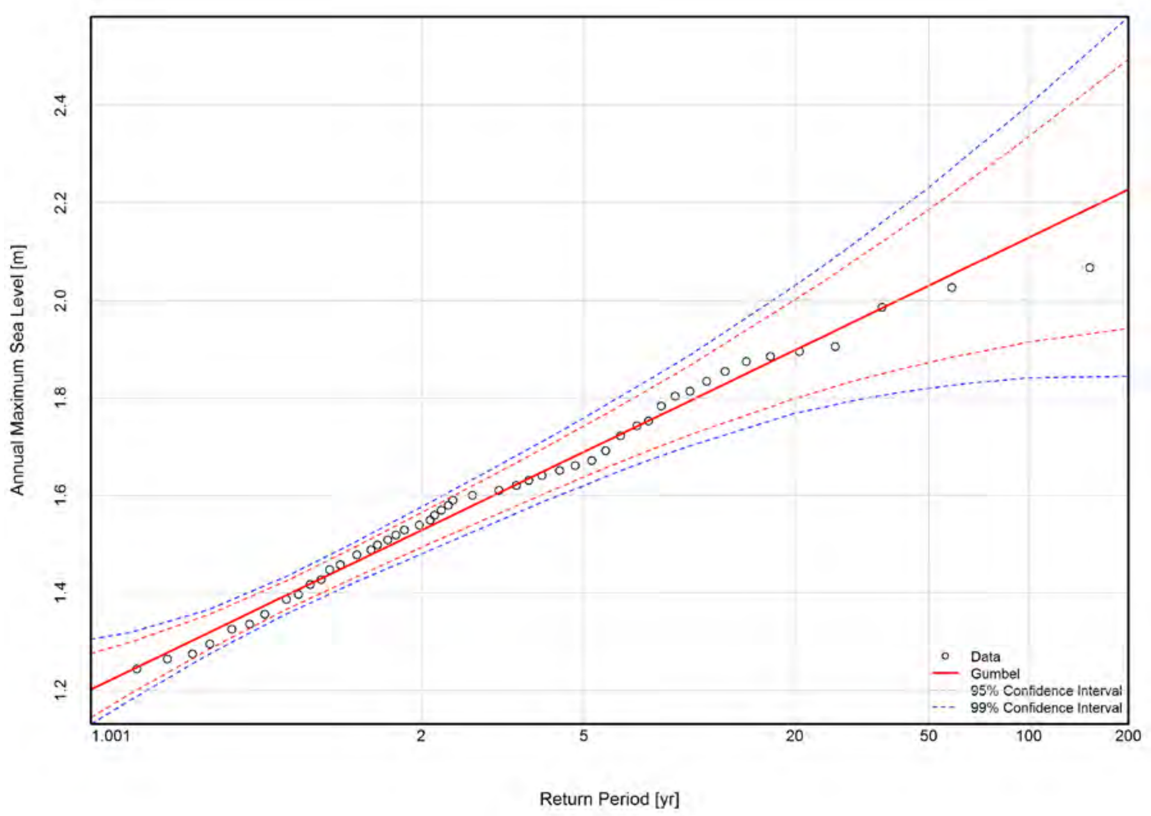


Figure 2.30 Return Period Plot with Confidence Limits for Adjusted Halifax Sea Level Data (Stationary)

Table 2.17 Comparison Between Sea Level Frequency Analyses and Previous Study

Return Period (Years)	Stationary Frequency Analysis Estimate (m CGVD28)	Non-Stationary (No De-trending) Frequency Analysis Estimate (m CGVD28)	1981 Interprovincial Engineering Study (m CGVD28)
5	1.67	1.85	Not reported
20	1.87	2.06	1.85
100	2.10	2.29	2.03

The sea level frequency results are summarized in Table 2.18. The non-stationary results for Adjusted Halifax data are presented.

Table 2.18 Summary of Sea Level Frequency Analysis Results

Return Period (Years)	Estimate (m CGVD28)	95% Confidence Interval (m CGVD28)	99% Confidence Interval (m CGVD28)
Adjusted Halifax Data			
5	1.85	1.80 – 1.91	1.79 – 1.92
20	2.06	1.96 – 2.16	1.93 – 2.19
100	2.29	2.08 – 2.50	2.00 – 2.55

2.3.4 Joint Flood and Sea Level Probability Analysis

A seasonal analysis was performed on the annual maxima for the two flow stations and the Halifax sea level station. The Sackville River at Bedford station is located approximately 0.4 km from the Bedford Basin, while the Little Sackville River at Middle Sackville station is approximately 6.2 km away from the Bedford Basin. The two flow stations have a significant amount of correlation: the annual maximum flows occur on the same date at both stations approximately 45% of the time. When the two rivers experience their annual maximum flows on the same date, the peak flow at Sackville River at Bedford is approximately two hours later than the peak flow at Little Sackville River at Middle Sackville. The peaks are measured at the WSC stations, and the travel time in the rivers must be determined in order to determine the timing of the peaks at the confluence. The two rivers may not peak at the same time. Due to its proximity to Bedford Basin, the Sackville River at Bedford station is expected to have a higher correlation with sea level than the Little Sackville River at Middle Sackville station. However, the Little Sackville River at Middle Sackville station was analyzed to confirm the lack of correlation between its floods and sea level.

The frequency of occurrence of the annual maxima in each month was determined (Figure 2.31). The Figure indicates that the annual maxima for all three data sets tend to occur from October to April, and relatively few events occur from May to September. However, there are differences in the seasonality of the stations. The annual maximum sea levels occur most frequently in January, but also occur frequently in December and February (total of 62% of the time). The annual maximum flows at Sackville River at Bedford occur in December most frequently, but occur from November to April at an equal frequency (total of 79% of the time). The annual maximum flows at Little Sackville River at Middle Sackville occur with equal frequency in November, December, and March, but also occur frequently in October (total of 59% of the time).

The annual maximum data were examined further to determine how often the annual maxima occur in the same month. The annual maxima for the Sackville River at Bedford and the Halifax Sea Level station occur in the same month 21% of the time (9 times out of 43 years). The annual maxima for the Little Sackville River at Middle Sackville and the Halifax Sea Level station occur in the same month 16% of the time (5 times out of 32 years). The annual maxima that occur in the same month are plotted in Figure 2.32. The product moment correlation coefficient (see Section 2.2.3.1) between the annual maximum flow and the annual maximum sea level is negative for Sackville River at Bedford, and very low for the Little Sackville River at Middle Sackville. Therefore, while the annual maxima for all three gauges have similar seasonality, the annual maxima do not tend to occur at the same time. When the annual maxima occur in the same month, there is little correlation between the annual maximum flow and annual maximum sea level.

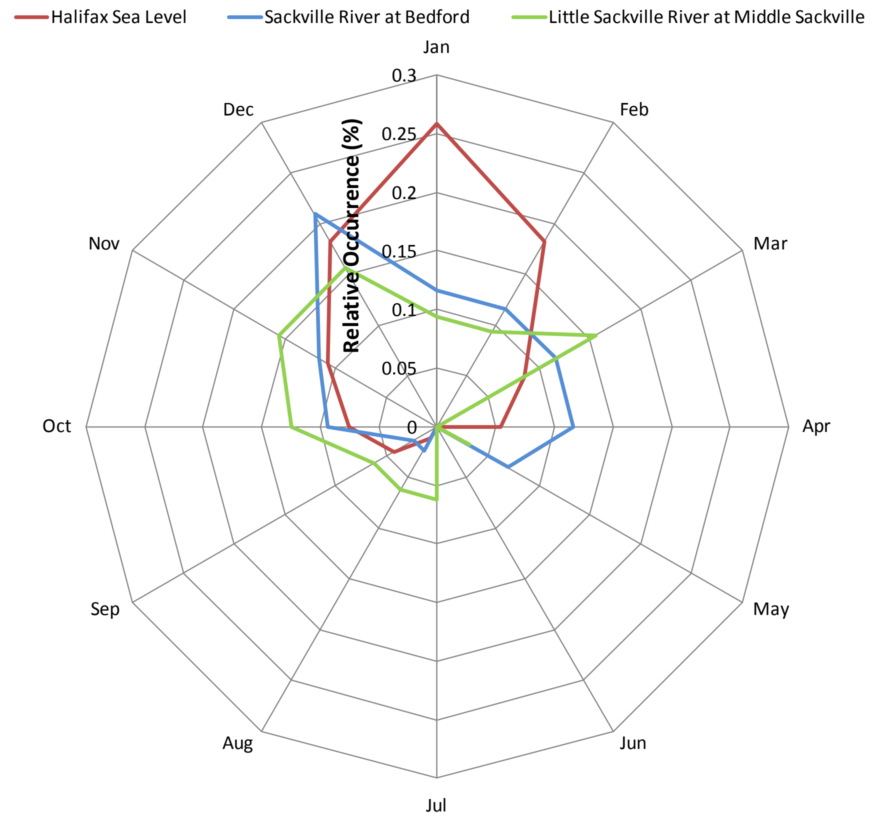


Figure 2.31 Frequency of Occurrence of Annual Maxima for Each Month

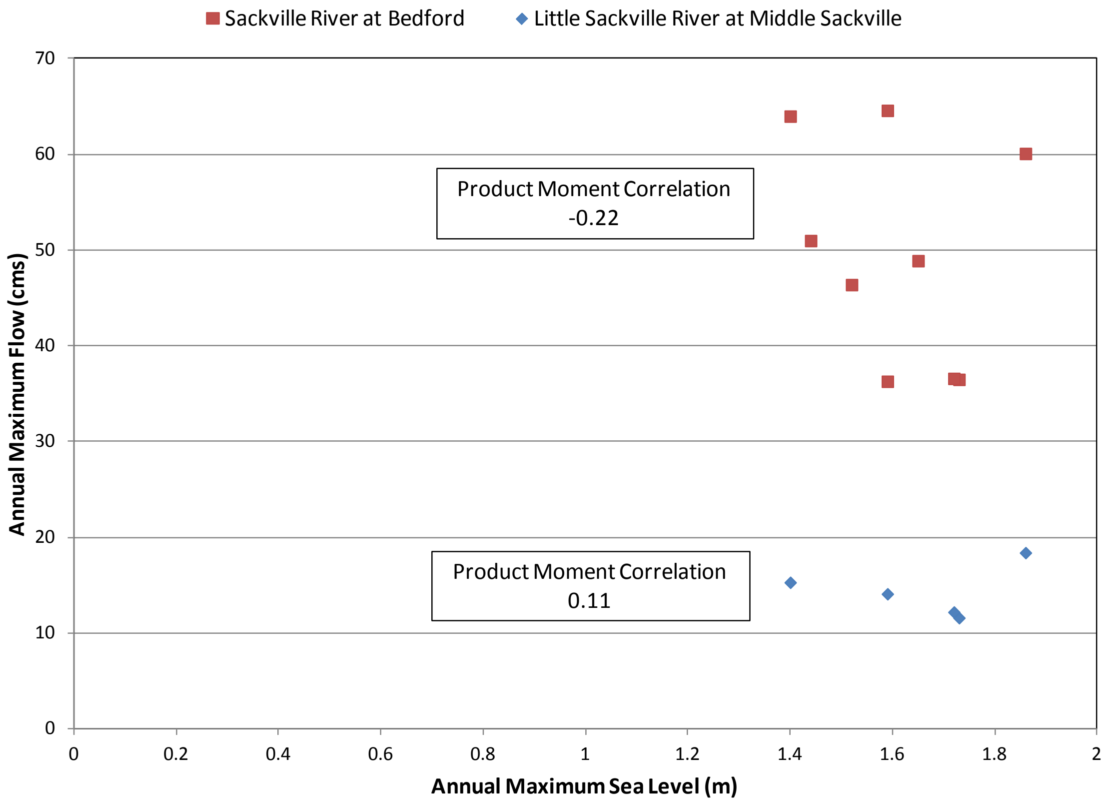


Figure 2.32 Annual Maximum Flow and Annual Maximum Sea Level That Occur in the Same Month

When the annual maxima occur in the same month, the numbers of days of separation between the annual maxima were found (Table 2.19). The closest distance between the annual maximum flow and the annual maximum sea level was three to four days. There were two events that were identified with a "window" of nine days (four days before the annual maxima for flow, the date of the annual maxima for flow, and four days after the annual maxima for flow). In 1984, the annual maximum flow occurred on March 15 (Little Sackville River at Middle Sackville) and March 16 (Sackville River at Bedford), while the annual maximum sea level occurred three to four days later on March 19. In 2006, the annual maximum flow occurred on February 5 (both stations), while the annual maximum sea level occurred four days earlier on February 1. Therefore, it is unlikely that the annual maxima in the historical record were due to the same meteorological event as they did not occur on the same date, but were at least three days apart (however, this does not imply that the events will not occur on the same date in the future).

Table 2.19 Number of Days of Separation Between Annual Maxima for Flow and Sea Level

Number of Days Apart	Width of Window	Sackville River at Bedford and Halifax Sea Level	Little Sackville River at Middle Sackville and Halifax Sea Level
Same day	1 day	0	0
±1 day	3 days	0	0
±2 days	5 days	0	0
±3 days	7 days	1	0
±4 days	9 days	2	2
Same month	31 days	9	5

Since there was little evidence that the annual maximum flow and sea level occur simultaneously, the relationship between the annual maximum flow and sea level on the same day was investigated (Figure 2.33 and Figure 2.34). On the dates of the annual maxima for flow, the corresponding maximum daily sea levels were found. Similarly, on the dates of the annual maxima for sea level, the corresponding average daily flows were found (instantaneous daily maximum flow data were not available). For the annual maximum flow with corresponding sea level on the same day, there was a negative correlation for both streamflow stations. For the annual maximum sea level with corresponding flow on the same day, there was a very low correlation (<0.11) for Sackville River at Bedford and a modest correlation (between 0.12 and 0.37) for Little Sackville River at Bedford. A lag of up to one day in either direction (three day window) was also investigated, but the product moment correlation coefficients were not significantly affected. When the two sets of data are combined, there is an overall negative correlation between the floods and the sea level. When the flow rate was high, the sea level tended to be low, and vice versa. There were no values with both high flow and high sea level.

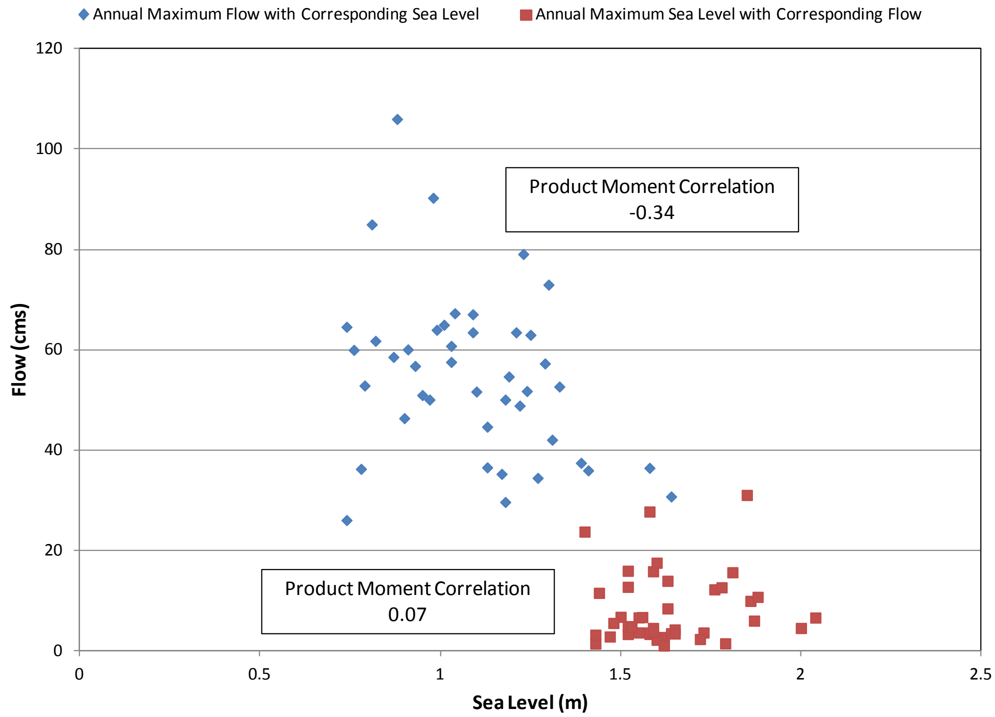


Figure 2.33 Correlation Between Annual Maxima and Corresponding Values on the Same Day (Flow for Sackville River at Bedford)

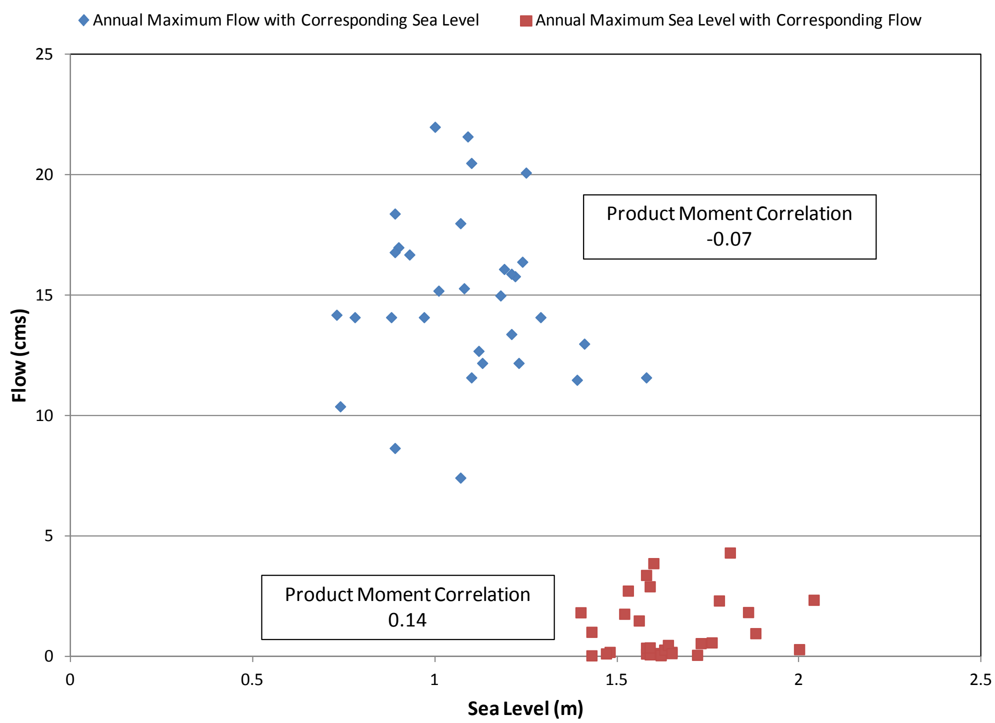


Figure 2.34 Correlation Between Annual Maxima and Corresponding Values on the Same Day (Flow for Little Sackville River at Middle Sackville)

The relationship between floods and sea level was further investigated using a Peaks-Over-Threshold (POT) approach. This was performed in order to determine if there was a relationship between floods and sea level that was not visible using only the annual maximum data. The POT approach used the daily average flow rates and the maximum daily sea level. Figure 2.35 shows the sea level plotted against flow for the Little Sackville River at Middle Sackville station, while Figure 2.36 shows the two variables for the Sackville River at Bedford station. On each figure, the points representing the highest combinations of flow and sea level are connected with a line, and the dates for these events are listed in Table 2.20. The figures reveal that there are no points that have both high flow and high sea level at either station. There are some points with medium flow and medium sea level.

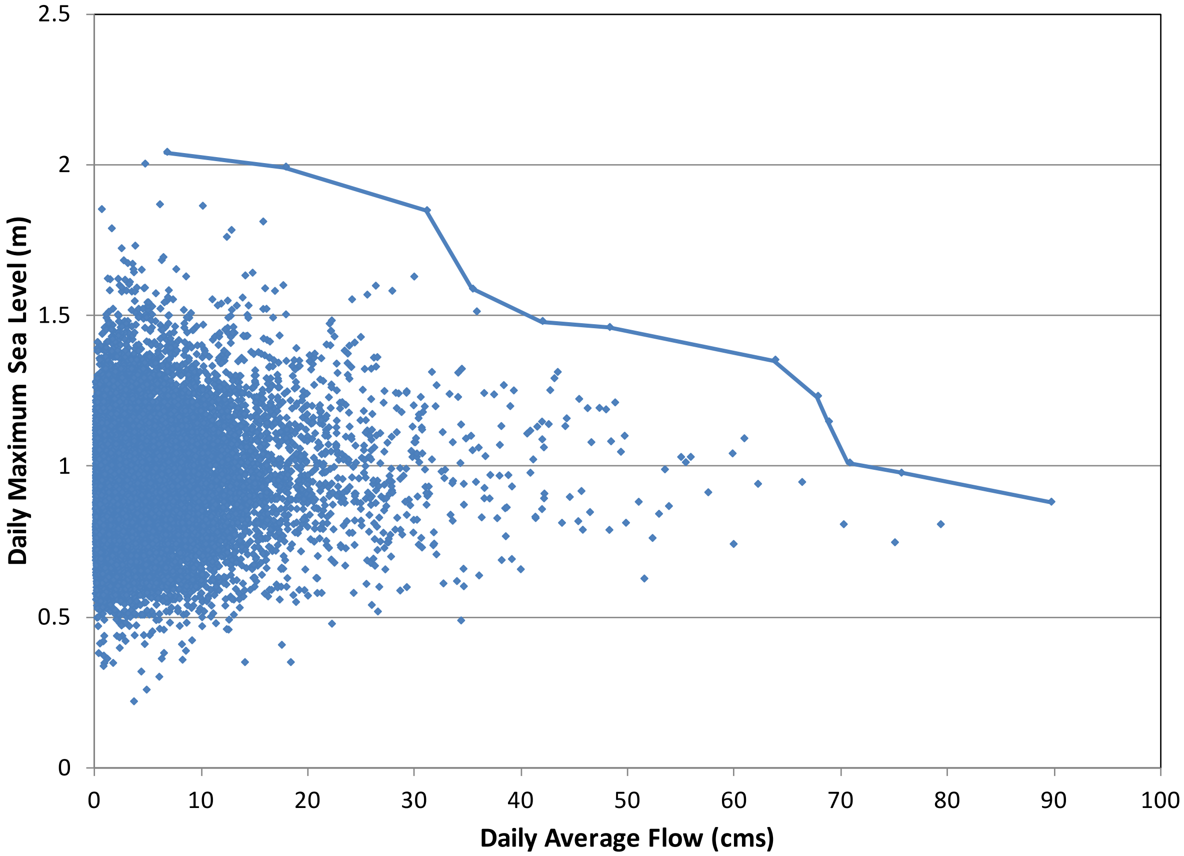


Figure 2.35 Daily Maximum Sea Level at Halifax and Daily Average Flow at Sackville River at Bedford

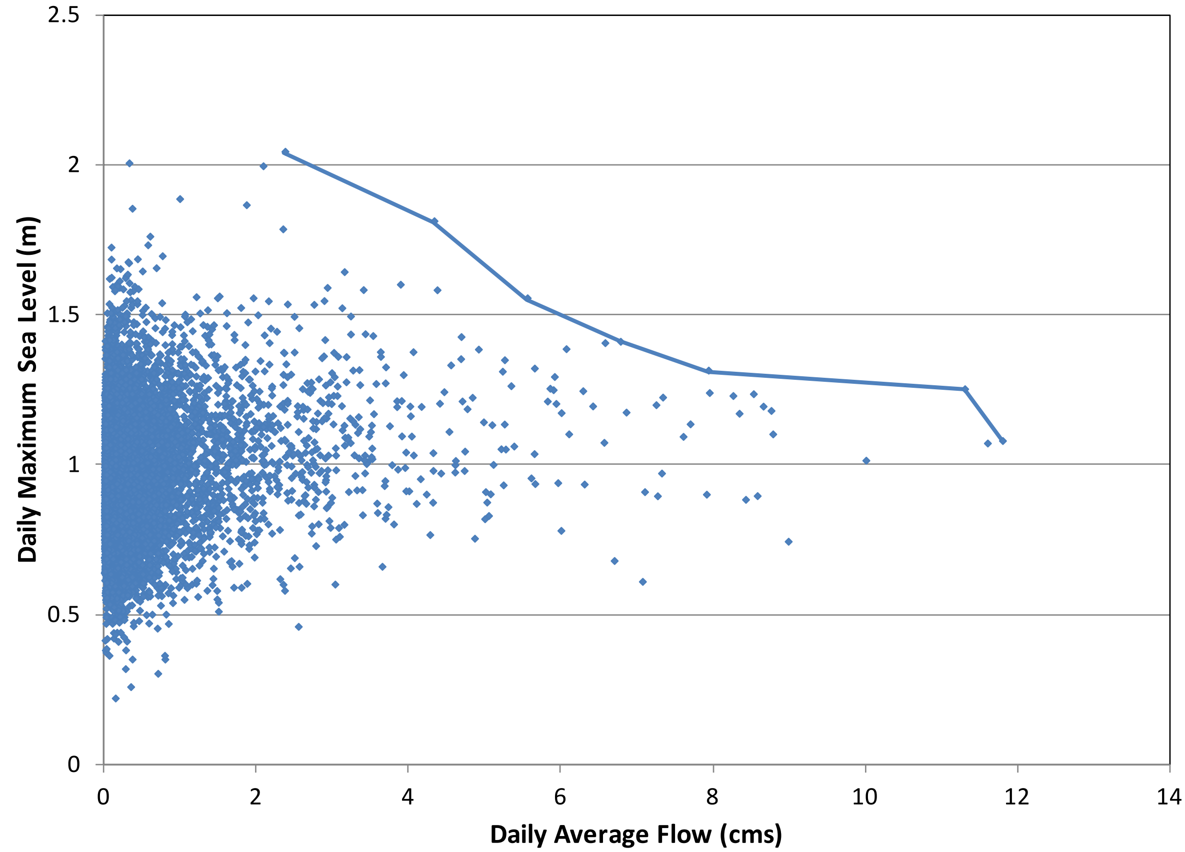


Figure 2.36 Daily Maximum Sea Level at Halifax and Daily Average Flow at Little Sackville River at Middle Sackville

Table 2.20 Dates With Highest Combinations of Sea Level and Flow

Sackville River at Bedford			Little Sackville River at Middle Sackville		
Date	Sea Level (m)	Flow (cms)	Date	Sea Level (m)	Flow (cms)
1/15/1978	1.15	68.8	3/15/1984	1.08	11.8
1/16/1978	0.98	75.6	12/1/1987	1.41	6.78
1/28/1979	1.59	35.4	2/17/1996	1.25	11.3
1/29/1979	1.85	31.1	9/14/1996	1.81	4.33
2/26/1998	1.46	48.2	9/29/2003	2.04	2.37
2/27/1998	1.48	41.9	5/8/2005	1.31	7.93
3/31/2003	1.01	70.7	2/26/2010	1.55	5.55
4/1/2003	0.88	89.6			
9/29/2003	2.04	6.68			
11/7/2010	1.23	67.7			
11/8/2010	1.35	63.7			
12/6/2010	1.99	17.8			

The POT data series was developed. A minimum separation of five days between peaks was chosen. Various thresholds were tested, ranging from the top 5% of the data to the top 15% of the data. To be selected in the POT data series, the peaks for both the flow and the sea level were above their respective threshold values. The analysis was performed for the same day and also for a three day window to allow for a lag (the peaks were at most one day apart). Finally, to ensure that sea level rise was not impacting the correlation, the correlation was also determined using the de-trended sea level data. The analysis was performed for the original sea level data and for the de-trended sea level data. The product moment correlation coefficient was calculated for the untransformed data and also for the data after it was transformed to a normal distribution (e.g. Hawkes, 2008). Therefore, multiple sets of results are presented: multiple thresholds, same day vs three-day window, original vs de-trended sea level, and untransformed vs transformed data. The results represent multiple different methods for determining the level of correlation floods and sea level, and were used together to ensure that the level of correlation between the variables was fully evaluated. Table 2.21 summarizes the product moment correlation coefficients found using the original sea level data. Table 2.22 summarizes the product moment correlation coefficients found using the de-trended sea level data. In general, most product moment correlation coefficients for all sets of data were very low (<0.11) or negative. Some product moment correlation coefficients were between 0.12 and 0.37 (modest correlation), they are: Little Sackville River at Middle Sackville using original sea level with 15% of the data; and Sackville River at Bedford using de-trended sea level with 5% of the data. However, in each case, the high correlation coefficients did not match with similar data (e.g., other thresholds using the same sea level data, or the same threshold using the other sea level data). Therefore, there was no consistent pattern in the modest correlation coefficients, and most of the correlation coefficients were very low.

Table 2.21 Product Moment Correlation Coefficients Using Peaks Over Threshold Method and Original Sea Level Data

WSC Station	Top Percent of Data (%)	Product Moment Correlation Coefficient Untransformed Data (Transformed Data)			
		Number of Pairs	Same Day	Number of Pairs	Three-Day Window
Sackville River at Bedford	15	39	-0.21 (-0.21)	97	-0.05 (-0.04)
	12.5	33	-0.01 (0.03)	86	-0.01 (-0.02)
	10	29	0.09 (0.10)	74	0.02 (0.00)
	7.5	18	-0.05 (-0.00)	52	-0.04 (-0.06)
	5	9	-0.08 (0.04)	29	-0.02 (0.03)
Little Sackville River at Middle Sackville	15	107	0.01 (0.12)	160	0.04 (0.14)
	12.5	94	-0.03 (0.05)	138	0.00 (0.06)
	10	78	-0.07 (0.00)	114	-0.05 (0.00)
	7.5	63	-0.12 (0.01)	89	-0.08 (0.03)
	5	40	-0.29 (-0.24)	54	-0.20 (-0.16)

Table 2.22 Product Moment Correlation Coefficients Using Peaks Over Threshold Method and De-trended Sea Level Data

WSC Station	Top Percent of Data (%)	Product Moment Correlation Coefficient Untransformed Data (Transformed Data)			
		Number of Pairs	Same Day	Number of Pairs	Three-Day Window
Sackville River at Bedford	15	42	-0.21 (-0.12)	89	0.02 (0.05)
	12.5	33	-0.19 (-0.07)	76	0.04 (0.02)
	10	30	-0.06 (0.06)	68	0.04 (0.01)
	7.5	19	-0.22 (-0.19)	59	0.04 (-0.04)
	5	11	-0.31 (-0.22)	30	0.16 (0.10)
Little Sackville River at Middle Sackville	15	107	-0.06 (0.04)	155	0.00 (0.07)
	12.5	95	-0.03 (0.11)	136	0.01 (0.11)
	10	83	-0.10 (0.01)	114	-0.06 (0.07)
	7.5	66	-0.10 (0.00)	92	-0.09 (-0.03)
	5	44	-0.28 (-0.23)	60	-0.22 (-0.20)

The annual maximum analysis and the POT analysis both confirmed that there was negative or very low (≤0.11) correlation between the floods at the two WSC stations and the sea level measured at the Halifax station. Note that a positive correlation may exist between floods and surge events (the difference between the sea level and the predicted tide). However, if a relationship exists between floods and surge events, the effect of the tidal cycle (spring tide, neap tide, timing of surge with respect to daily high/low tides, etc.) appears to mask the relationship so that there is no correlation between floods and sea level. Therefore, the two WSC stations and the sea level station were found to be independent from each other. The joint return period is then calculated as the product of the individual return periods. Table 2.23 summarizes the joint return periods.

Table 2.23 Joint Return Periods

Flood Return Period (Years)	Sea Level Return Period (Years)		
	5-Year	20-Year	100-Year
Sackville River at Bedford			
5-Year	25	100	500
20-Year	100	400	2,000
100-Year	500	2,000	10,000
Little Sackville River at Middle Sackville			
5-Year	25	100	500
20-Year	100	400	2,000
100-Year	500	2,000	10,000

3. Hydraulic Modelling

3.1 Data Sources

3.1.1 Digital Elevation Model Data

A Digital Elevation Model (DEM) was used in the hydraulic model to characterize the topographic features of the Sackville River channel and floodplain geometry. The DEM was provided by HRM, and was developed based on LiDAR data collected by HRM in 2007. The DEM was hydraulically corrected; water crossings were removed from the topographic data to generate a continuous river network.

3.1.2 Water Crossing Data

There are 11 water crossings in the lower reach of the Sackville River watershed. The water crossings must be entered accurately into the hydraulic model to allow development of accurate water levels under alternative recurrence interval scenarios. As-built drawings were available for 8 of the 11 water crossings (Table 3.1). The missing water-crossing as-built drawings were for the Railway Bridge, Highway 102 and Rifle Range Lane, which are not owned by HRM. The required water crossing information necessary for development of the hydraulic model for the Railway Bridge and Highway 102 were obtained during the field reconnaissance visit. Furthermore, only the piers of the Railway Bridge were included in the hydraulic model because the bridge deck was at such a high elevation that it was significantly out of the floodplain water surface elevation. Rifle Range Lane is owned by the Department of National Defense (DND) and due to the time constraints of this Study an as-built drawing and in-field measurements (during field reconnaissance visit) could not be obtained. However, as part of the topo-bathymetric survey data collection efforts, the survey crew was granted access to the property and was able to collect the required data necessary to define the Rifle Range Lane Bridge within the hydraulic model for this study.

Table 3.1 Water Crossing Data Sources

Number	Water Crossing Name	HEC-RAS Number	Data Source
1	Shore Drive	18	As-Built Drawing
2	Railway Bridge	37	Not modelled
3	Bedford Highway	190	As-Built Drawing
4	Bedford Place Mall, Entrance #1	912	As-Built Drawing
5	Bedford Place Mall, Entrance #2	1056	As-Built Drawing
6	Bedford Place Mall, Entrance #3: River Lane	1311	As-Built Drawing
7	Bedford Place Mall, Pedestrian Bridge	1410	As-Built Drawing
8	Highway 102	1925	Hydraulic Inventory Sheet
9	Rifle Range Lane	2463	Field Survey
10	Bedford-Sackville Connector Greenway Trail Pedestrian Bridge #1	2694	As-Built Drawing
11	Bedford-Sackville Connector Greenway Trail Pedestrian Bridge #2	3289	As-Built Drawing

3.1.3 Field Reconnaissance

On July 14, 2015, GHD performed field reconnaissance of the Sackville and Little Sackville Rivers. There were three objectives for the field visit:

- Collection of field measurements at each of the 11 water crossings on the lower reach of the Sackville River.
- Field verification of channel and floodplain roughness parameters and top of bank locations.
- Development of an understanding of the unique factors that influence the hydraulic regime in the lower reaches of the Sackville River.

The GHD field crew walked the entire section of the lower Sackville River modelled in the Phase 1 study, and visited all water crossings in both the Sackville and Little Sackville Rivers.

In preparation for the field visit, GHD developed Hydraulic Structure Inventory Sheets (field sheets) to assist in the collection of the necessary field measurements required to properly model water crossings in a hydraulic flood model. The required field measurements for each of the water crossing on the field sheets included bridge widths, lengths, height, skew angle, obvert to top of road, inlet type and additional field notes. A field sheet was completed for 10 of the water crossing structures on the lower reach of the Sackville River. A field sheet was not completed for Rifle Range Lane, as permission to enter the property could not be obtained within the given timeframe. Copies of the field sheets are included in Appendix B.

The factors influencing the hydraulics include channel and floodplain roughness (Manning's 'n'), channel slope, and areas with turbulent or laminar flow characteristics. The field team took pictures with a GPS camera and recorded field notes to document any significant factors influencing the hydraulics on the Sackville River as they walked the lower reach of the Sackville River. Appendix C presents the photolog for the features that were identified as influencing the hydraulics on the Sackville River.

3.2 Methodology

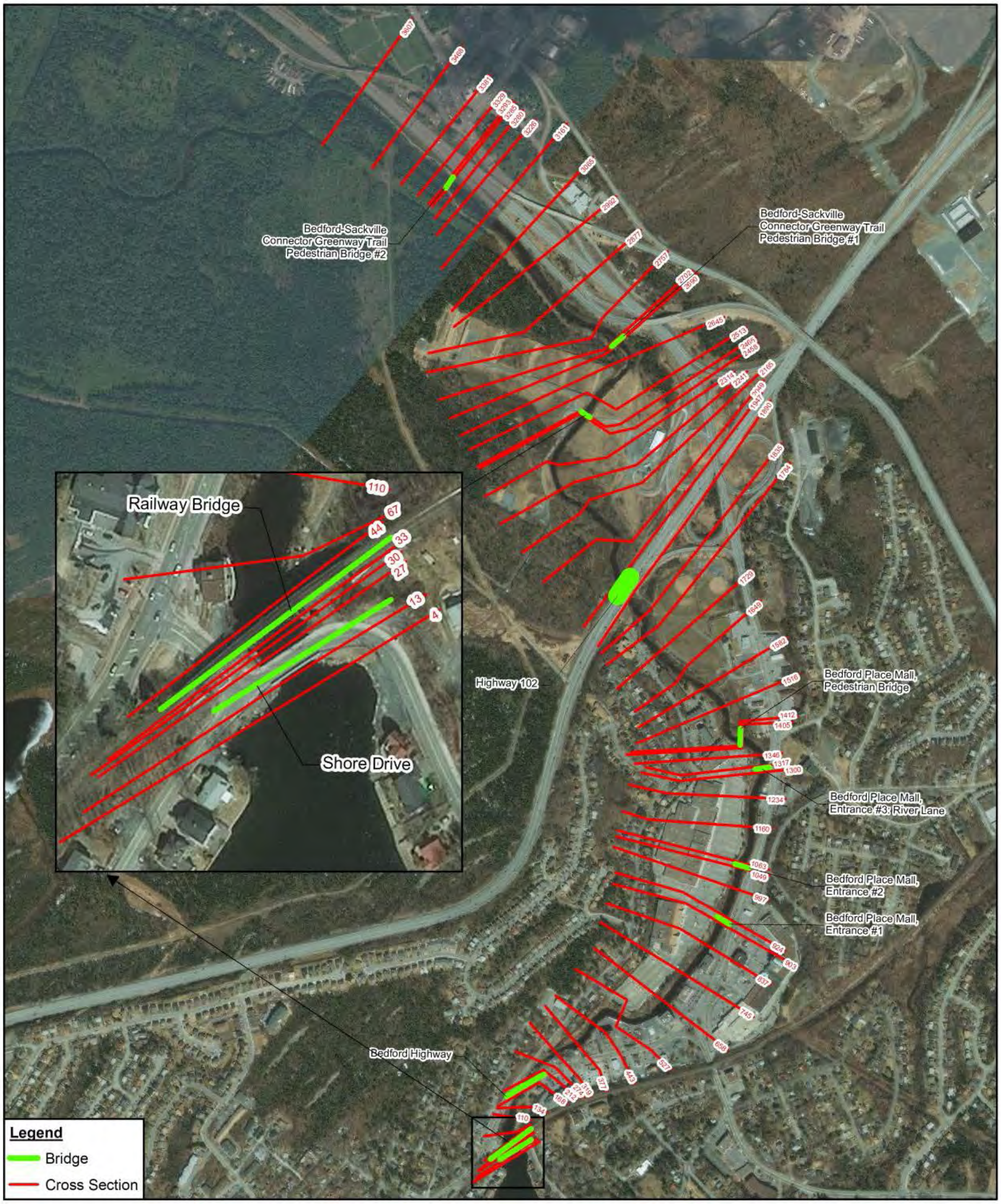
3.2.1 Hydraulic Model Pre-processing

The hydraulic modelling employed two computer modelling programs; the Hydrologic Engineering Center's Geospatial Hydrologic Modelling Extension (HEC-GeoRAS) and Hydrologic Engineering Center's River Analysis System (HEC-RAS). HEC-GeoRAS is an ArcView Geographical Information System (GIS) extension specifically designed to pre-process geospatial data for use with HEC-RAS (United States Army Corps of Engineers, USACE, 2009). The HEC-RAS Version 4.1.0 hydraulic model used in this study is a one-dimensional model that has the capability to simulate steady and unsteady state hydraulics and is commonly used to calculate estimates of water surface elevation and extent of floodplains (USACE, 2010).

ArcGIS was used to convert the 1 meter (m) DEM into a triangulated irregular network (TIN), which is a triangulated mesh, constructed on the (x, y, and z) locations of a set of data points for use within HEC-GeoRAS. A TIN allows for a dense network of points where the land surface is complex and detailed, such as a river channel, and for a lower point density in flat or gently sloping areas as is seen around the Bedford Place Mall and the recreational area (Range Park) near Highway 102.

Additional HEC-RAS Themes were created to extract additional geometric data about the river for import in HEC-RAS. These additional HEC-RAS Themes included the stream centerline, right and left banks, and flow path centerlines. The stream centerline Theme was created starting at the upstream boundary of the model domain (i.e., confluence of the Sackville River and Little Sackville River) and followed the channel thalweg to the downstream boundary of the Sackville River (Bedford Basin). The main channel banks Theme was created by drawing lines along the left and right banks of the rivers. Flow path centerlines were created for the stream centerline, left and right overbanks.

Additional HEC-RAS Themes were also created for the cross-sectional cut lines and water crossing cut lines. A total of 63 cross-sectional cut lines and 11 water crossings were created along approximately 3.5 km of the Sackville River. Cross-sectional cut lines were drawn perpendicular to the flow path lines, from the left overbank to the right overbank (when facing downstream) and were spaced on average approximately 60 m apart, with a maximum spacing of no greater than 144 m. Cross-sectional cut lines were spaced closer together along meanders and additional cross-sectional cut lines were added near the bridges. Figure 3.1 presents the cross-section locations used in the HEC-RAS model to characterize the river networks within the lower reaches of the Sackville River.



Source:ESRI Data, World Imagery. Accessed 2015;

0 100 200 300
Meters

Coordinate System:
NAD 1983 CSRS MTM 4

HALIFAX REGIONAL MUNICIPALITY
HALIFAX, NOVA SCOTIA
SACKVILLE RIVERS FLOODPLAIN STUDY: PHASE I

HEC-RAS MODEL SET UP

11102282-04
Oct 1, 2015

GIS File: I:\IWRM-GROUP\GIS\11100000s\11102282\Layouts\REP003\11102282-04(REP003)GIS-IWRM007-V103.mxd

Figure 3.1 HEC-RAS Model Set Up

3.2.2 Hydraulic Model Development

Once all the Themes were defined, GIS calculations were performed in HEC-GeoRAS to extract geometric data for each HEC-RAS Theme for input into HEC-RAS. After all of the data were extracted, the geo-referenced HEC-RAS import file was created so that the hydraulic analysis could be completed using HEC-RAS. The data were imported into HEC-RAS and further edited to streamline the modelling (e.g., channel bank stations, cross-section data points). Additional information was added to the model to characterize hydraulic structures (bridges, culverts, etc.), ineffective flow areas, levees, and Manning's n.

The main channel bank stations were modified from what was entered in HEC-GeoRAS to ensure that the left and right channel bank stations were located in the correct location. Many of the cross-sections created in HEC-GeoRAS reached or exceeded the maximum number of data points allowed in HEC-RAS (500 points); several of which were duplicate points. Therefore, the cross-section data points were edited to ensure all significant topographic features were accounted for, and all duplicate points were removed. In-stream geometry was estimated from the information collected during the field reconnaissance.

The 11 water crossings were modelled as hydraulic structures using the HEC-RAS bridge design, deck/roadway and pier editors. Geometric data (i.e., bridge high and low chords, width, etc.) and hydraulic coefficients (i.e., weir coefficient and submergence) were inputted into the HEC-RAS model based on the as-built drawings and data collected during the field reconnaissance visit (hydraulic inventory sheets and site photographs). Photographs for each water crossing were imported into the HEC-RAS model for future reference. A total of four cross-sections were used to represent each of the water crossings in order to properly calculate the energy losses due to flow through the structure. The first and fourth cross-sections were located sufficiently downstream and upstream, respectively, from the structure so that the flow was not affected by the structure. This distance was based on the structure constriction, channel slope, magnitude of the flow, and the velocity of the flow. The appropriate distances were determined during the field visit and review of the DEM and aerial photographs. The second and third cross-sections were located a short distance downstream and upstream, respectively, from the water crossing structure.

Ineffective flow areas represent areas of the river system that contain water that is not actively being conveyed (velocity of water that is close to or equal to zero). The water located in the ineffective flow areas is included in the storage calculations and other wetted cross-section parameters, but is not included as part of the active flow area. For instance, at a bridge, ineffective flow areas normally occur just upstream and downstream of the road embankment. Areas that are normally ineffective were modelled as permanent ineffective areas and were added to the channel cross-sections located upstream and downstream of bridges. The size of the upstream and downstream cross-section ineffective flow areas were determined based on the assumption of a 1:1 contraction rate and a 1:1 expansion rate, respectively. The elevation of the ineffective flow areas for the upstream and downstream cross-sections were based on the bridge high chord elevation, and average elevation between the bridge high and low chord elevations, respectively.

The values of Manning's n for the left overbank, channel, and right overbank areas were assigned using a horizontal variation in n value. This allows for assigning a changing Manning's n value in the horizontal direction. The values used for Manning's n were based on the data collected during the field reconnaissance visit and standard Manning's n reference tables (Chow, 1959). The Manning's n value assigned to the channel varied between 0.045 (boulders in the channel) and 0.030

(sandy/rocky channel). The left and right overbank Manning's n values ranged between 0.080 (representing heavily forested surfaces) to 0.04 (representing paved surfaces such as the parking lot for Bedford Place Mall).

The completed hydraulic model was verified using the Federal Emergency Management Agency (FEMA) cHECk-RAS program. cHECk-RAS verifies the validity of an assortment of parameters and produces a summary report of all errors, warnings and notes based on standard HEC-RAS application. An iterative process was used to fix the errors and warnings and address the notes, with multiple runs of cHECk-RAS to ensure the solutions solved the issues. The final cHECk-RAS report for a model with no errors or warnings is a blank report. The final Sackville River hydraulic model produced a blank cHECk-RAS report.

3.2.3 Model Calibration and Validation

Calibration and validation of hydraulic models is essential for the model to produce reliable and accurate results. With HEC-RAS, calibration is the adjustment of model parameters such as roughness (Manning's n), hydraulic structure coefficients and appropriate locations of ineffective flow areas and levees. The hydraulic model was calibrated using a split sample technique with manual calibration techniques. The evaluation of the performance of the hydraulic model was completed by assessing the model's ability to reproduce historical flood events for which observed discharge, water level and sea level data were available. The observed data were split into two groups: one for model calibration and the other for model validation. Model input parameters were calibrated to the first set of observed data and the validity of the model was then tested by running the calibrated model using the input data from the second set. The resulting projections for the output variables from the model were compared against the observed variables.

The December 10-11, 2014 flooding event was used for model calibration. This event was chosen due to the large amount of data available to perform calibration. Flow and sea level data were available to be used as boundary conditions in the model, and water level data were available at the WSC gauge station. In addition, a significant amount of information about the extent of flooding was available, including aerial photographs taken from a drone flight. Therefore, the calibration process involved matching both the water level data obtained from WSC and the flood extents as seen on the photographs collected by the drone flight.

Using the calibrated hydraulic model, flow data and tidal data for multiple high flow events observed in 2011 were inputted and used to validate the model. No modifications were made to the input parameters other than the boundary conditions. The calculated water surface elevations at the location of the WSC gauge station on the Sackville River were compared to the WSC water levels and the results were assessed based on two statistical error tests: coefficient of determination and Root Mean Square Error (RMSE).

At the completion of the calibration and validation process the hydraulic model of the Sackville River was used to calculate the water surface profiles for the combination of nine flood and sea level frequency events. The objective of this analysis was to determine the combination of frequency events that produced the extent of the worse-case flooding event in the lower reach of the Sackville River.

3.2.4 Hydraulic Model Post-processing

The resulting water surface profiles generated for the December 2014 calibration event and the worst-case scenario frequency event from the HEC-RAS model were imported back into HEC-GeoRAS for post-processing and flood map delineation.

HEC-GeoRAS allows for easy-to-use post-processing techniques of attributing water surface profiles to topographic maps and aerial photographs for validation and final figure generation. HEC-GeoRAS was used to extract the calculated water surface elevation at each cross-section and combine these data with the TIN to build bounding flood extent polygons and flood depth raster images. Due to the nature of the TIN grid, manual flood extent smoothing was necessary to ensure the flood extents matched the contour data. The smoothing of the floodplain can induce errors if not done correctly. Therefore, edits to the flood line were only performed in locations where the flood line clearly did not follow the contour map.

3.3 Results

3.3.1 Calibration and Validation

The flood extent for the December 10-11, 2014, calibration event, as calculated by the hydraulic model, is presented in Figure 3.2. Maximum water extents matched very well with the flooding seen on the drone photographs. Water levels measured at the WSC gauge station (6.4 m) also matched well with the calculated water surface elevation from the hydraulic model (6.04 m).

Table 3.2 presents the results from the validation analysis. A statistical error analysis was performed on the validation results using the RMSE and coefficient of determination statistics. The RMSE value was 0.16 m and the coefficient of determination was 0.98. The agreement between the calculated and observed data in Table 3.2 indicated an acceptable model calibration.

Table 3.2 Model Validation Results

Event Date (dd/mm/yyyy)	Observed Discharge (m^3/s)	Observed Tidal Level (m)	Observed Water Level (m)	Calculated Water Level (m)
06/10/2011	42.0	0.35	5.51	5.60
16/10/2011	17.3	0.42	4.72	4.94
20/10/2011	36.4	0.40	5.27	5.48
21/10/2011	57.4	0.35	5.89	5.88

Figure 3.2 Model Calibration Result for 2014 Event

3.3.2 Water Surface Profiles

Utilizing the calibrated hydraulic model, the water surface profiles were determined for the nine combinations of flood and sea level frequency events as shown in Table 3.3. Careful consideration was given to the encroachment of the water surface profiles at each hydraulic crossing and cross section to ensure that the floodplain storage was accurately modelled. This was completed by ensuring that levees were in the appropriate location to reflect the hydraulics and floodplain storage for each frequency event. This resulted in the creation of three separate hydraulic models, one for each of the three flood frequency events modelled.

The water surface profiles of the lower reach of the Sackville River for the nine combinations of flood and sea level frequency events are presented in Figures 3.3 to 3.5. The analysis used the worst-case flood and sea level return period estimates in order to ensure that the largest possible flooding extent was identified. Non-stationary frequency analysis was used for both flood and sea level. The profiles obtained for the same flood estimate but different sea levels were combined in one plot to allow visual assessment of the effects of sea level on flooding in the lower Sackville River. Figure 3.6 presents a comparison of the water surface profiles of the lower reach of the Sackville River for the 5-, 20- and 100-year flood event with the downstream boundary condition set to the 100-year sea level.

Table 3.3 Combinations of Flood and Sea Level Frequency Estimates Used for Hydraulic Modelling

River Flow Return Period (Years) and Amount (cms)	Sea Level Return Period (Years) and Amount (m)		
	5-Year: 1.85 m	20-Year: 2.06 m	100-Year: 2.29 m
5-Year: 73.4 cms	1	2	3
20-Year: 93.0 cms	4	5	6
100-Year: 115 cms	7	8	9

The sea level in Bedford Basin was used to define the downstream boundary condition of the hydraulic model. However, the Sackville River has a steep gradient in the last 500 m before it discharges into Bedford Basin. The hydraulic back water impact of the sea level in Bedford Basin on flooding in the Sackville River watershed was therefore low. The sea level impacts the hydraulic profile for a distance of approximately 200 m, which is a small portion of the river. In addition, the sea level does not impact the areas of the Sackville River that are historically affected by flooding. Thus, the sea level is not an important factor in floodplain modelling of the Sackville River.

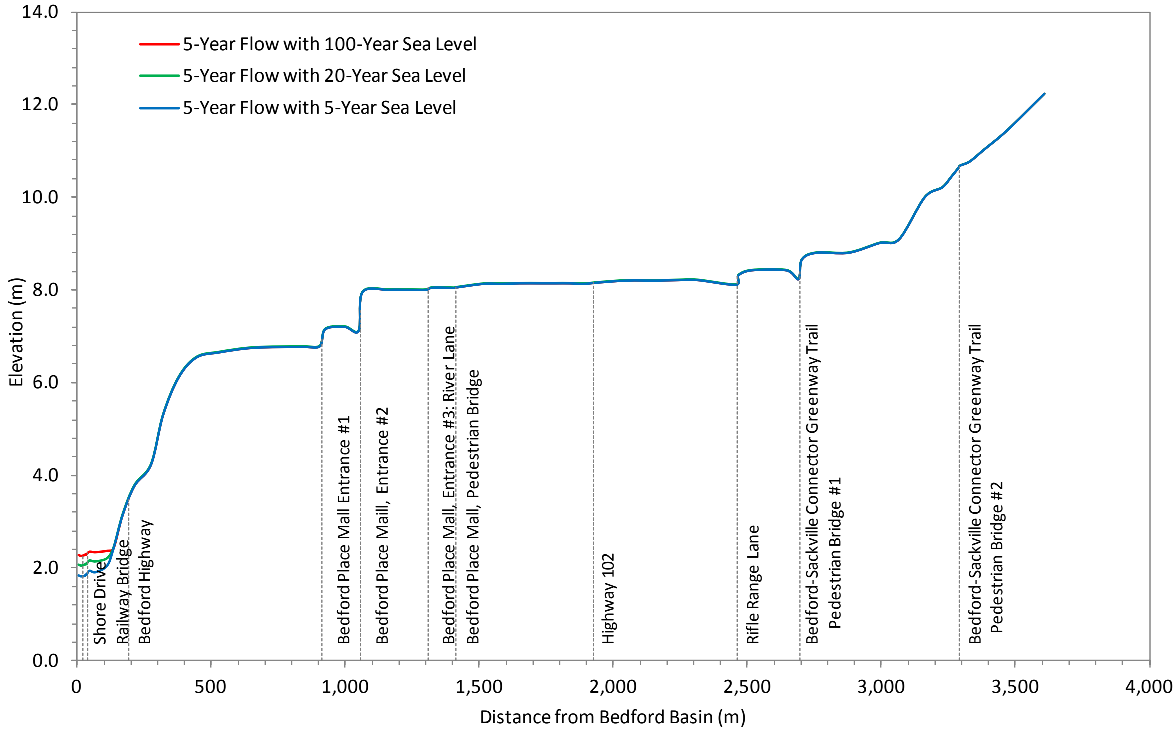


Figure 3.3 Water Surface Profiles of Sackville River for 5-Year Flood With 5-, 20-, and 100-Year Sea Level

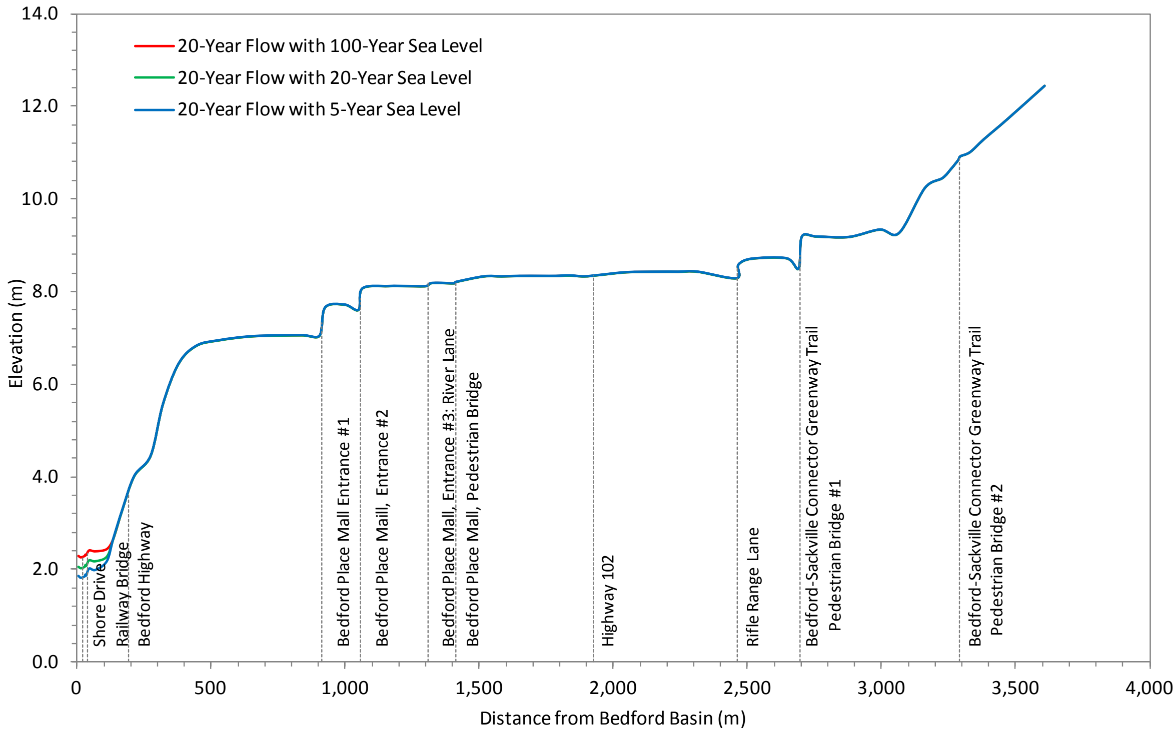


Figure 3.4 Water Surface Profiles of Sackville River for 20-Year Flood With 5-, 20-, and 100-Year Sea Level

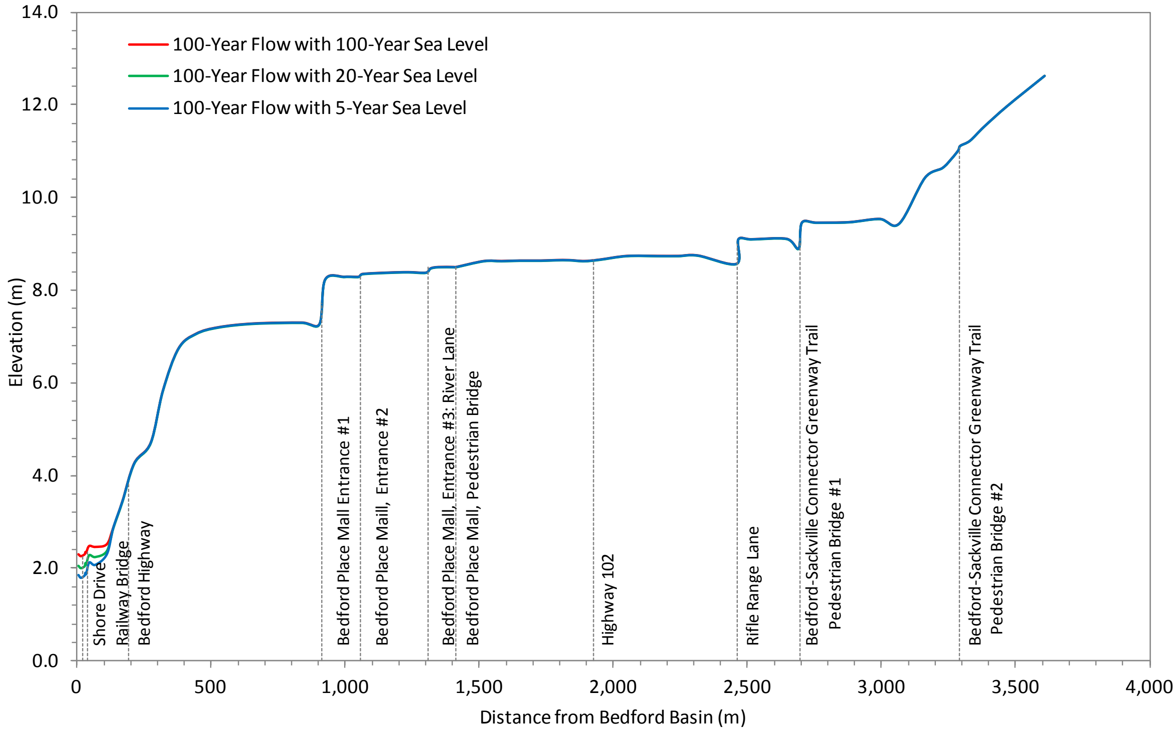


Figure 3.5 Water Surface Profiles of Sackville River for 100-Year Flood with 5-, 20-, and 100-Year Sea Level

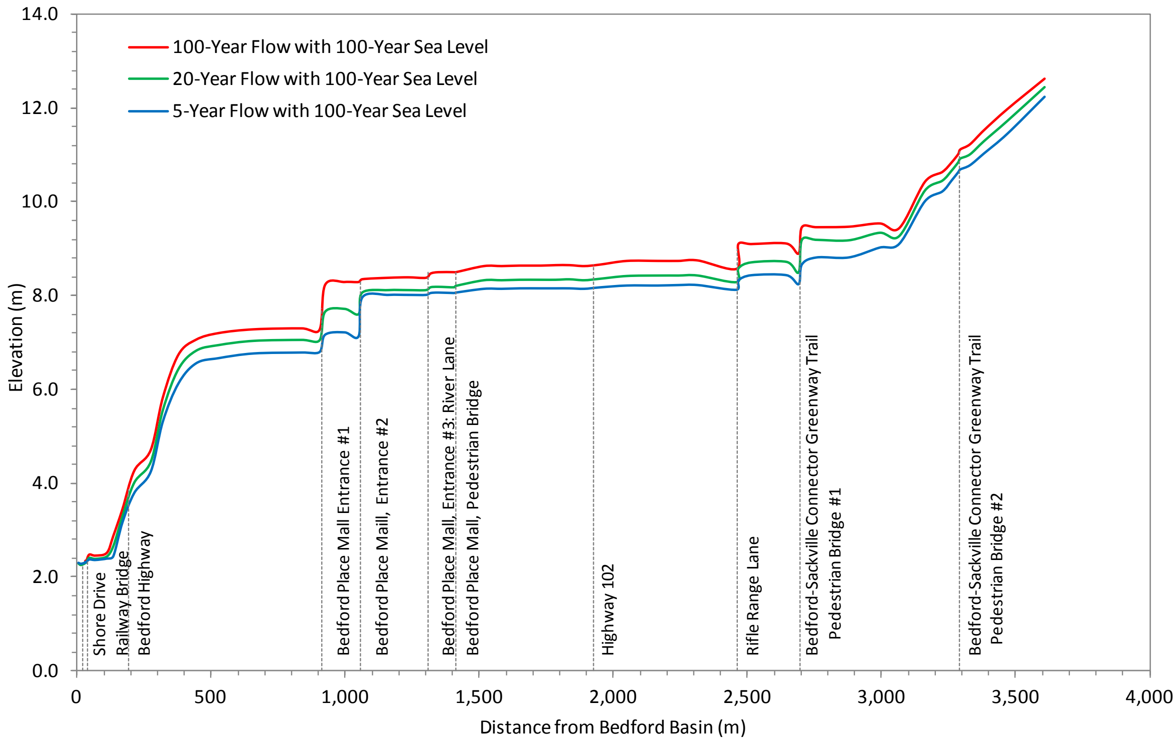


Figure 3.6 Water Surface Profiles of Sackville River for 5-, 20-, and 100 Year Flood with 100 Year Sea Level

These water surface profile results compare favourably with the results from the Interprovincial Engineering, 1981 Hydrotechnical Study of the Sackville River. The calculated water surface at key locations for the 100-year return flood are similar in elevation between the 1981 study and this study; however, water levels in this study tend (on average) to be slightly higher but fall within the 95% confidence limit of the 1981 study. The largest difference between the 100-year flood levels occurs between the Bedford Place Mall and Highway 102, where there is a maximum difference of approximately 1 m. Upstream of Highway 102 the difference in the calculated water surface elevations becomes much smaller (<0.5m) and at the upstream limit essentially the same. This result was expected because of the purpose of the hydraulic model, and intended use of the resulting flood extents. The preliminary hydraulic model developed in this study was intended to be conservative in nature in order to identify the maximum potential flood extents to define the required horizontal limits of the topo-bathymetric survey in the floodplain/overbank area.

The 1981 report also came to a similar conclusion as the results from this study with regards to the influence of tide levels on the floodplain extents. Both studies concluded that the tide levels only impacted a short reach of the river downstream of the Highway 2 and CNR bridge, and had no effect upon water surface profiles through the Bedford Place Mall area and upstream.

The hydraulic model developed in Phase I was high-level and designed to identify the topo-bathymetric survey extent. Worst-case return period estimates for flood and sea level were used. The water surface profiles calculated by the high-level hydraulic model indicated that for all scenarios modelled, the following areas have potential for damaging floods:

- Bedford Place Mall Entrance #2
- Bedford Place Mall parking lot
- Condominium development on River Lane immediately north of Bedford Place Mall
- Recreational area (Range Park) in the vicinity of Highway 102
- Department of National Defense gun range located north of Highway 102

The water surface profiles obtained from the scenarios using the 20-year flood indicated that the following areas also have potential for damaging floods:

- Fish Hatchery Park
- Residential neighbourhood east of Union Street in the vicinity of Bedford Place Mall
- Bedford Place Mall Pedestrian Bridge

The water surface profiles obtained from the 100-year flood scenarios indicated that the following areas also have potential for damaging floods:

- Bedford Tower parking lot located at 1496 Bedford Highway
- Bedford-Sackville Connector Greenway Trail Pedestrian Bridge #1
- Water elevation was near the crest of Highway 101 at the confluence of the Sackville River and Little Sackville River

The worst-case flood extent was the combination of the 100-year flood and the 100-year sea level (Figure 3.7). The flooded area indicates the minimum area that should be measured during the topo-bathymetric survey data collection.

Figure 3.7 Flood Extent of Sackville River for 100-Year Flood and 100-Year Sea Level

4. Topo-bathymetric Data Collection

The topo-bathymetric data collection began on September 17, 2015 and was completed on September 30th, 2015. A combination of Trimble R8 RTK GPS (absolute accuracy +/- 0.02m horizontal and +/- 0.04m vertical) and Trimble S6 Total Station (absolute accuracy +/- 0.02m horizontal and +/- 0.04m vertical) was used to collect the required survey data. The GPS unit was used for the majority of the data collection activity, only switching to the Trimble S6 Total Station when tree canopy cover caused a loss in connection to satellites. A map indicating which points were collected by which method and the field survey field notes are provided in Appendix D. For the majority of the cross-section data collection the water level was low enough for the survey crew to walk across the river, however, a few cross-sections, mainly in the lower reaches and mouth of the Sackville River, required a boat to collect the necessary bathymetric data.

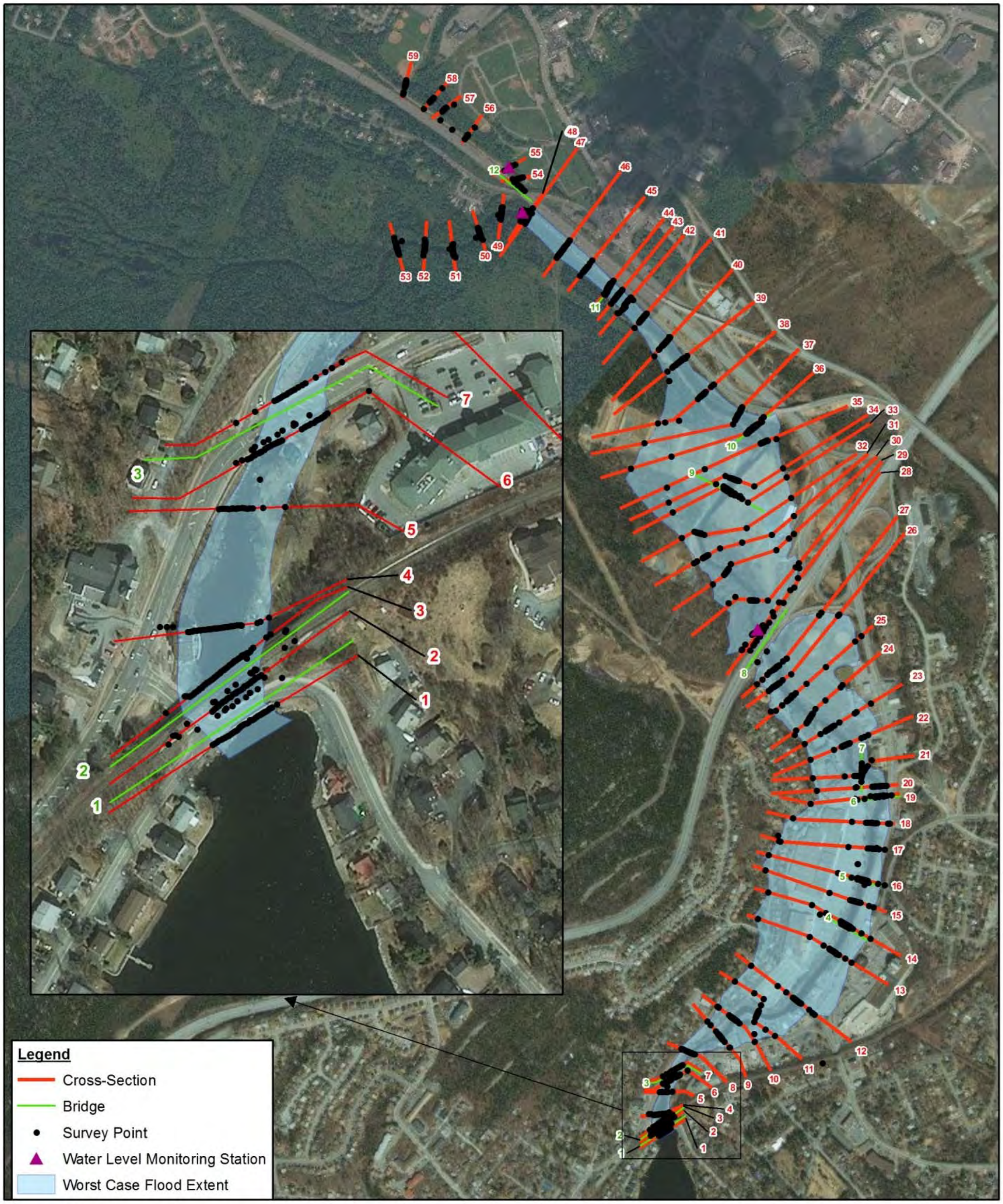
The results from the hydraulic modelling completed in Section 3 provided the basis for defining the limits of the surveying data collection. Figure 4.1 presents the location of the detailed topo-bathymetric survey. The purpose of the topo-bathymetric data collection was to:

- Characterize the bathymetry for the modelled cross-sections.
- Characterize the water crossings.
- Perform confirmatory survey in the floodplain/overbank area to validate the HRM 2007 LiDAR data.

A total of 59 cross-sections and 12 hydraulic structures (bridges and culverts) were captured in the ground survey data collection. The flood extent determined in Section 3 for the worst-case flood (100-year flood and 100-year sea level) was used to establish the limits of the data collection in the overbank/floodplain area. Detailed topo-bathymetric data were collected within the channel and banks with a maximum spacing between points of one meter. Additional survey points were collected in the overbank/floodplain area to field verify the LiDAR data collected by HRM in 2007. These additional points were strategically located to verify the floodplain extents and other key locations that flooded during the worst-case event (e.g., Bedford Place Mall parking lot, Highway 101, the baseball diamonds/Bedford Legion along Highway 1, etc.). The topo-bathymetric data collection extents also included the area north and west of the confluence of the Sackville River and Little Sackville River, due to the high water levels calculated by the hydraulic model near the confluence. The area near the confluence is critical, due to its proximity to Highway 101, and the interaction between the two rivers may further increase the risk of flooding in this area.

In addition to the topo-bathymetric points identified above additional points were collected to represent the location of Dalhousie University water level monitoring stations. A total of three monitoring locations were surveyed and these are identified on Figure 4.1.

The topo-bathymetric data were collected in the same coordinate system and vertical datum as the original DEM, NAD83(CSRS) UTM Zone 20 and CGVD28, respectively. The survey data has also been converted to the ATS77 horizontal datum and CGVD 2013 vertical datum. All versions of the topo-bathymetric data are included on the project FTP site. The data are provided in three different formats: 1) AutoCAD DWG 2) ASCII (x,y,z) format, and 3) ESRI shapefile.



Bing Imagery: ESRI Data, World Imagery, Accessed 2015

0 100 200 300
Meters

Coordinate System:
NAD 1983 CSRS MTM 4

HALIFAX REGIONAL MUNICIPALITY
HALIFAX, NOVA SCOTIA
SACKVILLE RIVERS FLOODPLAIN STUDY: PHASE I

11102282-04
Oct 30, 2015

TOPO-BATHYMETRIC SURVEY EXTENT

GIS File: I:\IWRM-GROUP\GIS\11100000s\11102282\Layouts\REP003\11102282-04(REP003)GIS-IWRM015-V103.mxd

Figure 4.1 Topo-bathymetric Survey Extent

5. Historical Review of Flooding Factors

5.1 Data Sources

5.1.1 Climate Stations Located In and Near the Sackville River Watershed

The flooding factors analysis and the analysis of the ten highest precipitation events used a collection of Environment Canada climate stations with sub-daily data that are located in and near the Sackville River watershed. The flooding factors analysis identified the main causes of the instantaneous annual maximum flows for both the Sackville River at Bedford and Little Sackville River at Middle Sackville stations. Climatological data were used to identify the antecedent conditions for each flow. The ten highest precipitation events were used to identify a suitable synthetic rainfall distribution for the area. Hourly precipitation data were used for this purpose. The Environment Canada (EC) Public Weather Alert regions for Nova Scotia were used to identify stations to include in the analysis. These regions identify areas with similar weather patterns, and storms are expected to be similar within each region. The Sackville River area is located across two regions: Halifax Metro and Halifax County West, and Hants County. However, the Public Weather Alert regions are large, and there were stations that were located a significant distance from the watershed (e.g., Martock stations, located near Minas Basin), which were considered to be too far away to include in the analysis. The stations that were selected to use in the analysis are listed in Table 5.1, and shown in Figure 5.1.

Table 5.1 Environment Canada Sub-Daily Climate Stations

Station Name	Station ID	Daily Data: Air Temperature, Rainfall, Snowfall, Snow on the Ground	Hourly Data: Precipitation
Bedford Range	8200574	None	2013-2015
Halifax	8202200	1939-1974	1960-1974
Halifax Intl A	8202251	2012-2015	2012-2014
Halifax Stanfield Int'l A	8202250	1953-2012	1970-1988, 2006-2012
Shearwater A	8205090	1944-2007	1955-2007
Shearwater Auto	8205091	1996-2010	2004-2010
Shearwater Jetty	8205093	1994-2015	2013-2015
Shearwater RCS	8205092	2008-2015	2008-2015

The 24-hr data were used to characterize the antecedent conditions for each instantaneous annual maximum flow event. This included analysis of rainfall, snowfall, air temperature, and snow on the ground. Air temperature, snowfall, and snow on the ground data were used to determine if there was snowmelt contributing to the analyzed flood events. The daily maximum, mean, and minimum air temperatures were used. The data for Halifax Stanfield Int'l A were used for all years except 2012 (no data were available in 2012). The data for Shearwater RCS were used for 2012.

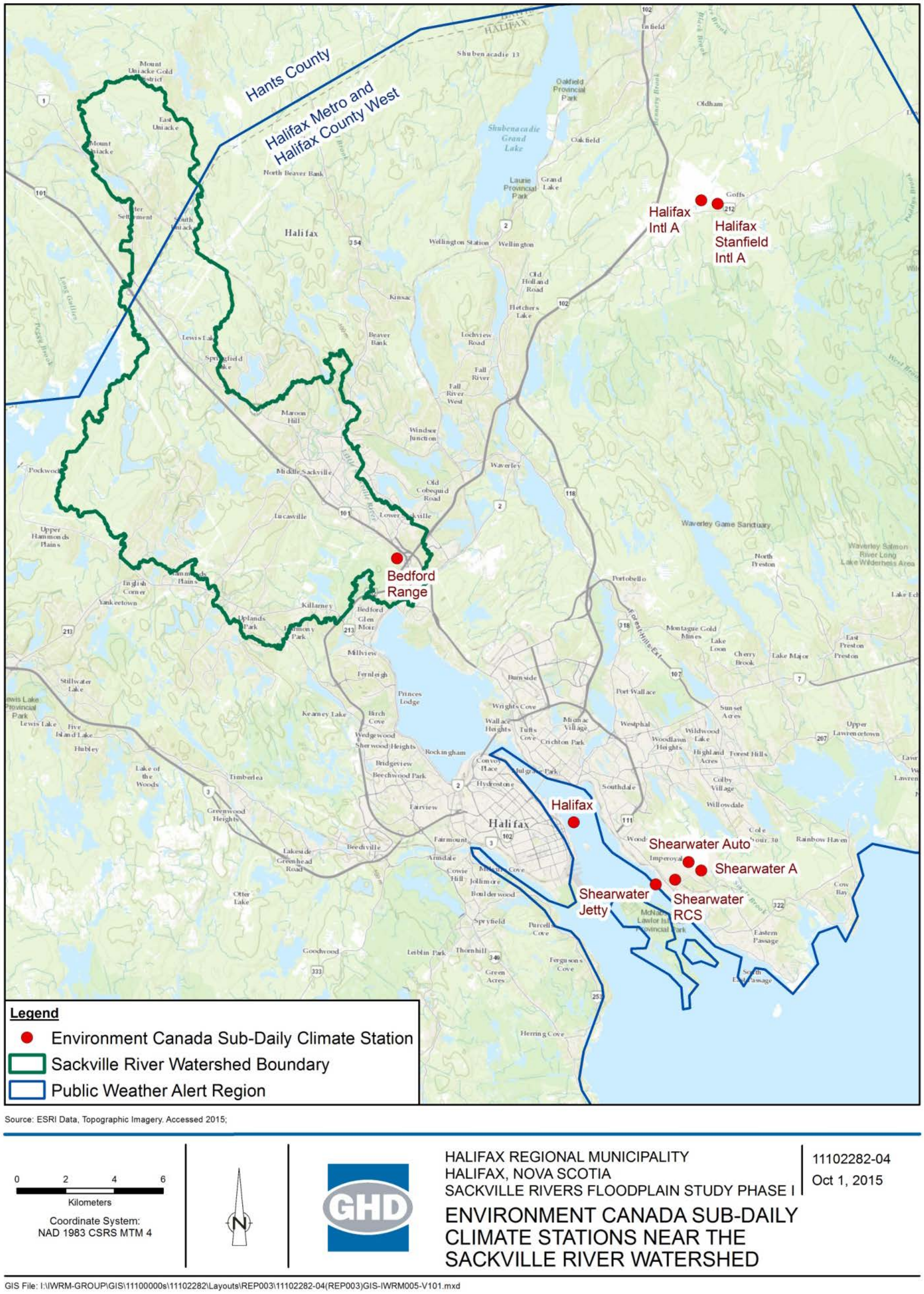


Figure 5.1 Environment Canada Sub-Daily Climate Stations Near the Sackville River Watershed

EC publishes the 24-hr rainfall, the 24-hr snowfall, and the 24-hr total precipitation for each station. The rainfall and snowfall data were used to determine whether the precipitation was fully rain, fully snow, or a rain/snow mix for each flood event. The 24-hr precipitation data are generally recorded using the Meteorological Service of Canada (MSC) Type B standard rain gauge, which is a high-quality manual rain gauge (often installed in key locations such as airports). Some 24-hr data are collected using other manual gauges. The data are recorded for a fixed 24-hr period, usually a standard "climate day" of 0600 Coordinated Universal Time (UTC) to 0600 (UTC).

The sub-daily data were used to characterize the temporal distribution of significant rainfall events. The hourly data were recorded with a combination of Tipping Bucket Rain Gauges (TBRG) and precipitation weighing gauges. A TBRG only operates when the air temperature is above zero Celsius, and hence only record rainfall. Precipitation weighing gauges are all-weather gauges, recording both liquid and solid precipitation. The 1-hr data are archived by EC, with no QA/QC performed on the data. Spurious outliers may exist in the data (e.g., more than 100 mm of precipitation occurring in 1 hour). The hourly data were compared to other hourly data and daily data to ensure that the precipitation was accurate, and outliers were marked as "missing".

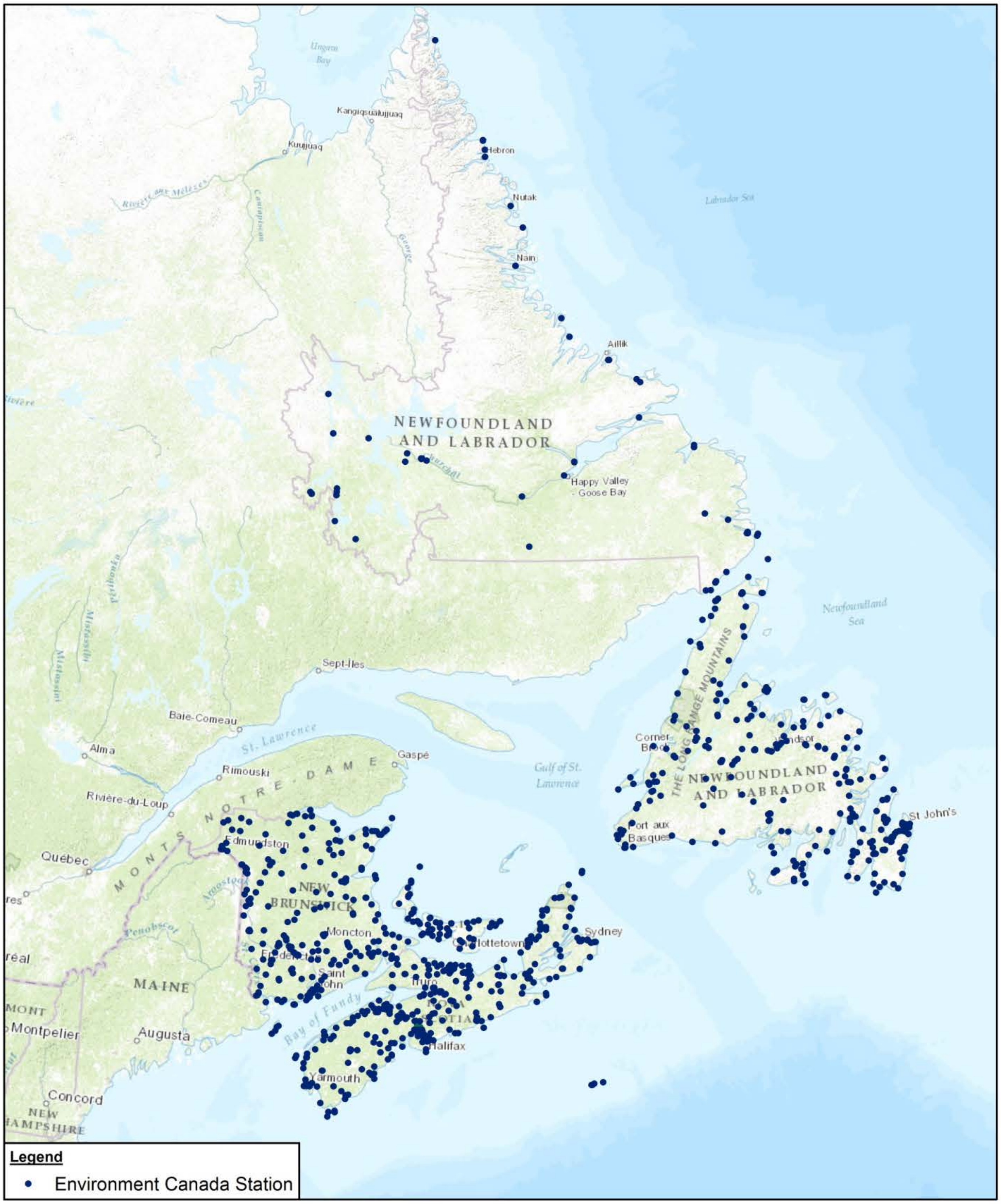
5.1.2 Stations Located in the Atlantic Provinces

The regional rainfall events in the Atlantic Provinces with precipitation near the 100-year rainfall event for Halifax were used to characterize the types of large precipitation events that have occurred historically in the Atlantic Provinces. They were also used to compare the 24-hour, 100-year precipitation events from the three IDF curves near the Sackville River watershed. For this analysis, the climate stations in each of the Atlantic Provinces were identified. Environment Canada maintains a number of climate stations in each province (Table 5.2 and Figure 5.2). For the climate stations that record precipitation, Environment Canada publishes the 24-hr rainfall, the 24-hr snowfall, and the 24-hr total precipitation. For the regional analysis, only the 24-hr rainfall data were used, as the purpose was to identify significant rainfall events.

Table 5.2 Environment Canada Climate Stations Located in the Atlantic Provinces

Province	Number of Stations	Earliest Year of Data	Data Used
Nova Scotia	309	1870	24-hr Rain
New Brunswick	224	1871	24-hr Rain
Newfoundland and Labrador	335	1871	24-hr Rain
Prince Edward Island	56	1872	24-hr Rain

The 24-hr data are recorded for a fixed 24-hr period (generally for the 24 hours ending at 0600 UTC). However, a significant 24-hour rain event may begin at 1800 UTC one day and continue until 1800 UTC the next day. In this case, the rain would be recorded on two separate days in the 24-hr station data. The total 24-hour precipitation might be near the 100-year rainfall event for Halifax, but the precipitation recorded on each day would be less. This would result in a significant rain event being missed if only the 24-hr daily total was used. To account for this problem, the two-day rainfall totals were also analyzed. The two-day rainfall totals can represent up to 48 hours of rain, but often represent less than 48 hours.



Source: ESRI Data, Topographic Imagery. Accessed 2015;

0 100 200 300
Kilometers

Coordinate System:
NAD 1983 CSRS MTM 4

HALIFAX REGIONAL MUNICIPALITY
HALIFAX, NOVA SCOTIA
SACKVILLE RIVERS FLOODPLAIN STUDY: PHASE I

11102282-04
Oct 1, 2015

ENVIRONMENT CANADA CLIMATE STATIONS IN THE ATLANTIC PROVINCES

GIS File: I:\IWRM-GROUP\GIS\11100000s\11102282\Layouts\REP003\11102282-04(REP003)GIS-IWRM004-V101.mxd

Figure 5.2 Environment Canada Climate Stations in the Atlantic Provinces

There were significant rain events that lasted for three or more days, where each two-day total was near the magnitude of the 24-hour, 100-year precipitation event. The three-day total could not be used, as it would represent more than the maximum of 48 hours of rainfall. When this occurred, one or more of the two-day totals were just above the threshold for inclusion in the analysis (i.e., there were no multiple-day events with extremely high two-day rainfall totals for every set of two days in the event). Therefore, only the largest two day total was retained in the analysis. The use of only the largest two-day total (instead of every two-day total) ensured that all of the rainfall events that were identified were independent from each other. It also removed the smaller events that were just above the threshold for inclusion in the analysis, which were of less interest.

5.1.3 Intensity-Duration-Frequency Curves

EC has collected tipping bucket rain gauge (TBRG) data at four stations near Halifax. When there are at least ten years of valid data at a TBRG station, EC uses the data to produce an Intensity-Duration-Frequency (IDF) curve for that station. Table 5.3 and Figure 5.3 present the four IDF stations located near Halifax.

Table 5.3 Environment Canada Intensity-Duration-Frequency Curve Stations Located Near Halifax

Station Name	Station ID	Years of Data	100-year, 24-hour Precipitation Amount (mm)
Halifax	8202200	1941-1973	232.9
Halifax Intl A	8202251	1977-2013	126.5
Shearwater Auto	8205091	1955-2009	151.1
Shearwater RCS	8205092	2008-2013	<10 years

Source: Environment Canada Intensity-Duration-Frequency Curves, V2.3, Published 2015.

There is considerable variation in the 100-year, 24-hour precipitation amount at the different stations. Three of the stations are located near the coast, while the airport station is located some distance inland. The largest value comes from the station that is most out-of-date (Halifax, last year of data: 1973), while the most current and up-to-date station has the lowest value (Halifax Intl A). The primary reason for the discrepancy is that different time periods are included in each curve. The Halifax IDF data includes two years with 24-hour precipitation totals greater than 200 mm (1942 and 1971) in a relatively short time series (23 years of data). Both events were hurricanes (unnamed hurricane in 1942 and Hurricane Beth in 1971). These have caused the 24-hour, 100-year precipitation estimate to be very large. The Shearwater Auto IDF data includes only the large event in 1971, while the Halifax Intl A IDF data does not include either extreme event. EC produced a comparison document describing the differences between the curves (EC, 2014). For this analysis, all three IDF curves were compared with the results.

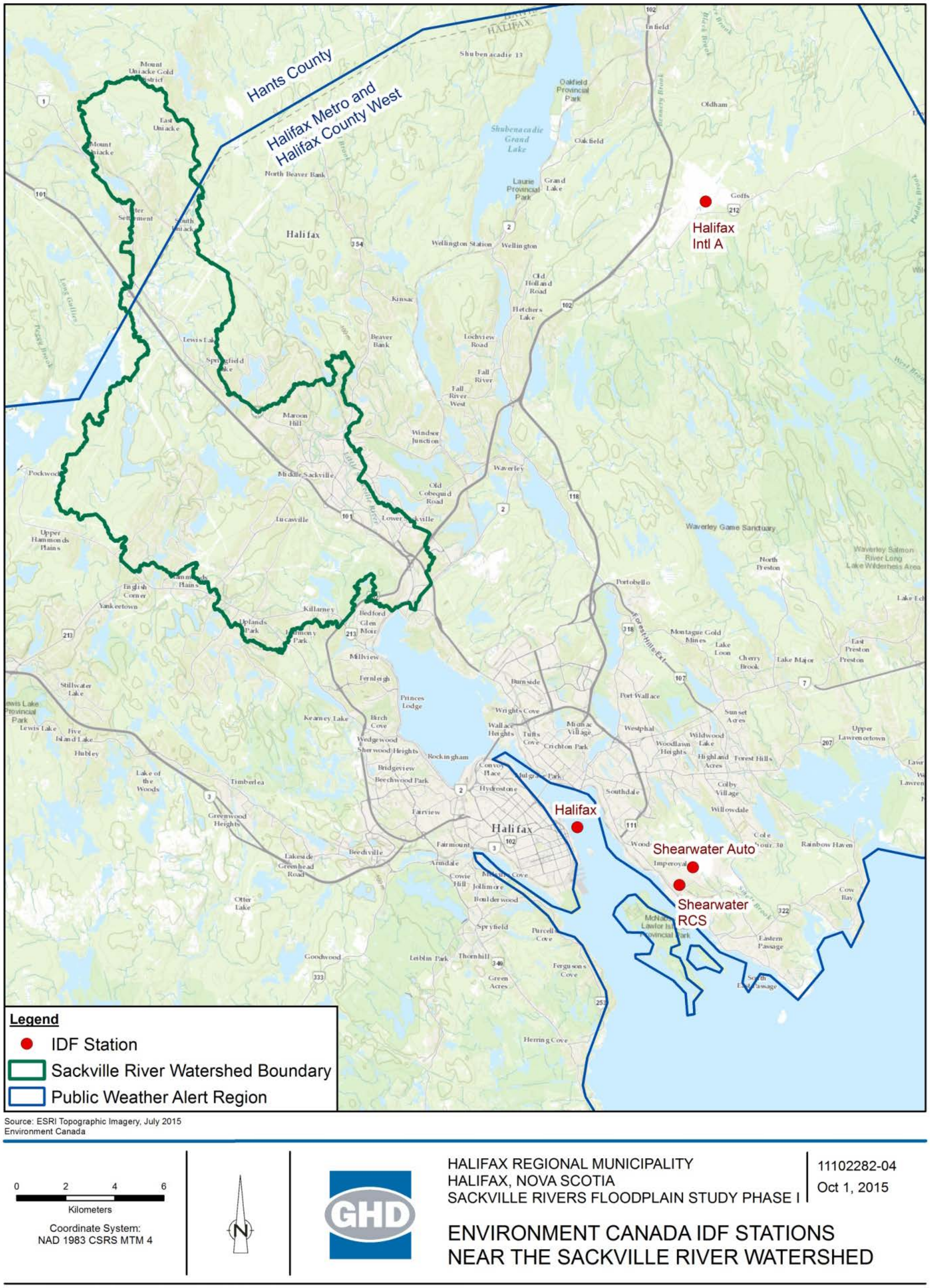


Figure 5.3 Environment Canada IDF Stations Near the Sackville River Watershed

5.1.4 Tidal Predictions

Tidal predictions were compared with actual sea level data to determine if there was a surge at the time of the instantaneous annual maximum flow event. The tidal predictions accounted for the natural variation in sea level due to the effect of the location of the Earth relative to the moon and the sun. Tidal predictions were obtained from the XTide website for Halifax, Nova Scotia: http://tides.mobilegeographics.com/locations/2369.html. The date of the instantaneous annual maximum flow event was entered into the website, and the tidal prediction for Halifax for that date in history was obtained. The tidal prediction for the time of the instantaneous annual maximum flow was read from the chart. However, because the data were read from a chart, they were approximate (i.e., ±0.1 m).

5.1.5 Extra-Tropical Cyclone Inventory

As part of identifying the regional storm events, the Canadian Tropical Cyclone Season Summaries (http://ec.gc.ca/ouragans-hurricanes/default.asp?lang=en&n=23B1454D-1) were consulted to identify the extra-tropical cyclone events that affected Canada. Some extra-tropical cyclones had become weaker and were no longer classified as hurricanes when they affected Canada, but were included in the database. Seasonal summaries were available from 1954 to 2013.

Prior to 1954, other historical sources were consulted to find the extra-tropical cyclone events that affected Canada. These included web searches and encyclopedia entries. However, the lists obtained may not be comprehensive, due to the lack of historical data (especially prior to 1900).

Nova Scotia and the other Atlantic Provinces are subject to various types of large regional precipitation events. Hurricanes/extra-tropical storms are a major source of large precipitation events. However, frontal systems can also move across the entire region, and result in significant precipitation. In addition, nor'easters (large storms which start in the Atlantic Ocean and affect the east coast of North America) occur in the winter. Regional precipitation events were identified as hurricanes/extra-tropical storms whenever possible. However, some of the events were not caused by extra-tropical cyclones. These were left in the data but were not identified with a storm name.

5.1.6 Flooding Extent Information

Information regarding the extent of flooding for the five largest instantaneous annual maximum streamflow events on both the Sackville River and the Little Sackville River was also included. The Nova Scotia Flood Event Database, the Sackville Rivers Association, previous hydrotechnical studies of the Sackville and Little Sackville Rivers, Halifax Regional Council minutes, and newspaper articles were used for these data.

The Nova Scotia Flood Event Database is maintained by Dalhousie University. Kindervater (1977 and 1988) summarized the flood events from 1759 to 1987 in Nova Scotia according to their causes. The data for floods from 1992 to 2015 have been added and are included in online interactive maps of the Nova Scotia Flood Event Database at Dalhousie University (http://mathstat.dal.ca/~ameliay/flood/). The database included some information about the extent of flooding. The causes of the floods were also used to verify the flooding factors analysis.

The Sackville Rivers Association maintains some information regarding flooding in the Sackville Rivers. The previous Hydrotechnical Studies of the Sackville and Little Sackville Rivers also reported some information on flooding extents for historical floods (Interprovincial Engineering, 1981; Nolan Davis, 1987; Porter Dillon, 1999). Halifax Regional Council minutes were also searched for flooding extents. Finally, a newspaper search was conducted to fill in information regarding the flooding extent where it was not available in the other databases.

5.2 Methodology

5.2.1 Flooding Factors

The analysis examined a number of flooding factors that have historically caused instantaneous annual maximum flows. All instantaneous annual maximum flows for both the Sackville and Little Sackville Rivers were investigated. The flowchart for the methodology is shown in Figure 5.4. The first step of the analysis identified the key factors contributing to flooding in the Sackville Rivers. The following flooding factors were identified and investigated: rainfall, snowmelt, sea level/surge, river ice, antecedent conditions, and other information. Based on the results of each investigation, the flooding factors contributing to each flood were summarized. For the floods due to rainfall (partially or fully), the temporal distribution of the precipitation was obtained from the EC climate data archive and investigated for each watershed. For the five largest floods at each station, the information regarding flooding extents was summarized.

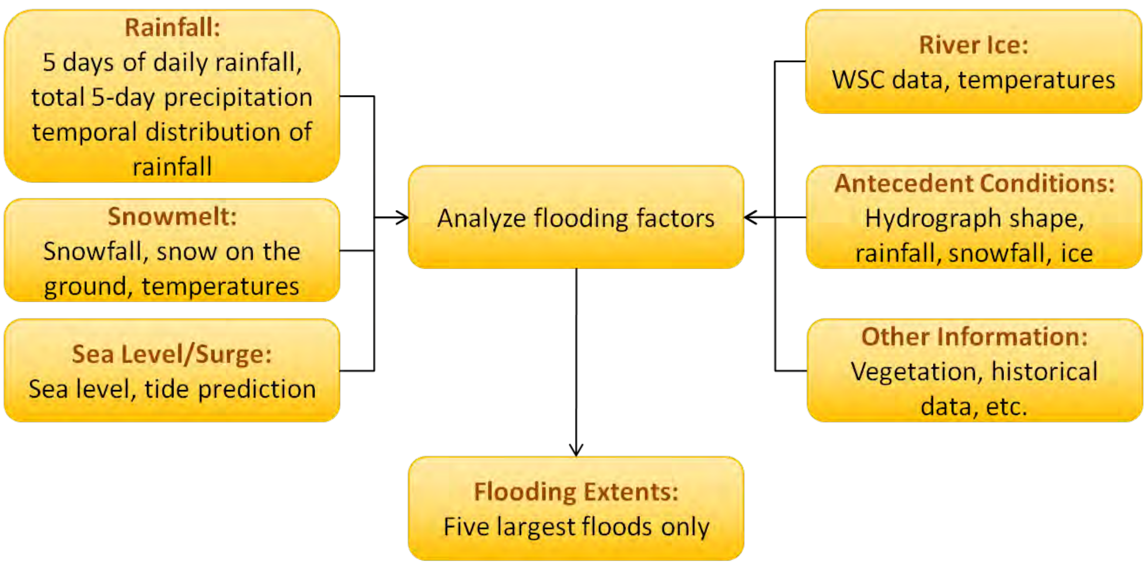


Figure 5.4 Flowchart for Flooding Factors Analysis

The rainfall analysis used the 24-hour rainfall and the 24-hour precipitation from the EC climate stations. The data for Halifax Stanfield Int'l A was used for all years except 2012. The data for Shearwater RCS were used for 2012 because the data were missing at Halifax Stanfield Int'l A. Five days of rainfall were used, so that the antecedent conditions prior to the annual maximum could be investigated in addition to the rainfall that caused the annual maximum. In addition to the five days of rainfall, the total precipitation (rain and snow) for the five days prior to the annual maximum was also analyzed, so that the relative contributions of rain and snow could be investigated.

The snowmelt analysis used the 24-hour snowfall, the depth of snow on the ground, and the air temperatures from the EC climate stations. If there was significant snowfall and/or the depth of snow on the ground was greater than zero prior to the annual maximum flow, then the rainfall occurred on snow. If snowfall occurred on the same day as the rainfall, then the event was a rain/snow mix. The air temperatures and/or depth of snow on the ground were used to determine if the snow had melted or accumulated.

The sea level/surge analysis compared the sea level from the Halifax station to the tidal prediction. As the tidal prediction was approximate, a difference of 0.2 m or less was not considered to be a storm surge. From the high-level hydraulic analysis performed during Phase I, it is known that the sea level does not cause flooding at the Sackville River at Bedford station. However, the sea level/surge analysis was left in the analysis so that the presence of a storm surge could be detected (even though it does not cause flooding). The sea level/surge analysis was not performed for the Little Sackville River at Middle Sackville station, as it is located further upstream from Bedford Basin.

The river ice analysis used the daily average streamflow data for the two WSC stations and the air temperatures from the EC climate stations. When the river is ice-covered, WSC adds a flag to the streamflow data because these data are less certain than data obtained when the river is not ice-covered. The flags were used to determine if the river was ice-covered or had just melted (one or two days before). Due to the frequent air temperature fluctuations throughout the winter months, the river was generally only ice-covered for short periods of time (for Sackville River at Bedford, the average length of ice coverage was 12 days, ranging from 1 day to 81 days). The annual maximum flow events that occurred in the winter months often occurred just after the ice melted during a warmer period. Ice melting is a key time for the formation of ice jams. The Interprovincial Engineering (1981) and Nolan Davis (1987) reports stated that there were numerous locations in the Little Sackville and Sackville River watersheds with potential for ice jams and/or debris blockage (e.g., flow constriction locations and channel singularities).

The antecedent conditions analysis used the shape of the hydrograph in addition to the rainfall, snowfall, and ice conditions analyses. The shape of the hydrograph could be used to indicate if the watershed was wet. For instance, if there were previous peaks on the hydrograph and streamflow was still high, then the watershed was wet from previous rainfall events. Similarly, if the flow was gradually rising, then a snowmelt event was occurring, and the watershed was wet/frozen. If the hydrograph showed that the streamflow was low or had receded significantly from the last event, then the watershed was mainly dry. The hydrograph shape was also compared to the other data sources already described. The watershed was then characterized as dry, wet, or wet/frozen.

Other information was also considered in the analysis. Examples of other information included: the vegetation conditions, the name of the hurricane, shape of the hydrograph (rapid rise, gradual rise), and if the annual maximum flow events for both rivers occurred on the same date for both Sackville River at Bedford and Little Sackville River at Middle Sackville.

Factors contributing to each annual maximum flow event were then summarized. For all of the annual maximum flow events that were due to rainfall (partially or fully), the sub-daily precipitation data were extracted from the EC climate data archive, so that the effect of the temporal distribution of the rainfall (e.g., duration, maximum intensity) could be examined. The sub-daily precipitation data are not separated according to rainfall or snowfall in the EC climate data archive. No analysis was performed to separate the rainfall from the snowfall for the sub-daily data. Finally, the historical information regarding the extent of flooding for the five largest annual maximum flow events was summarized.

5.2.2 Ten Largest Precipitation Events

The methodology for the analysis of the ten largest precipitation events is shown in Figure 5.5. The ten largest rainfall events were identified, and candidate synthetic rainfall distributions were selected. Statistical testing was performed to determine which synthetic rainfall distribution fits the observed rainfall events. The average of the largest ten rainfall events was also tested. The synthetic rainfall distribution that fit the most events was recommended for use.

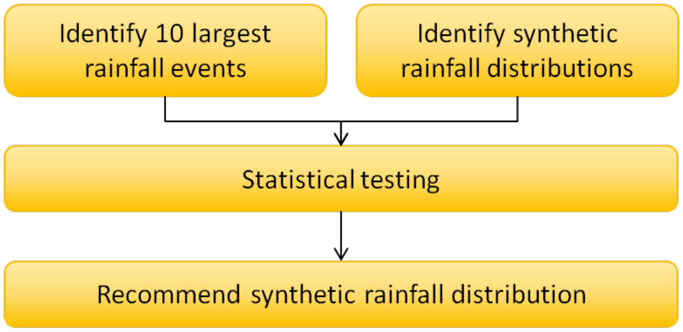


Figure 5.5 Flowchart for Determination of Recommended Synthetic Storm

The largest ten rainfall events were selected from the available hourly precipitation data. All events were assumed to be 24 hours in duration. Running 24-hour totals were calculated (the total could begin at any hour and included the next 23 hours). Some precipitation events stop and restart within a 24-hour period (e.g., rain for 12 hours, no rain for 3 hours, rain for 6 hours, and no rain for 3 hours). These events were considered to be a single 24-hour rain event and the total for all periods of rain (or no rain) within the 24-hour period was used. The largest 24-hour rain totals for all stations were compared to obtain the 10 largest 24-hour precipitation events at the stations near the Sackville River watershed. Note that where the same precipitation event was measured at more than one location, the station with the largest 24-hour precipitation total was used in the analysis. For each rainfall event, the standardized cumulative rainfall distribution was calculated. The precipitation in each hour was divided by the total 24-hour precipitation. The standardized precipitation was accumulated for each hour, to obtain an observed rainfall distribution that began at zero and ended at one.

Several 24-hour synthetic rainfall distributions were compared to the 10 largest storms. Note that synthetic rainfall distributions (also known as "design storms") have been established for the purpose of determining the peak flow for sizing of stormwater infrastructure (e.g., pipes, culverts, ponds, etc.). Synthetic rainfall distributions have a single, intense peak. There is typically very little rain before and after the peak. Observed rainfall events, however, may have multiple peaks or have a low intensity for many hours. As such, it is expected that some of the observed rainfall events will not match any of the synthetic rainfall distributions well. Therefore, it was not required for this analysis that the observed rainfall event and the synthetic rainfall distribution be a "good" fit using a statistical goodness-of-fit test. The best-fitting synthetic rainfall distribution was chosen without regard to whether it was statistically a "good" fit to the observed data. This approach is conservative, as a search to find "good" observed storms (i.e., similar to a design storm) would require that some of the largest storms be ignored in the analysis, and therefore the choice of design storm would be based on smaller storms. This would affect the selection of the preferred distribution.

Three different synthetic rainfall distributions were selected: Soil Conservation Service (SCS), Huff, and Chicago. The SCS (1986) synthetic rainfall distributions are designed to maximize the peak runoff at a given storm depth. There are four SCS design storms (Types I, IA, II, and III), which are designed primarily for durations up to 24-hours and frequencies up to 100 years. The Type I and IA curves are used for the Pacific coast, Type II is used for continental areas, and Type III is used for the Atlantic coast. For this analysis, the ten precipitation events were compared to the SCS Type III curve only. The Huff (1967) synthetic rainfall distributions were developed by considering heavy storms in the mid-western United States. The storms were grouped according to the portion of the storm where rainfall was heaviest. There are four Huff distributions, with peaks in each of the four quartiles of the storm (each quartile is six hours long for a 24-hour precipitation event). For this analysis, the quartile of each storm with the heaviest rain was identified, and the matching Huff distribution was selected for comparison. To distinguish between the Huff distributions, they have been identified as Huff-I, Huff-II, Huff-III, and Huff-IV in this report, where the Roman numeral corresponds to the quartile with the heaviest rain. The Chicago (Kiefer and Chu, 1957) synthetic rainfall distribution was developed to assist with drainage design. This synthetic rainfall distribution is recommended for use in design and construction of water conveyance structures by Halifax Water (2014). It is based on three parameters, which are derived from the IDF curve for the area. The parameters affect the magnitude of the peak intensity and the shape of the distribution, and they vary for every return period of an IDF curve. When used for design, the parameters are selected according to the needs of the design (e.g., a 2-year storm is required, so the parameters are selected using the 2-year IDF curve for the region of interest). For this analysis, only a single set of parameters were used, based on the 100-year IDF curve for Halifax (EC IDF curves, V2.3, 2015). The following coefficients were obtained for the A, B, and C parameters of the Chicago distribution using the 100-year IDF curve: 300.15, 0.001, and 0.482. The time to peak is also a parameter for the Chicago distribution. When the Chicago rainfall distribution is used for design, a standard time to peak is used in the analysis. The ratio of time to peak to total storm duration is often selected as 0.35, (e.g., Smith, 2004). However the peak intensity may occur at any time during an observed precipitation event. Therefore, for this analysis, the time to peak was allowed to vary to obtain the best-fitting Chicago distribution. The SCS and Huff rainfall distributions are standardized so that the total precipitation is one (dimensionless). For the purpose of comparison, the Chicago rainfall distribution was also standardized to be dimensionless. The cumulative synthetic rainfall distributions are shown in Figures 5.6 to 5.8. For the Chicago rainfall distribution, four different times to peak are shown as examples.

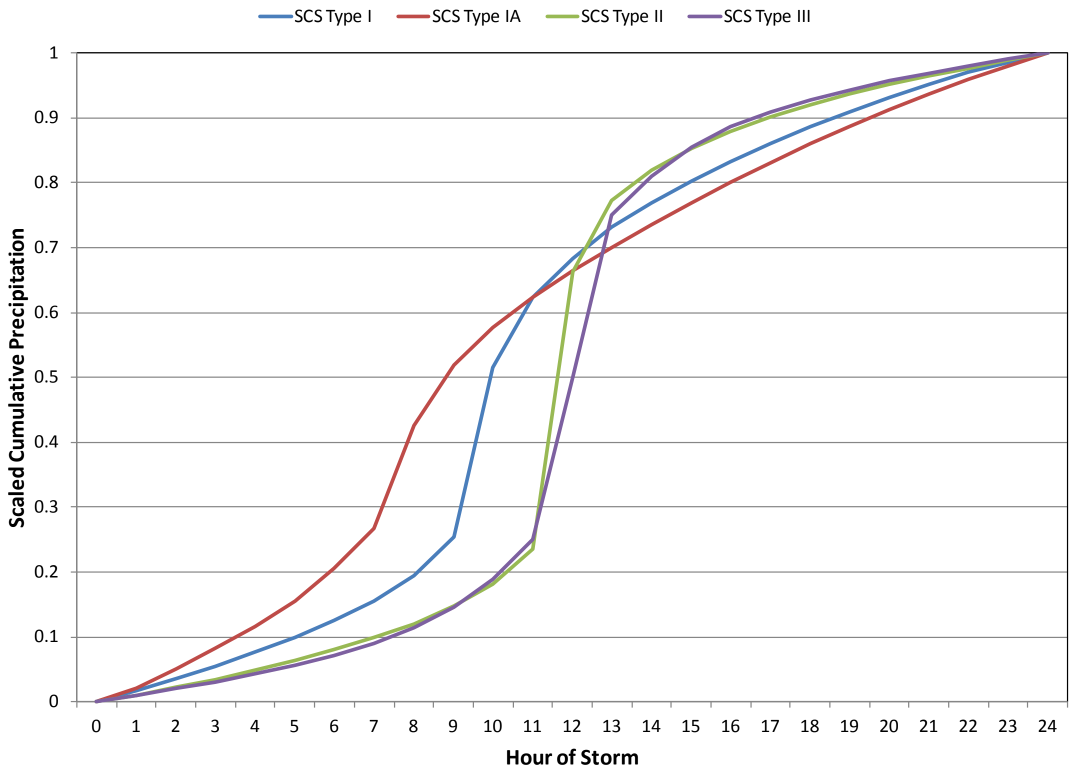


Figure 5.6 Soil Conservation Service 24-hour Synthetic Rainfall Distributions

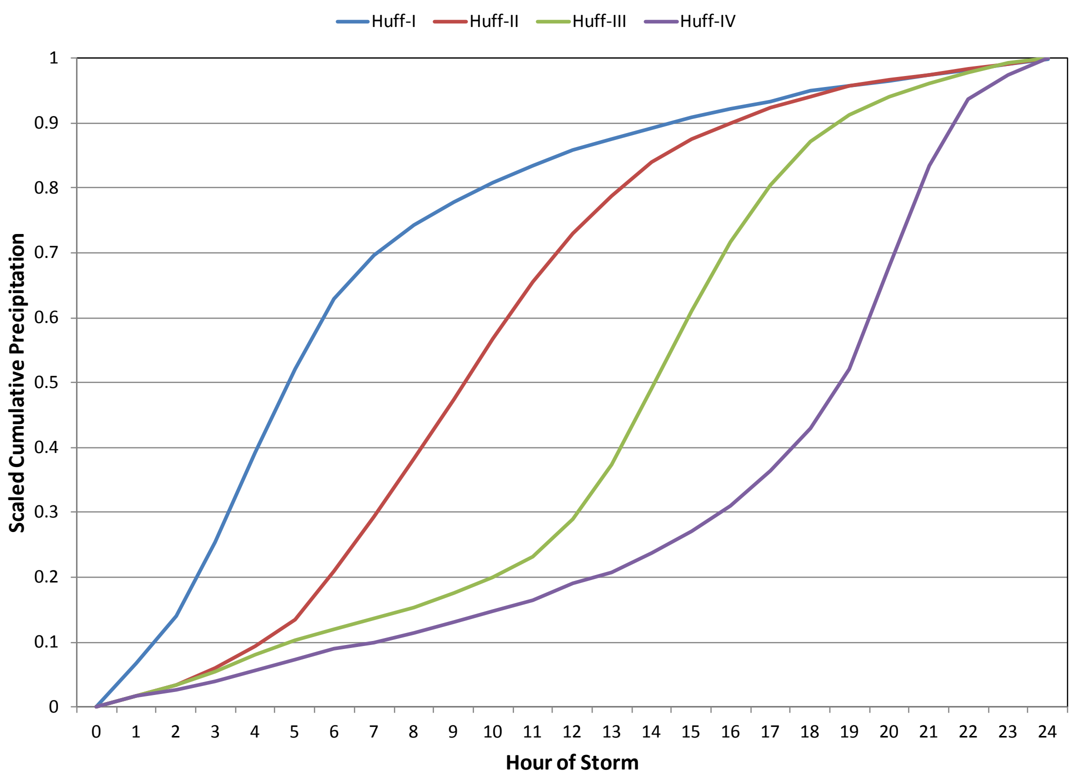


Figure 5.7 Huff 24-hour Synthetic Rainfall Distributions

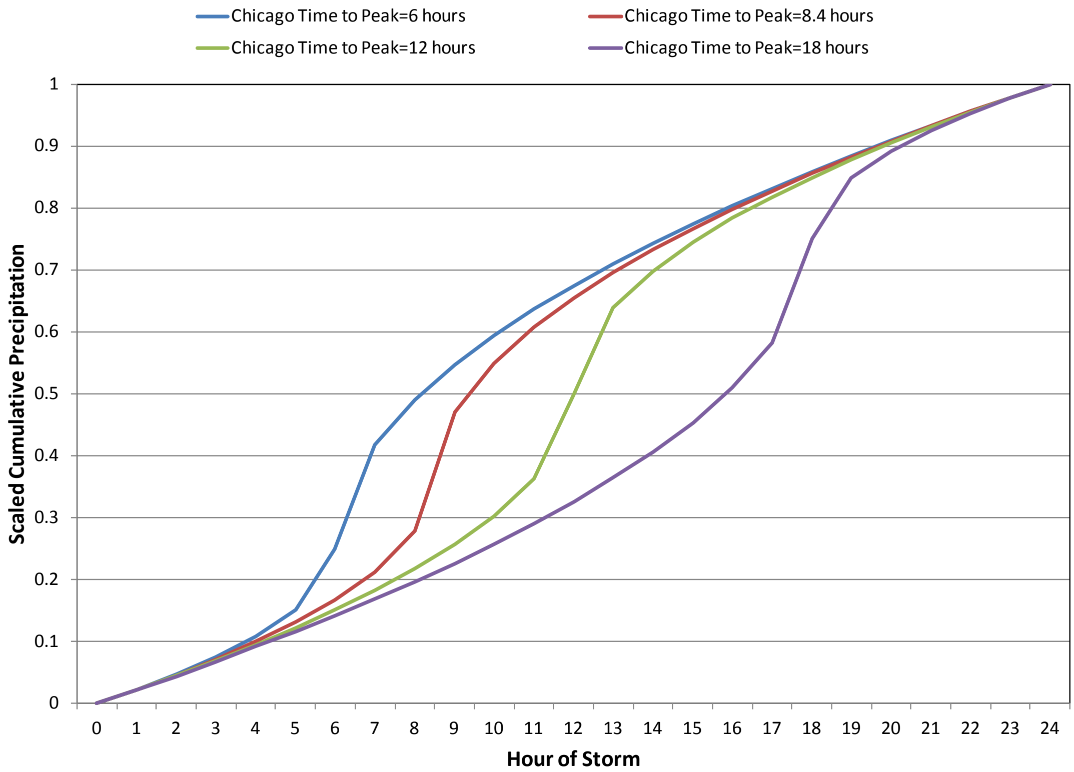


Figure 5.8 Chicago 24-hour Synthetic Rainfall Distributions

Three different statistical measures were used to determine which rainfall distribution fit the observed storm the best. The statistics were: pattern index (Kimoto, et al., 2011), mean absolute error, and mean relative error. For the pattern index statistic, the pattern index is calculated separately for the observed storm and the synthetic rainfall distributions. The best-fitting synthetic rainfall distribution is the one with the pattern index that is closest to the pattern index for the observed storm event. The pattern index statistic is calculated as:

$$PI = \frac{1}{P_n T_n} \sum_{i=1}^{n-1} \left(\frac{P_i + P_{i+1}}{2} \right) (T_{i+1} - T_i)$$

Where:

PI is the pattern index statistic

$\mathrm{P_i}, \mathrm{P_{i+1}}$ are the cumulative precipitation amounts at observations i and i+1

$\mathrm{T_i}, \mathrm{T_{i+1}}$ are the times of the storm at observations i and i+1

n is the number of observations

$\mathrm{P_n}$ is the total precipitation

$\mathrm{T_n}$ is the storm duration

For the mean absolute error (MAE) and mean relative error (MRE) statistics, the differences between the observed storm and the synthetic rainfall distributions are used to calculate the statistics. The best-fitting synthetic rainfall distribution is the one with the lowest MAE or MRE. The MAE and MRE statistics are calculated as:

$$MAE = \frac{1}{n} \sum_{i=1}^{n} abs(Pobs_i - Psyn_i)$$

$$MRE = \frac{1}{n}\sum_{i=1}^{n}\frac{(Pobs_i - Psyn_i)}{Pobs_i}$$

Where:

MAE is the mean absolute error statistic

MRE is the mean relative error statistic

$\mathrm{Pobs_i}, \mathrm{Psyn_i}$ are the observed and synthetic rainfall distributions at observation i

$\mathrm{abs}(\cdot)$ is the absolute value operator

n is the total number of observations

All calculations for the pattern index, MAE, and MRE statistics were performed on the standardized cumulative rainfall for both the observed and synthetic rainfall distributions. The overall best-fitting synthetic rainfall distribution was selected as the distribution that was the best-fitting distribution according to at least two of the statistics.

In addition to the statistical analysis for the 10 largest storms, the average storm was also tested. The average storm was calculated as the average of the standardized cumulative rainfall distributions of the 10 largest storms. The standardized cumulative rainfall distributions start at zero and end at one. If a storm was less than 24 hours long (i.e., precipitation did not occur for the full 24 hours for that storm), the hours after the end of the storm had a value of one. In this case, the value of one was averaged in with the values for the other storms where precipitation was still occurring (i.e., the storm was not "stretched" to be 24 hours long or otherwise modified). Stretching or otherwise adjusting a storm to make it "fit" with the other storms would affect the average time to peak for all storms, which is a key factor in design storm analysis. The same statistical measures were applied for the average storm.

5.2.3 Regional Rainfall Events

Regional rainfall events in the range of the 100-year rainfall event for Halifax were desired for the analysis, as possible "near misses" for the watershed. The regional rainfall events were found using the methodology shown in Figure 5.9. Localized precipitation events (e.g., a thunderstorm that affected one station only) were removed from the analysis so that only regional events were identified. There are three IDF curves near Halifax, with 100-year, 24-hour rainfall estimates of 126.5 mm, 151.1 mm, and 232.9 mm (Halifax Intl A, Shearwater Auto, and Halifax EC IDF Curves V2.3, 2015). A 100 mm rainfall total was used as the search threshold. A lower threshold was used so that it would be more likely for multiple stations to be identified when there was a large regional event. This was conservative, so that more events would be retained in the analysis. The EC Climate Data Archive was searched for dates with greater than 100 mm of rainfall or two consecutive dates with greater than 100 mm of rainfall (note that only rainfall was used: snowfall and total precipitation were not used). The identified events were sorted, and localized events were removed from the analysis. The historical record of hurricanes was used to identify the events that were caused by hurricanes. To be retained in the analysis, events must be at least one of the following:

- Event occurred on the date of a historical hurricane and station was located in the path of the hurricane.
- Multiple stations within one province received greater than 100 mm of precipitation over one or two days.

- Stations within different provinces (but near to each other) received greater than 100 mm of precipitation over one or two days.

As storms track across the Atlantic Provinces, they affect different regions on different dates. Therefore, storm dates were allowed to vary by up to a day between regions. Finally, the regional storm events were characterized by province, type of storm (hurricane/extra-tropical storm or other), and seasonality.

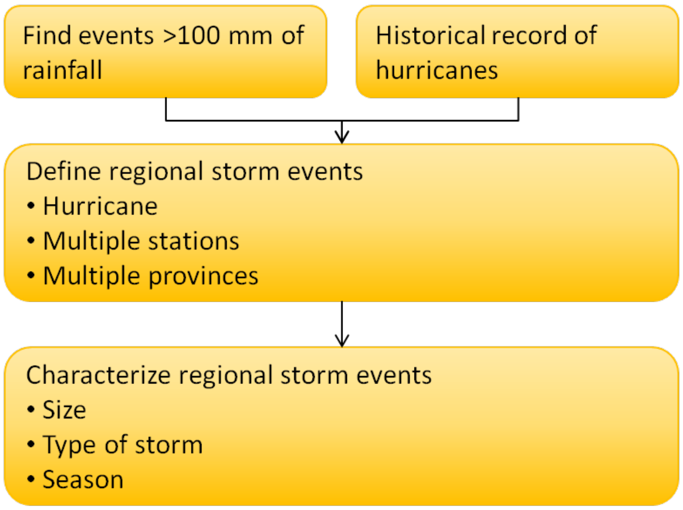


Figure 5.9 Flowchart for Derivation of Regional Storm Events

5.3 Results

5.3.1 Flooding Factors

The flooding factors were analyzed for each instantaneous annual maximum flow event for the Sackville River at Bedford and Little Sackville River at Middle Sackville Station. The results are summarized in this section. Detailed results for individual events are included in Appendix E. They are listed in order from largest event to smallest event for each station.

The Sackville River at Bedford watershed is 146 km^2, and is mainly rural (except for the Little Sackville River watershed). The Little Sackville River at Middle Sackville watershed is 13.1 km^2, and is mainly urbanized. Therefore, it is expected that the two watersheds will have different hydrological responses and therefore different flooding factors. The flooding factors for both stations are summarized in Table 5.4. Pie charts illustrating the flooding factors are shown in Figure 5.10.

Table 5.4 Summary of Flooding Factors Analysis

Station Name	Station ID	Number of Years	Percent of Occurrence of Each Factor (%)				
			Rainfall	Snowmelt	Ice	Surge	Antecedent Conditions
Sackville River at Bedford	01EJ001	43	100	56	35	0	93
Little Sackville River at Middle Sackville	01EJ004	32	100	44	34	N/A	66

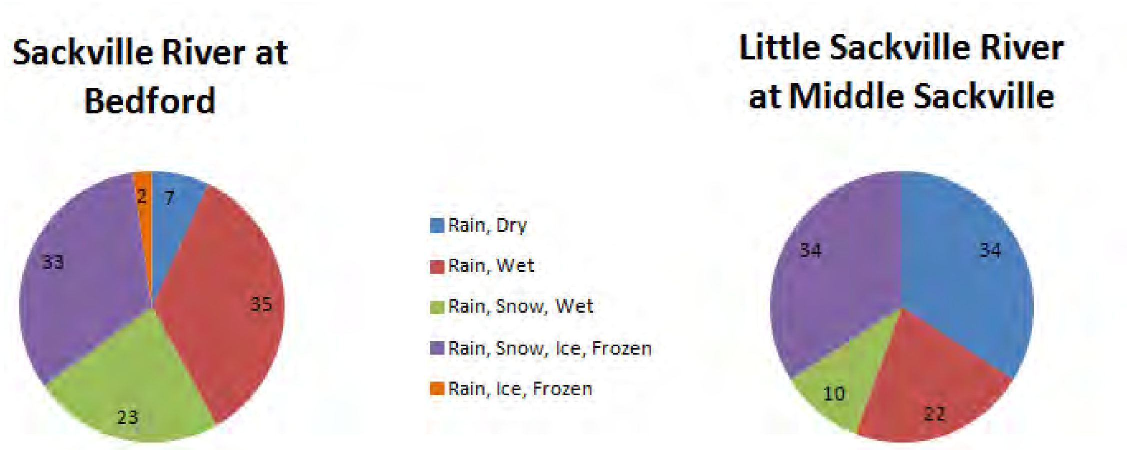


Figure 5.10 Pie Charts of Flooding Factors

The main flooding factor is rainfall for both watersheds. All instantaneous annual maximum flow events are attributed to rainfall, at least in part. Approximately 42% of instantaneous annual maximum flow events for the Sackville River at Bedford are attributed to rainfall alone or combined with wet conditions. For Little Sackville River at Middle Sackville, approximately 56% of the instantaneous annual maximum flow events are attributed to rainfall alone or combined with wet conditions. The antecedent conditions are generally drier for the Little Sackville River at Middle Sackville because the watershed responds quickly and is mainly urbanized with significant impervious area. Surge and sea level events do not affect the floods, as the sea level is below the elevation of the WSC gauge. The instantaneous annual maximum events that occur from December to March tend to be caused partly by snowmelt and are often associated with ice melt. Snowmelt and ice melt occur in combination with rainfall events and are not the sole cause of an instantaneous annual maximum flow event.

The instantaneous annual maximum flow events range from events that are near the 100-year return period to events that are near the 1-year return period. Of interest for this analysis are the events that result in very high flow rates, as these are the events that cause significant flooding. Therefore, the five largest instantaneous annual maximum flow events at both WSC stations are discussed in greater detail. They are summarized in Table 5.5. The hydrographs for each of the five largest instantaneous annual maximum flow events for each station are included in Appendix E. Each hydrograph shows the daily average flow for a period of two weeks before the instantaneous annual maximum flow event, and two weeks after the instantaneous annual maximum flow event.

Table 5.5 Summary of Flooding Factors Analysis

Station Name	Date and Time	Flow (cms)	Rainfall (mm)	Maximum Intensity (mm/hr)	Snowmelt	Ice	Antecedent Conditions
Sackville River at Bedford (01EJ001)	04/01/2003 00:17	106	105.9 (2 days)	16.0	No	Yes	Wet/frozen
	01/16/1978 02:51	90.3	125.8 (2 days)	13.0	Yes	Yes	Wet/frozen
	08/16/1971 21:03	85.0	296.4 (2 days)	20.8	No	No	Dry
	11/07/2010 16:02	79.1	131.8 (3 days)	6.2	No	No	Wet
	03/14/1980 22:37	73.0	52.9 (1 day)	12.7	Yes	No	Wet/frozen
Little Sackville River at Middle Sackville (01EJ004)	07/21/1981 17:43	22.0	71.1 (1 day)	28.5	No	No	Dry
	12/20/2000 10:00	21.6	80.2 (1 day)	12.8	No	No	Wet
	10/28/1993 02:41	20.5	62.8 (2 days)	6.5	No	No	Dry
	02/17/1996 11:00	20.1	96.9 (2 days)	10.6	Yes	Yes	Wet/frozen
	10/20/2011 14:01	18.4	111.0 (2 days)	15.0	No	No	Wet

The largest instantaneous annual maximum flow event for Sackville River at Bedford occurred on April 1, 2003, with a peak flow of 106 cms. The event was preceded by 105.9 mm of rain occurring on March 30 and 31. There was no snow on the ground and no snowfall. However, there was 11 cm of snow on the ground on March 26 which melted by March 27, contributing to a wet watershed. The river was ice-covered on March 30 and not ice-covered on March 31. The watershed was wet/frozen due to the recent snowmelt and ice melt. The hydrograph showed a single peak (three days to rise). The main causes of this event were rainfall and wet/frozen conditions, and ice melt also contributed.

The second largest instantaneous annual maximum flow event for Sackville River at Bedford occurred on January 16, 1978, with a peak flow of 90.3 cms. The event was preceded by 125.8 mm of rain occurring on January 14 and 15. There was 14 cm of snow on the ground on January 14, and no snow on the ground on January 15. The river was ice-covered on January 14 and not ice-covered on January 15. The watershed was wet/frozen due to the recent snowmelt and ice melt. The hydrograph showed a single peak (three days to rise). The main causes of this event were rainfall and wet/frozen conditions, and snowmelt and ice melt also contributed.

The third largest instantaneous annual maximum flow event for Sackville River at Bedford occurred on August 16, 1971, with a peak flow of 85.0 cms. This peak flow event was caused by the passage of Hurricane Beth. The event was preceded by 296.4 mm of rain occurring on August 15 and 16. There was no snow or ice during this event. Prior to this event, the streamflow in the river was negligible, and the total rainfall in the nine days prior to August 15 was only 3 mm. Therefore, the watershed was dry. The hydrograph showed a single peak (two days to rise). The main cause of this event was rainfall.

The fourth largest instantaneous annual maximum flow event for Sackville River at Bedford occurred on November 7, 2010, with a peak flow of 79.1 cms. The event was preceded by 131.8 mm of rain occurring on November 5, 6, and 7. There was no snow or ice during this event. Prior to this event, a previous rain event caused a smaller peak on October 28, and the flow was receding from that event. There was rain on October 30 and 31, and November 1 and 4. Therefore, the watershed was wet. The hydrograph showed a single peak (three days to rise). The main causes of this event were rainfall and wet conditions.

The fifth largest instantaneous annual maximum flow event for Sackville River at Bedford occurred on March 14, 1980, with a peak flow of 73.0 cms. There was 52.9 mm of rain on March 14, and 16.6 mm on March 11. The peak snow on the ground was on March 2 (21 cm) and there was only 3 cm on the ground on March 14. Previous rain on March 8, 9, and 11 caused the streamflow to rise gradually beginning on March 9. There was no river ice during this period. Therefore, the watershed was wet/frozen due to the recent rain/snowmelt. It is worth noting that the daily average streamflow on this date was low, indicating that the peak flow was very short. The hydrograph showed a gradual increase, following by a peak on March 14. The main causes of this event were rainfall, snowmelt, and wet/frozen conditions.

The five largest instantaneous annual maximum flow events for Sackville River at Bedford occurred at various times throughout the year and had various causes. The four largest instantaneous annual maximum flow events were all caused by rainfall totals in excess of 100 mm, occurring over two to three days. For each of these events, there was a gradual increase (two to three days to rise) in the hydrograph, beginning approximately one day after the beginning of the rainfall. The snowmelt contribution, if any, for each of these events was small. The fifth largest instantaneous annual maximum flow event at Sackville River at Bedford was different from the other four events. It was caused by a relatively small rainfall event (as measured at Halifax Stanfield Int'l A, it is possible that more rain occurred over the watershed), but the rainfall event occurred during a significant snowmelt event, when the flow was already relatively high. The antecedent conditions for four of the five largest events were wet or frozen.

The largest instantaneous annual maximum flow event for Little Sackville River at Middle Sackville occurred on July 21, 1981, with a peak flow of 22.0 cms. There was 71.1 mm of rain on July 21. There was no snow or ice during this event. Prior to this event, the streamflow in the river was negligible, and there were five days with no rainfall. Therefore, the watershed was dry. The hydrograph showed a single peak (one day to rise). The main cause of this event was rainfall.

The second largest instantaneous annual maximum flow event for Little Sackville River at Middle Sackville occurred on December 20, 2000, with a peak flow of 21.6 cms. There was 80.2 mm of rain on December 20. There was no snow or ice during this event. Prior to this event, there were several small peaks in the streamflow, and multiple dates with rainfall. Therefore, the watershed was wet. The hydrograph showed a single peak (one day to rise). The main causes of this event were rainfall and wet conditions.

The third largest instantaneous annual maximum flow event for Little Sackville River at Middle Sackville occurred on October 28, 1993, with a peak flow of 20.5 cms. There was 47.2 mm of rain on October 27 and 15.6 mm of rain on October 28. There was no snow or ice during this event. Prior to this event, the streamflow was negligible (there were previous peaks but the streamflow was near zero prior to the rainfall). There were three days of no rainfall prior to the beginning of the rain. Therefore, the watershed was mainly dry. The hydrograph showed a single peak (two days to rise). The main cause of this event was rainfall, although the watershed may have been slightly wet.

The fourth largest instantaneous annual maximum flow event for Little Sackville River at Middle Sackville occurred on February 17, 1996, with a peak flow of 20.1 cms. There was 12.0 mm of rain on February 16 and 84.9 mm of rain on February 17. There was 15 cm of snow on the ground on February 16, and only 2 cm on February 17. The river was ice-covered on February 16 and not ice-covered on February 17. Prior to this event, the streamflow was negligible. The watershed was wet/frozen due to the presence of snow and ice on February 16. The hydrograph showed a single peak (one day to rise). The main causes of this event were rainfall, snowmelt, ice melt, and wet/frozen conditions.

The fifth largest instantaneous annual maximum flow event for Little Sackville River at Middle Sackville occurred on October 20, 2011, with a peak flow of 18.4 cms. There was 6.6 mm of rain on October 19 and 104.4 mm of rain on October 20. There was no snow or ice during this event. Prior to this event, the streamflow was receding from previous rainfall events on October 13-15 and 17. Therefore, the watershed was wet. The hydrograph showed a single peak (one day to rise). The main causes of this event were rainfall and wet conditions.

The five largest instantaneous annual maximum flow events at Little Sackville River at Middle Sackville were generally caused by intense rainfall events. For four of the events, a large amount of rainfall (more than 70 mm) occurred in one day. The third largest event was different from the other events in that only 62.8 mm of rain fell over two days and the peak rainfall intensity was low. It is possible that more rain fell on the watershed, since the rainfall data were taken from the Halifax Stanfield Int'l A station, which is located outside of the watershed. This may be the cause for the discrepancy. Note that the fifth largest instantaneous annual maximum flow event resulted from the largest rainfall event (111.0 mm, where 104.4 mm occurred in one 24-hour period, as measured by the Halifax Stanfield Intl A station). However, the intensity was lower for the storm on October 20, 2011 than for the storm that caused the largest instantaneous annual maximum flow (July 21, 1981). The hydrographs for all five events indicate that the flow rate increased rapidly on the day of the rainfall. The watershed was wet or wet/frozen for three of the five largest flow events. Snowmelt and ice melt were a factor for one flood event.

Given the above findings, the conditions to produce large flow events are concluded to be similar for both stations. Rainfall events occurring when the watershed is wet or frozen tend to result in high flow rates. Snowmelt is a factor in some events and ice melting is also associated with some events. Note, however, that although the instantaneous annual maximum flow rates for both watersheds tend to occur on the same day approximately 45% of the time, the five largest flow events all occurred on different days. In addition, many high flow events for the Little Sackville River station tend to correspond with relatively lower flow events for the Sackville River, and vice-versa (Table 5.6). Within the top five largest flow events at Sackville River at Bedford, only the fourth largest flow event corresponded with the instantaneous annual maximum flow event for Little Sackville River at Middle Sackville, and it was ranked 26 (32 observations total). The rainfall for this event occurred over three days with a low intensity (maximum intensity: 6.2 mm/hour). Within the top five largest flow events at Little Sackville River at Middle Sackville, the first event (July 21, 1981) was not the instantaneous annual maximum flow event for Sackville River at Bedford. The other four events corresponded with the instantaneous annual maximum flow events at Sackville River at Bedford, with ranks ranging from 11 to 26 (43 observations total). The duration and maximum intensity for each storm were: December 20, 2000:13 hours duration, maximum intensity of 12.8 mm/hour; October 27-28, 1993: 17 hours duration, maximum intensity of 6.5 mm/hour; February 17, 1996: 19 hours duration, maximum intensity of 10.6 mm/hour; October 19-20, 2011: 27 hours duration, maximum intensity of 15.0 mm/hour. The rainfall for these events were short (approximately one day long or less) and more intense. The exception was the storm on October 27-28, 1993, where relatively little rain was recorded at Halifax Stanfield, but perhaps a greater amount of rain occurred over the watershed.

Table 5.6 Relationship Between Flow Magnitudes of Sackville River at Bedford and Little Sackville River at Middle Sackville

Sackville River at Bedford (01EJ001)			Little Sackville River at Middle Sackville (01EJ004)		
Date and Time	Flow (cms)	Rank (43 observations)	Date and Time	Flow (cms)	Rank (32 observations)
Comparison of top five flow events for Sackville River at Bedford (01EJ001)					
04/01/2003 00:17	106	1	N/A		
01/16/1978 02:51	90.3	2	N/A		
08/16/1971 21:03	85.0	3	N/A		
11/07/2010 16:02	79.1	4	11/07/2010 13:01	12.2	26
03/14/1980 22:37	73.0	5	N/A		
Comparison of top five flow events for Little Sackville River at Middle Sackville (01EJ004)					
N/A			07/21/1981 17:43	22.0	1
12/20/2000 12:00	63.5	11	12/20/2000 10:00	21.6	2
10/28/1993 04:29	51.7	26	10/28/1993 02:41	20.5	3
02/17/1996 13:00	63.0	13	02/17/1996 11:00	20.1	4
10/21/2011 11:02	60.1	16	10/20/2011 14:01	18.4	5

This indicates that there is a key difference between the two watersheds, as a rainfall event may result in large flow at one station and relatively lower flow at the other station. Due to its larger size, generally rural nature, and several lakes, the response time for the Sackville River is approximately one day. Rainfall accumulations must be very large to result in high flow rates, but rainfall may occur over durations of two to three days. The Little Sackville River watershed is small and generally urban. Rainfall events must be intense to result in large flow rates because the response time of the Little Sackville River is less than one day. The Porter Dillon (1999) report estimated a time of concentration of two hours for the Little Sackville River watershed to the confluence with the Sackville River. Snowmelt can be a significant factor for both watersheds. Rain-on-snow and rain/snow events are common in the area, and these can cause large floods in the watershed. Snowmelt has been investigated in previous studies in the Little Sackville River watershed (Nolan Davis, 1987; Porter Dillon, 1999), and was found to not increase the peak flows above those due to a summer rain event. However, the combination of rainfall and snowmelt is a major factor in some of the five largest flow events at the two stations.

Ice jams have the potential to partially block flow constriction locations and therefore increase the flooding extent associated with a high flow. Some high flow events have been associated with river ice melting, although it is not known whether ice jams occurred during any of the historical instantaneous annual maximum flow events. Numerous locations were identified in previous studies as potential ice jam locations (Interprovincial Engineering, 1981; Nolan Davis, 1987); some of the water crossings on the lower reach of the Sackville River were identified (e.g., Shore Drive, Bedford Highway). However, the water crossings may have been changed and/or new water crossings may have been added, changing the hydraulic behaviour of the river.

The historical information on flooding extents from the five largest instantaneous annual maximum flow events is included in Table 5.7.

Table 5.7 Summary of Flooding Extent Information

Station Name	Date and Time	Flow (cms)	Flooding Extent Information	Reference(s)
Sackville River at Bedford (01EJ001)	04/01/2003 00:17	106	Flooding along east side of Union Street upstream from Bedford Highway, water rose almost to underside of Towers Bridge Flooding in Range Park (ballfield) Flooding in Rifle Range	Photographs from Sackville Rivers Association
	01/16/1978 02:51	90.3	Flooding of Bedford Place Mall parking lot and 10 to 12 homes along Union Street costing $5,000 to $10,000 each Water level rose to the underside of a bridge in Bedford	Nolan Davis (1987)
	08/16/1971 21:03	85	Flooding of basements in Bedford area businesses	Interprovincial Engineering (1981)
	11/07/2010 16:02	79.1	Flooding of Fish Hatchery Park, Bedford-Sackville Greenway Connector Trail	"Weekend Rain Soaks Province," Chronicle Herald, Nov. 8, 2010
	03/14/1980 22:37	73	Flooding of basements in Bedford No flooding problems from Union Street	"River Rises to Banks," Bedford-Sackville Daily News, Mar. 17, 1980
Little Sackville River at Middle Sackville (01EJ004)	07/21/1981 17:43	22.0	Flooding in Sackville/Bedford: residents in district 16 (Bedford-Wentworth) received $5,000 to $6,000 in damage, a resident in District 19 received $10,000 damage, District 20 had 69 homes affected one costing $7,000 in damage	Nova Scotia Flood Events Database
	12/20/2000 10:00	21.6	Flooding on Meadowbrook Drive, plugged storm drain on Union Street	Halifax Regional Council Minutes, Jan. 9, 2001.
	10/28/1993 02:41	20.5	Flooding of properties along Union Street, Rifle Range, and Range Park	Sackville Rivers Association
	02/17/1996 11:00	20.1	Flooding of properties along Union Street and in Sackville Estates area between Stanley St and Sharon St, off of Sackville Drive	"Bedford-Sackville Awash," Chronicle Herald, Feb 19, 1996.
	10/20/2011 14:01	18.4	Flooding of the Range Park ballfield and Bedford Place Mall parking lot Max height Sackville River at Bedford: 5.27 m (CGVD28) Max height Little Sackville River at Middle Sackville: 2.813 m (WSC datum)	"Deluge Turns Streets to Rivers," Chronicle Herald, Oct. 21, 2011; WSC peak data

5.3.2 Ten Largest Precipitation Events

The hourly precipitation data were accumulated to develop 24-hour totals for every hour. The 10 largest precipitation totals (that were due to separate precipitation events) were selected. The hourly precipitation data are included in Appendix F. The data were standardized using the 24-hour total precipitation, and accumulated to develop the standardized cumulative precipitation. The data are summarized in Table 5.8 and the standardized cumulative precipitation distributions are shown in Figure 5.11.

Table 5.8 Summary of Ten Largest 24-hour Precipitation Events

Rank	Start Date and Time	Total Precipitation (mm)	Maximum Intensity (mm/hr)	Date and Time of Maximum Intensity	Station Name	Climate ID
1	8/15/1971 4:00 AM	205.5	20.8	8/15/1971 3:00 PM	Halifax	8202200
2	12/10/2014 8:00 AM	117.1	19.9	12/10/2014 6:00 PM	Shearwater RCS	8205092
3	11/11/2011 3:00 AM	114.2	17.2	11/11/2011 2:00 PM	Halifax Stanfield	8202250
4	8/6/1983 11:00 PM	113.0	20.1	8/7/1983 4:00 AM	Shearwater A	8205090
5	1/14/1978 10:00 AM	107.4	13.0	1/14/1978 1:00 PM	Halifax Stanfield	8202250
6	10/19/2011 11:00 PM	105.6	15.0	10/20/2011 2:00 PM	Halifax Stanfield	8202250
7	9/21/2014 7:00 PM	104.1	18.0	9/22/2014 6:00 AM	Bedford Range	8200574
8	3/31/2003 12:00 AM	103.7	16.0	3/31/2003 12:00 PM	Shearwater A	8205090
9	12/8/1990 9:00 AM	100	13.4	12/9/1990 12:00 AM	Shearwater A	8205090
10	4/28/1982 1:00 AM	98.9	15.7	4/28/1982 3:00 PM	Shearwater A	8205090

The 10 largest precipitation events varied widely in their characteristics. The location of the heaviest rain period within each storm varied (high intensity precipitation appears as a steep section in Figure 5.11), from near the beginning of the storm (e.g., January 14, 1978) to near the end of the storm (e.g., December 8, 1990). Some storms were shorter than 24 hours (e.g., August 6, 1983 ended at hour 10), while others were taken from storms longer than 24 hours (e.g., April 28, 1982). In the case where precipitation lasted for more than 24 hours, the largest 24 hour precipitation accumulation portion of the storm was used in the analysis. Some storms had multiple parts, such as the storm on August 15, 1971 (Hurricane Beth), which stopped from hour 18 to 20. Some storms had multiple peaks (e.g., September 21, 2014 had three peaks; December 10, 2014, October 19, 2011, and November 11, 2011 had two peaks each).

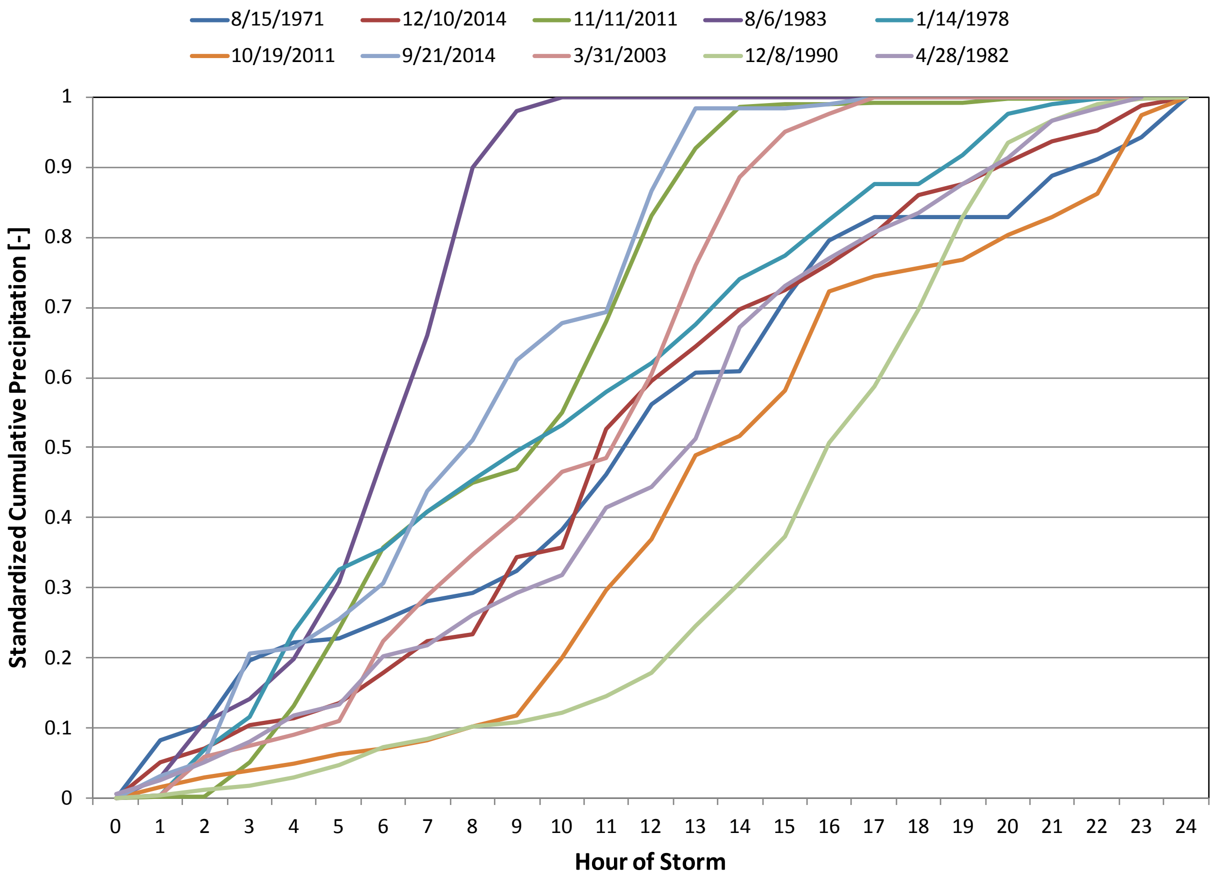


Figure 5.11 Standardized Cumulative Precipitation for 10 Largest Precipitation Events

Synthetic rainfall distributions were selected for comparison. The SCS Type III curve was used. However, there are multiple Huff and Chicago distributions, so the best Huff and Chicago distributions were selected to use in the statistical tests. There are four Huff distributions (with peaks in each of the four quartiles of the storm). The observed precipitation distribution was examined to determine when the majority of the precipitation occurred (which quartile). The corresponding Huff rainfall distribution was selected. There are an infinite number of Chicago distributions, with different times to peak. The time-to-peak was chosen to obtain the Chicago distribution that matches the observed precipitation distribution the best. The initial estimates for time-to-peak were taken from the data (i.e., the hour with peak rainfall). The time-to-peak was adjusted when necessary to obtain a better match with the observed precipitation distribution.

The results of the statistical testing are summarized in Table 5.9. The observed and synthetic rainfall distributions are compared graphically in Figures 5.12 to 5.22. The Chicago distribution was the best fitting synthetic rainfall distribution for the majority of the storms (six out of ten). The main reason that the Chicago distribution was the best-fitting synthetic rainfall distribution was that the Chicago distribution could be adjusted so that the time to peak matched the observed time to peak. The remaining storms selected one of the Huff distributions. The Chicago distribution was also the best fitting synthetic rainfall distribution for the average storm.

Table 5.9 Summary of Synthetic Rainfall Distribution Fitting

Storm	Start Date	Pattern Index	Mean Absolute Error	Mean Relative Error	Overall
1	8/15/1971	Chicago	Chicago	Huff-II	Chicago
2	12/10/2014	Chicago	Chicago	Huff-II	Chicago
3	11/11/2011	Huff-II	Huff-II	SCS-III	Huff-II
4	8/6/1983	Huff-I	Huff-I	Huff-I	Huff-I
5	1/14/1978	Chicago	Chicago	Chicago	Chicago
6	10/19/2011	Huff-III	Huff-III	SCS-III	Huff-III
7	9/21/2014	Huff-I	Chicago	Chicago	Chicago
8	3/31/2003	Huff-II	Huff-II	Chicago	Huff-II
9	12/8/1990	Chicago	Chicago	Huff-IV	Chicago
10	4/28/1982	Chicago	Chicago	Huff-III	Chicago
Average Storm		Chicago	Chicago	Huff-II	Chicago

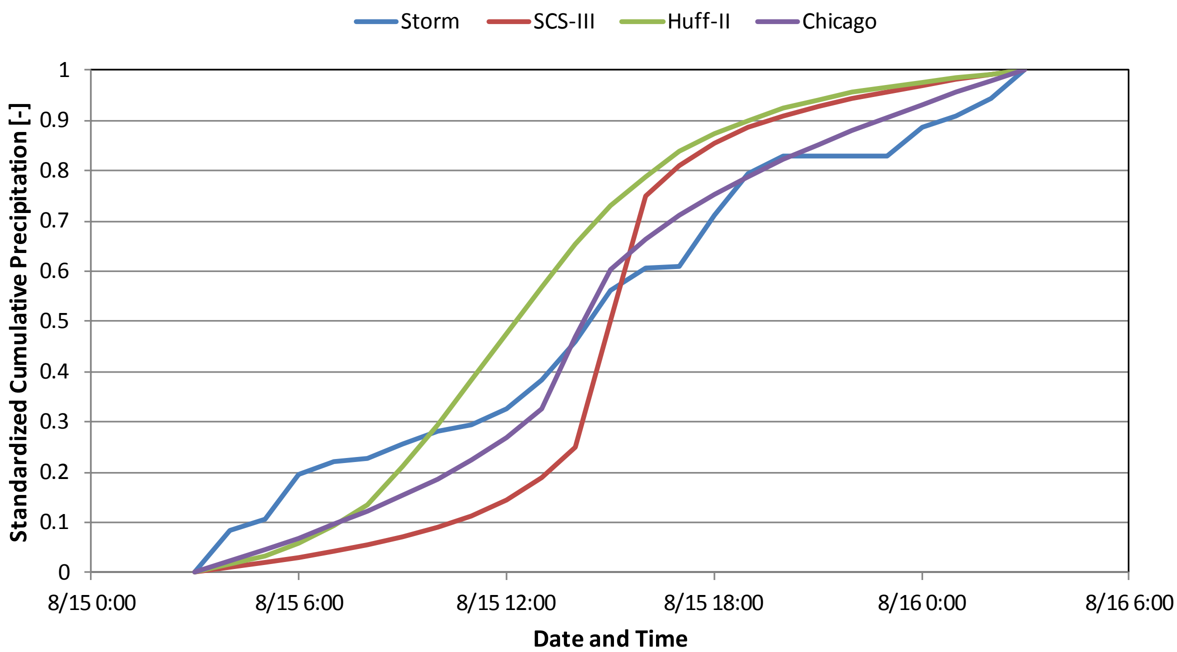


Figure 5.12 Comparison of Observed and Synthetic Rainfall Distributions for Storm 1: August 15, 1971

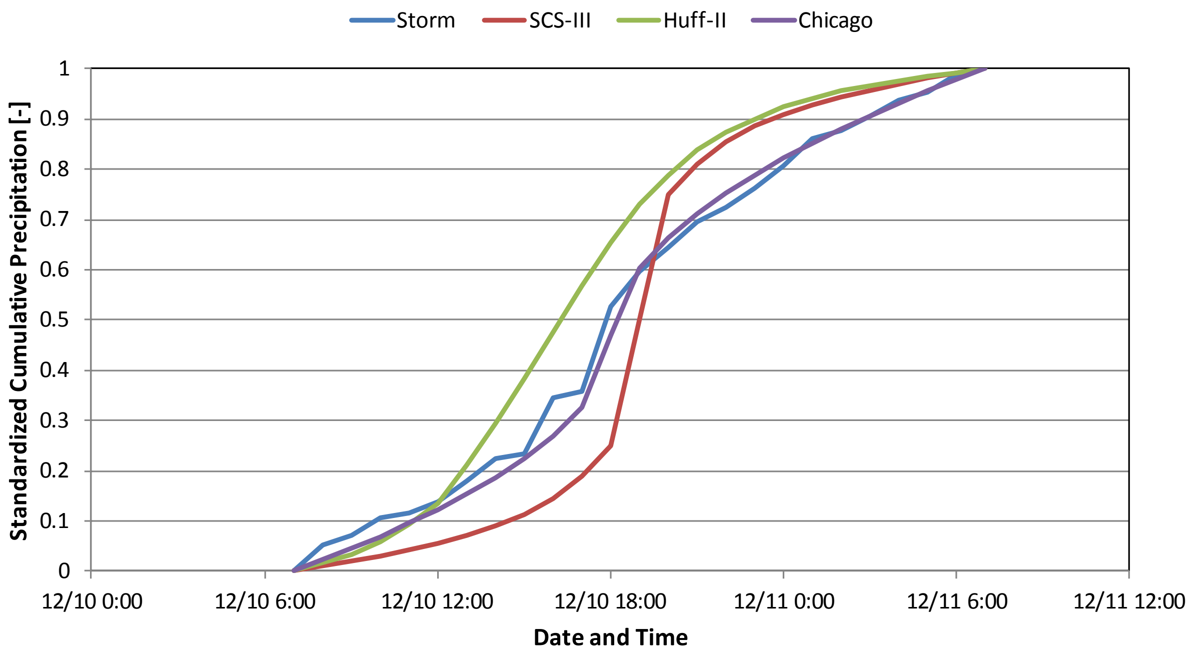


Figure 5.13 Comparison of Observed and Synthetic Rainfall Distributions for Storm 2: December 10, 2014

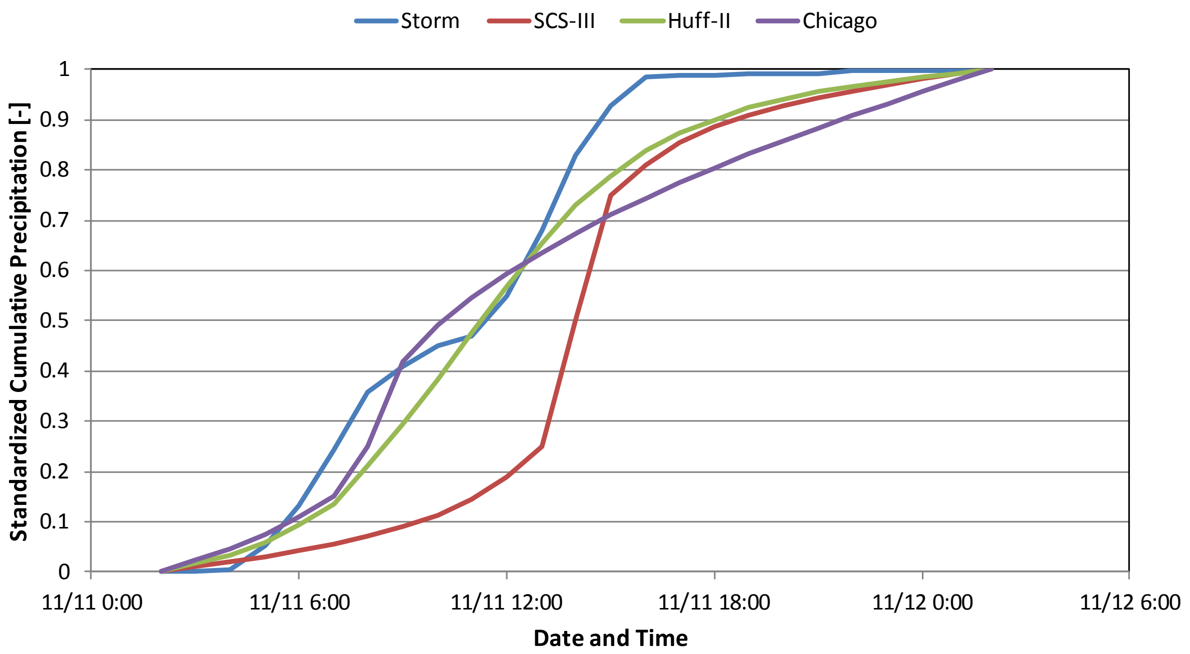


Figure 5.14 Comparison of Observed and Synthetic Rainfall Distributions for Storm 3: November 11, 2011

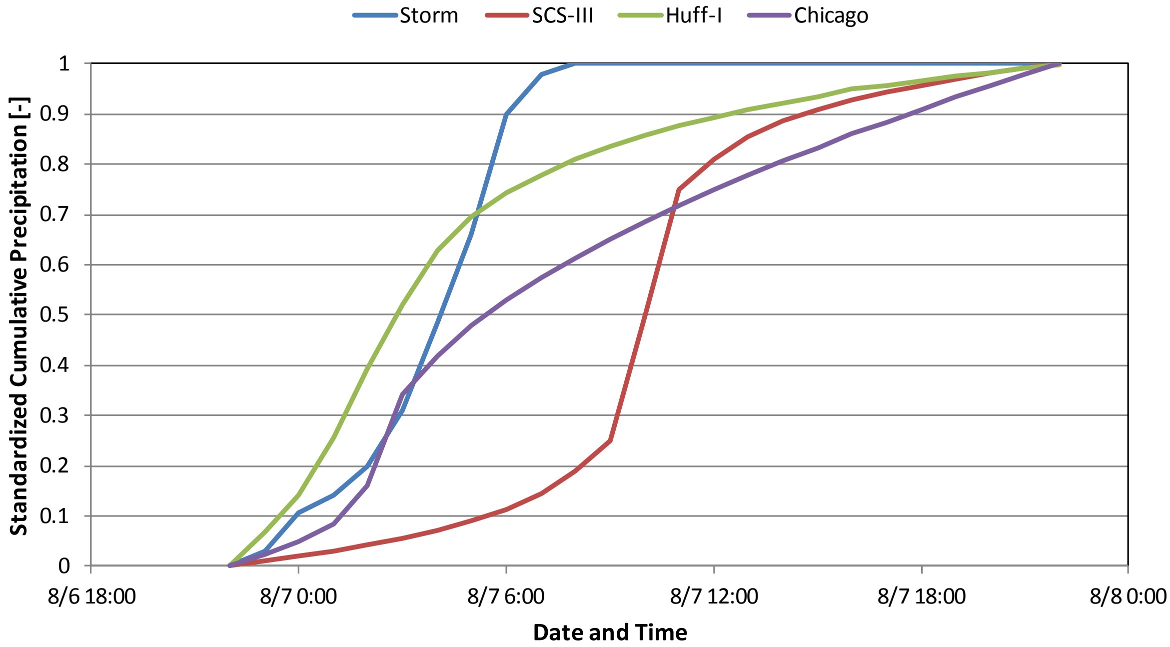


Figure 5.15 Comparison of Observed and Synthetic Rainfall Distributions for Storm 4: August 6, 1983

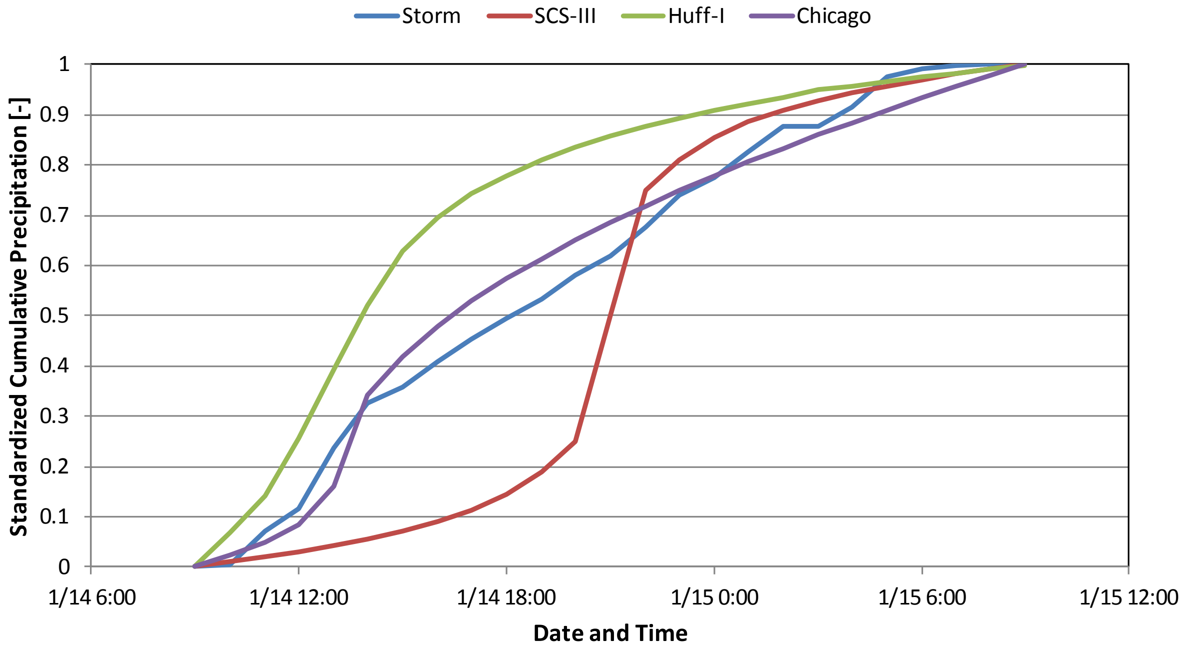


Figure 5.16 Comparison of Observed and Synthetic Rainfall Distributions for Storm 5: January 14, 1978

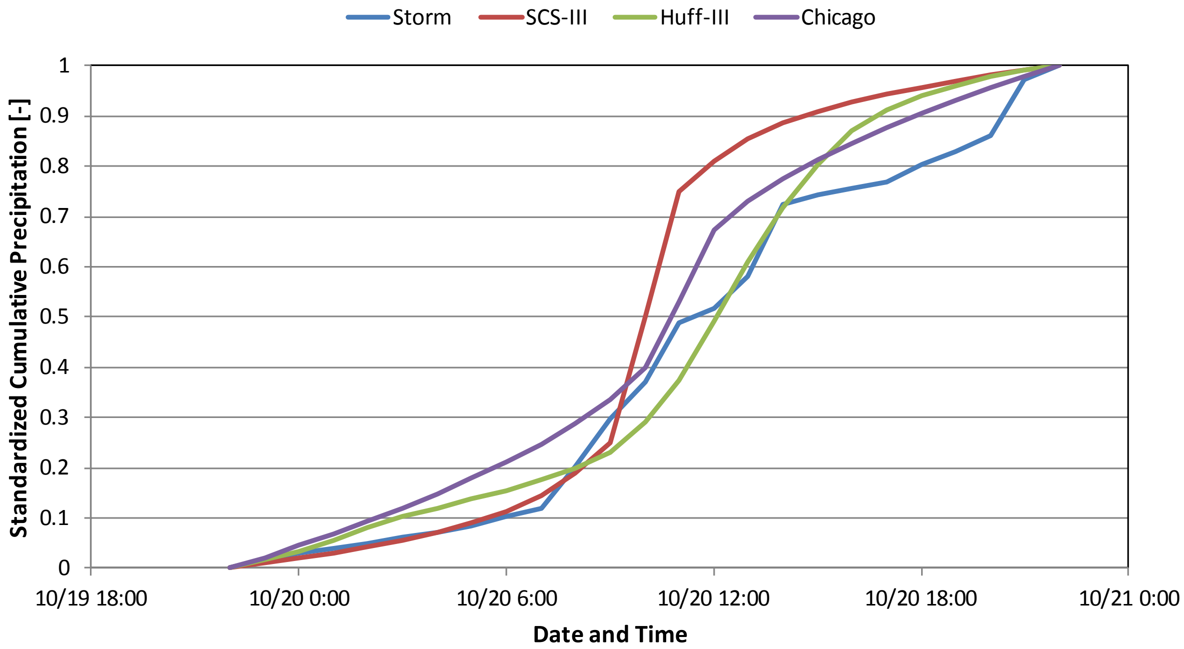


Figure 5.17 Comparison of Observed and Synthetic Rainfall Distributions for Storm 6: October 19, 2011

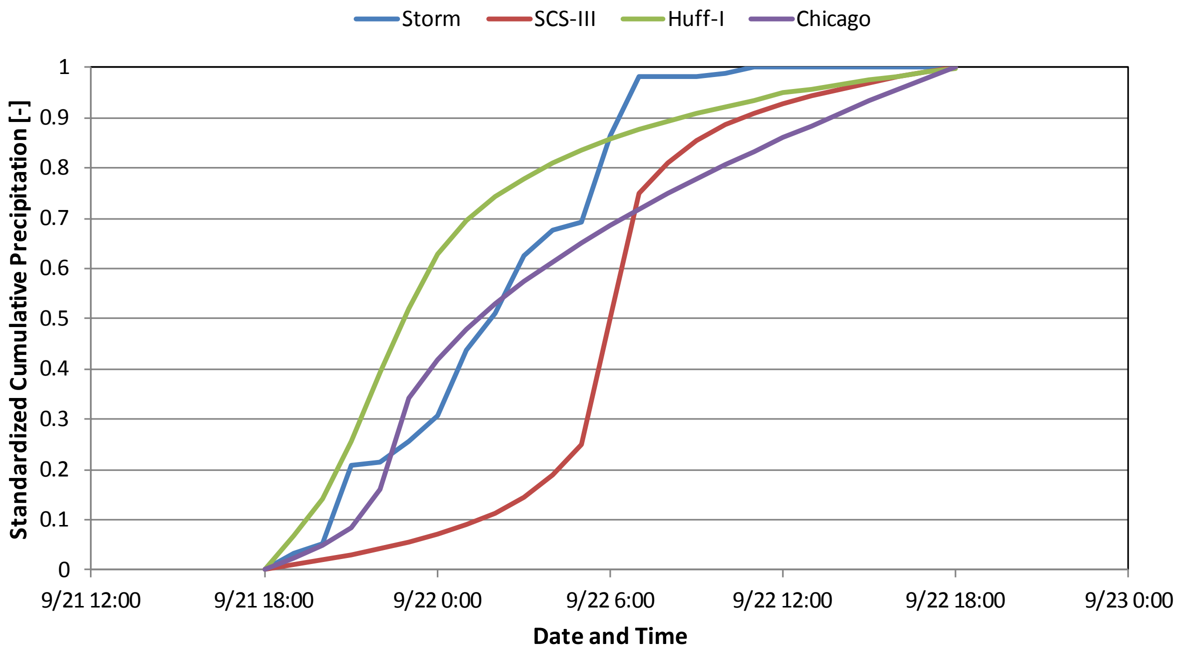


Figure 5.18 Comparison of Observed and Synthetic Rainfall Distributions for Storm 7: September 21, 2014

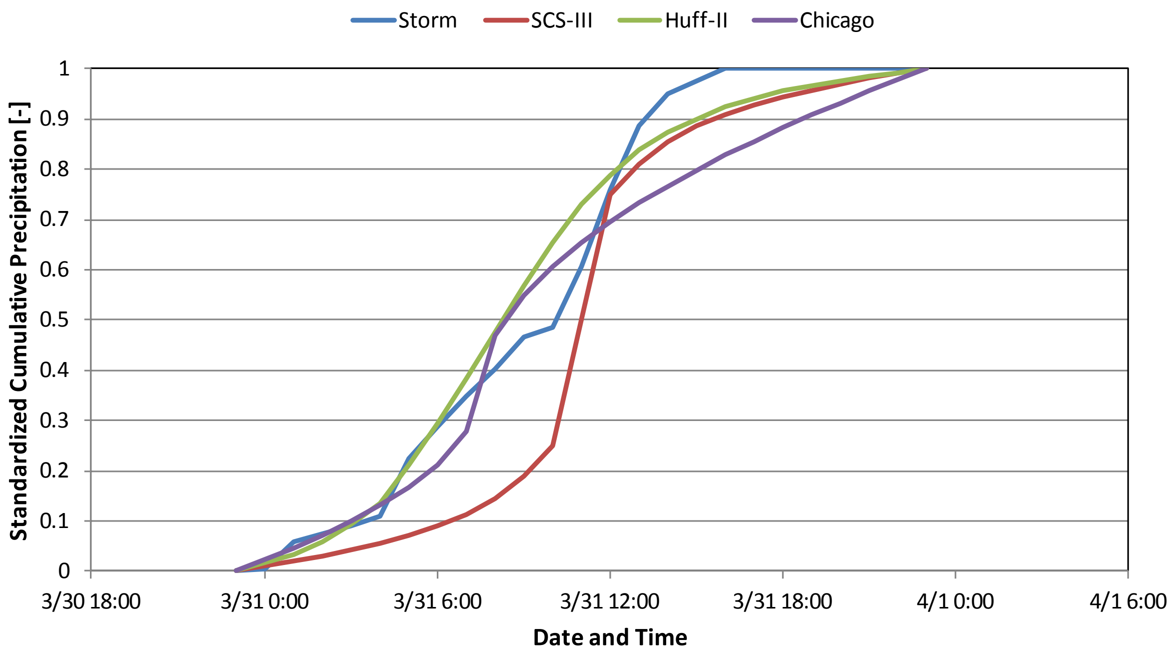


Figure 5.19 Comparison of Observed and Synthetic Rainfall Distributions for Storm 8: March 31, 2003

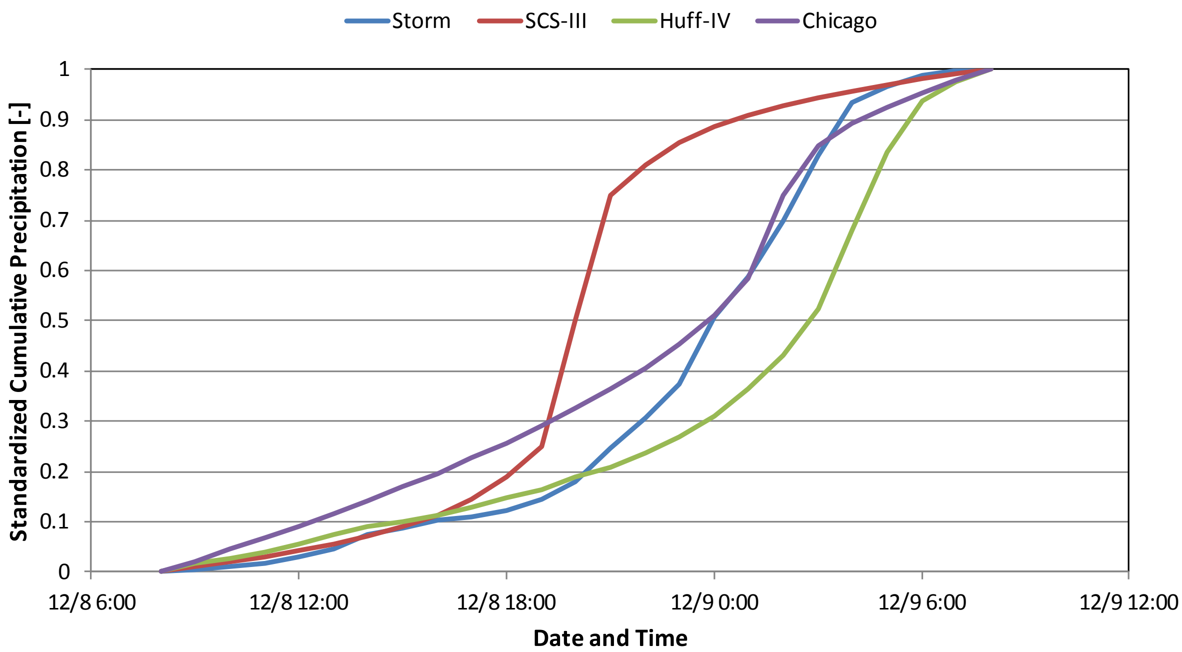


Figure 5.20 Comparison of Observed and Synthetic Rainfall Distributions for Storm 9: December 8, 1990

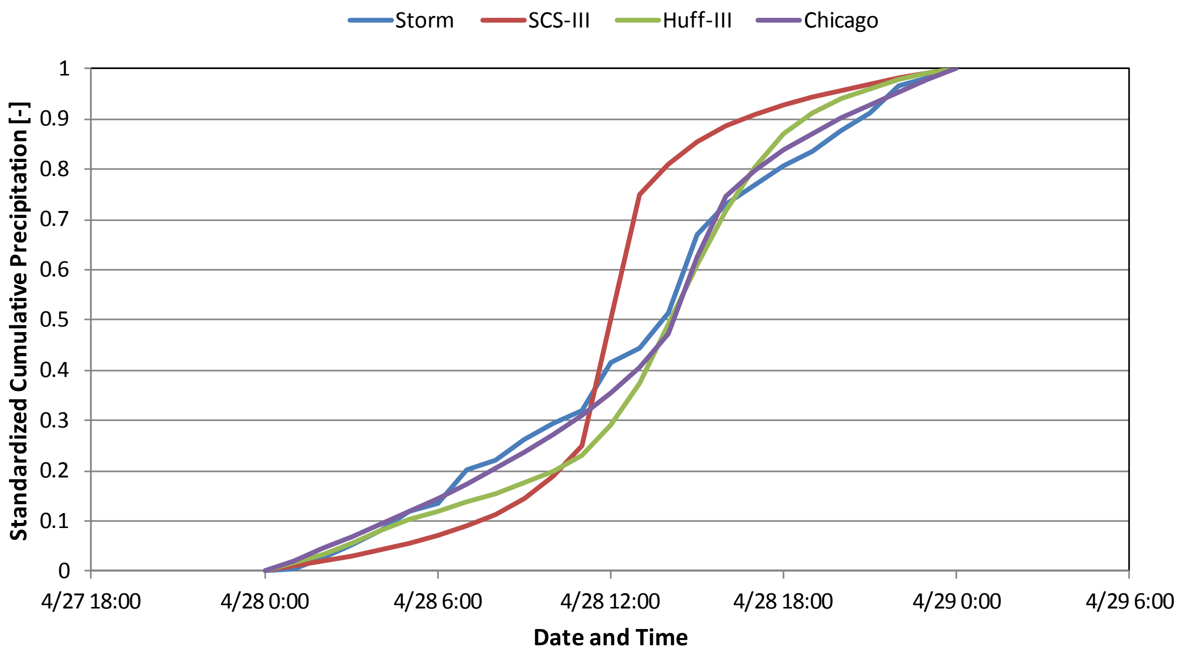


Figure 5.21 Comparison of Observed and Synthetic Rainfall Distributions for Storm 10: April 28, 1982

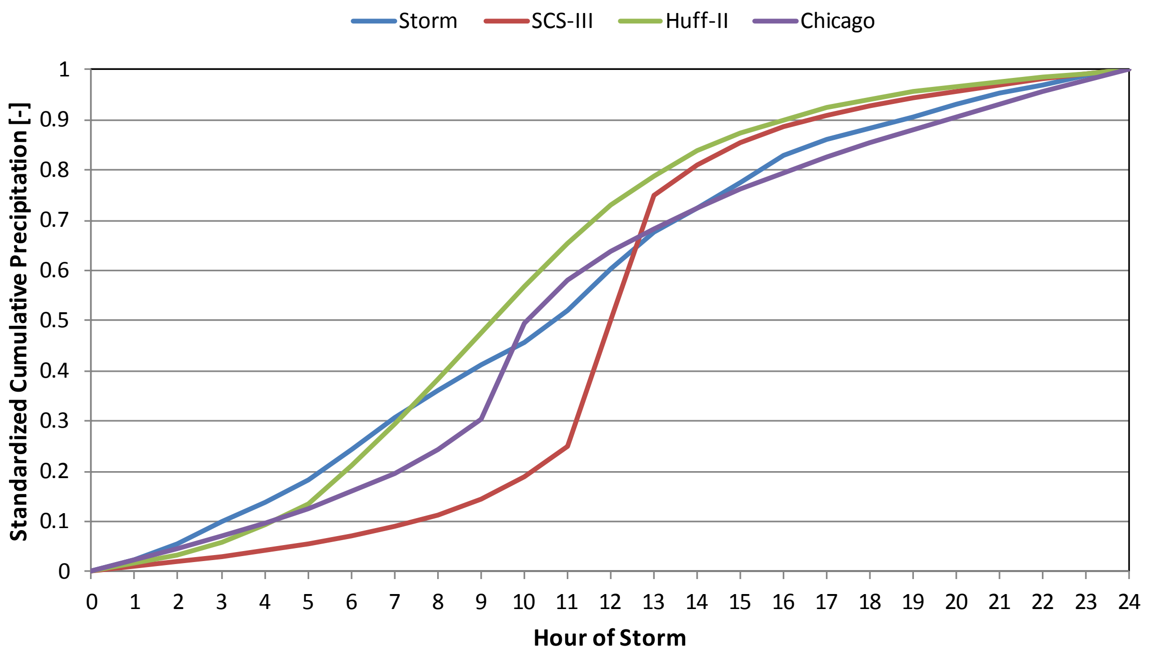


Figure 5.22 Comparison of Observed and Synthetic Rainfall Distributions for Average Storm

The use of the Chicago distribution for the design storm is consistent with the recommendations in Halifax Water (2014). It is particularly suitable for the Little Sackville River watershed (which has a response time of less than one day). Short and intense rainfall events are a significant flooding factor for this watershed. The Sackville River watershed has a response time of approximately one day. Longer and less intense rainfall events are significant for this watershed.

The ratio of time to peak to storm duration is generally selected as 0.35 (Smith, 2004). For the ten storms analyzed, the ratio of time to peak to storm duration ranged from 0.17 to 0.75 (average of 0.43), while for the average storm it was 0.40. The ratio of 0.35 results in the highest peak precipitation intensity, and it would be conservative to use the highest peak precipitation intensity.

5.3.3 Regional Rainfall Events

The regional rainfall events for individual stations are included in Appendix G. The regional rainfall events are characterized by province, type of storm (hurricane/extra-tropical storm or other), and seasonality in this Section.

The numbers of rainfall events by province and type of storm are summarized in Table 5.10. The largest number of regional rainfall events occurred in Nova Scotia. It is estimated that Nova Scotia has more storms than the rest of Canada (Canadian Geographic, 2015). This is likely due to the location of Nova Scotia along several common storm tracks. Various large storm events are common: hurricanes and extra-tropical storms (large cyclonic storms that develop in the tropics) in late summer and fall, and nor'easters (large storms which start in the Atlantic Ocean and affect the east coast of North America) in the winter. The Gulf Stream travels northwards along the east coast of North America, while the Labrador Current travels southwards along Labrador, around Newfoundland, and then along the east coast of North America. The Nova Scotia Current travels southwest along Nova Scotia, mixing with the Labrador Current and Cape Breton Current. The interaction of these ocean currents impact the weather in Nova Scotia and can cause large precipitation accumulations. Winter storms commonly track over Nova Scotia, while summer storms tend to track eastwards of Nova Scotia (however, hurricanes and extra-tropical have been known to make landfall in Nova Scotia). The other provinces are more inland or further north and do not receive as much rainfall as Nova Scotia (i.e., the storm may impact another province, but the rainfall accumulation is less than 100 mm). For type of storm, approximately 25% were due to a hurricane or extra-tropical storm. Therefore, the most common regional rainfall events to affect Atlantic Canada are frontal systems and/or other storms that are not tropical in origin.

Table 5.10 Number of Regional Storm Events by Province and Type of Storm

Province	Number of Storms With Rainfall > 100 mm	Number of Hurricanes/Extra-Tropical Storms	Number of Other Storms
Nova Scotia	200	44	156
New Brunswick	83	20	63
Newfoundland and Labrador	86	28	58
Prince Edward Island	15	7	8
Total[1]	291	73	218

Note:

1 Some storms caused large rainfall events in more than one province. The total number of storms is therefore not equal to the total of the number of storms in each province.

The frequency of occurrence of regional rainfall events by month is shown in Figure 5.23. Regional rainfall events can occur in any month of the year, but occur most commonly from July to November (a total of 70% of regional rainfall events). Although the regional rainfall events tend to occur from July to November (blue line), the instantaneous annual maxima for streamflow tend to occur from October to April (green line). This is likely due to the fact that it is relatively rare for a regional rainfall event to occur over the watershed. The large rainfall events measured by the Halifax stations, the Halifax Airport stations, and the Shearwater stations (Climate IDs: 8202198, 8202200, 8202250, 8202251, 8205090, 8205091, and 8205092) were obtained and used to identify the rainfall events that have occurred over the watershed. Many of the rainfall events that have occurred over the watershed (red line) have occurred in October and December. The large number of December events corresponded with a large number of December instantaneous annual maximum flow events. However, for the October events there was no corresponding increase in October instantaneous annual maximum flow events. The daily average streamflow data for Sackville River at Bedford were checked to verify that there was a response in the watershed for October events identified in the period 1971-2012. In each case, there was a strong response in the watershed. The analysis to identify regional rainfall events allowed multiple events to be identified in each year. However, the instantaneous annual maximum data only allow for a single event in each year. In many cases where there was a large October rainfall event, the annual maximum occurred at another time of year due to a different event. The watershed was dry for many of the October events and there were no snow or ice contributions.

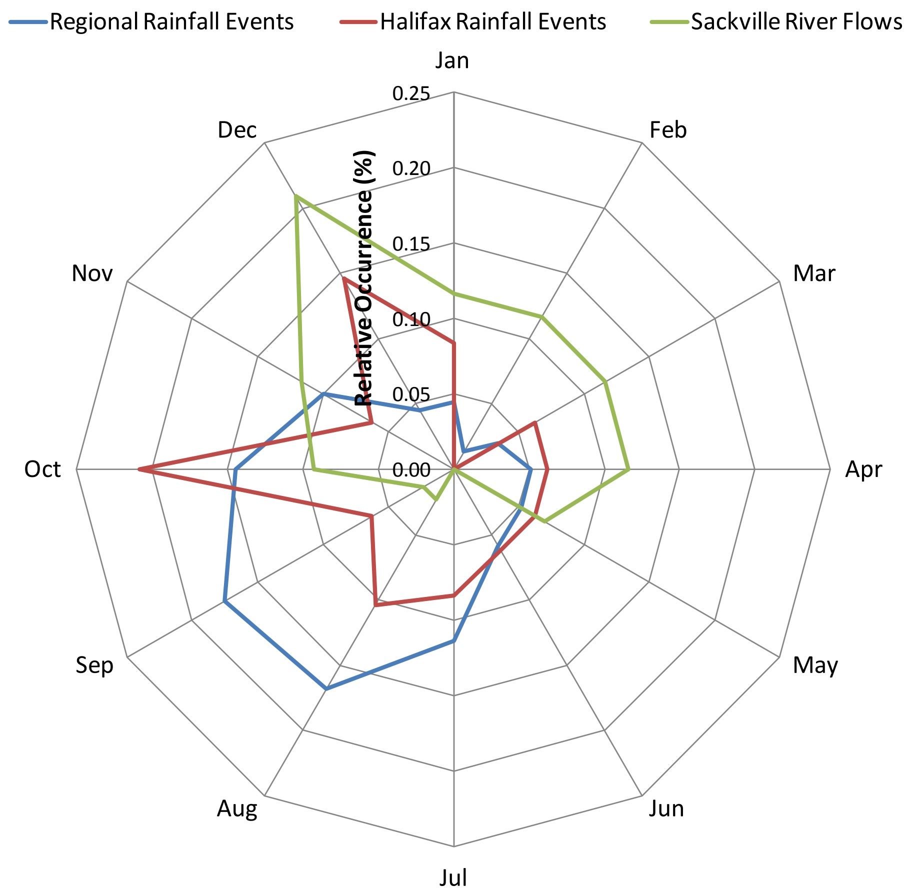


Figure 5.23 Frequency of Occurrence for Regional Rainfall Events, Halifax Rainfall Events, and Instantaneous Annual Maximum Flows for Sackville River at Bedford

The maximum rainfall accumulation for each event was plotted in a histogram (Figure 5.24). The 24-hour, 100-year precipitation estimates from the three IDF curves near Halifax were also plotted on the histogram. The histogram shows that many of the events were between 100 mm and 125 mm, and then the total precipitation accumulation gradually decreased. There were many events that were larger than the Halifax Intl A estimate for the 24-hour, 100-year precipitation event (126.5 mm). Therefore, the Halifax Intl A IDF curve likely underestimates the true magnitude of the 100-year event. This is due to the fact that the largest 24-hour precipitation amount in the times series used for this IDF curve is only 114.2 mm. The Halifax 24-hour, 100-year precipitation estimate (232.9 mm) was greater than most of the events. The three events that were larger than the Halifax 24-hour, 100-year precipitation estimate are listed in Table 5.11. The events also occurred near Halifax, but had lower rainfall totals. The Halifax IDF curve may be an overestimate of the true magnitude of the 100-year event, due to the presence of two extreme precipitation events with over 200 mm of precipitation (1942 and 1971) in a relatively short time series (23 years of data). The Shearwater Auto 24-hour 100-year precipitation event was the best estimate of the three IDF curves. However, the Shearwater Auto curve may still be an underestimate of the magnitude of the 100-year event, as there are many events with higher 24-hour precipitation totals.

Table 5.11 Events With 24-Hour Rainfall Accumulation Greater Than Halifax IDF 100-Year Event

Date	Station Name	Province	Station ID	24-Hour Rainfall Amount (mm)	24-Hour Rainfall at Halifax (mm)
9/23/1942	Upper Stewiacke	Nova Scotia	8206200	248.9	239.5 (Halifax IDF curve)
8/15/1971	Lower Meaghers Grant	Nova Scotia	8203165	247.7	205.7 (Halifax IDF curve)
8/4/2008	Wreck Cove Brook	Nova Scotia	8206450	286.6	90.6 (Shearwater RCS IDF curve)

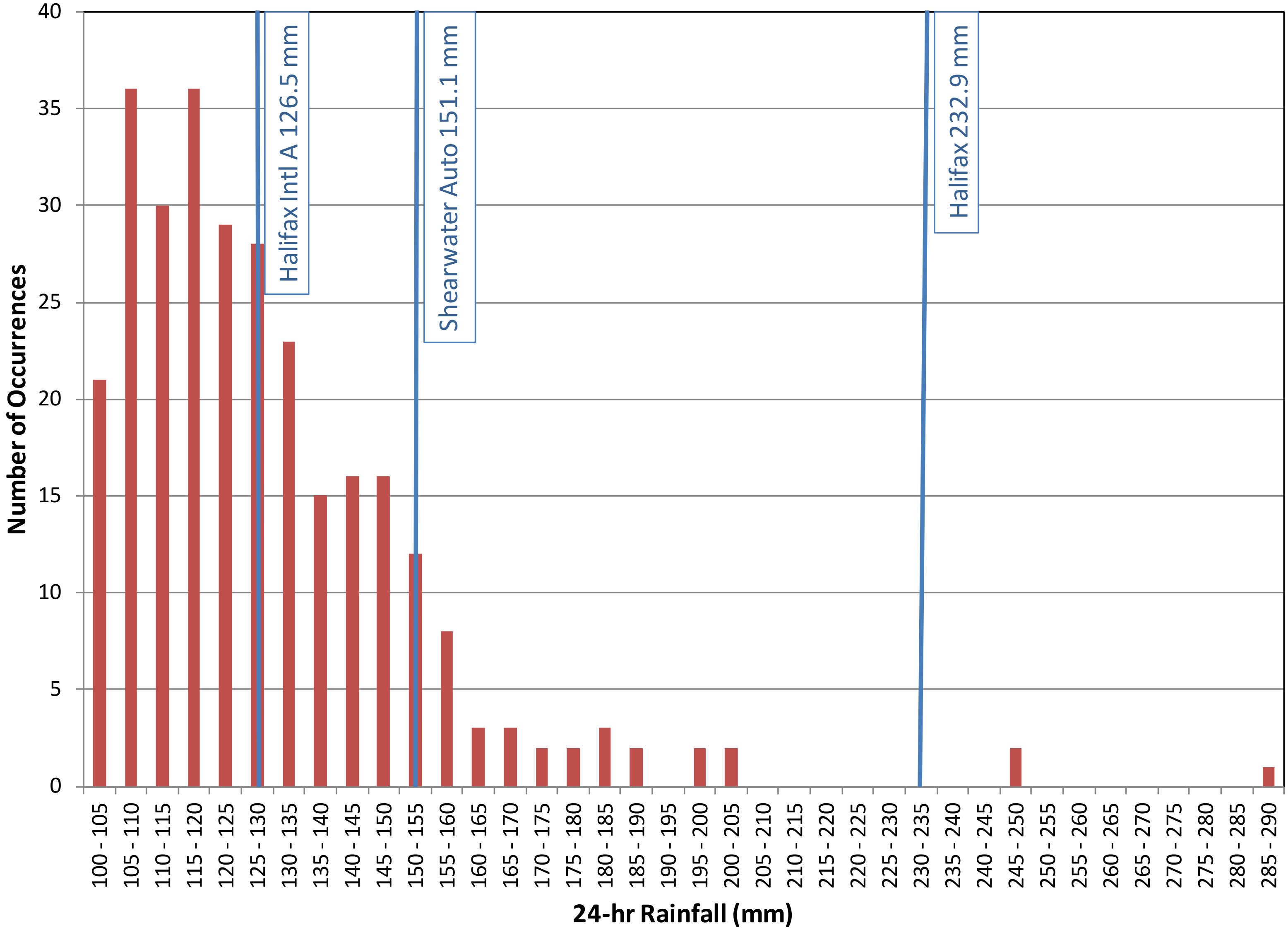


Figure 5.24 Histogram of Maximum Rainfall Accumulation for Regional Rainfall Events

6. Conclusions

Conclusions of the Phase I Study are provided below. The conclusions are organized according to the main tasks of the Study.

Flood Frequency Analysis

- This was the first time that single-station flood frequency analysis could be performed for the Sackville River at Bedford and Little Sackville River at Middle Sackville stations, as the record lengths for both stations were greater than 30 years.
- The flood frequency estimates for the Sackville River at Bedford station were similar to the estimates obtained by the previous study (Interprovincial Engineering, 1981).
- The flood frequency estimates for the Little Sackville River at Middle Sackville station were lower than the estimates obtained by the previous studies (Nolan Davis, 1987; Porter Dillon, 1999). The previous studies used an OttHymo hydrologic model, whereas this study used frequency analysis. There have not been any historical floods (in the period of record of 1981-2012) at this station in the range of the 20-year or 100-year flood estimates obtained by the OttHymo model.
- Annual maximum flows were found to be increasing in the Sackville River at Bedford. The long-term upward trend was not statistically significant; however, the recent period (1995-2012) shows an increasing magnitude of the trend (also not statistically significant). It is expected that the trend will become statistically significant in the near future.
- There was no long-term trend in annual maximum flows at the Little Sackville River at Middle Sackville station, but the recent period (1995-2012) also shows an increasing trend that is not statistically significant. A long-term trend was expected, given the trend in the Sackville River at Bedford data. The lack of trend in the data for Little Sackville River at Middle Sackville indicates that there may be a hydraulic constriction upstream/near the WSC gauge that restricts the flow.

Stationary frequency analysis was performed for both stations. Non-stationary frequency analysis was also performed for the Sackville River at Bedford station due to the long-term increasing trend (even though it was not statistically significant).

Flow Pro-rating

- The increase in flow between the Little Sackville River at Middle Sackville station and the Little Sackville River at the confluence was lower than the increase estimated by the previous studies (Nolan Davis, 1987; Porter Dillon, 1999).
- The decrease in flow between the Sackville River at Bedford station and the Sackville River below the confluence was minor. There are no tributaries in the lower reach of the Sackville River, so the flow increase is due to local inflow in the lower reach.
- The flood estimates for Sackville River at Bedford were also pro-rated to develop the flood estimates for the Sackville River above the confluence. The flood estimates for the Sackville River above the confluence cannot be added directly to the flood estimates for the Little Sackville River at the confluence due to the difference in timing of floods in the two watersheds.

Sea Level Frequency Analysis

- There was a statistically significant long-term increasing trend in the sea level data of approximately 3.8 mm/year, which can be divided into land subsidence (approximately 1.6 mm/year) and actual sea level rise (approximately 2.2 mm/year).
- The Halifax sea level data are measured relative to land ("relative sea level"). The relative sea level data were used for the frequency analysis and for the high-level hydraulic modelling, as both land subsidence and sea level rise increase the flooding potential in coastal areas.
- The stationary and non-stationary sea level frequency analyses were performed and compared to the sea level estimates used in the previous study (Interprovincial Engineering, 1981). The stationary sea level estimates were similar but slightly higher than the previous estimates, which reflected the continuing rise in sea level. The non-stationary sea level estimates were significantly higher than the previous estimates.

Joint Probability Analysis

- The instantaneous annual maximum flow events and the annual maximum sea level events have similar seasonality of occurrence. The instantaneous annual maximum flow events tend to occur from October to March, while the annual maximum sea level events tend to occur from December to February.
- The instantaneous annual maximum flow events and annual maximum sea level events have not occurred at the same time during the overlapping historical period of record. In addition, there were no joint occurrences of high flow and high sea level within the daily average flow data and the daily maximum sea level data.
- The floods and sea level data were found to be independent. The joint return period of flood and sea level occurring simultaneously was calculated as the product of the individual return periods.
- The relationship between floods and sea level (if there is one) was masked by other factors (such as the timing of the tides with respect to surge events, occurrence of spring tides/neap tides, etc.). It is noted however that such a relationship (if it exists) would be unimportant for floodplain modelling considering the magnitude of observed tidal sea level variation.

Hydraulic Modelling

- The hydraulic impact of the sea level was found to be limited to the first 200 m of the river upstream from Bedford Basin, and the sea level did not affect flooding in the areas that are historically affected by flooding.
- The modelling showed that the simulated water level near the confluence was very high.The interaction between the rivers may increase flooding potential in this area. Therefore, several cross-sections above the confluence were surveyed to allow for more detailed modelling of the confluence during Phase II of the study.
- The hydraulic model indicated that several areas are prone to flooding. These areas are:
  - Bedford Place Mall parking lot.
  - Condominium development on River Lane immediately north of Bedford Place Mall.
  - The recreational area immediately downstream of Highway 102.

- Department of National Defense gun range located upstream of Highway 102.
- Fish Hatchery Park.
- Residential neighborhood east of Union Street in the vicinity of Bedford Place Mall.
- Bedford Tower parking lot located at 1496 Bedford Highway.

- The Bedford Place Mall entrances #1 and #2 bridges acted as hydraulic "bottle-necks," causing flooding in downtown Bedford.

Flooding Factors

- The main factors contributing to flooding in the watershed were rainfall, antecedent conditions (wet, wet/frozen), and snowmelt.
- The most significant factor was rainfall. All historical instantaneous annual maximum flow events were caused (partially or fully) by rainfall. Different types of rain events cause high instantaneous annual maximum flow events for each watershed. The rain events that result in high flows for the Sackville River watershed are mostly frontal systems with large accumulations and longer durations. The rain events that result in high flows for the Little Sackville River watershed are mostly local convective systems with shorter durations and higher intensities. This difference is due to the differences between the two watersheds. The Sackville River watershed is larger, generally rural, has many lakes, and has a response time of approximately one day. The Little Sackville River watershed is smaller, generally urban, and has a response time less than one day.
- Wet antecedent conditions were significant factors for both watersheds. However, the Little Sackville River watershed is mainly urban and has more impervious area. Therefore, wet conditions were not as significant for this watershed.
- Snowmelt was also a significant factor for both watersheds. It was a factor in over half of the historical instantaneous annual maximum flow events for Sackville River at Bedford, but just under half of the historical instantaneous annual maximum flow events for Little Sackville River at Middle Sackville.
- Ice jams can occur during ice melting conditions, and some water crossings have significant ice jamming potential. However, no evidence of historical ice jams causing flooding was found during the study.

Synthetic Rainfall Distribution

- There was wide variation in the characteristics of the ten largest precipitation events identified. The observed events varied in duration, some events had more than one peak, and they varied greatly in maximum intensity.
- The observed precipitation events did not match the synthetic rainfall distributions well. The synthetic rainfall distributions have a single peak, and most rainfall occurs near the peak.
- The Chicago distribution was the best-fitting distribution for the majority of the precipitation events, and also for the average of the ten largest precipitation events. This was mainly due to the flexibility of this distribution, which allowed for the time to peak to be adjusted to any time in the storm.

- The Chicago distribution is recommended by Halifax Water (2014), and the use of this distribution will ensure that the results are consistent with other design standards in use in the Region.

Regional Rainfall Events

- Nova Scotia has the largest number of regional rainfall events out of the four Atlantic Provinces. This is due to Nova Scotia's location with respect to ocean currents and prevailing storm tracks.
- In the Atlantic Provinces, the majority of the regional rainfall events occur in the July to November period.
- Approximately 75% of the regional rainfall events were not caused by hurricanes or extra-tropical storms.
- The Halifax area has a relatively large number of winter storms, which accounts for the prevalence of instantaneous annual maximum flow events in the Sackville River throughout the winter months.
- A histogram of the maximum observed rainfall for each event showed that the Shearwater Auto IDF appears to be the best estimate of the 24-hour, 100-year precipitation accumulation.

7. Recommendations

The purpose of Phase I was to collect background information in preparation for Phase II. Recommendations to continue and expand on the work performed in Phase I are provided below.

- The non-stationary flood and sea-level frequency results (Tables 2.10 and 2.18) are recommended for Phase II modelling considering the increasing trends found in the time series and the updating frequency of floodplain mapping.
- The non-stationary flood and sea-level frequency results were generated for 2015; it is recommended to periodically update the results (every 5 years).
- The use of non-stationary flood and sea-level frequency results generated for 2020 or another future year should also be considered for floodplain mapping.
- The relative sea level data are recommended for hydraulic floodplain modelling. For other applications, such as the investigation of climate change impacts on sea level rise, it is recommended to use the absolute sea level rise data (removing the effect of land subsidence).
- The discrepancies between the flood frequency results and the previous hydrologic modelling results for Little Sackville River at Middle Sackville should be investigated in the next phase of the study. The investigation should include the following:
  - Field work to determine if there are flow constrictions limiting channel hydraulic capacity upstream from the WSC gauge.
  - Combined hydrologic and hydraulic modelling for the development of flows at flow-change locations (a combined hydrologic/hydraulic approach accounts for the effect of hydraulic constrictions on flow).
  - Streamflow monitoring to verify flow pro-rating coefficients between the WSC station and the confluence. The streamflow monitoring stations owned by Dalhousie may be useful for this analysis.
- Investigate the individual behaviour of the two watersheds and the interaction between the Sackville River and Little Sackville River, including the timing of peak flows, and determine the effect on hydraulic conditions near the confluence.
- Investigate the potential for ice jams at each hydraulic crossing and their effect on the flooding extents. Some historical instantaneous annual maximum flow events have been associated with ice melting, which is a key time for ice jam formation. Owners of hydraulic crossings should be asked about frequency of historical ice jams at the crossing. Partial blockage due to ice jams should be considered as a scenario in Phase II modelling.
- Include a scenario for potential future development in the Sackville River watershed in Phase II modelling. Future development in the watershed will likely increase flow rates and volumes in the Sackville River and decrease response time, but the effect may be partially mitigated through the use of stormwater management measures.
- Use the Chicago synthetic design storm for Phase II modelling. Long storm durations (more than one day) should be considered for the Sackville River watershed, while short storm durations (one day or less) should be considered for the Little Sackville River. The worst-case ratio should be investigated in Phase II and backed up by historical observations.

- Define historical storms for both watersheds for unsteady-state modelling purposes. The storms causing the five largest instantaneous annual maximum flow events should be considered for this purpose.
- Investigate combining the IDF curves to obtain a longer time series that is more representative of the precipitation characteristics near the Sackville River watershed. There are four IDF curves near the Sackville River watershed: Halifax, Halifax Intl A, Shearwater Auto, and Shearwater RCS (incomplete IDF curve). The Shearwater Auto station may be the most representative but missed the 1942 event and consequently may underestimate precipitation intensities/amounts. Combining the IDF curves may not be feasible for all (short) duration intensities given the distance between the stations but may be achievable for longer duration intensities.
- Develop a detailed hydraulic model which will utilize the topo-bathymetric survey data. The Phase II hydraulic model should extend further upstream and include the confluence of the Sackville River and the Little Sackville River. Additional historical high flow events should be collected and used to calibrate the hydraulic model for both the Sackville River and the Little Sackville River.

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Appendices

Appendix A
Additional Frequency Analysis Results

Table of Contents

Table Index

1. Additional Flood Frequency Analysis Results

Table 1.1 Flood Frequency Analysis Results for Different Frequency Distributions (Stationary)

Frequency Distribution	Return Period (years)		
	5	20	100
	Sackville River at Bedford		
Gumbel	67.2	86.7	108
Lognormal	68.0	86.9	107
Generalized Extreme Value	68.3	84.2	98.2
Log Pearson III	68.4	83.5	96.8
3-parameter Lognormal	68.2	84.0	99.2
	Little Sackville River at Middle Sackville		
Gumbel	17.5	21.7	26.3
Lognormal	17.7	21.6	25.4
Generalized Extreme Value	17.8	20.9	23.3
Log Pearson III	17.8	20.8	23.2
3-parameter Lognormal	17.8	20.8	23.6

Table 1.2 Flood Frequency Analysis Results for Sackville River at Bedford (Stationary)

	Return Period (years)						
	2	5	10	20	25	50	100
Estimate (cms)	52.1	67.2	77.1	86.7	89.8	99	108
95% Confidence Interval (cms)	47.3 - 57.3	60.4 – 75.0	68 - 88.1	73.8 - 102	75.2 - 107	79.2 - 123	81.8 - 140
99% Confidence Interval (cms)	45.7 - 59.1	58.4 - 77.4	65.5 - 91.4	70.7 - 107	71.7 - 113	74 - 131	74.4 - 151

Table 1.3 Flood Frequency Analysis Results for Sackville River at Bedford for 2015 (Non-Stationary, No Detrending)

	Return Period (years)						
	2	5	10	20	25	50	100
Estimate (cms)	58.4	73.4	83.4	93.0	96.0	105	115
95% Confidence Interval (cms)	53.5 - 63.5	66.7 - 81.2	74.2 - 94.3	79.9 – 108	81.3 – 113	85.2 – 129	87.7 - 146
99% Confidence Interval (cms)	51.9 - 65.3	64.5 - 83.5	71.6 - 97.5	76.8 - 113	77.7 - 119	79.9 – 136	80.1 - 156

Table 1.4 Flood Frequency Analysis Results for Sackville River at Bedford for 2015 (Non-Stationary, With Detrending)

	Return Period (years)						
	2	5	10	20	25	50	100
Estimate (cms)	58.4	73.2	82.9	92.3	95.2	104	113
95% Confidence Interval (cms)	53.7 - 63.4	66.5 - 80.7	73.9 - 93.5	79.5 - 107	80.8 - 112	84.6 - 127	87 - 144
99% Confidence Interval (cms)	52.1 - 65.2	64.4 - 83.0	71.3 - 96.6	76.4 - 112	77.3 - 117	79.3 - 134	79.5 - 154

Table 1.5 Flood Frequency Analysis Results for Sackville River at Bedford for 2020 Extrapolation (Non-Stationary, No Detrending)

	Return Period (years)						
	2	5	10	20	25	50	100
Estimate (cms)	59.6	74.7	84.6	94.2	97.2	107	116
95% Confidence Interval (cms)	54.7 – 64.7	67.9 – 82.4	75.4 – 95.5	81.1 – 110	82.5 – 114	86.4 – 130	88.8 – 147
99% Confidence Interval (cms)	53.1 – 66.5	65.7 – 84.7	72.8 – 98.6	78.0 – 114	78.9 – 120	81.0 – 137	81.2 – 157
Notes: Extrapolation to 2020 assumes that the existing trend does not change until 2020. Extrapolated estimates are not for design purposes.							

Table 1.6 Flood Frequency Analysis Results for Sackville River at Bedford for 2020 Extrapolation (Non-Stationary, With Detrending)

	Return Period (years)						
	2	5	10	20	25	50	100
Estimate (cms)	59.7	74.4	84.1	93.5	96.5	105.6	115
95% Confidence Interval (cms)	54.9 – 64.6	67.7 – 81.9	75.1 – 94.7	80.7 – 109	82.0 – 113	85.8 – 128	88.2 – 145
99% Confidence Interval (cms)	53.3 – 66.4	65.6 – 84.2	72.5 – 97.8	77.6 – 113	78.5 – 118	80.5 – 136	80.6 – 155
Notes: Extrapolation to 2020 assumes that the existing trend does not change until 2020. Extrapolated estimates are not for design purposes.							

Table 1.7 Flood Frequency Analysis Results for Little Sackville River at Middle Sackville (Stationary)

	Return Period (years)						
	2	5	10	20	25	50	100
Estimate (cms)	14.3	17.5	19.6	21.7	22.3	24.3	26.3
95% Confidence Interval (cms)	13.1 - 15.6	15.8 - 19.4	17.3 - 22.2	18.5 - 25.4	18.8 - 26.5	19.4 - 30.1	19.7 – 34.0
99% Confidence Interval (cms)	12.7 - 16	15.3 – 20.0	16.7 – 23.0	17.6 - 26.5	17.8 - 27.7	18.1 - 31.8	17.9 - 36.2

2. Additional Sea Level Frequency Analysis Results

Table 2.1 Sea Level Frequency Analysis Results for Different Frequency Distributions (Stationary)

Frequency Distribution	Return Period (years)		
	5	20	100
	Original Halifax Data		
Gumbel	1.67	1.87	2.10
Lognormal	1.68	1.83	1.98
Generalized Extreme Value	1.68	1.86	2.03
Log Pearson III	1.68	1.85	2.03
3-parameter Lognormal	1.68	1.85	2.03
	Adjusted Halifax Data		
Gumbel	1.69	1.90	2.13
Lognormal	1.70	1.86	2.00
Generalized Extreme Value	1.70	1.88	2.06
Log Pearson III	1.70	1.88	2.06
3-parameter Lognormal	1.70	1.88	2.06

Table 2.2 Sea Level Frequency Analysis Results for Adjusted Halifax Data for 2015 (Non-Stationary, No Detrending)

	Return Period (years)						
	2	5	10	20	25	50	100
Estimate (m CGVD28)	1.69	1.85	1.96	2.06	2.10	2.20	2.29
95% Confidence Interval (m CGVD28)	1.66 - 1.73	1.80 - 1.91	1.89 - 2.03	1.96 - 2.16	1.98 - 2.21	2.04 - 2.35	2.08 - 2.50
99% Confidence Interval (m CGVD28)	1.65 - 1.74	1.79 - 1.92	1.87 - 2.05	1.93 - 2.19	1.95 - 2.24	1.98 - 2.39	2.00 - 2.55

Table 2.3 Sea Level Frequency Analysis Results for Adjusted Halifax Data for 2020 Extrapolation (Non-Stationary, No Detrending)

	Return Period (years)						
	2	5	10	20	25	50	100
Estimate (m CGVD28)	1.71	1.87	1.98	2.08	2.11	2.21	2.31
95% Confidence Interval (m CGVD28)	1.67 – 1.75	1.82 – 1.92	1.91 – 2.05	1.98 – 2.18	2.00 – 2.22	2.05 – 2.37	2.09 – 2.52
99% Confidence Interval (m CGVD28)	1.66 – 1.76	1.80 – 1.94	1.88 – 2.07	1.95 – 2.21	1.96 – 2.26	2.00 – 2.41	2.02 – 2.57
Notes: Extrapolation to 2020 assumes that the existing trend does not change until 2020. Extrapolated estimates are not for design purposes.							

Appendix B
Hydraulic Structure Inventory Sheets

HYDRAULIC STRUCTURE INVENTORY SHEET

Watershed and Location Information	Structure Configuration and Dimensions	Current Flow Information
Date (mm/dd/yy):07/14/2015	Structure Type (Culvert/Bridge): Bridge	Flow Present (Y/N): Yes
Field Crew: Juraj Cunderlik (JC), Andrew Betts (AB), Patrick Weeks (PW)	Number of Cells: 1	Approx. Depth (mm): 2500
Watershed Name: Sackville River	Material (Concrete/Steel): Concrete	Approx. Velocity (m/s): 0.2
Subcatchment Area No: Lower Reach	Open Footing (Yes/No): No	Upstream Erosion (Y/N): N/A
Tributary Name: Sackville River	Height (m) x Width (m) (If Applicable): H: 3.9 W: 17.3	Downstream Erosion (Y/N): N/A
Floodplain Map Sheet No.: N/A	Diameter (m) (If Applicable): N/A	Additional Flow Information:
Cross Section Range: N/A	Length (m): 9.5	
Municipality: Halifax Regional Municipality	Inlet Type (Projecting/Mitered/Headwall): Mitered	
Location (Road Name/Intersection): Shore Drive	Skew Angle of Crossing (Degrees): 0	
	Height from Obvert to Top of Road (m): 1.35 m	
	Depth of Siltation (mm): N/A	

Site Photograph and Additional Field Notes

Additional Field Notes:

Site Sketch (Optional):

Description of Photograph: Shore Drive looking downstream

HYDRAULIC STRUCTURE INVENTORY SHEET

Watershed and Location Information	Structure Configuration and Dimensions	Current Flow Information
Date (mm/dd/yy): 07/14/2015	Structure Type (Culvert/Bridge): Bridge	Flow Present (Y/N): Yes
Field Crew: JC, AB, PW	Number of Cells: 3	Approx. Depth (mm): 2500
Watershed Name: Sackville River	Material (Concrete/Steel): Stone piers with steel bridge	Approx. Velocity (m/s): 0.2
Subcatchment Area No: Lower reach	Open Footing (Yes/No): Yes	Upstream Erosion (Y/N): N/A
Tributary Name: Sackville River	Height (m) x Width (m) (If Applicable): H: 7.35 W: 19.5	Downstream Erosion (Y/N): N/A
Floodplain Map Sheet No.: N/A	Diameter (m) (If Applicable): N/A	Additional Flow Information:
Cross Section Range: N/A	Length (m): 5	
Municipality: Halifax Regional Municipality	Inlet Type (Projecting/Mitered/Headwall): Projecting	
Location (Road Name/Intersection): Railway bridge immediately upstream of Shore Drive	Skew Angle of Crossing (Degrees): 0	
	Height from Obvert to Top of Road (m): 2	
	Depth of Siltation (mm): N/A	

Site Photograph and Additional Field Notes

Additional Field Notes:

Site Sketch (Optional):

Description of Photograph: Railway Bridge while standing on Shore Drive looking upstream

HYDRAULIC STRUCTURE INVENTORY SHEET

Watershed and Location Information	Structure Configuration and Dimensions	Current Flow Information
Date (mm/dd/yy): 07/14/2015	Structure Type (Culvert/Bridge): Bridge	Flow Present (Y/N): Yes
Field Crew: JC, AB, PW	Number of Cells: 1	Approx. Depth (mm): 450
Watershed Name: Sackville River	Material (Concrete/Steel): Concrete	Approx. Velocity (m/s): 1.2
Subcatchment Area No: Lower reach	Open Footing (Yes/No): No	Upstream Erosion (Y/N): N/A
Tributary Name: Sackville River	Height (m) x Width (m) (If Applicable): H: 2.98 W: 14.3	Downstream Erosion (Y/N): N/A
Floodplain Map Sheet No.: N/A	Diameter (m) (If Applicable): N/A	Additional Flow Information:
Cross Section Range: N/A	Length (m): 32	
Municipality: Halifax Regional Municipality	Inlet Type (Projecting/Mitered/Headwall): Headwall	
Location (Road Name/Intersection): Bedford Highway	Skew Angle of Crossing (Degrees): 0	
	Height from Obvert to Top of Road (m): 1.9	
	Depth of Siltation (mm): N/A	

Site Photograph and Additional Field Notes

Additional Field Notes:

Site Sketch (Optional):

Description of Photograph: (left) Bedford Hwy looking upstream; (right) Bedford Hwy looking downstream

HYDRAULIC STRUCTURE INVENTORY SHEET

Watershed and Location Information	Structure Configuration and Dimensions	Current Flow Information
Date (mm/dd/yy): 07/14/2015	Structure Type (Culvert/Bridge): Bridge	Flow Present (Y/N): Yes
Field Crew: JC, AB, PW	Number of Cells: 1	Approx. Depth (mm): 1000
Watershed Name: Sackville River	Material (Concrete/Steel): Concrete	Approx. Velocity (m/s): 0.05
Subcatchment Area No: Lower reach	Open Footing (Yes/No): No	Upstream Erosion (Y/N): N/A
Tributary Name: Sackville River	Height (m) x Width (m) (If Applicable): H: 3.3 W: 20.3	Downstream Erosion (Y/N): N/A
Floodplain Map Sheet No.: N/A	Diameter (m) (If Applicable): N/A	Additional Flow Information:
Cross Section Range: N/A	Length (m): 14	
Municipality: Halifax Regional Municipality	Inlet Type (Projecting/Mitered/Headwall): Headwall	
Location (Road Name/Intersection): Bedford Place Mall Entrance #1	Skew Angle of Crossing (Degrees): 0	
	Height from Obvert to Top of Road (m): 1.4	
	Depth of Siltation (mm): N/A	

Site Photograph and Additional Field Notes

Additional Field Notes:

Site Sketch (Optional):

Description of Photograph: (left) Bedford Place Mall entrance #1 looking upstream; (right) Bedford Place Mall entrance #1 looking downstream

HYDRAULIC STRUCTURE INVENTORY SHEET

Watershed and Location Information	Structure Configuration and Dimensions	Current Flow Information
Date (mm/dd/yy): 07/14/2015	Structure Type (Culvert/Bridge): Bridge	Flow Present (Y/N): Yes
Field Crew: JC, AB, PW, Kaitlyn Bailey (KB)	Number of Cells: 1	Approx. Depth (mm): 500
Watershed Name: Sackville River	Material (Concrete/Steel): Concrete	Approx. Velocity (m/s): 0.1
Subcatchment Area No: Lower reach	Open Footing (Yes/No): No	Upstream Erosion (Y/N): N/A
Tributary Name: Sackville River	Height (m) x Width (m) (If Applicable): H: 2.31 W: 24.5	Downstream Erosion (Y/N): N/A
Floodplain Map Sheet No.: N/A	Diameter (m) (If Applicable): N/A	Additional Flow Information:
Cross Section Range: N/A	Length (m): 9.5	
Municipality: Halifax Regional Municipality	Inlet Type (Projecting/Mitered/Headwall): Headwall	
Location (Road Name/Intersection): Bedford Place Mall Entrance #2	Skew Angle of Crossing (Degrees): 0	
	Height from Obvert to Top of Road (m): 1.6	
	Depth of Siltation (mm): N/A	

Site Photograph and Additional Field Notes

Additional Field Notes:

Site Sketch (Optional):

Description of Photograph: Bedford Place Mall entrance #2 looking upstream

HYDRAULIC STRUCTURE INVENTORY SHEET

Watershed and Location Information	Structure Configuration and Dimensions	Current Flow Information
Date (mm/dd/yy): 07/14/2015	Structure Type (Culvert/Bridge): Bridge	Flow Present (Y/N): Yes
Field Crew: JC, AB, PW, Kaitlyn Bailey (KB)	Number of Cells: 1	Approx. Depth (mm): 300
Watershed Name: Sackville River	Material (Concrete/Steel): Concrete	Approx. Velocity (m/s): 0.3
Subcatchment Area No: Lower reach	Open Footing (Yes/No): No	Upstream Erosion (Y/N): N/A
Tributary Name: Sackville River	Height (m) x Width (m) (If Applicable): H:3.6 W: 22.8	Downstream Erosion (Y/N): N/A
Floodplain Map Sheet No.: N/A	Diameter (m) (If Applicable): N/A	Additional Flow Information:
Cross Section Range: N/A	Length (m): 11	
Municipality: Halifax Regional Municipality	Inlet Type (Projecting/Mitered/Headwall): Headwall	
Location (Road Name/Intersection): Bedford Place Mall Entrance #3	Skew Angle of Crossing (Degrees): 0	
	Height from Obvert to Top of Road (m): 2	
	Depth of Siltation (mm): N/A	

Site Photograph and Additional Field Notes

Additional Field Notes:
Bridge slopes down from left to right looking downstream (i.e. larger opening on east side)

Site Sketch (Optional):

Description of Photograph: Bedford Place Mall entrance #3 looking upstream

HYDRAULIC STRUCTURE INVENTORY SHEET

Watershed and Location Information	Structure Configuration and Dimensions	Current Flow Information
Date (mm/dd/yy): 07/14/2015	Structure Type (Culvert/Bridge): Bridge	Flow Present (Y/N): Yes
Field Crew: JC, AB, PW, Kaitlyn Bailey (KB)	Number of Cells: 1	Approx. Depth (mm): 300
Watershed Name: Sackville River	Material (Concrete/Steel): Concrete	Approx. Velocity (m/s): 0.3
Subcatchment Area No: Lower reach	Open Footing (Yes/No): No	Upstream Erosion (Y/N): N/A
Tributary Name: Sackville River	Height (m) x Width (m) (If Applicable): H:3.6 (bank) H: 3.9 (middle)	Downstream Erosion (Y/N): N/A
Floodplain Map Sheet No.: N/A	Diameter (m) (If Applicable): N/A	Additional Flow Information:
Cross Section Range: N/A	Length (m): 2.02	
Municipality: Halifax Regional Municipality	Inlet Type (Projecting/Mitered/Headwall): Headwall	
Location (Road Name/Intersection): Bedford Place Mall Pedestrian Entrance	Skew Angle of Crossing (Degrees): 0	
	Height from Obvert to Top of Road (m): 0.27	
	Depth of Siltation (mm): N/A	

Site Photograph and Additional Field Notes

Additional Field Notes:
Bridge slopes down from left to right looking downstream (i.e. larger opening on east side)

Site Sketch (Optional):

Description of Photograph: Bedford Place Mall pedestrian entrance, looking downstream

HYDRAULIC STRUCTURE INVENTORY SHEET

Watershed and Location Information	Structure Configuration and Dimensions	Current Flow Information
Date (mm/dd/yy): 07/14/2015	Structure Type (Culvert/Bridge): Bridge	Flow Present (Y/N): Yes
Field Crew: JC, AB, PW, Kaitlyn Bailey (KB)	Number of Cells: 2	Approx. Depth (mm): 200
Watershed Name: Sackville River	Material (Concrete/Steel): Concrete	Approx. Velocity (m/s): 0.7
Subcatchment Area No: Lower reach	Open Footing (Yes/No):Yes	Upstream Erosion (Y/N): N/A
Tributary Name: Sackville River	Height (m) x Width (m) (If Applicable): H: 6.74 W: 30.2	Downstream Erosion (Y/N): N/A
Floodplain Map Sheet No.: N/A	Diameter (m) (If Applicable): N/A	Additional Flow Information:
Cross Section Range: N/A	Length (m): 41.95	
Municipality: Halifax Regional Municipality	Inlet Type (Projecting/Mitered/Headwall): Projecting	
Location (Road Name/Intersection): Highway 102	Skew Angle of Crossing (Degrees): 15-20	
	Height from Obvert to Top of Road (m): 1.67	
	Depth of Siltation (mm): N/A	

Site Photograph and Additional Field Notes

Additional Field Notes:

Site Sketch (Optional):

Description of Photograph: Highway 102, looking upstream

HYDRAULIC STRUCTURE INVENTORY SHEET

Watershed and Location Information	Structure Configuration and Dimensions	Current Flow Information
Date (mm/dd/yy): 07/14/2015	Structure Type (Culvert/Bridge): Bridge	Flow Present (Y/N): Yes
Field Crew: JC, AB	Number of Cells: 1	Approx. Depth (mm): 400
Watershed Name: Sackville River	Material (Concrete/Steel): Steel	Approx. Velocity (m/s): 0.5
Subcatchment Area No: Lower reach	Open Footing (Yes/No):No	Upstream Erosion (Y/N): N/A
Tributary Name: Sackville River	Height (m) x Width (m) (If Applicable): H: 3.98 W: 23.6	Downstream Erosion (Y/N): N/A
Floodplain Map Sheet No.: N/A	Diameter (m) (If Applicable): N/A	Additional Flow Information:
Cross Section Range: N/A	Length (m): 3.6	
Municipality: Halifax Regional Municipality	Inlet Type (Projecting/Mitered/Headwall): Projecting	
Location (Road Name/Intersection): 09 Bedford-Sackville Connector Greenway Trail Pedestrian Bridge #1	Skew Angle of Crossing (Degrees): 0	
	Height from Obvert to Top of Road (m): 0.25	
	Depth of Siltation (mm): N/A	

Site Photograph and Additional Field Notes

Additional Field Notes:

Site Sketch (Optional):

Description of Photograph: Bedford-Sackville Connector Greenway Trail Pedestrian Bridge #1, looking

HYDRAULIC STRUCTURE INVENTORY SHEET

Watershed and Location Information	Structure Configuration and Dimensions	Current Flow Information
Date (mm/dd/yy): 07/14/2015	Structure Type (Culvert/Bridge): Bridge	Flow Present (Y/N): Yes
Field Crew: JC, AB	Number of Cells: 1	Approx. Depth (mm): 1000
Watershed Name: Sackville River	Material (Concrete/Steel): Steel	Approx. Velocity (m/s): 0.5
Subcatchment Area No: Lower reach	Open Footing (Yes/No):No	Upstream Erosion (Y/N): N/A
Tributary Name: Sackville River	Height (m) x Width (m) (If Applicable): H: 4.8 W: 23.6	Downstream Erosion (Y/N): N/A
Floodplain Map Sheet No.: N/A	Diameter (m) (If Applicable): N/A	Additional Flow Information:
Cross Section Range: N/A	Length (m): 2.9	
Municipality: Halifax Regional Municipality	Inlet Type (Projecting/Mitered/Headwall): Projecting	
Location (Road Name/Intersection): 09 Bedford-Sackville Connector Greenway Trail Pedestrian Bridge #2	Skew Angle of Crossing (Degrees): 0	
	Height from Obvert to Top of Road (m): 0.32	
	Depth of Siltation (mm): N/A	

Site Photograph and Additional Field Notes

Additional Field Notes:

Site Sketch (Optional):

Description of Photograph: Bedford-Sackville Connector Greenway Trail Pedestrian Bridge #2, looking across

Appendix C
Field Reconnaissance Photo Log

Table of Contents

Figure Index

1. Field Reconnaissance Photograph Log

A total of 13 photos were taken during the field reconnaissance visit to illustrate the river conditions in the lower reaches of the Sackville River. The locations of the photographs are indicated in Figure 1.1. The photographs and notes about each photograph are included in this Appendix.

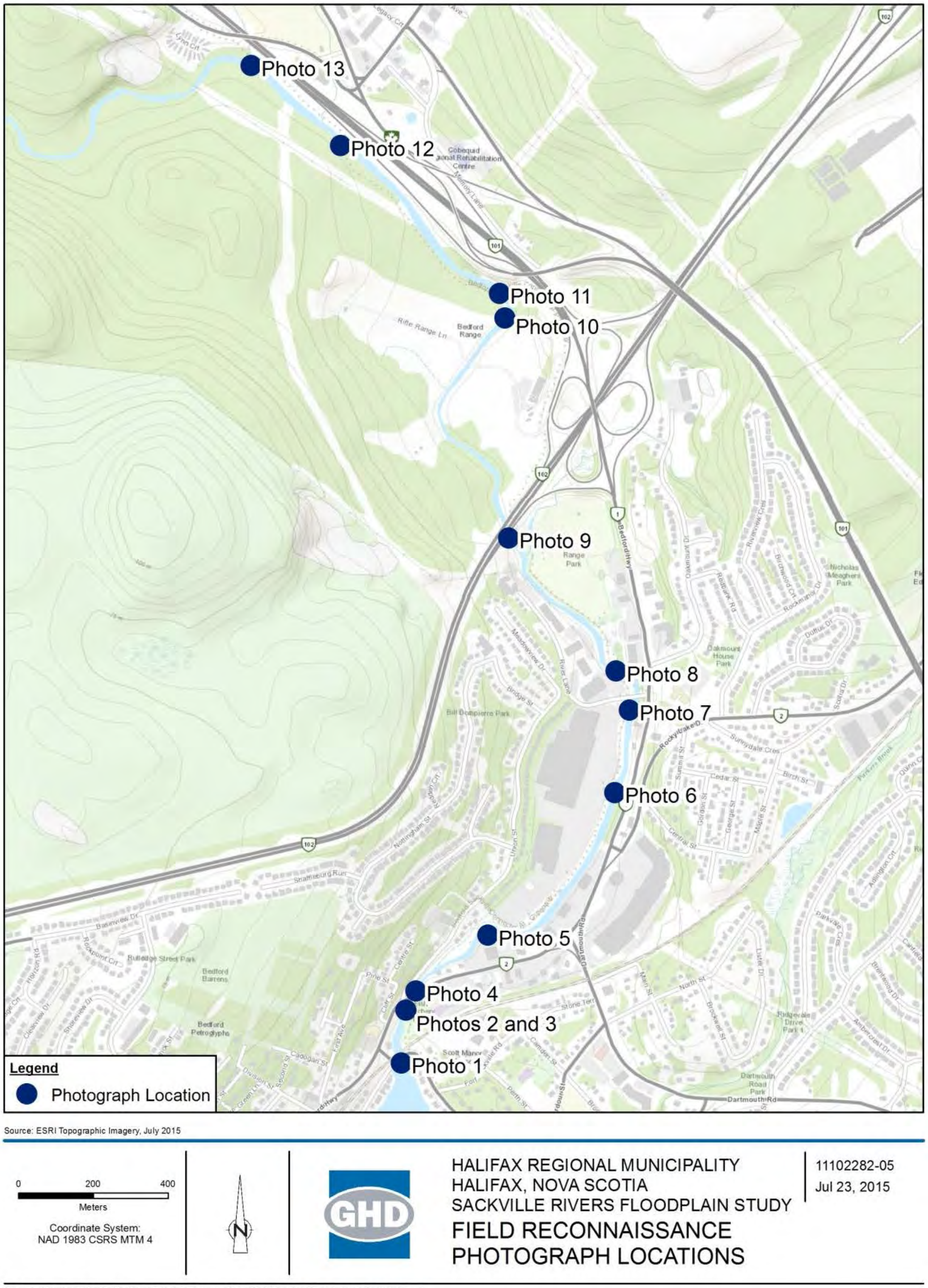


Figure 1.1 Map of Lower Sackville River and Photograph Locations

Field notes for Photograph 1:
Sackville River, at discharge into Bedford Basin, looking downstream
Downstream boundary of hydraulic model

Figure 1.2 Photograph 1: Bedford Basin, at Discharge into Bedford Basin, Looking Downstream

Field notes for Photograph 2:
Sackville River, just downstream of Bedford Highway, looking downstream
Large boulders on river bottom (Manning’s n: 0.045)
High slope, shallow water, turbulent flow

Figure 1.3 Photograph 2: Sackville River Downstream of Bedford Highway, Looking Downstream

Field notes for Photograph 3:
Sackville River, just downstream of Bedford Highway, looking upstream
Large boulders on river bottom (Manning's n: 0.045)
High slope, shallow water, turbulent flow

Figure 1.4 Photograph 3: Sackville River Downstream of Bedford Highway, Looking Upstream

Field notes for Photograph 4:
Sackville River, just upstream of Bedford Highway, looking upstream
Large boulders on river bottom (Manning’s n: 0.045)
Large boulders on river banks (Manning’s n: 0.060)
High slope, shallow water, turbulent flow

Figure 1.5 Photograph 4: Sackville River Upstream of Bedford Highway, Looking Upstream

Field notes for Photograph 5:
Sackville River, near Bedford Tower (1496 Bedford Highway)
Too deep to see river bottom
Vegetated banks (Manning's n: 0.060)
Low slope, deep water, laminar flow

Figure 1.6 Photograph 5: Sackville River near Bedford Tower (1496 Bedford Highway)

Field notes for Photograph 6:
Sackville River, Bedford Place Mall Entrance #2, looking downstream
Sandy/rocky and partially vegetated river bottom (Manning's n: 0.035)
Vegetated banks (Manning's n: 0.060)
Low slope, deep water, laminar flow

Figure 1.7 Photograph 6: Sackville River, Bedford Place Mall Entrance #2, Looking Downstream

Field notes for Photograph 7:
Sackville River, downstream of River Lane, looking upstream
Sandy/rocky river bottom (Manning's n: 0.035)
Vegetated banks (Manning's n: 0.060)
High slope, shallow water, turbulent flow

Figure 1.8 Photograph 7: Sackville River, Downstream of River Lane, Looking Upstream

Field notes for Photograph 8:
Sackville River, Bedford Place Mall Pedestrian Bridge, looking upstream
Sandy/rocky river bottom (Manning’s n: 0.035)
Vegetated banks (Manning’s n: 0.060)
Low slope, deep water, laminar flow

Figure 1.9 Photograph 8: Sackville River, Bedford Place Mall Pedestrian Bridge, Looking Upstream

Field notes for Photograph 9:
Sackville River, Highway 102 Bridge, looking downstream
Large boulders in river (Manning’s n: 0.045)
Heavily vegetated banks (Manning’s n: 0.080)
High slope, shallow water, turbulent flow

Figure 1.10 Photograph 9: Sackville River, Highway 102 Bridge, Looking Downstream

Field notes for Photograph 10:
Sackville River, upstream of Rifle Range Lane, looking downstream
Rocky river bottom with some boulders (Manning’s n: 0.04)
Heavily vegetated west bank (Manning’s n: 0.080), Grassland on east bank (Manning’s n: 0.06)
High slope, shallow water, turbulent flow

Figure 1.11 Photograph 10: Sackville River, Upstream of Rifle Range Lane, Looking Downstream

Field notes for Photograph 11:
Sackville River, Bedford Sackville Connector Greenway Trail Pedestrian Bridge #1, looking upstream
Rocky river bottom (Manning's n: 0.035)
Heavily vegetated west banks (Manning's n: 0.080)
Medium slope, Medium depth

Figure 1.12 Photograph 11: Sackville River, Bedford Sackville Connector Greenway Trail Pedestrian Bridge #1, Looking Upstream

Field notes for Photograph 12:
Sackville River, Bedford Sackville Connector Greenway Trail Pedestrian Bridge #2, looking upstream
Rocky river bottom with some boulders (Manning’s n: 0.040)
Heavily vegetated southwest bank (Manning’s n: 0.080), Vegetated with Highway 101 on northeast bank (Manning’s n: 0.050)
Medium slope, shallow water

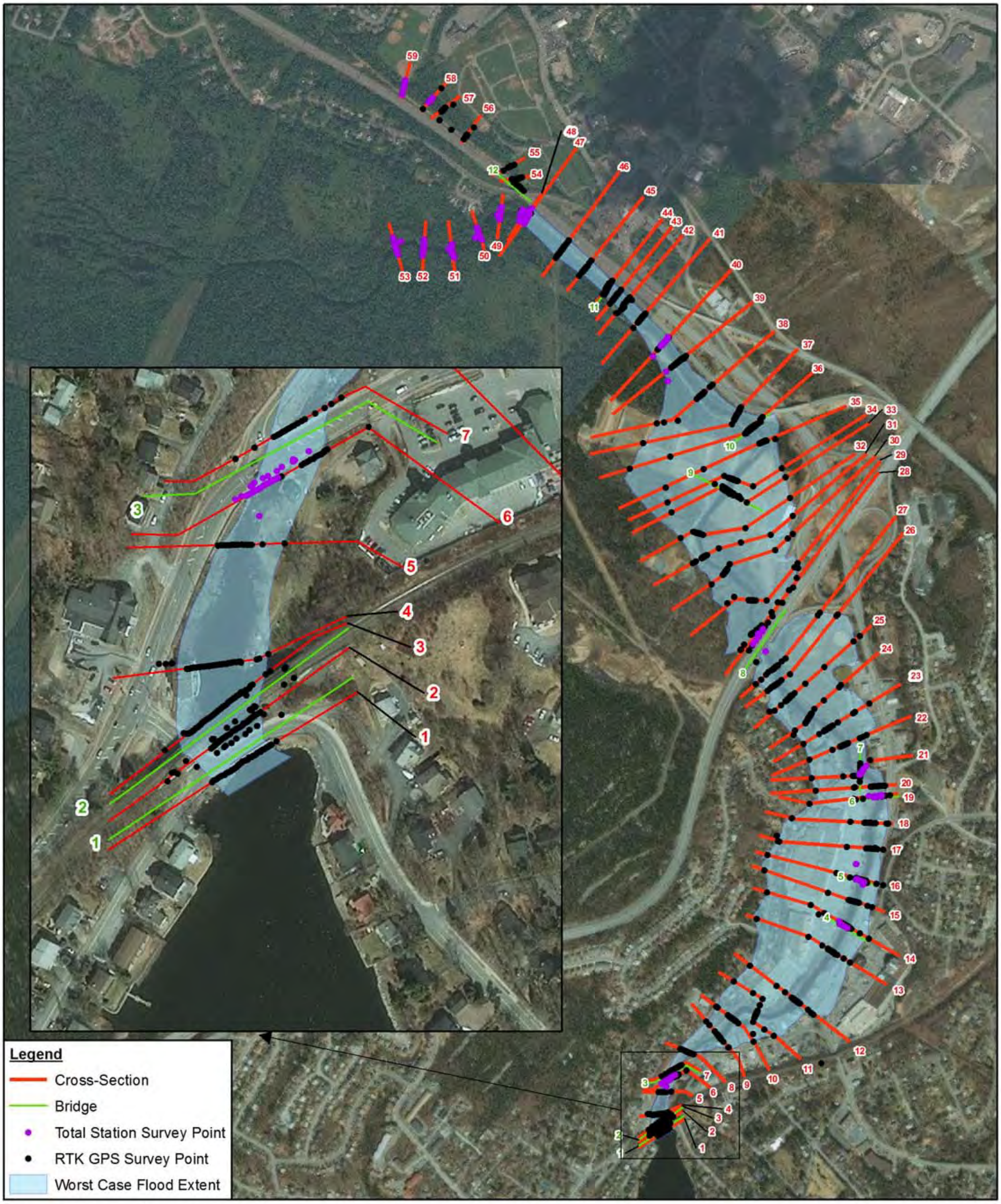
Figure 1.13 Photograph 12: Sackville River, Bedford Sackville Connector Greenway Trail Pedestrian Bridge #2, Looking Upstream

Field notes for Photograph 13:
Sackville River, at confluence with Little Sackville River, looking upstream
Rocky river bottom with some boulders (Manning's n: 0.040)
Heavily vegetated banks (Manning's n: 0.080)
Medium slope, shallow water

Figure 1.14 Photograph 13: Sackville River, at Confluence with Little Sackville River, Looking Upstream

Appendix D
Topo-bathymetric Survey Field Notes

Figure Index



Bing Imagery: ESRI Data, World Imagery, Accessed 2015

0 100 200 300
Meters

Coordinate System:
NAD 1983 CSRS MTM 4

HALIFAX REGIONAL MUNICIPALITY
HALIFAX, NOVA SCOTIA
SACKVILLE RIVERS FLOODPLAIN STUDY: PHASE I

Figure D.1
11102282-04
Oct 30, 2015

TOPO-BATHYMETRIC SURVEY EXTENT

GIS File: I:\IWRM-GROUP\GIS\11100000s\11102282\Layouts\REP003\11102282-04(REP003)GIS-IWRM014-V103.mxd

SEPT. 17, 2015

151-10202

N. HUGHES

23°C, SUNNY

PTS: 999 – 1141

~~1142 – 1488~~

JOB: 10202SEP1715GPS

CONTROL

206118	HPN	100 – 102
200002	NSCM	103 – 104
200004	NSCM	109 – 110

- SEPT. 18, 2015
  25°C, SUNNY
  PTS 1142 – 1488

- SEPT 21, 2015
  20°C, SUNNY
  PTS 1489 – 2005

NOTES: XSEC4 NOT COMPLETE
XSEC37 " "

- UBRIDGE 7 - INTENDED TO BE 12 INCH OFFSET VERTICALLY TO BOTTOM SIDE OF WALKING BRIDGE

- XSEC 25 - TREES OBSTRUCTION
- XSEC 24 - HOUSE OBSTRUCTION

- XSEC23-8 WAS 2m + 1FT HEIGHT.
(2.304m)

- RENAME XSEC6-14 TO 7-15.

- UB9 IS MEASURED TO UNDERSIDE OF BRIDGE.

- UBRIDGE10 - 0.3m VERTICAL OFFSET TO UNDERSIDE BRIDGE.

No.652

5 . 23 . 15 PTS 7025 - 7346

10202 SEP2215TS

NEH, TJD

20°C , SUNNY

1.995

HI 1.277 HR ~~2.0~~ (10mm o/s)

π 111 BS 117 ΔH 0.025 ΔV 0.048

7025 - 7143

HI 1.497 HR 1.995

π 117 BS 111

7144 - 7183

HI 1.25

π 125 BS 127

7184 - 7231

HI 1.358

π 127 BS 125

7232 - 7279

7280 MARKER DOT

HI 1.618

π 7280 BS 127

7281 - 7307, 7309, 7310 XSEC 50

5.23.15
NEH

HI 1.344
π 7308 BS 7280
7311 - 7346 XSEC 51

NOTE: XSEC 47 WAS CREATED TO ENCOMPASS
A PALOUSE MONITORING STATION.
THE XSEC I MOVED WAS LATER
OBSERVED ; NAMED XSEC 48. THIS ERROR / ADDITIONAL TOPO
ALLOWS FOR MORE DETAIL AT
~~CONFLUENCE~~ CONFLUENCE.

JL DARLING LLC
Tacoma, WA, USA • RiteintheRain.com

No.652

5.23.15
NEH

NOTES:

NAME IN FIELD	RENAME TO:	PTS:
XSEC47	→ ~~RENAME TO~~ XSEC47A	7031 - 7094
XSEC 48	XSEC47	7144 - 7183
XSEC 49	XSEC 48	7189 - 7231
XSEC 50	XSEC 50	7281 - 7307, 7309, 7310
XSEC 50	XSEC 49	7232 - 72

3 of 3

DURA Rite WATERPROOF

S. 24 .15

10202SEP2415TS JOB

N. HUGHES

20°C, SUNNY

PTS 7347 - 7453

HI 1.84

π 119 BS 121

7347 - 7353 XSEC20 → BOAT NEEDED

HI 1.578

π 123 BS 121

7354 - 7382 XSEC 19

7383 - 7388 BRIDGE6 TOPO (UNDERSIDE)

JOB: 10202SEP2415GPS

PTS 2387 - 264~~4~~6

POINTS

121 CHK 129/130

1000 HELD 131

DELETE 2595 - 2597

1 of 2

SEPT2415TS GPS

HI 1.07

⊼ 132 BS 134

7001 - 7015

* THESE WERE SHOT IN GPS JOB. IF USABLE THEY NEED TO BE RENUMBERED TO 7389 - 7403.

SEPT2415TS

HI 1.793

⊼ 138 BS 136

7404

HI 1.733

⊼ 136 BS 138

7405 - 7406

HI 1.708

⊼ 138 BS 136

7408 - 7453 XSEC 39

2 of 2

No.652

20°C, SUNNY

10202SEP2515GPS

NEH, TJD

☆ COPIED SEP1715GPS CALIBRATION

MS 2647 - 2714

CHK - 1000 PT 2714

~~1020SEP2515TS~~

NEH, TJD

HI 1.637 HR 1.76 HF 1.757

π 150 BS 152

7570 PS

7506 - 7547 XSEC 2

LAST POINT 7577

HI HR

π 7570 BS 150

7578 - 7586 XSEC 4

7586 - AGAINST BUILDING

~~7587 - BUILDING OBSTACLE~~

7587 - 7599 XSEC 3

7600 - 7603 XSEC 4

7604 - 7641 XSEC 3

☆ 7500 - 7641 SHOT IN GPS JOB...

GOPS.

1 of 3

DURA Lite

HI 1,753 ~~HR 1.65~~ 1.644 10202 SEP1515 TS

π 152 BS 150

7642 - 7677

~~π~~ HI 1,927 HR 1.5 H 2.64

π 119 BS 121

7678 - 7693 DELETE

7694 - 7715 XSEC 20

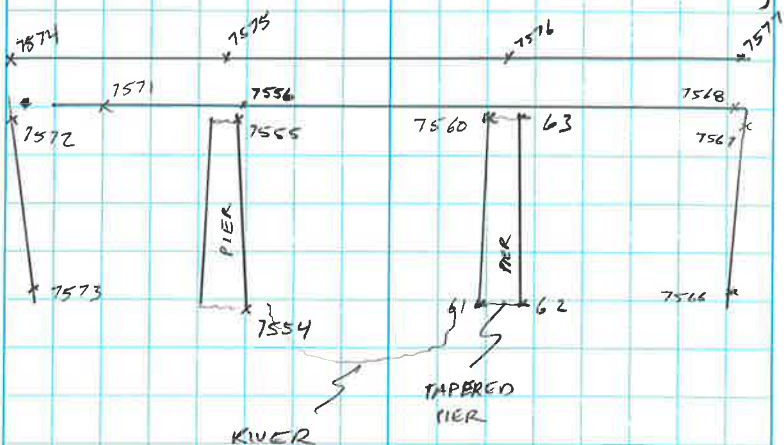
5.25.15

NEH

2 of 3

5.25.15 NEH

PROFILE OF SOUTH SIDE TRAIN BRIDGE
(BRIDGE 2)



NOTE:

7566 & 7567 ARE ON NORTH SIDE OF BRIDGE & ARE THE CONCRETE ABUTMENT

S. 28. 15

1020 25 SEP 2015

NEH, TJD

20°C, SUNNY

HI 1.755 HR 1.798

π 113 BS 115

7716

7717

HI 1.65 HR 1.76

π 7716 BS 113

7718 - 7736 XSEC 56

NOTE: BS 113 & BS 7716 ARE ALSO XSEC 56

HI 1.735 HR 1.76

π 7717 BS 113

7737 - 7756 XSEC 57

HI 1.673

π 170 BS 172

7757 - UB8

S. 28.15

10202 SEP2815 GPS

NEH, TJD

☆ COPIED SEP1715GPS CALIBRATION

170	PS
171	PS (CHK)
172	PS
173	PS (CHK)

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Appendix E
Analysis of Flooding Factors

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Table Index

1. Analysis of Flooding Factors for Sackville River at Bedford

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
04/01/2003 00:17	106	Halifax Stanfield 03/28: 0.0 03/29: 1.0 03/30: 14.4 03/31: 91.5 04/01: 0.0	Shearwater A 3/31: 16.0	Halifax Stanfield 106.9	None	Wet/frozen	0.60/0.6 No surge	Ice just melted	April Low	Single peak (rapid rise)	Rainfall, ice melt, frozen conditions
01/16/1978 02:51	90.3	Halifax Stanfield 01/12: 0.0 01/13: 0.0 01/14: 94.1 01/15: 17.8 01/16: 0.0	Halifax Stanfield 01/14: 13.0	Halifax Stanfield 125.8	Rain on snow, melting	Wet/frozen	1.57/1.6 No surge	Ice just melted	January Low	Single peak (rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions
08/16/1971 21:03	85	Halifax Stanfield 08/12:3.0 08/13: 0.0 08/14: 0.0 08/15: 218.2 08/16: 78.2	Halifax 8/15: 20.8	Halifax Stanfield 299.4	None	Dry	0.46/0.5 No surge	None	August High	Hurricane Beth Single peak (rapid rise)	Rainfall
11/07/2010 16:02	79.1	Halifax Stanfield 11/03: 0.0 11/04: 7.6 11/05: 53.5 11/06: 41.7 11/07: 36.6	Halifax Stanfield 11/07: 6.2	Halifax Stanfield 139.4	None	Wet	0.25/0.1 No surge	None	November High	Same date Single peak (gradual rise)	Rainfall, wet conditions

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
03/14/1980 22:37	73	Halifax Stanfield 03/10: 0.0 03/11: 16.6 03/12: 0.0 03/13: 0.0 03/14: 52.9	Halifax Stanfield 03/14: 12.7	Halifax Stanfield 69.5	Rain on snow, melting	Wet/frozen	0.68/0.6 No surge	None	March Low	Second peak (rapid rise, snowmelt), daily average is low	Rainfall, snowmelt, wet conditions
11/26/2004 18:37	67.3	Halifax Stanfield 11/22:0.8 11/23: 0.0 11/24: 0.0 11/25: 87.8 11/26: 0.0	Shearwater Auto 11/25: 14.4	Halifax Stanfield 88.6	Rain on snow, melting	Wet/frozen	1.59/1.5 No surge	None	November High	Day after Single peak (rapid rise)	Rainfall, snowmelt, wet conditions
05/09/2005 13:27	67.1	Halifax Stanfield 05/05: 0.0 05/06: 0.0 05/07: 27.9 05/08: 66.7 05/09: 0.0	Shearwater A 05/08: 6.8	Halifax Stanfield 94.6	None	Wet	0.77/0.8 No surge	None	May Medium	Single peak (gradual rise)	Rainfall, wet conditions
04/05/2009 00:47	65	Halifax Stanfield 04/01: 0.0 04/02: 0.0 04/03: 38.8 04/04: 20.7 04/05: 1.4	Halifax Stanfield 04/04: 11.3	Halifax Stanfield 60.9	Rain on snow, melting	Wet/frozen	1.22/0.7 Surge	Ice just melted	April Low	Second peak (rapid rise, snowmelt)	Rainfall, snowmelt, ice melt, frozen conditions

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
11/14/2002 17:37	64.6	Halifax Stanfield 11/10: 0.2 11/11: 5.1 11/12: 9.1 11/13: 73.4 11/14: 33.4	Shearwater A 11/13: 7.0	Halifax Stanfield 121.2	None	Wet	1.31/1.3 No surge	None	November High	Single peak (rapid rise)	Rainfall, wet conditions
03/16/1984 19:19	64	Halifax Stanfield 03/12: 0.0 03/13: 0.0 03/14: 27.4 03/15: 52.0 03/16: 0.0	Halifax Stanfield 03/14: 5.5	Halifax Stanfield 79.8	Rain on snow, melting	Wet/frozen	1.79/1.9 No surge	None	March Low	Day after Single peak (rapid rise)	Rainfall, snowmelt, wet conditions
01/25/1998 23:59	63.5	Halifax Stanfield 01/21: 0.0 01/22: 0.0 01/23: 0.0 01/24: 57.6 01/25: 36.2	Shearwater A 01/24: 7.6	Halifax Stanfield 99.8	Rain/snow mix and rain on snow, melting	Wet/frozen	0.33/0.3 No surge	Ice just melted	January Low	Single peak (rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions
12/20/2000 12:00	63.5	Halifax Stanfield 12/16: 0.0 12/17: 9.9 12/18: 5.6 12/19: 0.0 12/20: 80.2	Shearwater A 12/20: 12.8	Halifax Stanfield 96.0	Small amount of snow (0.3 cm)	Wet	0.90/0.6 Small surge	None	December Low	Same day Single peak (rapid rise, previous peaks)	Rainfall, wet conditions

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
02/17/1996 13:00	63	Halifax Stanfield 02/13: 0.0 02/14: 0.0 02/15: 0.0 02/16: 12.0 02/17: 84.9	Shearwater A 02/17: 10.6	Halifax Stanfield 117.8	Rain/snow mix and rain on snow, melting	Wet/frozen	0.16/0.0 No surge	Ice just melted	February Low	Same day Single peak (rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions
02/12/1981 10:39	61.8	Halifax Stanfield 02/08: 19.4 02/09: 0.8 02/10: 0.0 02/11: 5.6 02/12: 10.3	Halifax Stanfield 2/12: 4.1	Halifax Stanfield 42.4	Rain/snow mix, melting	Wet/frozen	0.58/0.5 No surge	None	February Low	Third peak (rapid rise, snowmelt)	Rainfall, snowmelt, wet conditions
03/17/1994 06:34	60.8	Halifax Stanfield 03/13: 0.0 03/14: 20.2 03/15: 16.9 03/16: 24.4 03/17: 2.8	No data	Halifax Stanfield 67.1	Rain on snow, melting	Wet/frozen	0.85/0.7 No surge	Ice just melted	March Low	Day after Third peak (rapid rise, snowmelt)	Rainfall, snowmelt, ice melt, frozen conditions
10/21/2011 11:02	60.1	Halifax Stanfield 10/17: 9.5 10/18: 0.0 10/19: 6.6 10/20: 104.4 10/21: 0.0	Halifax Stanfield 10/20: 15.0	Halifax Stanfield 120.5	None	Wet	0.97/0.7 Small surge	None	October High	Day after Second peak (rapid rise) Max height: 5.96 m (CGVD28)	Rainfall, wet conditions

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
05/16/2001 01:02	60	Halifax Stanfield 05/12: 0.0 05/13: 0.0 05/14: 78.8 05/15: 25.8 05/16: 0.0	Shearwater A 05/14: 13.8	Halifax Stanfield 104.6	None	Wet	1.56/1.1 Surge	None	May Medium	Day after Second peak (rapid rise)	Rainfall, wet conditions
05/17/1972 13:21	58.6	Halifax Stanfield 05/13: 0.0 05/14: 0.0 05/15: 5.1 05/16: 51.6 05/17: 8.1	Halifax 05/17: 8.1	Halifax Stanfield 64.8	None	Wet	1.46/1.5 No surge	None	May Medium	Single peak (rapid rise)	Rainfall, wet conditions
11/12/1991 13:34	57.6	Halifax Stanfield 11/08: 1.6 11/09: 0.0 11/10: 27.0 11/11: 61.4 11/12: 0.0	Shearwater A 11/11: 9.3	Halifax Stanfield 90.0	None	Wet	1.40/1.3 No surge	None	November High	Day after Single peak (rapid rise)	Rainfall, wet conditions
03/16/1999 02:00	57.3	Halifax Stanfield 03/12: 0.2 03/13: 0.0 03/14: 0.0 03/15: 38.9 03/16: 2.0	Shearwater A 03/16: 12.1	Halifax Stanfield 55.1	Rain/snow mix, melting	Wet/frozen	0.98/0.6 Small surge	None	March Low	Same date Third peak (rapid rise, snowmelt)	Rainfall, snowmelt, wet conditions

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
09/23/2012 05:36	56.8	Shearwater RCS 09/19: 18.8 09/20: 40.2 09/21: 36.0 09/22: 15.4 09/23: 12.6	Shearwater RCS 09/22: 14.0	Shearwater RCS 123.0	None	Wet	0.94/1.0 No surge	None	September High	Same date Single peak (rapid rise) Max height: 5.88 m (CGVD28)	Rainfall, wet conditions
12/23/1975 01:01	54.7	Halifax Stanfield 12/19: 0.0 12/20: 0.0 12/21: 2.0 12/22: 82.6 12/23: 4.6	Shearwater A 12/22: 7.4	Halifax Stanfield 109.0	Rain/snow mix, incomplete melting	Wet/frozen	1.61/1.6 No surge	Ice just melted	December Low	Single peak (rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions
04/30/1982 02:23	52.9	Halifax Stanfield 04/26: 0.0 04/27: 19.4 04/28: 70.7 04/29: 4.4 04/30: 0.0	Shearwater A 04/28: 15.7	Halifax Stanfield 100.4	Rain/snow mix, no melting	Dry	1.42/1.5 No surge	None	April Low	Single peak (rapid rise)	Rainfall
02/27/1979 15:39	52.7	Halifax Stanfield 02/23: 0.0 02/24: 5.8 02/25: 29.6 02/26: 35.7 02/27: 36.6	Shearwater A 02/25: 9.9	Halifax Stanfield 115.4	Rain/snow mix, melting	Wet/frozen	0.04/0.0 No surge	None	February Low	Single peak (gradual rise)	Rainfall, snowmelt, wet conditions

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
11/17/1983 04:47	51.8	Halifax Stanfield 11/13: 0.0 11/14: 0.0 11/15: 0.0 11/16: 50.1 11/17: 16.6	Shearwater A 11/17: 10.2	Halifax Stanfield 66.7	None	Wet	2.04/1.5 Surge	None	November High	Same date Third peak (rapid rise)	Rainfall, wet conditions
10/28/1993 04:29	51.7	Halifax Stanfield 10/24: 0.0 10/25: 0.0 10/26: 0.0 10/27: 47.2 10/28: 15.6	Shearwater A 10/28: 6.5	Halifax Stanfield 62.8	None	Dry	1.63/1.0 Surge	None	October High	Same date Single peak (rapid rise)	Rainfall
04/29/1973 14:30	51	Halifax Stanfield 04/25: 0.5 04/26: 0.0 04/27: 0.0 04/28: 14.7 04/29: 60.5	Halifax 04/29: 11.2	Halifax Stanfield 75.7	None	Wet	1.00/0.9 No surge	None	April Low	Single peak (rapid rise)	Rainfall, wet conditions
03/13/1985 06:52	50.1	Halifax Stanfield 03/09: 0.0 03/10: 0.0 03/11: 0.0 03/12: 30.6 03/13: 35.2	Halifax Stanfield 03/13: 11.2	Halifax Stanfield 66.0	Rain on snow, melting	Wet/frozen	0.64/0.6 No surge	Ice just melted	March Low	Same date Single peak (rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
12/09/1990 05:49	50.1	Halifax Stanfield 12/05: 12.8 12/06: 0.0 12/07: 0.0 12/08: 22.4 12/09: 18.88	Shearwater A 12/09: 13.4	Halifax Stanfield 54.0	None	Wet	0.96/1.0 No surge	None	December Low	Same date Second peak (rapid rise)	Rainfall, wet conditions
12/13/2008 02:02	48.9	Halifax Stanfield 12/09: 7.0 12/10: 18.9 12/11:17.9 12/12:40.1 12/13: 0.0	Shearwater Auto 12/12: 10.5	Halifax Stanfield 84.9	Rain on snow, melting	Wet/frozen	0.45/0.4 No surge	None	December Low	Single peak (gradual rise)	Rainfall, snowmelt, wet conditions
02/24/1974 09:00	46.4	Halifax Stanfield 02/20: 61.0 02/21: 0.0 02/22:18.5 02/23: 25.1 02/24: 0.0	Shearwater A 02/23: 4.8	Halifax Stanfield 107.4	Rain on snow, melting	Wet/frozen	1.40/1.5 No surge	Ice just melted	February Low	Single peak (rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions
12/26/1977 06:58	44.7	Halifax Stanfield 12/22: 29.6 12/23: 0.0 12/24: 0.0 12/25: 7.0 12/26: 28.2	Halifax Stanfield 12/26: 11.9	Halifax Stanfield 64.8	None	Wet	1.86/1.6 Small surge	None	December Low	Second peak (gradual rise)	Rainfall, wet conditions

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
10/23/1988 06:20	42.1	Halifax Stanfield 10/19: 57.5 10/20: 22.4 10/21: 0.0 10/22: 39.6 10/23: 9.4	Shearwater A 10/22: 7.7	Halifax Stanfield 128.9	None	Wet	2.11/1.9 Small surge	None	October High	Second peak (rapid rise)	Rainfall, wet conditions
01/19/2007 20:17	37.5	Halifax Stanfield 01/15: 0.8 01/16: 0.5 01/17: 0.0 01/18: 0.0 01/19: 47.2	Halifax Stanfield 01/19: 12.4	Halifax Stanfield 67.0	Rain on snow, melting	Wet/frozen	2.09/1.9 Small surge	Ice conditions, melting	January Low	Same date Single peak (rapid rise), daily average is low	Rainfall, snowmelt, ice melt, frozen conditions
02/05/2006 19:02	36.6	Halifax Stanfield 02/01: 0.0 02/02: 0.0 02/03: 5.7 02/04: 0.0 02/05: 37.8	Shearwater Auto 02/05: 9.7	Halifax Stanfield 63.9	Rain on snow, melting	Wet/frozen	1.01/0.5 Surge	Ice just melted	February Low	Same date Single peak, daily average is low	Rainfall, snowmelt, ice melt, frozen conditions
12/10/1995 11:25	36.5	Halifax Stanfield 12/06: 6.4 12/07: 0.0 12/08: 0.0 12/09: 0.0 12/10: 47.1	Shearwater A 12/10: 10.5	Halifax Stanfield 63.7	Rain on snow, melting	Wet/frozen	2.00/1.6 Surge	None	December Low	Same date Single peak (rapid rise)	Rainfall, snowmelt, wet conditions

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
01/20/1986 13:30	36.3	Halifax Stanfield 01/16: 0.0 01/17: 0.0 01/18: 0.0 01/19: 3.2 01/20: 45.2	Halifax Stanfield 01/20: 7.6	Halifax Stanfield 48.4	Rain on snow, melting	Wet/frozen	0.98/0.9 No surge	Ice conditions, melting	January Low	Same date Single peak (rapid rise), daily average is low	Rainfall, snowmelt, ice melt, frozen conditions
12/01/1987 07:37	36.0	Halifax Stanfield 11/27: 0.0 11/28: 0.0 11/29: 0.0 11/30: 7.8 12/01: 47.0	Halifax Stanfield 12/01: 11.0	Halifax Stanfield 59.0	Rain on snow, melting	Wet/frozen	1.70/1.2 Surge	None	December Low	Same date Single peak (rapid rise)	Rainfall, snowmelt, wet conditions
01/05/1992 22:18	35.3	Halifax Stanfield 01/01: 0.0 01/02: 0.0 01/03: 0.0 01/04: 0.0 01/05: 52.8	Shearwater A 01/05: 7.9	Halifax Stanfield 53.3	Rain on snow, melting	Wet/frozen	1.88/1.6 Small surge	Ice just melted	January Low	Day before Single peak (gradual rise), daily average is low	Rainfall, snowmelt, ice melt, frozen conditions
12/22/1976 18:30	34.5	Halifax Stanfield 12/18: 0.0 12/19: 0.0 12/20: 5.6 12/21:49.8 12/22: 0.0	Shearwater A 12/21: 4.8	Halifax Stanfield 59.2	Rain on snow, melting	Wet/frozen	0.51/0.6 No surge	Ice just melted	December Low	Single peak (rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions

Table 1.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Sackville River at Bedford

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
12/30/1997 10:35	30.8	Halifax Stanfield 12/26: 0.8 12/27: 0.0 12/28: 0.0 12/29: 0.0 12/30: 45.4	Shearwater A 12/30: 7.1	Halifax Stanfield 61.6	Rain on snow, melting	Wet/frozen	1.50/1.4 No surge	Ice just melted	December Low	Single peak (rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions
04/03/1970 09:23	29.7	Halifax Stanfield 03/30: 0.0 03/31: 0.0 04/01:0.0 04/02:33.5 04/03: 17.3	Halifax 04/03: 9.9	Halifax Stanfield 58.4	Rain/snow mix	Wet/frozen	1.01/0.9 No surge	None	April Low	Second peak (rapid rise)	Rainfall, snowmelt, wet conditions
10/11/1989 23:14	26.1	Halifax Stanfield 10/07: 3.2 10/08: 0.0 10/09: 3.0 10/10: 0.0 10/11: 49.6	Shearwater A 10/11: 14.3	Halifax Stanfield 55.8	None	Wet	0.34/0.3 No surge	None	October High	Same date Single peak (rapid rise), daily average is low	Rainfall, wet conditions

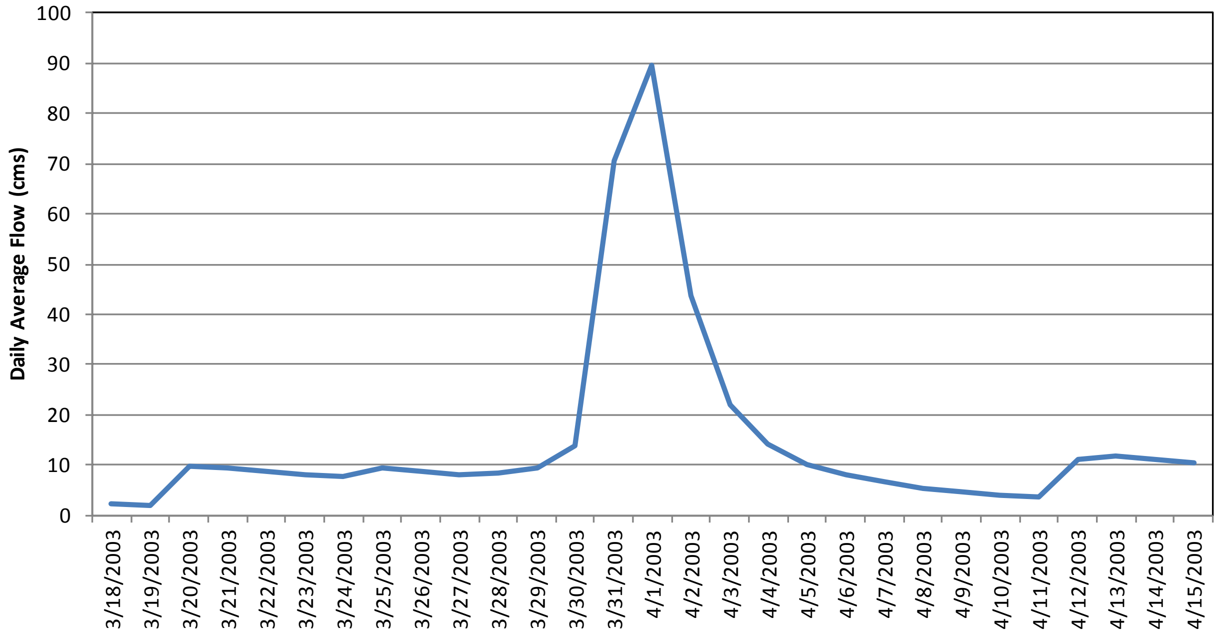

Figure 1.1 Daily Average Flow Hydrograph for the Largest Instantaneous Annual Maximum Flow Event: April 1, 2003 (Sackville River at Bedford)

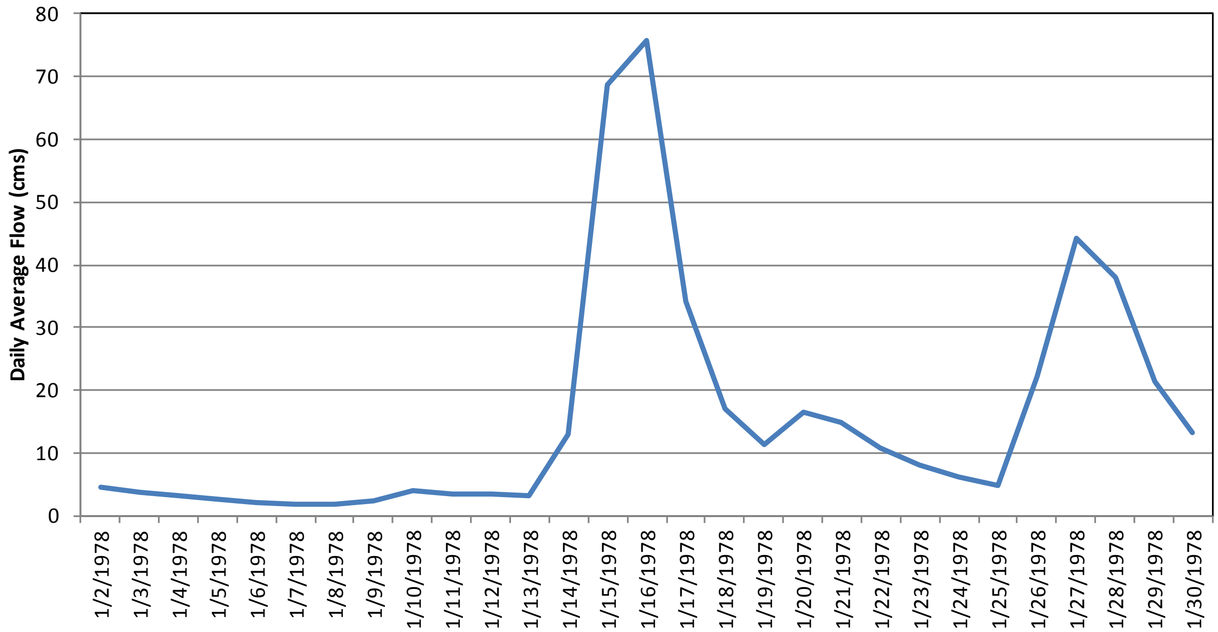

Figure 1.2 Daily Average Flow Hydrograph for the 2nd Largest Instantaneous Annual Maximum Flow Event: January 16, 1978 (Sackville River at Bedford)

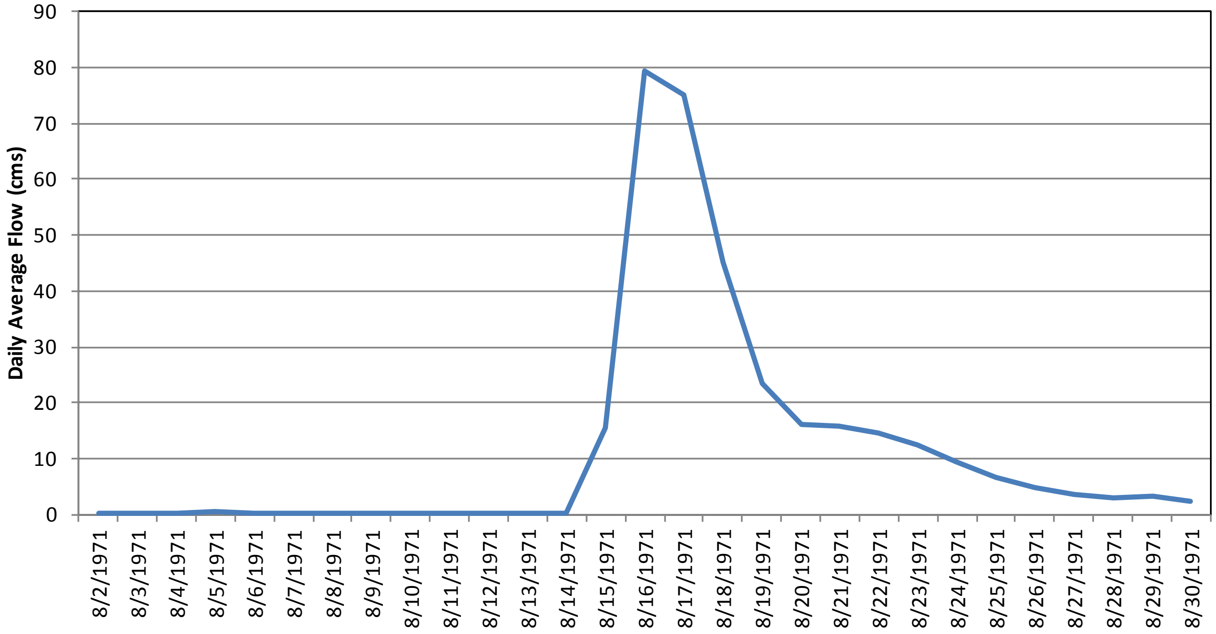

Figure 1.3 Daily Average Flow Hydrograph for the 3rd Largest Instantaneous Annual Maximum Flow Event: August 16, 1971 (Sackville River at Bedford)

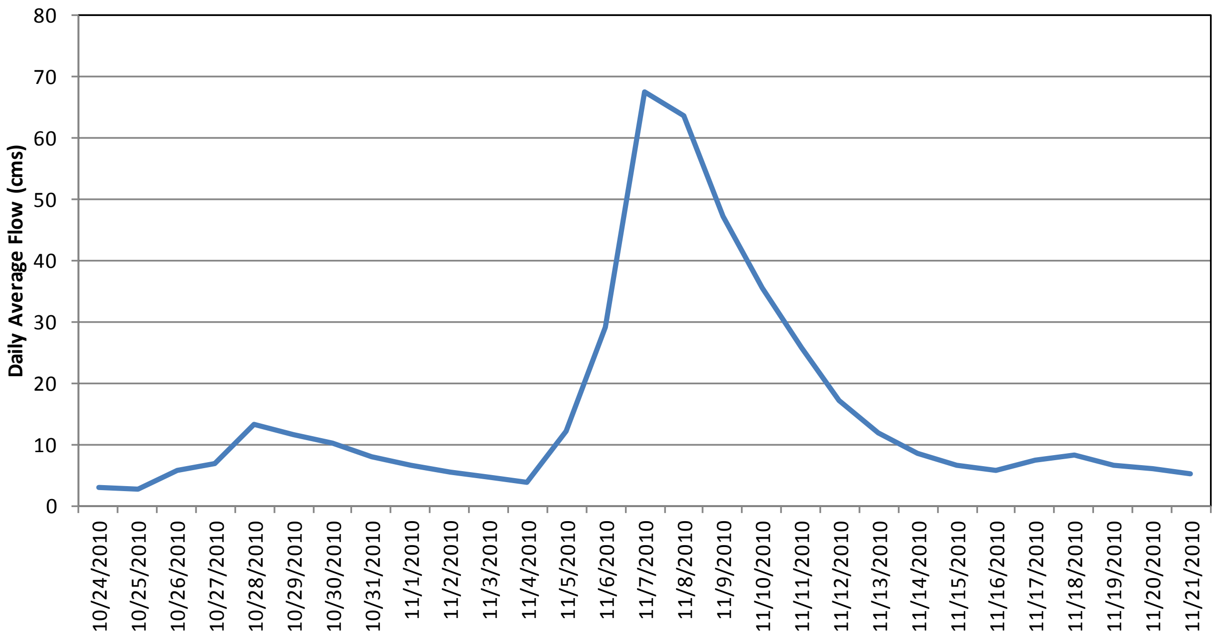

Figure 1.4 Daily Average Flow Hydrograph for the 4th Largest Instantaneous Annual Maximum Flow Event: November 7, 2010 (Sackville River at Bedford)

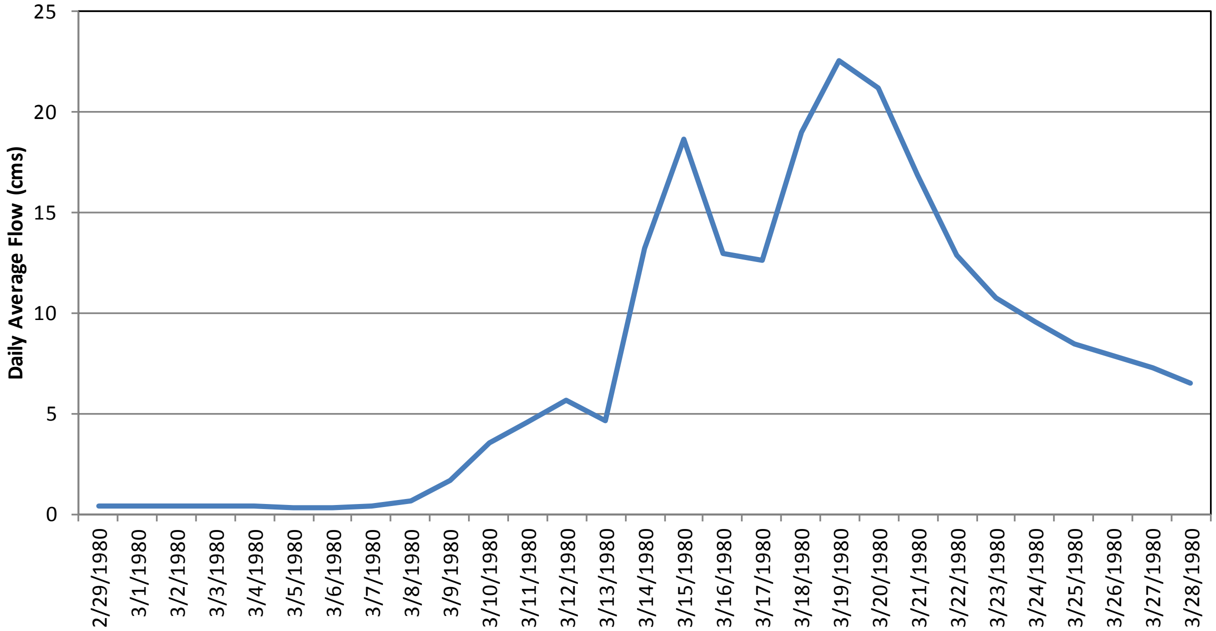

Figure 1.5 Daily Average Flow Hydrograph for the 5th Largest Instantaneous Annual Maximum Flow Event: March 14, 1980 (Sackville River at Bedford)

2. Analysis of Flooding Factors for Little Sackville River at Middle Sackville

Table 2.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Little Sackville River at Middle Sackville

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
07/21/1981 17:43	22.0	Halifax Stanfield 07/17: 0.0/0.0 07/18: 0.0/0.0 07/19: 0.0/0.0 07/20: 0.0/0.0 07/21: 71.1	Halifax Stanfield 07/21: 28.5	Halifax Stanfield 71.1	None	Dry	N/A	None	July High	Single peak (rapid rise)	Rainfall
12/20/2000 10:00	21.6	Halifax Stanfield 12/16:0.0 12/17: 9.9 12/18: 5.6 12/19: 0.0 12/20: 80.2	Shearwater A 12/20: 12.8	Halifax Stanfield 96.0	Small amount of snow	Wet	N/A	None	December Low	Same date Single peak (previous small peaks, rapid rise)	Rainfall, wet conditionbs
10/28/1993 02:41	20.5	Halifax Stanfield 10/24: 0.0 10/25: 0.0 10/26: 0.0 10/27: 47.2 10/28: 15.6	Shearwater A 10/28: 6.5	Halifax Stanfield 62.8	None	Dry	N/A	None	October High	Same date Single peak (rapid rise, previous peaks)	Rainfall
02/17/1996 11:00	20.1	Halifax Stanfield 02/13: 0.0 02/14: 0.0 02/15: 0.0 02/16: 12.0 02/17: 84.9	Shearwater A 02/17: 10.6	Halifax Stanfield 117.8	Rain on snow, melting	Wet/frozen	N/A	Ice just melted	February Low	Same date Single peak (rapid rise)	Rainfall, snowmelt, ice, frozen conditions

Table 2.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Little Sackville River at Middle Sackville

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
10/20/2011 14:01	18.4	Halifax Stanfield 10/16: 0.0 10/17: 9.5 10/18: 0.0 10/19: 6.6 10/20: 104.4	Halifax Stanfield 10/20: 15.0	Halifax Stanfield 120.5	None	Wet	N/A	None	October High	Day before Single peak (rapid rise) Max height: 2.813 (WSC datum)	Rainfall, wet conditions
11/11/1991 15:34	18.0	Halifax Stanfield 11/07: 3.9 11/08: 1.6 11/09: 0.0 11/10: 27.0 11/11: 61.4	Shearwater A 11/11: 9.3	Halifax Stanfield 93.9	None	Wet	N/A	None	November High	Day before Single peak (rapid rise)	Rainfall, wet conditions
10/20/1988 04:35	17.0	Halifax Stanfield 10/16: 0.0 10/17: 0.0 10/18: 0.0 10/19: 57.5 10/20: 22.4	Shearwater A 10/19: 15.3	Halifax Stanfield 79.9	None	Dry	N/A	None	October High	Single peak (rapid rise)	Rainfall
08/30/2009 03:22	16.8	Halifax Stanfield 07/26: 0.0 08/27: 0.0 08/28: 0.0 08/29: 79.3 08/30: 17.5	Shearwater RCS 08/30: 13.9	Halifax Stanfield 96.8	None	Dry	N/A	None	August High	Single peak (rapid rise)	Rainfall

Table 2.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Little Sackville River at Middle Sackville

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
09/23/2012 04:21	16.7	Shearwater RCS 09/19: 18.8 09/20: 40.2 09/21: 36.0 09/22: 15.4 09/23: 12.6	Shearwater RCS 09/22: 14.0	Shearwater RCS 123.0	None	Wet	N/A	None	September High	Same date Single peak (gradual rise) Max height: 2.767 (WSC datum)	Rainfall, wet conditions
11/17/1983 03:59	16.4	Halifax Stanfield 11/13: 0.0 11/14: 0.0 11/15: 0.0 11/16: 50.1 11/17: 16.6	Shearwater A 11/17: 10.2	Halifax Stanfield 66.7	None	Wet	N/A	None	November High	Same date Single peak (rapid rise)	Rainfall, wet conditions
11/25/2004 19:47	16.1	Halifax Stanfield 11/21: 0.0 11/22: 0.8 11/23: 0.0 11/24: 0.0 11/25: 87.8	Shearwater Auto 11/25: 14.4	Halifax Stanfield 88.6	Rain on snow, melting	Wet/frozen	N/A	None	November High	Day before Single peak (snowmelt then rapid rise)	Rainfall, snowmelt, wet conditions
08/04/2008 19:07	15.9	Halifax Stanfield 07/31: 0.0 08/01: 0.0 08/02: 36.9 08/03: 24.1 08/04: 83.2	Shearwater RCS 08/03: 8.9	Halifax Stanfield 144.2	None	Dry	N/A	None	August High	Single peak (gradual rise)	Rainfall

Table 2.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Little Sackville River at Middle Sackville

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
02/11/2002 11:07	15.8	Halifax Stanfield 02/07:0.0 02/08: 0.0 02/09: 0.0 02/10: 0.4 02/11: 21.7	No data	Halifax Stanfield 31.6	Rain/snow mix, melting	Wet/frozen	N/A	Ice just melted	February Low	Single peak (rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions
03/15/1984 01:42	15.3	Halifax Stanfield 03/11: 0.0 03/12: 0.0 03/13: 0.0 03/14: 27.4 03/15: 52.0	Halifax Stanfield 03/14: 5.5	Halifax Stanfield 86.1	Rain on snow, melting	Wet/frozen	N/A	Ice just melted	March Low	Day before Single peak (rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions
11/22/2005 22:37	15.2	Halifax Stanfield 11/18: 0.0 11/19: 0.0 11/20: 0.0 11/21: 0.0 11/22: 38.9	Shearwater Auto 11/22: 2.5	Halifax Stanfield 38.9	None	Dry	N/A	None	November High	Single peak (previous peaks, rapid rise)	Rainfall
03/13/1985 04:58	15.0	Halifax Stanfield 03/09: 0.0 03/10: 0.0 03/11: 0.0 03/12: 30.6 03/13: 35.2	Halifax Stanfield 03/13: 11.2	Halifax Stanfield 66.0	Rain on snow, melting	Wet/frozen	N/A	Ice just melted	March Low	Same date Single peak (snowmelt, rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions

Table 2.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Little Sackville River at Middle Sackville

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
12/25/2003 13:32	14.2	Halifax Stanfield 12/21: 0.0 12/22: 0.0 12/23: 0.0 12/24: 0.0 12/25: 70.6	Shearwater A 12/25: 13.8	Halifax Stanfield 70.6	None	Dry	N/A	None	December Low	Single peak (rapid rise)	Rainfall
01/20/1986 12:30	14.1	Halifax Stanfield 01/16: 0.0 01/17: 0.0 01/18: 0.0 01/19: 3.2 01/20: 45.2	Halifax Stanfield 01/20: 7.6	Halifax Stanfield 48.4	Rain on snow, melting	Wet/frozen	N/A	Ice conditions, melting	January Low	Same date Single peak (snowmelt, rapid rise)	Rainfall, snowmelt, ice, frozen conditions
12/09/1990 04:34	14.1	Halifax Stanfield 12/05: 12.8 12/06: 0.0 12/07: 0.0 12/08: 22.4 12/09: 18.8	Shearwater A 12/09: 13.4	Halifax Stanfield 54.0	None	Wet	N/A	None	December Low	Same date Single peak (previous peak, rapid rise)	Rainfall, wet conditions
03/16/1999 00:00	14.1	Halifax Stanfield 03/12: 0.2 03/13: 0.0 03/14: 0.0 03/15: 38.9 03/16: 2.0	Shearwater A 03/16: 12.1	Halifax Stanfield 55.1	Rain/snow mix, melting	Wet/frozen	N/A	None	March Low	Same date Single peak (previous peaks, snowmelt, rapid rise)	Rainfall, snowmelt, wet conditions

Table 2.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Little Sackville River at Middle Sackville

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
05/15/2001 02:32	14.1	Halifax Stanfield 05/11: 0.9 05/12: 0.0 05/13: 0.0 05/14: 78.8 05/15: 25.8	Shearwater A 05/14: 13.8	Halifax Stanfield 105.5	None	Wet	N/A	None	May Medium	Day before Single peak (previous peak, rapid rise)	Rainfall, wet conditions
01/06/1992 02:57	13.4	Halifax Stanfield 01/02: 0.0 01/03: 0.0 01/04: 0.0 01/05: 52.8 01/06: 10.6	Shearwater A 01/05: 7.9	Halifax Stanfield 63.9	Rain on snow, melting	Wet/frozen	N/A	Ice conditions	January Low	Day after Single peak (gradual rise, snowmelt)	Rainfall, snowmelt, ice, frozen conditions
12/01/1987 05:42	13.0	Halifax Stanfield 11/27: 0.0 11/28: 0.0 11/29: 0.0 11/30: 7.8 12/01: 47.0	Halifax Stanfield 12/01: 11.0	Halifax Stanfield 59.0	Rain on snow, melting	Wet/frozen	N/A	Ice just melted	December Low	Same date Single peak (rapid rise)	Rainfall snowmelt, ice melt, frozen conditions
07/21/1982 03:49	12.7	Halifax Stanfield 07/17: 0.0 07/18: 0.0 07/19: 0.2 07/20: 17.8 07/21: 63.8	Shearwater A 07/21: 30.4	Halifax Stanfield 81.8	None	Dry	N/A	None	July High	Single peak (rapid rise)	Rainfall

Table 2.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Little Sackville River at Middle Sackville

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
02/05/2006 19:47	12.2	Halifax Stanfield 02/01: 0.0 02/02: 0.0 02/03: 5.7 02/04: 0.0 02/05: 37.8	Shearwater Auto 02/05: 9.7	Halifax Stanfield 63.9	Rain on snow, melting	Wet/frozen	N/A	Ice just melted	February Low	Same date Single peak (snowmelt, then rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions
11/07/2010 13:01	12.2	Halifax Stanfield 11/03: 0.0 11/04: 7.6 11/05: 53.5 11/06: 41.7 11/07: 36.6	Halifax Stanfield 11/07: 6.2	Halifax Stanfield 139.4	None	Dry	N/A	None	November High	Same date Single peak (gradual rise)	Rainfall
03/16/1994 04:57	11.6	Halifax Stanfield 03/12: 0.0 03/13: 0.0 03/14: 20.2 03/15: 16.9 03/16: 24.4	No data	Halifax Stanfield 74.9	Rain on snow, melting	Wet/frozen	N/A	Ice just melted	March Low	Day before Single peak (snowmelt, gradual rise, previous peaks)	Rainfall, snowmelt, ice melt, frozen conditions
12/10/1995 10:17	11.6	Halifax Stanfield 12/06: 6.4 12/07: 0.0 12/08: 0.0 12/09: 0.0 12/10: 47.1	Shearwater A 12/10: 10.5	Halifax Stanfield 63.7	Rain on snow, little melting	Wet/frozen	N/A	None	December Low	Same date Single peak (some snowmelt, rapid rise)	Rainfall, snowmelt, wet conditions

Table 2.1 Analysis of Flooding Factors for Instantaneous Annual Maximum Flows for Little Sackville River at Middle Sackville

Date and Time	Peak Flow (cms)	5-day Rainfall (mm)	Maximum Hourly Intensity (mm/hr)	5-day Precip Total (mm)	Snow	Antecedent Conditions	Sea Level/Tide (m) Chart Datum	River Ice	Vegetation	Other	Flooding Factors
01/19/2007 22:27	11.5	Halifax Stanfield 01/15: 0.8 01/16: 0.5 01/17: 0.0 01/18: 0.0 01/19: 47.2	Halifax Stanfield 01/19: 12.4	Halifax Stanfield 67.0	Rain on snow, melting	Wet/frozen	N/A	Ice conditions, melting	January Low	Same date Single peak (snowmelt, rapid rise)	Rainfall, snowmelt, ice melt, frozen conditions
10/11/1989 21:35	10.4	Halifax Stanfield 10/07: 3.2 10/08: 0.0 10/09: 3.0 10/10: 0.0 10/11: 49.6	Shearwater A 10/11: 14.3	Halifax Stanfield 55.8	None	Dry	N/A	None	October High	Same date Single peak (gradual rise)	Rainfall
09/27/1998 18:00	8.7	Halifax Stanfield 09/23: 15.5 09/24: 0.0 09/25: 0.0 09/26: 0.0 09/27: 26.6	Shearwater A 09/27: 12.9	Halifax Stanfield 42.1	None	Dry	N/A	None	September High	Single peak (rapid rise)	Rainfall
03/26/1997 04:57	7.4	Halifax Stanfield 03/22: 0.0 03/23: 0.0 03/24: 0.0 03/25: 0.0 03/26: 27.8	No data	Halifax Stanfield 46.0	Rain/snow mix, melting	Wet/frozen	N/A	Ice just melted	March Low	First of two peaks (rapid rise, snowmelt)	Rainfall, snowmelt, ice melt, frozen conditions

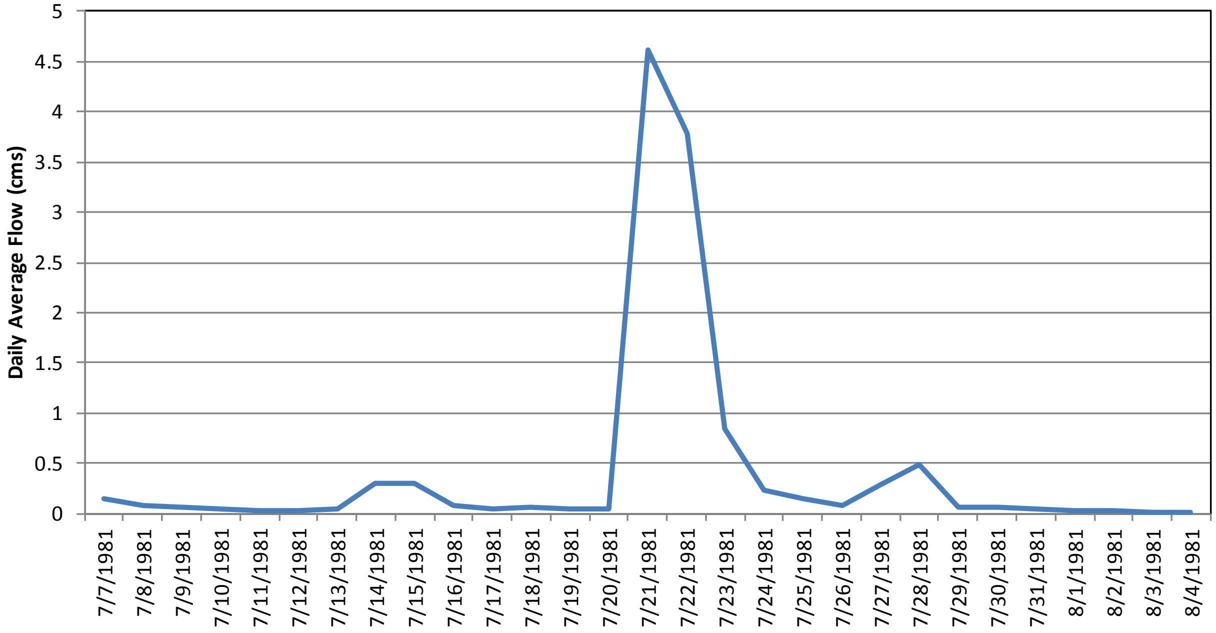

Figure 2.1 Daily Average Flow Hydrograph for the Largest Instantaneous Annual Maximum Flow Event: July 21, 1981 (Little Sackville River at Middle Sackville)

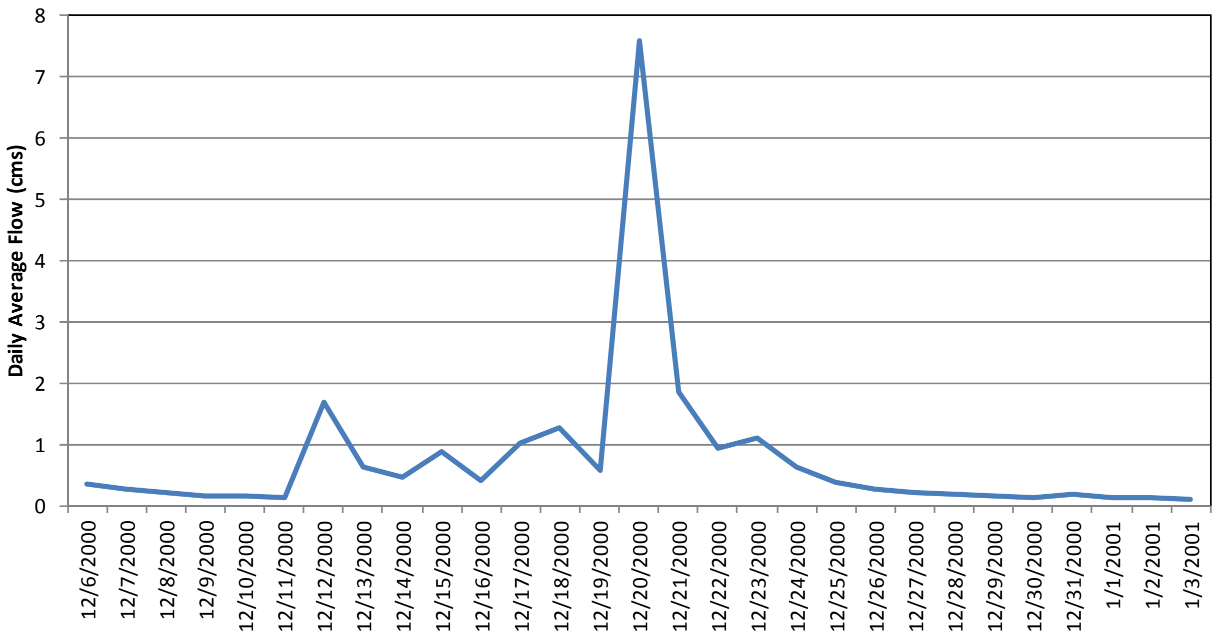

Figure 2.2 Daily Average Flow Hydrograph for the 2nd Largest Instantaneous Annual Maximum Flow Event: December 20, 2000 (Little Sackville River at Middle Sackville)

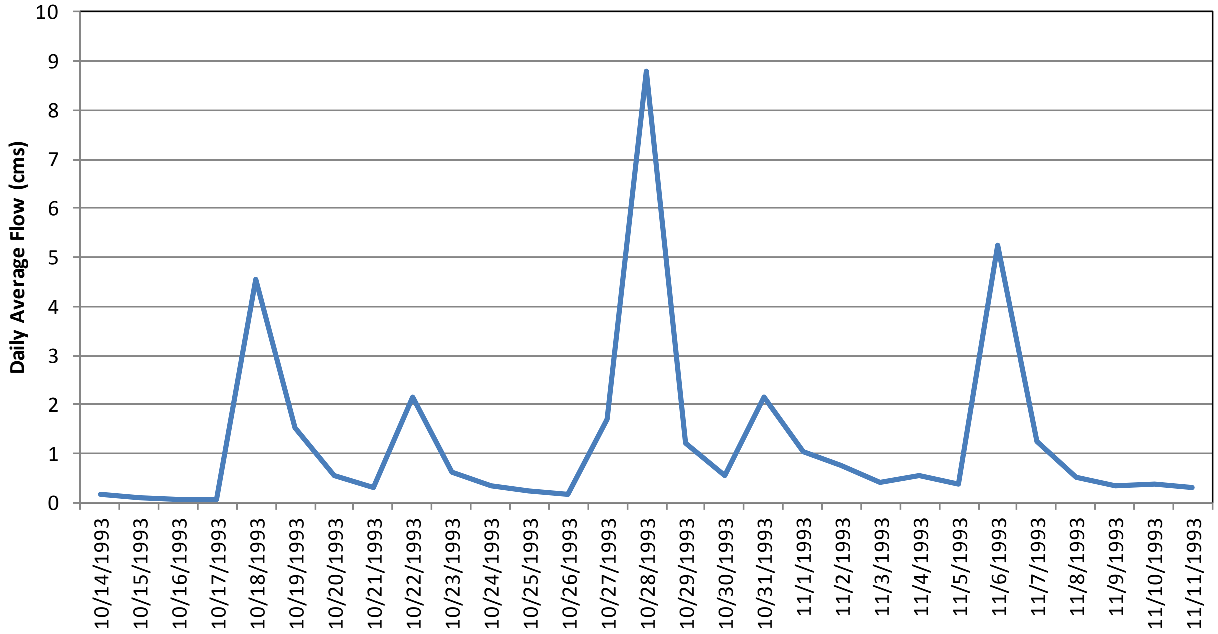

Figure 2.3 Daily Average Flow Hydrograph for the 3rd Largest Instantaneous Annual Maximum Flow Event: October 28, 1993 (Little Sackville River at Middle Sackville)

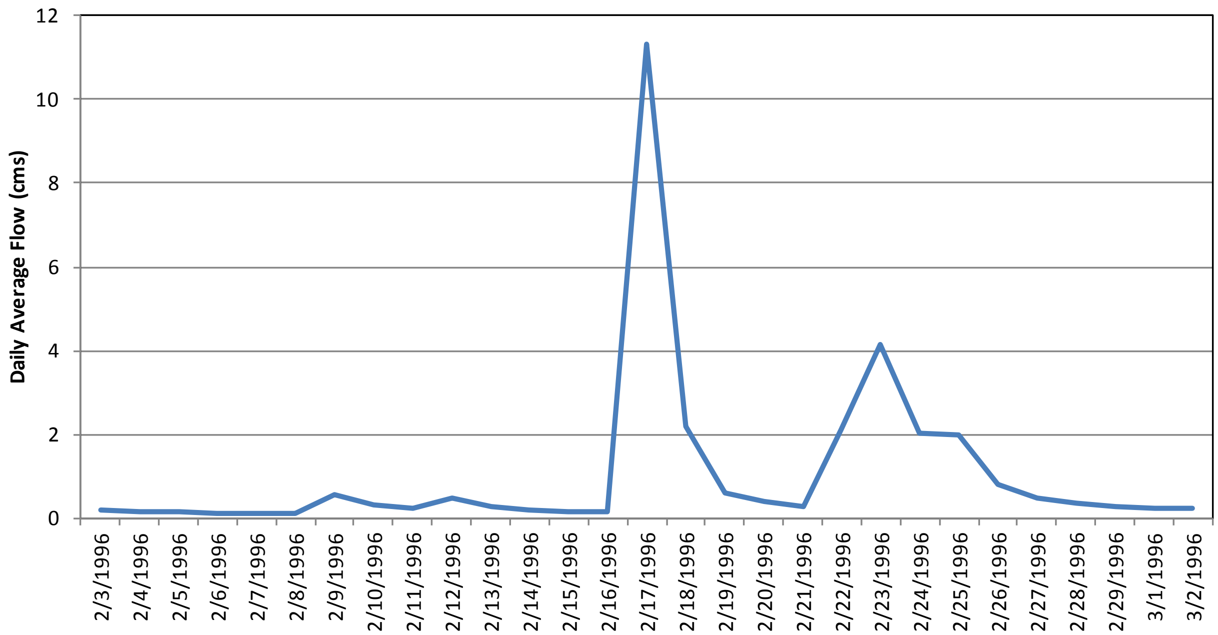

Figure 2.4 Daily Average Flow Hydrograph for the 4th Largest Instantaneous Annual Maximum Flow Event: February 17, 1996 (Little Sackville River at Middle Sackville)

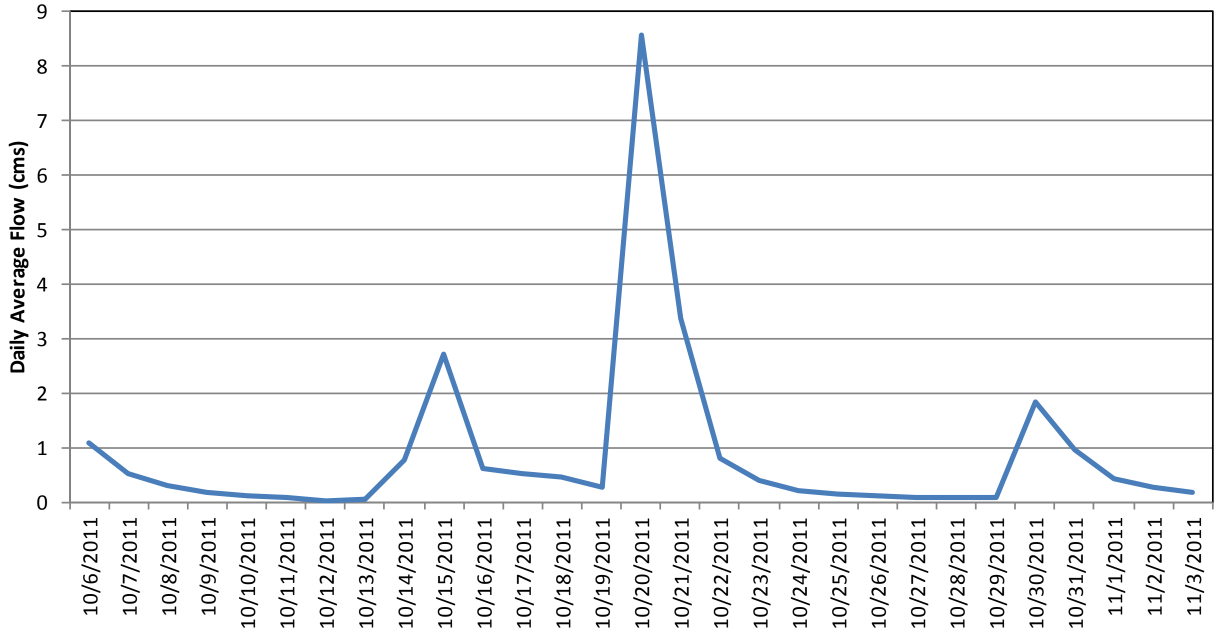

Figure 2.5 Daily Average Flow Hydrograph for the 5th Largest Instantaneous Annual Maximum Flow Event: October 20, 2011 (Little Sackville River at Middle Sackville)

Appendix F
Hourly Precipitation for Ten Largest Precipitation Events

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1. Hourly Precipitation for Ten Largest Precipitation Events

Table 1.1 Hourly Precipitation for Ten Largest Precipitation Events (Storms 1 to 5)

Storm 1 Halifax 8202200		Storm 2 Shearwater RCS 8205092		Storm 3 Halifax Stanfield Int'l A 8202250		Storm 4 Shearwater A 8205090		Storm 5 Halifax Stanfield Int'l A 8202250	
Date and Time	Precipitation (mm)	Date and Time	Precipitation (mm)	Date and Time	Precipitation (mm)	Date and Time	Precipitation (mm)	Date and Time	Precipitation (mm)
8/15/1971 4:00	17.0	12/10/2014 8:00	6.1	11/11/2011 3:00	0.2	8/6/1983 23:00	3.3	1/14/1978 10:00	0.5
8/15/1971 5:00	4.6	12/10/2014 9:00	2.3	11/11/2011 4:00	0.2	8/7/1983 0:00	8.9	1/14/1978 11:00	7.0
8/15/1971 6:00	18.8	12/10/2014 10:00	3.9	11/11/2011 5:00	5.6	8/7/1983 1:00	3.8	1/14/1978 12:00	5.0
8/15/1971 7:00	5.1	12/10/2014 11:00	1.1	11/11/2011 6:00	9.2	8/7/1983 2:00	6.4	1/14/1978 13:00	13.0
8/15/1971 8:00	1.5	12/10/2014 12:00	2.6	11/11/2011 7:00	12.4	8/7/1983 3:00	12.5	1/14/1978 14:00	9.6
8/15/1971 9:00	5.3	12/10/2014 13:00	5.0	11/11/2011 8:00	13.2	8/7/1983 4:00	20.1	1/14/1978 15:00	3.2
8/15/1971 10:00	5.3	12/10/2014 14:00	5.3	11/11/2011 9:00	5.8	8/7/1983 5:00	19.5	1/14/1978 16:00	5.5
8/15/1971 11:00	2.8	12/10/2014 15:00	1.1	11/11/2011 10:00	4.8	8/7/1983 6:00	27.1	1/14/1978 17:00	5.0
8/15/1971 12:00	6.4	12/10/2014 16:00	12.9	11/11/2011 11:00	2.2	8/7/1983 7:00	9.1	1/14/1978 18:00	4.3
8/15/1971 13:00	11.9	12/10/2014 17:00	1.5	11/11/2011 12:00	9.2	8/7/1983 8:00	2.3	1/14/1978 19:00	4.0
8/15/1971 14:00	16.0	12/10/2014 18:00	19.9	11/11/2011 13:00	14.8	8/7/1983 9:00	0.0	1/14/1978 20:00	5.2
8/15/1971 15:00	20.8	12/10/2014 19:00	8.0	11/11/2011 14:00	17.2	8/7/1983 10:00	0.0	1/14/1978 21:00	4.3
8/15/1971 16:00	9.1	12/10/2014 20:00	5.7	11/11/2011 15:00	11.0	8/7/1983 11:00	0.0	1/14/1978 22:00	6.0
8/15/1971 17:00	0.5	12/10/2014 21:00	6.2	11/11/2011 16:00	6.8	8/7/1983 12:00	0.0	1/14/1978 23:00	7.0
8/15/1971 18:00	20.8	12/10/2014 22:00	3.3	11/11/2011 17:00	0.4	8/7/1983 13:00	0.0	1/15/1978 0:00	3.5
8/15/1971 19:00	17.5	12/10/2014 23:00	4.4	11/11/2011 18:00	0.0	8/7/1983 14:00	0.0	1/15/1978 1:00	5.5
8/15/1971 20:00	6.9	12/11/2014 0:00	5.0	11/11/2011 19:00	0.2	8/7/1983 15:00	0.0	1/15/1978 2:00	5.5
8/15/1971 21:00	0.0	12/11/2014 1:00	6.5	11/11/2011 20:00	0.0	8/7/1983 16:00	0.0	1/15/1978 3:00	0.0
8/15/1971 22:00	0.0	12/11/2014 2:00	1.7	11/11/2011 21:00	0.0	8/7/1983 17:00	0.0	1/15/1978 4:00	4.3
8/15/1971 23:00	0.0	12/11/2014 3:00	3.6	11/11/2011 22:00	0.8	8/7/1983 18:00	0.0	1/15/1978 5:00	6.4
8/16/1971 0:00	11.9	12/11/2014 4:00	3.6	11/11/2011 23:00	0.0	8/7/1983 19:00	0.0	1/15/1978 6:00	1.5
8/16/1971 1:00	4.8	12/11/2014 5:00	1.9	11/12/2011 0:00	0.0	8/7/1983 20:00	0.0	1/15/1978 7:00	0.9
8/16/1971 2:00	6.6	12/11/2014 6:00	4.1	11/12/2011 1:00	0.0	8/7/1983 21:00	0.0	1/15/1978 8:00	0.2
8/16/1971 3:00	11.9	12/11/2014 7:00	1.4	11/12/2011 2:00	0.2	8/7/1983 22:00	0.0	1/15/1978 9:00	0.0
Total	205.5	Total	117.1	Total	114.2	Total	113.0	Total	107.4

Table 1.2 Hourly Precipitation for Ten Largest Precipitation Events (Storms 6 to 10)

Storm 6 Halifax Stanfield Int'l A 8202250		Storm 7 Bedford Range 8200574		Storm 8 Shearwater A 8205090		Storm 9 Shearwater A 8205090		Storm 10 Shearwater A 8205090	
Date and Time	Precipitation (mm)	Date and Time	Precipitation (mm)	Date and Time	Precipitation (mm)	Date and Time	Precipitation (mm)	Date and Time	Precipitation (mm)
10/19/2011 23:00	1.8	9/21/2014 19:00	3.3	3/31/2003 0:00	0.5	12/8/1990 9:00	0.4	4/28/1982 1:00	0.6
10/20/2011 0:00	1.4	9/21/2014 20:00	2.3	3/31/2003 1:00	5.7	12/8/1990 10:00	0.8	4/28/1982 2:00	2.0
10/20/2011 1:00	1.0	9/21/2014 21:00	16.0	3/31/2003 2:00	1.6	12/8/1990 11:00	0.6	4/28/1982 3:00	2.5
10/20/2011 2:00	1.0	9/21/2014 22:00	0.7	3/31/2003 3:00	1.7	12/8/1990 12:00	1.2	4/28/1982 4:00	2.9
10/20/2011 3:00	1.4	9/21/2014 23:00	4.4	3/31/2003 4:00	1.9	12/8/1990 13:00	1.7	4/28/1982 5:00	3.8
10/20/2011 4:00	1.0	9/22/2014 0:00	5.3	3/31/2003 5:00	11.9	12/8/1990 14:00	2.7	4/28/1982 6:00	1.5
10/20/2011 5:00	1.2	9/22/2014 1:00	13.7	3/31/2003 6:00	6.7	12/8/1990 15:00	1.2	4/28/1982 7:00	6.7
10/20/2011 6:00	2.0	9/22/2014 2:00	7.4	3/31/2003 7:00	6.0	12/8/1990 16:00	1.6	4/28/1982 8:00	1.7
10/20/2011 7:00	1.8	9/22/2014 3:00	12.0	3/31/2003 8:00	5.6	12/8/1990 17:00	0.6	4/28/1982 9:00	4.2
10/20/2011 8:00	8.6	9/22/2014 4:00	5.4	3/31/2003 9:00	6.7	12/8/1990 18:00	1.4	4/28/1982 10:00	3.1
10/20/2011 9:00	10.2	9/22/2014 5:00	1.6	3/31/2003 10:00	2.1	12/8/1990 19:00	2.3	4/28/1982 11:00	2.5
10/20/2011 10:00	7.6	9/22/2014 6:00	18.0	3/31/2003 11:00	12.3	12/8/1990 20:00	3.5	4/28/1982 12:00	9.6
10/20/2011 11:00	12.6	9/22/2014 7:00	12.2	3/31/2003 12:00	16.0	12/8/1990 21:00	6.5	4/28/1982 13:00	2.9
10/20/2011 12:00	3.0	9/22/2014 8:00	0.0	3/31/2003 13:00	13.1	12/8/1990 22:00	6.1	4/28/1982 14:00	6.7
10/20/2011 13:00	6.8	9/22/2014 9:00	0.0	3/31/2003 14:00	6.7	12/8/1990 23:00	6.7	4/28/1982 15:00	15.7
10/20/2011 14:00	15.0	9/22/2014 10:00	0.6	3/31/2003 15:00	2.7	12/9/1990 0:00	13.4	4/28/1982 16:00	5.9
10/20/2011 15:00	2.2	9/22/2014 11:00	1.2	3/31/2003 16:00	2.5	12/9/1990 1:00	8.1	4/28/1982 17:00	3.8
10/20/2011 16:00	1.2	9/22/2014 12:00	0.0	3/31/2003 17:00	0.0	12/9/1990 2:00	11.0	4/28/1982 18:00	3.8
10/20/2011 17:00	1.2	9/22/2014 13:00	0.0	3/31/2003 18:00	0.0	12/9/1990 3:00	13.1	4/28/1982 19:00	2.7
10/20/2011 18:00	3.8	9/22/2014 14:00	0.0	3/31/2003 19:00	0.0	12/9/1990 4:00	10.5	4/28/1982 20:00	4.0
10/20/2011 19:00	2.6	9/22/2014 15:00	0.0	3/31/2003 20:00	0.0	12/9/1990 5:00	3.1	4/28/1982 21:00	3.6
10/20/2011 20:00	3.6	9/22/2014 16:00	0.0	3/31/2003 21:00	0.0	12/9/1990 6:00	2.4	4/28/1982 22:00	5.3
10/20/2011 21:00	11.8	9/22/2014 17:00	0.0	3/31/2003 22:00	0.0	12/9/1990 7:00	0.8	4/28/1982 23:00	1.7
10/20/2011 22:00	2.8	9/22/2014 18:00	0.0	3/31/2003 23:00	0.0	12/9/1990 8:00	0.3	4/29/1982 0:00	1.7
Total	105.6	Total	104.1	Total	103.7	Total	100.0	Total	98.9

Appendix G
Listing of Regional Rainfall Events

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Table Index

1. Listing of Regional Rainfall Events

Table 1.1 Large Rainfall Events for Nova Scotia (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1883-08-30	N/A	Antigonish	8200150	111.8
1886-05-09	N/A	Halifax	8202198	127.3
		Beaverbank	8200550	112.5
1891-09-08	Unnamed	Digby	8201600	121.9
1892-08-21	N/A	Sable Island	8204700	155.7
1892-08-22	N/A	Sable Island East End	8204702	112.3
1892-08-28	N/A	Sable Island	8204700	121.9
		Sable Island East End	8204702	103.1
1896-10-19	N/A	Halifax	8202198	111.5
1919-06-12	N/A	Sable Island	8204700	140.7
1919-11-28	N/A	Whitehead	8206300	133.4
1920-03-14	N/A	Digby	8201600	104.6
1922-07-06	N/A	Liverpool	8203001	113
1922-10-11	N/A	South Alton	8205170	123.4
		Whitehead	8206300	104.4
1923-10-02	Unnamed	Antigonish	8200150	125.7
1924-08-13	N/A	Stillwater	8205600	101.6
1924-08-26	Unnamed	Digby	8201600	102.1
1927-08-24	Unnamed	Digby	8201600	119.9
		Yarmouth	8206490	114.3
		Springfield	8205200	106.7
1927-08-25	Unnamed	Saulnierville	8205070	119.9
1929-09-18	N/A	St Margaret's Bay	8204800	104.1
1929-09-19	N/A	Trafalgar	8205900	148.6
1932-09-11	N/A	Whitehead	8206300	134.9
1934-11-06	N/A	Mahone Bay	8203300	122.4
1935-08-24	Unnamed	Whitehead	8206300	102.6
1936-09-19	N/A	Mahone Bay	8203300	147.8
		Liverpool	8203001	130
		Digby	8201600	111.3
1936-09-20	N/A	Whitehead	8206300	108
1940-06-20	N/A	Collegeville	8201000	101.6
1940-09-16	Unnamed	Digby	8201600	113
		Collegeville	8201000	104.1
		Liverpool Big Falls	8203100	103.6
		Yarmouth A	8206500	103.4
1942-07-03	N/A	Meteghan River	8203500	120.7
		Liverpool	8203000	117.1
1942-09-21	Unnamed	Halifax	8202200	238.8
		Liverpool	8203000	203.2
		Mount Uniacke	8203600	184.2
		Stellarton	8205400	167.4
		Mahone Bay	8203300	128.5
1942-09-22	Unnamed	Parrsboro	8204400	193
		Nappan CDA	8203700	153.7
		Kentville CDA	8202800	144.5
		St Margaret's Bay	8204800	132.1
		Wolfville	8206440	132.1
		Windsor Kings College	8206410	124
		Truro Nsac	8206000	116.8
		Noel	8204100	107.2

Table 1.1 Large Rainfall Events for Nova Scotia (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1942-09-23	Unnamed	Upper Stewiacke	8206200	248.9
		Stellarton	8205400	144.3
1943-05-04	N/A	Stillwater	8205600	100.8
1943-07-08	N/A	Lake Rossignol	8202900	129
		Liverpool Big Falls	8203100	106.9
1943-08-04	N/A	Annapolis Royal	8200100	116.8
		Kentville CDA	8202800	110.2
		Middleton	8203550	103.6
1945-06-27	Unnamed	Mahone Bay	8203300	101.3
1946-09-15	Unnamed	New Glasgow Trenton	8203905	110.5
		Chain Lake	8200800	100.8
1947-05-01	N/A	St Margaret's Bay	8204800	113.5
1947-05-03	N/A	Whitehead	8206300	118.9
1948-01-14	N/A	Whitehead	8206300	106.2
1948-08-13	N/A	Liverpool	8203000	129.8
		Noel	8204100	126.5
		Chain Lake	8200800	100.3
1949-08-18	N/A	Mahone Bay	8203300	102.6
1949-08-19	N/A	Spruce Hill Lake	8205300	121.7
		Salmon Hole	8205000	116.1
		Chain Lake	8200800	115.1
		St Margaret's Bay	8204800	112
1949-09-10	Unnamed	Whitehead	8206300	104.1
1950-08-20	Able	Greenwood A	8202000	113.3
		Digby	8201600	109.2
1950-08-21	Able	Parrsboro	8204400	144.8
		Avon	8200200	115.6
1950-08-22	Able	Five Mile Lake	8201800	100.1
1950-10-04	George	Sable Island	8204700	166.1
1950-11-27	N/A	Yarmouth A	8206500	111.3
1950-11-29	N/A	Ingonish Beach	8202500	105.2
1952-05-27	N/A	Ingonish Beach	8202500	107.7
1952-08-17	N/A	Yarmouth A	8206500	101.1
1952-08-18	N/A	Kemptville	8202700	110.7
		Tusket	8206100	106.7
1953-02-08	N/A	Digby	8201600	123.2
		Bear River	8200500	111.5
1954-01-04	N/A	Barrie Brook	8200400	114.8
1954-06-23	N/A	Bear River	8200500	109.7
		Annapolis Royal	8200100	109.2
		Digby	8201600	103.6
1954-07-20	N/A	Shearwater A	8205090	131.6
1954-07-21	N/A	Spruce Hill Lake	8205300	115.6
1955-09-22	Ione	Pleasant Bay Grand Anse	8204450	105.4
1956-01-05	N/A	Parrsboro	8204400	124.5
		Windsor	8206400	123.4
		Avon	8200200	116.8
		Five Mile Lake	8201800	116.8
		Noel Shore Exp St	8204125	111.8
		Mount Uniacke	8203600	100.3
		Noel	8204100	100.3
1956-01-06	N/A	Copper Lake	8201100	108.7
1956-01-09	N/A	St Margaret's Bay	8204800	113
1956-08-08	N/A	Liverpool	8203000	108.7

Table 1.1 Large Rainfall Events for Nova Scotia (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1958-01-16	N/A	Spruce Hill Lake	8205300	140.5
		Mahone Bay	8203300	122.7
		Timberlea	8205800	111.8
		Mount Uniacke	8203600	106.7
1958-02-08	N/A	Chain Lake	8200800	117.9
1958-08-25	Betsy	Digby	8201600	121.9
1959-06-19	Escuminac Hurricane	New Germany	8203800	108
1959-10-01	N/A	Yarmouth A	8206500	172.5
		Tusket	8206100	154.7
		Yarmouth CDA EPF	8206600	118.1
		Liverpool Big Falls	8203100	105.2
1959-10-25	N/A	Parrsboro	8204400	152.7
		Bear River	8200500	117.1
		Liverpool Big Falls	8203100	115.8
		New Grafton	8204000	106.9
		Five Mile Lake	8201800	106.7
1959-10-26	N/A	Salmon Hole	8205000	134.4
1959-11-16	N/A	Digby	8201600	106.7
		Deming	8201410	103.4
1961-10-20	Gerda	Baccaro	8200250	125.2
		Western Head	8206240	122.2
		Spruce Hill Lake	8205300	111.8
1962-04-01	N/A	Nappan CDA	8203700	106.7
1962-08-08	N/A	Annapolis Royal	8200100	115.6
1962-09-29	N/A	Western Head	8206240	108.7
1962-10-10	Daisy	Liscomb Game Sanctuary	8202975	108
1963-08-24	N/A	Ingonish Beach	8202500	117.3
		Dickie Brook	8201500	105.2
		Baddeck	8200300	100.6
1963-08-25	N/A	Loch Lomond	8203150	132.8
1964-07-22	N/A	St Margaret's Bay	8204800	118.1
		Lower Sackville	8203170	113.3
1964-09-14	Dora	Ruth Falls	8204620	104.6
1967-05-27	N/A	Indian Brook	8202465	104.4
1967-05-28	N/A	Birchtown	8200581	133.4
1967-07-17	N/A	Tusket	8206100	101.9
1967-10-10	N/A	Rawdon	8204550	119.9
		Tusket	8206100	111.5
		Yarmouth A	8206500	100.6
		Avon	8200200	100.3
1967-12-04	N/A	Kejimkujik Park	8202590	126
		Yarmouth A	8206500	110.7
		Bridgewater	8200600	107.4
		Spruce Hill Lake	8205300	106.7
		Weymouth Falls	8206275	100.8
1968-06-13	N/A	Meteghan River	8203500	156.7
		Weymouth Falls	8206275	149.9
		Clementsvale	8200875	107.4
		Digby Prim Point	8201605	106.9
1968-08-29	N/A	Liscomb Game Sanctuary	8202975	119.4

Table 1.1 Large Rainfall Events for Nova Scotia (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1968-08-30	N/A	Port Hood	8204500	142.2
		Collegeville	8201000	136.4
		Copper Lake	8201100	136.4
		Port Hastings	8204480	127.8
		River Denys	8204565	126.5
		Ecum Secum	8201700	124.2
1969-11-09	N/A	Dickie Brook	8201500	113
		Birchtown	8200581	103.1
1969-11-11	N/A	Indian Brook	8202465	103.6
1970-08-11	N/A	Roseway	8204600	127
		Harmony	8202300	119.4
		Kejimkujik Park	8202590	110.5
		Baccaro	8200250	109.2
		Liverpool Milton	8203120	103.4
1970-08-12	N/A	Cape Sable	8200700	154.2
		Ingonish Beach	8202500	143.8
1971-08-15	Beth	Lower Meaghers Grant	8203165	247.7
		Halifax Stanfield Int'l A	8202250	218.2
		Westphal	8206250	217.9
		Chain Lake	8200800	211.8
		Collegeville	8201000	203.2
		Hopewell	8202415	193.8
		Spruce Hill Lake	8205300	189.2
		Halifax	8202200	185.2
		Shearwater A	8205090	184.9
		River Denys	8204565	178.6
		Bridgewater	8200600	177.5
		Lower Sackville	8203170	177
		Middle Musquodoboit	8203535	172.7
		Western Head	8206240	172.7
		Roseway	8204600	170.7
		Stellarton Lourdes	8205401	165.6
		Copper Lake	8201100	164.3
		Liverpool Milton	8203120	162.1
		Avon	8200200	157.2
		Mount Uniacke	8203600	151.4
		Port Hood	8204500	139.7
		Salmon Hole	8205000	139.2
		Ingonish Beach	8202500	134.1
		Upper Stewiacke	8206200	132.6
		April Brook IHD	8200155	130.6
		Windsor Falmouth	8206405	128.8
		Baccaro	8200250	125.7
		Ruth Falls	8204620	124.5
		St Margaret's Bay	8204800	124.5
		Five Mile Lake	8201800	123.4
		Halifax Citadel	8202220	118.1
		Kentville CDA	8202800	117.6
		Margaree Forks	8203422	114.8
		Port Hastings	8204480	113.8
		Stillwater Sherbrooke	8205601	112
		Clifton	8200900	111.8
		Rawdon	8204550	111.8
		Indian Brook	8202465	106.7
		Pictou Lyons Brook	8204423	104.9
		Truro	8205990	100.8

Table 1.1 Large Rainfall Events for Nova Scotia (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1971-08-16	Beth	Upper Musquodoboit	8206180	212.1
		Tatamagouche	8205775	130.8
		Garland	8201925	101.6
1971-09-15	Heidi	Loch Lomond	8203150	104.9
1972-03-23	N/A	Chain Lake	8200800	124.5
1972-05-16	N/A	Stillwater Sherbrooke	8205601	105.9
1972-10-07	N/A	Springfield	8205200	124.5
		Liverpool Milton	8203120	117.3
		Liverpool Big Falls	8203100	103.4
1972-11-09	N/A	Spruce Hill Lake	8205300	104.1
1973-06-17	N/A	Pleasant Bay Grand Anse	8204450	123.7
		Cheticamp	8200825	110
1975-11-13	N/A	Bear River	8200500	111.3
		Clementsvale	8200875	108.2
		Kemptville	8202700	107.2
1975-12-10	N/A	Bridgewater	8200600	135.1
		Liverpool Milton	8203120	134.9
		Stillwater Sherbrooke	8205601	114.3
		Mill Village	8203570	113.5
1976-07-10	N/A	Clementsvale	8200875	107.7
1976-07-12	N/A	Kejimkujik Park	8202590	157.5
		Paradise	8204300	150.6
		Clarence	8200860	122.7
		Greenwood A	8202000	106.7
		Annapolis Royal	8200100	103.6
1976-11-18	N/A	Deming	8201410	115.6
1976-11-19	N/A	Loch Lomond	8203151	100.3
1977-07-13	N/A	Annapolis Royal	8200100	119.4
		Weymouth Falls	8206275	108
1977-08-17	N/A	Baddeck	8200300	115.8
		Parrsboro	8204400	106.7
1977-09-14	N/A	Wreck Cove Brook	8206450	122.2
		Ingonish Beach	8202500	107.2
1978-01-14	N/A	Mount Uniacke	8203600	139.7
		Avon	8200200	120.4
		Salmon Hole	8205000	115.8
		Springfield	8205200	114.3
		Port Hastings	8204480	108
		Digby Prim Point	8201605	106.2
		Bridgewater	8200600	101.6
		Five Mile Lake	8201800	101.6
1978-10-15	N/A	Collegeville	8201000	115.1
		Stillwater	8205600	109.6
1981-05-23	N/A	Ingonish Beach	8202500	105.2
		Louisbourg	8203161	105
1982-04-28	N/A	Lower L'Ardoise	8203164	104.4
		Deming	8201410	103
1983-07-22	N/A	Springhill	8205217	107.4
		Nappan CDA	8203700	104
		Pugwash	8204525	101.6
1983-08-06	N/A	Sandy Cove NRC	8205062	102
		Lower Meaghers Grant	8203165	101.6
1983-08-31	N/A	Harmony	8202300	105.6
1983-11-06	N/A	Wreck Cove Brook	8206450	114.6
1983-11-16	N/A	Liverpool Milton	8203120	106

Table 1.1 Large Rainfall Events for Nova Scotia (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1984-04-16	N/A	Liverpool Milton	8203120	108.6
		Mill Village	8203570	107.9
1986-04-09	N/A	Ingonish Beach	8202500	140.4
		Wreck Cove Brook	8206450	106.6
1986-08-19	Charley	Sable Island	8204700	116
		Lower L'Ardoise	8203164	102
1988-11-02	N/A	Ingonish Beach	8202500	140.4
		Wreck Cove Brook	8206450	114.4
1990-08-01	Bertha	Stillwater Sherbrooke	8205601	134.8
		Big Intervale	8200579	125.4
		Port Hawkesbury A	8204491	117
		Ingonish Beach	8202500	102.8
1990-12-08	N/A	Collegeville	8201000	100.2
1991-04-21	N/A	Liverpool Milton	8203120	128
		Mill Village	8203570	104.6
		Bridgewater	8200600	103.8
1991-11-11	N/A	Liverpool Milton	8203120	113.1
1992-03-08	N/A	Dickie Brook	8201500	112.2
1992-10-19	N/A	Point Aconi	8204456	112.6
1993-10-27	N/A	Liverpool Milton	8203120	104
		Deming	8201410	100.2
1994-09-29	N/A	Ingonish Beach	8202500	106.8
		Wreck Cove Brook	8206450	102.8
1995-07-18	Chantal	Sandy Cove NRC	8205062	110
1996-09-02	Edouard	Dayton	8201336	143.8
		Tusket	8206100	139
		Pockwock Lake	8204453	133.2
		Farmington	8201766	129.1
		Yarmouth A	8206500	127.4
		Westphal	8206250	120
		Mount Uniacke	8203600	118
		Bridgewater	8200600	115
		Liverpool Big Falls	8203100	107
1996-09-14	Hortense	Stillwater Sherbrooke	8205601	142.6
		Sandy Cove NRC	8205062	116.6
		Westphal	8206250	109.2
1996-09-15	Hortense	Malay Falls	8203400	153.5
		Port Hawkesbury A	8204491	141
		Wreck Cove Brook	8206450	133.6
1996-09-18	N/A	Deming	8201410	103.6
1998-01-24	N/A	Jackson	8202565	102.8
		Mount Uniacke	8203600	100.8
1998-01-25	N/A	Wreck Cove Brook	8206450	117
		Malay Falls	8203400	114
1998-06-17	N/A	Louisbourg	8203161	100.5
1998-09-05	Earl	Wreck Cove Brook	8206450	116
1998-10-11	N/A	Weymouth Falls	8206275	111.8
1999-08-15	N/A	Salmon Hole	8205000	148
1999-09-22	Gert	Annapolis Royal	8200100	145
		Liverpool Milton	8203120	136
		Bear River	8200500	115
		Weymouth Falls	8206275	104.4
1999-09-23	Gert	Salmon Hole	8205000	195.2
2000-10-09	Leslie	Wreck Cove Brook	8206450	113
2000-10-28	Unnamed	Wreck Cove Brook	8206450	145
		Louisbourg	8203161	112.8

Table 1.1 Large Rainfall Events for Nova Scotia (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
2000-10-29	Unnamed	Point Aconi	8204456	165.5
2000-11-01	Unnamed	Louisbourg	8203161	106.5
2002-09-11	Gustav	Liverpool Big Falls	8203100	102
		Ashdale	8200180	101.8
		Bridgewater	8200600	101.8
2002-10-27	N/A	Louisbourg	8203161	101.5
2002-11-13	N/A	Salmon Hole	8205000	135.8
2003-04-22	N/A	Deming	8201410	114
2004-10-11	Nicole	Wreck Cove Brook	8206450	124
2005-05-07	N/A	Liverpool Milton	8203120	141
2005-09-18	Ophelia	Wreck Cove Brook	8206450	109.8
2005-10-09	N/A	Liverpool Milton	8203120	156
		Bear River	8200500	150
		Bridgewater	8200600	139.6
		Annapolis Royal	8200100	133
		Liverpool Big Falls	8203100	107.4
2005-10-10	N/A	Bridgetown	8200596	162.2
		St Margaret's Bay	8204800	147
		Wreck Cove Brook	8206450	113.8
		Point Aconi	8204456	109.8
		Charlesville	8200810	108.9
2007-08-31	N/A	Baddeck Bell	8200301	111.8
		Deming	8201410	107.6
2008-07-22	Cristobal	Baccaro Pt	8200255	138.4
2008-08-04	N/A	Wreck Cove Brook	8206450	286.6
2009-08-29	Danny	Bridgewater	8200600	101.8
2010-11-05	N/A	Yarmouth A	8206500	109.6
2011-10-20	N/A	Middle Musquodoboit	8203535	107
		Halifax Stanfield Int'l A	8202250	104.4
		Deming	8201410	100.8
2011-11-11	N/A	Lake Major	8202896	108.4
		Halifax Stanfield Int'l A	8202250	106.4
2014-12-10	N/A	St Margaret's Bay	8204800	115

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1877-10-12	N/A	Halifax	8202198	102.4
1878-03-30	N/A	Halifax	8202198	106.4
		Windsor Kings College	8206410	102.7
1883-08-30	N/A	Sydney	8205698	108
1884-06-03	N/A	Baddeck	8200300	117.6
1892-08-21	N/A	Sable Island East End	8204702	118.1
1896-10-19	N/A	Truro	8205988	102.4
1908-08-03	Unnamed	Windsor Kings College	8206410	101.3
1912-07-23	N/A	South Alton	8205170	118.6
		Wolfville	8206440	111.7
1913-10-13	N/A	Liverpool	8203001	115.6
1913-10-14	N/A	Wolfville	8206440	131.1
1913-10-15	N/A	Sable Island	8204700	129.6
1917-10-21	N/A	Annapolis Royal	8200100	134.7

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1917-10-22	N/A	Saulnierville	8205070	133.8
		Windsor Kings College	8206410	113
		Truro Nsac	8206000	102.9
		Liverpool	8203001	101.6
1917-10-23	N/A	Wolfville	8206440	117.6
1919-06-12	N/A	Sable Island East End	8204702	127
1920-03-14	N/A	Annapolis Royal	8200100	111
1922-07-07	N/A	Stillwater	8205600	103.1
1923-10-02	Unnamed	Sydney	8205698	115.8
1924-08-14	N/A	Collegeville	8201000	116.1
		Sydney	8205698	102.7
1924-08-16	N/A	Sable Island	8204700	157
1927-08-25	Unnamed	Springhill	8205215	114.8
		Kentville CDA	8202800	103.2
1927-11-06	N/A	Collegeville	8201000	102.3
		Antigonish	8200150	101.6
1927-11-07	N/A	Whitehead	8206300	107.4
1928-12-09	N/A	Windsor Kings College	8206410	101.1
1928-12-10	N/A	St Margaret's Bay	8204800	105.6
1929-09-19	N/A	Upper Stewiacke	8206200	129.1
1932-09-10	N/A	Sydney	8205698	125
		Mount Uniacke	8203600	101.6
1933-08-25	N/A	Mahone Bay	8203300	130
		Halifax Citadel	8202220	104.7
1933-09-10	N/A	Collegeville	8201000	108
1933-09-11	N/A	Stillwater	8205600	161.5
1933-10-07	N/A	Halifax Citadel	8202220	125.5
		Liverpool	8203001	119.9
1934-11-06	N/A	Mount Uniacke	8203600	152.4
		Liverpool	8203001	141.7
		Halifax Citadel	8202220	138.6
		Noel	8204100	115.1
1934-11-07	N/A	St Margaret's Bay	8204800	109.3
1935-01-09	N/A	Mount Uniacke	8203600	109.2
1935-01-10	N/A	Digby	8201600	148.6
		Annapolis Royal	8200100	128.8
		Middleton	8203550	123
		Parrsboro	8204400	110.2
1935-01-11	N/A	Saulnierville	8205070	103.4
1935-08-23	Unnamed	Trafalgar	8205900	108.4
1935-08-24	Unnamed	Baddeck	8200300	127.8
		St Paul Island	8204900	123.9
		Five Mile Lake	8201800	102.1
1936-09-19	N/A	Halifax Citadel	8202220	135.4
		Yarmouth	8206490	123.7
1936-09-20	N/A	St Margaret's Bay	8204800	113.1
1940-06-20	N/A	Baddeck	8200300	108.8
1940-09-16	Unnamed	Yarmouth	8206490	101.9
1942-07-04	N/A	Digby	8201600	108
1942-09-22	Unnamed	Liverpool Big Falls	8203100	197.6
		Lake Rossignol	8202900	159.6
		Salmon Hole	8205000	143.5
		Middleton	8203550	124.7

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1942-09-23	Unnamed	Springfield	8205200	155.7
		Five Mile Lake	8201800	149.4
1942-10-26	N/A	Lake Rossignol	8202900	150.9
		Liverpool	8203000	128.8
		Liverpool Big Falls	8203100	124
		Mahone Bay	8203300	104.4
1942-10-27	N/A	St Margaret's Bay	8204800	118.9
1943-05-04	N/A	Mount Uniacke	8203600	104.4
1943-07-08	N/A	Halifax	8202200	110.7
1943-08-04	N/A	Greenwood A	8202000	117.9
		Wolfville	8206440	100.4
1943-08-05	N/A	Five Mile Lake	8201800	105.4
1944-11-06	N/A	Sydney A	8205700	110
		St Margaret's Bay	8204800	121.7
		Five Mile Lake	8201800	110.5
		Chain Lake	8200800	102.6
		Salmon Hole	8205000	100.6
1946-09-15	Unnamed	Stellarton	8205400	126.7
		Salmon Hole	8205000	101.8
1947-05-01	N/A	Shearwater A	8205090	129
		Liverpool	8203000	128
		Halifax	8202200	126.2
		Ecum Secum	8201700	119.2
		Liverpool Big Falls	8203100	115.5
		Debert A	8201400	108.5
		Lake Rossignol	8202900	107.4
		Noel	8204100	103.7
1947-05-02	N/A	Spruce Hill Lake	8205300	147.8
		Chain Lake	8200800	130.8
1948-01-14	N/A	Chain Lake	8200800	100.1
1949-08-19	N/A	Noel	8204100	134.4
		Liverpool	8203000	106
		Mount Uniacke	8203600	103.9
		Wolfville	8206440	100.1
1949-08-20	N/A	Five Mile Lake	8201800	154.7
1949-09-09	Unnamed	Sydney A	8205700	110.7
1950-08-21	Able	Annapolis Royal	8200100	143.2
		Springfield	8205200	134.6
		Kentville CDA	8202800	121.9
		Harmony	8202300	115.1
		New Grafton	8204000	114.3
		Meteghan River	8203500	106.7
		Cornwall	8201200	100.6
1950-11-28	N/A	Springfield	8205200	141.3
		Avon	8200200	137.1
		Tusket	8206100	117.1
		New Grafton	8204000	116.3
		Liverpool Big Falls	8203100	105.2
1950-11-29	N/A	Harmony	8202300	121.1
		Copper Lake	8201100	109.5
		Timberlea	8205800	107.1
		Trafalgar	8205900	102.6
		Five Mile Lake	8201800	101.6
		Clifton	8200900	101.1

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1952-05-27	N/A	Sheet Harbour	8205100	103.7
1952-05-28	N/A	Malay Falls	8203400	115.4
1953-02-08	N/A	Liverpool Big Falls	8203100	118.3
		Annapolis Royal	8200100	107
		Yarmouth A	8206500	106.4
		Roseway	8204600	105.6
		Mount Uniacke	8203600	100.3
1953-02-09	N/A	Kemptville	8202700	112
		Harmony	8202300	100.1
1953-10-06	Unnamed	Sable Island	8204700	101.3
1953-10-29	N/A	Halifax	8202200	101.3
1953-10-30	N/A	Spruce Hill Lake	8205300	117.6
		Chain Lake	8200800	100.6
1954-01-04	N/A	Trafalgar	8205900	114.3
		Mount Uniacke	8203600	111.5
		Halifax Stanfield Int'l A	8202250	108.7
		Chain Lake	8200800	100.8
1955-09-20	Ione	Ingonish Beach	8202500	100.9
1956-01-05	N/A	Salmon Hole	8205000	137.9
		Lake Rossignol	8202900	113.5
1956-01-06	N/A	Collegeville	8201000	132.1
		Stillwater	8205600	119.4
		Trafalgar	8205900	117.9
		Debert A	8201400	110.3
		Greenwood A	8202000	103.9
		Paradise	8204300	101.3
		Clifton	8200900	100.4
		Dickie Brook	8201500	100.1
1956-01-08	N/A	New Germany	8203800	116.8
		Springfield	8205200	114
		New Grafton	8204000	106.4
		Harmony	8202300	105.5
1956-01-09	N/A	Cornwall	8201200	117.1
		Timberlea	8205800	103.9
1956-08-09	N/A	Liverpool Big Falls	8203100	126.8
1957-11-02	N/A	Ecum Secum	8201700	102.6
1957-11-03	N/A	Ingonish Beach	8202500	120.9
		Glenora Falls	8201950	119.9
1958-01-16	N/A	Liverpool Big Falls	8203100	195.9
		New Germany	8203800	152.4
		Lily Dale	8202950	143
		Roseway	8204600	142.7
		Bedford	8200575	130.6
		Lake Rossignol	8202900	125.2
		St Margaret's Bay	8204800	125.2
		Avon	8200200	116.9
		Harmony	8202300	109
		New Grafton	8204000	101.9
		Shearwater A	8205090	100.3
1958-01-17	N/A	Chain Lake	8200800	150.4
		Beaverbank	8200550	133.1
		Westphal	8206250	105.4
1958-02-09	N/A	Spruce Hill Lake	8205300	118.3

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1958-08-26	Betsy	Tusket	8206100	114.1
		Yarmouth A	8206500	106.7
		Clarence	8200860	100.9
1959-10-25	N/A	Paradise	8204300	111.5
		Annapolis Royal	8200100	106.7
1959-10-26	N/A	Springfield	8205200	131.1
		Avon	8200200	129.8
		Kemptville	8202700	127.8
		Kentville CDA	8202800	122.7
		Nappan CDA	8203700	120.1
		Cape Sable	8200700	113.1
		Trafalgar	8205900	109.2
		Sheffield Mills	8205120	106.4
		Debert A	8201400	105.6
		Mount Uniacke	8203600	104.4
1959-10-27	N/A	Beaverbank	8200550	107.2
1959-11-16	N/A	Western Head	8206240	147.6
		Sheet Harbour	8205100	142.2
		Westphal	8206250	140.2
		Chain Lake	8200800	138.7
		Spruce Hill Lake	8205300	133.8
		Ecum Secum	8201700	128.3
		Shearwater A	8205090	124.5
		Mahone Bay	8203300	116.1
		Whitehead	8206300	115.8
		Yarmouth CDA EPF	8206600	115.4
		Dickie Brook	8201500	115.3
		Baccaro	8200250	108.2
		Malay Falls	8203400	104.7
		Kemptville	8202700	102.9
		Bedford	8200575	100.6
1961-05-20	N/A	Ingonish Beach	8202500	117.1
		Dickie Brook	8201500	106.5
1961-10-21	Gerda	Bridgewater	8200600	100.8
1961-10-25	N/A	Chain Lake	8200800	135.6
		Bedford	8200575	133.3
		Spruce Hill Lake	8205300	123.2
		Halifax	8202200	103.3
		St Margaret's Bay	8204800	100.6
1962-04-01	N/A	Annapolis Royal	8200100	101.6
1962-04-08	N/A	St Margaret's Bay	8204800	100.3
1962-04-09	N/A	Kemptville	8202700	100.8
1962-08-08	N/A	Paradise	8204300	100.3
1962-09-29	N/A	Bridgewater	8200600	109.2
1962-11-15	N/A	Western Head	8206240	135.9
		Baccaro	8200250	100.6
1963-08-25	N/A	Deming	8201410	104.7
1963-10-29	Ginny	Meteghan River	8203500	105.7
		Westport	8206260	105.4
1963-11-08	N/A	Liverpool Big Falls	8203100	127.5
		Roseway	8204600	102.1
1964-06-12	N/A	Stellarton Lourdes	8205401	141
		Trafalgar	8205900	101.3
1964-07-05	N/A	Kemptville	8202700	100.6
1964-07-06	N/A	Dickie Brook	8201500	106.9

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1964-07-23	N/A	Bedford	8200575	104.1
1964-09-15	Dora	Canso	8200640	115.6
1964-12-01	N/A	Kentville CDA	8202800	113
		Spruce Hill Lake	8205300	106.1
		Halifax Stanfield Int'l A	8202250	101.4
		Lower Sackville	8203170	100.4
1965-08-20	N/A	Dickie Brook	8201500	110.5
		Port Hood	8204500	110.5
		Baddeck	8200300	106.4
1967-05-26	N/A	Deming	8201410	113.6
		Ecum Secum	8201700	109.2
		Port Hastings	8204480	103.1
1967-05-27	N/A	Sydney A	8205700	150.9
		Ingonish Beach	8202500	142
		Dickie Brook	8201500	101.6
1967-07-18	N/A	Springfield	8205200	160
1967-10-10	N/A	Stillwater Sherbrooke	8205601	144.8
		Halifax	8202200	133.4
		Upper Stewiacke	8206200	131.5
		Liscomb Game Sanctuary	8202975	129.5
		Westphal	8206250	124.7
		Kejimkujik Park	8202590	121.9
		Bridgewater	8200600	120.2
		Liverpool Big Falls	8203100	117.6
		April Brook IHD	8200155	117.1
		Ecum Secum	8201700	113.5
		Trafalgar	8205900	113.3
		St Margaret's Bay	8204800	112.5
		Lower Meaghers Grant	8203165	112
		Port Hood	8204500	111
		Lower Sackville	8203170	109.5
		Spruce Hill Lake	8205300	106.9
		Salmon Hole	8205000	106.7
		Mount Uniacke	8203600	106.1
		Ruth Falls	8204620	105.6
		Springfield	8205200	105.2
		Harmony	8202300	104.9
		Parrsboro	8204400	104.4
		River Denys	8204565	102.9
		Chain Lake	8200800	101.9
		Indian Brook	8202465	101.3
1967-10-11	N/A	Kemptville	8202700	157.8
		Copper Lake	8201100	111
		Shearwater A	8205090	104.9
1967-11-23	N/A	Ingonish Beach	8202500	103.7
1967-11-24	N/A	River Denys	8204565	101.6
1967-12-04	N/A	Tusket	8206100	132.6
		Meteghan River	8203500	127
		Roseway	8204600	116.4
		Harmony	8202300	116.1
		Digby Prim Point	8201605	115.5
		Liverpool Big Falls	8203100	113.8
		Westport	8206260	111.5
		Springfield	8205200	110.2
		Clarence	8200860	104.9

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
		Annapolis Royal	8200100	103.1
		Bear River	8200500	102.1
1967-12-05	N/A	Kemptville	8202700	131.5
1968-06-13	N/A	Annapolis Royal	8200100	104.9
		Nappan CDA	8203700	102.1
		Paradise	8204300	102.1
		River Hebert	8204570	101.9
		Bear River	8200500	100.8
1968-08-30	N/A	Ruth Falls	8204620	147.6
		Dickie Brook	8201500	137.2
		Stillwater Sherbrooke	8205601	134.6
		Birchtown	8200581	122.2
		Deming	8201410	114.1
		Loch Lomond	8203150	112.5
1968-08-31	N/A	Canso	8200640	105.7
1968-10-21	Gladys	Kentville CDA	8202800	116.4
		River Hebert	8204570	115.8
		Sharpe Brook IHD	8205085	115.3
1969-11-06	N/A	Loch Lomond	8203150	105.5
1969-11-07	N/A	Indian Brook	8202465	119.2
1969-11-08	N/A	Stillwater Sherbrooke	8205601	108.9
1969-11-09	N/A	Trafalgar	8205900	119.1
		Port Hastings	8204480	106.7
		Copper Lake	8201100	105.9
		Ecum Secum	8201700	103.8
		Port Hood	8204500	101.6
1969-11-10	N/A	Deming	8201410	104.4
1969-11-12	N/A	Ingonish Beach	8202500	154.7
1971-08-15	Beth	Ecum Secum	8201700	157.8
		Sharpe Brook IHD	8205085	152.9
		Fraser Brook IHD	8201850	122.9
1971-08-16	Beth	Oxford	8204200	163.1
		Northeast Margaree	8204150	148.6
		Summerville	8205650	124.7
		Cape Sable	8200700	116.6
		Barrie Brook	8200400	114.8
		Aylesford	8200220	114.6
		Baddeck	8200300	113.5
		River Hebert	8204570	106.5
		Birchtown	8200581	102.1
		Greenwood A	8202000	101.9
		Pugwash	8204525	101.8
1972-03-24	N/A	Halifax Stanfield Int'l A	8202250	103.9
		Westphal	8206250	100.1
1972-05-17	N/A	Ruth Falls	8204620	127
		Ecum Secum	8201700	100.6
1972-07-27	N/A	Trafalgar	8205900	103.9
		Clifton	8200900	100.4
1972-11-09	N/A	Westphal	8206250	105.4
1972-11-10	N/A	Halifax Citadel	8202220	119.4
1973-06-17	N/A	Collegeville	8201000	109.7
1973-07-11	N/A	Summerville	8205650	120.9
		Tusket	8206100	111
1973-07-12	N/A	Mount Uniacke	8203600	108.2
		Parrsboro	8204400	106.4

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1974-09-04	Dolly	Clarence	8200860	104.4
		Paradise	8204300	103.4
1975-12-11	N/A	Ingonish Beach	8202500	157.8
		East River St Mary's	8201690	112.5
		Ecum Secum	8201700	109.7
		Port Hastings	8204480	107
		Halifax Stanfield Int'l A	8202250	104.4
		River Denys	8204565	101.6
1976-07-13	N/A	Springfield	8205200	101.1
1976-11-19	N/A	River Denys	8204565	130.8
		Ingonish Beach	8202500	117.1
		Indian Brook	8202465	104.9
		Cheticamp	8200825	101.8
1977-06-04	N/A	Wreck Cove Brook	8206450	123.2
		Ingonish Beach	8202500	112.3
		Indian Brook	8202465	103.6
1977-07-13	N/A	Digby Prim Point	8201605	111
		Meteghan River	8203500	103.4
1977-07-14	N/A	Clementsvale	8200875	103.9
1978-01-14	N/A	Liverpool Milton	8203120	105.9
		Mill Village	8203570	103.2
1978-01-15	N/A	Halifax Stanfield Int'l A	8202250	111.9
		Trafalgar	8205900	104.6
		Camden IHD	8200635	100.8
		Lower Meaghers Grant	8203165	100.3
1979-04-30	N/A	Mill Village	8203570	111.5
		Pentz	8204405	101.8
		Liverpool Milton	8203120	101
1979-07-29	N/A	Deming	8201410	144
		Ecum Secum	8201700	142
		Stillwater	8205600	111.8
1979-08-05	N/A	Ruth Falls	8204620	133.4
		Ecum Secum	8201700	126.6
1980-04-24	N/A	Wreck Cove Brook	8206450	128.9
		Ingonish Beach	8202500	127.8
1980-05-09	N/A	Stillwater Sherbrooke	8205601	153.1
		Ecum Secum	8201700	139.4
		Ruth Falls	8204620	103
1981-05-23	N/A	Pockwock Lake	8204453	103.4
1981-05-24	N/A	Sydney A	8205700	103.6
1981-09-23	N/A	Meteghan River	8203500	109
1981-09-24	N/A	Wreck Cove Brook	8206450	115.8
		Ingonish Beach	8202500	100.8
1982-04-28	N/A	Westphal	8206250	121.6
		Shearwater A	8205090	119.5
		St Margaret's Bay	8204800	113
		Halifax Citadel	8202220	110.4
		Stillwater Sherbrooke	8205601	110
		Pockwock Lake	8204453	106.6
		Ruth Falls	8204620	102.6
1982-04-29	N/A	Baddeck	8200300	125.6
		Eddy Point	8201716	120.8
		Dickie Brook	8201500	110.6
		River Denys	8204565	101.2
1982-09-17	Debby	Sable Island	8204700	168.4

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1983-01-12	N/A	Louisbourg	8203161	116
1983-01-13	N/A	Sable Island	8204700	149.3
1983-03-03	N/A	Wreck Cove Brook	8206450	114.6
		Ingonish Beach	8202500	104.8
1983-07-22	N/A	Lower Meaghers Grant	8203165	133
		Middle Musquodoboit	8203535	123.8
1983-07-25	N/A	Wreck Cove Brook	8206450	109.4
1983-08-07	N/A	Shearwater A	8205090	113.1
		Westphal	8206250	100.1
1983-09-01	N/A	Dickie Brook	8201500	106
1983-11-06	N/A	Port Hastings	8204480	114.2
		River Denys	8204565	107.2
1983-11-17	N/A	Ingonish Beach	8202500	121.2
1984-09-01	Cesar	Sydney A	8205700	100.7
1985-07-16	Ana	Liverpool Big Falls	8203100	109.2
		Roseway	8204600	106.2
		Charlesville	8200810	104.7
1985-07-17	Ana	Shelburne	8205126	103
1985-11-06	N/A	Mill Village	8203570	107.3
1985-11-07	N/A	Wreck Cove Brook	8206450	104
		Ingonish Beach	8202500	101.6
1986-07-28	N/A	Farmington	8201766	132
		Springfield	8205200	122.4
		Bridgewater	8200600	119.2
		Liverpool Big Falls	8203100	115
		Harmony	8202300	107.4
		Greenwood A	8202000	105.5
		Seafoam	8205079	103
1987-09-21	N/A	Liverpool Milton	8203120	108.2
		Yarmouth A	8206500	106.8
1988-04-09	N/A	Ingonish Beach	8202500	102.2
1988-04-10	N/A	Wreck Cove Brook	8206450	137.8
		Indian Brook	8202465	130.4
		Pleasant Bay Grand Anse	8204450	101
1988-07-24	N/A	Sandy Cove NRC	8205062	120.9
1988-07-25	N/A	Sugar Camp Brook	8205623	106.8
		Urbania	8206208	101.8
1988-08-16	N/A	Indian Brook	8202465	125.6
1988-08-17	N/A	Wreck Cove Brook	8206450	118.8
1988-10-23	N/A	Ingonish Beach	8202500	146.4
		Wreck Cove Brook	8206450	131.2
1990-08-01	Bertha	Wreck Cove Brook	8206450	121
1990-08-02	Bertha	Pleasant Bay Grand Anse	8204450	142.6
1990-10-30	N/A	Jackson	8202565	101.4
		Dickie Brook	8201500	101
1990-11-18	N/A	Liverpool Big Falls	8203100	101.8
1990-11-19	N/A	Salmon Hole	8205000	120.1
		College Grant	8200989	102.2
1990-12-08	N/A	Nappan CDA	8203700	116
1990-12-09	N/A	Dickie Brook	8201500	111.2
		Shearwater A	8205090	100.2
1991-04-22	N/A	Middle Clyde River	8203520	101.2

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1991-11-11	N/A	Halifax Citadel	8202220	126.4
		Dartmouth	8201292	124.9
		Bridgewater	8200600	123.4
		Bayswater	8200437	120.6
		Liverpool Big Falls	8203100	118
		Sandy Cove NRC	8205062	115.2
		South Side	8205192	110.6
		Salmon Hole	8205000	109.4
		Mill Village	8203570	107.3
		Roseway	8204600	106.2
		Pockwock Lake	8204453	102.3
1992-03-08	N/A	Louisbourg	8203161	112
		Deming	8201410	102.8
1992-10-20	N/A	Sydney A	8205700	100.7
1995-07-18	Chantal	Roseway	8204600	110
1996-09-02	Edouard	Charlesville	8200810	102.8
1996-09-03	Edouard	Malay Falls	8203400	112
		St Margaret's Bay	8204800	107.6
		Liverpool Milton	8203120	103.6
1996-09-14	Hortense	Deming	8201410	140
		Salmon Hole	8205000	134.6
		Lyons Brook	8203230	127
		Summerville	8205650	117
		Collegeville	8201000	114.8
		Halifax Stanfield Int'l A	8202250	112.4
		Avon	8200200	109
		White Rock	8206316	108.8
		Windsor Martock	8206415	105.6
		Great Village	8201980	103.4
		Milford Station	8203567	103.1
		Middle Musquodoboit	8203535	102.3
		Jackson	8202565	102.2
		Pockwock Lake	8204453	101.5
1996-09-19	N/A	Wreck Cove Brook	8206450	106.5
1996-12-09	N/A	Ingonish Beach	8202500	135.2
		Wreck Cove Brook	8206450	128.2
1998-01-25	N/A	Westphal	8206250	102.6
1998-01-26	N/A	Tusket	8206100	104.4
1998-02-26	N/A	Ingonish Beach	8202500	122.8
		Wreck Cove Brook	8206450	117.4
1998-06-16	N/A	Middle Musquodoboit	8203535	115.4
		Upper Stewiacke	8206200	104
1998-09-05	Earl	Louisbourg	8203161	115.2
		Inverness	8202535	114.4
		Margaree Forks	8203423	111.8
1998-10-11	N/A	Bear River	8200500	124.1
		Bridgewater	8200600	123.4
1999-07-27	N/A	Wreck Cove Brook	8206450	138
1999-08-15	N/A	Debert	8201380	111.4
		Mount Uniacke	8203600	108.4
		Charlesville	8200810	105.4
		Tatamagouche	8205774	104
1999-09-22	Gert	Charlesville	8200810	106

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1999-09-23	Gert	Parrsboro	8204400	150.2
		Nappan CDA	8203700	132.5
		Jackson	8202565	129.6
		Windsor Martock	8206415	118.2
		Avon	8200200	117
		Avondale	8200210	116.2
		Summerville	8205650	104
2000-10-10	Leslie	Point Aconi	8204456	101.6
2000-11-01	Unnamed	Point Aconi	8204456	125.6
		Wreck Cove Brook	8206450	107.8
2000-11-02	Unnamed	Sydney A	8205700	129.8
2001-05-10	N/A	Pockwock Lake	8204453	118.2
		Salmon Hole	8205000	118
		Ashdale	8200180	111
2002-09-12	Gustav	Lyons Brook	8203230	109.5
		Tatamagouche	8205774	105
		Jackson	8202565	102
		Middleboro	8203510	100.3
2002-11-13	N/A	Tatamagouche	8205774	123.8
		Ashdale	8200180	117.2
		Jackson	8202565	117
		Middleboro	8203510	111.7
		Windsor Martock	8206415	107
		Avondale	8200210	104.2
		Summerville	8205650	103
		Bridgewater	8200600	101.2
2002-11-14	N/A	Halifax Stanfield Int'l A	8202250	106.8
2003-03-31	N/A	Salmon Hole	8205000	124
		Halifax Stanfield Int'l A	8202250	105.9
		Lake Major	8202896	103.8
		Shearwater A	8205090	103.8
		Bear River	8200500	101
2003-04-23	N/A	Baddeck Bell	8200301	122
		Wreck Cove Brook	8206450	114.9
		Point Aconi	8204456	105.2
2003-08-05	N/A	St Margaret's Bay	8204800	115
		Bear River	8200500	113
		White Rock	8206316	106
2004-10-12	Nicole	South Mountain	8205185	103
2005-05-08	N/A	Bridgewater	8200600	117.6
		Pockwock Lake	8204453	115.5
		Lake Major	8202896	104
2005-05-22	N/A	Liverpool Milton	8203120	151
		Bridgewater	8200600	143.8
		Lake Major	8202896	105
2005-05-23	N/A	Liverpool Big Falls	8203100	103
2005-10-08	N/A	Salmon Hole	8205000	108
2005-10-09	N/A	Pockwock Lake	8204453	161.8
		Yarmouth A	8206500	126.2
		Berwick	8200578	125.6
		Waterville Cambridge	8206222	125
		White Rock	8206316	124.5
		South Mountain	8205185	124.2
		Tusket	8206100	121.1
		Halifax Stanfield Int'l A	8202250	118.4

Table 1.2 Large Rainfall Events for Nova Scotia (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
2005-10-10	N/A	Greenwood A	8202000	113.2
		Shearwater A	8205090	137.5
		Lake Major	8202896	132.4
2006-04-18	N/A	Wreck Cove Brook	8206450	125.8
		Point Aconi	8204456	119.4
2008-08-04	N/A	Halifax Stanfield Int'l A	8202250	107.3
2009-08-30	Danny	Sydney A	8205700	105.2
2010-11-06	N/A	Liverpool Big Falls	8203100	137.3
		Bridgewater	8200600	135.2
		Bridgetown	8200596	120.6
		St Margaret's Bay	8204800	102
2010-12-15	N/A	Sydney A	8205700	173
		Point Aconi	8204456	123
		Wreck Cove Brook	8206450	118
2010-12-21	N/A	Wreck Cove Brook	8206450	132
		Point Aconi	8204456	118.4
2011-06-15	N/A	Deming	8201410	119.4
		Middle Musquodoboit	8203535	109.8
2011-10-20	N/A	Bridgewater	8200600	106.6
		Lake Major	8202896	106
2012-09-10	Leslie	Lyons Brook	8203230	138
		Yarmouth A	8206495	107.4
2014-09-22	N/A	Lake Major	8202896	104.4
2014-12-10	N/A	Pockwock Lake	8204453	119.9
2014-12-11	N/A	Halifax Intl A	8202251	107

Table 1.3 Large Rainfall Events for New Brunswick (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1900-10-11	N/A	Grand Manan	8101920	136.1
		Saint John	8104800	103.1
		Point Lepreau	8104200	101.6
1901-06-24	N/A	Saint John	8104800	123.7
		Point Lepreau	8104200	104.1
1920-03-13	N/A	Saint John	8104800	109.7
1924-08-26	Unnamed	Saint John	8104800	123.2
		Point Lepreau	8104200	100.3
1924-08-27	Unnamed	St George	8104700	134.6
		Gagetown 2	8101800	115.3
		Musquash	8103400	104.1
1926-10-25	N/A	Harvey Station	8102200	114.3
		Chipman	8101098	110.7
		Hardwood Ridge	8102160	105.4
		Saint John	8104800	105.2
		St George	8104700	101.6
1933-09-17	Unnamed	Fredericton UNB	8101700	111.8
		Fredericton CDA	8101600	105.4
1933-09-18	Unnamed	St George	8104700	122.2
1940-09-16	Unnamed	Musquash	8103400	152.1
		Blissville	8100550	122.2
		Saint John A	8104899	120.4
		Saint John	8104800	117.9

Table 1.3 Large Rainfall Events for New Brunswick (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1950-08-20	Able	Saint John A	8104899	122.7
		Hampton	8102100	109
1950-11-29	N/A	Burnt Church	8100600	104.1
1954-09-11	Edna	Grand Falls	8101900	159
		McAdam	8102600	143.8
		Tide Head	8105300	133.4
		Tower Hill CDA	8105500	124.2
		Aroostook	8100300	120.4
		Harvey Station	8102200	117.6
		Mcgivney	8102800	111.8
		Plaster Rock	8104000	106.7
		Tobique Narrows	8105400	103.9
1956-01-09	N/A	Hampton	8102100	125.5
1956-01-14	N/A	Rexton	8104400	183.6
1957-11-04	N/A	Rexton	8104400	119.4
1961-05-27	N/A	Tower Hill CDA	8105500	136.1
		Harvey Station	8102200	116.3
		Mcgivney	8102800	113
		Brockway	8100570	111
		Fredericton CDA	8101600	109.7
		McAdam	8102600	103.6
1962-04-01	N/A	Alma	8100200	179.1
		Moncton A	8103200	131.8
		Saint John A	8104900	125.5
		Moncton	8103100	113.3
1962-11-22	N/A	Alma	8100200	118.1
1963-08-24	N/A	Mcgivney	8102800	101.6
1963-08-25	N/A	Rexton	8104400	105.9
		Nepisiguit Falls	8103500	104.4
1968-10-21	Gladys	Moncton A	8103200	103.1
1970-07-11	N/A	Searsville	8104938	108.2
1970-08-01	N/A	Oromocto	8103800	103.6
1970-08-02	N/A	Saint John A	8104900	125.2
1972-07-26	N/A	Dawson Settlement	8101178	119.1
		Turtle Creek	8105520	110.2
		Rosevale	8104475	104.9
1972-10-07	N/A	Dawson Settlement	8101178	102.1
1973-07-05	Alice	Buctouche	8100590	117.6
		Penobsquis	8103860	114.8
1975-11-13	N/A	Alma	8100200	182.6
		Saint John A	8104900	154.4
		Saint John Bridge	8104920	149.6
		Musquash	8103400	106.7
		Coleson Cove	8101151	102.4
1976-07-12	N/A	Alma	8100200	110.7
1976-08-10	Belle	Edmundston Fraser Co	8101301	109.5
		Nine Mile Brk (Camp 68)	8103706	109.2
1979-01-08	N/A	Alma	8100200	112.4
1979-03-06	N/A	Nictau	8103700	107
1979-05-30	N/A	St Andrews	8104600	146.5
1979-07-27	N/A	Southwest Head	8105065	126.5
1981-08-15	N/A	Pennfield	8103845	111
1981-12-02	N/A	Pennfield	8103845	103.8
1987-09-20	N/A	Southwest Head	8105065	101

Table 1.3 Large Rainfall Events for New Brunswick (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1989-08-05	Dean	Fredericton A	8101500	148.6
		Acadia Forest Exp St	8100100	119
		Royal Road	8104480	114.8
1990-07-24	N/A	Nauwigewauk	8103441	147
		Havelock	8102210	100.7
1998-01-24	N/A	Alma	8100200	117
1998-02-25	N/A	Bertrand	8100518	135.4
1999-09-22	Gert	Fredericton A	8101500	124
		Sussex	8105200	113.4
		Turtle Creek	8105520	104.2
2001-07-11	N/A	Charlo A	8100880	113.2
2005-10-08	N/A	Moncton A	8103200	120.6
2008-09-07	Hanna	Saint John A	8104900	104.4
2009-08-29	Danny	Alma	8100200	110
		Saint John A	8104900	107.5
2014-07-05	Arthur	Upsalquitch Lake	8105551	162
		Bathurst A	8100505	114
		Bas Caraquet	8100468	103.8
		Gagetown A	8101792	102.8
2014-12-10	N/A	Moncton Intl A	8103201	122.2

Table 1.4 Large Rainfall Events for New Brunswick (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1879-08-19	N/A	Fredericton UNB	8101700	104.7
		Saint John	8104800	101.3
1888-10-08	N/A	St Andrews	8104600	116.1
		Fredericton UNB	8101700	115.3
1888-10-09	N/A	Woodstock	8105600	111.7
		Point Lepreau	8104200	106.7
1895-08-19	N/A	Saint John	8104800	113.5
1900-10-10	N/A	Grand Manan	8101920	112
		Saint John	8104800	103.7
1900-10-11	N/A	Fredericton UNB	8101700	178.8
		Sussex	8105200	107
1902-03-19	N/A	Sussex	8105200	116.5
		St Stephen	8104936	100.1
1909-09-27	N/A	Grand Manan	8101920	108.5
1909-09-28	N/A	Chatham	8100990	100.1
1909-09-29	N/A	Fredericton UNB	8101700	149.1
		St Stephen	8104936	102.1
1912-07-23	N/A	Moncton	8103100	101.6
1920-09-14	N/A	Point Lepreau	8104200	124.9
1920-10-01	N/A	Bathurst	8100500	111.8
1920-10-02	N/A	Upsalquitch	8105550	142.2
		Grand Falls	8101900	107.2
1923-10-01	Unnamed	Moncton	8103100	107.9
1924-08-27	Unnamed	Rexton	8104400	116.4
1926-10-25	N/A	Musquash	8103400	108
1930-08-17	N/A	Chipman	8101098	146.6
		Point Lepreau	8104200	123.9
		Hardwood Ridge	8102160	112
		Chatham	8100990	104.9

Table 1.4 Large Rainfall Events for New Brunswick (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1933-08-25	N/A	Fredericton UNB	8101700	119.9
		Saint John	8104800	107.2
		Musquash	8103400	105.9
		Fredericton CDA	8101600	103.6
1933-08-26	N/A	Point Lepreau	8104200	104.1
1935-01-10	N/A	Saint John	8104800	119.4
1940-09-17	Unnamed	Moncton A	8103200	105.7
1944-09-15	Unnamed	Mount Pleasant	8103300	106.4
1950-08-21	Able	Sussex	8105200	119.8
1950-11-28	N/A	Saint John A	8104899	130.1
		Saint John	8104800	119.4
		Nepisiguit Falls	8103500	103.2
		Bathurst	8100500	102.6
1953-02-08	N/A	Alma	8100200	104.6
1954-09-11	Edna	Sisson Dam	8105000	118.1
		Campbellton	8100700	103.4
1958-01-16	N/A	St George P And P Co	8104705	124
1958-01-17	N/A	Renous	8104300	134.6
		Gagetown 2	8101800	118.6
1959-10-25	N/A	Musquash	8103400	104.9
1959-10-26	N/A	Alma	8100200	102.8
		Mcdonalds Corner CDA	8102700	102.1
		Coldbrook	8101150	101.3
1961-05-27	N/A	Hampton	8102100	131.3
		Riley Brook	8104450	123.2
		Magaguadavic Lake	8102550	119.4
		St George	8104700	116.9
		St George P And P Co	8104705	111.5
		Woodstock	8105600	108.7
		Doaktown	8101200	102.6
		Aroostook	8100300	102.1
1962-04-01	N/A	Sussex	8105200	128
		Saint John	8104800	122.7
		Gagetown 2	8101800	120.2
		Musquash	8103400	118.9
		Hampton	8102100	114.8
		Penobsquis	8103860	106.9
		Hillsborough	8102220	101.6
1962-08-07	N/A	Nepisiguit Falls	8103500	104.1
1962-08-08	N/A	Little River Mine	8102350	100.6
1963-08-24	N/A	Harcourt	8102150	100.6
1963-08-25	N/A	Miramichi A	8101000	126.7
		Renous	8104300	103.1
1963-10-30	Ginny	Saint John A	8104900	113.2
		Moncton A	8103200	100.1
1967-10-10	N/A	Alma	8100200	115.1
1967-11-23	N/A	Pennfield	8103845	101.6
1967-12-04	N/A	Saint John A	8104900	102.8
1968-10-21	Gladys	Sackville	8104500	128
		Buctouche	8100590	127
		Dawson Settlement	8101178	103.9
1969-07-13	N/A	Saint John Bridge	8104920	128.2
		Musquash	8103400	116.3
		Saint John A	8104900	107.4
		St George	8104700	101.4

Table 1.4 Large Rainfall Events for New Brunswick (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1969-09-09	Gerda	Little River Mine	8102350	109
		Grand Falls Drummond	8101904	106.5
		Pennfield	8103845	102.1
1970-02-03	N/A	Saint John Bridge	8104920	116.6
		Pennfield	8103845	116.3
		Mcgraw Brook	8102808	109.7
		Mcgivney	8102800	108.9
		Penobsquis	8103860	105.4
		Searsville	8104938	104.9
		St Andrews	8104600	103.9
		Milltown	8102975	102.4
		Musquash	8103400	101.1
1970-02-04	N/A	Saint John A	8104900	132.1
		Dawson Settlement	8101178	112
		Sussex	8105200	104.7
		Doaktown	8101200	100.4
1972-07-26	N/A	Alma	8100200	130.6
1972-11-10	N/A	Dawson Settlement	8101178	102.4
1973-04-28	N/A	Milltown	8102975	117.1
		St Andrews	8104600	108.7
		McAdam	8102600	108
		Royal Road West	8104482	106.7
		Harvey Station	8102200	106.2
		Juniper	8102275	105.9
		Royal Road	8104480	105.4
		Kingsley IHD	8102316	103.1
		Pennfield	8103845	102.7
		Canterbury	8100775	100.9
		Hamtown Corner	8102110	100.6
1973-07-04	Alice	Centreville	8100850	136.4
		Bon Accord	8100566	129.3
		Holmesville	8102226	128.3
1975-11-13	N/A	Pennfield	8103845	129.8
1975-11-14	N/A	Searsville	8104938	102.6
1976-07-13	N/A	Rogersville	8104465	116.1
	N/A	Little River Mine	8102350	104.2
1976-08-10	Belle	Rapids Depot	8104284	115.4
1977-06-03	N/A	Alma	8100200	126.4
1977-09-14	N/A	Southwest Head	8105065	100.4
1978-01-26	N/A	Musquash	8103400	111.7
		Pennfield	8103845	110.5
		Saint John A	8104900	102.2
		Coleson Cove	8101151	101.4
1980-04-24	N/A	Charlo A	8100880	111.2
1981-08-16	N/A	Saint John A	8104900	134.6
		Sussex	8105200	102.2
1981-09-24	N/A	Milltown	8102975	132.5
1981-12-03	N/A	Saint John A	8104900	106.8
1982-07-21	N/A	Hoyt Blissville	8102234	103.4
1988-08-07	Alberto	Bas Caraquet	8100468	112.4
1989-08-05	Dean	Mactaquac Prov Park	8102536	124.5
		Harvey Station	8102201	112
		Wiggins Point	8105568	109.4
		Buctouche	8100590	108.8
		Fredericton CDA	8101600	107.2

Table 1.4 Large Rainfall Events for New Brunswick (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
		Harcourt	8102151	105
1990-07-24	N/A	Kouchibouguac	8102325	106.6
		Plaster Rock	8104000	103.4
		Nepisiguit Falls	8103500	102
1990-07-25	N/A	St Andrews	8104600	129.6
		Coles Island	810JAE0	106.4
		Saint John A	8104900	105.4
		Buctouche CDA	8100592	102.4
1991-09-26	N/A	Doaktown	8101200	122.6
		Nauwigewauk	8103441	120.8
		Alma	8100200	118.4
		Mactaquac Prov Park	8102536	113.4
		Royal Road	8104480	112.6
		Mcgraw Brook	8102808	109
		Harvey Station	8102201	108.8
		Kouchibouguac	8102325	107.3
		Saint John A	8104900	107.3
		Sussex	8105200	104.2
		Pennfield	8103845	102.6
1999-09-17	Floyd	Bathurst A	8100503	116.1
		Upsalquitch Lake	8105551	115
		South Tetagouche	8105058	114.4
		Nepisiguit Falls	8103500	105
		Aroostook	8100300	103.8
1999-09-22	Gert	Hoyt Blissville	8102234	127.2
		Fredericton CDA	8101600	109
		Acadia Forest Exp St	8100100	104
1999-09-23	Gert	Parkindale	8103828	148.2
		Moncton A	8103200	146.8
		Alma	8100200	143.5
		Moncton	8103100	142.6
		Sackville	8104501	138.6
		Saint John A	8104900	134.8
		Rexton	8104400	118
		Miramichi A	8101000	101.9
2003-03-30	N/A	Alma	8100200	121.6
2004-10-12	Nicole	Moncton A	8103200	129.8
2005-10-08	N/A	Moncton	8103100	134.6
		Alma	8100200	113.6
2005-10-09	N/A	Saint John A	8104900	131
		Sussex	8105200	103.8
2006-06-04	N/A	Sussex	8105200	118.4
		Saint John A	8104900	116
		Moncton	8103100	108
		Moncton A	8103200	101.8
		Gagetown 2	8101800	100.2
2008-09-07	Hanna	Sussex	8105200	106.4
2014-07-05	Arthur	Oak Point	8103780	126.8
		Woodstock	8105600	108.6
2014-10-23	N/A	Oak Point	8103780	104.8
2014-12-10	N/A	Oak Point	8103780	101.9
		Saint John A	8104901	100.2

Table 1.5 Large Rainfall Events for Newfoundland and Labrador (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1872-08-22	N/A	Belle Isle	8500500	106.7
1874-09-08	N/A	Belle Isle	8500500	117.1
1902-03-21	N/A	Belle Isle	8500500	112.5
1905-07-25	N/A	Channel	8401125	101.6
1937-11-21	N/A	Grand Bank	8402000	106.7
1953-09-08	Carol	Hebron	8502200	106.2
1953-10-06	Unnamed	St John's	8403500	111
		St John's West CDA	8403600	100.3
1967-12-05	N/A	Bay D'Espoir Gen Stn	8400413	112.8
1967-12-06	N/A	Bay D'Espoir St Albans	8400415	103.6
1970-08-08	N/A	Westbrook St Lawrence	8404201	112
1973-10-27	Gilda	St Albans	8403290	113.5
1978-01-15	N/A	St Albans	8403290	103.4
1981-08-17	N/A	Buchans	8400698	105
1982-04-29	N/A	Tompkins	8403870	109
1983-01-12	N/A	Pools Cove Fortune Bay	8402973	125.2
		St Albans	8403290	116.4
		Bay D'Espoir Gen Stn	8400413	113
1983-01-13	N/A	Upper Salmon	8404080	142.8
		St Albans	8403290	141
		Bay D'Espoir Gen Stn	8400413	125.5
1983-06-01	N/A	Western Arm Brook	8404210	121.2
1983-08-07	N/A	Buchans	8400698	139
1983-09-01	N/A	Westbrook St Lawrence	8404201	106
1983-11-17	N/A	Pools Cove Fortune Bay	8402973	107.4
1984-09-01	Cesar	Isle Aux Morts	8402450	114
1986-06-08	Andrew	Fortune	8401618	124.2
		Harbour Breton	8402071	114.5
1988-02-16	N/A	Pools Cove Fortune Bay	8402973	121.6
		Arnolds Cove	8400135	108
		Swift Current	8403825	108
		Come By Chance	8401257	101
1988-10-05	N/A	Salt Pond	8403623	109.6
1990-07-24	N/A	St Georges	8403450	106
1990-12-09	N/A	Pools Cove Fortune Bay	8402973	103.7
1995-06-08	Allison	Stephenville A	8403800	130.7
		Daniels Harbour	8401400	109
		Black Duck	8400570	106
1995-09-10	Luis	Boat Harbour	8400578	133.4
		Red Harbour PB	8403083	129.8
		Winterland	8404240	122
		Garnish	8401728	121.8
		Salt Pond	8403623	119.6
		St Lawrence	8403615	116
		Lockston	8402565	114
		Lamaline	8402516	113
1998-02-26	N/A	Pools Cove Fortune Bay	8402973	100.2
2002-07-20	N/A	North Harbour	8402874	142
		Whitbourne	8404234	104.2
		Salmonier Nature Park	8403621	102.2
2004-09-19	Ivan	Whitbourne	8404234	123.2
		Butlerville	8400QJK	112
2004-09-20	Ivan	Port Union	8403050	140

Table 1.5 Large Rainfall Events for Newfoundland and Labrador (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
2005-03-30	N/A	Salt Pond	8403623	201
		Red Harbour PB	8403083	198.5
		Harbour Breton	8402071	122
		Winterland	8404240	115
		Boat Harbour	8400578	110.2
2006-04-17	N/A	Middle Arm	8402644	124.4
2007-08-01	Chantal	Argentia	8400104	189.3
		Whitbourne	8404234	150
2010-09-20	Igor	Branch	8400666	108.2
2012-10-28	N/A	Whitbourne	8404234	204.4

Table 1.6 Large Rainfall Events for Newfoundland and Labrador (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1884-07-11	N/A	Belle Isle	8500500	142.5
1884-07-18	N/A	Belle Isle	8500500	128.8
1887-08-28	N/A	Belle Isle	8500500	130
1909-12-04	N/A	St John's	8403500	120.7
1935-08-25	Unnamed	Grand Falls	8402050	127.3
1944-09-15	Unnamed	Fogo	8401600	102.9
1945-11-05	N/A	Burgeo 2	8400800	132.1
1945-11-06	N/A	Buchans	8400699	112.5
		Buchans A	8400700	106.4
1948-09-02	Unnamed	Corner Brook	8401300	118.2
1951-04-11	N/A	St John's A	8403506	131.1
		St John's	8403500	122.2
		Gander Int'l A	8401700	100.9
1951-04-12	N/A	St John's West CDA	8403600	119.4
1951-08-06	N/A	Gander Int'l A	8401700	117.6
		Glenwood	8401800	113
1953-08-16	Barbara	Goose A	8501900	144.7
		Hopedale (AUT)	8502400	117.6
1953-10-07	Unnamed	Grand Bank	8402000	102.7
1959-11-02	N/A	Petty Harbour	8402925	149.8
		Pierres Brook	8402950	131.3
		Cape Broyle	8400850	115.6
		Tors Cove	8403950	114.3
1960-09-14	Donna	Burgeo 2	8400800	103.3
1964-06-12	N/A	Burgeo 2	8400800	100.6
1965-08-20	N/A	Daniels Harbour	8401400	102.7
1966-12-21	N/A	Cape Broyle	8400850	117.3
		Petty Harbour	8402925	114.6
		Tors Cove	8403950	110.8
		Pierres Brook	8402950	109.5
		Seal Cove	8403650	107.4
		St John's West CDA	8403600	105.6
		St John's A	8403506	102.8
1968-08-28	N/A	Burgeo	8400798	100.5
1969-09-25	Unnamed	New Chelsea	8402840	131.3
		Hearts Content	8402080	114.6

Table 1.6 Large Rainfall Events for Newfoundland and Labrador (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1970-08-08	N/A	Tors Cove	8403950	127.3
		Salmonier	8403620	115.6
		Colinet	8401200	108
		Avondale CDA	8400225	106.4
		Hearts Content	8402080	105.2
		Pierres Brook	8402950	102.6
		Long Harbour	8402569	101.6
1970-08-09	N/A	St Lawrence	8403615	119.7
1970-08-12	N/A	Pierres Brook	8402950	117.3
		Colinet	8401200	100.6
1970-08-19	Unnamed	St John's	8403501	153
		St John's A	8403506	102.3
1971-08-16	Beth	Burgeo	8400798	109.2
		Hearts Content	8402080	105.7
		New Chelsea	8402840	104.1
1972-11-11	N/A	St John's A	8403506	115.4
1973-10-27	Gilda	Bay D'Espoir Gen Stn	8400413	121.4
		Westbrook St Lawrence	8404201	101.1
		Ebbegunbaeg Lake	8401530	100.8
1977-10-03	N/A	St Albans	8403290	108.6
1977-11-14	N/A	Burnt Pond	8400812	107.2
1978-01-15	N/A	Bay D'Espoir Gen Stn	8400413	111
1979-03-08	N/A	Burgeo	8400798	109.9
1979-07-18	N/A	Burgeo	8400798	116.4
1979-07-28	N/A	Rocky Harbour	8403096	112.6
1979-12-27	N/A	Burgeo	8400798	107.2
		Port Aux Basques	8402975	105.5
1980-05-10	N/A	Port Aux Basques	8402975	110.1
1981-08-18	N/A	Plum Point	8402958	108.6
		Daniels Harbour	8401400	105
		Western Arm Brook	8404210	100.8
1981-12-03	N/A	Tompkins	8403870	129
1982-04-29	N/A	Port Aux Basques	8402975	133.9
		Doyles	8401EK4	106
1983-01-12	N/A	Upper Salmon	8404080	108.6
1983-01-13	N/A	Bay D'Espoir Long Pond	8400414	182.2
		Burnt Pond	8400812	135.6
		Burgeo	8400798	123.5
		Grand Falls	8402050	116.4
		Wooddale Bishop's Falls	8404310	102
1983-03-03	N/A	Pools Cove Fortune Bay	8402973	103.2
1983-11-18	N/A	Markland	8402590	113.4
		Lockston	8402565	104
1984-09-02	Cesar	Salt Pond	8403623	106.3
		Port Aux Basques	8402975	106
		Harbour Breton	8402071	103.8
		St Lawrence	8403615	102.5
		Winterland	8404240	101
		Bay D'Espoir Long Pond	8400414	127
		Burgeo	8400798	122.4
1985-07-18	Ana	Arnolds Cove	8400135	119.2
		Boat Harbour	8400578	107
1985-11-08	N/A	Salt Pond	8403623	108

Table 1.6 Large Rainfall Events for Newfoundland and Labrador (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1986-01-28	N/A	Burnt Pond	8400812	101.7
1986-04-11	N/A	Swift Current	8403825	113.4
		La Scie	8402520	107.2
1986-06-09	Andrew	Long Harbour	8402569	101.8
1988-11-03	N/A	Grey River	8402057	103
1989-08-05	Dean	Black Duck	8400570	115
1989-08-06	Dean	Stephenville A	8403800	131.8
1990-04-12	N/A	Pools Cove Fortune Bay	8402973	103.8
1990-05-20	N/A	St John's Thorburn Road	8403523	111.6
1990-05-21	N/A	Terra Nova Nat Park HQ	8403852	116.2
		Gander Int'l A	8401700	110.2
		Robert's Arm	8403093	108.8
1990-07-25	N/A	Gallants	8401642	101.4
1990-12-09	N/A	Hope Brook	8402383	120.4
		Lockleven	8402563	107.6
		Tompkins	8403870	107.2
1992-10-14	N/A	Branch	8400666	127.8
1993-03-14	N/A	Pools Cove Fortune Bay	8402973	101.8
1995-06-08	Allison	Gallants	8401642	149.2
		Woody Point	8404320	103.4
1995-07-19	Chantal	Middle Arm	8402644	107.4
1995-09-10	Luis	Swift Current	8403825	109
		Port Union	8403050	104
1995-09-11	Luis	Bonavista	8400600	110
1996-09-15	Hortense	Butlerville	8400QJK	103.2
1997-09-05	N/A	Harbour Breton	8402071	113
		Salt Pond	8403623	106.8
		Red Harbour PB	8403083	105.5
		Boat Harbour	8400578	102.8
		Grand Bank	8401999	100.2
1998-02-27	N/A	Red Harbour PB	8403083	132.8
		Winterland	8404240	124.6
		Boat Harbour	8400578	104
1998-09-06	Earl	Point Leamington	8402966	115.3
1999-04-28	N/A	Winterland	8404240	141
		Boat Harbour	8400578	131
		Salt Pond	8403623	119.1
		Red Harbour PB	8403083	112.8
		Holyrood Gen Stn	8402309	110
		Salmonier Nature Park	8403621	105.8
		Hearts Content	8402080	105
2001-08-28	Dean	Boat Harbour	8400578	111.8
		Red Harbour PB	8403083	111.8
		Salt Pond	8403623	108.6
2001-09-14	Erin	Harbour Breton	8402071	116.2
2001-09-19	Gabrielle	Portugal Cove	8403044	120.6
		St John's A	8403506	118.6
		Logy Bay	8402568	110
		Salmonier Nature Park	8403621	105
2003-03-31	N/A	Gallants	8401642	150.2
		Corner Brook	8401300	105.4
2004-09-10	Frances	Gallants	8401642	109.2

Table 1.6 Large Rainfall Events for Newfoundland and Labrador (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
2004-09-19	Ivan	Branch	8400666	138
		North Harbour	8402874	131
		Holyrood	8402303	114
		Goobies	8401880	112
		Lethbridge	8402544	108
		Swift Current	8403825	102.6
		Portugal Cove	8403044	101.4
2004-09-20	Ivan	Charleston	8401128	147.6
		Rattling Brk Norris Arm	8403085	137
		Point Leamington	8402966	120.5
		Gander Int'l A	8401700	112.2
		Clarenville	8401141	112
		Port Blandford	8403008	109
		Goobies	8401880	108
2004-09-21	Ivan	Middle Arm	8402644	103.6
2010-09-20	Igor	Harbour Breton	8402071	112
2010-09-21	Igor	Lethbridge	8402544	186
		Whitbourne	8404234	144.4
		Gander Int'l A	8401700	124.4
		Butlerville	8400QJK	123.5
		St John's A	8403506	120.2
		Brownsdale	8400675	105.4
2012-09-10	Leslie	Cow Head	8401335	108.8

Table 1.7 Large Rainfall Events for Prince Edward Island (One Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	24-hr Rainfall (mm)
1942-09-22	Unnamed	Charlottetown CDA	8300400	163.8
		Summerside CDA	8300600	119.4
		Summerside A	8300700	109.2
1971-08-15	Beth	Alliston	8300100	127.5
		Montague	8300445	124
		Souris	8300585	120.9
		Monticello	8300447	106.4
1990-08-01	Bertha	Monticello	8300447	101
2014-12-10	N/A	Elmwood	8300425	110

Table 1.8 Large Rainfall Events for Prince Edward Island (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1900-10-11	N/A	Charlottetown	8300298	105.2
1912-07-23	N/A	Hamilton	8300438	140.5
1935-08-25	Unnamed	Charlottetown CDA	8300400	108.2
1944-11-06	N/A	Summerside A	8300700	118.3
		Charlottetown A	8300300	121.2
1950-08-21	Able	Charlottetown CDA	8300400	119.6
1962-04-01	N/A	Borden	8300150	108.7
1967-10-10	N/A	Borden	8300150	111.8

Table 1.8 Large Rainfall Events for Prince Edward Island (Two Day Rainfall Totals)

Date	Name of Storm (if applicable)	Station Name	Station ID	48-hr Rainfall (mm)
1970-08-12	N/A	Alberton	8300080	105.7
1990-08-02	Bertha	Bangor	8300128	116.2
		East Baltic	8300416	114.4
1996-09-14	Hortense	Alliston	8300100	107
2003-08-06	N/A	Kingsboro	8300442	105.4
2012-09-10	Leslie	Alliston	8300100	116.1
2014-12-10	N/A	New Glasgow	8300497	116

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