4.1.7

HALIFAX
REGIONAL MUNICIPALITY

PO Box 1749
Halifax, Nova Scotia
B3J 3A5 Canada

North West Community Council
February 23, 2006

TO: Chairman and Members of North West Community Council

SUBMITTED BY: Tony Blouin

Tony Blouin, PhD.
Acting Director, Environmental Management Services

DATE: February 17, 2006

SUBJECT: **Union Street Flooding**

ORIGIN

At the North West Community Council Meeting of January 26, 2006, Item No. 4.17, a motion was passed stating "Councillor Goucher advised that he received a final report, commissioned by HRM, from SGE Acres. Motion passed to have the report forwarded to the Bedford Waters Advisory Board and staff for review and comment."

RECOMMENDATION

It is recommended that Community Council forward this matter to Regional Council for consideration amongst other capital priorities as part of the 2006/07 Capital Budget deliberations.

BACKGROUND

The rainfall event of March 31, 2003 was extreme, and resulted in flooding of many properties throughout the Halifax Regional Municipality, and in other parts of the Province. One area that was affected was Union Street in Bedford, located adjacent to the Sackville River. A number of homes on Union Street experienced property and/or basement flooding.

On September 30, 2004 and on January 11, 2005 staff forwarded to the North West Community Council information reports (see attached) on this issue. Subsequently Councillor Len Goucher requested that Environmental Management Services engage an engineer to investigate the concept of raising the effective height of the bank of the Sackville River, adjacent to Union Street, in order to provide additional flood protection to approximately 25 homes which are located in the floodplain. The study was to also investigate the possibility that recent high flow events indicates a trend of increased frequency of extreme events.

SGE Acres Limited was retained to undertake this study. Their report, Union Street Flood Control, has been completed and has been circulated to the North West Community Council and the Bedford Water Advisory Board (BWAB).

DISCUSSION

Staff have reviewed and accepted the contents of the SGE Acres Limited report. The following is a summary of the key findings:

- Presently some homes on Union Street could experience flooding during the 1 in 5 year exceedance probability event, that is, a 20% probability in any given year that the flood would be equalled or exceeded.

- Raising the effective height of the bank of the Sackville River by 600 mm should protect the residences from a 1 in /20 year exceedance probability event and this would have a negligible effect on flooding of structures on the opposite side of the River and upstream structures. It is expected that water levels in these areas would increase by one or two centimeters (approximately 3/4 inch). If raising the effective height of the bank (via concrete blocks or other means) is to proceed, an engineering design should first be undertaken.

- A statistical analysis concluded that, based on historical data, there has not been an increase in the frequency of extreme events. Recent high flow events are likely due to the natural variability of flows.

Throughout the past three years that this project has been discussed between Councillor Goucher and staff, Legal Services has consistently maintained that HRM is not legally responsible or liable to provide the proposed flood protection measures at Union Street. Accordingly, Environmental Management Services has assigned a low priority (Category 5, in accordance with Regional Council's Priority Rating Process) to this project. As a result, given the severe under funding of wastewater/ stormwater works in HRM, the Union Street project continues to fall outside of Regional Council's annual capital funding envelope.

Staff certainly empathize with the flooding faced by the homeowners on Union Street and staff fully understands why Councillor Goucher wishes this project to proceed immediately and be constructed prior to Spring, 2006. This project is not currently within the 05/06 Budget and therefore must proceed to Regional Council for consideration and removal of offsetting capital funds from the 05/06 Budget.

At this late date, staff are not confident that this project can be approved by Regional Council, funded, tendered, designed and built prior to Spring, 2006. As a result, staff recommend that Community Council forward this matter to Regional Council for consideration amongst other capital priorities as part of the 2006/07 Capital Budget deliberations.

Should both Community and Regional Councils wish to proceed with the project, staff recommend that the next step would be to engage an engineering firm to provide an appropriate design. A properly engineered design is required to mitigate against a failure of the new system. The potential consequence of a failure of this type of system can be significant (ie. catastrophic mode of failure resulting in a wave of water) and if HRM was found to be negligent in how the improvements were undertaken then HRM could be liable for damages. The engineered design would provide detail as to how to add 600 mm (24 inches) in height to the existing 200 metre (650 foot) long berm (via concrete blocks, earth fill, etc.) and confirm the overall stability of this new configuration. Preliminary estimates for the complete project (assuming earthen fill) are in the range of $200K to $250K, excluding contingency funds. Prior to proceeding with this work, the status of land ownership and easements would need to be confirmed. Staff have made a preliminary review and, at this time, it is unknown if HRM has the legal right to access all land along the alignment of the existing berm.

There are many homes located within floodplains in HRM. Proceeding with the Union Street project could potentially raise expectations among citizens that Council intends to fund a program of flood protection measures for all homes located within HRM floodplains. Staff does not know the extent of these areas but expects that it may be vast, and a flood protection program would be a very substantial cost to HRM.

If it is Regional Council's objective to provide flood protection for residents throughout HRM, then it may be a consideration to investigate the option of a larger water control structure project upstream on the Sackville River. Such a structure might provide better value for money in terms of providing flood protection for many more potentially impacted properties within this floodplain.

BUDGET IMPLICATIONS

None directly resulting from this report.

FINANCIAL MANAGEMENT POLICIES / BUSINESS PLAN

This report complies with the Municipality's Multi-Year Financial Strategy, the approved Operating, Capital and Reserve budgets, policies and procedures regarding withdrawals from the utilization of Capital and Operating reserves, as well as any relevant legislation.

ALTERNATIVES

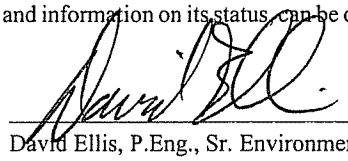
Community Council could forward this matter for consideration by Regional Council as an addition

to the 05/06 Budget. Staff are not optimistic that the project can be properly completed prior to Spring 2006 and therefore recommend that this project be given appropriate consideration by Regional Council during the 2006/07 budget deliberations.

ATTACHMENT

1. Information Report - September 30, 2004
2. Information Report - January 11, 2005

Additional copies of this report, and information on its status, can be obtained by contacting the Office of the Municipal Clerk at 490-4210, or Fax 490-4208.

Report Prepared by: 

David Ellis, P.Eng., Sr. Environmental Engineer 490-6716

HALIFAX
REGIONAL MUNICIPALITY

PO Box 1749
Halifax, Nova Scotia
B3J 3A5 Canada

North West Community Council
September 30, 2004

TO: Chairman and Members of North West Community Council

SUBMITTED BY: Brad Anguish, P.Eng., PMP, MBA,
Director, Environmental Management Services

DATE: August 9, 2004

SUBJECT: Union Street Flooding

INFORMATION REPORT

ORIGIN

At the North West Community Council Meeting of September 25, 2003, Item No. 12.1 - Request for Status Reports, a motion was passed requesting a status report on Union Street Flooding.

BACKGROUND

The rainfall event of March 31, 2003 was extreme, and resulted in flooding of many properties throughout the Halifax Regional Municipality, and in other parts of the Province. One area that was affected was Union Street in Bedford, located adjacent to the Sackville River. A number of homes on Union Street experienced property and/or basement flooding.

DISCUSSION

HRM staff has analyzed the rainfall data collected by Environment Canada for the March 31 rainfall event. For a watershed the size of the Sackville River watershed, this rainfall was approximately equal to a 1 in 15 year rainfall event. A review of the weather records preceding the storm indicates that other factors (e.g. high water levels in lakes and rivers, wet ground and snowmelt) contributed to the actual stormwater runoff being much greater than that normally expected from a 1 in 15 year event.

Staff has reviewed flow data from an Environment Canada monitoring station located near the mouth of the Sackville River. This data indicates that the peak measured flow rate at the mouth of the Sackville River was approximately equal to the 1 in 100 year flow estimated for the Sackville River in the hydro-technical study conducted by the Canada-Nova Scotia (CNS) Flood Reduction Program. The peak flow at the measuring station occurred at approximately 11:30 pm on March 31, 2003.

The Union Street properties which flooded are located within the 1 in 100 year floodplain of the Sackville River, identified in the CNS Hydro-technical Study. It is therefore predictable that these properties would have flooded during the March 31, 2003 event, as a result of the flood levels in the Sackville River and the floodplain where these homes are located.

It is the understanding of staff that the drainage ditch that runs along the back of the properties on the east side of Union Street flooded on March 31st. The drainage ditch was upgraded in 1996 as a cost-shared project with a local developer, Redden Brothers, who were developing land in the local watershed at that time. The ditch was intended to carry stormwater from the watershed and convey that stormwater to the Sackville River. The upgrading work was not intended to control flood water from the Sackville River, although the outfall of the storm system was extended to reduce to some extent the impact of the river on the ditch.

Also, a berm was constructed south of the Union Street access road into Bedford Place Mall at that time, in order for the contractor to gain access to carry out a portion of the upgrading work on the ditch. The berm was not intended or designed to control or to prevent flood water from the Sackville River from entering into the upgraded drainage system, or into the floodplain of the Sackville River where the Union Street properties that flooded are located.

The Bedford Watershed Advisory Board (BWAC) requested that HRM staff do an assessment of the March 31st flooding at Union Street. On September 11, 2003, staff attended the BWAC meeting and presented the findings of the assessment. A number of residents from Union Street attended this meeting.

It has been suggested that HRM consider raising the banks of the Sackville River adjacent to Union Street, in order to protect the homes which are located in the floodplain. This proposed solution would also require the existing local drainage channel to be piped, and perhaps a portion of the existing Sackville River channel to be excavated. The cost to construct these works is estimated to be $500,000 or perhaps more depending on the required scope of work. Additionally the following potential problems with this approach should be considered:

- Raising the river bank will remove a major part of the natural floodplain near the mouth of the river, which will have the effect of constricting flow and creating higher flow levels upstream, which may result in more flooding upstream and perhaps exposing Union Street residents to additional flooding from upstream areas.

- Raising the bank of a river or constructing engineered works to act as flood control (i.e. within the natural floodplain) is generally not considered to be a preferred approach. Flood control works tend to give residents a false sense of security. These works have the potential to fail in extreme events, and the resulting damage is often worse than the damage from natural flooding.

- Works in a river such as those proposed above are regulated by various Federal and Provincial Departments such as Fisheries and Oceans and the Department of Environment and Labour. Depending on the exact scope of work, compliance with these regulations may be difficult and add significant cost to the project. Preliminary contact has been made with NS Department of Environment and Labour.

- Another possible approach to the Union Street situation is to apply flood proofing techniques at the individual homes. Possible techniques include landscaping, sealing openings below certain flood levels and relocating electrical panels and furnaces to higher levels. It is strongly recommended that professionals be consulted prior to making any changes such as those described above.

A proposal to use Jersey barriers for flood control has been identified as a possibility. Any technique to keep flood waters out of any part of the floodplain will have the effect of raising the flood levels in the river, thereby increasing flooding of other properties. As discussed above, this can possibly be mitigated by excavating a portion of the river channel.

Although the provision of Jersey barriers in the flood plain may not require provincial approval, any excavation of the river channel to mitigate increased flooding would require provincial approval, and there is no guarantee that such approval would be granted.

Staff of EMS met with staff of the provincial Department of Environment and Labour on July 22 to confirm their position on this matter.

HRM does not have a program to protect properties located in the floodplain of rivers from flooding. However, Regional Council could direct staff to investigate what options are available to reduce the risk of flooding at Union Street and assess the resulting impacts on the area. If this course of action is chosen, staff recommends that a qualified consultant be hired to evaluate the available options, examine regulatory implications, develop cost estimates and cost recovery approaches, analyse the associated risk and make recommendations as to the feasibility of each option. This study could be funded from a Local Improvement Charge or an Area Rate to be recovered from a defined Charge Area. Any works that may result from such a study could similarly be funded from a Local Improvement Charge or Area Rate.

The MGA enables the HRM to define Charge Areas for the purpose of funding storm water works. The Charge Area could be as small as the Union Street properties which flood. Another possibility is that the Charge Area be comprised of the full Sackville River Watershed. There is some logic to the latter approach in that the full watershed contributes flow to the Sackville River.

BUDGET IMPLICATIONS

None at this time.

FINANCIAL MANAGEMENT POLICIES / BUSINESS PLAN

This report complies with the Municipality's Multi-Year Financial Strategy, the approved Operating, Capital and Reserve budgets, policies and procedures regarding withdrawals from the utilization of Capital and Reserve budgets, policies and procedures regarding withdrawals from the utilization of Capital and Operating reserves, as well as any relevant legislation.

ALTERNATIVES

None recommended. However, staff could be directed by Regional Council to fund a project through the Capital Budget (only after an offsetting project(s) has been removed from the budget) to reduce the opportunity of flooding of Union Street properties from the Sackville River. If this approach is taken, it is possible that similar requests will be received from other property owners near the Sackville River or near other rivers in HRM, to resolve their flooding problems caused by the effects of river flooding. It is expected that the financial implications of this could be significant.

ATTACHMENT

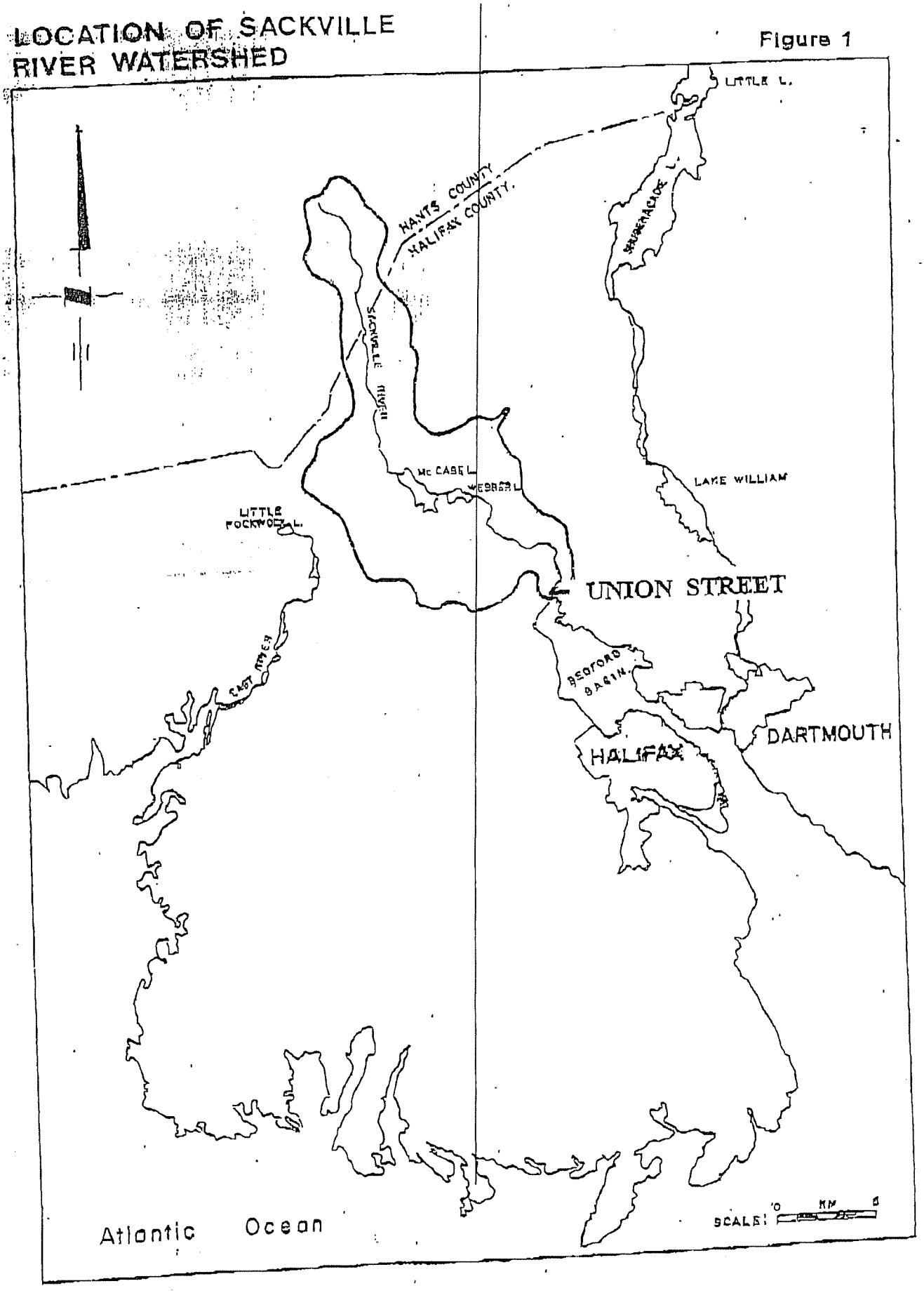
Sketch - Location of Sackville River Watershed

Additional copies of this report, and information on its status, can be obtained by contacting the Office of the Municipal Clerk at 490-4210, or Fax 490-4208.

Report Prepared by:	Charles Lloyd, P.Eng., Sr. Environmental Engineer	490-6942
Report Approved by:	John P. Sheppard, P.Eng., Manager, Environmental Services	490-6958

LOCATION OF SACKVILLE RIVER WATERSHED

Figure 1



HALIFAX
REGIONAL MUNICIPALITY

PO Box 1749
Halifax, Nova Scotia
B3J 3A5 Canada

North West Community Council
January 28, 2005

TO: Chairman and Members of North West Community Council

SUBMITTED BY: Brad Anguish, P.Eng., PMP, MBA,
Director, Environmental Management Services

DATE: January 11, 2005

SUBJECT: **Union Street Flooding**

INFORMATION REPORT

ORIGIN

At the North West Community Council Meeting of September 30, 2004, Item No. 4.1.4, a motion was passed requesting staff review the idea of using concrete barriers as an interim measure for the Union Street Flooding issue and report back.

BACKGROUND

The rainfall event of March 31, 2003 was extreme, and resulted in flooding of many properties throughout the Halifax Regional Municipality, and in other parts of the Province. One area that was affected was Union Street in Bedford, located adjacent to the Sackville River. A number of homes on Union Street experienced property and/or basement flooding.

DISCUSSION

Staff have previously submitted an Information Report (see attached September 30, 2004 report) on this matter to the North West Community Council. The current request asked staff to consider the feasibility of using concrete barriers as an interim measure for the Union Street Flooding issue.

The concept of concrete barriers (i.e. Jersey barriers) was addressed in the September 30, 2004 report. The report stated "Any technique to keep flood waters out of the floodplain will have the effect of raising the flood levels in the river, thereby increasing flooding of other properties." Based on this staff does not recommend concrete barriers, even as an interim measure.

BUDGET IMPLICATIONS

None.

FINANCIAL MANAGEMENT POLICIES / BUSINESS PLAN

This report complies with the Municipality's Multi-Year Financial Strategy, the approved Operating, Capital and Reserve budgets, policies and procedures regarding withdrawals from the utilization of Capital and Operating reserves, as well as any relevant legislation.

ALTERNATIVES

None recommended.

ATTACHMENT

Information Report dated September 30, 2004.

Additional copies of this report, and information on its status, can be obtained by contacting the Office of the Municipal Clerk at 490-4210, or Fax 490-4208.

Report Prepared by: David Ellis, P.Eng., Senior Environmental Engineer (490-6716)

Report Approved by: John Sheppard, P.Eng., Manager of Environmental Engineering Services (490-6958)

4.1.7

HALIFAX
REGIONAL MUNICIPALITY

P.O. Box 1749
Halifax, Nova Scotia
B3J 3A5 Canada

North West Community Council
February 23, 2006

TO: Members of North West Community Council

SUBMITTED BY: Stephanie Pauers
for Don Lowther, Chair, Bedford Waters Advisory Board

DATE:

SUBJECT: **Union Street Flooding - SGE Acres Report**

ORIGIN

At the North West Community Council meeting, held on January 25, the Community Council tabled the SGE Acres report and referred it to the Bedford Watershed Advisory Board for input and comment.

RECOMMENDATION

It is recommend that North West Community Council recommend that staff proceed with the proposed installation of Jersey Barriers along the right (westerly) bank of the Sackville River from the existing barriers up to the service road off Union Street leading to the Superstore.

BACKGROUND

This matter had been raised at the Bedford Watershed Advisory Board meetings on numerous occasions. At the January 12, 2005 meeting the Board passed a motion recommending that HRM staff initiate interim measures to prevent flooding of the Union Street area and provide a staff report on a permanent solution.

DISCUSSION:

See draft minute extract dated February 8, 2006.

BUDGET IMPLICATIONS

There are budget implications inherent in the recommendation. They are unknown at this time.

FINANCIAL MANAGEMENT POLICIES/BUSINESS PLAN

This report complies with the Municipality's Multi-Year Financial Strategy, the approved Operating, Capital and Reserve budgets, policies and procedures regarding withdrawals from the utilization of Capital and Operating reserves, as well as any relevant legislation.

ALTERNATIVES

1. North West Community Council may choose not approve the recommendation.
2. North West Community Council can approve the recommendation with amendments.

ATTACHMENTS

1. Minute Extract February 8, 2006
2. SGE Acres report dated December 2005.

Additional copies of this report, and information on its status, can be obtained by contacting the Office of the Municipal Clerk at 490-4210, or Fax 490-4208.

Report Prepared by: Stephanie Parsons Legislative Assistant 490-6519

BEDFORD WATERSHED ADVISORY BOARD

Draft Minute Extract

February 8, 2006

4.1.5 Storm Water Management: Union Street Area

- A report entitled Union Street Flood Control - Final Report dated December 2005, commissioned by HRM to SGE Acres was circulated to the Committee for discussion.

Councillor Goucher advised that the report by SGE Acres was tabled at the January 25, 2006 meeting of Northwest Community Council and was referred to the Bedford Watershed Board for input and comment. The scope of the report was to determine what the impact of the installation of 600 mm by 600 mm barriers to water levels upstream and the adjacent properties along Union Street. The report indicates that there would be negligible impact.

A discussion ensued and board members had differing views as to the purpose of the report and wether or not a trend exist as per the statistical analysis provided by SGE Acres, given the fact that a number of residential homes have been flooded in recent years. Those who agreed with the analysis commented that the report indicates that there maybe a change in the future but there is no trend at this time.

The Chair suggested that:

- the berm be leveled
- the existing barriers be secured
- additional barriers be installed up to the service road leading to the Superstore

He commented that the proposal is not a permanent fix but will mitigate the current flooding issues until such time that resources are available to address the entire area.

Councillor Goucher clarified that the intent of the report was to advise HRM on the impact of installing barriers, specifically, assurance that there would be no impact on flows upstream and on adjacent properties before installing them. The question to the Board is whether they concur with the report that there would be no impact

Ms. Loney raised concern with providing a recommendation when the report suggest that other information is required to determine the capacity of the ditch. Councillor Goucher commented that the drainage ditch was outside the scope of the report.

After further discussion the following motion was placed given the fact that the report by SGE Acres indicates that the proposed protection plan has a negligible effect on flooding

of structures on the opposite side of the river and upstream structures.

MOVED BY Mr. Dean, seconded by Mr. Reeder that the Bedford Watershed Advisory Board recommend that North West Community Council recommend that staff proceed with the proposed installation of jersey barriers along the right (westerly) bank of the Sackville River from the existing barriers up to the service road leading to the Superstore. MOTION PUT AND PASSED.

Prepared for

Halifax Regional Municipality

P.O. Box 1749, Halifax, Nova Scotia B3J 3A5

Consulting Services for

Union Street Flood Control - Final Report

Prepared by

SGE Acres Limited

December 2005

P16896.00

SGE Acres

Table of Contents

List of Figures

Acronyms

AEP	Annual Exceedence Probability
DND	Department of National Defense
EC	Environment Canada
HEC-RAS	Hydrologic Engineering Centre – River Analysis Software
HRM	Halifax Regional Municipality
HYFRAN	Hydro-Québec Frequency Analysis Software Package

Executive Summary

Halifax Regional Municipality engaged SGE Acres Limited to conduct a study regarding flood control in the Union Street area in the Bedford region of Halifax, Nova Scotia. Several residences along Union Street have experienced flooding in recent years due to high water levels in the Sackville River. Water levels have been a concern to these residents on at least four occasions in the past three years.

This flooding is not a recent problem. In 1981, a hydrotechnical study of the Sackville River concluded that some homes in this area were within the twenty year floodplain[1]. Based on current modeling, some of the residences on Union Street could experience flooding during the 1/5 annual exceedance probability (AEP) event, that is, a probability every year of 20 percent that the flood would be equaled or exceeded.

There is a proposal to install 600 mm by 600 mm concrete blocks to the top of the right (westerly) bank of the Sackville River to provide some flood protection to these houses. The current study concludes that water levels would reach the top of this proposed barrier in a flow of 102 m^3/s (exceeding the estimated 1/20 AEP event). Water levels in the location of structures on the opposite side of the river and upstream would be a few centimeters higher as a result of this proposed flood protection. Water levels would be about 1100 mm above the existing level of the right bank in a flow of 126 m^3/s (estimated 1/100 AEP event). The design of flood protection should include an allowance for freeboard.

Modeling of the adjacent storm drainage system was outside the scope of the present study. In large floods high water levels at the outlet of the stormwater culvert could reduce the capacity of the culvert and lead to flooding. The capacity of the culvert and drainage ditch should therefore be checked.

Due to the occurrence of several high flow events in recent years, some members of the public have an impression that there is a trend of increasing frequency of extreme events. To address this concern, a statistical analysis was performed on flow and rainfall records in the area. This analysis concluded that based on historical data, none of the data sets show significant trend and the recent events are likely due to the natural variability of flows.

Recent research by Environment Canada suggests that in the future, however, the frequency of extreme precipitation events may increase. One study predicts that an extreme precipitation event in Greenwood, Nova Scotia that has a classification of 1/100 AEP today, could become a 1/10 AEP event by the 2050s[2]. For this reason, it would be prudent to be conservative in the design of flood protection.

Executive Summary

Introduction

1 Introduction

In September 2005, Halifax Regional Municipality (HRM) engaged SGE Acres Limited (SGE Acres) to complete a flood control study for a portion of the Sackville River in the Bedford area of Halifax. A general location plan and an aerial photo of the study area are included as Figures 1.1 and 1.2, respectively. Recent high flow events have lead to flooding of residences in the Union Street area; the purpose of this study is to examine the effectiveness of the proposed flood protection plan. In addition, this study examines the public perception that there is a trend of increasing frequency of extreme events.

Throughout this report, the term 'annual exceedance probability' (AEP) is used to describe the severity of floods. This is the inverse of what is often referred to as the 'return period' (in years). A flood with an AEP of 1/100 has a probability of one percent of being equaled or exceeded in any given year.

1.1 Scope of Work

The main objectives of this study are as follows.

- Comment on the proposed flood protection plan.
- Determine any additional flooding that may occur as a result of the proposed flood protection plan.
- Comment on the frequency of flood events.
- Comment on the perception of a trend of increasing flood frequency.

The assessment described herein relates only to estimating water levels with or without flood protection. No assessment of structural and geotechnical issues has been completed, nor has an assessment of the use of concrete blocks as water retaining structures been made.

1.2 Background Information

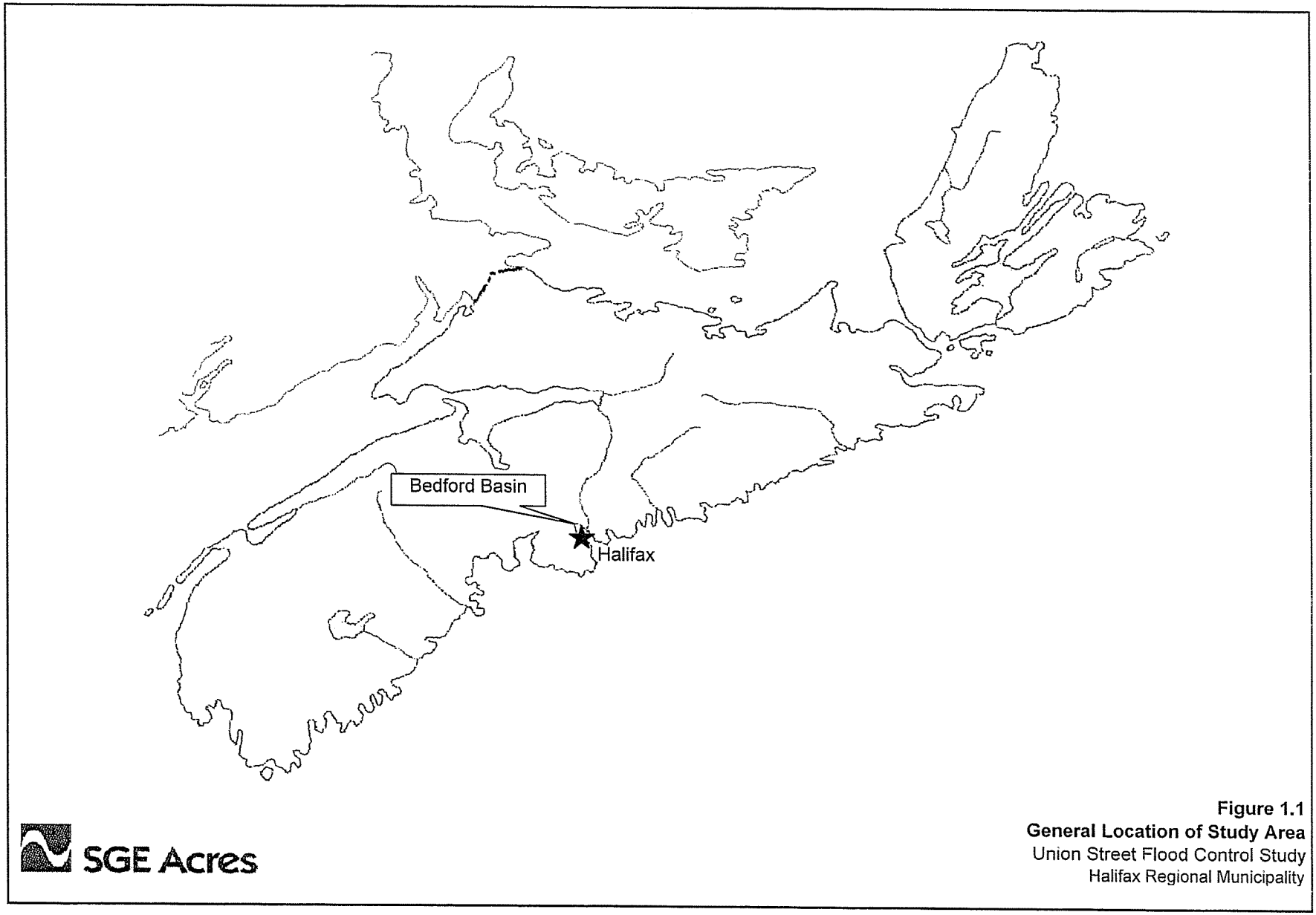
The Sackville River is urbanized and channelized along its lower reaches and has a mild gradient. Flooding of residential and commercial properties in the floodplain has occurred various times over the years.

The most recent severe flooding occurred in March 2003. There have been several events since that time (November 2004, and two events in May 2005) that

have also led to water levels of concern to local residents. Most of the flooding has occurred on the east side of Union Street, just upstream of the intersection with the Bedford Highway. It is flooding in this area that is of prime interest to this study.

In 1981, a "Hydrotechnical Study of the Sackville River" (1981 Study) was completed as part of the Canada – Nova Scotia Flood Damage Reduction Program[1]. In the 1981 Study, the 1/20 and 1/100 AEP floodplains were delineated, and some of the houses of concern to this study are within that 1/20 AEP floodplain.

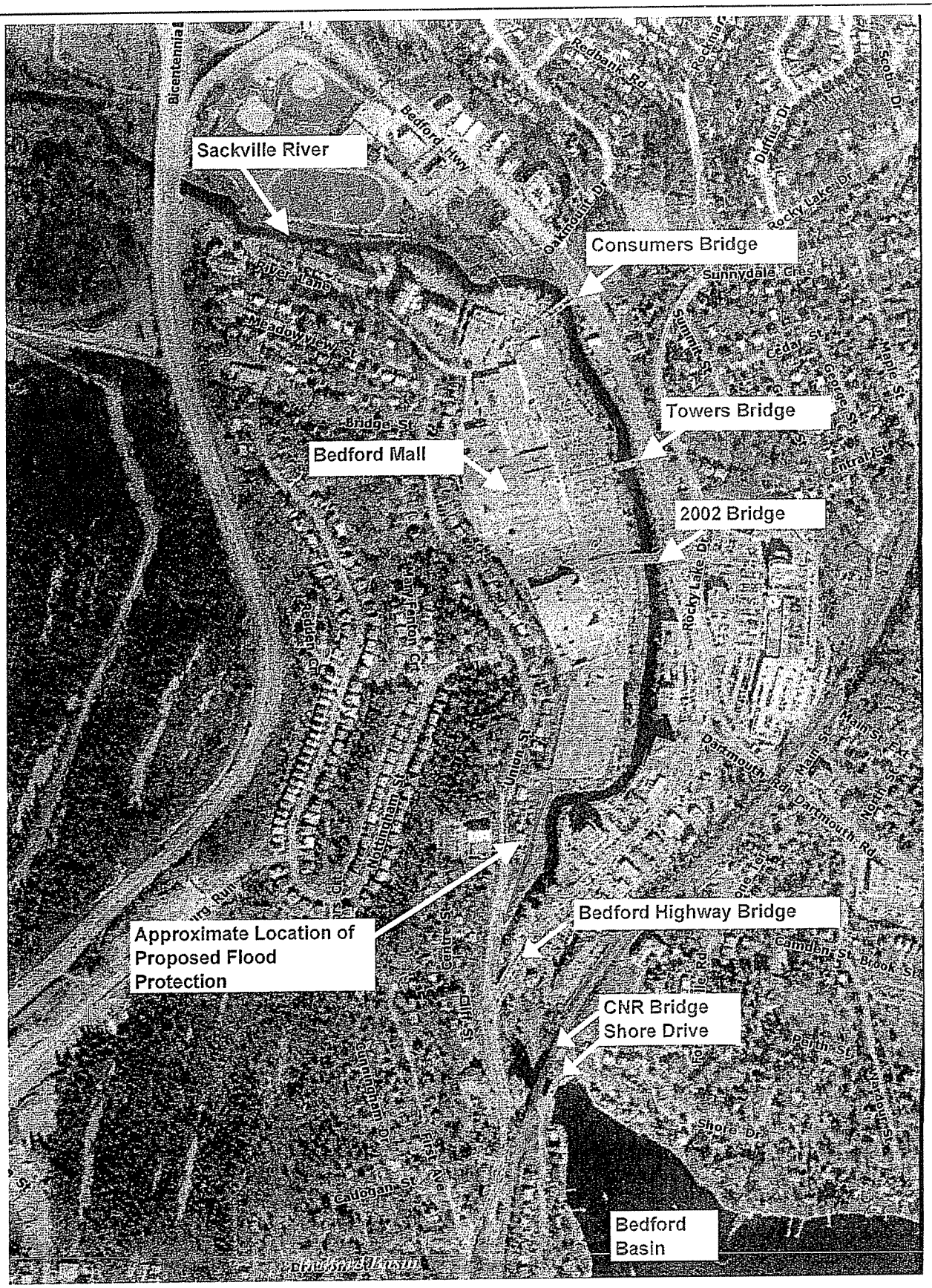
Currently there are sand bags and jersey barriers along portions of the top of the right bank. HRM is now considering the installation of 600 mm by 600 mm concrete blocks to this bank as a permanent flood control measure.



SGE Acres

Figure 1.1
General Location of Study Area
Union Street Flood Control Study
Halifax Regional Municipality

P:\2005\1689600 - Union St\Hydr\aprysephillips\Final Report\[Figures.xls]Figure 1.1



SGE Acres

Figure 1.2 Aerial Photo of Study Area
Union Street Flood Study
Halifax Regional Municipality

Site Visit and Survey

2 Site Visit and Survey

2.1 Site Visit

On September 27, 2005 following a kick-off meeting with HRM, Kevin Skebo (Project Manager) and Joanna Barnard (Lead Engineer) visited the site to gain an appreciation for the layout and topography and to plan the required survey. The temperature was approximately 15°C, and it was cloudy with some rain showers.

Starting on the left bank near the Sun Tower, Ms. Barnard and Mr. Skebo walked along the river bank first downstream to the Bedford Highway Bridge, then across the bridge and upstream on the right (westerly) bank as far as Towers Bridge. In the area of the planned flood protection they walked along the bank to view the partially completed jersey barrier wall, the drainage ditch and the sandbagging, and also along Union Street to see the front of the homes.

Following the walkover, they drove north (upstream) looking at the river where possible, as far as the DND lands to see where new pedestrian bridges were being constructed.

2.2 Survey

A limited survey of the area of interest was done by Servant Dunbrack of Halifax in the week of October 3, 2005.

The surveyors determined the following.

- Elevations of the low points of homes and commercial buildings on both sides of the Sackville River in the area of interest;
- Cross sections at the three bridges upstream of the site;
- Elevations of the top of the bank in the area of the planned flood protection;
- Elevations of Union Street in the area of the planned flood protection;
- The location of the start of the rapids just below the Environment Canada (EC) hydrometric gauge;
- A cross section at the fish weir upstream of the area of interest.

Data were provided to SGE Acres digitally, in the form of a drawing, on October 12, 2005.

Flood Hydrology Analysis

3 Flood Hydrology Analysis

3.1 Methodology

The steps involved in the flood hydrology analysis are as follows.

- Complete a frequency analysis on maximum daily and instantaneous flow records from the Sackville River.
- Complete a frequency analysis on maximum daily flow records from nearby basins and develop regional flood frequency estimates for the Sackville River.
- Compare the results of these two methods and develop flood estimates for the current study.
- Complete a trend analysis on rainfall and flow records from several stations in the region to address the public perception that floods are occurring more frequently.

3.2 Review of Hydrometric Data

EC maintains a network of hydrometric stations that measure flow and water level on rivers throughout the country. One such station is located on the Sackville River, in the reach of interest of the current study.

Flood frequency analyses were completed on this flow record as well as those from four other hydrometric stations in nearby basins, listed in Table 3.1. Of particular value are records on two rivers that extend back into the 1920s, on East River (gauged at St. Margaret's Bay) and Beaver Bank River. The Sackville River record is only 35 years long and thus these longer records are valuable for comparison.

A time series must pass standard statistical tests before a flood frequency analysis can be performed. All series were found to be independent, random, homogeneous, and showed no statistically significant trend.

Table 3.1 - EC Hydrometric Stations

Station ID	Station Name	Drainage Area (km^2)	Period of Record
01EJ004	Little Sackville River at Middle Sackville	13.1	1981-2004
01EH003	East River at St. Margaret's Bay	26.9	1926-1995
01DG003	Beaverbank River near Kinsac	96.9	1922-2004
01EJ001	Sackville River at Bedford	146	1970-2004
01DG006	Shubenacadie River at Enfield	389	1975-1995

3.3 Flood Frequency Analysis

A flood frequency analysis was performed on flow records from the Sackville River hydrometric station as well as the four other stations in surrounding basins, as summarized in Table 3.1 above. A statistical software package (HYFRAN) was used to fit several distributions to the series of annual maximum flows. The results were used to update the regional flood frequency analysis completed by SGE Acres in 2003 for the Bedford Basin area.

The resulting flood frequency curve is shown in Figure 3.1. It was obtained by applying the average ratio of instantaneous to daily flow from the Sackville River record to the daily flood estimates. The value of the adjustment ratio is 1.29, which is similar to the regional ratio determined from the 2003 regional study completed by SGE Acres for the Bedford Basin area.

Table 3.2 provides the estimated frequency (AEP) associated with four recent flood events that lead to water levels of concern in the Union Street area.

Table 3.2 - Estimated Frequency of Recent Events

Event Date	Maximum Flow (m^3/s)	Estimated Frequency (1/yr)
March 31, 2003	106	1/20 to 1/50
November 26, 2004	67.5	1/5
May 9, 2005	68.5	1/5
May 27, 2005	61.2	1/3

As shown in Table 3.2, the largest event so far this year corresponds to an event with an AEP of approximately 1/5 based on the results of the frequency analysis. The March 2003 flow of 106 m^3/s is close to the 1981 estimate of 109 m^3/s for the 1/100 AEP event, which was based on regional flood frequency equations developed using data up to the late 1970s. The 1981 study indicated that the estimate seemed abnormally low. The present analysis, using over 20 years of

additional data, confirms this judgment, and indicates a higher probability of experiencing such a flow (1/20 to 1/50 AEP).

As described in Section 3.4 below, at present there is no statistical evidence of trend. The additional data provide a better indication of natural variability in the time series, and therefore improves the estimate of extreme events.

It should be noted that recent research completed by Michael Pancura and Gary Lines of Environment Canada suggests that due to climate change, the frequency of flood events is expected to increase in the future[2]. In particular, the projection of the maximum annual 5-day total precipitation event at Greenwood NS from the base climate period (1961-1990) to the 2050s (2040-2069) would experience a 10-fold increase in frequency (that is, a 1/100 AEP event would become a 1/10 AEP event by 2050).

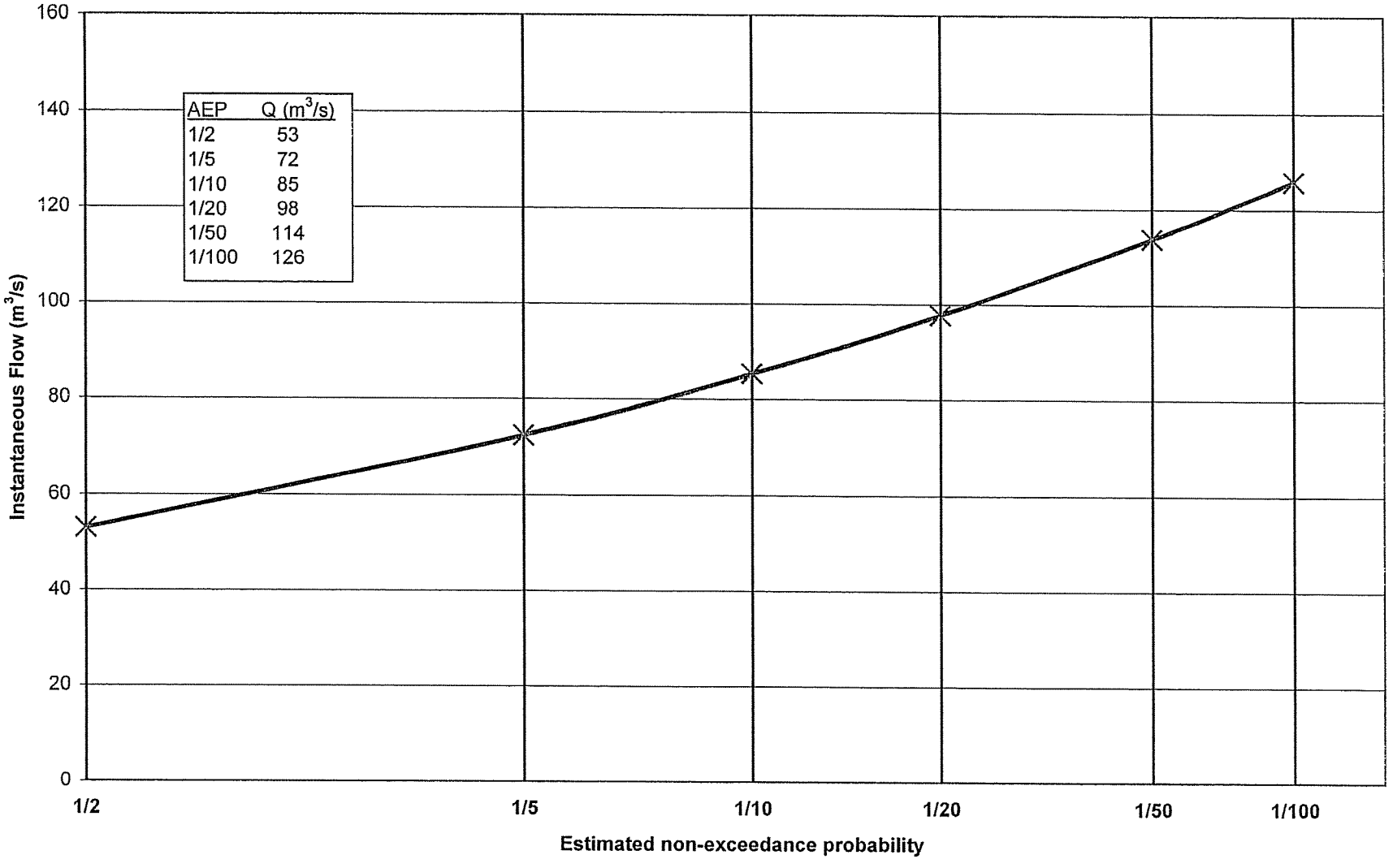
3.4 Statistical Analysis of Trend

Annual maximum daily flow records from three hydrometric stations and maximum daily rainfall from two climate stations were analyzed to investigate the public perception that there is a trend of increasing frequency of extreme events.

Appendix A includes a summary of the statistical analysis undertaken by Dr. Leonard Lye of Memorial University's Faculty of Engineering. This appendix also provides illustrative time series plots which show the recent period compared to the entire period of record for the three hydrometric records. The conclusion of this analysis is that there is no significant trend in any of the data series, and that any apparent increase over recent years is likely due to natural variability. This is not to say that there will be no trend in the future. In light of the recent research completed by Pancura and Lines, and the uncertainty regarding the effects of climate change, it would be prudent to be conservative in the design of flood protection.

Figure 3.2 illustrates the annual maximum time series for the Sackville River and the Beaver Bank River. There is good correlation between these two series for the overlapping period of record and therefore the Beaver Bank series (which has a much longer period of record) can be viewed as a surrogate for the Sackville River in terms of pattern and relative magnitudes of flood events. The actual values are lower because the Beaver Bank River basin is smaller. Although the

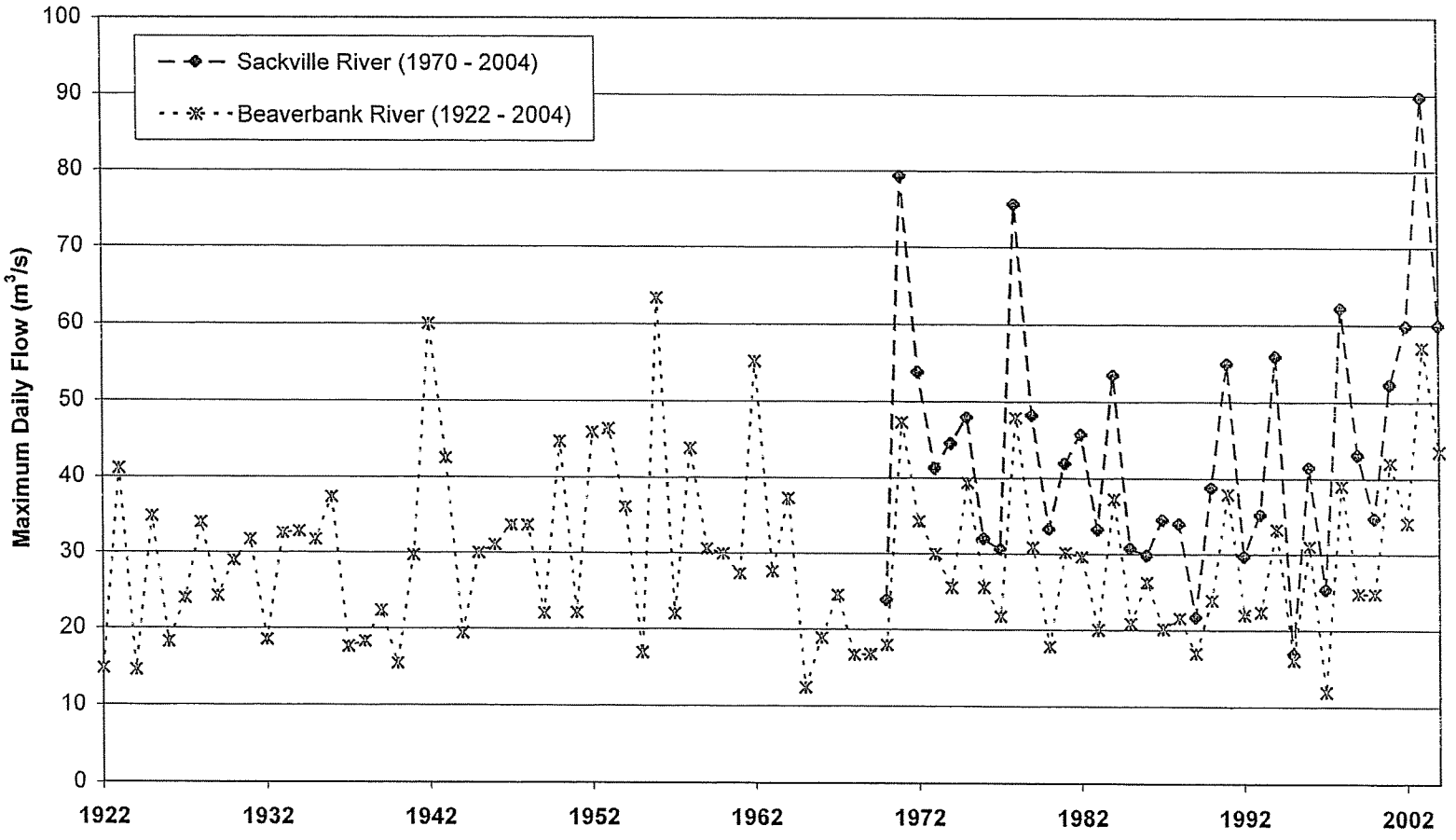
recent high flow events are noticeable on these plots, it is apparent from the Beaver Bank series that similar high flow events have occurred in the past. A large range of natural variability is visible on the Beaver Bank series and the recent cluster of large events does not seem out of proportion.



SGE Acres

Figure 3.1 Sackville River Flood Frequency Estimates
Union Street Flood Study
Halifax Regional Municipality

P:\2005\1689600 - Union St\Hydr\aprysephillips\Flood Frequency Analysis\[HYFRAN results (incl Fig 3.1).xls]Figure 3.1



SGE Acres

Figure 3.2
Maximum Daily Flow Time Series Plot
Union Street Flood Control Study
Halifax Regional Municipality

P:\2005\1639600 - Union St\Hydr\aprvaephillips\[Annual Max Time Series Plot (Fig 3.2).xls]Figure 3.2

Hydraulic Modeling

4 Hydraulic Modeling

4.1 Methodology

A hydraulic model of the Sackville River from Consumers Bridge downstream to the outlet in the Bedford Basin was created in HEC-RAS, a two-dimensional backwater model developed by the U.S. Army Corps of Engineers and widely used in the industry.

Information from previous studies, surveyed cross sections and elevations, topographical mapping, and data collected during the site visit were compiled for model development. Once the model was set up, the results were compared with known flow and water level data (both measured and anecdotal). Finally, the proposed flood protection plan was modeled by extending the elevation of the right bank vertically by 600 mm for about 200 m from Station 435 to Station 625. Additional simulations were run to determine the required height of the barrier such that it would not be overtopped in the 1/100 AEP event.

4.2 Model Development

The reach modeled in the current study extends approximately 1.4 km upstream of the outlet to the Bedford Basin. A schematic of the model is presented as Figure 4.1. The cross section stationing refers to meters above the most downstream section, which is located approximately 85 m into the Bedford Basin from the Shore Drive Bridge. Table 4.1 summarizes the locations of each of the user-defined cross sections. For the purposes of the simulation, the user-defined cross sections were interpolated by the model at a five meter interval.

Table 4.1 – Model Cross Sections

Station	Description
90	Bedford Basin. Constant water level of 0.5 m assumed at this location (results are not sensitive to this assumption).
175	Shore Drive Bridge
435	Approximate location of control section where gradient becomes steeper and rapids begin to form. This section has been assumed to be the downstream end of the proposed flood protection and was surveyed for this study.
480	Location of the upstream extent of jersey barriers, which were located on the top of the right bank at the time of the survey. This section was surveyed for this study.
510	Location of the Environment Canada hydrometric gauge, just upstream of Bedford Highway #1480.
625	Copy of section 510. This section was assumed to represent the upstream extent of

Station	Description
	the proposed flood protection.
1065	2002 Bridge (surveyed for this study).
1215	Towers Bridge (surveyed for this study).
1435	Consumers Bridge (surveyed for this study). Normal depth assumed at this location.

The lower (downstream) portion of the modeled reach is steep (0.01 to 0.02 m/m), and there exists a control section near the current veterinary clinic at #1440 Bedford Highway (approximate cross section 435). Upstream of this location, the gradient of the river is milder (approximately 0.001 m/m), with some sections having an adverse slope.

The channel roughness (Manning's n) values assumed in the model were taken from the 1981 Study, in which extensive field investigations and surveying were conducted for the development of a similar hydraulic model of the Sackville River. Channel roughness values varied from 0.025 to 0.035 in the modeled reach; over-bank roughness was assumed to be constant at 0.045.

The natural river bank was modeled, that is the jersey barriers and sand bags were not included. The storm drainage ditch and culvert between Union Street and the Sackville River were also not modeled as this modeling was outside the scope of work of the study.

Appendix B includes the geometry HEC-RAS input file for the existing case simulation.

4.3 Model Comparison Events

Three separate methods of model comparison were used in this study: EC gauged water levels for four recent events, estimates of water levels based on photographs taken by HRM during the March 2003 event, and anecdotal evidence concerning the water level in the area of interest during the November 2004 event. Each of these is discussed below.

Figure 4.2 illustrates the simulated maximum water surface profile for the largest event that occurred in each of 2003, 2004, and 2005. Also shown is the profile of the top of the right bank of the Sackville River near Union Street, the profile of

Union Street in this area, and the lowest ground elevation next to each structure surveyed along the modeled reach.

4.3.1 Environment Canada Gauged Water Levels

Maximum flows and water levels at the hydrometric gauge for several recent events were available from EC. The EC datum provided for this study is not geodetic, but for model comparison, the difference between the EC level and the simulated level was examined. This difference is expected to be constant.

Table 4.2 summarizes the measured and simulated maximum water levels experienced during four recent events at the hydrometric station. As shown, the difference between measured and simulated water levels is constant, within a few centimeters, indicating that the model gives reasonable water level estimates at this location.

Table 4.2 – Model Comparison Results

Event Date	Maximum Flow (m^3/s)	EC Measured Water Level (m)	Simulated Water Level (m)	Difference (m)
March 31, 2003	106	3.60	6.48	2.88
November 26, 2004	67.5	2.89	5.81	2.92
May 9, 2005	68.5	2.92	5.83	2.91
May 27, 2005	61.2	2.76	5.68	2.92

4.3.2 March 2003 Event

Photos of the flooding during the March 2003 event were made available by HRM, and these were useful to confirm that the flooding predicted by the model for the maximum flow of the event is similar to the actual flooding that was experienced.

HRM also surveyed high water marks following the flood and indicated these levels on some photos. Caution must be exercised when comparing the simulated results with the water levels shown or marked on the photos since the photos were not taken at the time of the instantaneous maximum flow. The photos were taken during the day on March 31; the instantaneous maximum flow occurred in the middle of the previous night (12:17 am). Therefore, the simulated water levels would be expected to be somewhat higher than shown on photographs. Despite these uncertainties, this

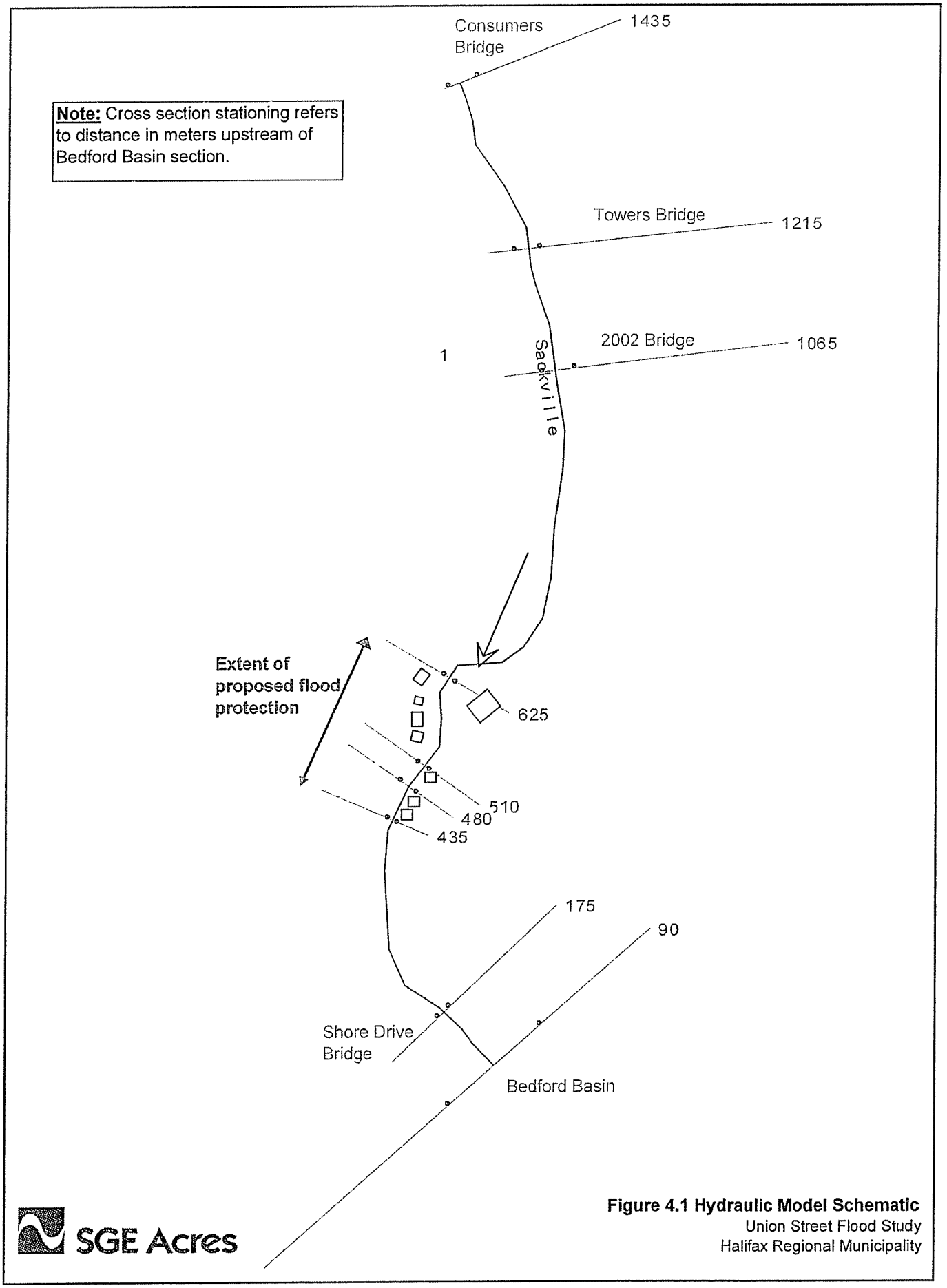
comparison is a useful one, and confirms that the model produces reasonable estimates of water levels throughout the reach of interest.

Flooding of Union Street occurred at approximately Station 440 in the March 2003 event. It appears that the river flooded the overbank upstream, with the overflow generally following the storm drainage ditch. The water flowed over Union Street and back into the river near the location of the storm drain culvert intake (not modeled). The model simulates the high water levels upstream leading to overbank flooding, but does not reflect the rapidly changing lateral and longitudinal flow patterns at this particular location. With the proposed flood protection in place, this overbank flooding is not expected to occur, so these local flow patterns are not of concern.

Appendix C includes photos of seven locations at which the simulated maximum water levels during the March 2003 event were compared to the photographed level. The HRM surveyed water level, elevations of roadways, buildings, and bridge decks are specified where available to allow comparison of simulated and actual flood levels.

4.3.3 November 2004 Event

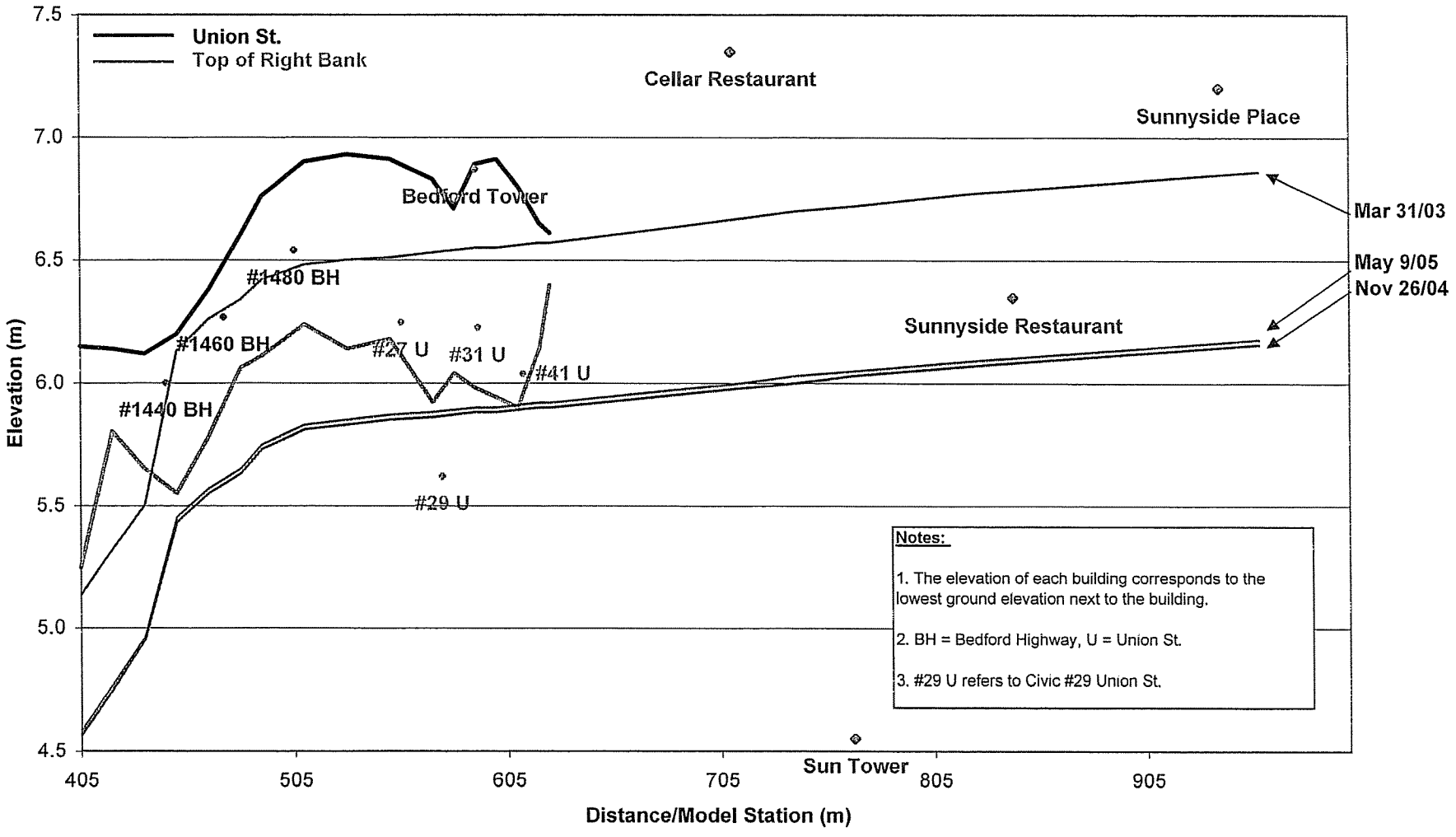
Anecdotal evidence suggests that during the November 2004 event, the water level just reached the top of the right bank. Figure 4.2 illustrates this simulated result in the model (at approximately Station 610). This flow of 67.5 m^3/s corresponds to an event with an AEP of approximately 1/5, as summarized in Table 3.2.



Note: Cross section stationing refers to distance in meters upstream of Bedford Basin section.

SGE Acres

Figure 4.1 Hydraulic Model Schematic
Union Street Flood Study
Halifax Regional Municipality



SGE Acres

Figure 4.2 Simulated Maximum Water Surface Profiles
Union Street Flood Study
Halifax Regional Municipality

Hydraulic Modeling Results

5 Hydraulic Modeling Results

5.1 Simulations

Following the comparisons of model results, the HEC-RAS model was run with flows corresponding to a range of AEP events as described in Section 3.3. Three configurations were modeled: the existing case without flood protection (the input file of which is included in Appendix B), the proposed 600 mm flood protection extending about 200 m from Station 435 to Station 625, and finally a case with the flood protection extending to the water level corresponding to a flow of 126 m^3/s (estimated 1/100 AEP event).

5.2 Effectiveness of Proposed Flood Protection Plan

There are a number of residences on Union Street that have experienced flooding in recent flood events. These residences are all located on the east side of Union Street, between the road and the Sackville River. Table 5.1 illustrates the depth of flooding predicted by the model (above the lowest point surveyed at each residence) for the existing case, and with the proposed 600 mm flood protection (f.p.).

Table 5.1 - Effectiveness of Proposed Flood Protection Plan (depth of flooding in m)

Union St.	53 m^3/s (estimated 1/2 AEP)		72 m^3/s (estimated 1/5 AEP)		85 m^3/s (estimated 1/10 AEP)		98 m^3/s (estimated 1/20 AEP)		114 m^3/s (estimated 1/50 AEP)		126 m^3/s (estimated 1/100 AEP)	
Residence	exist	f.p.	exist	f.p.	exist	f.p.	exist	f.p.	exist	f.p.	exist	f.p.
#27	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.6	0.6
#29	0.0	0.0	0.3	0.0	0.6	0.0	0.8	0.0	1.0	1.1	1.2	1.2
#31	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.4	0.4	0.6	0.6
#41	0.0	0.0	0.0	0.0	0.2	0.0	0.4	0.0	0.6	0.7	0.8	0.8

Note:
- 'exist' case corresponds to the top of the right bank, with no additional protection.
- 'f.p.' case corresponds to a 600 mm concrete barrier on top of the right bank.

Figure 5.1 illustrates the simulated water level at model Station 610 (near Union Street #41) for a range of flood events. This corresponds to the approximate location at which the right bank is first overtopped, as shown in Figure 4.2. The existing right bank elevation and the proposed elevation of the top of the barrier at

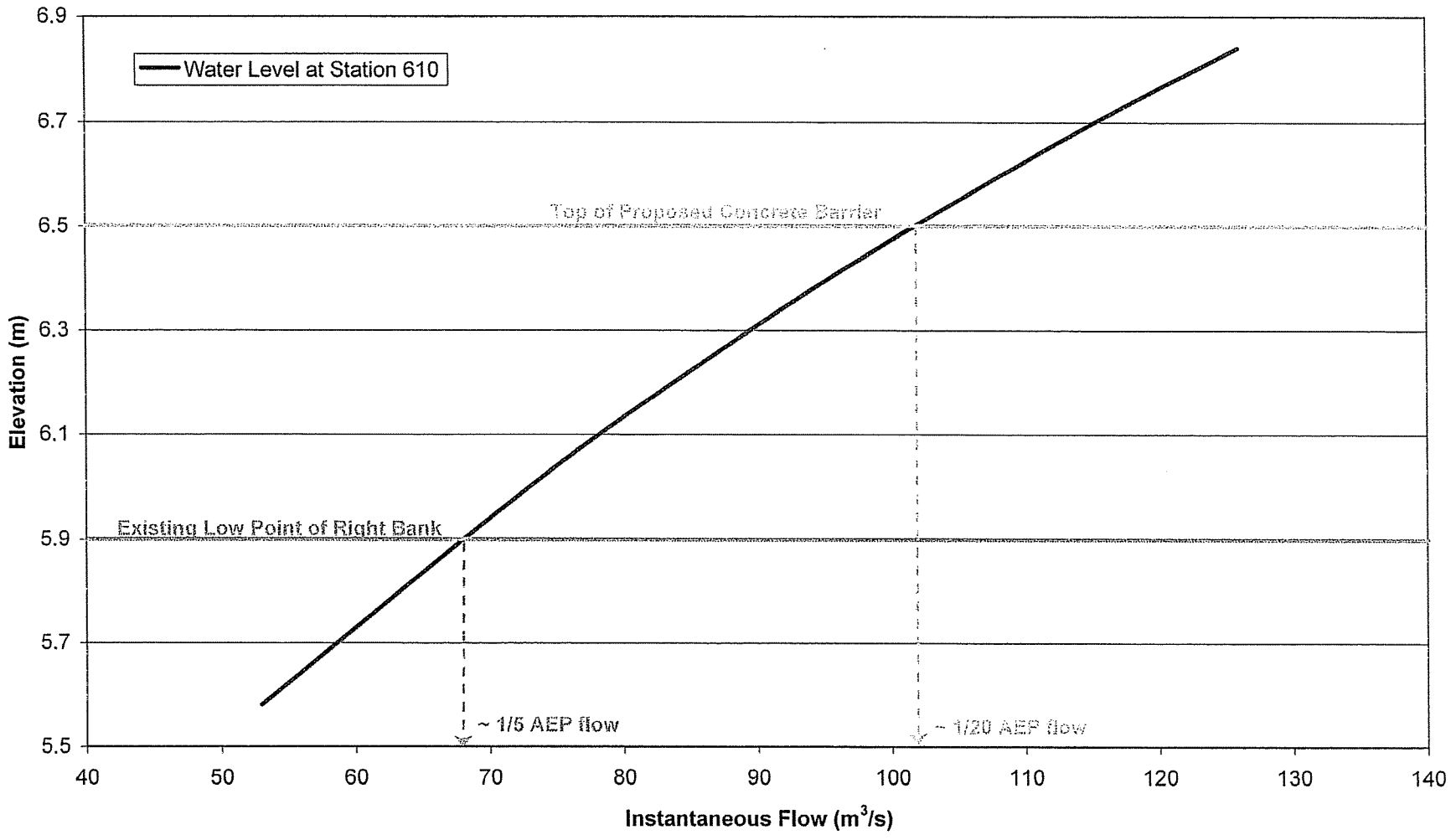
this location are shown, as well as the flow and approximate AEP of t
leads to these water levels.

The first homes start to be flooded in events with a flow of 68 m^3/s (approximat
AEP of 1/5). With the proposed flood protection plan, the homes start to be flooded in events with a flow of 102 m^3/s (approximate AEP of 1/20). Note that the water level estimates do not include a freeboard allowance.

The proposed flood protection plan has a negligible effect on flooding of structures on the opposite side of the River (on the Bedford Highway) and upstream structures. Simulated water levels in these areas increased by only one or two centimeters (water levels are shown in the table in Appendix D).

In order for water levels to be at or below the top of the barrier in a flow of 126 m^3/s (estimated 1/100 AEP event), the barrier should extend at least 1100 mm higher than the existing elevation of the right bank. The effect on water levels on the opposite side of the channel and upstream would be an increase of approximately two to three centimeters, see Appendix D.

Modeling of the adjacent storm drainage system was outside the scope of the present study. In large floods high water levels at the culvert outlet could lead to a reduced capacity in this drainage system, which could lead to flooding.



SGE Acres

Figure 5.1 Simulated Water Levels at Station 610
Union Street Flood Study
Halifax Regional Municipality

P:\2005\1689600 - Union St\Hydr\aprysephillips\[HEC RAS Results (incl Fig 4.2, 5.1).xls]Figure 5.1

Conclusions and Recommendations

6 Conclusions and Recommendations

6.1 Conclusions

Based on the results of the flood frequency analysis, the following frequency estimates of recent events are made.

- March 31, 2003 flow of 106 m^3/s has an estimated AEP between 1/20 and 1/50.
- November 24, 2004 flow of 67.5 m^3/s has an estimated AEP of 1/5.
- May 9, 2005 flow of 68.5 m^3/s has an estimated AEP of 1/5.
- May 28, 2005 flow of 61.2 m^3/s has an estimated AEP of 1/3.

The results of hydraulic modeling of a reach of the Sackville River in the Bedford region of HRM have indicated the following.

- Currently, residences along Union Street just upstream of the Bedford Highway Bridge could experience flooding in a flow of 68 m^3/s (approximate 1/5 AEP event).
- Water levels in the river would reach the top of the proposed 600 mm by 600 mm concrete barrier in an event with a flow of 102 m^3/s (exceeding the estimated 1/20 AEP event), with a negligible effect on upstream river levels.
- The height of the proposed barrier would have to be nearly doubled (to approximately 1100 mm) so that river water levels do not overtop the barrier in a flow of 126 m^3/s (estimated 1/100 AEP event).

There have been a number of large flow events on the Sackville River in recent years that have lead to flooding of properties in the study area. They have also lead to concern that there is a trend of increasing flood frequency. A statistical analysis was completed on three annual maximum daily flow series and two maximum daily rainfall series to address this perception. Results indicate that there is no significant trend in the historical data records and that the recent cluster of large events is likely due to natural variability. However, this does not mean that there will be no increasing trend in the future. The effects of climate change are still uncertain; some recent research suggests that extreme events will occur on a more frequent basis in future.

6.2 Recommendations

If HRM proceeds with the construction of the proposed flood protection, it should ensure adequate hydraulic, structural, and geotechnical design. The design should also include a freeboard allowance.

Any flood protection should be conservatively designed to account for the uncertainty of the effects of climate change.

The capacity of the adjacent storm drain ditch and culvert should be checked to ensure that flooding does not occur due to high water levels in the ditch.

References

7 References

1. Interprovincial Engineering Ltd., Proctor & Redfern Ltd. "Hydrotechnical Study of the Sackville River". (August 1981)

2. Michal Pancura and Gary S. Lines, Meteorological Service of Canada, Atlantic Region. "Variability and Extremes in Statistically Downscaled Climate Change Projections at Greenwood Nova Scotia". (October 2005)

Appendix A – Statistical Analysis of Trend

Union Street Flood Control Project

Statistical Analysis of Flow and Rainfall Data

Leonard Lye, PhD, PEng

A. Flood Data

Annual maximum daily flow data from three rivers in the vicinity of the project site were analysed. The rivers were:

1. 01EJ001, Sackville River at Bedford (1970-2004), n = 35 years
2. 01DG003, Beaverbank River near Kinsac (1922-2004), n = 83 years
3. 01EJ004, Little Sackville at Middle Sackville (1981-2004), n = 24 years

Since the historical record for the Sackville River is fairly short (n=35 years), it is prudent to look at nearby rivers to check if similar trends had occurred during concurrent years as well as in earlier periods.

Statistical Analysis

1. Comparison of Flow Patterns

The three sets of time series data were each standardized by subtracting the mean and dividing by the standard deviation of the respective series. This forces each series to have a mean of zero and a standard deviation of one. When plotted together, it will reveal whether the flow patterns of the rivers are similar. Figure 1a shows the all three standardized series plotted together on the same graph. Figure 1b compares the Beaverbank flows with the Little Sackville flows, Figure 1c compares the Sackville and the Little Sackville flows, and Figure 1d compares the Beaverbank and the Sackville flows. It is clear that for the concurrent periods, the flows of the Beaverbank and the Sackville rivers are very similar in pattern. In fact they are almost identical. This means that the Beaverbank River, which goes back to 1922, is a very good surrogate for the Sackville River. The Little Sackville flows on the other hand do not match either the Beaverbank or the Sackville rivers well. This is partly due to the fact that the Little Sackville River is a small tributary of the Sackville with a much smaller drainage area.

2. Analysis of River Flows

Each time series was subjected to several statistical tests:

a) Autocorrelation analysis – to test for independence of the series;
b) Analysis of runs – to test for unusual patterns of local trends and clustering;
c) Simple regression of flows with time – to test for long term trends; and
d) Plot of all flows above the 75th percentile – to check for unusual grouping of high flows

While (d) is not a statistical test per se, the plot will give a good indication as to whether the recent consecutive high flow events are unusual or something that has happened in the past, and part of natural variability.

(i) Sackville River at Bedford (n = 35) 1970-2004.

The results of the analysis for the Sackville River are shown in Figure 2. Figure 2a shows that the autocorrelation function of the annual maximum flows is well within the 95% confidence limits indicating that the flows are independent from year to year. Figure 2b shows that the tests for clustering, mixture, trends, and oscillation all show non-significance at the 5% level. This means that the flows are just a random series with no unusual patterns. Figure 2c shows that there is no statistically significant long term trend in the flows (fitted line is practically horizontal). Figure 2d however shows that for flows above the 75th percentile (53.8 m^3/s), there seems to be three such flows since 2000 which has not occured since the start of record on the Sackville River.

(ii) Beaverbank River near Kinsac (n = 83) 1922-2004.

The results of the analysis for the Beaverbank River are shown in Figure 3. This river has a very similar flow pattern to the Sackville River as seen in Figure 1d. Hence the results from this river will shed more light on the Sackville River since the period of record is much longer. Figures 3a to 3c all show similar results to the Sackville River in that all tests are not statistically significant at the 5% level. That is, the flows are independent and random from year to year, and there is no long term trend. Figure 3d shows all flows above the 75th percentile (36.2 m^3/s). The period in common with the Sackville River shows similar high flows were observed. However, looking back at the entire record of the Beaverbank River reveals that such high flows have occurred in clusters in the 1940s and 1950s in addition to that in the 2000s. Hence, the cluster of high flows in recent years is probably due to natural variability rather than an increasing trend. The statistical evidence does not support an increasing trend of high flows although once cannot be certain what the future may hold.

(iii) Little Sackville River at Middle Sackville (n=24) 1981-2004.

Similar analysis was carried out for the Little Sackville River and the results are shown in Figure 4. All tests showed that nothing is significant at the 5% level. Flows are random and independent, no long term trend, and there are occasional high flows.

B. Maximum Daily Rainfall Data

The maximum daily rainfall data for two weather stations were also subjected to statistical analysis. The stations are:

1. Shearwater A Climate Station (n = 60), 1945-2004
2. Halifax Int'l A Climate Station (n = 41), 1961-2004

The maximum rainfall data for both stations were subjected to similar statistical analysis as the flows. The purpose here was to check whether there were unusual patterns in the rainfall data.

(i) Shearwater A Station

Results for the Shearwater station are shown in Figure 5. Figure 5a shows that the maximum daily rainfall series is quite independent from year to year. Figure 5b and 5c show that there is no long term trend in the data, and Figure 5d shows that the data is quite random with nothing unusual as all tests were not significant at the 5% level. There is however a very large rainfall event in 1971.

(ii) Halifax Int'l A Station

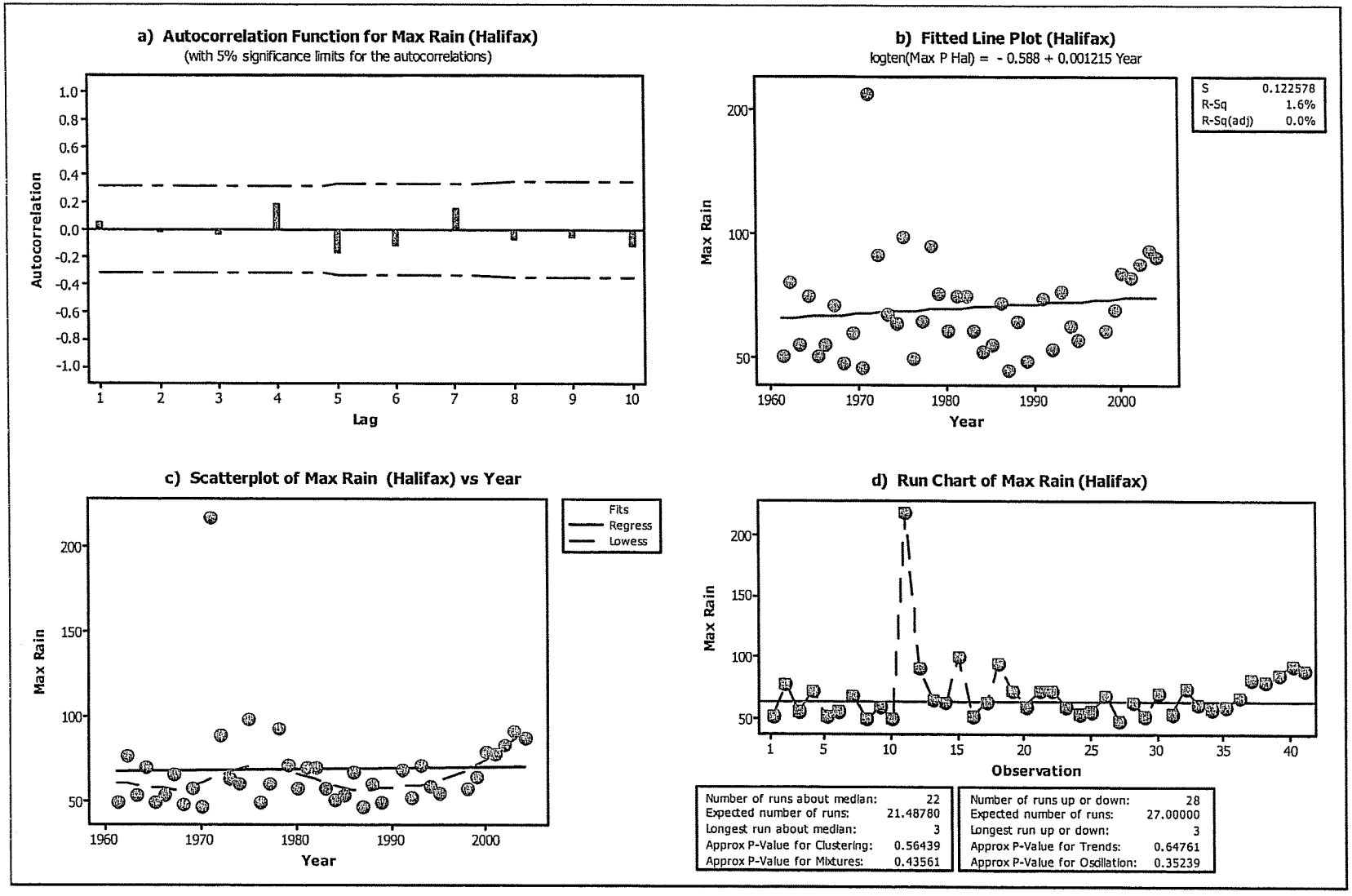
Results for the Halifax station are shown in Figure 6. The large rainfall event of 1971 is clearly seen. The tests showed that the annual maximum rainfall is independent, random and no long term trend. There is however an apparent increasing trend since about 2000 but this cannot be confirmed without a longer data set, and the analysis of additional rainfall records in the area.

Summary

From a preliminary analysis of the flow and rainfall data, it can be concluded that the apparent increasing trend observed in recent years is nothing unusual and is most likely due to natural variability.

List of Figures

Figure 6: Statistical Analysis of Halifax Maximum Daily Rainfall Data



Appendix B – HEC-RAS Input File (existing case)

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Program Version=3.13
Viewing Rectangle=-191.78 , 2330.09 , 1871.33 , 59.91

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     978.4656422    1741.9463303      982.707844    1703.7665138
    1025.1298624    1642.2545872    1056.9463761    1578.6215596
    1063.3096789    1521.3518349    1069.6729817    1493.7775229
    1090.8839908    1432.2655963    1101.4894954    1343.1793578
        1112.095    1271.0619266    1109.9738991    1213.7922018
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Rch Text X Y=933.3922477,1399.3885321
Reverse River Text= 0

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Consumers Bridge (surveyed)
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Node Last Edited Time=Nov/03/2005 17:37:52
#Sta/Elev= 16
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4.7
      14     4.1      15    3.85    16.5    3.74      23    2.98      25
3.86
      30    4.15    31.5    4.66      33    5.35      36    6.48      40
8.76
    42.5     9.1
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Exp/Cntr=0.3,0.1

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Towers Bridge (surveyed)
END DESCRIPTION:
Node Last Edited Time=Nov/03/2005 17:37:52
#Sta/Elev= 13
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3.85
      10    3.75      17    3.08      27    3.88      28    4.64      30
5.38
      33    6.75      37    6.88      65      10
#Mann= 3 , 0 , 0
    -260    .045       0       4    .025       0      33    .045       0
Bank Sta=4,33
Exp/Cntr=0.3,0.1

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2002 Bridge (surveyed)
END DESCRIPTION:
```

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4.82
      13    4.74      16    3.67      25    3.25      32    3.83    33.5
4.94
      40    7.42      84      10
#Mann= 3 , 0 , 0
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Exp/Cntr=0.3,0.1

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2.85
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Bank Sta=73,89
Exp/Cntr=0.3,0.1

Type RM Length L Ch R = 1 ,510     ,30,30,30
BEGIN DESCRIPTION:
assumed location of EC gauge
END DESCRIPTION:
Node Last Edited Time=Nov/03/2005 17:37:52
#Sta/Elev= 9
       0      10      32    6.91      58    6.24      73    5.75      76
2.75
      86    2.75      89    5.75      97    6.54     167      10
#Mann= 3 , 0 , 0
       0    .045       0      73     .03       0      89    .045       0
Bank Sta=73,89
Exp/Cntr=0.3,0.1

Type RM Length L Ch R = 1 ,480     ,45,45,45
BEGIN DESCRIPTION:
Start of Jersey Barrier (surveyed)
END DESCRIPTION:
Node Last Edited Time=Nov/03/2005 17:37:52
#Sta/Elev= 14
       0      10    28.5     6.6      52    6.06      54    5.76    55.5
5.47
      58    3.55      59     3.5      68     3.5      69    3.56    70.5
4.45
      72    5.82      74    6.03      81    6.28     149      10
#Mann= 3 , 0 , 0
       0    .045       0      52     .03       0      74    .045       0
Bank Sta=52,74
Exp/Cntr=0.3,0.1

Type RM Length L Ch R = 1 ,435     ,260,260,260
BEGIN DESCRIPTION:
Downstream end of jersey barrier (surveyed)
END DESCRIPTION:
Node Last Edited Time=Nov/03/2005 17:37:52
#Sta/Elev= 14
       0      10      25    6.12      35    5.65      39    5.53      42
```
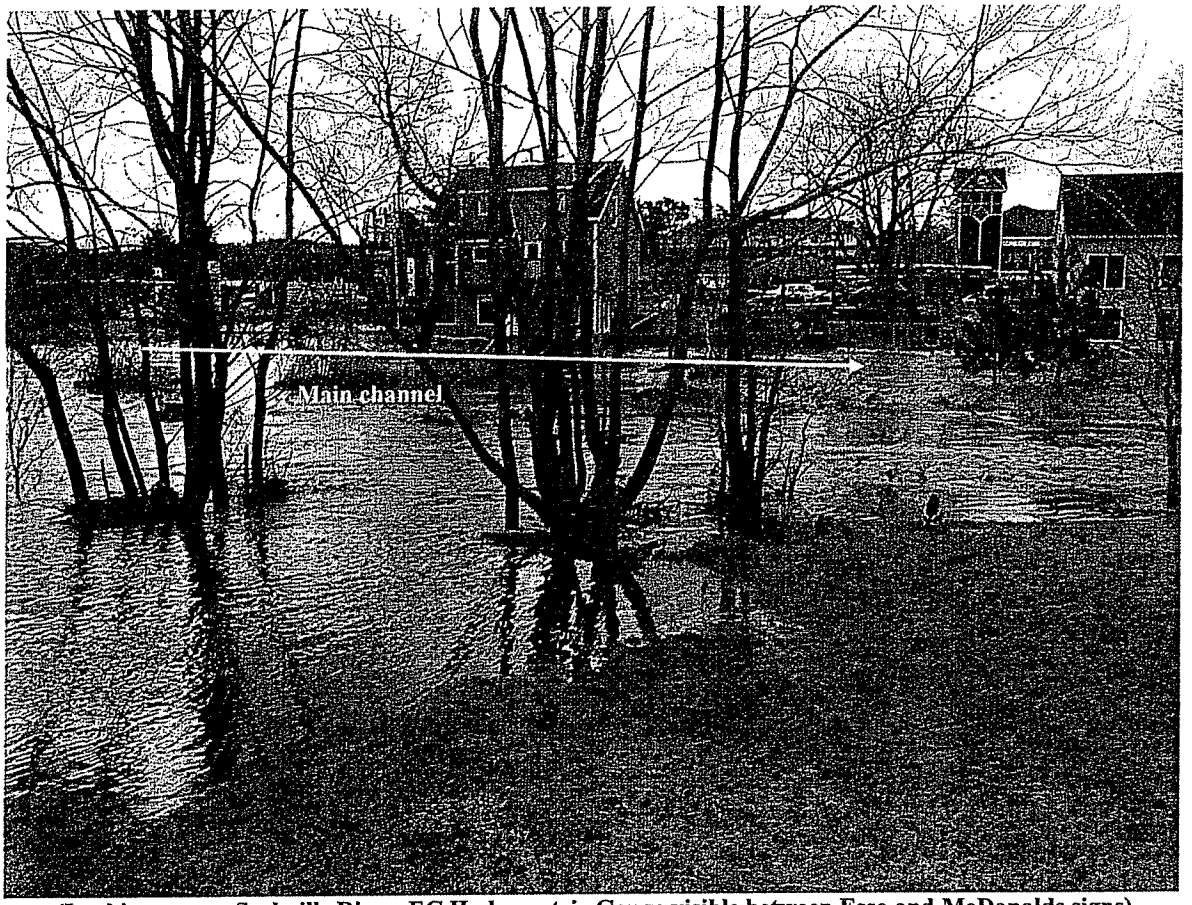

```
3.44
    43.5    3.17      44    3.12      49    3.12      50    3.18    50.5
3.54
    52.5    5.53    54.5    6.71    57.5    6.92     135      10
#Mann= 3 , 0 , 0
       0    .045       0      39     .03       0    52.5    .045       0
Bank Sta=39,52.5
Exp/Cntr=0.3,0.1

Type RM Length L Ch R = 1 ,175     ,85,85,85
BEGIN DESCRIPTION:
Bridge at outlet to Bedford Basin
END DESCRIPTION:
Node Last Edited Time=Nov/03/2005 17:37:52
#Sta/Elev= 9
       0      15      75      10     160       5     172       4     181   -
1.07
     190       4     207       5     236      10     266      15
#Mann= 3 , 0 , 0
       0    .045       0     172    .035       0     190    .045       0
Bank Sta=172,190
Exp/Cntr=0.3,0.1

Type RM Length L Ch R = 1 ,90      ,0,0,0
BEGIN DESCRIPTION:
Bedford Basin
END DESCRIPTION:
Node Last Edited Time=Nov/03/2005 17:37:52
#Sta/Elev= 10
       0      25      50      20     100      15     138      10     168
5
     240    -1.5     310       5     370      10     492      15     650
20
#Mann= 3 , 0 , 0
       0    .045       0     168    .035       0     310    .045       0
Bank Sta=168,310
Exp/Cntr=0.3,0.1

Chan Stop Cuts=-1
Geom Raster=P:\2005\1689600 - Union St\Hydr\aprysephillips\aerial photo
scan.JPG,True,image,, 0
Use User Specified Reach Order=0
User Specified Reach Order=Sackville       ,1
```

Appendix C – Model Comparison Photos

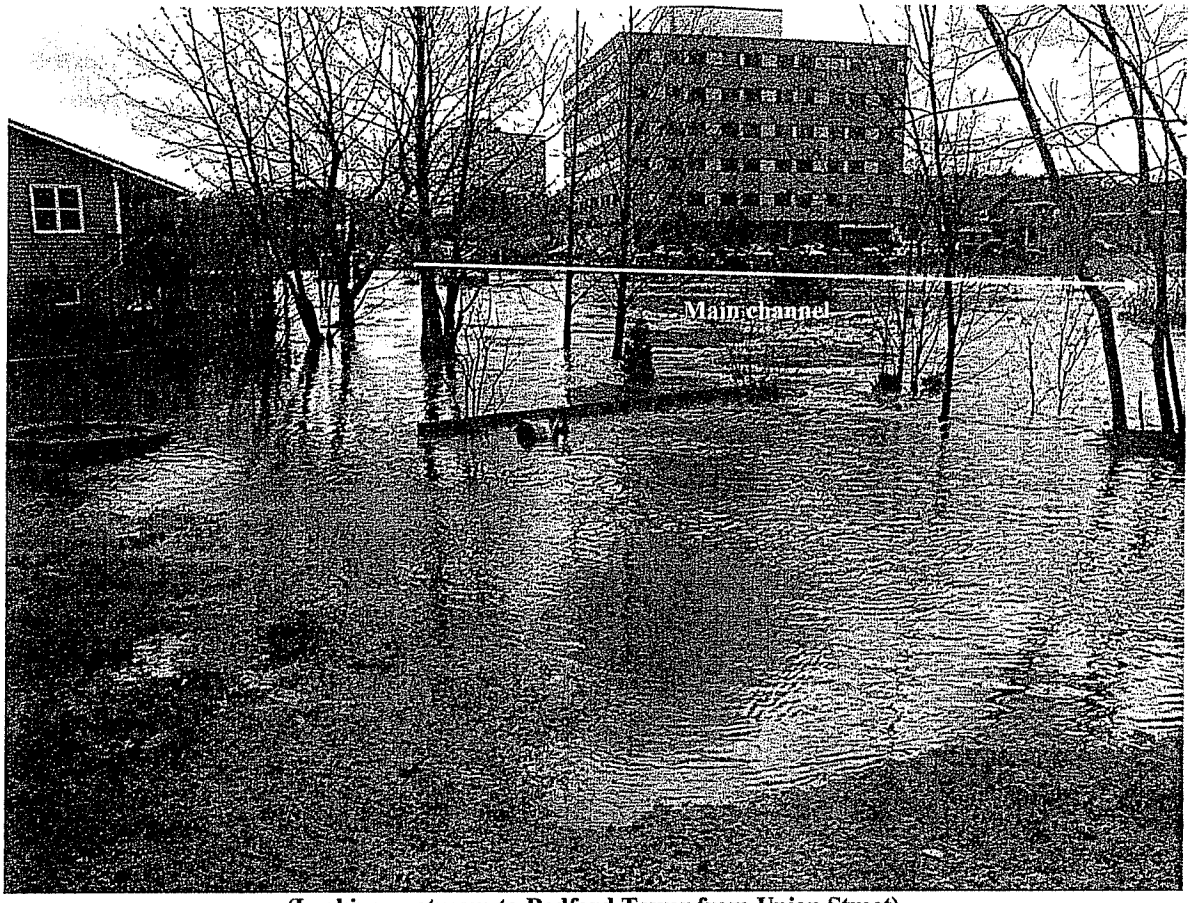
Location #1 (Bedford Highway #1480, at hydrometric gauge location)
Simulated Level (STA 510) = 6.5 m
Lowest Elevation of Residence = 6.54 m



(Looking across Sackville River, EC Hydrometric Gauge visible between Esso and McDonalds signs)

Note: Photos taken on March 31, 2003. Flow unknown due touncertainty re: time of phob relative to time of peak.

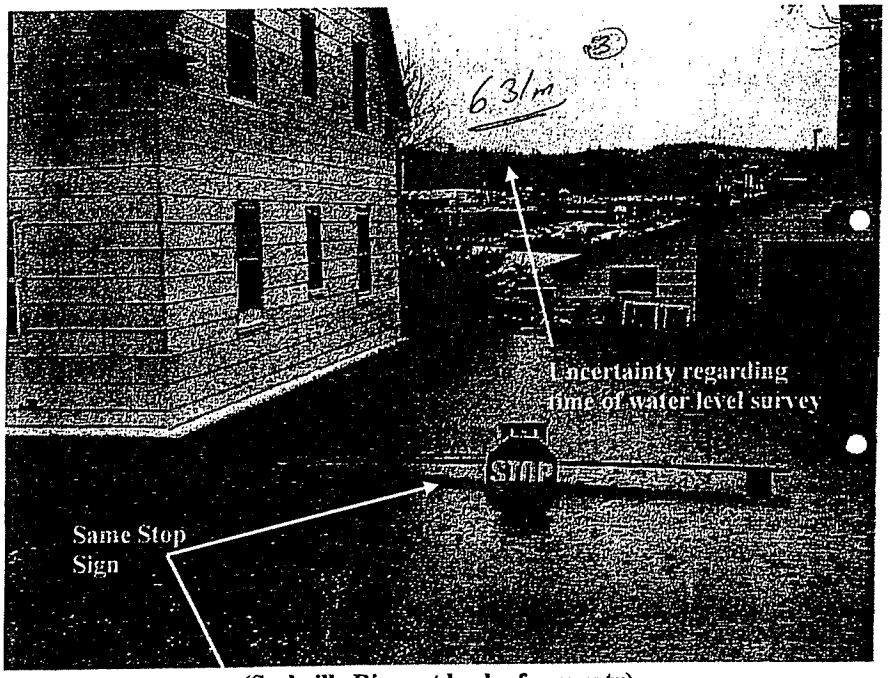
Location #2 (Union St. #27, just downstream of Bedford Tower)
Simulated Level (STA 530) = 6.5 m
Lowest Elevation of Residence = 6.37 m



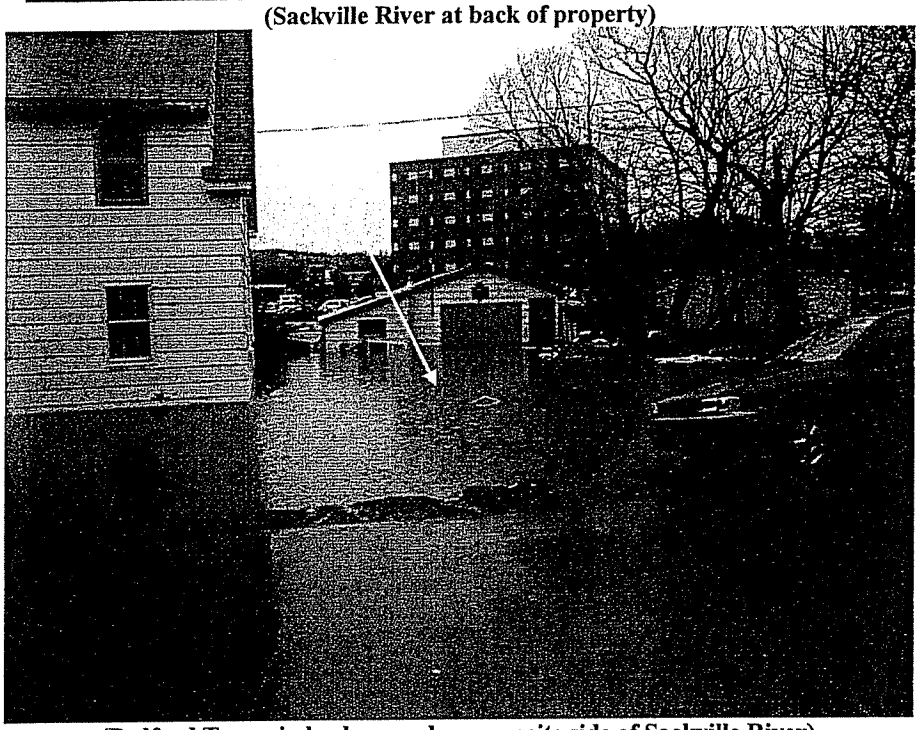
(Looking upstream to Bedford Tower from Union Street)

Note: Photos taken on March 31, 2003. Flow unknown due to uncertainty re: time of photo relative to time of peak.

Location #3 (Union Street #41)
Simulated Level (STA 615) = 6.6 m
Lowest Elevation of Residence = 6.04 m
Elevation of Union St. = 6.74 m



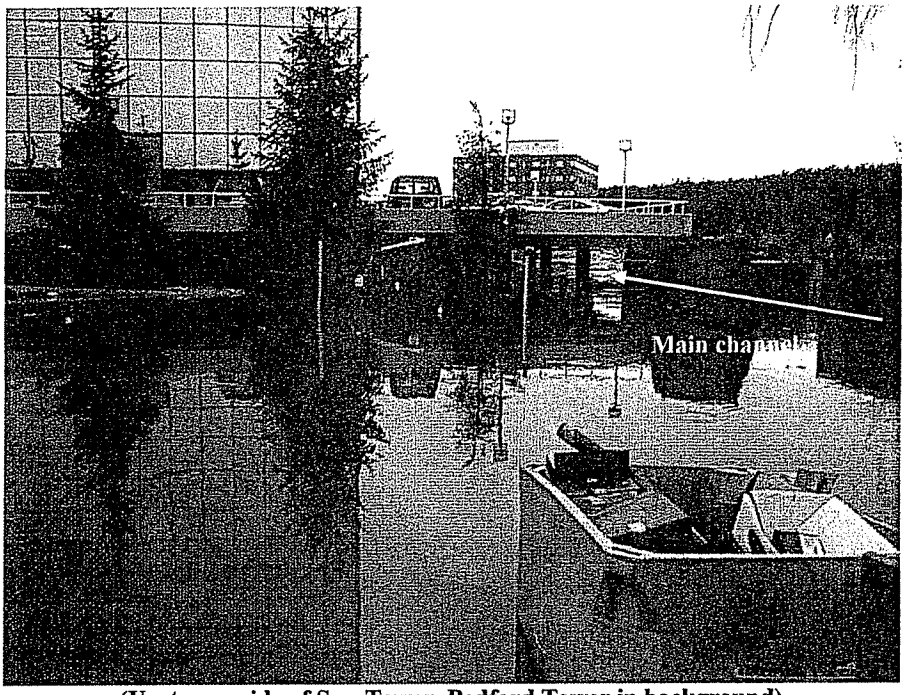
(Sackville River at back of property)



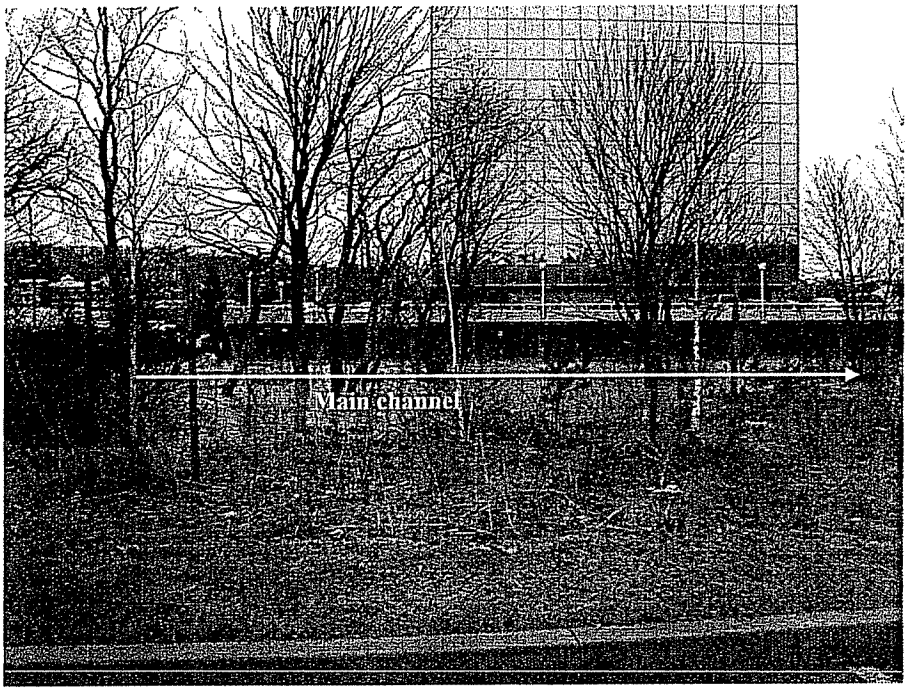
(Bedford Tower in background on opposite side of Sackville River)

Note: Photos taken on March 31, 2003. Flow unknown due touncertainty re: time of phob relative to time of peak.

Location #4 (Sun Tower)
Simulated Level (STA 790) = 6.7 m
Lowest Elevation of Parking Structure Foundation = 4.85 m



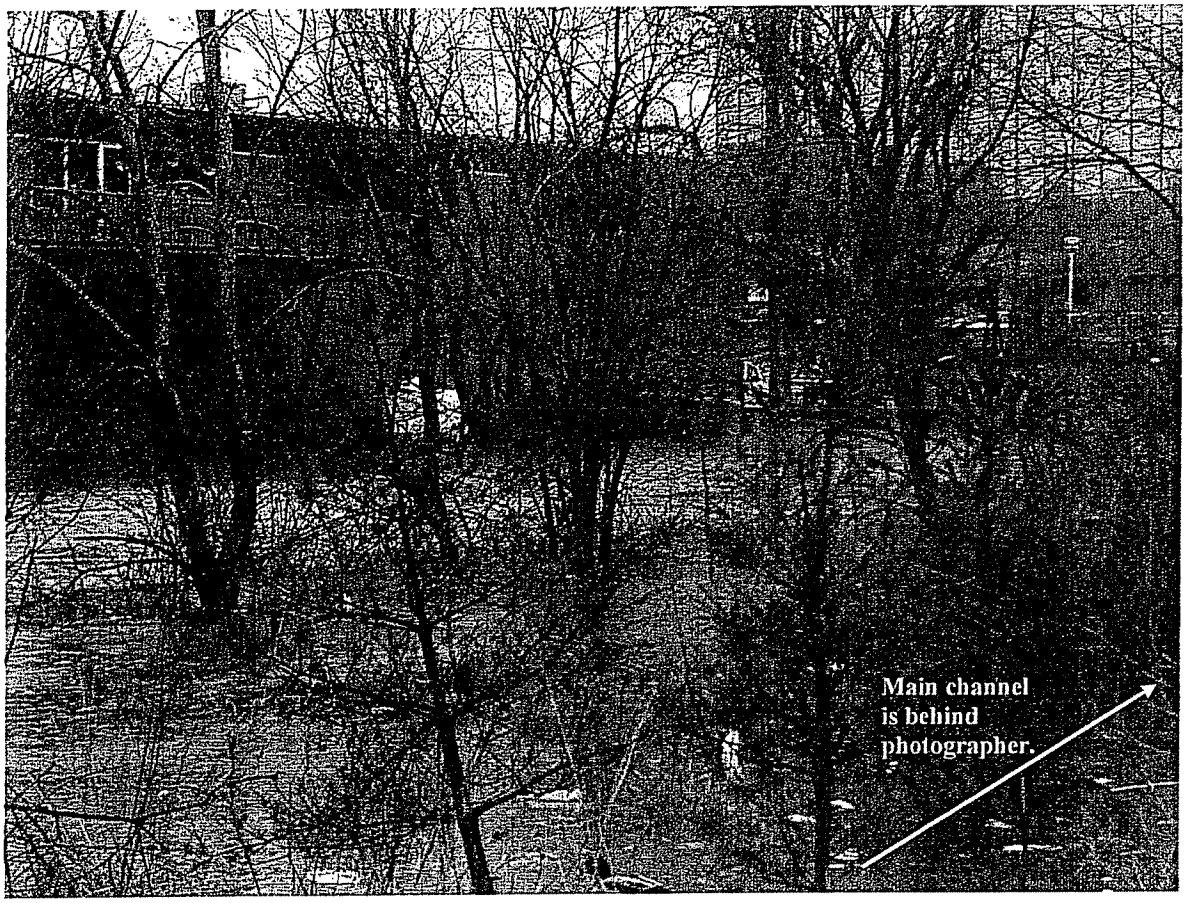
(Upstream side of Sun Tower, Bedford Tower in background)



(Looking East across Sackville River to Sun Tower)

Note: Photos taken on March 31, 2003. Flow unknown due touncertainty re: time of photo relative to time of peak.

Location #5 (Sunnyside Restaurant and Smitty's, just upstream of Sun Tower)
Simulated Level (STA 840) = 6.8 m
Lowest Elevation of Building = 6.35 m



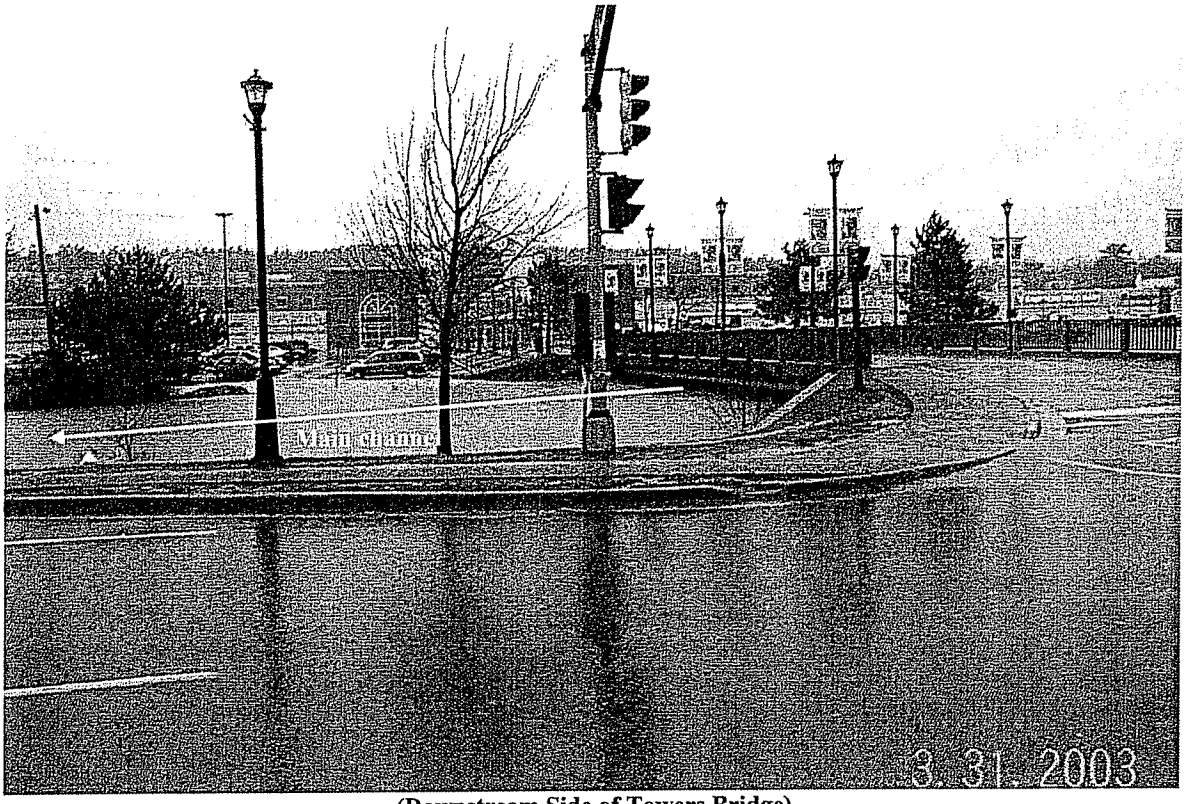
Note: Photos taken on March 31, 2003. Flow unknown due to uncertainty re: time of photo relative to time of peak.

Location #6 (Bridge constructed in 2002 downstream of Towers Bridge)
Simulated Level (STA 1065) = 6.9 m
Elevation of Bridge Deck = 7.87 m to 8.79 m

(Downstream Side of 2002 Bridge)

Note: Photos taken on March 31, 2003. Flow unknown due to uncertainty re: time of photo relative to time of peak.

Location #7 (Towers Bridge)
Simulated Level (STA 1215) = 7.0 m
Elevation of Bridge Deck = 7.53 m to 7.62 m



(Downstream Side of Towers Bridge)

Note: Photos taken on March 31, 2003. Flow unknown due touncertainty re: time of phob relative to time of peak.

Appendix D – Simulated Water Levels

Structures		53 m^3/s (estimated 1/2 AEP event)		72 m^3/s (estimated 1/5 AEP event)		85 m^3/s (estimated 1/10 AEP event)		98 m^3/s (estimated 1/20 AEP event)		114 m^3/s (estimated 1/50 AEP event)		126 m^3/s (estimated 1/100 AEP event)		
Model Station	Description	existing	600 mm	existing	600 mm	existing	600 mm	existing	600 mm	existing	600 mm	existing	600 mm	1100 mm
940	Sunnyside Place	5.81	5.81	6.24	6.24	6.50	6.50	6.72	6.72	6.97	6.98	7.14	7.15	7.16
820	Sunnyside Restaurant	5.73	5.73	6.16	6.16	6.41	6.42	6.64	6.64	6.89	6.90	7.06	7.07	7.08
770	Sun Tower Parking Structure	5.70	5.70	6.12	6.13	6.37	6.38	6.60	6.60	6.85	6.86	7.01	7.03	7.04
735	Canadian Tire Gas Station	5.67	5.67	6.09	6.10	6.34	6.35	6.56	6.57	6.81	6.83	6.98	7.00	7.01
710	Cellar Pub	5.65	5.65	6.07	6.07	6.32	6.32	6.54	6.55	6.79	6.80	6.96	6.98	6.99
610	White House (Union St. #41)	5.58	5.58	5.98	5.98	6.22	6.22	6.44	6.44	6.68	6.70	6.84	6.86	6.87
590	Blue House (Union St. #31)	5.56	5.56	5.97	5.97	6.21	6.21	6.42	6.43	6.67	6.68	6.83	6.85	6.86
590	Bedford Tower	5.56	5.56	5.97	5.97	6.21	6.21	6.42	6.43	6.67	6.68	6.83	6.85	6.86
575	Brick front House (Union St. #29)	5.55	5.55	5.95	5.96	6.20	6.20	6.41	6.42	6.65	6.67	6.82	6.84	6.85
555	Salmon/Beige House (Unions St. #27)	5.54	5.54	5.94	5.94	6.18	6.18	6.39	6.40	6.64	6.66	6.80	6.82	6.83
505	Green House (Bedford Highway #1480)	5.49	5.49	5.89	5.89	6.13	6.13	6.34	6.34	6.59	6.60	6.76	6.77	6.78
470	Daycare (Bedford Highway #1460)	5.27	5.28	5.67	5.68	5.92	5.93	6.15	6.15	6.42	6.41	6.61	6.59	6.59
445	Vet (Bedford Highway #1440)	5.08	5.08	5.46	5.47	5.70	5.70	5.92	5.92	6.20	6.17	6.39	6.33	6.32

Note:
Water levels shown in the main text have been rounded to the nearest 0.1 m. Results here are shown here to the nearest 0.01 m to facilitate comparison between scenarios.

Figure 1: Standardized Flows Comparison

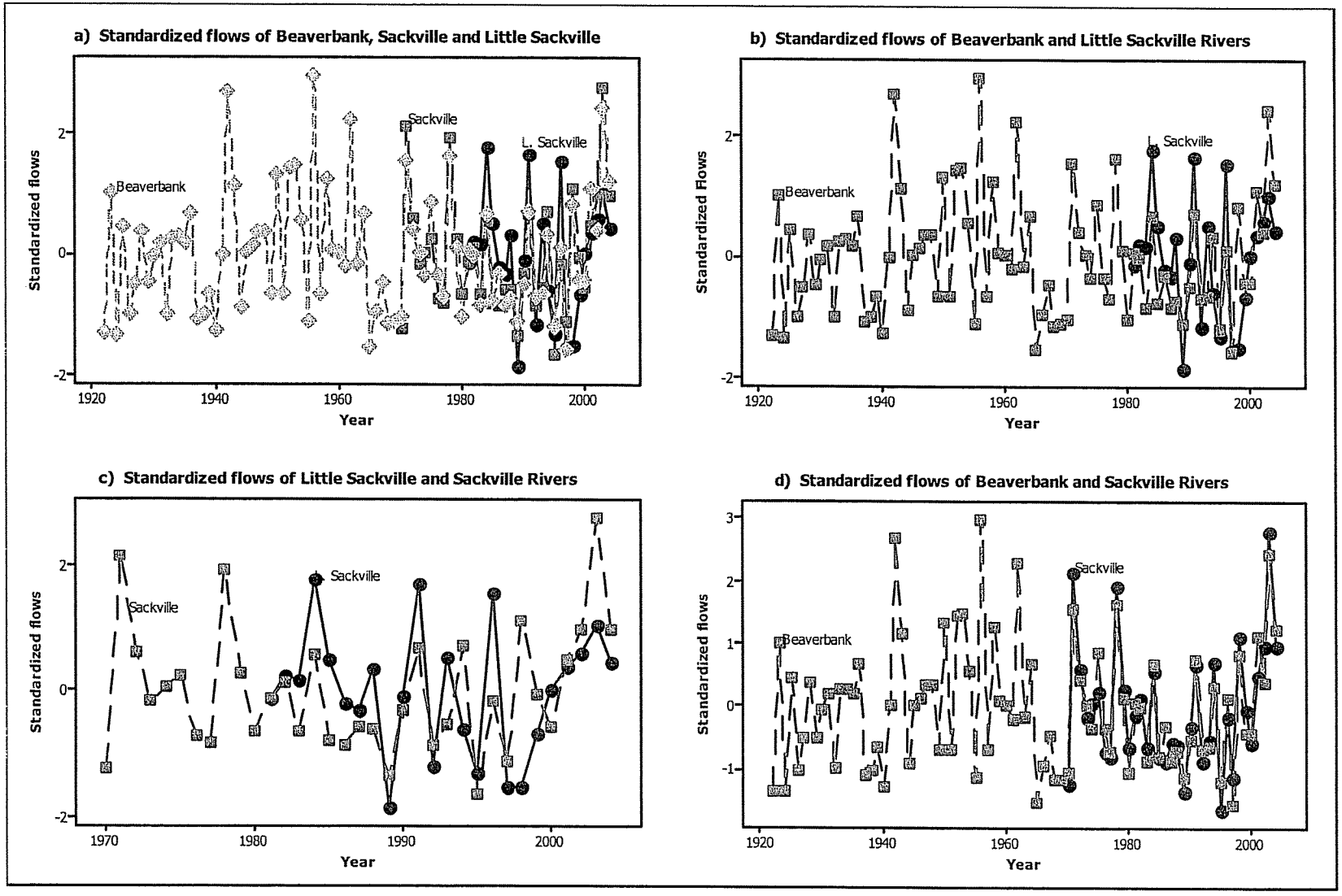


Figure 2: Statistical Analysis of Sackville River at Bedford

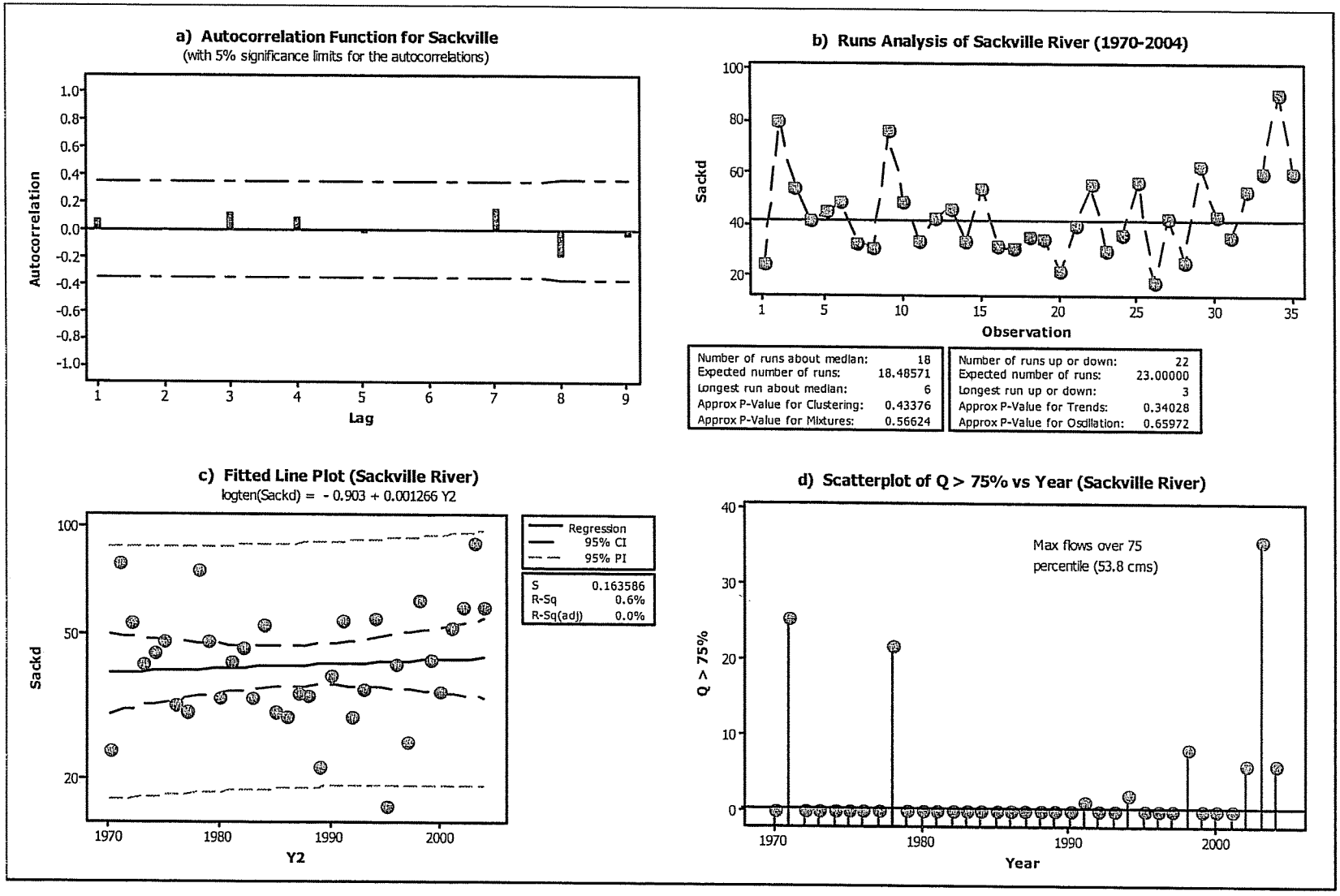


Figure 3: Statistical Analysis of Beaverbank River

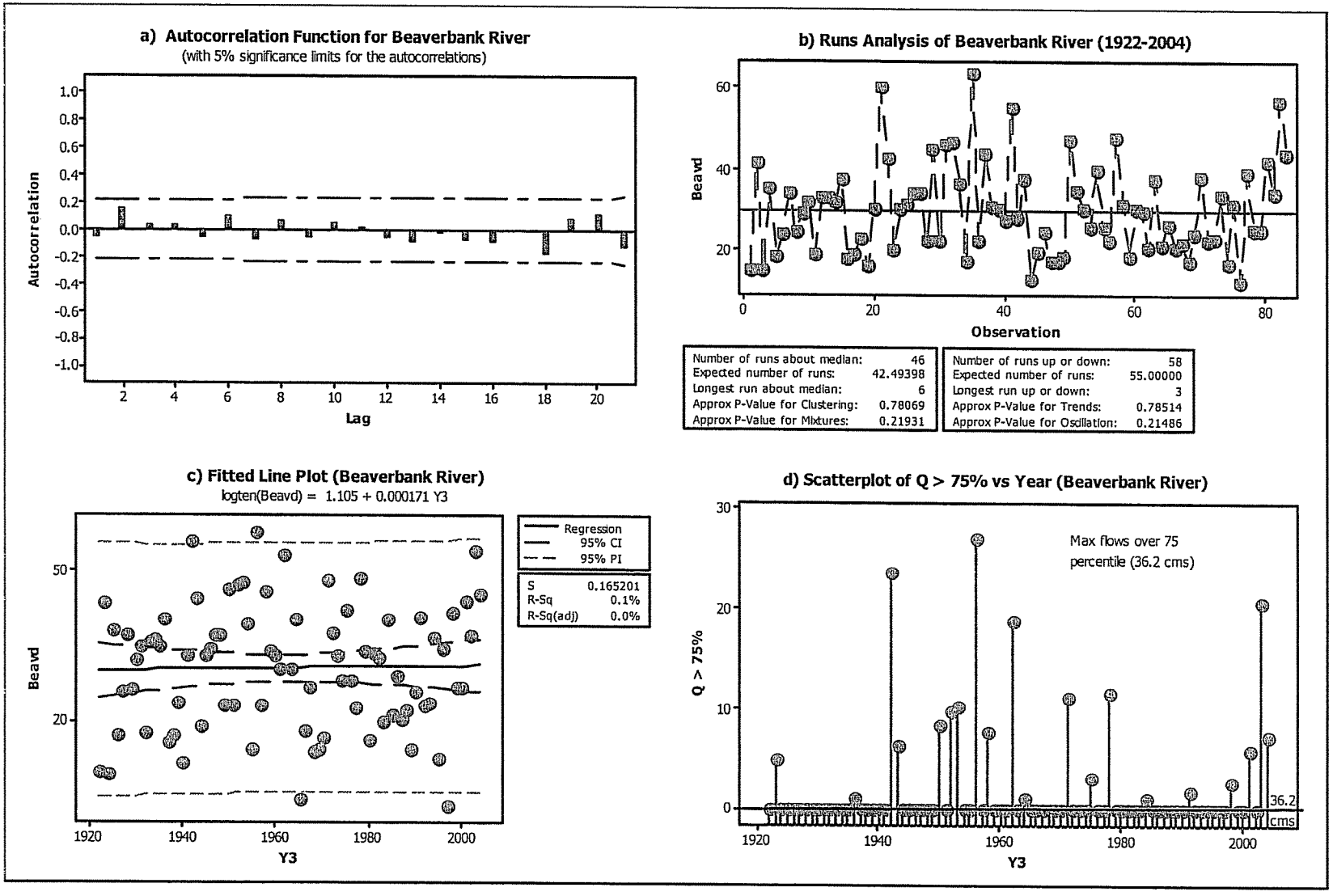


Figure 4: Statistical Analysis of Little Sackville River

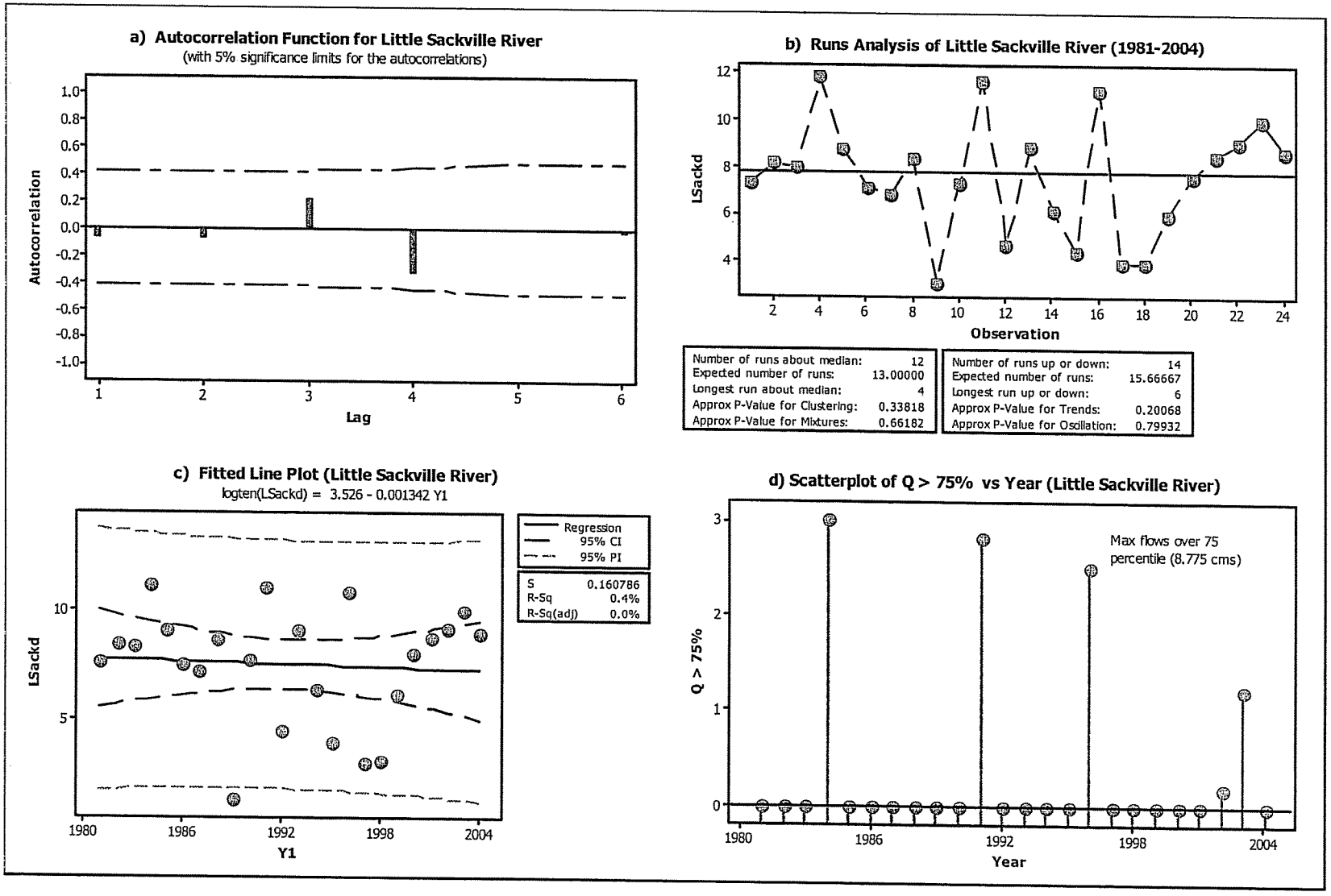


Figure 5: Statistical Analysis of Shearwater Maximum Daily Rainfall Data