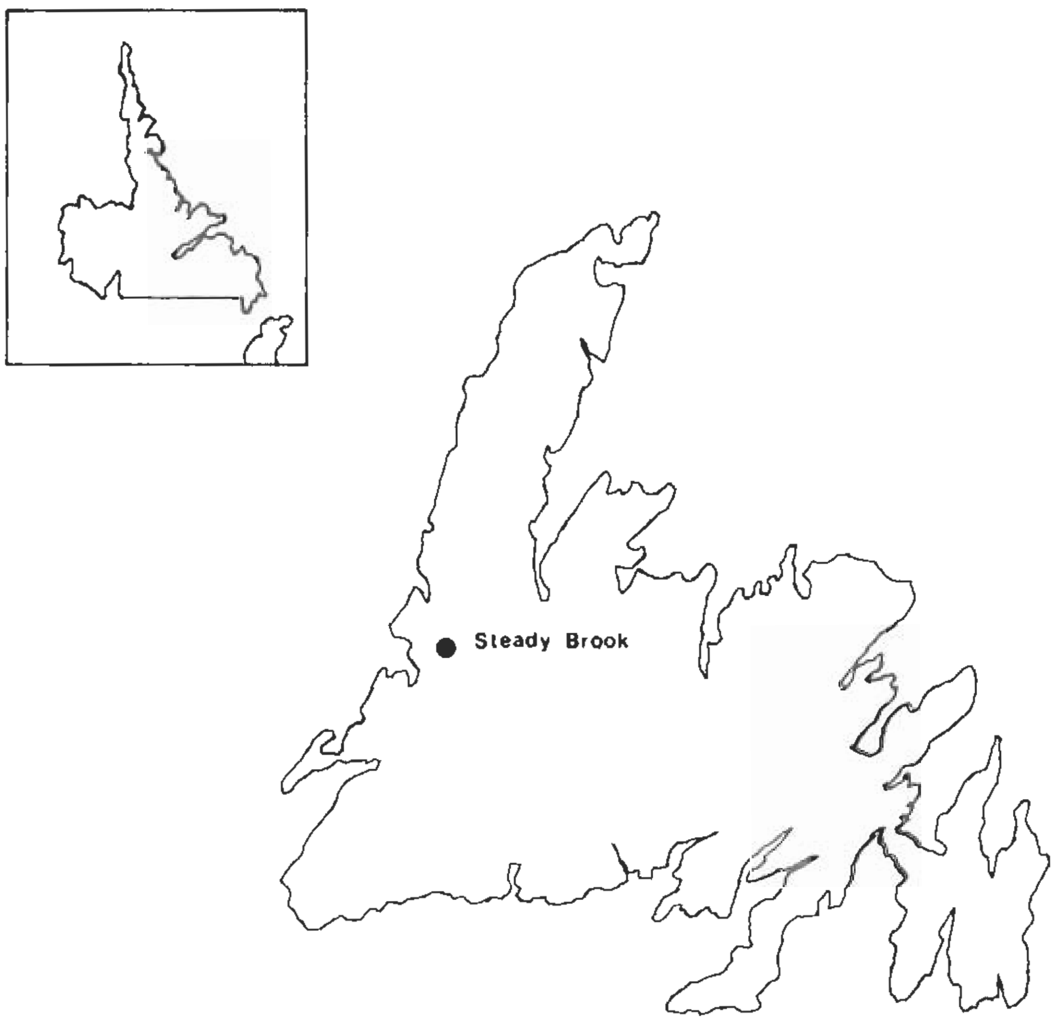
Canada – Newfoundland
Flood Damage Reduction Program

OCTOBER, 1984

HYDROTECHNICAL STUDY OF THE STEADY BROOK AREA

Volume 1 of 2 MAIN REPORT



NOLAN DAVIS & ASSOCIATES LIMITED
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Department of Environment

Environment Canada

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CONSULTING ENGINEERS AND GEOLOGISTS

7085
November 27, 1984

Government of Newfoundland and Labrador
Department of Environment
Water Resources Division
Elizabeth Towers
St. John's, Newfoundland
A1C 5T7

Attention: Dr. Wasi Ullah, P. Eng.
Chairman, Technical Committee
Canada-Newfoundland Flood Damage
Reduction Program

Gentlemen:

Re: Hydrotechnical Study of the Steady Brook Area

We take pleasure in submitting our final report on the above mentioned study. The comments and suggestions from the Technical Committee on the previous interim and draft reports have been incorporated in this version.

The methodology and main findings of our investigations are discussed herein with additional information on the field program provided in a supplementary report. We respectfully suggest that serious consideration be given to immediately implementing the recommendations found in our report.

We would like to express our sincere thanks to you and the other members of the Committee for your cooperation and assistance throughout this study.

Yours very truly,

NOLAN DAVIS & ASSOCIATES LIMITED

REGISTERED PROFESSIONAL ENGINEER
B. F. DAVIS
SIGNATURE
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President

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CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

HYDROTECHNICAL STUDY
OF THE
STEADY BROOK AREA

VOLUME 1 OF 2: MAIN REPORT

BY
NOLAN DAVIS & ASSOCIATES LIMITED
in association with
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OCTOBER 1984

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1:20	One in Twenty Year Recurrence Interval
1:100	One in One Hundred Year Recurrence Interval
ACLS	Area Controlled by Lakes and Swamps (%)
AMC II	Average Antecedent Moisture Condition
AMC III	Saturated Antecedent Moisture Condition
b	Watershed Unit Hydrograph Parameter
B	Surveyed Bridge Section
BII	Baseflow Infiltration Index
C.K.	Coefficient of Kurtosis
CL	Confidence Limit
cms	Cubic Metres Per Second (m^3/s)
CN	Average Soil Cover Complex Number
CNFDRP	Canada-Newfoundland Flood Damage Reduction Program
C.S.	Coefficient of Skew
DA	Drainage Area (km^2 or mi^2)
dam^3	Cubic Decametres
d/s	Downstream
ETI	Evapotranspiration Index
g	Acceleration Due to Gravity (m/s^2)
h	Depth of Flow (m)
HR	Field Surveyed Cross-section (Humber River)
i	Year
k	Frequency Factor
K	Hydrograph Recession Parameter (hrs)
L	Watershed Length (km or mi)

LN	Log Normal Probability Distribution
LP3	Log Pearson Type III Probability Distribution
mcf	Million Cubic Feet
n	Manning's Roughness Coefficient
N	Number of Years
NP	Number of Phases
P	Precipitation Amount (mm or in)
Q	Amount of Runoff (mm or in)
q_p	Unit Hydrograph Peak Flow Rate (m^3/s)
Q_p	Annual Maximum Instantaneous Peak Flow (m^3/s)
$\overline{Q_p}$	Mean Annual Maximum Instantaneous Peak Flow (m^3/s)
QP	Annual Flood Peak (m^3/s)
QP_{100}	Maximum Instantaneous 1:100 Year Recurrence Interval Flow Rate (m^3/s)
QP_2	Maximum Instantaneous 1:2 Year Recurrence Interval Flow Rate (m^3/s)
QP_{20}	Maximum Instantaneous 1:20 Year Recurrence Interval Flow Rate (m^3/s)
QP_N	Cumulative Moving Mean at Year N
QP_T	Derived Design Flood Peak at Selected Locations in the Study Area for Return Period T-years (m^3/s)
R	Hydraulic Radius
RG	Runoff Excess
s	$\frac{1000}{CN} - 10$
SB	Field Surveyed Cross-section (Steady Brook)
SD	Standard Deviation
S_f	Boundary Frictional Effect
SHAPE	Watershed Shape Parameter (1/km)
SLOPE	Slope of Watershed (%)
SLP	Slope of Watershed (m/km or ft/mi)

SMI	Soil Moisture Index
S_o	Bottom Channel Slope (m/m)
SQ_p	Standard Deviation of Maximum Instantaneous Peak Flow Series
S-SS	Surface-subsurface Flow Separation
TS	Time of Storage
T_p	Hydrograph Time to Peak Parameter (hrs)
TSBII	Baseflow Infiltration Index
3PLN	3 Parameter Log Normal Probability Distribution
u/s	Upstream
v	Velocity in Direction of Flow (m/s)
WP	Weighted Precipitation
x	Distance in Direction of Flow (m)
Y_T	Logarithmic Transformed Flood Estimate

ACKNOWLEDGEMENTS

The information and conclusions presented in this report were derived with assistance from several individuals and organizations.

The following members of the Flood Risk Mapping Technical Committee provided significant input and direction throughout the study:

- Dr. W. Ullah	Government of Newfoundland and Labrador Department of Environment
- Ms. E. Langley	Inland Waters Directorate, Environment Canada
- Mr. R. Picco	Government of Newfoundland and Labrador Department of Environment

The background information presented in this report was obtained from several sources including the Atmospheric Environment Services; the Water Survey of Canada; the Water Planning and Management Branch - all of Environment Canada and the Tides and Water Levels Branch of the Department of Fisheries and Oceans. Background data collected by the Water Resources Division of the Newfoundland Department of Environment also proved most useful during these investigations.

Essential data was provided by the staff of Bowater Power Company and Bowater Pulp and Paper Limited. In particular, we would like to thank Mr. G. Slade, Mr. C. Stratton, and Mr. Maynard for their cooperation and assistance throughout this project.

The field work was supervised and undertaken by Mr. B. Davis, P.Eng., and Mr. W. Pye. The office studies were undertaken by Mr. C. Jarratt, P. Eng., and Mr. S. Smith, C.E.T. and supervised by Mr. H. Belore, P. Eng.

Information on local flooding conditions was kindly provided by several individuals in the study area, including Mr. G. Manion and Mr. B. Fahey.

We would also like to express our appreciation for the time and effort of all others who contributed to this project by way of information, discussions and otherwise.

EXECUTIVE SUMMARY

Introduction

The serious consequences of flooding in the Steady Brook area have been well documented, and there is continuing pressure to develop additional lands in the Steady Brook floodplain areas.

On May 22, 1981, the Province of Newfoundland and the Government of Canada entered into a General Agreement Respecting Flood Damage Reduction; recognizing that the potential for future flood damages can be reduced by controlling the use of areas prone to flooding. The primary purpose of this Hydrotechnical Study of the Steady Brook Area was to determine flood discharge and associated water levels and flood prone areas for the 1:20 and 1:100 year recurrence interval flood events. A secondary objective was to identify possible flood remedial measures for future investigation. The extent of the study area for the hydraulic and floodplain mapping investigations extended from the outlet of Deer Lake to just downstream of the confluence of Steady Brook with the Humber River.

The main report and associated appendices and supplementary report concerning the field investigations describe in detail the methodology and findings of the hydrotechnical investigations.

Main Findings

Computer simulation techniques, taking into account hydrologic conditions at upstream locations (e.g. snowmelt) and the effects of lake, reservoir and channel routing, were utilized in order to estimate the peak flow rates and associated flood levels in the study area.

The following points briefly summarize the main findings of the hydrotechnical investigations:

1) Peak flow estimates for the Humber River just downstream from Steady Brook were found to be 1180 and 957 m^3/s for the 1:100 and 1:20 year peak flows respectively. These estimates were determined by means of the calibrated SSARR model and were verified by comparison to secondary estimates.

2) Peak flow estimates for the stream of Steady Brook were estimated to be 105 and 134 m^3/s for the 1:20 and 1:100 year flood events respectively. These estimates were determined by means of a regional flood frequency equation and were verified by comparison to secondary estimates.

3) The meteorologic data base available for the Humber River watershed was found to be marginally sufficient for hydrologic modelling in the continuous simulation mode. However, use of the SSARR model for real-time flood forecasting would require upgrading the meteorlogical data collection network. This would include installation of additional stations and adoption of a telemetered data collection system (refer to Appendix B).

4) Calibration and testing of the backwater models has confirmed the accuracy of the flood level simulations along the Humber River. The computed flood levels along Steady Brook are also considered to be accurate based on the results of sensitivity testing.

5) The 1:100 and 1:20 year flood levels were plotted on new topographic maps at a scale of 1:2500. The main flood hazard areas were then identified as follows:

i) The Community of Steady Brook is classified as having a high flood risk due to peak flows in the Humber River. Peak flows and ice jams along Steady Brook also contribute to flood risk from the confluence of the Brook up to the C.N.R. trestle.

ii) Small areas of development in the vicinity of Humber Village, Russell and Harrison are susceptible to some flooding.

iii) There is a moderate to low risk of flooding in the area of Governors Point at the outlet of Deer Lake.

6) The most attractive structural alternatives for reducing flood losses presently appear to be:

i) A combination of raising the roads and berming or dyking at several locations within the Community of Steady Brook.

ii) Individual flood proofing of structures located in flood fringe areas currently susceptible to potential flood damages.

7) The most attractive non-structural measures for reducing flood losses presently appear to be:

i) Implementation of floodplain regulations to prevent development in flood susceptible areas.

ii) Review and improve the operational policies of the Grand Lake Dam such that the usefulness of this structure in reducing downstream flood peaks is improved.

iii) Implementation of a flood warning system to be used in conjunction with modified operation of Grand Lake.

Main Recommendations

1) The 1:20 and 1:100 year flood profiles and associated flood-plains as delineated on topographic maps at a scale of 1:2500 should be adopted and utilized for future regulation of development along the Humber River and Steady Brook.

2) The SSARR model should be adopted and utilized for real-time flood forecasting along the Humber River. A real-time (telemetered) data collection system for discharge and meteorologic data should be implemented in the watershed for flood forecasting purposes.

3) Additional feasibility investigations should be undertaken in order to determine the cost-benefit ratio for possible structural flood control measures within the Community of Steady Brook.

4) Investigations should be undertaken to determine the potential for modifying the operational policies of the Grand Lake Dam in order to improve the usefulness of this structure in reducing downstream flood peaks.

5) Additional hydrotechnical studies should be carried out in the areas of South Brook, Bell's Brook and Governors Point in order to better define the potential flood risk in these areas.

1.0 INTRODUCTION

1.0 INTRODUCTION

1.1 General

Historically, the development of urban centres in many areas of Canada including Newfoundland, has taken place on flood prone lands. These lands were developed by the first settlers because of their agricultural productiveness and, in some cases, so that the river could be utilized as the main transportation route. These early uses of the floodplain have evolved into present day highly urbanized communities which still attempt to utilize floodplain lands. An increasing trend towards urban developments in Canada has resulted in an increased potential for higher flood losses. A nation-wide survey of potential flood hazards (8)* has indicated that more than 200 communities in Canada have some developments located in flood hazard areas. In particular, the serious consequences of flooding in Newfoundland and more specifically, in the Steady Brook area have been well documented in a number of reports (17,23,40,41).

There is continuing pressure to develop additional lands in the Steady Brook floodplain areas, as evidenced by recent attempts to provide some form of flood and erosion control along parts of the Humber River and Steady Brook. The development pressures have led to an increased potential for future flood losses in the Steady Brook and Humber River floodplain. However, structural measures to provide protection are very costly to construct and do not provide absolute protection from flood damages. In addition, structural measures to provide flood protection tend to invite additional development in the floodplain. Controls to prevent development in the flood prone areas are a more desirable means for reducing the potential for increased flood losses in the future.

On May 22, 1981, the Province of Newfoundland and the Government of Canada entered into a General Agreement Respecting Flood Damage Reduction. The main objective of this Agreement is to reduce the potential

Note: * (8) Number(s) in brackets denote sources given in the list of references.

for flood damages in floodplains and along the shores of lakes, rivers and the sea. This Agreement also recognizes that the potential for future flood damages can be reduced by controlling the development in the areas prone to flooding.

The General Agreement Respecting Flood Damage Reduction allows the two levels of government to enter into a number of other agreements on specific aspects of flood damage reduction, including but not limited to; land use planning, flood proofing, flood risk mapping, flood forecasting, flood control works and flood studies.

To provide for the identification and delineation of flood prone areas in Newfoundland, the "Agreement Respecting Flood Risk Mapping" was also signed on May 22, 1981. Under the terms of this agreement, a number of flood prone areas in the Province are to be mapped and flood risk zones delineated and ultimately designated as areas where the Federal and Provincial governments will agree to restrict their funding of new development. These agreements were amended in May, 1983 and a related "Studies Agreement" was signed in June, 1983. (In this report, projects completed under these agreements are referred to as work done under the Canada Newfoundland Flood Damage Reduction Program; abbreviated to CNFDRP.)

The reach of the Humber River from the outlet of Deer Lake to 0.5 km downstream of its confluence with Steady Brook and the portion of Steady Brook downstream of the falls was considered to be of high priority in regard to the potential for reducing future flood losses and is one of the first areas in the province to be studied in detail under this program. Subsequent to this investigation, future work may be required to provide structural or non-structural measures for flood damage reduction and/or to provide regulations for preventing future development in flood prone areas.

The primary purpose of the present study was to determine flood discharge and water levels and to identify flood prone areas and possible remedial measures along the Humber River and Steady Brook.

1.2 Authorization and Scope of Study

The agreements previously mentioned provide for the establishment of two committees; the Steering Committee which is responsible for general administration of the agreements and the Technical Committee which provides technical support to the Steering Committee. On June 10, 1983, Nolan-Davis & Associates Limited, in association with Cumming-Cockburn & Associates Limited were commissioned by the Newfoundland Department of Environment on behalf of the Steering Committee to undertake a "Hydrotechnical Study of the Steady Brook Area". As described in the Terms of Reference (10), the main objective of this investigation was to develop the 1:20 and 1:100 year recurrence interval flood hydrographs and associated backwater profiles for the study area.

The scope of the study is described in detail in the Terms of Reference (10) and is summarized by the following points:

1) Review of background information to characterize the flooding problem
2) Evaluate the significance of various factors affecting flooding in the Steady Brook area
3) Design, coordinate and manage a field program for the purpose of collecting hydrologic and hydraulic data for calibration and validation of models
4) Determine 1:20 and 1:100 year recurrence interval open water flood discharge and backwater profiles for:
    - the Humber River from the Deer Lake outlet to 0.5 km downstream of its confluence with Steady Brook
    - Steady Brook downstream of the water supply pump house.
5) Produce the 1:20 and 1:100 year flood profiles and plot the 1:20 and 1:100 year recurrence interval flood lines on topographic maps to determine the areal extent of flood prone areas
6) Undertake sensitivity analyses of peak flow estimates and backwater profiles
7) Assess the significance of ice jamming, debris jamming and other hydraulic factors affecting flood lines

8. Identify possible remedial measures for flood damage reduction which may be analysed as required in possible future phases of the flood hazard investigations.

1.3 Study Area Description

The general location of the study area is depicted on Figure 1.1. The Community of Steady Brook is located on the south bank of the Humber River between Corner Brook and Deer Lake. The upstream drainage area is comprised of the Humber River system which has a drainage area of over 7800 km^2 to Steady Brook. The Humber River watershed is drained primarily by two main branches; Upper Humber River and Grand Lake. The Upper Humber River is relatively large (over 2100 km^2 to its outlet at Deer Lake) and remains in a relatively natural state (with respect to both land use and streamflow regulation). The watercourse originates in the north in Gros Morne National Park and flows in a southerly direction eventually outletting into Deer Lake. The subwatershed representing the discharge from Grand Lake can also be characterized as being relatively large (over 5000 km^2). A significant portion of this subwatershed consists of Grand Lake itself, which is used to produce hydroelectric power. The outflow from Grand Lake discharges to Deer Lake which is an unregulated natural reservoir. Downstream from Deer Lake, the watercourse flows in a southwesterly direction to the Gulf of St. Lawrence.

As previously discussed, a portion of the study area consists of floodplain lands adjacent to Steady Brook. This is a relatively small watercourse which drains an area of 81.4 km^2, and outlets into the Humber River at the Community of Steady Brook.

A large portion of the historical flood damages along the Humber River have occurred in the low-lying portions of the Community of Steady Brook, due to flood conditions on both the Humber River (which can occur at any time of the year) and Steady Brook (which occurs primarily during spring runoff).

1.4 Overview of Study Methodology

The accurate determination of 1:20 and 1:100 year flood profiles along the study area depends on several hydrologic and meteorologic factors, including the following:

- historical flood conditions in the study area
- climatologic and hydrologic characteristics of the Humber River and Steady Brook watersheds
- peak discharge rates associated with the 1:20 and 1:100 year recurrence interval floods
- hydraulic characteristics of the channel and floodplain in the vicinity of the study area
- upstream regulation of flow along the Humber River system.

The complex interrelationships between the above mentioned factors have been considered in the course of undertaking these investigations.

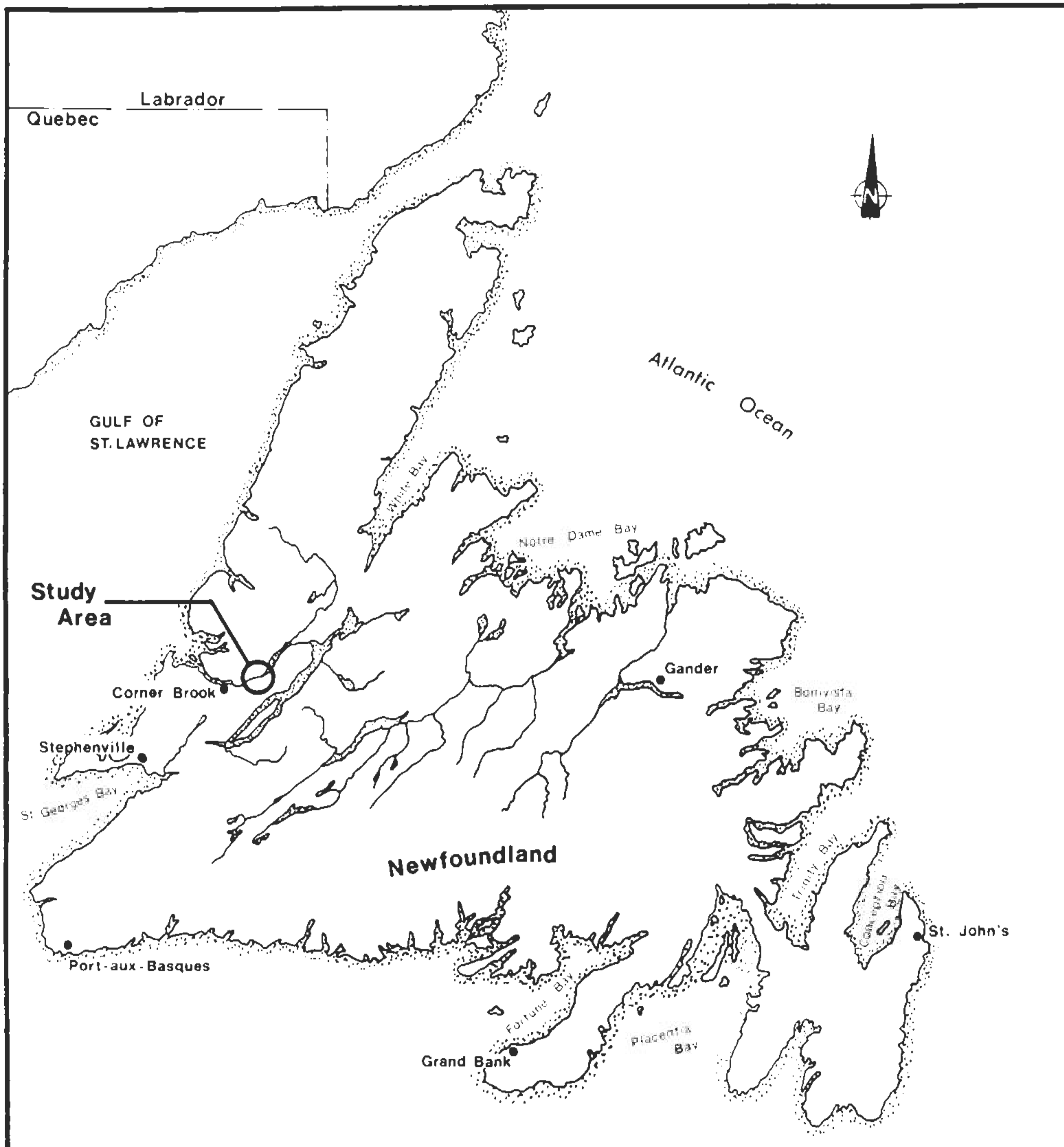
The first step in the investigations was the collection and review of available background information and existing data on climatologic and flood flow characteristics. This information is briefly summarized in Chapter 2.0, entitled, "Background Information".

The next step was the determination of appropriate 1:20 and 1:100 year peak discharge rates, including the effects of upstream storage. In order to determine the 1:20 and 1:100 year peak flows and associated water levels, it was necessary to simulate the hydrologic response of the entire Humber River watershed for flood conditions. This was undertaken for the Humber River using the SSARR model, as described in Chapter 3.0. Computed peak flows were also compared to secondary estimates undertaken by statistical techniques, as described in Appendix B and discussed in Chapter 3.0. Peak flow estimates for Steady Brook were undertaken by statistical techniques, and compared to secondary estimates undertaken by the HYMO model as described in Section 3.3.

The peak flow estimates were then converted to flood water levels (profiles) along the study reaches by means of a computer model of hydraulic characteristics. The hydraulic investigations were undertaken along those reaches of the floodplain and channel of the Humber River and Steady Brook as indicated in Figure 1.2. This is discussed in Chapter 4.0 including model calibration, verification and sensitivity testing of the most important hydraulic parameters. Supporting information describing the field surveys which were undertaken to provide input for set-up and testing of the computer models is described in Volume II which is a supplementary report.

Finally, the extent of the flood hazard area was plotted on copies of new topographic mapping for the study area. It was then possible to identify possible remedial measures which might be considered in more detail in the future for alleviating the potential for future flood losses. These measures are identified in Chapter 5.0.

As required by the Terms of Reference (10), the documents entitled, "Hydrologic and Hydraulic Procedures for Flood Plain Delineation" (24) and "Surveying and Mapping Procedures for Flood Plain Delineation" (31), developed by Environment Canada were used as basic guidelines throughout the course of these investigations.



Canada - Newfoundland
Flood Damage Reduction Program

General Location of Study Area

Nolan Davis & Associates Ltd
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Figure 1.1

2.0 BACKGROUND INFORMATION

2.1 Summary of Historical Floods

Documentation on historical floods along the Humber River covers the period 1944 to present. Table 2.1 presents a summary of flood susceptible areas along Steady Brook and the Humber River, together with an indication of the extent of damage and the cause of flooding. (Additional discussions concerning historical flooding in the Steady Brook area are provided in Appendix A.)

With reference to Table 2.1, it is evident that the majority of damage producing flood events have been associated with rain on snowmelt conditions. However, it is also evident that flood damages can occur as a result of heavy rains in the summer or fall. The approximate locations of these historically flood sensitive areas are depicted graphically on Figure 2.1.

The earliest records of flooding along the Humber River suggest that flood damages have predominantly occurred in the vicinity of Corner Brook. To a lesser degree, the areas of South Brook, Bell's Brook and Governors Point were also found to be historically sensitive to periodic flooding. Based on these findings, it is recommended that detailed hydrotechnical studies should also be carried out in these areas to better define the potential flood risk.

In recent years, the Community of Steady Brook has also been subjected to severe flooding (post 1970). The increased frequency of damage reports in recent years may be indicative of additional development of floodplain lands.

It is also noted that the effect of ice and debris jamming along Steady Brook may increase the flood risk to this area.

Furthermore, long-time residents of the Community of Steady Brook believe that the more significant flooding in recent years corresponds to the construction of the Trans Canada Highway on the southern shore of the Humber River. It is alleged that partial infilling of the channel has caused a backwater effect resulting in increased flooding in the Community just upstream.

The Humber River has been used for transporting logs for a number of years. As a result of the logging operations, long term residents have also complained about the accumulation of logs and debris in the channel, especially just upstream of the old log boom piers. This may be resulting in increased flood levels in the vicinity of the Community of Steady Brook.

2.2 Previous Studies

2.2.1 General

A number of investigations documenting flood conditions in the Humber River watershed have been completed in recent years, and have found that the predominant cause of flooding has been excessive rainfall during the spring months, leading to rapid snowmelt and peak flows resulting in flooding at various locations.

Existing regional flood frequency studies on peak flows for the island portion of the Province were useful in providing an overall assessment of flood characteristics in the area (11,27,44). This information indicates that peak flows along the Humber River frequently exceed the channel capacity, requiring use of additional conveyance capacity in natural floodplain areas.

2.2.2 Shawmont Report

A report pertaining to the high flows in the Humber River system during May 1969 was undertaken by Shawmont Newfoundland Ltd. (50). This report discusses the causes and effects of the high levels and flows on the Humber River system during that time period. In addition, the impacts and effects of the Bowater Power Company hydroelectric development on

Grand Lake were also analysed with respect to the May 1969 flooding. The report concludes that if the hydroelectric plant had not been built, then the flooding, past and future, would be, or would have been, at least as severe and most probably more severe than with the development of the storage system. These statements apply equally to Deer Lake and the reach of the Humber River between Deer Lake and at least as far downstream as Steady Brook. With respect to the period of high flows, which occurred in May 1969, it was concluded that the hydro development had a beneficial effect on the water levels and flows downstream from Deer Lake. It was also concluded that the addition of the Indian Brook Diversion had a negligible influence on flooding at downstream locations.

2.2.3 MacLaren Report

Some flooding at the Community of Steady Brook has been attributed to the construction of the Trans Canada Highway on the southern shore of the Humber River. Two reports entitled, "Humber River Flooding at Steady Brook" were completed for the Newfoundland Clean Air, Water and Soil Authority in 1972 (40,41). The first investigation consisted of a review of the report by Shawmont Newfoundland Ltd. undertaken for the Bowater Power Company Ltd. subsequent to the 1969 flooding at Steady Brook (50). This review confirmed several of the findings previously stated in the Shawmont study, and recommended an additional study to determine the factors contributing to periodic flooding of the Steady Brook area and to investigate the feasibility of remedial works which would alleviate undesirable conditions. The second investigation included peak flow estimates and determination of flood profiles culminating in the identification of the areal extent of the 1:60 year floodplain (40). The effect of infilling a small part of the Humber valley section during construction of the Trans Canada Highway on flood levels along the Humber River was also assessed, and was reported to be relatively insignificant.

Various structural alternatives, ranging from major schemes such as upstream storage, and widening of the channel, to more localized alternatives such as dykes and floodproofing were discussed for reducing flood damages. An analysis of the cost of these measures and their potential to reduce the physical extent of the hazard was also addressed. Nonstructural measures were assessed on a similar basis (such as development of an early flood warning system), although the discussion was substantially more qualitative in nature, compared to the assessment of possible structural modifications. It was generally concluded that the most cost effective means of reducing the flood potential along the Humber River would be floodproofing or relocation of highly flood susceptible structures, or the refinement of operating policies at the Grand Lake control structure to restrict outflows to the downstream reaches.

2.2.4 Department of Environment Report

Subsequent to high flows in the Grand Lake system during May 1981, the Department of Environment undertook an investigation on the flooding of the area. This preliminary report (17) briefly reviews the recurring flooding problem experienced by the residents of the Humber Valley and the reservoir operational requirements of the Bowater Power Company. The investigation concludes that the Steady Brook area is prone to flooding even without any contribution from the Main Dam spillway as the Humber River channel capacity is only about 25,000 cfs (708 m^3/s). Other findings were that the regulatory effects of the reservoir may be significant for small floods, but for relatively large floods, the effects were insignificant. It was also pointed out that in certain hydrologic situations and operational schemes, the Grand Lake reservoir may have adverse downstream effects. Recommendations included the completion of flood risk maps for the area and the implementation of a flood warning system. It was also recommended that upgrading be undertaken on existing hydrometric stations and the snow survey program.

2.2.5 Environment Canada Report

Finally, a report on historic flooding in Newfoundland was recently completed by Environment Canada, and includes perspectives on flooding along the Humber River study area (23). The general findings in regard to historical flooding in the study area are summarized briefly in Table 2.1, and discussed in Section 2.2. The existing studies on the hydrologic, hydraulic and climatic characteristics of the Humber River and Steady Brook basins have confirmed that a high potential exists for future flood losses in the study area, particularly within the area of the Community of Steady Brook itself.

2.3 Existing Data

2.3.1 Meteorological Data

Background information describing climatic characteristics of the Humber River watershed is available from the Atmospheric Environment Service and other agencies such as the Newfoundland Department of Environment (16, 34).

The period of record of climatological data available within and in the vicinity of the Humber River watershed is summarized in Table 2.2. With the exception of several stations for which no records were available on magnetic tape (see Table 2.2), all of this data was obtained from the Atmospheric Environment Service for use in the hydrologic investigations of the Humber River watershed. This data includes the following six meteorological parameters:

- daily maximum temperature
- daily minimum temperature
- daily mean temperature
- daily total rainfall
- daily total snowfall
- daily total precipitation

Table 2.2 summarizes graphically the period of record available for meteorologic stations which are located in and adjacent to the watershed. The location of the meteorologic stations which were included in the hydrologic modelling analysis are also shown on Figure 2.2. It should be noted that the selection of applicable stations was based on several factors including adjacent physiographic and hydrometeorologic characteristics and available record length.

Table 2.3 summarizes average meteorological parameters for several selected locations.

The annual average daily temperature within the study area varies from 2.7°C at Buchans to 5.1°C at Corner Brook. The mean monthly temperature is below freezing for the period of December through March. The warmest period is from July to August when the average daily temperature ranges between 15° to 17°C. The total annual precipitation varies between 990.8 to 1199.7 mm as determined from the meteorologic data summarized in Table 2.3. It is evident that the greatest amount of precipitation occurs along the west coast and upland areas of the Long Range Mountains and the Topsails, possibly due to orographic effects (34).

Additional information concerning a frequency analysis of rainfall intensities, etc. is discussed in Appendix D. The available data base is considered to be sparse, but the quality of existing data was found to be suitable for the purposes of this investigation. Locations for additional meteorological stations which may be required for future flood forecasting are discussed in Appendix B.

2.3.2 Snow Survey Data

Snow course data are collected by Environment Canada and the Bowater Power Company (29) near the locations indicated on Figure 2.2. To date, snow course data have been collected for the winters of 1954 to 1983. A summary of available snow cover data for the study watershed is presented in Table 2.4. Snow cover was found to be highly variable, and frequently in excess of 100 cm depth.

About 20 locations are monitored anually by the Bowater Power Company with only one set of snow cover measurements taken at each location, usually during the month of March. While this information may be adequate for estimating total runoff volumes for the purposes of power production, more frequent measurements should be taken for the purpose of providing additional input for calibration and verification of flood forecasting techniques.

2.3.3 Hydrographic Data

Field surveys of channel and floodplain characteristics were carried out in the lower reaches of the study area as part of previous investigations of flood characteristics along the Humber River (40). This included the collection of channel and floodplain cross-sections, determination of the stream channel profiles, and measurements of bridges and hydraulic structures. However, due to possible sedimentation and erosion processes and the resulting changes in cross-sectional properties since the time of the survey, it was necessary to update this information as part of the present investigations, as described in Section 4.2.1.

For example, a comparison of cross-section measurements from these surveys (undertaken in 1972 and 1983 respectively) indicates that some erosion and sedimentation has occurred in the reaches downstream of the confluence with Steady Brook. However, these changes were found to be minor in nature and had not significantly altered the hydraulic configuration of the river channel.

2.3.4 Hydrometric Data

Streamflow data at several locations within the Humber River watershed are collected for the hydrometric stations noted in Table 2.5 by the Water Survey of Canada*. The hydrometric station locations are shown on Figure 2.2.

Station 02YL003, the Humber River at Humber Village, measures discharge from most of the watershed upstream of the study area. However, the short period of record currently available at this location precludes a rigorous statistical analysis of peak flows for the study area.

Water level records and rating tables are also available at all hydrometric gauge locations.

NOTE: * Hydrometric stations are operated under the Canada-Newfoundland Hydrometric Survey Agreement

It has been noted that, due to diversions within some upstream subwatersheds, and changes to the operating policies of Grand Lake, the hydrologic response of the watershed draining to the study area may have changed. Therefore, an analysis was undertaken (see Section 3.0) to determine if the available long term hydrometric data requires any adjustments or modifications to ensure that it represents present conditions.

From an analysis of the available hydrometric data, it was found that, for all practical purposes, the annual maximum mean daily flow is equivalent to the annual maximum instantaneous flow along the Humber River. This was also substantiated by utilizing deterministic simulation techniques (see Section 3.0).

Some information on the characteristics of tides is also available near the confluence of the Humber River with the Humber Arm at Corner Brook. Tidal information is published by the Canadian Hydrographic Services, Department of Fisheries and Oceans (33). Corner Brook is referred to as a secondary tidal port where tidal information is given in relation to the primary tidal port at Harrington Harbour on the eastern coast of the Gulf of St. Lawrence. Relevant tide characteristics are summarized in Table 2.6.

2.3.5 Ice Cover

While little information on ice characteristics is available for the study area, some data on extent of ice cover is available through the Water Survey of Canada. Similarly, some historical documentation of ice related flood events is available through local agencies and Newfoundland Department of Environment. However, this data is sparse and is available only in a qualitative form such as photographs of some ice related flood events and newspaper articles commenting on ice jams. It is recommended that additional data on ice characteristics and ice thickness should be collected in the future.

2.3.6 Surficial Geology

The surficial geology within the Humber River watershed ranges from bedrock outcropping, areas of glacial tills, and areas of sands and gravels to areas of organic soils. Figure 2.3 illustrates the major subdivision of soil types found within the watershed.

Based on the available information, the most common type of surficial geology is exposed bedrock which forms extensive rock plains, knolls and ridges throughout most of the watershed. The rock, in most cases is covered by a thin veneer of till soils or concealed by vegetation of either forest, scrub or peat bog. The area that comprises the highlands of the Long Range Mountains, Topsail Uplands and Burlington Peninsula is mostly exposed with rock talus or calluvium occurring on the mountain slopes.

The glacial tills found throughout the watershed demonstrate considerable variability in thickness. These soils are found as a thin veneer or extensive moraine deposit overlying the bedrock. The composition of the tills vary from grey silty sand or sand silt within the Long Range Mountains and Topsail Uplands, and red clayey silt within the Humber River Valley. There are various local areas of till cover which are comprised of unsubdivided deposits of ice contact sand and gravel. In general, the composition of all tills closely reflect the lithology of the underlying bedrock (34).

The sand and gravel deposits found within the study area are outwash and fluvial in origin and are generally confined to stream and river valleys. The major sand and gravel deposits are found in the Deer Lake, Upper Humber River Valley, and the Sandy Lake and Birchy Lake areas. Additional buried deposits of sand and gravel occur at various points interstratified within the till deposits.

Peat deposits are found commonly throughout the watershed in areas with poor surface drainage. These deposits occur extensively on the barren Topsail Uplands just south of Grand Lake. Peat accumulations in the form of high moor bogs and string bogs are found on the highland plateaus of the Long Range Mountains. Peat deposits can attain thicknesses of several metres overlying bedrock or till deposits.

The soil types in the watershed are generally not suitable for agricultural uses due to excessive soil moisture, and adverse relief because of steepness or pattern of slopes, stoniness and shallowness to bedrock.

2.3.7 Forest Cover

The study area is located within the Boreal Forest Region of Canada (47). The Boreal Forest Region can be further divided into two subregions, Predominantly Forest Boreal Region and Forest and Barren Boreal Region. Both of these subregions are found within the Humber River watershed. The characteristic dominant species include White Spruce, Black Spruce, Balsam Fir in association with Tamarack, White Pine, White Birch, Yellow Birch, Trembling Aspen and Balsam Poplar.

The forest cover within the study area can be divided into four major classes; mature forest, scrub land, barren and peat bog. Figure 2.4 illustrates the forest cover for the watershed.

Mature forest is the most common forest cover class within the study area. The densest mature forest cover generally occurs where the glacial tills are the thickest above the bedrock. However, most of the forest within this class is fairly sparse due to the thin veneer till soils and exposed bedrock. The dominant tree species within this class is Balsam Fir and Black Spruce, with White Birch, Trembling Aspen and Balsam Poplar also being found. In general, sparse mature forest cover is found in all subwatersheds. The most densely treed area within the watershed is located downstream of Deer Lake to the Community of Steady Brook where Balsam Fir and Black Spruce dominate with softwood scrub land, White Birch and peat bog also being found.

The remainder of the study area is comprised of softwood and hardwood scrub lands, rock barrens and peat bogs. The vegetation classes follow closely the soil type, soil depth and moisture regime. Therefore, the vegetation groups are usually small in area and are well scattered. Peat bogs are found in plateau depressions within the highlands and along river valleys and around lakes within the lowlands.

2.4 Operation of Reservoir System

At present, there are a total of three major reservoirs (Grand Lake, Deer Lake and Hinds Lake) within the Humber River system. Two of these reservoirs (Grand Lake and Hinds Lake are operated almost exclusively for power production with some consideration to flooding. The Bowater Power Company has had the rights to use Grand Lake for power production since the early 1900's. The Hinds Lake dam is relatively new (1980) and is operated by the Newfoundland and Labrador Hydro. Deer Lake is a natural reservoir located downstream from Grand Lake and operates under a free flow condition. A number of other small natural ponds and lakes located within the watershed have relatively little impact on the magnitude of peak flows along the Humber River.

The outflow from Grand Lake can be any combination of the following:

- power house penstocks; usually a uniform flow of about 198 m^3/s (7000 cfs)
- main dam spillway; overflow during peak events
- log sluiceway; discharge rates up to about 1.5 m^3/s (53 cfs)

In the past, there have been a number of significant alterations to the Grand Lake watershed. The changes with the most significance to the present study include the diversion of 238 km^2 from Indian Brook to Birchy Lake (directly connected to Grand Lake) with minor return flow to Indian Brook, and the regulation of Hinds Lake for hydroelectric generation in 1980. Minor adjustments in the natural storage on Sheffield Lake and Little Grand Lake were made during the 1966 drought.

In order to operate the Grand Lake and Hinds Lake power stations efficiently, the water levels are maintained at target elevations as specified by reservoir rule curves for Grand Lake and Hinds Lake (see Figure 2.5). However, it should be noted that due to the unpredictable nature of inflows to Grand Lake, and the absence of an accurate flood forecasting technique, the rule curves are only used as rough estimates for reservoir levels. At the highest target elevations specified on the rule curves, the potential storage of Grand Lake and Hinds Lake is 1.72×10^6 dam^3 and 2.68×10^5 dam^3 respectively. However, based on a number of previous studies (40, 36), it is evident that the effects of the reservoir are small in reducing peak discharges downstream from Deer Lake due to inflows from the Upper Humber River.

TABLE 2.1

Historical Summary of Flooding in the Humber River Basin

Date	Cause	Description/Location
Sept. 14-16, 1944	Heavy rain (2.92 inches (74.2 mm) of rain at Deer Lake)	Railway reported to have taken precautions to prevent washouts from Grate's Point to Humbermouth.
Oct. 4-5, 1944	High winds, heavy rainfall	A section of the Newfoundland Railway (east of Humbermouth) washed out.
Nov. 16, 1944	Autumn gale	Grand Lake reported to be high and waves created by gale resulted in a railway washout at Sandy Pond dump.
Nov. 4-5, 1945	Heavy rain	Storm weekend with heavy rain caused three minor washouts on railway line at South Brook, Harry's Brook, and Humbermouth.
May 18-19, 1948	Heavy rain, snowmelt	Rivers and brooks on West Coast reported to be in flood. Railway washout at East Humbermouth
May 21-30, 1969	Rain, melting snow	Several homes along Humber River from Corner Brook to Nicholsville were inundated. Highways were blocked for a period of time.
May 22 - June 3, 1970	Heavy rainfall, debris blockages	Several streets in Corner Brook inundated. Majestic Brook overflowed its banks. Culvert blockages at Brakes Cove resulting in flooding of CNR crossing.
Nov. 24-26, 1970	Heavy rains	In Corner Brook, catchbasins blocked and many basements flooded. C.N. tracks washed out in Mount Morish area.
Feb. 14-15, 1971	Rain, melting snow and ice, ice jams	In Corner Brook, some roads washed out and many basements flooded.

TABLE 2.1 (cont'd)

Date	Cause	Description/Location
Mar. 9-10, 1972	Rain and mild temperatures	In Corner Brook, blocked culverts and storm drains resulted in damages to streets and city property.
May 15-18, 1972	Spring runoff accompanied by rainfall	Section of TCH inundated west of Corner Brook. Child drowned in swollen brook behind her home in Corner Brook. Several homes flooded at Steady Brook.
Nov. 27-28, 1972	Rain, mild temperatures, melting snow	In Corner Brook, drainage systems overtaxed. Bell's & Petrie Brooks overflowed their banks resulting in inundation of some streets and basements.
Dec. 7-8, 1972	Heavy rain	Bell's Brook overflowed inundating property on Walbourne's Road, Corner Brook.
Feb.2-3, 1973	Mild temperatures, rain, melting snow and ice jams	Minor washouts on several gravel roads throughout Corner Brook.
June 23-24, 1973	Heavy rain	Considerable damage to Corner Brook streets.
Aug. 1-4, 1973	3-day heavy rainfall	Corner Brook Stream and Bell's Brook overflowed resulting in some inundation. South Brook near Pasadena in flood and problems also occurred at Blue Gulch Brook.
Sept. 12-13, 1974	Heavy rainfall	A home on Old Humber Road, Corner Brook was inundated.
Sept. 21-22, 1975	Heavy rainfall	In Corner Brook, storm sewers and ditches couldn't cope with runoff. Flooded streets, basements and washouts resulted.
Dec. 22-25, 1975	Rain, snow and unseasonally high temperatures	In Corner Brook, storm damages reported to be extensive to city streets.

TABLE 2.1 (cont'd)

Date	Cause	Description/Location
Jan. 27-28, 1976	Rain, melting snow and ice jams	In Corner Brook, several road washouts reported. Homes in Frenchman's Cove, Benoits' Cove and Lark Harbour damaged by flood waters. Steady Brook reported to be clogged with ice causing inundation of 4 homes and threatening another 10.
Mar. 21-23, 1976	Rain, melting snow and ice with blockages	In Corner Brook, flooding of city streets, businesses and private property was reported. Roads flooded in Frenchman's Cove area. Section of TCH inundated at Duncan's Brook.
Jan. 4-5, 1977	Rain, snow and melting snow	In Corner Brook, blocked catch-basins resulted in some flooding.
Mid-January, 1977	Heavy rainfall and thaw	At least two homes in Steady Brook inundated.
June 8-10, 1977	Spring runoff, three Main Dam gates opened	Inundation of homes, roads and yards reported at Steady Brook.
Nov. 18, 1977	Power outage tripped emergency spillway	Heavy spilling of water resulted in inundation of TCH at Spillway Brook closing the highway for a period of time.
Dec. 11-12, 1977	High tides and strong onshore winds	Bay of Islands, Cox's Cove, Lark Harbour and Frenchman's Cove reported damages due to inundation.
Dec. 27-29, 1977	High temperatures,	In Corner Brook, several roads were damaged and some homes were inundated. Guard rails and hydro poles along the Humber River were left with little support as the flood had eroded tons of earth. The TCH was reported to be inundated at Little Rapids & near Birchy Lake.

TABLE 2.1 (cont'd)

Date	Cause	Description/Location
Jan. 14-16, 1978	Rain, melting snow and rafting ice	Streets damaged in Corner Brook Minor flooding of highway at Gillams (north shore Bay of Islands). Blocked culvert at Little Rapids resulted in overflow of TCH.
May 17-20, 1978	Spring freshet unseasonable temperature	Properties at Steady Brook were reported to be inundated.
March 6-9, 1979	Rain, melting snow and debris blockage	In Corner Brook, some flooding of basements and minor road damage reported. Corner Brook Stream reported to be high.
July 17-20, 1979	Heavy rainfall, debris blockages	In Corner Brook, a few minor washouts occurred.
Nov. 4-7, 1979	2 days of heavy rain	Flooding and rockslides reported at several locations on West Coast. Problem area was reported to be TCH at Gallant's Hill near George's Lake.
Aug. 10-11, 1980	Heavy rainfall	In Corner Brook, minimal damage reported to city streets. One family forced to vacate their flooded basement apartment.
Feb. 3-4, 1981	Heavy rain, melting snow and ice, and some blockages	In Corner Brook, 20-25 washouts were reported. The Burgeo Road also reported to be inundated.
Feb. 12-13, 1981	Rain	Minor flooding reported in Corner Brook.
May 8-16, 1981	Spring rains, main dam gates open	Properties inundated in Nicholsville, Steady Brook as as well as other communities.
May 4-10, 1982	Spring runoff	Some property flooding was recorded in the Community of Steady Brook.
April 20 - May 10, 1983	Heavy rains and snowmelt	Minor flooding in the Steady Brook area and along the Humber River downstream of Deer Lake.
Aug. 10-19, 1983	Heavy rainfall	Many properties were noted to be partially under water along Steady Brook and the Humber River.

TABLE 2.2

Summary of Record Period of Available Meteorological Data

Station Nos.	Name	Lat.	Long.	Period of Record Began Year	Began Month	Ended Year	Ended Month
B400300	Badger	48 59	56 03	1955	08	1956	06
				1956	06	1963	09
				1964	10	1964	11
				1965	04	1966	05
				1966	10	1967	04
B400301***	Badger (Aut)	48 58	56 04	1971	06	1971	12
				1972	01	to date	
B400350	Baie Verte	49 56	56 12	1958	06	1962	12
			56 11	1963	08		
B400698	Buchans	48 50	56 52	1965	07	1967	06
				1968	05	1973	03
				1973	10	to date	
B400699**	Buchans	48 49	56 51	1937	01	1938	06
				1938	11	1947	01
B400700**	Buchans A	48 51	56 50	1943	11	1945	12
				1946	01	1951	12
				1952	01	1960	08
				1960	09	1965	06
B400812**	Burnt Pond	48 10	57 21	1972	07	to date	
B401300**	Corner Brook	48 57	57 57	1933	04	1936	12
				1937	02	1942	03
				1943	04	1952	04
				1952	05	to date	
B401302*	Corner Brook Avalon	48 57	57 57	1960	06	1963	01
B401305*	Corner Brook Lake	48 52	57 52	1933	04	1936	09
				1936	11	1937	05
B401500**	Deer Lake	49 10	57 26	1933	03	1936	08
				1936	10	1952	04
				1952	05	to date	
B401501**	Deer Lake A	49 13	57 24	1965	07	1965	10
				1965	11	to date	

TABLE 2.2 (cont'd)

Station Nos.	Name	Lat.	Long.	Period of Record Began Year	Month	Ended Year	Month
B401550	Exploits Dam	48 46	56 36	1956	06	to date	
B402060	Gull Pond	49 12	56 08	1964	11	1965	08
			56 09	1965	09	1967	05
			56 09	1967	10	1971	11
B402065	Hampoen	49 33	56 52	1958	06	1962	07
B402415*	Howley	49 11	57 06	1934	11	1935	05
				1937	02	1944	06
B402755	Millertown	49 00	56 21	1934	11	1934	12
				1935	01	1946	07
B403096	Rocky Harbour	49 35	57 55	1972	07	1976	10
				1976	11	to date	
B403700	Springdale	49 30	56 05	1955	07	1961	08
				1961	08	to date	
B403800	Stephenville A	48 32	58 33	1942	02	1967	05
				1967	06	1968	01
				1968	01	1968	95
				1968	06	1978	04
				1978	05	to date	
B403815	Stephenville Crossing	48 32	58 26	1967	06	1967	11

* data not available on magnetic tape
** applicable meteorologic data used in SSARR modelling analysis
*** data referred to as questionable by AES

TABLE 2.3

Summary of Meteorologic Data for Selected Stations

● CORNER BROOK
48° 57'N 57° 57'W 5 m

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	CODE
Daily Maximum Temperature	-1.8	-2.4	1.3	5.8	11.3	17.3	21.6	20.7	16.3	10.5	5.7	0.3	8.9	1
Daily Minimum Temperature	-8.4	-10.1	-6.4	-1.3	2.7	7.9	12.4	12.1	8.0	3.6	0.1	-5.5	1.3	1
Daily Temperature	**-5.1**	**-6.3**	**-2.6**	**2.3**	**7.1**	**12.6**	**17.0**	**16.4**	**12.1**	**7.1**	**2.9**	**-2.6**	**5.1**	**1**
Standard Deviation, Daily Temperature	2.8	3.3	2.4	1.6	1.5	1.2	1.5	1.3	1.1	1.1	1.5	2.2	0.9	1
Extreme Maximum Temperature	13.0	12.8	18.9	19.4	27.2	33.3	34.4	34.4	31.1	25.0	21.7	16.7	34.4	
Years of Record	44	43	45	47	47	47	46	47	47	47	47	47		
Extreme Minimum Temperature	-31.7	-31.7	-29.4	-15.6	-7.2	-4.4	1.1	0.0	-2.8	-7.8	-16.1	-20.6	-31.7	
Years of Record	44	43	45	47	46	47	46	47	47	47	47	45		
Rainfall	28.7	15.4	24.2	28.3	58.1	74.0	73.5	94.6	92.4	102.6	91.7	38.7	722.2	1
Snowfall	104.4	73.8	57.9	25.0	4.8	0.2	0.0	0.0	0.0	6.3	38.8	99.7	410.9	1
Total Precipitation	**133.1**	**89.3**	**82.1**	**53.2**	**63.0**	**74.2**	**73.5**	**94.6**	**92.4**	**109.3**	**130.4**	**138.4**	**1133.5**	**1**
Standard Deviation, Total Precipitation	34.2	36.6	35.6	22.9	20.7	28.8	34.3	38.0	40.4	40.9	41.6	44.7	135.8	1
Greatest Rainfall in 24 hours	35.8	26.7	47.0	48.0	45.0	52.3	44.5	72.4	82.6	79.8	63.5	32.8	82.6	
Years of Record	45	43	45	47	46	47	46	47	47	46	47	47		
Greatest Snowfall in 24 hours	48.3	61.0	26.7	29.0	17.8	2.5	0.0	0.0	T	16.5	38.1	43.2	61.0	
Years of Record	45	43	45	47	47	47	46	47	47	47	46	47		
Greatest Precipitation in 24 hours	48.3	61.0	47.0	48.0	45.0	52.3	44.5	72.4	82.6	79.8	64.5	43.2	82.6	
Years of Record	45	43	45	47	46	47	46	47	47	46	46	47		
Days with Rain	5	3	5	7	12	13	13	15	14	16	13	6	122	1
Days with Snow	21	18	13	8	2	*	0	0	0	2	9	19	90	1
Days with Precipitation	24	18	17	14	13	13	13	15	14	18	20	23	202	2

● BUCHANS A
48° 51'N 56° 50'W 276 m

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	CODE
Daily Maximum Temperature	-4.3	-4.6	-1.2	3.1	10.0	17.0	21.2	19.5	15.1	8.9	3.7	-1.9	7.2	8
Daily Minimum Temperature	-12.1	-13.7	-9.9	-4.6	0.1	5.4	9.7	9.0	5.1	0.8	-2.9	-9.3	-1.9	8
Daily Temperature	**-8.2**	**-9.2**	**-5.6**	**-0.8**	**5.0**	**11.2**	**15.4**	**14.3**	**10.1**	**4.9**	**0.4**	**-5.6**	**2.7**	**8**
Standard Deviation, Daily Temperature	3.3	3.6	2.3	2.1	1.4	1.4	1.3	1.1	1.0	0.7	1.1	1.9	0.8	4
Extreme Maximum Temperature	8.3	7.8	11.7	15.6	27.2	31.7	34.4	30.6	28.3	20.0	17.2	11.7	34.4	
Years of Record	22	22	22	22	21	22	21	20	21	21	22	21		
Extreme Minimum Temperature	-33.3	-37.2	-30.0	-23.3	-10.0	-2.2	1.1	-1.1	-3.3	-10.0	-15.6	-30.6	-37.2	
Years of Record	22	22	22	22	21	22	21	20	21	21	22	21		
Rainfall	22.9	14.1	15.0	22.0	52.7	65.1	77.1	100.1	91.7	95.7	77.2	37.3	670.9	8
Snowfall	79.6	71.7	59.2	37.5	6.4	2.1	0.0	0.0	0.0	6.1	30.2	63.1	355.9	8
Total Precipitation	**88.4**	**76.7**	**73.0**	**47.8**	**58.2**	**66.9**	**77.1**	**100.1**	**91.7**	**103.3**	**112.1**	**95.5**	**990.6***	**6**
Standard Deviation, Total Precipitation	31.3	43.9	28.7	30.8	26.6	21.9	37.0	38.7	41.0	38.1	38.9	43.2	160.4	5
Greatest Rainfall in 24 hours	31.8	27.2	22.4	34.5	45.0	35.1	46.0	64.0	67.1	62.2	84.3	41.9	84.3	
Years of Record	22	22	22	22	19	22	21	20	21	21	22	21		
Greatest Snowfall in 24 hours	43.2	62.7	23.8	28.7	10.9	15.2	0.0	0.0	T	14.5	17.3	25.1	62.7	
Years of Record	22	22	22	22	19	22	21	20	21	21	22	21		
Greatest Precipitation in 24 hours	43.2	61.2	27.4	36.1	45.0	35.1	46.0	64.0	67.1	62.2	84.3	41.9	84.3	
Years of Record	22	22	22	22	19	22	21	20	21	21	22	21		
Days with Rain	4	2	3	5	9	11	12	13	11	12	9	5	96	8
Days with Snow	17	12	13	10	3	0	0	0	0	2	8	16	81	8
Days with Precipitation	18	13	14	12	11	11	12	13	11	13	15	17	160	6

Source: (16) Dept. of Environment, Atmospheric Environment Service, Canadian Climate Normals, "Temperature and Precipitation 1951-1980, Atlantic Provinces", Downsview, Ontario

NOTE: Units: Temperatures expressed in °C, Rainfall in mm and Snowfall in cm

TABLE 2.3 (cont'd)

● DEER LAKE 49° 10'N 57° 26'W 11 m	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	CODE
Daily Maximum Temperature	-2.8	-3.1	0.8	5.4	11.8	18.0	22.1	21.0	16.2	10.3	5.2	-0.6	8.7	2
Daily Minimum Temperature	-10.6	-12.5	-8.4	-3.0	1.2	6.4	10.9	10.7	6.6	2.2	-1.5	-7.6	-0.5	2
Daily Temperature	**-6.8**	**-7.8**	**-3.9**	**1.2**	**6.5**	**12.2**	**16.6**	**15.8**	**11.4**	**6.3**	**1.8**	**-4.1**	**4.1**	**2**
Standard Deviation, Daily Temperature	2.9	3.3	2.5	1.7	1.4	1.3	1.4	1.2	1.1	0.8	1.3	2.3	0.9	2
Extreme Maximum Temperature	13.3	13.3	17.0	23.0	27.8	31.7	35.6	32.2	28.9	23.3	21.1	16.7	35.6	
Years of Record	46	46	47	45	46	45	48	44	46	45	47	48		
Extreme Minimum Temperature	-33.9	-37.2	-35.0	-21.7	-10.6	-4.4	-0.6	-2.2	-3.9	-8.9	-20.6	-29.4	-37.2	
Years of Record	46	46	47	46	46	45	48	44	46	45	47	48		
Rainfall	21.8	17.9	26.8	34.9	63.9	76.3	78.2	105.7	89.8	109.7	82.1	37.7	744.6	2
Snowfall	70.0	52.8	46.9	26.2	2.9	T	0.0	0.0	0.0	3.0	25.9	62.5	290.2	2
Total Precipitation	**91.8**	**70.7**	**73.7**	**61.2**	**66.1**	**76.3**	**78.2**	**105.7**	**89.8**	**112.8**	**107.3**	**99.7**	**1033.1**	**2**
Standard Deviation, Total Precipitation	31.8	42.9	29.0	28.0	20.5	35.3	35.4	33.6	36.3	40.0	35.4	37.3	117.0	2
Greatest Rainfall in 24 hours	28.4	77.5	48.5	42.7	72.6	45.2	53.8	54.1	74.2	85.1	49.6	57.4	85.1	
Years of Record	45	46	46	46	45	45	48	44	46	44	47	48		
Greatest Snowfall in 24 hours	38.1	40.8	27.9	35.6	15.7	7.9	T	0.0	T	21.3	45.2	35.8	45.2	
Years of Record	45	46	46	46	45	45	48	44	46	45	47	48		
Greatest Precipitation in 24 hours	38.1	82.6	48.5	42.7	72.6	45.2	53.8	54.1	74.2	85.1	49.6	57.4	85.1	
Years of Record	45	46	46	46	46	45	48	44	46	44	47	48		
Days with Rain	4	2	5	7	13	13	13	14	14	16	12	5	118	2
Days with Snow	13	9	10	6	1	*	0	0	0	1	5	11	56	2
Days with Precipitation	17	11	14	12	13	13	13	14	14	16	16	15	168	2

● ROCKY HARBOUR 49° 35'N 57° 55'W 37 m	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	CODE
Daily Maximum Temperature	-2.4	-3.1	0.4	4.8	10.3	16.0	19.7	19.1	14.9	9.6	5.3	-0.2	7.9	8
Daily Minimum Temperature	-9.0	-11.3	-7.3	-2.2	2.1	7.2	11.6	11.6	7.3	3.0	-0.7	-5.8	0.5	8
Daily Temperature	**-6.7**	**-7.2**	**-3.4**	**1.3**	**6.2**	**11.6**	**15.7**	**15.4**	**11.2**	**6.4**	**2.3**	**-3.0**	**4.2**	**8**
Standard Deviation, Daily Temperature	2.8	2.0	2.4	1.4	1.8	1.4	1.6	0.6	1.2	0.9	1.5	2.5	0.8	6
Extreme Maximum Temperature	15.5	13.3	17.2	20.0	25.0	27.0	29.5	27.6	26.1	20.6	18.3	16.7	29.5	
Years of Record	8	8	8	8	8	8	9	9	9	9	9	9		
Extreme Minimum Temperature	-23.4	-27.2	-25.6	-15.8	-8.1	-2.8	1.7	0.0	-1.7	-3.9	-15.0	-23.9	-27.2	
Years of Record	8	8	8	8	8	8	9	9	9	9	9	9		
Rainfall	49.2	18.2	30.5	39.0	73.7	83.0	93.4	106.4	99.8	115.6	102.4	48.3	856.5	8
Snowfall	84.1	59.2	55.4	25.5	3.3	0.0	0.0	0.0	0.1	3.1	27.0	78.2	335.9	8
Total Precipitation	**129.4**	**78.9**	**91.2**	**64.1**	**74.1**	**82.7**	**93.4**	**106.4**	**99.9**	**116.0**	**130.9**	**132.7**	**1199.7**	**8**
Standard Deviation, Total Precipitation	66.1	33.4	61.3	31.8	34.6	42.3	61.8	44.9	40.5	49.9	58.5	58.5	236.2	6
Greatest Rainfall in 24 hours	41.9	22.9	33.6	22.1	26.7	49.5	59.0	52.2	43.9	79.0	58.0	64.8	79.0	
Years of Record	8	8	8	8	7	8	9	9	8	9	9	9		
Greatest Snowfall in 24 hours	35.5	34.0	30.5	14.0	14.5	T	0.0	0.0	0.0	12.7	26.0	27.5	35.5	
Years of Record	8	7	8	8	8	8	9	9	9	9	9	9		
Greatest Precipitation in 24 hours	45.7	34.0	33.8	22.1	26.7	49.5	59.0	52.2	43.9	79.0	58.0	67.8	79.0	
Years of Record	8	7	8	8	7	8	9	9	8	9	9	9		
Days with Rain	4	2	4	8	13	11	12	13	14	18	12	4	111	8
Days with Snow	18	14	12	7	1	0	0	0	0	1	7	16	76	8
Days with Precipitation	21	16	15	13	15	15	14	16	18	20	19	21	201	8

Source: (16) Dept. of Environment, Atmospheric Environment Service, Canadian Climate Normals, "Temperature and Precipitation 1951-1980, Atlantic Provinces", Downsview, Ontario

NOTE: Units: Temperatures expressed in °C, Rainfall in mm and Snowfall in cm

TABLE 2.4

Snow Course Data

Location	Years of Record	Location Lat.	Location Long.	Mean Snow Depth* (cm)	SD of Snow Depth**(cm)
Upper Humber River	17	49/14	57/22	66.9	24.1
N.E. Whetstone Pt.	25	49/05	57/24	67.1	26.9
Hinds plain	24	49/00	57/03	74.4	26.7
Valley of Lakes	24	48/52	57/43	116.0	35.7
Glover Island	22	48/46	57/43	53.4	27.5
South shore	23	48/39	57/36	61.2	27.1
Little Grand Lake S.	25	48/39	57/36	86.2	32.0
Little Grand Lake N.	25	48/39	57/36	85.3	33.8
Grand L. Storage Pond	25	48/90	58/05	90.0	30.4
Grand Lake S.W. Ind.	25	48/40	58/05	84.3	39.2
Sandy Lake	24	49/19	57/03	70.8	22.0
Sandy Lake Beatons Bk.	24	49/19	56/41	62.0	22.1
Birchy Lake E. Slope	25	49/15	56/49	77.3	23.6
Sheffield Lake N. Shore	25	49/15	56/49	76.5	25.5
Sheffield Lake S. Shore	25	49/15	56/49	76.8	24.1
Sandy Lake	25	49/11	56/56	72.0	22.5
Glide Brook	25	49/05	57/25	83.7	27.4
Indian Pond	19	49/26	56/38	101.0	20.8

NOTES:

* approximate date of measurement is March 15-25

** SD is one standard deviation

TABLE 2.5

Summary of Hydrometric Data

Station Nos.	Station Name	Period of Record	Gauge Type	Drainage Area (km^2)	Mean Annual Discharge (m^3/s)	Mean Annual Unit Runoff (mm)	Flood Peaks A (m^3/s)	Flood Peaks B (m^3/s)	Flood Peaks C (m^3/s)	Flood Peaks D (m^3/s)
02YL002	Corner Brook @ Watsons Br. Powerhouse	1959 to date	R	127	4.3	1063	24.4	44.7	N/A	N/A
02YL003	Humber River @ Humber Village	1982 to date	R	7860	N/A	N/A	N/A	N/A	N/A	N/A
02YK001	Humber R. @ Grand L. Outlet	1925 to date	R	5020	142.0	893	338.0	796.0	N/A	N/A
02YL001	Upper Humber R. near Reidville	1928 to date	N	2110	83.2	1244	558.0	813.0	566.0	776.0
02YK002	Lewaseechjeech Bk @ Little Grand Lake	1952 to date	N	470	16.9	1135	85.8	137.0	91.5	141.0
02YK003/ 02YK005	Sheffield R. nr T.C.H.	1955 to date	N	391	10.5	847	70.5	108.0	70.1	100.0
02YK004	Hinds Brook nr. Grand L.	1956-1979	N	529	16.5	981	90.4	129.0	94.4	136.0
02YK006	Hinds Bk @ Power House	1981 to date	R	651	24.9	1204	24.9	234.0	N/A	N/A
02YM002	Indian Bk Diversion to Birchy Lake	1964 to date	N	238	5.67	752	36.4	46.2	37.4	52.1

NOTES FOR FLOOD PEAKS:
A - Mean Annual Mean Daily Flood
B - Maximum Recorded Mean Daily Flood
C - Mean Annual Instantaneous Flood
D - Maximum Recorded Instantaneous Flood

R - Regulated
N - Natural Flow
N/A - Not Available

TABLE 2.6

Maximum Tidal Elevations at Corner Brook

	Geodetic Elevation in metres*
Mean High Tide **	0.67
Maximum High Tide ***	0.98
Maximum Recorded Tide ****	1.68

NOTES:

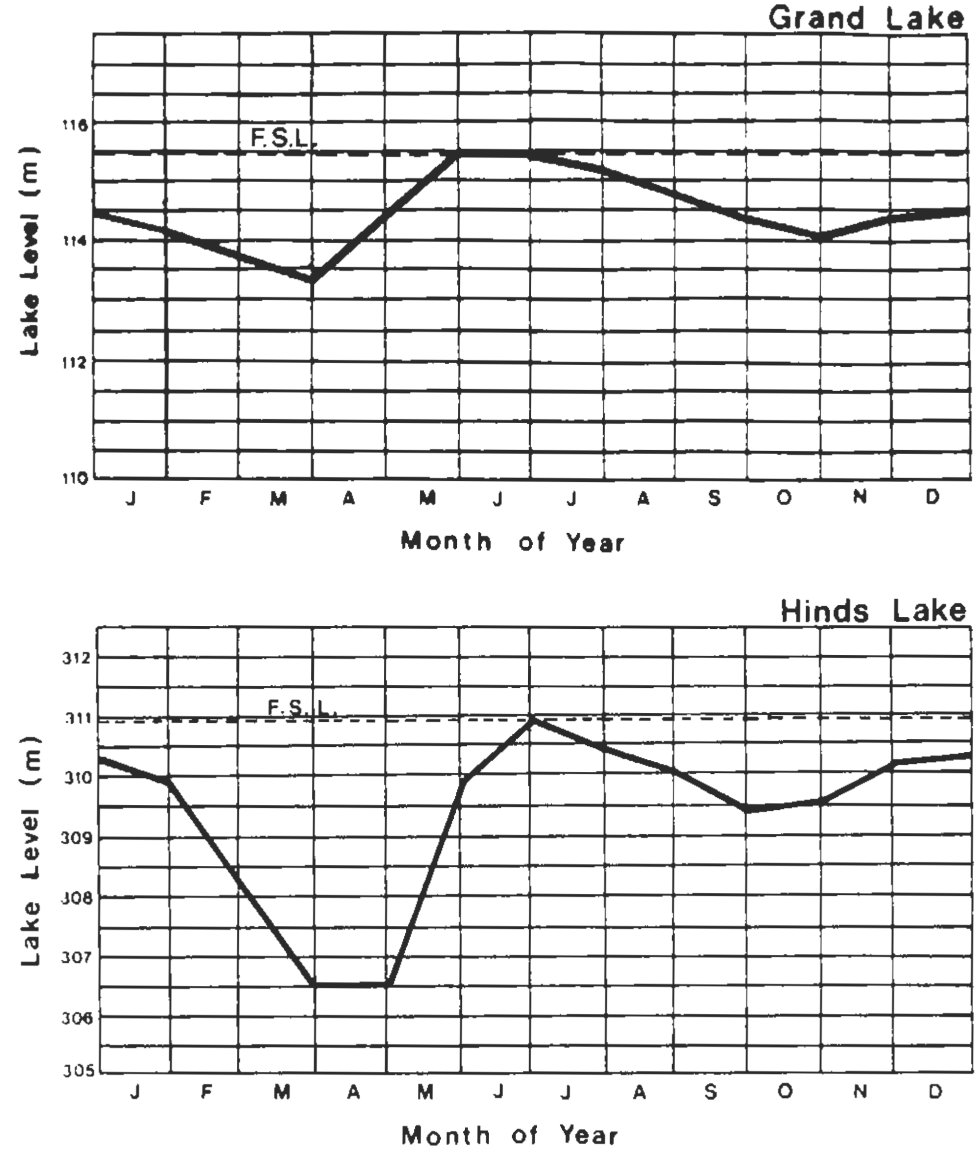
* Elevations are expressed as approximate geodetic elevations by subtracting the mean water level relative to local chart datum

** Mean High Tide is the mean tide for Higher High Water

*** Maximum High Tide is the mean large tide for Higher High Water

**** Maximum Recorded Tide is the Recorded extreme for Highest High Water

Source: Reference (33)



Canada - Newfoundland
Flood Damage Reduction Program

Rule Curves for Grand Lake and Hinds Lake

Nolan Davis & Associates Ltd

Cumming Cockburn & Associates Limited

Figure 2.5

3.0 HYDROLOGIC ANALYSES

3.0 HYDROLOGIC ANALYSES

3.1 General

The short period of record available for measured peak flows of the Humber River at Humber Village precludes the use of standard single station statistical analyses for determining the 1:20 and 1:100 year recurrence interval peak flows. In addition, no discharge measurements are available for Steady Brook. Therefore, a combination of deterministic computer simulations and regional techniques were used as the primary means of determining peak flow estimates in the study area. The simulation model was used for the Humber River (see Section 3.2) and the regional flood frequency method was used for Steady Brook (see Section 3.3).

The use of the simulation model allowed an assessment of the effects of man-made changes to the hydrologic regime within the watershed which have occurred in the past. In addition, an assessment of the effects of upstream regulation on peak flows along the Humber River was also undertaken.

However, alternative techniques were also used for comparison purposes in order to assess the reliability and accuracy of the peak flow estimates provided by the simulation model.

The following sections outline the procedures used in determining peak discharge associated with the 1:20 and 1:100 year recurrence interval flood events.

The secondary peak flow estimates for the Humber River and Steady Brook are described in Appendix C and D respectively. Details on the SSARR application are given in Appendix B. The comparisons to the deterministic models and original analyses are discussed in Sections 3.2 and 3.3 for the Humber River and Steady Brook respectively.

3.2 Humber River Hydrologic Analyses

3.2.1 Model Selection

The selection and application of a hydrologic modelling technique to the watershed upstream of the Steady Brook study area has taken into account a number of complex hydrologic and operational constraints. The following constraints and factors were considered during the model selection and application phases:

1) Available climatologic data base
2) Location of hydrometric stations for model calibration/validation
3) Available snowcourse data
4) Operational characteristics of reservoirs
5) Channel routing characteristics
6) Future flood forecasting requirements
7) Capability to simulate water management options
8) Capability to simulate 1:20 and 1:100 year peak flows
9) Capability of model to accurately simulate flow volumes
10) Capability to simulate flows from several tributaries and sub-watersheds
11) Capability to simulate antecedent soil moisture conditions
12) Capability to simulate long periods of record in a continuous simulation mode.

At present, there are many hydrologic simulation models available which could be applied to the Humber River watershed. The available techniques can be classified according to two groups of simulation models.

1) Single Event - simulates hydrologic response to individual meteorologic events
2) Continuous Simulation - simulates hydrologic response for long periods of meteorologic data.

On the basis of the available data, the changes to the hydrologic regime of the watershed and the significant extent of reservoir regulation within the watershed, it was determined at an early stage that a continuous simulation model would be most appropriate for the estimation of flood peaks. Such a model accounts for antecedent conditions prior to peak flows and includes snowpack accumulation and ablation, which are considered to be important factors affecting peak flows in the study area.

Based on a review of the constraints and factors previously listed, it was determined that the SSARR (Streamflow Synthesis and Reservoir Regulation) model was currently the most appropriate model to use for developing a mathematical base describing the hydrology of the Humber River watershed. The SSARR model was conceived and developed by the U.S. Army Corps of Engineers for analysing and forecasting runoff from various types of watersheds (57). The model was originally developed for use in water resources and flood simulation planning and has subsequently been used in many other regions in all major continents of the world. Two recent applications within Canada of particular interest are the Saint John River (New Brunswick) (28) and the Ottawa River (Ontario/Quebec) (46). The use of the SSARR model has the following advantages:

1) The model is simple in structure and uses readily available data compared to other continuous simulation models
2) It has a relatively fast simulation time with associated low computer time cost compared to other continuous simulation models.
3) It has the benefit of transferring model parameters and experience from other Canadian applications (e.g. Saint John River, Ottawa River)
4) It has excellent reservoir routing capabilities
5) A variable computational time step is possible (i.e. could be a mixture of weekly and/or daily, etc.)
6) It has good capabilities for accounting for areal distribution of snowmelt

7) The model is non-proprietary and has been well-proven in a number of practical applications.
8) The model is widely used in the flood forecasting. A new interactive version is currently available for flood forecasting.

The application of the SSARR model to the Humber River watershed is described briefly in the following sections and in more detail in Appendix B.

3.2.2 Structure of SSARR Model

i) Introduction

The basic concept of the SSARR Model involves a closed hydrologic system in which the water budget is defined by meteorologic inputs (such as rainfall and/or snowmelt) and hydrologic outputs such as runoff, soil storage and evapotranspiration losses. The model is derived so that the main components of the hydrologic cycle are represented in a simplified but rigorously applied manner. The parameters utilized in the model are such that they allow for an extremely flexible means of representing the various hydrologic components. This unique feature allows the SSARR model to be applied to virtually any drainage basin or hydrologic system. A detailed discussion of the algorithms and data processing techniques utilized in the SSARR model can be found in Appendix B and in the Users Manual (57).

ii) Hydrologic Parameters

The SSARR model has been developed to describe the main components of the hydrologic cycle. (A detailed description of the model and hydrologic parameters is given in Appendix B.). A schematic representation of the basic elements of the SSARR watershed model is presented in Figure 3.5.

The following basic hydrologic elements are evaluated individually for each relatively homogeneous watershed:

a) Net Basin Precipitation (WP), determined as the time variable weighted mean period precipitation from observed point values for a watershed.

b) Soil Moisture (SMI), determined as a time-variable index of runoff effectiveness to represent the variable conditions of soil moisture which determine, in part, the amount of precipitation which contributes to runoff.

c) Evapotranspiration Loss (ETI), determined from potential evapotranspiration, expressed either as watershed mean monthly values or determined from daily evaporation data.

d) Runoff Excess (RG), determined from net basin precipitation, minus losses to evapotranspiration, deep percolation, and soil moisture replenishment. The residual provides water input to each of three zones of temporary storage delay to runoff.

e) Surface Storage (NP, TS, TSBII), representing the storage effect of the upper zones of the soil mantle. This storage provides a time delay of the surface component of runoff.

f) Subsurface Storage (NP, TS, TSBII), representing the storage effect of the middle aquifers, thus providing a time delay of the subsurface component of runoff.

g) Groundwater Storage (NP, TS, TSBII), representing the storage effect of flow that reaches the underlying aquifers.

h) Flow Separation Relationships (BII, S-SS), for computing that portion of the water excess which enters each storage zone.

Using the above indices and relationships, the program provides a theoretically sound model of the physical processes of runoff, and yet is practical for utilization on large segments of river basins. Furthermore, by varying the hydrologic elements, it is possible to represent an unlimited number of hydrologic scenarios.

In addition to a detailed analysis of subwatershed runoff responses, the SSARR Model also has the capability of analysing the time rate of change of streamflow due to routing by channel reaches and reservoirs or lakes. The reservoir regulation provision in the SSARR model provides the user several methods of specifying reservoir regulation or free flow conditions. The reservoir regulation option is suited to analyzing storage systems such as Grand Lake and Hinds Lake which are extensively utilized for power production. Furthermore, the free flow option is also particularly useful for modelling unregulated reservoirs such as Deer Lake.

A more detailed discussion of the hydrologic parameters found in the SSARR model is presented in Appendix B and in the Users Manual (57).

iii) Application of the SSARR Model to the Humber River

The first step in application of the SSARR Model was to identify and isolate the various subwatersheds, reservoirs and channel reaches required to facilitate model calibration and validation using observed discharge data. Subwatersheds were selected by separating the total watershed into relatively homogeneous hydrologic units. Consideration was also given to the meteorologic and hydrometric data available for a given subwatershed to aid in the calibration and validation of the model (see Section 3.2.4). In addition to the selection of the subwatersheds, the reservoirs and river reaches which have a significant impact on the flows to downstream hydrometric gauges were also identified and modelled in order to give an accurate representation of the hydrologic and hydraulic response of the system.

Figure 3.1 summarizes the period of record for which hydrometric data exists for stations within the Humber River watershed. The location of the hydrometric recording stations is presented in Figure 3.2. The location of individual subwatersheds for which no specific hydrometric data exist is also evident with reference to Figure 3.2.

The model schematic corresponding to the watershed discretization is shown on Figure 3.3. The main elements of the Humber River watershed are represented in the SSARR model by 11 subwatersheds and three reservoirs and lakes.

The distribution of available meteorologic data (see Section 3.2.3) also influenced the watershed discretization summarized on Figures 3.2 and 3.3.

It was evident from a review of the hydrometeorologic characteristics of the Humber River watershed that flooding conditions often result from spring snowmelt and rain on snow conditions. The temperature index snowmelt option and the snowband option for the simulation of snow accumulation and melt were selected for this application. A comparison to other available snow modelling options included in the SSARR Model and additional details of the snowmelt capabilities are presented in Appendix B.

3.2.3 Meteorologic Input Data

i) Introduction

An unique and useful feature of the SSARR model is that it allows distribution of data from a number of meteorologic stations to the various subwatersheds. This capability is particularly useful in hydrologic representations of large watershed systems such as the Humber River, as it accounts for the spatial variation of the various meteorologic input data.

It was found that there is presently a marginally sufficient amount of meteorologic data available for the Humber River watershed which is considered to be suitable for hydrologic modelling via the SSARR model. These data are in the form of temperature, precipitation and snowcourse measurements and have been collected mainly by the Atmospheric Environment Service and the Bowater Power Company (see Section 2.3). However, none of this information is telemetered to a central location and hence, upgrading the meteorological data collection network would be required before using the SSARR Model in the flood forecasting mode.

Furthermore, the Bowater Power Company undertakes snow surveys at approximately 20 locations within the Grand Lake watershed. At present, data is collected once each year during the month of March (usually middle to end of month). In addition to the Bowater Power Company snowcourse data, one station is currently operated by Environment Canada in the Upper Humber watershed. Measurements at this station are generally taken two times a year. However, because data is collected only once per year at most stations, a correlation between snowcourse data and snowmelt rates cannot be made and the data is of fairly limited usefulness for the purposes of model calibration and did not affect the level of model schematization.

ii) Selection of Stations

It is evident from Table 2.2 that a number of meteorologic stations are situated in and around the Humber River watershed for which temperature and/or precipitation data is available. However, several stations could not be used for the purposes of this investigation and were, therefore, eliminated for the following reasons:

- too much missing data in the record
- measurement time increment too long for application to SSARR model
- period of record incompatible with period of hydrometric data
- located too far outside the watershed boundary

The period of record currently available for the selected meteorologic stations is presented graphically in Figure 3.4.

iii) Weighting of Meteorologic Stations

The SSARR model allows the user the option of assigning data available for several meteorologic stations to any subwatershed. In addition, the user also has the option of weighting meteorologic stations applied in the subwatershed. The initial meteorologic station weights were determined by Thiessen polygons and are described in more detail in Appendix B. The initial Thiessen polygon weighting factors were applied to both temperature and precipitation data records. Some of the meteorologic stations are located along the coast, and as such, have significantly lower elevations than found in the inland subwatersheds. Therefore, further modification to the weighting factors was made by utilizing published isohyetal maps of mean annual precipitation and mean annual runoff (49, 27) to account for the areal variations in precipitation which are primarily attributed to elevation and geographic differences.

Appendix B presents the calculated weighting factors applied to the various subwatersheds utilized in the SSARR model. In summary, it was found that the SSARR weighting factors for precipitation varied significantly depending on station location relative to the subwatershed area. Likewise, the weighting factors for temperature varied significantly for each station. The resulting adjustments were subsequently confirmed during the model calibration and verification phase. The degree of adjustment required implies that a number of additional meteorological stations should be located within the Humber River watershed for forecasting purposes (see Appendix B).

3.2.4 Model Calibration and Validation

i) Introduction

The various hydrologic input parameters were adjusted by comparison of observed and simulated hydrographs according to the following general criteria:

- emphasis on accurate simulation of peak flow events
- comparison of simulated and observed runoff volume
- hydrologic conditions antecedent to the flood peaks should be correctly represented by the model.

Appendix B presents a detailed discussion of the methodology used to calibrate and validate the SSARR model to gauged watersheds.

ii) Model Calibration and Validation Results

Of the 11 subwatersheds which represent the Humber River watershed, 5 have sufficient hydrometric data to enable direct calibration and validation. In addition to the 5 gauged subwatersheds, there exists a long term hydrometric record at the outlet of Grand Lake, and a short term hydrometric gauge located just downstream of Deer Lake (less than two years of published data). This data was utilized to ensure that the distinctive reservoir routing characteristics within the Humber River are accurately represented by the SSARR Model. Due to hydroelectric power production, Grand Lake is operated as a regulated reservoir as opposed to free flowing. Therefore, rather than deconvoluting the outflow from Grand Lake to obtain the inflow hydrograph, calibration of ungauged subwatersheds draining to Grand Lake was undertaken utilizing historic water levels.

Gauged Subwatersheds

The calibration was initially undertaken for the five gauged subwatersheds in the Humber River system. The procedure followed for the calibration and validation of these subwatersheds was that outlined in Appendix B. The calibration entailed simulating complete summer/fall/winter/spring periods to ensure that the model accurately represents both snowmelt and non-snowmelt flood conditions.

The validation of the SSARR Model was undertaken by simulating additional flow series which also included complete summer/fall/winter/spring time periods. Comparisons of observed and predicted flood hydrographs are given in Appendic B for selected runoff periods for which high flows were recorded. Simulations were undertaken for complete summer/fall/winter/spring continuous periods to ensure that the model accurately simulates low flow conditions and also accurately defines antecedent conditions prior to high flow events. However, only periods of high flows were selected for presentation in Appendix B as these are the periods of primary concern.

A further assessment of simulation accuracy was made by undertaking the following graphical comparisons:

- cumulative mass curves of computed and observed flow volumes
- comparisons of simulated and observed mean daily peak flows by means of a partial duration flood frequency analyses.

It was evident from these comparisons (See Appendix B) that the SSARR model appears to be accurately representing the hydrologic response of the gauged subwatersheds within the Humber River watershed with respect to runoff volumes and peak flows.

Ungauged Watersheds

In addition to calibrating the SSARR model using measurements from the gauged subwatersheds, estimation of parameters for the ungauged subwatersheds are also possible for the 4 subwatersheds draining to Grand Lake utilizing the historic lake level data which is available. Since the reconstitution of natural discharges by inverse reservoir routing greatly diminishes the precision of the data, model parameters were calibrated by matching observed and simulated lake levels.

The parameters estimated for ungauged subwatersheds obtained in this manner were found to be similar to those calculated for gauged subwatersheds, and are described in more detail in Appendix B. It should be noted that the calibration of the ungauged subwatersheds draining to Grand Lake results in a relatively accurate representation of the hydrologic response with respect to runoff volumes. Unfortunately, hydrograph timing parameters for the ungauged subwatersheds draining to Grand Lake could not be calibrated in this manner. However, hydrograph timing parameters were estimated based on those calculated for the surrounding gauged subwatersheds. This was found to be adequate since the reservoir routing effects of Grand Lake greatly diminish any influence which the shape of the inflow hydrographs may have on discharge rates at the outlet and at downstream locations. A comparison between simulated and observed Grand Lake water levels indicates that the ungauged subwatersheds draining to Grand Lake are adequately represented in the SSARR model for the purposes of this investigation. Examples of the simulations of the Grand Lake water levels are presented in Appendix B.

In addition to the 5 gauged subwatersheds and the 4 ungauged subwatersheds draining to Grand Lake, there are two other ungauged subwatersheds for which there is very little available calibration data. Therefore, comparisons of ground cover and soil types of gauged and ungauged subwatersheds were undertaken in order to estimate watershed parameters for ungauged areas. Data was taken from the Canada Land Inventory: Soil Capabilities for Agriculture (1:1,000,000 series) (58) and the Newfoundland Forest Type Maps (1:30,000 series) (59) for the Humber Valley (see Section 2.0).

In this manner, it was possible to estimate subwatershed parameters for the two ungauged subwatersheds located downstream of Grand Lake in the Humber River watershed. It should be noted that the total drainage area of these ungauged subwatersheds located downstream of Grand Lake is less than 10% of the total drainage area of the Humber River.

Grand Lake Routing

For the initial model calibration attempts, the historic Grand Lake water levels were utilized in the model to simulate flows at the outlet.

Unfortunately, it was found that although a relatively accurate representation of the Grand Lake inflows was utilized (due to extensive calibration to upstream gauges), the resulting simulated flows downstream of Grand Lake were highly erratic in magnitude and not representative of discharge variations when compared to published discharge records.

It was also found that on several occasions, unrealistic flows were simulated by the model (negative flows).

The phenomena of negative flows is discussed in more detail in Appendix B and is attributed to time periods when inadequate inflows are available to reach the "target" elevation specified in the reservoir rule curve. It was concluded that the major factor which contributed to unrealistic flow simulation was errors associated with observed Grand Lake water levels. For example, it was found that a lake level measurement error of less than 3 cm (.1 ft) results in a discharge error at the outlet of Grand Lake of approximately 170 m^3/s which is similar in magnitude to the mean annual discharge from Grand Lake. Therefore, it is evident that factors such as wind and wave set up and inaccurate water level measurements can contribute to significant discharge errors when simulating Grand Lake outflows. Suggestions for recording additional water level data are discussed in Appendix B.

Deer Lake Routing

As previously discussed, Deer Lake is a natural reservoir which operates under free flow conditions. Therefore, only a stage/discharge/storage relationship is required to route a hydrograph through the reservoir. The stage/discharge/storage relationship was derived by utilizing a rating curve for the outlet which was developed by the Bowater Power Company and a storage relationship developed from existing 1:50,000 topographic mapping. The stage-storage relationship was verified by reference to historical air photos of Deer Lake during flood stage. The effects of Deer Lake reservoir routing in the SSARR model were validated by simulating the 1982 and 1983 flow hydrographs to the gauge (02YL003) located near the outlet of Deer Lake. Utilizing the observed hydrographs available for the Upper Humber River and from Grand Lake, the peak discharges in excess of 700 m^3/s downstream of Deer Lake were simulated to within an average of ±5% of that recorded. It was also noted that reductions in peak flows due to the reservoir routing effects of Deer Lake ranged from less than 5% to greater than 30%, with an average of approximately 15%. Due to the short period of record at the hydrometric gauge located downstream of Deer Lake (May, 1982 to December, 1983), further refinements to the Deer Lake rating curve were not possible. However, further validation of the Deer Lake routing characteristics was accomplished by simulating additional flood hydrographs and comparing the simulated and observed maximum annual water levels in Deer Lake. The results of this analysis also indicated that simulated water levels in Deer Lake closely matched those recorded by the Bowater Power Company, taking into account head losses along Deer Lake.

3.2.5 Peak Flow Estimates

Due to the simulation problems encountered when routing flows through Grand Lake, it was decided to utilize the extensive hydrometric record available for the outlet of Grand Lake and the Upper Humber River to simulate a long-term hydrometric record in the vicinity of the study reach. Inflows from subwatersheds for which no hydrometric data exists were estimated by the SSARR model which also accounted for the routing effects of the river channels and Deer Lake. This assumes that up-stream routing has a relatively small effect on peak flows, which is a reasonable assumption since the reservoirs have not been operated for flood control purposes.

Consideration was also given to possible requirements for adjusting the historic hydrometric record from Grand Lake to account for changes to the hydrologic regime within the watershed. This includes discharge records at the following locations:

- Indian Brook Diversion
- Hinds Lake Power Station
- revised rule curves for Grand Lake power production.

In summary, it was found that the above mentioned changes have negligible effects on peak discharges during major floods and, therefore, did not warrant adjustments to the hydrometric record. Additional details concerning these analyses can be found in Appendix B.

Utilizing the SSARR model, a 39 year sequence of peak flows was simulated. (As explained above, the model combines the long-term measured discharge sequences at upstream locations with flow simulated by SSARR from ungauged watersheds using available long-term meteorologic input data.) The annual maximum flows were then extracted from the simulated record in order to undertake a flood frequency analysis for the study area.

Based on an assessment of available peak flow records on the Humber River (02YL0003), the difference between maximum instantaneous and mean daily flows is less than one percent. Therefore, for the purpose of this investigation, it is assumed that instantaneous and mean daily peak flows are equivalent for all practical purposes for the study area.

The simulated data set of annual maximum mean daily peak flows was tested for high and low outliers, independence, trend and randomness as discussed in Appendix B. The results of this analysis reveal that the data can be regarded as independent, and free from trend and persistence. Furthermore, no high or low outliers were detected.

Several distributions were fitted to the available peak flow data set, including Gumbel, Log-Normal (LN), Three Parameter Log Normal (3PLN) and Log Pearson Type III (LP3) (See Appendix B). Table 3.1, Item A presents the flood estimates for the 1:20 and 1:100 year recurrence intervals, assuming a Three Parameter Log Normal Distribution.

3.2.6 Comparison to Secondary Peak Flow Estimates

i) General

Comparative peak flow estimates for the Humber River have been derived by means of alternative and independent estimating techniques; namely:

a) Regional Flood Frequency Analysis (CNFDRP)

b) Frequency Analysis of Deer Lake Water Levels

c) SSARR Single Event Simulation.

In addition, 1:100 year design snowmelt sequences were input to the SSARR model in the single event simulation mode and the resulting peak flows in the study area used for comparative purposes. The following sections describe the findings of these comparative estimating techniques. Additional computational details for the statistical analyses are found in Appendix C.

ii) Regional Flood Frequency Analysis

The Water Resources Division of the Newfoundland Department of Environment, in conjunction with the Inland Waters Directorate of Environment Canada, have recently undertaken a Regional Flood Frequency Analysis for the Island of Newfoundland (27). The regional prediction equations were found to take the following general form:

$$\log_{10} Q_T = K + a\log_{10}DA + b\log_{10}MAR + c\log_{10}ACLS + d\log_{10}SHAPE \qquad (3.1)$$

where Q_T = T year recurrence interval instantaneous peak flow

K, a, b, c, d = regression coefficients

DA = drainage area (km^2)

MAR = index of mean annual runoff (mm)

ACLS = percentage of drainage area controlled by lakes or swamp

SHAPE = index of basin shape defined as (0.28 x basin perimeter) / $\sqrt{DA}$ where the perimeter is measured in km from 1:50,000 topographic maps.

The resulting peak flow estimates for the Humber River at the outlet of Deer Lake are summarized in Table 3.1 (Item B). Additional computational details and parameters are given in Appendix C.

It must be noted that the drainage area at the outlet of Deer Lake exceeds the upper limit of size recommended for application of the regional prediction equations. Also, the possible effects of artificial regulation by operating the Grand Lake control structures is not explicitly accounted for by the prediction procedures. However, reference to peak flow comparisons given in Appendix C indicates that the instantaneous peak flow estimates provided by this method are "reasonable" and can be used for comparison purposes in this study, recognizing that such estimates are likely on the high side in the study area.

iii) Frequency Analysis of Deer Lake Water Levels

Records of maximum water levels in Deer Lake have been collected since about 1930 by the Bowater Power Company Limited. A frequency analysis of annual maximum water levels in Deer Lake was undertaken in order to determine the 1:2, 1:20 and 1:100 year levels in the lake. The data and the results of these analyses are given in Appendix C.

An empirical rating curve determined for the Deer Lake outlet was also obtained from historical records available from Bowater. The rating curve was developed utilizing historical discharge and water level measurements taken at a location near Governors Point (see Appendix C). While there is a significant degree of scatter in the available data points, it was found that the HEC-2 backwater model and recent discharge and water level measurements (Humber Village gauge and water levels collected during this project on Deer Lake) confirms the accuracy of the Bowater's rating curve, which was also used in the SSARR model for routing through Deer Lake.

The stage-discharge rating curve for Deer Lake was then utilized in order to convert the 1:2, 1:20 and 1:100 year water levels to peak discharge estimates with a corresponding recurrence interval. These discharge estimates are also summarized in Table 3.1 (Item C) and are within 6-7% of those provided by the long term SSARR simulations.

As would be expected, the peak flow estimates are consistently smaller than those provided by the regional flood frequency analysis. This is attributed in part to the peak flow attenuation caused by routing through Deer Lake and possible effects of artificial regulation by Grand Lake.

iv) SSARR Single Event Simulation

For comparison purposes the SSARR model was run in a single event simulation mode to simulate the 1:100 year design snowmelt sequence. The rainfall plus snowmelt amounts for various recurrence intervals was established by analysis of available data for the pertinent meteorologic stations identified in Section 3.2.3. This analysis uses historical recorded meteorologic data to obtain the 1 to 10 day melt plus rainfall totals available for runoff (4). The algorithm used was derived from an energy budget method developed by the U.S. Army Corps of Engineers for forested areas (56). Using this algorithm, the 1:100 year 10-day snowmelt plus rainfall amounts were calculated for all stations.

The resulting 1:100 year recurrence interval hydrographs were then routed through the system, assuming the Grand Lake rule curve and Deer Lake rating curves presently used by the Bowater Power Company. The resulting peak flows are somewhat high when compared to the continuous simulation 1:100 year flood estimate (Item D, Table 3.1). However, because the 1:100 year single event flood simulation is calculated assuming that a 1:100 year snowmelt event is occurring at every location in the watershed, it is logical to expect a runoff event significantly higher in magnitude than the other peak flow estimates. Therefore, this flood estimate was used for comparison purposes only, since accurate determination of the input design snowmelt sequence requires additional data for a watershed of this size.

v) <u>Discussion of Peak Flow Comparisons</u>

Peak flow estimates undertaken by the Regional Flood Frequency Analysis are on the high side compared to the SSARR generated peak flows. This is consistent with the fact that the regional equations do not specifically account for the large upstream storage-regulation effects.

It was found that the peak flow estimates obtained by the frequency analysis of Deer Lake water levels are similar in magnitude to the long-term SSARR simulation results.

Finally, the secondary estimate of the 1:100 year peak which was obtained by using SSARR in the single event simulation mode, produced a peak flow considered to be on the high side. However, this estimate was found to be comparable to other peak flow estimates.

The comparisons support the use of the long-term SSARR generated peak flow estimates. Therefore, it is recommended that the peak flow estimates provided by the SSARR long-term simulation method should be used for calculating flood profiles in the study reach.

It was also subsequently found (see Section 4.0) that the recommended peak flows, when converted to flood profiles, are consistent with observed flood conditions along the study reach.

3.3 Steady Brook Hydrologic Analyses

3.3.1 General

The watershed boundary (see Figure 3.6) was determined through examination and interpretation of existing 1:50,000 scale mapping of the study area. This mapping was also used to measure the drainage area, slopes and land-use characteristics, etc. The watershed area was found to be 81.4 km^2 to the confluence of the Brook with the Humber River in the Community of Steady Brook.

No streamflow measurements are available for Steady Brook. As a consequence, the results of the Regional Flood Frequency Analysis (27) were utilized to provide peak flow estimates of the outlet of Steady Brook.

As a means of verifying the results of the regional estimates, a secondary peak flow analyses was undertaken utilizing the deterministic HYMO model (54), as discussed in Section 3.3.3. Experience with this technique in other flood studies has proven its usefulness as a means of estimating peak flows for ungauged watersheds. Also, this watershed was considered to be too small to utilize the SSARR model. In addition, no data was available to calibrate SSARR for other similar small watersheds in the Humber River Basin, thereby enabling transfer of calibration parameters, etc.

3.3.2 Regional Peak Flow Estimates

The results of the recent regional analysis (27), developed to derive peak instantaneous flow estimates for ungauged basins based on watershed characteristics, was used to determine design flows at the outlet of Steady Brook.

The regression equations which were developed are based on a single station instantaneous flood frequency analysis at hydrometric stations with at least 10 years of record located on the Island of Newfoundland. The regression equations are the same as that presented in Equation 3.1 (see Section 3.2.6 and Appendix C).

The various parameter values and additional equation details can be found in Appendix C.

The 1:20 and 1:100 year recurrence interval peak flow estimates calculated using the regression equations at the outlet of Steady Brook were found to be 105 m^3/s and 134 m^3/s respectively.

3.3.3 Comparison to Secondary Peak Flow Estimates

As a means of verifying the derived peak flow estimates for Steady Brook, secondary estimates were undertaken using the deterministic model HYMO (54).

The input requirements for this simulation technique include both meteorological (rainfall/snowmelt) data and physiographic characteristics (land use, time to peak values, constituent soil characteristics, etc.) of the study area. The derivation of model input parameters and the model set-up and sensitivity testing are described in Appendix D.

The resulting secondary 1:20 and 1:100 year instantaneous flow estimates were then compared to those obtained through the regional technique, as noted in Table 3.2.

It is evident from the comparisons that the peak flows estimated by application of the HYMO model are reasonable estimates since they fall within the confidence limits of the regional estimating technique. However, these flows were found to be somewhat lower in magnitude than those derived through the regional regression techniques. For this reason, and in order to be conservative, the results of the regional regression analysis were adopted for application in the backwater modelling along Steady Brook.

3.4 Summary and Conclusions of Hydrologic Analyses

3.4.1 Humber River

1) It was evident from a review of the hydrometeorological characteristics of the Humber River that flooding conditions often result from spring snowmelt and rain on snow conditions. However, floods have also occurred at other times of the year resulting from summer and autumn rainstorms.

2) The SSARR model was selected to simulate the hydrologic regime of the Humber River. The model was calibrated and validated using available data and produced acceptable discharge estimates along the Humber River.

3) There is presently a marginally sufficient amount of meteorologic data available for the Humber River watershed in a form suitable for hydrologic modelling in the continuous simulation mode. However, it was found that significant adjustment of meteorological data was required via determination of calibrated weighting factors for precipitation and temperature. The degree of adjustment required implies that a number of additional meteorological

stations should be located within the Humber River watershed if the model is to be used in the forecast mode.

4) Since the available meteorological data base is not telemetered in real time to a central location, upgrading the data collection network would be required before attempting to utilize the SSARR model in the flood forecasting mode. (See Appendix B.1.6 for recommended upgrading to network.)

5) Peak flows along the study reach were estimated by combining the daily mean hydrometric records at the outlet of Grand Lake and the Upper Humber River via the SSARR model structure. Inflows from watersheds for which no hydrometric data exists were estimated by the calibrated SSARR model, which also accounted for the routing effects of the river channels and Deer Lake.

6) The 1:20 and 1:100 year peak flow estimates along the study area were found to be:

1:20	1:100	Location
948	1180	At outlet of Deer Lake
957	1180	Just downstream of Steady Brook

7) Comparative peak flow estimates for the Humber River were derived by means of alternative and independent estimating techniques; namely:

   a) Regional Flood Frequency Analysis (CNFDRP)
   b) Frequency analysis of Deer Lake Water Levels
   d) Application of SSARR as a single event model.

   The comparative peak flow estimates confirm the reliability of the SSARR model to determine the 1:20 and 1:100 year peak flows for the study area.

3.4.2 Steady Brook

1) The Steady Brook watershed was considered to be too small to utilize the SSARR model for peak flow estimates. In addition, no data was available to calibrate the SSARR model for other similar small watersheds in the Humber River basin for the purpose of deriving model parameters for transfer to the Steady Brook watershed.

2) The peak flows were computed by application of the Regional Flood Frequency equations. It was evident from the secondary comparisons that the peak flows estimated by the application of the regional equations are reasonable estimates which can be utilized in undertaking backwater computations along Steady Brook.

3) The HYMO model was selected to provide secondary peak flow estimates. While no data was available to calibrate the model to Steady Brook, this model has previously proven capabilities for simulating peak flows in a number of other practical applications, including the Stephenville Hydrotechnical Study (16). HYMO peak flow estimates confirmed the reliability of peak flows estimated by the Regional prediction equation.

4) The peak flows for the 1:20 and 1:100 year events were found to be 105 and 134 m^3/s respectively at the confluence of Steady Brook with the Humber River. These flows are adopted for development of 1:20 and 1:100 year flood profiles along Steady Brook.

TABLE 3.1

Peak Flow Estimates

Humber River at Steady Brook

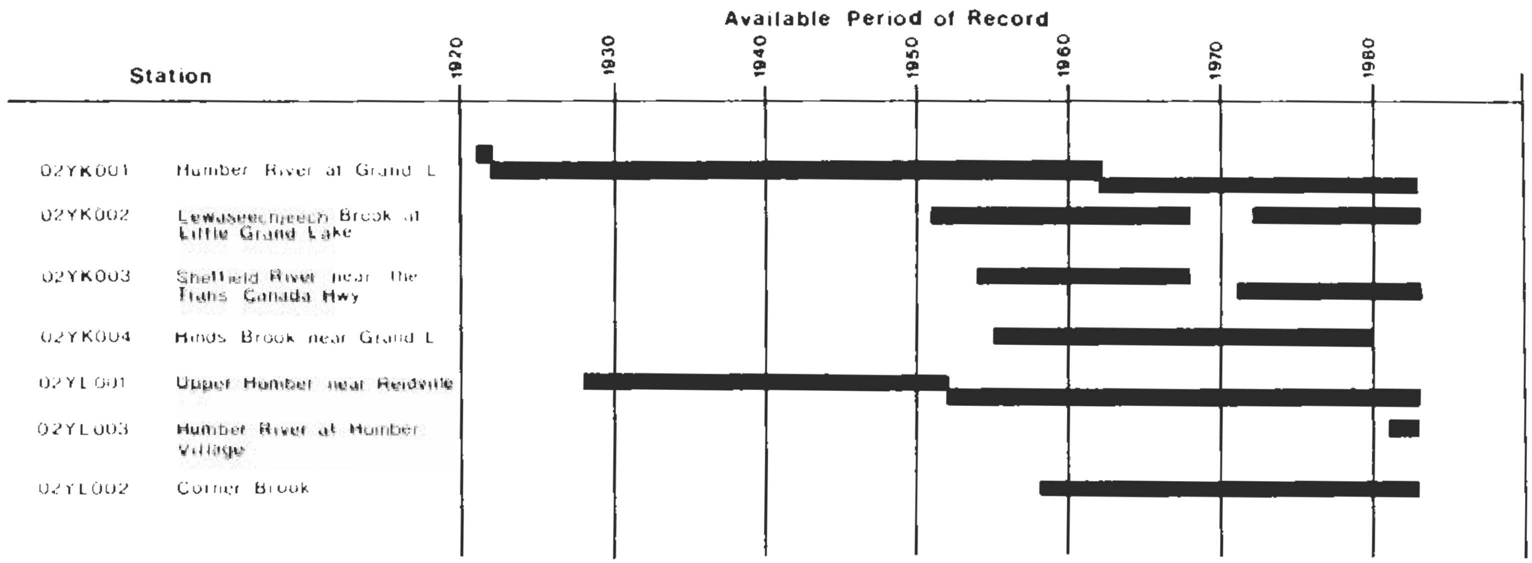
Row	Description	Peak Flow Estimate (m^3/s)						Comments
		-95%	1:20	+95%	-95%	1:100	+95%	
A	SSARR - Long-Term a)	797	948	1099	889	1180	1471	- Simulates 39 years of record
	b)	809	957	1105	889	1180	1462	- Accounts for Grand Lake regulation
B	Regional Flood Frequency Analysis a)	750	1210	1780	793	1380	2130	- Does not account for operation of Grand Lake - Equations applied outside range of application
C	Frequency Analysis on Deer Lake Water levels a)	949	1020	1161	1008	1246	1487	- Indirectly accounts for operation of Grand Lake and routing through Deer Lake
D	SSARR - Single Event Mode a)	N/A	954	N/A	N/A	1317	N/A	- Simulates flow from entire watershed - Routes through Grand and Deer Lakes

NOTES: a) Discharge at outlet of Deer Lake
b) Discharge downstream of confluence with Steady Brook
c) Underlined values denote values used in backwater analysis

TABLE 3.2
Peak Flow Estimates
Steady Brook at Confluence
with Humber River

Recurrence Interval	Peak Discharge (m^3/s) Regional Equation* -95%		+95%	HYMO
1:20 Year	65.2	105.	155.0	78.9
1:100 Year	76.8	134.	206.0	101.0

* Selected for application in backwater modelling.



Canada - Newfoundland
Flood Damage Reduction Program

Period of Record of Applicable Hydrometric Recording Stations

Nolan Davis & Associates Ltd

Cumming Cockburn & Associates Limited

Figure 3.1

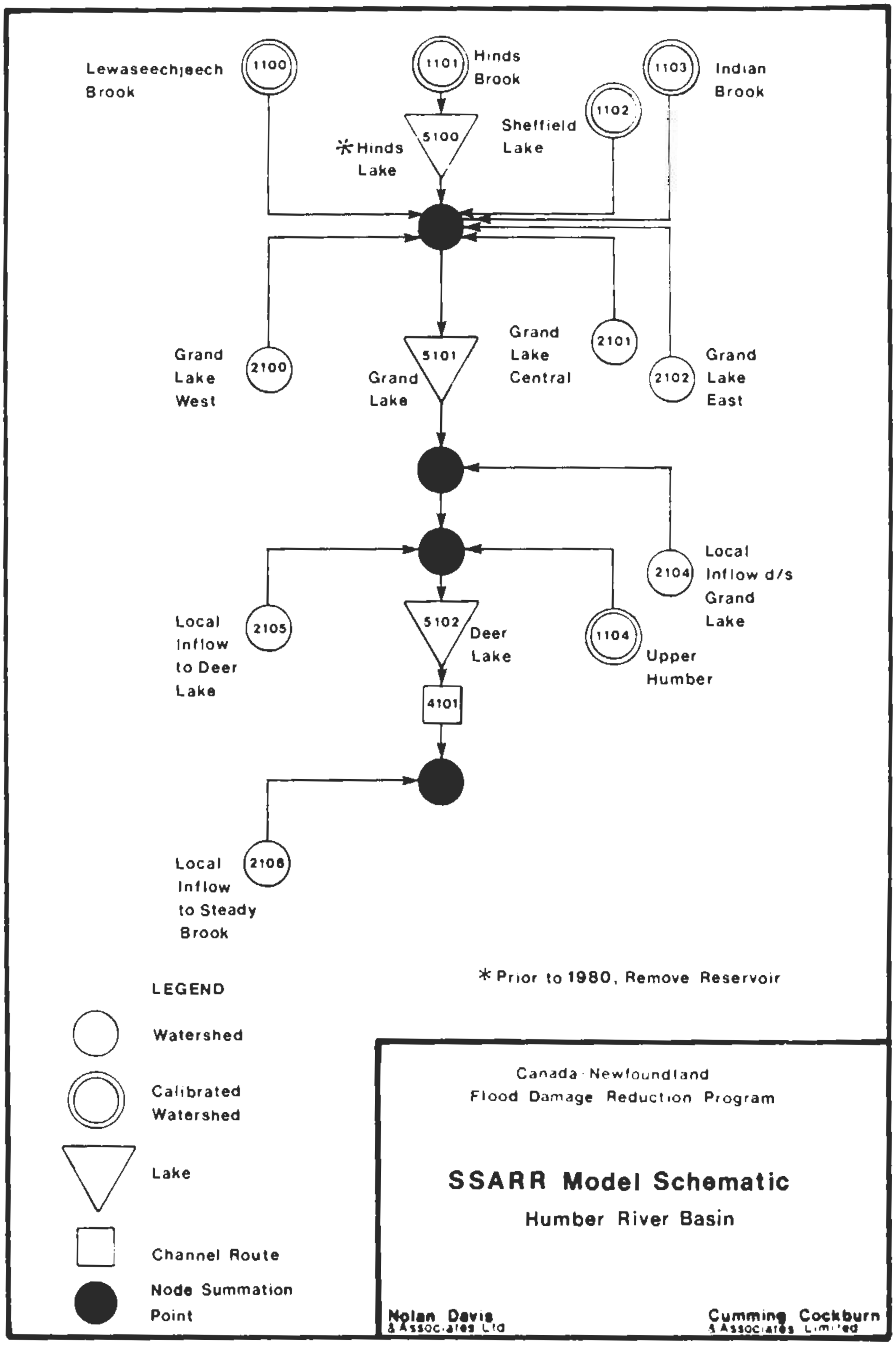
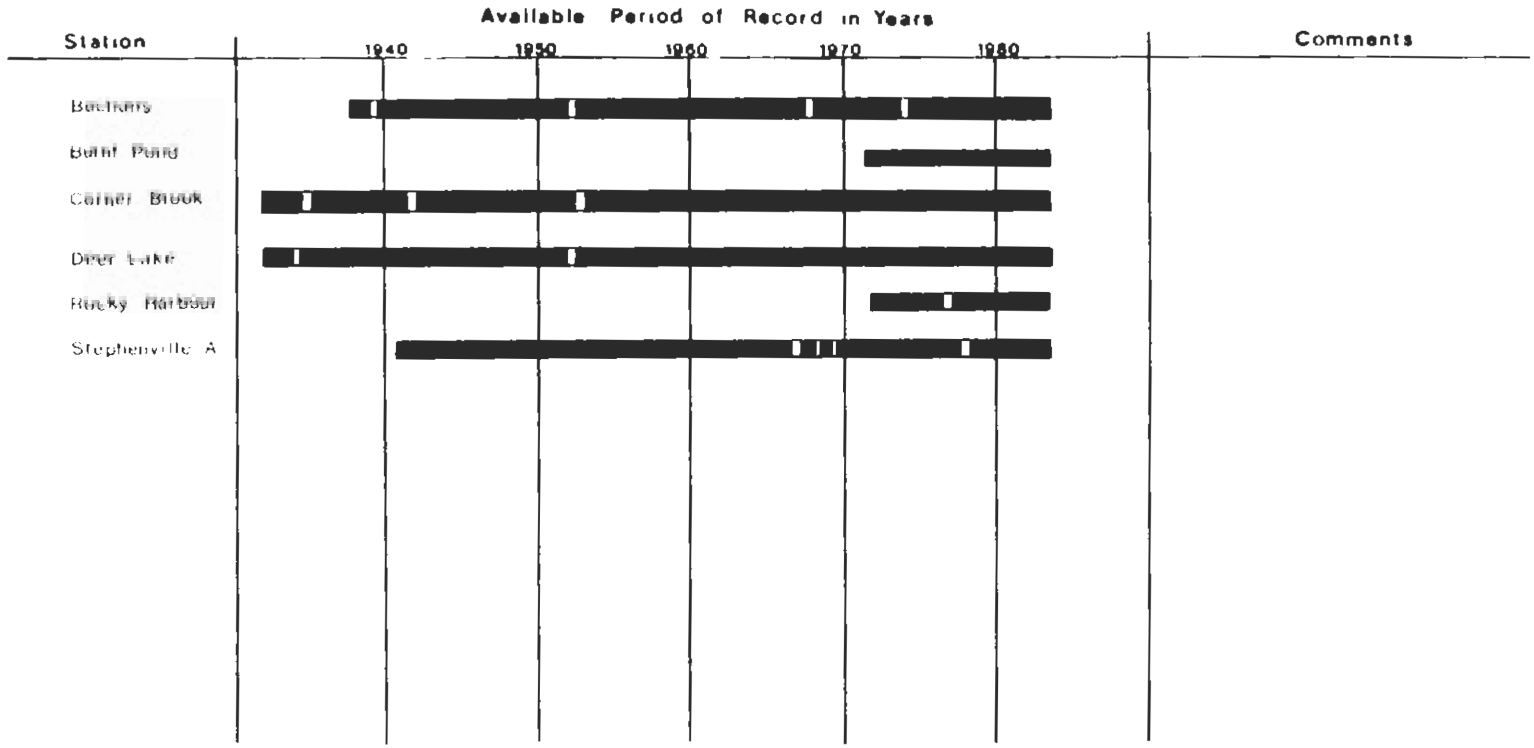

Lewaseechjeech Brook
1100
1101
Hinds Brook
1103
Indian Brook
1102
Sheffield Lake
5100
*Hinds Lake
Grand Lake West
2100
5101
Grand Lake
Grand Lake Central
2101
2102
Grand Lake East
2104
Local Inflow d/s Grand Lake
Local Inflow to Deer Lake
2105
5102
Deer Lake
1104
Upper Humber
4101
Local Inflow to Steady Brook
2106
* Prior to 1980, Remove Reservoir
LEGEND
Watershed
Calibrated Watershed
Lake
Channel Route
Node Summation Point
Canada-Newfoundland
Flood Damage Reduction Program
SSARR Model Schematic
Humber River Basin
Nolan Davis & Associates Ltd
Cumming Cockburn & Associates Limited

Figure 3.3



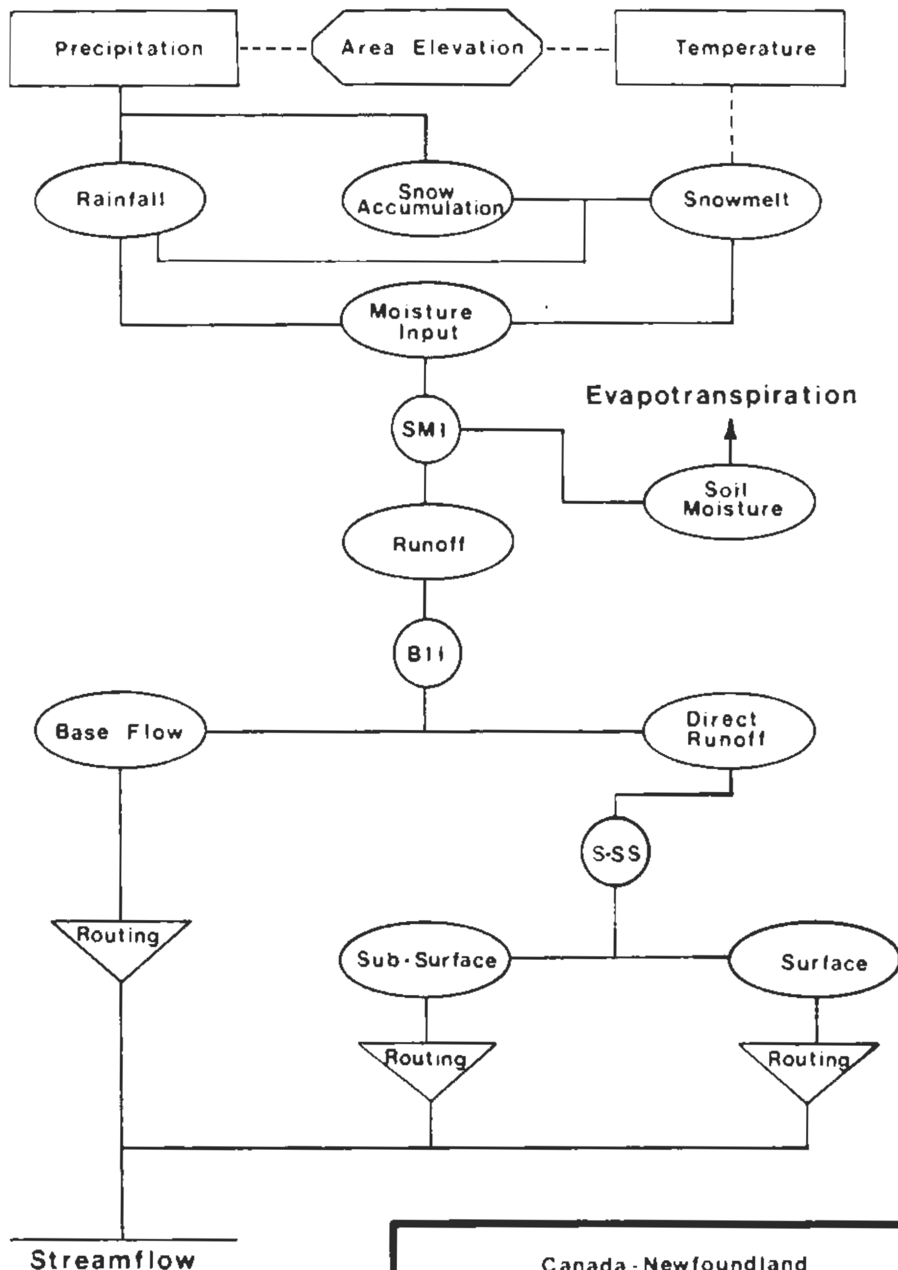
Canada - Newfoundland
Flood Damage Reduction Program

Period of Record of Applicable Meteorologic Stations

Nolan Davis & Associates Ltd

Cumming Cockburn & Associates Limited

Figure 3.4



Canada - Newfoundland
Flood Damage Reduction Program

SSARR Hydrologic Components

Nolan Davis & Associates Ltd

Cumming Cockburn & Associates Limited

Figure 3.5

4.0 HYDRAULIC ANALYSIS

4.0 HYDRAULIC ANALYSES

4.1 Methodology

4.1.1 General Overview

The main purpose of the hydraulic analysis was to transform peak discharge estimates into flood profiles along the study reaches. This was undertaken by utilizing a mathematical model to simulate water surface profiles corresponding to the 1:20 and 1:100 year flood events.

A backwater model was developed to simulate the existing hydraulic characteristics of the channel and floodplain as interpreted from 1:2500 scale mapping developed as part of these investigations (see Section 4.2), and from the results of comprehensive field topographic, bathymetric and reconnaissance surveys. The results of these surveys are discussed in Section 4.2, with further information provided in the supplemental report, "Physical Surveys and Field Program".

The backwater model was calibrated and verified using measured water levels collected as part of these and previous (40) investigations. The model calibration and verification is discussed in Section 4.3.

The flood profiles associated with the 1:20 and 1:100 year peak discharge rates were then established based on the calibrated model, and plotted on the 1:2500 scale mapping. The flood profiles and flood hazard areas are discussed in Section 4.4.

In order to define the degree of sensitivity of simulated flood profiles to variations in discharge rates and in the calibrated/verified hydraulic model input parameters (including the possible effects of ice and debris jams on flood profiles), sensitivity testing was undertaken. This aspect is discussed in Section 4.5.

4.1.2 Model Description

In order to estimate the flood levels associated with each of the 1:20 and 1:100 year flood peaks, a mathematical model was developed to simulate the hydraulic characteristics along the Humber River and Steady Brook.

The effects of channel and floodplain storage on flood profiles along the study reaches were not considered to be significant. In addition, it was postulated that tidal variations were not a significant factor in determining flood levels along the study reach (this was subsequently confirmed through the model sensitivity testing). In such cases, it is a standard practice to assume steady state flow conditions in the computation of the backwater profiles.

Where a steady state backwater computation is employed, the appropriate design peak discharge input to the model is the instantaneous peak of the flood hydrograph.

In the case of gradually varied steady flow, the equations of continuity and momentum describing the one-dimensional flow can be simplified to the form of the well-known Bernoulli equation:

$$\frac{\partial h}{\partial x} = (S_o - S_f) / (1 - v^2/gh) \qquad (4.1)$$

where h = depth of flow (m)

x = distance in direction of flow (m)

S_o = bottom slope (m/m)

S_f = boundary frictional effect (m/m)

v = velocity in direction of flow (m/s)

g = acceleration due to gravity (m/s^2)

For natural channels, energy losses occur due to flow resistance. The resulting friction slope can be determined from the Manning's equation:

$$S_f = (nv/R^{2/3})^2 \qquad (4.2)$$

where n = Manning's roughness coefficient
R = hydraulic radius

The HEC-2 model (55) has been successfully used in many similar practical applications. Therefore, this model was selected since it is a well-proven and well-documented non-proprietary technique which is flexible to use. The model can be applied in the future to evaluate the effects of recommended hydraulic improvements and proposed channelization along the study reach, etc.

The program calculates water surface profiles for flow in natural or man-made channels, assuming that such flow is steady and gradually varied. The simplified one-dimensional equations of continuity and motion are solved using the standard step method with energy losses due to friction evaluated by the Manning's equation.

In addition, the model can calculate critical depth at each cross-section and can compute profiles for supercritical flow, where required. This feature is especially useful for steep stream reaches such as those which occur along the upstream study reaches of Steady Brook, and which may intermittently occur along portions of the Humber River. Backwater profiles can be run for subcritical flow conditions by specifying a starting water level at the downstream end of a stream reach being simulated. For supercritical flow conditions flood profiles can be computed by starting the computation at a known water level at the upstream end of a given study reach.

The model can take into account the following factors:

1) Channel roughness
2) Floodplain roughness
3) Islands or flow divisions
4) Bends in the stream or floodplain
5) Cross-sectional area of the stream channel and floodplain
6) Slope of the channel and floodplain

7) Energy losses at hydraulic structures, including bridges, culverts, weirs, dams, etc.
8) Channel and floodplain expansion and contraction losses
9) Variation in discharge along the study reach (i.e. due to tributary inflows.)
10) The effect of ice/debris covers on the stream or floodplain.

The model requires input of channel and floodplain cross-sections and associated hydraulic parameters at frequent locations along the study reach. The cross-sections are normally located where changes occur in slope, cross-sectional area or channel roughness, and at bridges or culverts.

A major advantage of the HEC-2 model is that the channel and floodplain roughness (Manning's 'n') can be varied for each cross-section in the program. This allows a description of the various factors on which the roughness coefficient depends such as channel morphology, type and extent of vegetation, etc.

Energy losses created at hydraulic structures, such as bridges and culverts, are computed in the program in two parts. First the energy losses due to expansion and contraction of the flow at the cross-section on the upstream and downstream sides of the structure are calculated, and second, the energy loss through the structure itself is computed by either using the special bridge or the normal bridge sub-routine. Energy losses due to expansion and contraction of flow are calculated by employing expansion and contraction coefficients which are multiplied by the absolute difference in velocity heads between cross-sections to estimate the energy loss caused by the transition.

When the normal bridge sub-routine is used the water level is computed at the bridge or culvert section in the same manner as normal river cross-sections, but excluding the cross-sectional area of any existing piers, deck or wingwalls below the water surface. When the water surface elevation exceeds the bottom chord, the wetted perimeter of the section is also adjusted. The special bridge routine computes losses through the structure for low flow or for any combination of weir flow and pressure flow. Similarly, water levels associated with floating ice covers can be modelled with the program, excluding the cross-sectional area of the ice sheet from the channel area. The effect of the ice roughness coefficient and change in hydraulic radius is also taken into account.

The watercourses modelled consisted of the following stream reaches:

1) Humber River beginning at its outlet to the Humber Arm in the City of Corner Brook, and extending some 4.1 km upstream to just downstream of the Community of Steady Brook.

2) The Humber River from just downstream of the Community of Steady Brook to about 1000 m upstream of Governors Point at the outlet of Deer Lake.

3) Steady Brook beginning at its confluence with the Humber River in the Community of Steady Brook and extending approximately 0.9 km upstream to the study limit at the water supply pumphouse (upstream of the old T.C.H. bridge)

In all, a total of approximately 20 km of channel and floodplain were modelled, as discussed in detail later in this report.

4.2 Hydraulic Model Input Data

4.2.1 Field Survey

Cross-sectional data was available for the Humber River downstream of Steady Brook as a result of previous field surveys undertaken by MacLaren (40). However, it was found that special care was required in the use of this information since recent changes to the channel and floodplain may have occurred along the study reach. Therefore, field surveys were undertaken as part of this investigation to:

- measure typical channel and floodplain cross-sections along the study reach upstream of the Community of Steady Brook on the Humber River, and along the Steady Brook watercourse from its confluence with the Humber River to the water supply pumphouse

- validate the applicability of the previously surveyed cross-sections for use in the current model

All topographic information collected during the field surveys was related to geodetic elevation and where possible, all sections were located by means of reference to fixed physiographic points located near the floodplain.

Floodplain and channel roughness coefficients were also assessed in the field. An inventory of photographs documenting the present conditions of the floodplain and channel characteristics, as well as the hydraulic structures located therein is available as part of the supplementary report entitled, "Physical Surveys and Field Program".

i) Cross-sections

A total of 52 cross-sections were field surveyed along the study reaches. The complete inventory of cross-sections, including location and extent is described in detail in the supplementary report entitled, "Physical Surveys and Field Programs". Cross-section measurements were obtained at representative locations along the study reach, and located based on changes in the slope, cross-sectional area or channel roughness. Additional measurements were taken near all bridge crossings along the study reaches. Typical cross-sections for selected stream reaches are shown on Figure 4.1, and plots for each location are given in the supplementary report.

As stated previously, some cross-sectional data was available as a result of previous field surveys undertaken on the Humber River (40). However, in order to determine the usefulness of integrating these sections in the model development as part of present investigations, a detailed review of this material was undertaken.

Field surveys were repeated for approximately 25% of the sections previously measured (40). It was found that the overbank and channel characteristics along most areas of the Humber River had not changed appreciably since the time of the MacLaren study (40).

However, it was noted during subsequent sensitivity testing (see Section 4.5) that several of the old cross-sections were vertically extended at the end points internally by the HEC-2 program, illustrating that further cross-sectional data was required in the overbank areas of the reaches downstream of Steady Brook. Additional topographic information in the overbank areas of these reaches was collected by means of field surveys, supplemented by a review of the 1:2500 scale mapping.

By means of a comparison of field surveys to the new 1:2500 scale mapping, it was evident that both mapping and survey elevations were similar along the study reaches. Therefore, it was concluded that the new mapping could be used to supplement the field surveys.

A more detailed discussion of the physical characteristics of the stream channels and floodplain can be found in Section 4.2.2 of this report.

ii) Hydraulic Structures

Each of the hydraulic structures along the study reaches represents a potential flow constriction which may have a pronounced effect on water surface profiles during flood periods. Therefore, the physical dimensions and elevations of all hydraulic structures were field surveyed as described in detail in the supplementary report. These measurements included the size of the opening and the elevations of the soffit and bridge decks, etc.

iii) Staff Gauges

In order to collect peak water level data for the purpose of calibrating the hydraulic routing model, a total of 14 staff gauge stations were installed by the Department of Environment along the Humber River and Steady Brook in 1982 under the Canada-Newfoundland Flood Damage Reduction Program. Subsequent measurements of peak discharge and water levels were undertaken (by the former during 1982 and continued in 1983 by Nolan, Davis & Associates Limited - Cumming-Cockburn & Associates Limited) in order to collect data suitable for model calibration and verification. It should be noted that two of these gauges were damaged by ice and discontinued during the course of the subsequent field monitoring program, resulting in some loss of data. The locations of these gauges are given in Figure 4.3 with additional information on the data collected discussed in the supplementary report on the physical surveys and field program, and in the Canada-Newfoundland Flood Damage Reduction Program Report on Spring Flooding, 1982 (17).

The results of the field investigations and river and floodplain characteristics are discussed in the following section.

4.2.2 Channel and Floodplain Characteristics

i) General Hydraulic Characteristics

A review of the channel and floodplain characteristics of the two main study reaches was undertaken by means of field reconnaissance surveys, and interpretation of the available mapping and background information.

Based on the results of these surveys, it was determined that the study watercourses can best be characterized according to the following five main reaches:

1) Humber River from its outlet at the Humber Arm to its confluence with Steady Brook
2) Humber River upstream of its confluence with Steady Brook to Humber Village
3) Humber River from Humber Village to the Deer Lake outlet
4) Steady Brook from its confluence with the Humber River upstream to the C.N.R. trestle
5) Steady Brook above the C.N.R. trestle to the water supply pump house.

Typical channel and floodplain characteristics along the Humber River and Steady Brook are summarized in Tables 4.1 and 4.2 respectively.

description and density of a particular type of land use and soil cover, type and amount of vegetation, channel configuration and natural physical constraints relative to the channel and overbank reaches along the watercourse. Typical roughness coefficients were determined based on field observations of channel and overbank characteristics, experience in conducting similar investigations and with reference to the classifications derived by Chow (12). A summary of typical Manning's roughness coefficients determined for various reaches of the study area is given in Tables 4.1 and 4.2.

A brief description of the general hydraulic characteristics of the five main reaches is given in the following:

1) Humber River : Humber Arm to Steady Brook confluence:

The Humber River floodplain, from its outlet at the Humber Arm to its confluence with Steady Brook is characterized as being a narrow floodplain within a well defined valley. The overbank areas are heavily vegetated with heavy timber stands, brush and debris to the north, with more open areas, including the Trans Canada Highway (TCH) on the south side of the river. Development within the floodplain is limited in this area with some residential and light commercial areas located on the southern overbanks. The developed area gradually thins to a rural residential land use to the east of the Ballam Bridge, upstream of the Corner Brook City limits.

The majority of man-made influences on the channel and overbanks are related to the construction of the Trans Canada Highway on the southern shore of the river.

The channel along this reach is meandering and relatively flat with an average slope of about 0.0025 m/m. The channel banks are generally clean and well defined (man-made banks to barren rock outcrops withvertical walls), while the channel bed is comprised primarily of sand, stones and cobbles and areas of exposed rock. As a consequence of the type of channel material, there is virtually no channel vegetation present.

Manning's roughness values were found to range in the order of 0.035 to 0.060 for the channel and overbank areas respectively. Localized evidence of bank erosion was noted in some areas along this reach. Some erosion of the banks and sedimentation in the lower portions of this reach near the Corner Brook City limits may have slightly altered the characteristics of this reach in recent years. While some short term natural effects of erosion and sediment movement may have altered the hydraulic characteristics of this area, no significant effect on flood levels in this region is expected due to the minor nature of these changes relative to the existing discharge capacity of the channel and floodplain.

2) Humber River : Steady Brook to Humber Village:

This reach is characterized by overbank areas consisting of a mixture of heavily vegetated sections of trees and brush, as well as residential areas adjacent to some limited agricultural land use. The width of the floodplain is relatively broad in the central areas of the reach with typical widths ranging from 250 to 400 m. The floodplain then gradually reduces to a relatively narrower width (in the order of 150 m) in the vicinity of the Humber Village Bridge, as the valley section becomes more well-defined at this location. Residential land use is limited to the fringe areas of the floodplain in this region with the overbanks predominantly comprised of scattered stands of timber and moderate vegetative undergrowth. Overbank Manning's roughness values were found to range in the order of 0.040 to 0.060 in the majority of the areas upstream of the settlement of Russell where there are heavy stands of forest, with medium undergrowth. In localized areas with agricultural use of the valley section, the roughness parameter was adjusted to account for the increased flow conveyance characteristics of the area (see Table 4.1 for summary of typical Manning's roughness values).

With respect to the channel characteristics, the channel bedslope in this reach is non-uniform with an average slope of less than 0.001 m/m. The channel bed is comprised mainly of sand, cobbles, and the occasional stone or boulder. Deposition areas can be found along the channel at bends and meanders in the river and near the Humber Village bridge. Localized areas of rapids in the river bed are found along this reach during low flow conditions. However, these effects are not significant during high flow events.

With the exception of limited areas of erosion protection along the channel, little appreciable change has occurred in the floodplain areas in recent years along this reach.

3) Humber River : Humber Village to Deer Lake:

This reach is characterized by a moderately wide floodplain, ranging in width from 150 m to 200 m along most of the reach downstream of Rapid Pond. The floodplain then broadens gradually to a width in excess of 1000 m in the vicinity of Governors Point at the outlet of Deer Lake. The overbank areas are characterized primarily by intermittent residential land uses to the south with the northern areas of the reach comprised mainly of moderate to heavy stands of vegetation.

A mixture of groomed lands and densely vegetated regions characterize the areas upstream of Rapid Pond with an average valley slope of 0.0035 m/m. Manning's roughness values associated with these densely vegetated areas were found to be high, ranging in the order of 0.060 to 0.090 near the area of Rapid Pond, where heavy alder stands and scrub growth to moderate forest cover are evident. Man-made influences are limited in this area, restricted to localized urban developments on the southern shores of the Humber River.

The gradient of the overall channel reach is flat throughout with an average slope of 0.0005 m/m. The northern overbank of the floodplain has a somewhat limited flow carrying capacity relative to the southern overbank. This is due to the higher flow conveyance area associated with the southern overbank. It was noted that areas of channel rapids and pools are common along this reach, with the channel bed profile erratic and non-uniform in slope as shown on Figure 4.5.

4) Steady Brook : Confluence with the Humber River to CNR Trestle:

The Steady Brook floodplain, from the confluence of Steady Brook with the Humber River to the C.N.R. trestle, is characterized as being a wide floodplain with a relatively flat longitudinal gradient (average slope of about 0.0045 m/m). The overbank areas are comprised of swampy bog lands, groomed lawns and scattered trees and brush. Localized areas of heavy alder growth are also apparent in the upper areas of this reach. Development within the floodplain is extensive along the eastern overbanks (Community of Steady Brook), particularly in the lower reaches near the confluence with the Humber River. While this development is primarily residential, some commercial establishments are located in the floodplain fringe areas.

The channel in this reach is relatively straight and gently sloped, with an average slope of 0.005 m/m. The channel banks are poorly defined and comprised of grass lands and scrub growth while the channel bed is comprised of weedy reaches of sand and cobble bed types. Areas of sedimentation, shoals and local bank erosion are evident in the lower portions of this reach. These features have some effect on the flood conveyance capacity of the Brook.

Man-made influences along the channel and overbanks are mainly comprised of earth and roadway berms and retaining walls. These modifications are limited in extent, affecting about 20% of the banks along this reach.

5) Steady Brook : C.N.R. Trestle to the Water Supply Pumphouse:

Upstream of the CNR trestle, the Steady Brook channel is in a natural state and is relatively straight and steep with channel slopes averaging in the order of 0.021 m/m. The channel banks are well defined and the channel bed is comprised mainly of stones, cobbles, and boulders. While there is some channel vegetation in the lower portions of the reach, channel velocities are high enough to prevent growth of any significant vegetation.

The overbank and floodplain configuration along this reach is narrow (widths predominantly less than about 100 m) and differs substantially from the other reaches in the study area. The overbanks are characterized by a mixture of barren rock outcrops and densely vegetated areas of trees and brush (the predominant characteristic of this reach). The floodplain immediately upstream of the Trans Canada Highway is also narrow, with the eastern overbank having a slightly higher flow capacity than the western areas. The floodplain throughout this reach is steep, with an average slope of about 0.031 m/m.

The hydraulic characteristics of the study reaches may be briefly summarized as follows. The floodplain along the Humber River is relatively narrow while along the middle and upper reaches of the study area, the floodplain is wider (particularly in the area of the Community of Steady Brook and near Deer Lake) with the overbank areas predominantly composed of dense trees and brush. Tables 4.1 and 4.2 and Figures 4.1 and 4.2 summarize the typical channel and floodplain characteristics along the study reaches.

ii) Hydraulic Structures

The discharge and flood levels during peak flows are also controlled in part by some 5 bridges at various locations along the Humber River and Steady Brook. Many of these structures create some constriction to flow, thus increasing the flood risk to residences and businesses in the adjacent floodplain. Table 4.3 provides a summary of the bridge characteristics for each structure, which can be located by reference to Figures 4.3 and 4.4. Surcharging at these structures does not occur during the passage of peak flow events, as discussed in Section 4.4. Additional details on the hydraulic structures located along the study reaches, including field sketches made at each location, are available in the Supplementary Report on Field Surveys.

4.2.3 Model Structure

In order to simulate the flood levels associated with the 1:20 and 1:100 year peak flows, the available background and field data was input to the HEC-2 program. Figure 4.2 shows in schematic form the HEC-2 model structure developed for the hydraulic analysis.

With respect to input of available data, the following criteria were established in order to define cross-section locations and characteristics.

i) All sections are coded as if looking upstream along the watercourse.

ii) Field measured cross-sections used in the hydraulic model are referenced to the supplementary field report according to the following numbering system:

- For Humber River cross-sections, as surveyed by MacLaren (1972), cross-section numbers are unique to the "100" numeric series while the original section number is maintained. Thus, for example, MacLaren field survey cross-section No. 1 is identified in the backwater model as section number 101.
- For Humber River cross-sections undertaken as part of this analysis, the alphabetic characters, "HR" are substituted with the number "22". Thus, for example, field survey cross-section HR-14 is identified in the backwater model as section No. 2214.
- For Steady Brook cross-sections, the alphabetic characters "SB" are substituted with the number "30". Thus, for example, field surveyed cross-section SB-3 is identified in the backwater model as section number 303.

iii) In some cases, field measured cross-sections were used more than once as typical cross-sections along particular reaches. This is to facilitate the accurate coding of bridges and other such constraints at various locations on the watercourses, as described in the program documentation (55). Invert elevations were adjusted by applying the average slope between measured sections to the point of interest, while supplemental information for the overbank areas was also derived through interpretation of the new 1:2500 scale mapping developed in conjunction with this study. Repeated sections are denoted in the backwater model by a number to the right of a decimal point following the original section number identification (e.g. section 305.1 would be a repeated section based on the surveyed section number 305, or SB-5).

vi) All hydraulic structures are referenced to the field survey report through the use of comment cards.

The layout of cross-sections is shown on Figure 4.2 which illustrates in schematic form the extent and relative location of the field measured sections as input to the HEC-2 model. The approximate location of the surveyed cross-sections is also given on Figures 4.3 and 4.4 for the Humber River and Steady Brook respectively.

Head losses through all hydraulic structures (see Table 4.3) were simulated using the special bridge method, as described in the HEC-2 Users Manual (55). This option allows a combination of pressure and weir flow to be modelled. Thus, the most accurate method for calculating hydraulic losses through each structure was utilized.

Boundary conditions and other model input parameters were determined as follows:

i) All computations were initially performed assuming a condition of free flow. That is, all hydraulic structures were considered to be free from any temporary obstructions which would reduce their effective discharge capacity during the passing of peak storm flows. The model was subsequently revised during the assessment of ice and debris jam potential to account for possible blockage at the outlet of Steady Brook (as discussed in detail in Section 4.5 of this report.)

ii) The hydraulic coefficients were derived as previously outlined in Section 4.2.2 and subsequently applied in the sensitivity analysis as discussed in Section 4.5.

iii) The downstream starting elevation for the Humber River at the confluence with Humber Arm was assumed to be the maximum high tide with a corresponding geodetic elevation of 0.98 m, and was used for all design storm flood profile simulations.

Rapidly varying consecutive sections, bridge entrances and outlets, floodplain structures, etc. were accounted for through adjustments in the expansion and contraction coefficients, following recommended values found in the HEC-2 manual (55). The general criteria for determining these coefficients are summarized in Table 4.4, together with typical values.

The final results of the flood profile computations are discussed in Section 4.6.

4.3 Model Calibration and Verification

4.3.1 General

In order to accurately reflect the potential flood conditions along the Humber River, the HEC-2 model was calibrated and verified using field measured high water levels collected as part of a monitoring program conducted in 1982 and 1983 along the River. The monitoring program and data collected are discussed in the Supplementary Report. The observed water levels were utilized in order to refine the backwater model parameters determined during the field reconnaissance phase of the study.

The general procedures for calibration of the HEC-2 model are summarized in the following section.

4.3.2 Methodology

The HEC-2 model calibration and verification was undertaken by modifying the channel and floodplain roughness coefficients (Manning's "n") and other hydraulic parameters (e.g. expansion and contraction coefficients) until acceptable simulation accuracy was achieved. It was evident in undertaking the analysis that the Manning's roughness parameter was the most sensitive parameter with respect to calibration of water levels on the Humber River.

Discharge data used in the analysis was as recorded at the hydrometric station on the Humber River at Humber Village (No. 02YL003). No discharge information was available for calibration of flood profiles along Steady Brook. In the absence of data for calibration, sensitivity simulations (as discussed in Section 4.5) were undertaken to determine the degree of confidence associated with the derived 1:20 and 1:100 year water levels for the Steady Brook watershed.

The following outlines the general procedures for calibration and verification of the HEC-2 model along the Humber River:

1) Collect suitable water level measurements by field survey of high stage events at predetermined locations along the Humber River (refer to Figure 4.5 and supplementary report for gauging locations).

2) Obtain the associated peak flow records from the hydrometric station at Humber Village, corresponding to the high stage events collected as per Step 1.

3) Isolate the sensitive hydraulic model parameters in order to simulate the water levels obtained through step 1.

4) Compare computed water levels (using the hydraulic coefficients determined as part of the field reconnaissance surveys) to those recorded.

5) Vary the appropriate hydraulic parameters, as required, and iterate until a suitable comparison between measured and computed water levels at the pertinent gauge locations is achieved.

6) Validate the refined model by comparing computed and recorded water levels for an event not used in the calibration exercise.

As a result of the field monitoring programs carried out during this investigation, and those previously conducted under the Canada-Newfoundland Flood Damage Reduction Program in 1982 (17), the following events were documented for subsequent application in the HEC-2 model calibration and verification analyses:

1) A peak flow occurred on May 12, 1982 as a consequence of snowmelt and heavy rainfall. A corresponding peak discharge of 851 m^3/s (approximately a 1:10 year event) was recorded at the hydrometric station at Humber Village (see Figure 4.5 for gauge location). Figures 4.6 and 4.7 show the discretized water levels recorded for the event along the Humber River below and above Steady Brook respectively. A more detailed description of this event can be found in a Report on Spring Flooding, 1982 (17).

2) A peak flow also occurred on May 30, 1982 as a result of snowmelt and rainfall. The resultant peak discharge is associated with a return period of less than a 1:2 year recurrence interval of 545 m^3/s. The recorded water level measurements obtained as a result of this event are given in Figures 4.6 and 4.7 (see also reference 17).

3) A 1983 snowmelt event which, combined with heavy rains, resulted in a maximum discharge of 733 m^3/s at the Humber Village hydrometric station. This flow was found to correspond to about a 1:5 year event. Further documentation on this event can be found in the supplemental report, "Physical Surveys and Field Program". Figures 4.6 and 4.7 show the discretized water levels for this event.

4) A summer rainfall event which occurred on August 13, 1983, combined with flow releases from Grand Lake resulting in a discharge of 761 m^3/s (1:5 year flow) at the Humber Village gauge. The water levels recorded during this event are shown on Figures 4.6 and 4.7. A more detailed documentation of this event can be found in the supplemental report.

While various other events of lower magnitude were available for use in this analysis, those described above were found to be most suitable for use in the calibration and verification of the HEC-2 model.

For the purposes of this analysis, the model was calibrated to the event of May 12, 1982 and subsequently verified utilizing the other selected events as noted previously. A summary of the calibration results can be found in Table 4.5, with a corresponding discussion of calibration and validation results in Section 4.3.3 and 4.3.4.

Based on the findings of the model calibration and verification analyses, it was determined that the backwater model suitably represents the hydraulic characteristics of the Humber River in the study area. The applicability of the hydraulic model derived for Steady Brook, with respect to the determination of the 1:20 and 1:100 year flood profiles, is discussed in Section 4.5.

4.3.3 Corner Brook to Steady Brook

The following summarizes the calibration and verification results for the Humber River reach from the City of Corner Brook to Steady Brook:

i) Model Calibration Results

Figure 4.6 and the following summarize the results of the backwater model calibration on the Humber River study reach from Corner Brook to Steady Brook with respect to the event of May 12, 1982.

1) The initial uncalibrated backwater model utilized the hydraulic parameters as determined from the field reconnaissance surveys of the study area. The backwater calculation was initiated using water level elevations taken from the Bowater Wharf (Tideboard) gauging site (Gauge No. 14).

2) It was found that use of the Manning's roughness coefficients, as determined during the field reconnaissance survey, resulted in water levels marginally lower on average than those recorded. The calibrated model required an increase in roughness values in the order of 20% higher on average than those determined in the field.

3) The uncalibrated model was found to yield water levels 0.2 m lower on average than those recorded at the gauge sites.

4) The calibrated model yielded water levels averaging about 0.04 m higher than the recorded water levels.

ii) Model Verification

The results of the hydraulic model verification for the Humber River reach from Corner Brook to Steady Brook are shown on Figure 4.6 and summarized below and in Table 4.5.

1) The base hydraulic parameters used in this analysis reflected those determined for the calibrated model.

2) No refinements were required to the calibrated model with respect to the simulations undertaken on the three verification events. That is, the calibrated model was found to adequately reflect the flooding conditions associated with the verification events.

3) The hydraulic model was found to yield water levels with respect to those observed for the three verification events as follows (see also Table 4.5):

- the verified model yielded water levels within a range of 0.00 m to 0.14 m of those recorded for the May 30, 1982 event
- for the event of April 24, 1983; the verified model was found to differ in water levels 0.08 m on average from those recorded with a range of 0.01 m to 0.16 m
- for the event of August 13, 1983; the difference in verified water levels versus those recorded was found to be 0.10 m (based on limited data base recorded over the reach for this event).

4.3.4 Steady Brook to Deer Lake

The following summarizes the calibration and verification results on the Humber River from Steady Brook to Deer Lake:

i) Model Calibration

Figure 4.7 summarizes the results of the backwater model calibration on the Humber River between Steady Brook and Deer Lake using the May 12, 1982 event. The calibration results of this work are summarized by the following:

1) The initial uncalibrated backwater model applied in this analysis reflected the hydraulic parameters as determined from the field reconnaissance surveys of the study area. It was found that the Manning's roughness values determined in the field yielded water levels slightly lower on average than those recorded. The calibrated model required an increase in roughness values in the order of 15% higher on average than the field determined values.

2) The uncalibrated model yielded water levels of 0.10 m lower on average than the recorded event.

3) The calibrated model resulted in water levels averaging about 0.04 higher than the recorded water levels.

ii) Model Verification

The results of the hydraulic model verification are shown on Figure 4.7 and discussed below for the study reach between Steady Brook and Deer Lake.

1) The hydraulic parameters were those determined for the calibration event.

2) The calibrated model was found to adequately reflect the flooding conditions for the three verification events. The verified model was found to yield water levels with respect to those observed as follows:

   - the verified model yielded water levels within an average of 0.08 m of those recorded for the May 30, 1982 event (range of 0.01 m to 0.08 m)
   - for the event of April 24, 1983; the verified model was found to differ in water levels on average by 0.04 m, within a range of 0.00 m to 0.08 m
   - the mean difference in verified water levels versus recorded was found to be 0.01 m for the event of August 13, 1983 (within a range of 0.00 m to 0.02 m).

Table 4.5 summarizes the results of the HEC-2 model calibration and verification analysis on the Humber River.

Based on the findings of the model calibration and verification analysis, the 1:20 and 1:100 year flood profiles were then computed utilizing this model, as discussed in Section 4.4. Subsequent sensitivity testing of the model was undertaken (refer to Section 4.5) to further define the degree of confidence in the 1:20 and 1:100 year flood profiles.

4.3.5 Summary of Model Calibration and Verification

The following summarizes the main findings and conclusions of the HEC-2 model calibration and verification (see also Table 4.5):

1) The model calibration and verification has indicated a good comparison (within 0.05 m on average) of simulated and observed water levels using the existing data base. The HEC-2 model is considered to give an accurate simulation of flood profiles along the Humber River.

2) Due to absence of discharge data and water levels on Steady Brook, the model could not be calibrated along this reach. An assessment as to the applicability of the derived backwater model for Steady Brook is given in Section 4.5.

4.4 Flood Profiles

4.4.1 General

The main objective of this investigation was to determine flood profiles along the study reach for floods with a recurrence interval of 1:20 and 1:100 years.

The hydrologic analyses described in Section 3.0 resulted in the determination of 1:20 and 1:100 year instantaneous peak discharge values for the study area (see Table 3.1). The hydraulic model verification as described in Section 4.3 confirmed the accuracy of the hydraulic parameter estimates, while the sensitivity analyses confirmed the importance of accurate discharge estimates (see Section 3.0).

The HEC-2 backwater model was developed as discussed in Sections 4.2 and 4.3 and a schematic of the overall model structure is given on Figure 4.2. Channel and floodplain characteristics were determined as discussed in Section 4.2.2. The calibration and validation undertaken has increased the level of confidence in the ability of the backwater model to accurately simulate flood profiles along the Humber River. Subsequent sensitivity analyses have defined the degree of confidence in the backwater model developed for Steady Brook (see Section 4.5).

The boundary conditions and model structure are discussed in detail in Section 4.2. The following briefly outlines the main assumptions in the application of the calibrated model for the simulation of the 1:20 and 1:100 year flood profiles:

1) Water level profiles were computed assuming a subcritical flow condition. While supercritical flow was encountered for some short reaches of Steady Brook (intermittently upstream of the TCH), sensitivity testing demonstrated insignificant differences when supercritical vs. subcritical were compared in these reaches.

2) The hydraulic coefficients used in the development of the 1:20 and 1:100 year flood profiles were those as calibrated and verified to recorded events.

3) All bridges and hydraulic constraints were assumed free of any temporary obstruction which may reduce the hydraulic discharge capacity. (Historical records and discussions with local residents confirmed that blockage of such structures is not a significant factor on either of the study watercourses).

4) Peak flows as summarized in Tables 3.1 and 3.2 were used in determining the 1:20 and 1:100 year flood profiles.

5) The starting tidal level applied in the analysis was 0.98 m for the storm events assessed. This represents the maximum high tide value for the Humber Arm at Corner Brook (see Section 4.5.4).

6) Backwater modelling was undertaken utilizing refined cross-sectional data from previous studies (40) in the area downstream of Steady Brook in order to translate the tidal levels at Corner

Brook to a starting water elevation in the area of Steady Brook. For the areas upstream of and including Steady Brook, cross-sections were field surveyed for application in the backwater modelling.

Numerical values for the 1:20 and 1:100 year flood profiles are summarized in tabular form in Appendix E of this report.

The flood profiles corresponding to these backwater simulations are plotted on Figures 4.8 and 4.9 for the Humber River and Steady Brook respectively.

The extent of the flooded areas associated with the 1:20 and 1:100 year flood profiles were plotted on new topographic maps (scale 1:2500). Interpretation of the backwater profiles and associated computer output, together with an assessment of the extent of flooded areas was undertaken in order to identify flood hazard locations.

4.4.2 Humber River Flood Hazard Areas

In the Community of Steady Brook the flood hazard can be classified as being high. Numerous structures and properties are directly affected by flooding in the area, especially under the 1:100 year flood condition. With the associated flood depths in the region, numerous access roads could be flooded. Flooding to the southeast of the channel is widespread, encroaching on many residential developments. This area is the most susceptible to present and future flood damage. While flooding to the southwest of the channel is also widespread, the potential flood risk is low as development in this area is limited. This is due to the localized areas of bog and dense vegetation which is characteristic of this area, as previously discussed in Section 4.2.

Generally speaking, the potential flood hazard is low upstream from Steady Brook along the Humber River floodplain. However, several small developments (in the area of Humber Village, Russell and Harrison) can be classified as being susceptible to a moderate or high flood risk.

In these areas, while few buildings are directly affected by flooding, several access roads and some low-lying land are susceptible to flooding.

There also exists a moderate to low flood risk in the area of Governors Point near the outlet of Deer Lake. Here the low lying areas of the south shore of the Humber River would be flooded during the occurrence of a 1:100 year event.

As an indication of the areal extent of flooding, the average top width of flooding (in those areas where the channel capacity was exceeded) was found to be about 1200 m, compared to an average channel top width of 190 m. The main flooding hazards along the study reaches would appear to be related to the limited discharge capacity of the channel. The presence of ice and debris accumulating in the channel at the entrances to structures and at the confluence of the two study watercourses was not found to increase the local flood risk appreciably, as discussed in Section 4.5.7.

It should be noted that this reach is not sensitive to ice and debris jamming. The associated flood risk in this area is strictly related to peak runoff conditions on the watershed.

4.4.3 Steady Brook Flood Hazard Areas

The predominant flood hazards along the Steady Brook watercourse would appear to be related to the limited discharge capacity of the channel combined with backwater effects of peak flood stages in the Humber River. The presence of ice and debris accumulating in the channel at the confluence with the Humber River has some effect on the flood risk (as discussed in detail in Section 4.5.7). With respect to the above, the following provides a more site-specific discussion of the flood hazard areas in the Steady Brook area.

A high flood hazard exists in the reach along Steady Brook from its confluence to the C.N.R. trestle. While high magnitude floods would primarily affect the access routes and recreational facilities located in this area, localized urban pockets such as the north east shore would be inundated as a result of the 1:20 and 1:100 year floods. This creates a flood hazard in the area, especially with respect to potential future development in the region. Similarly, large areas of recreational lands would be inundated under very high discharge events.

The flooding of developed areas as described above relates to overland flow in the floodplain area and is primarily an effect of backwater conditions from high flood stages in the Humber River. In addition, some basements adjacent to the floodplain may also be flooded due to infiltration. However, the determination of this type of basement flooding was beyond the scope of the present study. Also, the first floor elevations and structure openings of all potentially flood prone structures must be field surveyed should it be necessary to determine flood damages in any possible future flood control investigations.

Upstream of the CNR trestle, the 1:100 year peak flows are confined to the natural channel section. Furthermore, the configuration of the valley limits the extent of development within the floodplain, due to the steep overbank gradients associated with the reach (see Section 4.2 for further documentation).

The average top width of flooding in the downstream reaches was found to be about 300 m, compared to an average channel top width of 30 m. Similarly, in the upstream areas an average floodplain width of 20 m versus 15 m average channel width was noted.

4.5 Sensitivity Testing of Flood Profiles

4.5.1 Methodology

In order to assess the potential variations in the magnitude of various calibrated model parameters on flood profiles along the study reaches, various sensitivity simulations were undertaken.

Based on a review of the initial model simulations, calibration/verification analyses, the field reconnaissance survey, and on previous results of backwater modelling on this watercourse, and other similar watercourses in Newfoundland, the following parameters were determined to be important with respect to definition of flood levels in the study area:

- peak discharge rates
- definition of channel and floodplain roughness coefficients (Manning's 'n')
- tidal variations
- expansion and contraction coefficients
- changes in floodplain configuration (aerial extent of field surveyed cross-sections)
- presence of ice and debris in the watercourse.

During the sensitivity testing, the relative importance of model variables was determined by changing one variable within prescribed limits while holding the remaining variables and input parameters constant during a simulation. By noting the change in magnitude of computed water levels, the relative importance and sensitivity of each parameter was established. All sensitivity analyses were undertaken utilizing the calibrated model and 1:100 year flow developed as part of these investigations.

Through examination of the 1:2500 scale mapping (and associated degree of accuracy), it was assumed that a change in water levels of ±0.5 m would have negligible effect in respect to the areal extent of flooding along the Humber River and Steady Brook. Therefore, any parameter changes which resulted in a change in the flood profiles in excess of about 0.5 m, were considered to be a significant variation since this would affect the areal extent of the floodplain.

The following sections outline the methodology and results of the sensitivity testing with respect to the parameters noted previously.

4.5.2 Sensitivity to Changes in Floodplain Configuration

The river section downstream from Steady Brook was modified as a consequence of widening the Trans Canada Highway. In order to assess the impact of changes to the conveyance area of the cross-sections on the Humber River and Steady Brook study reaches, sensitivity simulations were undertaken. Simulations were undertaken to compare the water levels associated with the present channel and floodplain configuration to the flood levels which would be associated with the hydraulic conditions prior to widening the highway. The cross-section characteristics prior to the widening of the TCH were assumed based on the results of previous investigations (40)

The resulting sensitivity simulations indicated that the construction of the TCH had some effect on the upstream flood levels in the Community of Steady Brook. The effect on flood levels along Steady Brook was found to be less than about 0.3 m. This is attributed to the hydraulic characteristics along Steady Brook such as increased slope resulting in reduced effects from downstream backwater. Differences in flood levels along the Humber River from the area of changes to the highway up to the Community of Steady Brook were found to range between 0.0 m to 0.5 m with an average difference of about 0.3 m.

The differences are not considered to be very significant since such changes in flood levels within the Steady Brook community were found to translate into an areal change in the floodplain which would affect only two existing dwellings.

These findings are also consistent with the results of previous investigations (40), in regard to the possible change in flood levels which might be attributed to the widening of the Trans Canada Highway which was carried out.

4.5.3 Sensitivity to Peak Discharge

Sensitivity simulations were conducted utilizing the computed 1:100 year peak discharge versus the 1:100 year peak discharge at the upper and lower 95% confidence limits, according to the values summarized in Table 4.6. With respect to this analysis, the following was noted:

i) Humber River:

As expected, the peak discharge had a large effect on variation of water levels, with the average difference being about 0.95 m above the mean at the +95% confidence level with differences ranging from 1.09 m to 0.89 m. Similarly, peak flows (refer to Table 4.6) at the -95% confidence level resulted in an average decrease of about 0.98 m in water levels compared to those computed for the mean, with a range of 1.09 m to 0.85 m. The smallest differences were found to be associated with the steeper stream reaches (such as near the Deer Lake outlet) while the largest differences were found to be in the Humber River floodplain in the vicinity of Steady Brook.

ii) Steady Brook:

The peak discharge had some effect on variation of water levels, with the average difference being about 0.65 m, above the mean at the +95% confidence level with differences ranging from 0.89 m to 0.28 m. Similarly, peak flows at the -95% confidence level resulted in an average decrease of about 0.69 m in water levels compared to those computed for the mean, with a range of 1.01 m to 0.38 m. The smallest differences were found to be associated with the steeper stream reaches while the largest differences were found to be in the area of the Humber River floodplain. Extreme differences were also found at hydraulic structures, where the effective discharge capacity of the structure directly affects the sensitivity to discharge.

In summary, it was found that the average difference of the median profile from the ±95% ("upper and lower profiles") was found to be approximately 1.95 m and 1.4 m along the Humber River and Steady Brook respectively

Comparing these analyses to sensitivity tests discussed in subsequent sections, it was evident that changes in flow had the most effect on water levels computed for the entire length of both watercourses, with the Humber River found to be the most sensitive to variation in discharge.

4.5.4 Sensitivity to Tidal Influence

The HEC-2 model requires the definition of initial starting levels along the study reach. Sensitivity simulations were undertaken to determine the effect of variations in the initial water levels at the Humber Arm on flood levels from Steady Brook to Deer Lake.

For the purpose of this investigation, the range of water levels at the Humber River outlet was chosen as 0.67 to 1.68 m. This represents a range from the mean high tide to the maximum recorded tide at the outlet of the River.

It was evident from this analysis that tidal influence is not a significant factor with respect to water levels along the study area of the Humber River. The water surface profile below the Ballam Bridge being the only area subject to any significant tidal influence. In terms of the study reaches, the influence of tides is noted along the majority of the Humber River study reach and downstream areas of Steady Brook, although to an insignificant degree. The average difference in water levels on the River was about 0.02 m, and ranging from 0.03 m to 0.00 m (excludes starting level at downstream section). These results, therefore, further justify the use of 0.98 m (average maximum tide) as the starting condition for backwater calculations.

Similarly, the average difference in water levels on Steady Brook was found to be 0.02 m and ranging from 0.03 m in the lower reaches near the Humber River confluence to 0.00 m in the upstream areas. It was further noted that no effects of tidal levels were evident upstream of the CNR trestle.

4.5.5 Sensitivity to Roughness Coefficient

Manning's roughness coefficients for the channel and floodplain were determined as described in Section 4.2.2. The sensitivity of the flood profile computations to variations in roughness coefficient was undertaken as a means of further substantiating the accuracy of the backwater model.

The range of Manning's "n" values applied in the analysis are summarized in Table 4.7. The discharge value used in the sensitivity testing corresponded to the median 1:100 year estimates of peak flow as given in Table 4.6.

The range of "n" values given in Table 4.7 corresponds to the range of potential values as described by Chow (12) and determined according to the channel characteristics of the study reach. For the purposes of these sensitivity tests, it was determined that the roughness coefficients could vary ±20% about the "mean calibrated value" previously discussed. This range is consistent with the range determined as part of the calibration/verification exercise.

i) Humber River

The average difference in water levels from the mean were found to be about +0.55 m and -0.61 m corresponding to +20% and -20% changes in the roughness coefficients respectively. The corresponding differences were found to range from about 0.53 m to 0.58 m and 0.57 m to 0.64 m respectively. Similarly, the corresponding average difference between the upper and lower range was about 1.14 m along the study reaches, with differences of from 1.08 m to 1.20 m. The largest differences were noted along the flatter reaches where the channel and floodplain slopes are less pronounced, such as in areas of the Community of Steady Brook.

ii) Steady Brook

The average difference in water levels about the mean were found to be approximately +0.19 m and -0.17 m corresponding to +20% and -20% changes in the roughness coefficients respectively. The corresponding differences were found to range from about 0.53 m to 0.0 m and 0.58 m to 0.00 m respectively. Similarly, the corresponding average difference between the upper and lower range was about 0.35 m along the study reaches, with differences of from 1.12 m to 0.00 m.

Along Steady Brook, the most sensitive areas were found to be in the lower reaches near the Canadian National Railway bridge. On the basis of these tests, it was concluded that there is an appreciable variation in peak flood levels along the watercourses as a result of possible variations in roughness coefficients, although not as significant as variations in discharge.

4.5.6 Sensitivity to Expansion and Contraction Coefficients

Sensitivity simulations were also undertaken in order to assess the effect of variations in expansion and contraction coefficients on the accuracy of the calibrated backwater model. Simulations were conducted by varying the expansion and contraction coefficients within a range of ±50% from the calibrated/verified values given in Table 4.4. From this analysis, it was found that negligible differences in water levels resulted over the study reaches (variations less than ±0.03 m and ±0.01 m resulting about the mean for the Humber River and Steady Brook respectively). It was, therefore, concluded that flood profiles along the study reaches are relatively insensitive to variations in expansion/contraction coefficients. The calibrated values given in Table 4.4 were, therefore, further substantiated as to their accuracy.

4.5.7 Sensitivity to Ice and Debris Jams - Steady Brook

According to historical flooding summaries, ice jams are not a problem along the Humber River. Therefore, the sensitivity analyses of ice and debris jams is restricted to Steady Brook.

Ice jams generally form at constricted sections and locations where irregularities occur. Some typical characteristic locations where ice jams could initiate include:

1) At a transition zone between a rapidly flowing stream reach and a section of more tranquil flow. On Steady Brook this occurs at the confluence with the Humber River

2) At channel singularities such as shoals, changes in alignment, constrictions in the flow and other channel obstructions (see Section 4.2.2 for a discussion of channel obstructions affecting ice jams)

3) At locations of hydraulic structures such as bridges along the watercourse (although not found to be significant for this study as noted in Section 4.2.2);

4) At locations where significant accumulations of anchor ice have formed along the stream. (No specific sites have been identified based on existing information).

If the flow velocity and Froude number are below 0.75 m/s and 0.08 respectively (6,15,38,52), then static ice jams will form and remain in place, allowing water passage beneath it. Such jams would have relatively low flood damage potential, being characterized by fairly uniform increases in water level along their length.

However, "dynamic" ice jams may evolve from unstable forms of simple or static ice jams. Dynamic jams may be formed at a flow obstruction or channel irregularity where a heavy run of ice is suddenly stopped, such as at undersized bridges. Higher flow rates, and associated Froude numbers, may also cause ice floes to underturn at the leading edge of a downstream ice cover, thickening the jam by shoving, breaking and crushing. The movement of the jam might continue until balanced by internal forces or until the jam catches on bottom irregularities, resulting in the formation of a so-called "dry jam". Both types of jams may remain in place until the river discharge changes significantly, or until the strength of the ice is weakened due to warm weather.

The flow velocity and depth values calculated from the HEC-2 model were utilized to estimate Froude numbers in order to assess the potential for ice jam formation. In general, it was found that the average velocity and Froude number along Steady Brook at historical and/or potential ice jam locations were found to be over 1.4 m/s and 0.11 respectively. This indicates a moderate to high potential for severe ice jam formation and growth at possible jam locations.

In order to assess the degree of sensitivity of the watercourses to the presence of ice and debris in the channel, the hydraulic model was revised to incorporate the following conditions and assumptions:

i) An ice jam equivalent to the potential volume of contributing ice on Steady Brook downstream of the C.N.R. trestle was applied at the Brook's confluence with the Humber River (approximately 5,000 m^3 of ice).
ii) An ice cover of 0.1 m thickness was also assumed from the jam location as noted in i), upstream to the C.N.R. trestle.
iii) The Humber River was assumed free of any ice/debris.
iv) The discharge applied in this analysis was that of the mean 1:20 year for Steady Brook, as noted in Table 4.6. The 1:2 year flow was applied in the Humber River to obtain levels for the backwater model.

The selection of jam locations and degrees of ice/debris cover were based on discussion with local residents and experience in undertaking similar investigations on similar watersheds in Canada.

Based on this analysis, it was noted that flood levels on Steady Brook are sensitive to the presence of ice and debris in the channel. Water surface elevations in the area of the Steady Brook Swimming Pool were increased as much as 0.6 m from those associated with free flow conditions. Furthermore, ice related water levels from the swimming pool to the CNR trestle along Steady Brook were found to be in the order of levels associated with the 1:100 year open water event in the area. It was further noted that the increase in water levels due to ice/debris jams are relatively local in effect, with affected flood levels extending 100 m to 150 m upstream.

4.5.8 Summary of Results and Conclusions of Sensitivity Analyses

The following points summarize the main findings and conclusions of the sensitivity analyses on computed flood profiles along the study watercourses (for the 1:100 year event unless otherwise noted):

1) Flood profiles are relatively insensitive to changes to overbank configuration of the study watercourses (average change of 0.3 m).

2) The flood profile along the watercourses were found to be sensitive to variation in peak discharge (refer to Table 4.6), as represented by the following confidence limits:

   i) Humber River:
   - average difference above the mean for +95% confidence limit was 0.95 m (range of 0.88 to 1.09 m)
   - average difference below the mean for -95% confidence limit was 0.98 m (range of 0.85 to 1.09 m)

   ii) Steady Brook:
   - average difference above the mean for +95% confidence limit was 0.65 m (range of 0.28 to 0.89 m)
   - average difference below the mean for -95% confidence limit was 0.69 m (range of 0.38 to 1.01 m)

3) Flood profiles along the Humber River are more sensitive to variation in discharge than are levels on Steady Brook.

4) The sensitivity of flood profiles along the Humber River and Steady Brook to variation in roughness coefficient resulted in relatively small changes in flood elevations:

   i) Humber River:
      - average difference above the mean for +20% confidence limit was +0.55 m (range of 0.53 m to 0.58 m)
      - average difference below the mean for -20% confidence limit was -0.61 m (range of 0.57 m to 0.64 m)

   ii) Steady Brook:
      - average difference about the mean for ±20% confidence limit was 0.35 m (range of 1.12 m to 0.00 m)

   The flood profiles along the watercourses are, therefore, sensitive to variations in roughness coefficient, with profiles along the Humber River floodplain more sensitive to "n" than along Steady Brook.

5) The influence of tidal variations is felt over the Humber River study reach, although this has little effect on the resulting flood profiles (within a range of ± 0.03 m). On Steady Brook, the variations in tidal levels are felt only in the extreme lower portion of the watercourse; specifically downstream of the C.N.R. Trestle (within a range of ± 0.03 m). The tidal variations have almost no effect on the areal extent of the floodplain along both watercourses.

6) The flood profiles are sensitive to the presence of ice and debris jams in the Steady Brook channel, with related water surface increases of about 0.6 m associated with the 1:20 year event (1:2 year flow in the Humber River). These would result in a significant increase in the areal extent of flooding. However, this effect is fairly localized due to the steepness of the stream, channel and floodplain.

7) Flooding as a result of ice jamming and/or peak flows in Steady Brook could occur independently of flooding on the Humber River.

8) Flood profiles were found to be insensitive to variations in expansion and contraction coefficients.

9) Variation in model parameters did not result in significant variations of the areal extent of the floodplain along Steady Brook. Therefore, the uncalibrated model used in this investigation is considered to be of acceptable accuracy.

4.6 Main Conclusions and Recommendations of Hydraulic Analyses

The HEC-2 backwater model was successfully utilized to determine flood profiles along the Humber River and Steady Brook using channel and floodplain characteristics determined from the field surveys.

Based on the results of the foregoing, the following main conclusions and recommendations are noted:

Conclusions:

1) Flood profiles along Steady Brook and Humber River are primarily sensitive to the following parameters:

   - variation in discharge
   - variation in channel and floodplain roughness coefficient
   - local ice jams along Steady Brook.

2) Testing of the backwater model by comparison to observed flood levels has, for the Humber River, confirmed the accuracy of the flood level simulations.

3) Due to the absence of discharge and water level measurements on Steady Brook, the backwater model was not calibrated for this

reach. However, the results of the sensitivity analysis illustrated that the accuracy of the computed flood profiles is acceptable.

4) Supercritical flow profiles were encountered at various locations along Steady Brook. However, the difference between subcritical and supercritical flow simulations was found to be relatively insignificant along these reaches (differences less than 0.05 m on average). Therefore, the subcritical flow simulations accurately reflect the design flood levels along the study reaches.

5) The computed 1:20 and 1:100 year hydraulic profiles utilizing the calibrated parameter values input in the model for the Humber River are given in Figure 4.8. The flood levels for the 1:20 and 1:100 year hydraulic profiles for Steady Brook are given in Figure 4.9. The water surface elevations for these events are also tabulated in Appendix E.

6) Flooding on the Steady Brook could result independently of flooding on the Humber River, especially with the formation of ice jams in the channel near the swimming pool.

7) The construction of the TCH had some effect on the upstream flood levels along Steady Brook. The differences are not considered to be very significant. Such changes in flood levels were found to translate into areal changes in the floodplain which would affect only two existing dwellings within the Community of Steady Brook.

   Flood profiles were found to vary 0.3 m on average over the Humber River from the Highway up to the Community of Steady Brook.

Recommendations:

1) The 1:20 and 1:100 year flood profiles for the Humber River and Steady Brook are summarized in Figures 4.8 and 4.9 and the water levels are given in a tabular summary in Appendix E. It is recommended that these profiles be adopted as the 1:20 and 1:100 year

water surface elevations for the study reaches, and thus utilized for future regulation of development along the study reaches. Similarly, the areal extent of flood hazard lands as shown on the 1:2500 scale mapping should be adopted as identifying the potential extent of flooding within the study area.

2) The HEC-2 model should be utilized to determine the effect of proposed remedial measures on the 1:20 and 1:100 year flood profiles and the associated areal extent of flooding.

TABLE 4.1

Typical Channel and Floodplain Characteristics
Humber River

Reach	Typical Channel Characteristics				Typical Floodplain Characteristics				*Typical Manning's "n"		
	Depth (m)	Width (m)	Slope (m/m)	Material	Width (m)	Slope (m/m)	Vegetation Conditions	No. of Bridges	Left Over-bank	Channel	Right Over-bank
1 Humber Arm to Steady Brook	10	350	0.0025	- stone & cobbles - some pools - some sand	-	0.005	- dense vegetation - grass land, paved areas - vertical exposed bedrock walls	1	0.060	0.035	0.060
2 Steady Bk. to Humber Village	8	250	0.001	- sand and stones - some cobbles	400	0.001	- heavy vegetation - scrub & timber - some residential landuse	1	0.040	0.025	0.040
3 Humber Village to Deer Lake	5	100	0.0005	- sand & stones - some sunken logs near Deer Lake outlet	200	0.0035	- grassland - scrub & moderate to dense vegetation - some debris - residential land use on fringes	0	0.050	0.020	0.050

NOTE: * For detailed description of Manning's "n" over the reach, refer to hydraulic model computer listing. (These values also reflect the results of model calibration and verification)

TABLE 4.2

Typical Channel and Floodplain Characteristics
Steady Brook

	Reach	Typical Channel Characteristics				Typical Floodplain Characteristics				*Typical Manning's "n"		
		Depth (m)	Width (m)	Slope (m/m)	Material	Width (m)	Slope (m/m)	Vegetation Conditions	No. of Bridges	Left Over-bank	Channel	Right Over-bank
4	Confluence to CNR Trestle	1.5-2	50	0.005	- stone & cobbles - some sand	300	0.0045	- grassland & pavement - moderate vegetation, scrub - Alder growth on banks	1	0.035	0.035	0.050
5	Upstream of CNR Trestle	5-6	30	0.021	- stone & cobbles - boulders	50	0.031	- exposed bedrock - vertical side slopes - dense vegetation - heavy Alder growth on banks	2	0.060	0.055	0.055

NOTE: * For detailed description of Manning's "n" over the reach, refer to hydraulic model computer listing. (These values also reflect the results of model calibration and verification)

TABLE 4.3

Summary of Hydraulic Structure Characteristics

Location	Type of Structure	Elevations *Road (m)	Elevations Soffit (m)	Area of Opening (m^2)	Approximate Capacity (m^3/s)**
B1 Ballam Bridge	Conc. bridge	4.88	3.56	494	5960
B2 Humber Village Bridge	Steel Girder bridge	9.97	7.87	651	6925
B3 CNR Trestle	Conc/steel	8.50	8.40	118	750
B4 TCH Bridge	Conc. bridge	16.58	15.36	220	800
B5 Old TCH Bridge	Conc. bridge	21.20	20.75	76	760

NOTES

* Denotes the minimum elevation of the roadway approach or bridge deck, dependent on which controls the potential for surcharge over the roadway.

** Assumed flood elevation is soffit of bridge.

TABLE 4.4
Summary of Typical Expansion
and Contraction Coefficients *

Parameter	Range of Typical Values
Expansion Coefficient:	
i) Gradually varying sections	0.3
ii) Rapidly varying sections and hydraulic constraints	0.5
iii) Abrupt variations between sections and severe hydraulic constraints	0.6 - 1.0
Contraction Coefficients:	
i) Gradually varying sections	0.1
ii) Rapidly varying sections and hydraulic constraints	0.3
iii) Abrupt variations between sections and severe hydraulic constraints	0.5 - 0.8

NOTE: * Source (55)

TABLE 4.5

Summary of Backwater Model Calibration and Verification for the Humber River

Gauge Station Location	No.	Difference in Simulated and Observed Water Levels (m) May 12/82 Event	*May 30/82 Event	*Apr 24/83 Event	*Aug.13/83 Event
i) Humber Arm to Steady Brook:					
Bowaters Wharf (Humber Arm)	14	0.00	0.00	-	-
Ballam Bridge	13	-0.01	-0.13	-	-0.10
Young Property (55 Riverside Dr.)	12	0.00	-0.07	-	-
Shellbird Island	11	0.04	-0.09	0.16	-
Quarry Pond	10	0.09	-0.14	0.01	-
Mean Difference		0.04	0.10	0.08	0.10
Maximum Difference		0.09	0.14	0.16	-
Minimum Difference		0.00	0.07	0.01	-
ii) Steady Brook to Deer Lake:					
Mitchell Property	9	-0.03	-0.06	-0.08	0.00
Falls Ave. (Steady Brook)	8	0.01	0.03	-	-
Thistle Property	7	0.05	0.07	0.02	0.00
Lundrigan Property	6	0.08	0.01	0.05	0.00
Strawberry Hill	5	0.03	0.08	0.04	0.02
Boom Siding	4	0.02	0.08	0.00	-0.01
Mean Difference		0.04	0.06	0.04	0.01
Maximum Difference		0.08	0.08	0.08	0.02
Minimum Difference		0.00	0.01	0.00	0.00

NOTES:

1) May 12/82 event taken as the calibration event
2)* Verification Events
3) Starting water levels omitted in computing difference ranges and mean.

TABLE 4.6
Maximum Discharge Applied
in Sensitivity Analysis

Section No.	Location	1:100 Year Discharge (-95% C.L.)	1:100 Year Discharge Q_{p100} (m^3/s)	1:100 Year Discharge (+95% C.L.)	1:20 Year Discharge Q_{p20} (m^3/s)
Humber River:					
119	d/s of Steady Brook	888.	1180.	1471.	957.
121	u/s of Steady Brook	889	1180	1471.	948.
Steady Brook:					
-121	@ Confluence with the Humber River	76.8	134.	206.	105.

TABLE 4.7

Summary of Roughness Coefficients

Used in Sensitivity Analysis

Reach	Manning's Roughness Coefficient: Left Overbank -20%	Left Overbank n	Left Overbank +20%	Channel -20%	Channel n	Channel +20%	Right Overbank -20%	Right Overbank n	Right Overbank +20%
Lower Humber River:									
Steady Brook to Lundrigan Property	0.032	0.040	0.048	0.020	0.025	0.030	0.034	0.042	0.050
Lundrigan Property to Humber Village Bridge	0.031	0.039	0.047	0.025	0.031	0.037	0.033	0.041	0.049
Humber Village Brook to Strawberry Hill	0.039	0.049	0.059	0.025	0.031	0.037	0.039	0.049	0.059
Strawberry Hill to Deer Lake	0.048	0.060	0.072	0.032	0.040	0.048	0.040	0.060	0.072
Steady Brook:									
Confluence to C.N.R. Trestle	0.028	0.035	0.042	0.028	0.035	0.042	0.040	0.050	0.060
C.N.R. Trestle to T.C.H.	0.040	0.050	0.060	0.032	0.040	0.048	0.040	0.050	0.060
T.C.H. to Water Supply House @ Study Limit	0.048	0.060	0.072	0.044	0.055	0.066	0.044	0.555	0.066

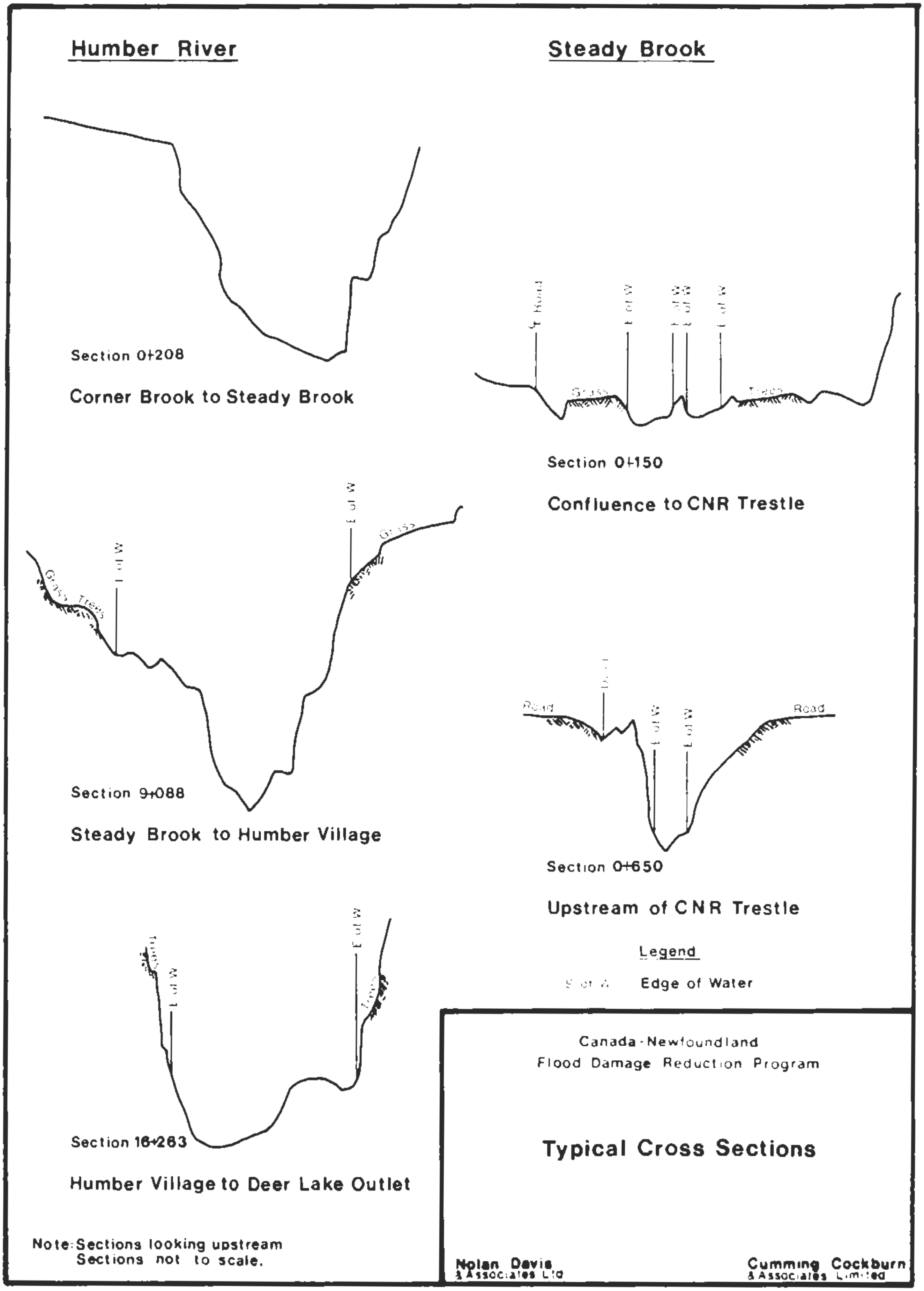
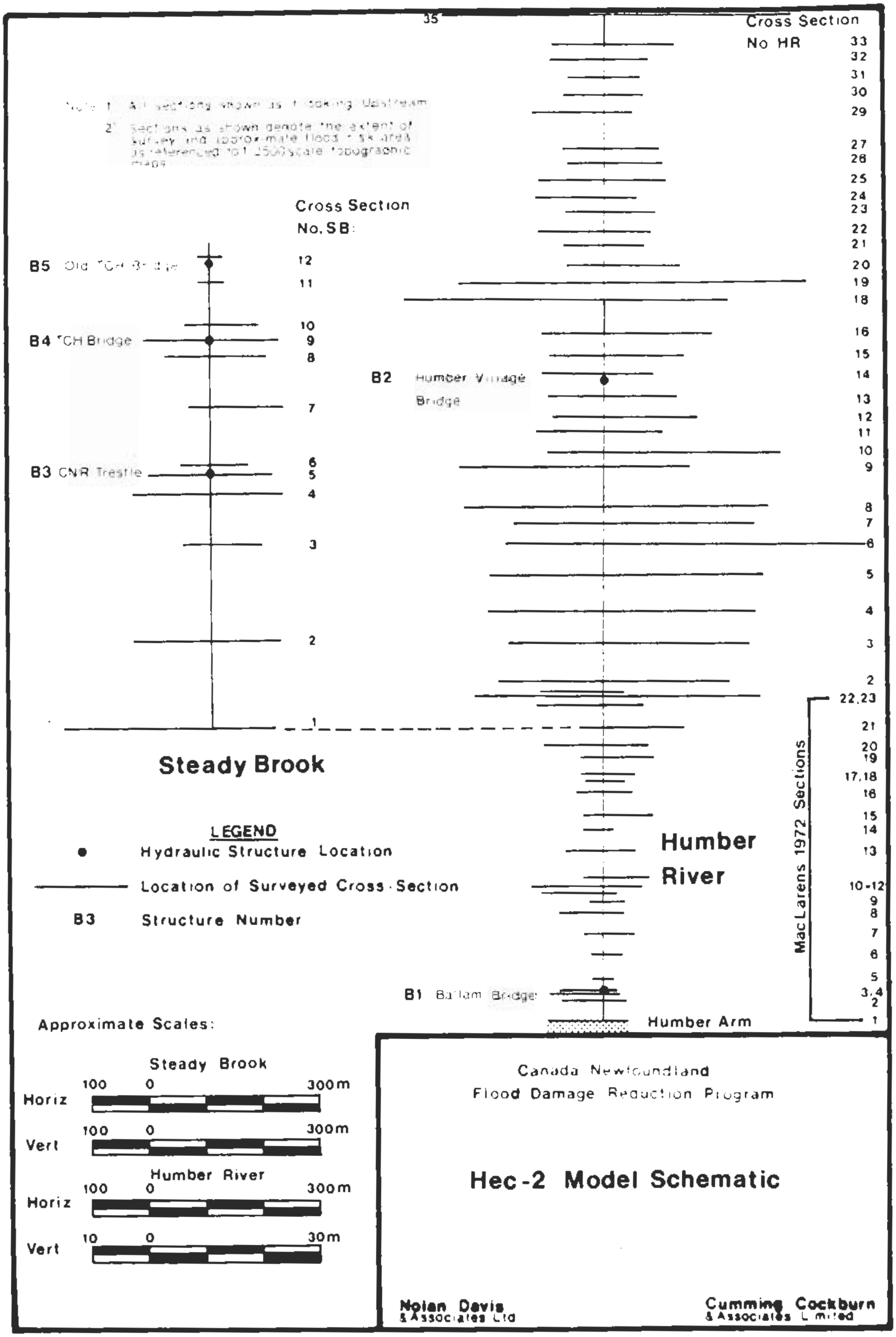

Humber River
Steady Brook
Section 0+208
Corner Brook to Steady Brook
Section 9+088
Steady Brook to Humber Village
Section 16+263
Humber Village to Deer Lake Outlet
E of W
Grass
Trees
Section 0+150
Confluence to CNR Trestle
Road
Section 0+650
Upstream of CNR Trestle
Legend
E of W Edge of Water
Note: Sections looking upstream
Sections not to scale.
Canada - Newfoundland
Flood Damage Reduction Program
Typical Cross Sections
Nolan Davis & Associates Ltd
Cumming Cockburn & Associates Limited

Figure 4.1



Cross Section
No HR
Cross Section
No. SB:
B5 Old TCH Bridge
B4 TCH Bridge
B3 CNR Trestle
B2 Humber Village Bridge
B1 Ballam Bridge
Steady Brook
Humber River
Humber Arm
MacLarens 1972 Sections
LEGEND
Hydraulic Structure Location
Location of Surveyed Cross-Section
B3 Structure Number
Approximate Scales:
Steady Brook
Horiz 100 0 300m
Vert 100 0 300m
Humber River
Horiz 100 0 300m
Vert 10 0 30m
Canada Newfoundland
Flood Damage Reduction Program
Hec-2 Model Schematic
Nolan Davis & Associates Ltd
Cumming Cockburn & Associates Limited

Figure 4.2

5.0 REMEDIAL MEASURES

5.0 REMEDIAL MEASURES

5.1 General

On the basis of the assessment of historical flooding and utilizing the results of the backwater model for the 1:20 and 1:100 year floods, it was possible to identify alternative remedial measures for alleviating the flood hazard along Steady Brook and the Humber River.

Broadly speaking, the basic elements for a flood damage reduction plan can be classified as:

1) Structural measures which directly affect the flood characteristics, and
2) Non-structural measures which are intended to modify the loss burden, either by reducing the potential for continued development in flood prone lands or by providing some form of economic relief from flood losses.

A detailed analysis of possible remedial measures was beyond the scope of the present investigations. However, based on the results of the study, it has been possible to identify a number of alternative remedial measures for further future detailed consideration, as shown on Figure 5.1 and discussed in the following sections.

5.2 Identification of Structural Measures

The following structural flood control measures should be considered in order of priority:

1) Construction of dykes or flood berms along selected reaches of the study watercourse

   The feasibility of constructing a flood control berm along the north-east side of the Steady Brook channel reach in the area downstream of the Canadian National Railway trestle should be considered.

- Approximately 600 m of berm may be required along the east bank of Steady Brook; extending from the confluence with the Humber River upstream to the C.N.R. trestle.

Similarly, the construction of more localized flood control berms or dykes should be considered in the following areas along the Humber River:

i) Along the southern overbank of the Humber River in the vicinity of Rapids Pond. This would be for localized relief only, and a detailed assessment of this area was beyond the scope of this investigation.

ii) About 1000 m of berm along the southern shore of the Humber River in the Community of Steady Brook; extending from the Steady Brook confluence upstream to the old log booms.

2) Raising of Roadways in the Community of Steady Brook

To minimize the extent of flooding in the Community of Steady Brook, consideration should be given to the raising of the roads bordering the channel downstream of the C.N.R. Trestle. While a potential for flood damages would still exist to those structures located between the channels and the roads in this region, this alternative would effectively flood proof roughly 90% of the structures currently susceptible to flood damages.

It should be noted that the application of such a measure may not be appealing aesthetically to the community, and that driveway access might be restricted in some areas.

3) Upstream detention on Deer Lake outflows

The SSARR simulation have indicated that the natural storage in Deer Lake significantly attenuates peak flows. Therefore, the installation of a dam and outlet control weir over the natural valley section at the outlet of Deer Lake could be considered to increase the degree of peak flow attenuation. The installation of such a structure would serve to attenuate the peak flows experienced along the downstream reaches of the Humber River. In assessing the feasibility of this scheme, the following should be examined:

a) The effect on the timing arrival of the peak flows on the Humber River to Steady Brook with respect to the present condition
b) The suitability of the proposed site with respect to environmental concerns
c) The maximum level of control provided for attenuating peak inflows and subsequent downstream water levels
d) The effect on the use of the Humber River and Deer Lake for recreational and commercial ventures.
e) The effect of fluctuation in water levels on the Communities of Deer Lake and Nicolsville.

However, it is not expected that this alternative would be cost-effective. The effects of water level fluctuation around Deer Lake would also likely be severe.

4) <u>Floodproofing of structures located within the floodplain</u>

The possibility of raising flood prone structures to a level above that associated with the 1:100 year storm should be considered. In assessing the feasibility of this scheme, it is evident that not all of the flood prone structures could be floodproofed in a cost effective manner (i.e. structures with basements or commercial buildings). The primary usefulness of this scheme would be pertinent to the localized developments along the southern shore of the Humber River, upstream of Steady Brook in the area of Governors Point and the Humber Village (Harrison).

5) Additional stream channel improvements

Maintain a program of debris clearing along the lower part of Steady Brook every fall to reduce the potential for debris blockage at sensitive locations along the channel during the spring freshet. Similarly, this alternative would reduce the potential for increased deposition of debris in the area, thus ensuring the hydraulic condition of the channel is maintained.

Figure 5.1 summarizes the locations most feasible for the structural measures as noted above.

5.3 Non-Structural Flood Control Measures

1) Flood Plain Regulations

In developing areas such as along the Humber River floodplain; regulations should be implemented to restrict future development and thus reduce the potential for continued increases in flood damages. In this case, a two-zone floodway flood-fringe concept is envisaged where zoning regulations would prohibit future development in the high hazard areas. Additional development might be permitted in the flood-fringe areas, depending on the degree of hazard and the implementation of flood proofing measures to protect these developments.

2) Flood Warning System

A flood warning system could be developed to reduce the potential for flood losses during peak runoff events. This is also required in conjunction with modified operation of the Grand Lake system in order to anticipate increased inflows during all peak flow conditions. This option would also require upgrading of the existing hydrologic and meteorologic monitoring system in the Humber River watershed to provide a better means for real time collection of discharge and meteorologic data. The economics of development of a flood warning system should also be evaluated. On the other hand, the increased warning time for flooding and possible implementation of emergency flood fighting measures could avoid the potential for loss of property and possible loss of life due to flood conditions along the Humber River.

3) Grand Lake Operation

The operation of the Grand Lake Dam could be modified, such that the usefulness of this structure to reduce downstream flood peaks during the spring freshet is improved. The present operating policies are geared mainly towards optimizing power production and avoiding overtopping of the dam and associated structures. Any changes in operating policy to provide flood protection would require a detailed economic evaluation of the cost of lost power production versus the benefits gained by reducing flood losses.

4) Other Measures

The relocation of flood prone structures should be considered. This could include expropriation of high hazard lands and restricted development in these areas.

5.4 Summary

The most attractive structural alternatives presently appear to be:

1) A combination of raising the roads and berming or dyking at several locations within the Community of Steady Brook.

2) Individual flood proofing of structures located in flood fringe areas currently susceptible to potential flood damages.

The most attractive non-structural measures include:

1) Implementation of floodplain policies to regulate development in flood hazard areas.

2) Implementation of a flood warning system to be used in conjunction with modified operation of the Grand Lake Dam.

3) Review and improve the operational policies of the Grand Lake Dam such that the usefulness of this structure in reducing downstream flood peaks is improved.

Each of these measures or any combination thereof would potentially serve to reduce the high flood risk presently occurring along the study reaches, particularly in the area of the Community of Steady Brook. The benefits of flood damage reduction should be assessed by estimating the potential flood damages associated with the occurrence of various flood events and calculating the associated cost/benefit ratios for the various alternatives.

It should be pointed out that none of the measures suggested would completely eliminate the risk of flooding in the study area although the potential for future flood losses would be reduced to varying degrees.

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6.0 LIST OF REFERENCES

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    - Humber River at Village Bridge, Station No. 02YL003
    - Indian Brook Diversion to Birchy Lake, Station No. 02YM002
    - Leweseechjeech Brook at Little Grand Lake, Station No. 02YK002
    - Sheffield River at Sheffield Lake, Station No. 02YK003
    - Sheffield River near T.C.H., Station No. 02YK005
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APPENDIX A

HISTORICAL FLOODING IN THE

STEADY BROOK AREA

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HISTORICAL FLOODING IN THE STEADY BROOK AREA

The following sections summarize the documented flooding events on the Humber River and Steady Brook as recorded over the period 1944 to present. The majority of the information supplied herein was extracted from material supplied by Environment Canada.

● FLOOD OF SEPTEMBER 14 - 16, 1944

Cause: Heavy rainstorm

Description:

The storm was felt mainly on the West Coast. Railway management reported very heavy rain between Gander and Badger Brook. The railway also took precautions to prevent washouts from Grate's Point to Humbermouth

Magnitude:

A rainfall of 0.34 inches (8.6 mm) was recorded at Gander International Airport on September 14th with an additional 1.54 inches (39.1 mm) of rain falling on September 15th. A total rainfall of 2.37 inches (60.2 mm) was recorded at Corner Brook and 2.92 inches (74.2 mm) of rain fell at Deer Lake.

Damages: No estimates or descriptions of the damages were available.

● FLOOD OF OCTOBER 4 - 5, 1944

Cause: High winds, heavy rainfall

Description:

On the West Coast, a section of the Newfoundland Railway (east of Humbermouth) was washed out. A landslide also occurred at Curling resulting in train delays from Port aux Basques.

On the Burin Peninsula, road washouts occurred near Point Bay and at Fortune. At St. Lawrence, the road leading from the public wharf was washed out.

Magnitude: No data was available.

Damages:

No estimates of the damage were available, however, the road washout near the public wharf at St. Lawrence was repaired jointly by the Department of Public Works and the St. Lawrence Fluorspar Company.

● FLOOD OF NOVEMBER 16, 1944

Cause: Accumulation of rainfall and gale ("one of the stormiest autumns")

Description:

Grand Lake was reported to be very high and the waves created by the gale resulted in a railway washout at Sandy Pond Dump (Mileage - 385), two miles west of Howley.

Magnitude: No information was available.

Damages: No estimates of the damage were available.

● FLOOD OF NOVEMBER 4 - 5, 1945

Cause: Heavy rain

Description:

On the West Coast, a stormy weekend with heavy rain caused three minor washouts on the railway line at South Brook, Harry's Brook, and Humbermouth.

Magnitude:

A total rainfall of 1.88 inches (47.8 mm) was recorded at Deer Lake on the 5th and 2.44 inches (62.0 mm) was recorded at Corner Brook.

Damages: No estimates of the damage were available.

● FLOOD OF MAY 18 - 19, 1948

Cause: Heavy rain, melting snow

Description:

Rivers and brooks on the West Coast were reported to be in flood. A railway washout was reported at East Humbermouth.

It was reported that this was the "first time this spring that the waters were really high".

Damages: No estimates of the damages were available.

FLOOD OF MAY 21-30, 1969

Cause:

Spring runoff (rain and melting snow); no ice was involved; Seven gates of Main Dam, Grand Lake were opened

Description:

Several homes along the Humber River, from Corner Brook to Deer Lake, were flooded.

At Steady Brook, eight homes were reported to be damaged by flood waters, two of which were said to be considered a total loss.

A section of the Trans Canada Highway, west of Spillway Bridge, Deer Lake was covered with about two feet of water for a period.

At Nicholsville, Deer Lake, three houses near the Humber River were flooded and a section of road was inundated with several inches of water. Rowboats were used to get to and from the houses.

It was also reported that the Lundrigan's residence at Little Rapids and Bowater's Strawberry Hill residence were damaged by flood waters. However, no confirmation of these reports were obtained from the newspapers.

Magnitude:

Reports claimed that at Steady Brook, the river had risen 11-14 feet above normal. Deer Lake was reported to have risen 4.7 feet (1.4 metres) between May 21st and May 24th. Some photos of the flooding at Steady Brook and Spillway Bridge were published.*

Damages:

At Steady Brook estimates of flood damages varied. Mr. K. Fosnaes considered his losses to be in the order of $40,000. His home was said to be new; he reported four inches of water over the floor and furniture damage.

Mr. Schmidt's home in Steady Brook had four feet (1.2 metres) of water over the main floor causing damage to the furnishings as well.

At Nicholsville, the residence of Harold Young was surrounded by four feet (1.2 metres) of water which seeped into the dwelling damaging furniture and stores of provisions in the basement. The residence of Frank Bailey, across the road from the Young residence was reported to have had three inches of water in the basement. The home of Augustus Bailey had also suffered water damage.

* The Evening Telegram, Monday, May 26, 1969, pg. 1 and The Evening Telegram, Tuesday, May 27, 1969, pg. 3.

FLOOD OF MAY 22 - JUNE 3, 1970

Cause: Heavy rainfall, debris blockages

Description:

In Corner Brook, several streets, one of which was Watson's Road, were inundated by heavy runoff resulting in erosion.

It was reported that every culvert crossing Riverside Drive was blocked with debris.

Majestic Brook overflowed its banks causing flooding in the vicinity of Reid, North and Church Streets. The streets were left cluttered with debris.

At Brakes Cove, a culvert blockage resulted in extensive flooding of the C.N.R. Crossing.

At Trout River, delays were experienced in starting construction of a breakwater because of the highwater. Fears were expressed concerning further damage to the structure and the demolition of the damaged section.

Magnitude:

Bowaters Technical Service reported a rainfall of 1.92 inches (48.8 mm) from 4 p.m. on June 2nd until 8 a.m. on June 3rd. A Bowaters spokesman stated that the 12-hour rainfall was the heaviest in the past 10 years.

Damages:

It was estimated that the street damage was in the order of $15 - $20,000 and that it would take 7-10 days to repair the damages in Corner Brook.

FLOOD OF NOVEMBER 24-26, 1970

Cause: Heavy rains

Description:

In Corner Brook, catchbasins were clogged with debris resulting in flooding. A major washout was reported in the Elizabeth Street area, as well as many others thoughout the City. Many basements were flooded resulting in damages.

C.N.R. trains were delayed because of a track washout in the Mount Moriah area.

Magnitude:

At Corner Brook, a rainfall of 2.03 inches (51.6 mm) was recorded on the 24th, 0.37 inches (9.40 mm) on the 25th and 1.57 inches (39.9 mm) on the 26th. Heavy rainfall was also recorded at other locations of the West Coast during the same period.

Damages:

No estimates of damages were published in newspaper accounts. C.N.R. damages at Mount Moriah were in the order of $525.

FLOOD OF FEBRUARY 14-15, 1971

Cause: Rain, melting snow and ice, ice jams

Description:

In Corner Brook, some roads were washed out or badly rutted and many basements were flooded.

A bridge on Harry's River, upstream of the Water Survey of Canada gauge site, was hit by flood waters and heavy ice dislodging and collapsing one-span, on the west bank.

At Port aux Basques, a bridge was reported to have been washed out.

A bridge at Burnt Island (South Coast) withstood the pressures of flood waters and ice. The flood waters had forced ice up onto the highway to a height of 8-10 feet for a distance of about 1/4 mile.

West of Corner Brook, the Trans Canada Highway was reported to be flooded to a depth of 2 feet (0.6 metres) [location not given].

Magnitude:

At Stephenville Airport, 2.13 inches (54.1 mm) of rain was recorded on the 14th while at Port aux Basques, 1.08 inches (27.4 mm) of rain was recorded.

Damages: No estimates of the damages were presented.

● FLOOD OF MARCH 9-10, 1972

Cause: Rain and mild temperatures

Description:

A photo* was published showing flooding on West Valley Road, Corner Brook, which was a result of clogged storm drains.

Magnitude:

It was reported that 0.80 inches (20.3 mm) of rain had occurred at Corner Brook. It is suspected that snowmelt was also a contributing factor. Temperatures were reported to be in the order of 45°F (7.2°C).

Damages:

Damage to streets and city property was estimated at $20,000. No estimates or descriptions of the damage to private property were presented.

● FLOOD OF MAY 15-18, 1972

Cause: Spring runoff accompanied by rainfall

Behind the Harmon Complex, a section of gravel road near the McAlpine Cement Plant washed out as water overflowed from a pond on one side of the road to a pond on the other side. Another section of this road was also inundated but did not wash out.

A section of the Trans Canada Highway, in the Gallant's area, was reported as being inundated (Gallant's is west of Corner Brook).

In Corner Brook, a 3-year old girl playing near a rain swollen brook behind her home, on Georgetown Road, in the City's west end, was drown.

At Steady Brook, several homes were flooded. A photograph* which was published shows water to be 2-4 feet (0.6-1.2 metres) deep around the residence of Dr. George Hatch. Water was reported as having flooded the basement of the Manuel residence.

Magnitude:

One resident of Steady Brook stated "spring flood waters do not usually get as far as the Manuel's home".

Damages:

No estimates of damages were presented. One life was lost. C.N.R. damages were reported to be approximately $1,500.

* The Western Star, March 4, 1972, pg. 2
The Western Star, June 9, 1972, pg. 3

FLOOD OF NOVEMBER 27-28, 1972

Cause: Rain, mild temperatures and several inches of melting snow

Description:

A newly constructed culvert and about 200 feet (60 metres) of the Branch - North Harbour Road (St. Mary's Bay) were washed out when the Beckford River overflowed its banks.

In Corner Brook, drainage systems were overtaxed and in some instances plugged causing overflow. Bell's Brook overflowed near Blackwood Hills, when the culvert was unable to handle the flow. A portion of Riverside Drive and the C.N.R. tracks were undermined. The Ball Diversion-Churchill Avenue intersection was submerged.

Problems were also encountered in the Petrie's Brook area. Many basements throughout the City were flooded.

Magnitude:

At Corner Brook, rainfall in the order of 1.6 inches (40.6 mm) with temperatures in the low 50's Farenheit, were reported. Pictures* were published showing the Bell's Brook overflow and the undermined C.N.R. tracks.

Damages:

Cost of repairs to the C.N.R. washout was reported to be in the order of $900. Estimates of the other damages were reported in the newspaper accounts to be in the order of $30,000.

The culvert on the Branch-North Harbour Road was installed two weeks previous and the contractor who completed the project reported the job was guaranteed for two years.

* The Western Star, Tuesday, November 28, 1972, pg. 2

- FLOOD OF DECEMBER 7-8, 1972

Cause: Heavy rain

Description:

In Corner Brook, Bell's Brook overflowed on the 7th inundating the road and flooding property at No. 1 Walbourne's Road.

Magnitude:

Residents claimed the bridge over the brook didn't have adequate capacity after a heavy rain and that flooding had been occurring for the past three years in that area.

Damages:

No damage estimates were presented. Council was reported to have replaced the culvert and the bridge which carried concrete encased water and sewer lines.

- FLOOD OF FEBRUARY 2-3, 1973

Cause: Rain, mild temperatures, melting snow and ice jams

Description:

In Corner Brook, minor washouts were reported to have occurred on several gravel roads throughout the city.

In Stephenville, on Blanche Brook, ice piled up across the Main Street Bridge. The wooden sidewalk on the bridge had to be replaced, but the bridge itself was not damaged. The Canada Manpower Office and Building 450 on the Harmon Complex were slightly damaged when ice was forced against them.

All buildings close to the Main Street Bridge had their parking lots blocked with ice which was piled 10 feet high in places. Water rose almost to floor level of the Indian Head Co-op, and also flooded Minnesota Drive opposite the brewery.

A tractor, engaged in removing the ice jam, was reported as having slipped through the ice into the brook.

Magnitude:

It was reported as being the worst ice condition in the history of the town.

Flooding of the brewery was prevented by the temporary dykes which had been built in the spring of 1972 when similar, but less extensive flooding occurred in the area.

Damages: No estimates of the damages were published.

● FLOOD OF JUNE 23-24, 1973

Cause: Heavy rainfall

Description:

In Corner Brook, heavy rains caused considerable damage to city streets. Elizabeth and Lomond Streets were reported to be hardest hit. A photo* was published showing the extent of damage on Lomond Street.

Magnitude: No information was presented.

Damage: Damages to the streets were estimated to be in the order of $30,000.

● FLOOD OF AUGUST 1-4, 1973

Cause: Heavy rainfall for a 3-day period

Description:

In the Port au Port Peninsula damage was reported to roads. At Fox Island River, a landslide occurred upstream bringing 30-40 cords of pulpwood and trees down the river with the flood which dragged anchors taking several boats out to sea. The highway was also reported to be closed near Piccadilly, Port au Port, because of a washout.

In the Stephenville area, Highway No. 47 (Hansen Highway) was under water in at least two places and a bridge, near Wheeler's Night Club above Noel's Pond, was washed out.

Basements, in the Mill Place area, north of Main Street, were flooded as Blanche (Cold) Brook swelled to several times its normal size.

Many residents were without water for about two days when a water line was broken because of the high water and debris.

Town equipment was kept busy clearing debris (at least 15 truck loads) from the bridges on Blanche Brook, thus averting serious damage. However, concerns were expressed as to their safety, owing to the remaining blockage.

The flood waters eventually broke through the temporary dykes protecting the brewery and reached a height of about 1.5 feet (0.45 metres) above the floor level. Three private vehicles in the parking lot were also inundated. Telephone and electrical services to the building had to be cut off.

At nearby Noel's Pond, at least four families were forced to leave their homes because of the flood waters.

* The Western Star, June 25, 1973.

In Corner Brook, a number of basements were flooded as Bell's Brook rushed through and around one of two culverts intended for re-alignment of the road below Blackwood's Hill. At the confluence of Bell's Brook and Corner Brook Stream, water was reported to be washing the Bowater's oil supply line across the brook. Some water also backed up as a result of a partial blockage on Corner Brook Stream by the temporary road near the entrance to Bowater's Pulp Mill. The parking lot behind the Western Star Building on Brook Street was also inundated.

A bailey bridge had to be erected over Blow-me-Down Brook (Blomidon Brook) to replace the one washed out between Frenchman's Cove and Lark's Harbour, Bay of Islands.

Near Pasadena, a water line crossing South Brook was severed by flood waters. A property adjacent to Blue Gulch Brook was eroded 6-8 feet (1.8 - 2.4 metres) when the brook rose to very high levels (photograph published*). At least one home in Pasadena was inundated.

Magnitude:

Rainfall for the three day period totalled 3.61 inches (91.7 mm) at Corner Brook, 2.92 inches (74.2 mm) at Stephenville Airport and 2.75 inches (69.9 mm) at Deer Lake.

The flooding at Stephenville was reported to be the worst in the history of the town.

The C.N.R. files stated that the following houses at Noel's Pond (Cormier Village) were inundated to the following depths:

Residence of Donald Cormier - ±6 in. on main floor
Residence of Eric Cormier - ±4-6 in. on main floor
Residence of Tom Cormier - ±4 feet on main floor
Residence of Mrs. Mildred Hynes - ±6 in. on main floor

Mrs. Vincent Cormier had no damage to her dwelling; however, she had been compensated for loss of hens and income from the sale of eggs.

Damages:

At Stephenville, the broken water main had been damaged during the 1969 flood and had been left dangerously exposed by ice gouging during the spring flood of 1973. After this, the town had spent approximately $21,000 on encasing it in concrete and burying it deep enough to avoid future problems from ice gouging. However, debris was the cause of this break.

Damages to interior and equipment as well as inventories of both goods in process and finished goods at the Brewery was said to be in the

* The Western Star, Monday, August 6, 1973; and The Western Star, Tuesday, August 7, 1973, pg. 13

FLOOD OF SEPTEMBER 12-13, 1974

Cause: Heavy rainfall

Description:

A house on Old Humber Road was inundated during the heavy rain. A picture* was published showing the residents attempting to divert the water flowing down the nearby hillside away from their homes.

Magnitude:

The Bowaters Technical Services Department reported a rainfall of 1.44 inches (36.6 mm).

Damages: No estimates of the damages were reported.

FLOOD OF SEPTEMBER 21-22, 1975

Cause: Heavy rainfall

Description:

Severe flooding was reported to have occurred in some sections of southwestern Newfoundland after almost three inches of rain.

In Corner Brook, storm sewers and ditches just couldn't cope with the heavy rain in a short period of time resulting in flooded streets and washouts. Many basements in low lying areas were inundated. The streams running through the city overflowed their banks compounding the problem of sewer backups.

The Mayor appealed to the residents of the city to try and handle minor flooding problems themselves as city work crews were hard pressed.

Magnitude:

A rainfall of 0.94 inches (23.9 mm) was recorded on the 21st with an additional 2.02 inches (51.3 mm) being recorded on the 22nd in Corner Brook. A total rainfall of 1.84 inches (46.7 mm) was recorded at Stephenville Airport and 2.72 inches (69.1 mm) were recorded at Deer Lake Airport for the 21st and the 22nd.

Damages:

Peddle's Lane, Corner Brook East, was reported to be severely damaged.

The Mayor estimated the cost of repairing street damages to be in the order of $50,000.

* The Western Star, September 13, 1974

● FLOOD OF DECEMBER 22-25, 1975

Cause: Rain, snow and unseasonable temperatures

Description:

In Stephenville, flooding of streets was said to be "extensive" as storm sewer systems were not able to handle the amount of water.

In Corner Brook, storm damage was reported to be quite extensive to the streets. Maple Valley Road and Blackwood Hills were reported to be hit the hardest. Road shoulders were reported as being damaged severely. Peddle's Lane, where storm sewers had been installed after the street was washed out by flooding in September, was not seriously affected.

In the Exploits River Valley, a section of the Trans Canada Highway four miles west of Grand Falls was closed because of flooding. The road was flooded to a depth of about two feet (about 0.6 metres) at 8 a.m. on December 24th. On January 8th, almost two weeks after the peak flow, part of the highway was still under water. Traffic was diverted by way of the Old Badger Road.

Magnitude:

A total of 2.05 inches (52.1 mm) of precipitation, including snow and rain was reported at Stephenville.

On December 22nd, a rainfall of 0.98 inches (24.9 mm) was recorded at Corner Brook. A rainfall of 1.79 inches (45.5 mm) was recorded on the 22nd at the Exploits Dam (Red Indian Lake).

On the Exploits River ice began to move downstream in stages as a result of the rainfall and high temperatures until it reached the area of Goodyear's gravel pit. At this point in the river, the ice was reported to have accumulated and partially blocked the channel. Increased water levels resulted upstream and subsequently began to flow through the gravel pit adjacent to the north bank until reaching the Trans Canada Highway.

The gauging station on the Exploits River below Stony Brook (Station No. 02YO005) indicated that the flow began to increase about 7 a.m. on December 23rd and reached a value of 13,000 cfs (368 m^3/s) by midnight and about 22,800 cfs (645 m^3/s) at 4 p.m. on December 24th. The flow receded to about 6,000 cfs (170 m^3/s) by midnight on December 26th.

The Exploits River drainage area, above Red Indian Lake, was reported as not having contributed to the flooding as Price Newfoundland Ltd. had closed the Exploits Dam in November 1975; to increase the storage which had been depleted because of insufficient runoff. As well, the company did not require any water for the power plant because of an on-going strike at the mill.

Damages:

The highway remained closed throughout most of the winter. No estimates of damages to the highway were given. This section of highway was reported as having been vulnerable to flooding due to the low lying land areas adjacent to the river and minor flooding had been noted by highway personnel "especially in the spring of the year".

It was also noted that approximately two miles of highway would be raised several feet to prevent the recurrence of flooding in the future.

- FLOOD OF JANUARY 27-28, 1976

Cause: Rain, melting snow and ice jams

Description:

The high runoff resulted in flooding and damages in Corner Brook and surrounding areas.

In Corner Brook, several road washouts had occurred. The Maple Valley area was reported to be hard hit due to blockage of runoff by ice. Massey Drive also experienced bad washouts and one resident was reported to have lost his driveway.

Homes in Frenchman's Cove, Benoits' Cove and Lark Harbour were reported to be damaged due to flooding.

At Benoits' Cove, ice was reported as having piled up at the mouth of Clark's Brook causing some problems in that area.

Steady Brook was reported to be plugged with ice causing the water to back up inundating four homes and threatening 10 others. Two families were forced to leave their homes.

The Highways Department in Deer Lake reported "extreme" flooding in the Trout River and Bonne Bay areas and several washouts had occurred.

Magnitude:

At Stephenville, a total rainfall of 1.64 inches (41.7 mm) was recorded for the 27th and 28th, while at Corner Brook the rainfall totalled 0.88 inches (22.4 mm) for the same period. At Rocky Harbour, Bonne Bay, a total rainfall of 3.11 inches (79.0 mm) was recorded on the 27th and 28th.

Damages:

The Department of Highways, Superintendent of Operations at Deer Lake toured the area on the south shore of the Bay of Island and assessed the damages. Members of the Legislature were seeking aid for several families whose homes were flooded in the communities of Benoits' Cove, Frenchman's Cove and Larks Harbour. Estimated damages to the homes were placed at about $100,000.

At Steady Brook, property damage and measures to alleviate the flooding were reported to have cost $5,000.

● FLOOD OF MARCH 21-23, 1976

Cause: Rain, melting snow and ice, and blockages

Description:

In Corner Brook, flooding of city streets, businesses and private property were reported. In the vicinity of Humber Heights and Curling, damages were said to be restricted to private property. Highland Avenue and West Valley Road areas were reported as having experienced some washouts. Several business premises in the Corner Brook Plaza as well as a downtown groceteria were reported as being affected by floodwaters. Majestic Brook was reported as being "clogged with slob ice" resulting in the flooding of East Valley Road and Central Street properties.

Flooded roads were also reported in the Frenchman's Cove area.

A section of the Trans Canada Highway at Duncan's Brook (east of Corner Brook) was inundated to a depth of about one foot. Snow and ice had clogged the culverts through which the brook flows into the Humber River. Several cars stalled as they attempted to get through the water on the flooded section of highway. Work crews used a backhoe to remove the ice and snow from the culvert.

A spokesman for the highways division in Deer Lake stated "traffic was moving slow between Trout River and Woody Point due to washouts and high water".

In Grand Falls, the Town Engineer, also reported flooding; however he stated that "conditions were not serious and were in fact normal for this time of year".

In Windsor, catchbasins on Main Street East overflowed.

At Botwood, several basements were flooded on Water Street.

In Gander, the basement floor of the Canadian National Telegraph building was reported as having been flooded to a depth of 8-10 inches (in the order of 0.20-0.25 metres), threatening disruption of telephone service.

Magnitude: No information was published.

Damages: No estimates of the damages were presented.

● FLOOD OF JANUARY 4-5, 1977

Cause: Rain, snow, melting snow

Description:

In Corner Brook, a blocked catchbasin on Humber Road overflowed as a result of heavy runoff from a parking lot.

Magnitude:

About 0.36 inches (9.1 mm) of rain fell at Corner Brook in association with about 1.00 inch (2.5 cm) of snow and temperatures ranging from 22°F to 47°F (-5.6°C to +8.3°C).

Damages: No estimates or detailed descriptions of the damage were mentioned.

● FLOOD OF MID-JANUARY, 1977

Cause: Heavy rainfall and thaw

Description:

A newspaper account of February 14, 1977 reported that two homes in the community of Steady Brook were flooded about a month ago. Partial blame for the flooding was being placed on recent alterations to the water course to divert water away from the base of a new chair lift installation at the Marble Mountain Ski Area.

Magnitude: No information was presented.

Damages: No information was presented.

● FLOOD OF JUNE 8-10, 1977

Cause: Spring runoff, three Main Dam gates opened

Description:

On the Humber River, discharges were said to be normal but water levels were reported to be high on the Upper Humber and Bowater's had three gates open on Main Dam. Two photographs* were published showing the flooding at Steady Brook. One photo shows the water up to the front door of a house built on a slab but the water was reported as having not seeped inside. The other photo shows properties at the end of River Road partially inundated and debris on the road and some lawns.

Magnitude:

A maximum instantaneous discharge of 23,600 cfs (668 m^3/s) was recorded on the Upper Humber River near Reidville, (Station No. 02YL001) on May 26th.

Damages:

No estimates of the damages were presented.

● FLOOD OF NOVEMBER 18, 1977

Cause: Power outage causing plant shutdown

Description:

A power outage at Bowater's Mill, in Corner Brook, sent a power surge back along the transmission line to the Deer Lake Power Plant resulting in a shutdown of the generators. Since no water was flowing through the generators, the emergency gate was tripped, allowing water to flow down the old spillway into Deer Lake. The heavy spilling of water caused flooding at the intersection of Spillway Brook and the Trans Canada Highway causing traffic to back up in both directions. The Highways Department closed the highway until the water receded and an inspection of the bridge abutments was made.

Magnitude: No information was presented.

Damages:

No damage to the bridge except for the minor cleanup operation was reported as a result of the temporary flooding.

* The Western Star, Thursday, June 9, 1977, pg. 1; and, the Western Star, Saturday, June 11, 1977, pg. 2.

FLOOD OF DECEMBER 11-12, 1977

Cause: High tides and strong onshore winds

Description:

Five West Coast and one South Coast communities were subjected to severe flooding as a result of the high seas and strong winds. The communities reported as receiving damages due to the high water were Cox's Cove, Lark's Harbour, Frenchman's Cove (all in the Bay of Island), Stephenville Crossing, Parson's Pond and Petites.

In Stephenville Crossing, the problem was reported as a recurring one resulting from a combination of high tides and onshore winds. Water was reported as having come over a section of breakwater and water levels rose to about 18 inches (0.46 metres) over Pleasant Street. Five families were forced to move from their homes. One home was said to have been damaged and the Town expressed some concern about damages to the sewer system.

The problem at Cox's Cove was also reported as being a recurring one. High tides cause the brook to back up and flood low lying areas of the community where a number of houses are located.

At Parson's Pond, about 21 families were forced to leave their homes as a result of the flooding which affected homes as far as a 1/4 mile (0.4 km) inland from the sea. More than 100 people were said to be affected. The reports stated that a general store was also inundated and some homes were evacuated by boat.

At Petites, some eight wharves and a community stage were reported as being destroyed.

Magnitude:

At Parson's Pond, the flooding was reported to have occurred between the highway and the beach inundating between 1/2 and 1 square mile (1.3 to 2.6 sq. km) to a depth of 2-5 feet (0.6 - 1.5 metres). Local residents reported that the area used to flood many years ago but "had remained dry for a long time before the houses were built". High tides last year, "the first in half a century, washed away embankments allowing more seawater to flow landward this year". This flooding was said to be much worse than last years.

Damages:

No estimates of the damage were given for most communities, however, at Parson's Pond it was reported that it was likely that some foundations were weakened.

It was reported that 12 to 14 fishermen were affected by the damaged facilities at Petites and that the damage would exceed $5,000.

FLOOD OF DECEMBER 27-29, 1977

Cause:

Combination of rain and high temperatures on Christmas Day and Boxing Day melted the accumulation of snow

Description:

Flooding was reported across insular Newfoundland, resulting in disruption of transportation and inconvenience to many home owners.

Trains were halted because of washouts along the C.N.R. rail lines across the Province. C.N.R. officials said some 40 washouts occurred and reported that the main problems were between Clarenville and Port aux Basques. Some of the damaged sections were reported to be up to 200 feet (60 metres) in length. C.N.R. also reported flooding on the line between Clarenville and Bonavista. It was reported that about two days would be required to affect repairs to the lines and about 130 laid-off seasonal employees were called back for this operation. A derailment of a work train also occurred near Fishell's Cove when the embankment collapsed after being weakened by the high water.

Flooding was also reported in the Noel's Pond area as a result of debris blocking the bridges or culverts.

In Corner Brook, several roads were damaged and some houses were inundated with water and mud. Extensive damages were reported in the Massey Drive. Benoit's Cove and several other areas of the City where the drainage was not adequate. Some of the streets which sustained damage were the Old Humber Road, Riverside Drive, Barrett's Road and Maple View. Curbing and road shoulders were damaged on East Valley Road, West Valley Road, Windsor Street, Meadows and Gillams Roads. In the Riverside Drive area, tons of mud and water inundated homes on the north side of Ballam Bridge. Much of the mud flowed onto the property of Owen Legge and filled the basement apartment. Several streets in the Curling NIP (Neighbourhood Improvement Program) area were damaged. Water also overtopped the dam at the Margaret Bowater Park.

A landslide occurred at Mount Moriah which blocked the highway.

Guard rails and hydro poles along the Humber River were reported as having little support as the flooding had washed away tons of earth.

The road to Cox's Cove was closed when portions of the roadbed along a quarter mile section was reported as having slid downhill when a culvert was washed out.

East of Corner Brook, the road to Trout River was reported to be washed out, as well as, the Trans Canada Highway at Little Rapids. The TCH was reported to be inundated near Birchy Lake but was said to be "passable".

At King's Point, Green Bay, floodwaters tore up a 100-foot section of the main street rupturing a water line and isolating about 40 families. The pumphouse was also inundated leaving 700 people without water. Debris was reported to have punctured the dam as well.

At Buchans, several miles of old workings and tunnels at the ASARCO* mines were flooded to a depth of about eight feet as a result of the mild spell and rain. The flooding was reported as not having affected production since the flooded tunnels are used mainly for access and ventilation.

In Grand Falls, Main Street was closed for some time because it was submerged. Work crews were kept busy clearing debris from storm sewers that caused water to back up and flood low lying sections of streets and several basements. Some tenants were forced to move out of their flooded basement apartments on Goodyear Avenue.

In Gander, many basement apartments were flooded and some residents had to leave their living quarters.

Six miles (9.7 km) east of Gander, Soulis Brook overflowed a 200-foot (60 metre) section of the TCH washing out the shoulders and undermining some pavement closing it to traffic for a period until waters receded.

The TCH was also reported to have been flooded in the Port Blandford area by Southwest Brook causing problems for vehicular traffic. The water was reported to be 10 inches (0.25 metres) deep.

On the Bonavista Peninsula, numerous roads were said to have been inundated and/or washed out and were impassable to all but large trucks and four wheel drive vehicles. Two of these areas were at Lethbridge and Lockers Brook (weakened bridge).

* ASARCO - American Smelting and Refining Company Ltd.

Other gravel roads in the Province were washed out and in some cases communities were isolated. Some of these roads were in the Buchans area and the Harbour Breton Road between Pool's Cove and St. Jacques.

In St. John's, basements were flooded and roads were inundated and some washed out.

The Waterford River overflowed its banks inundating sections of Bowring Park and the Kinsman Park on Squires Avenue. On the southside of Squires Avenue the flood waters were reported to have eroded several feet of land to the rear of the homes. Flooding was also reported around Quidi Vidi Lake and in the Higgins Line area. Houses in the newly developed Spratt Place, east of Canada Drive, experienced severe basement flooding. Problems were also experienced in the Highland Park Subdivision and on Southside Road as a result of clogged storm drains. The basement of the C.N.R. customer station and express building as well as the diesel building, tracks and parking lot on Water Street West were inundated. The problem was suspected to be related to the trunk sewer.

Magnitude:

At Corner Brook, 1.25 inches (31.8 mm) of rain and temperatures in the order of $11^{\circ}C$ to $13^{\circ}C$ ($52^{\circ}F$ to $55^{\circ}F$) were recorded. At Buchans, 1.27 inches (32.3 mm) of rain was recorded on the 27th. A rainfall of 1.80 inches (45.7 mm) was recorded at St. John's with temperatures in the order of $10^{\circ}C$ ($50^{\circ}F$).

Brooks and ponds were reported to be far above normal across the Province.

Residents of Riverside Drive, Corner Brook, said "problems had never occurred in that area until about three years ago when changes were made to the gravel pit on the hill behind their homes. Prior to this, the water from the pit normally flowed through a brook into the Humber River.

Damages:

In Corner Brook, damages to city streets were estimated at $100,000.

Newspaper accounts stated that highway damages could reach several hundred thousand dollars. No other estimates of damages were presented.

FLOOD OF JANUARY 14-16, 1978

Cause:

High water and rafting ice as a result of rain, snow and mild temperatures

Description:

Rain, snow and high temperatures combined to cause high water and ice rafting on the West Coast.

A 500-foot (152 metres) section of the Grand Bay Bridge on the Codroy River was taken out by high water and rafting ice. It also destroyed a 800-foot (244 metres) section of telephone cable which was attached to the structure. The loss of the structure resulted in isolation for some 1,500 residents of Codroy, Millville, Cape Anguille and O'Reagan's. Telephone services were also cut. A temporary bridge was erected five miles (8 km) downstream of the destroyed bridge and opened to traffic in April. During the interim, mail and supplies were transported across the Codroy River to the communities by boat, snowmobile and aircraft.

In Corner Brook, city work crews were kept busy repairing several city streets. Parts of Boland's Avenue and Conway Road in Curling and the shoulders along Maple Valley Road suffered most of the damage.

At Gillams, on the north shore of the Bay of Island, blocked culverts caused minor flooding of the highway.

At Little Rapids, 10 miles (16 km) east of Corner Brook, blocked culverts also resulted in overflow onto the Trans Canada Highway.

On the Bay d'Espoir Highway, culverts were unable to cope with the high flows resulting in flooding and washouts. The worst washout was reported to be at the head of Bay d'Espoir, where a section of pavement collapsed leaving a gap of about 30 feet (9 metres) wide and nine feet (2.7 metres) deep, halting traffic for 36 hours and isolating the communities of St. Alban's, St. Veronica's and St. Joseph's Cove.

Magnitude:

Bowater Newfoundland Ltd. reported a high of 13°C (55°F) and 17 millimetres of rain (0.07 inches) and about 12 centimetres (4 inches) of snow during this period.

Damages:

It was reported that the temporary crossing on the Grand Codroy River would cost in the order of $350,000. Transportation Minister, James Morgan said "a new permanent bridge will cost in the vicinity of $3 to $4 million".* Mr. Morgan also stated "storms this winter have done damage estimated between $5 million and $6 million to roads and bridges in the Province."

FLOOD OF MAY 17-20, 1978

Cause: Spring freshet

Description:

A spell of good weather had risen levels in the Humber River to overflowing at Steady Brook. A photo* was published showing Forest Drive where cars were parked at a barrier due to the flooding. It was reported that at least one resident had to use a boat to reach his home. Other properties were reported to be inundated.

Magnitude:

The Mayor of Steady Brook reported that the river had risen about six inches per day (15 cm per day) since May 13th. Bowater's Newfoundland Ltd. were reported as not having spilled water from Main Dam.

On the Humber River near Reidville, (Station No. 02YL001), a maximum daily discharge of 23,800 cfs (674 m^3/s) was recorded on the 20th with the maximum instantaneous discharge of 24,200 cfs (685 m^3/s) occurring on the same day.

Damages: No estimates of the damages or descriptions were presented.

* The Evening Telegram, January 17, 1978, pg. 3
The Western Star, May 19, 1978, pg. 1

FLOOD OF MARCH 6-9, 1979

Cause: Rain, melting snow, blockage of drainage systems by ice and debris

Description:

A four-day period of spring-like weather caused flooding and some washouts in central and western Newfoundland.

Both the Robinson's and Baracnois Rivers overflowed their banks when ice collected at the bridges resulting in flooded roadways.

In Stephenville, the high flows and ice in Blanche Brook undercut footings of four 20-foot (6 metres) sections of a retaining wall causing them to collapse. Town work crews were kept busy in an attempt to fill the breach with boulders and concrete to reduce the possibility of the Labatt Brewery complex being flooded.

In the Corner Brook area, some flooding of basements and minor road damages were reported throughout the city. Some flooding was reported at the intersection of Dave's Road and Primrose Avenue and on the highway between Brake's Cove and Riverside Drive. Corner Brook Stream rose to less than two feet from the bottom of the bridge on Main Street and backed up into the sewer system through an outfall.

In the Roddickton area, on the Northern Peninsula, blockage of culverts and ditches in several places caused overflow onto the roads.

The Baie Verte Peninsula also experienced some flooding of a minor nature and a few washouts.

In Central Newfoundland, flooded streets and basements were reported in most of the towns. A section of the Bay d'Espoir highway was inundated about 25 miles (40 km) south of Bishop's Falls at a point where Rattling Brook is closest to the highway. This resulted in a short closure of the highway.

Magnitude:

Total precipitation in the order of 64 millimetres (about 2.5 inches) was reported at Corner Brook during the period. Total precipitation for March at Corner Brook was 186.3 millimetres (7.33 inches) of which 142.1 millimetres (5.59 inches) was in the form of rain. The month was described as the wettest since 1938.

The flooded section of the Bay d'Espoir highway was reported as being flooded for the first time in the road's 12 year history.

Damages:

At Stephenville, the Town Manager was reported to have said that "the complete and permanent repair to the damaged cribbing is expected to be between $100,000 and $120,000". It was reported that Alexander Engineering was contracted by the Town to carry out permanent repairs at the site. The permanent structure was reported to be an interlocking steel sheet pile facewall.

No other estimates of the damages were presented. Some photographs* were published for Stephenville and the Corner Brook area.

* The Western Star, March 7, 1979, pg. 1; The Western Star, March 8, 1979, pg. 1 & 9; The Western Star, March 9, 1979, pg. 1; and the Western Star, March 13, 1979, pg. 2.

● FLOOD OF JULY 17-20, 1979

Cause: Heavy rainfall

Description:

In the Stephenville area, Blanche Brook, swollen by heavy rains, carried trees and other debris downstream which collected and jammed at the Hansen Highway Bridge. The section of Hansen Highway from Brook Street to the intersection of Queen Street was closed on the morning of the 18th. Transportation Department employees were kept busy attempting to keep debris from floating downstream causing further damage. The center pier of the bridge had been moved by the force of the debris and water. The structure collapsed around mid-day on the 19th.

Debris also was reported to have piled up where the brook runs between Carolina Avenue and Main Street but no damage resulted. Many Stephenville residents had flooded basements and the Harmon Convenience Store on Carolina Avenue foundered when its basement gave way.

In Corner Brook, a few minor washouts had occurred but no serious flooding or damages were reported within the city limits.

Magnitude:

The technical services department of Bowater Newfoundland Ltd. recorded 1.66 inches (42.2 mm) of rainfall from 1:30 p.m. on the 17th until 8:00 a.m. on the 18th.

Damages:

No estimate of the damage was reported for the Harmon Convenience Store; however, it was reported that they were open for business on the 19th. Hines Esso on the Hansen Highway near the collapsed bridge reported extensive losses in business and as a result was required to lay-off employees. No estimates for a replacement bridge were presented. The original bridge across Blanche Brook was built by the United States military in the mid-1950's. The newspaper accounts reported that it took about three weeks to get a Bailey Bridge in place. Some photos* of the structure were published (before and after the collapse).

● FLOOD OF NOVEMBER 4-7, 1979

Cause: Two days of heavy rain

Description:

The two days of heavy rain on the West Coast had caused flooding and rockslides in several locations, necessitating the closure or supervision of the highways by the R.C.M.P. and Department of Transportation personnel.

One rock slide had occurred on the Trans Canada Highway at Gallant's Hill near George's Lake [30 miles (48 km) west of Corner Brook] blocking one lane of the highway.

Near Portland Creek, [five miles (8 km) north of Parson's Pond], about 150 feet (45 metres) of the Great Northern Peninsula highway was reported to be under about 1.5 feet (0.5 metres) of water resulting in closure of the road.

At Hawkes Bay, south of Port Saunders, the big East River, swollen by the heavy rains, eroded the material from around the abutments of the highway bridge. The bridge was reported as not being in danger and the abutments have since been reinforced.

Magnitude:

The St. John's Weather Office stated that about 3.2 inches (91 mm) of rain fell in Deer Lake over the weekend, with similar amounts recorded in Corner Brook and Stephenville.

Damages: No estimates of the damages were presented.

* The Western Star, July 18, 1979, pg. 1; The Western Star, July 14, 1979, pg. 3; The Western Star, July 20, 1979, pg. 1

- <u>FLOOD OF AUGUST 10-11, 1980</u>

<u>Cause</u>: Heavy rainfall

<u>Description</u>:

A heavy rain storm resulted in flooding along Steady Brook and the Humber River. While no structures were affected, many properties were noted to be partially under water. The main spillway at the Bowater Power plant was operating.

<u>Damages</u>:

No estimates of damages were presented.

- <u>FLOOD OF FEBRUARY 3-4, 1981</u>

<u>Cause</u>: Heavy rain and melting snow and ice.

<u>Description</u>:

In Corner Brook, heavy rains and melting snow created blockages at culverts and bridges in the City. The Burgeo Road was reported to be inundated, while washouts were also reported at 20-25 other locations.

Damages:

No estimates were presented regarding damages.

- <u>FLOOD OF FEBRUARY 12-13, 1981</u>

<u>Cause</u>: Rain

<u>Description</u>:

Minor flooding was reported in the City of Corner Brook.

<u>Damages</u>:

No estimates were given.

- **FLOOD OF MAY 8-16, 1981**

Cause: Spring rains

Description:

Heavy spring rains. The main spillway gates were opened at Bowater Power plant, resulting in properties being inundated in Nicolsville and Steady Brook. Localized flooding was also noted in other communities in the area.

Damages:

No estimates of damages were given.

- **FLOOD OF MAY 4-10, 1982**

Cause: Spring runoff

Description:

Melting snow and heavy rainfall resulted in an average increase in flow depth of 7.3 m on the Humber River in the area downstream of Deer Lake. Some property flooding was recorded in the Community of Steady Brook.

Damages:

No damage estimates were provided.

- **FLOOD OF APRIL 20-MAY 10, 1983**

Cause: Heavy rain and snowmelt

Description:

Minor flooding was reported in the Steady Brook area and along the Humber River downstream of Deer Lake.

Damages:

No estimates of damages were noted.

- **FLOOD OF AUGUST 10-19, 1983**

Cause: Heavy rainfall

Description:

A heavy rain storm combined with high flow releases from Grand Lake resulted in flooding along Steady Brook and the Humber River. While no structures were affected, many properties were noted to be partially under water.

Damages:

No estimates were given.

APPENDIX B

DETERMINISTIC HYDROLOGIC ANALYSES

HUMBER RIVER

APPENDIX B

DETERMINISTIC HYDROLOGIC ANALYSES
- HUMBER RIVER

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B.1 BACKGROUND FOR THE SSARR MODEL

B.1.1 General

The SSARR model was initially developed beginning in 1956 in order to meet the needs of the U.S. Corps of Engineers in analysing and forecasting the hydrologic and reservoir systems in the North Pacific Division area of the Corps of Engineers. (This area comprises the Columbia River System in the U.S. and Canada, Coastal rivers in Western Oregon and Washington, and the State of Alaska.) Since that time, the SSARR Model has been updated and widely used in many applications throughout the world.

The functioning and the method of using the SSARR program are explained in detail, and with numerous examples, in the instruction manual provided by the U.S. Army Corps of Engineers, entitled, "Program Description and User Manual for SSARR - Program 724-K5-G0010 - September 1972". Information and text in the following sections is summarized from the users manual (57) and a paper by Rockwood (45) and modified as required for the model application on the Humber River watershed.

The SSARR program carries out the following three distinct functions:

1) It calculates the natural discharges for each of the elementary sub-basins within a subwatershed, for which the hydrological characteristics are relatively homogeneous. A detailed process for accomplishing the calculations is illustrated on Figure 3.5 in the main text.

2) It calculates the natural discharges as well as routing and adding hydrographs through river reaches and natural lakes, up to the exit point of the entire watershed.

3) It calculates the variations in discharge caused by the regulation of artificial reservoirs for hydroelectric generation or flood control operations.

B.1.2 Hydrologic Principles Utilized in the SSARR Model

The matter of hydrologic representation of runoff processes in a watershed model is highly subjective. No two hydrologists look at watershed runoff processes in exactly the same light. Nevertheless, there are some underlying principles that must be preserved in the formulation of a deterministic hydrologic watershed model. These include the logical accounting of each of the basic elements in the hydrologic cycle (rainfall, snowmelt, interception, soil moisture, interflow, groundwater recharge, evapotranspiration, and the various time delay processes), together with the ability to maintain continuity of each of the processes and to represent each by objective functions, which relate them to observed hydrometeorological parameters. The differences between model representations are in the various complexities that are incorporated to represent a particular process.

The streamflow routing functions contained in the SSARR model provide a generalized system for solving the unsteady flow conditions in river channels where streamflow and channel storage effects are related, either at one point or at a series of points along a river system. In principle, the method involves a direct solution of a storage-flow relationship involved in maintaining continuity of streamflow and storage in each element of the river, through use of a procedure which solves the relationships in finite elements of time and river reach. This involves a completely general and flexible method for solving the flow routing equations which can be applied in many waysdepending upon the type of basic data available, and the conditions of the river system with respect to backwater effects from variable stage discharge effects, such as tidal fluctuations or reservoir fluctuations.

The SSARR model was designed to include the effects of reservoirs or other water control elements within the streamflow simulation process. Reservoirs may be described for any location in a river system, whereby inflows are defined from single or multiple tributaries, derived either from watershed simulation for river basins upstream, or from specified flows as a time series, or combination of the two.

Outflows from reservoirs are determined on the basis of specified operating conditions. The processing of the hydraulic conditions at reservoirs is performed sequentially with all other elements in the river basin simulation, in order to provide a once-through process for the system as a whole, including all natural and man-caused effects.

B.1.3 Hydrologic Input Parameters

This section defines and discusses hydrologic input parameters in general terms. Specific data input and parameter tables for various sub-watersheds of the Humber River are presented and discussed in Section B.2.

Net precipitation input (WP) - The average net precipitation value for a drainage basin or hydrologic unit is derived as a weighted daily or period amount from a series of individually reported or observed values. The weighting is generalized, and each station may be assigned its individual weighting value. The station weights may be determined on the basis of previously derived relationships between station and basin normal annual or normal seasonal precipitation; or the weighting values may be derived on an areal basis using the Thiessen Polygon or other similar technique.

The total precipitation on a watershed is computed from period precipitation amounts at one or more stations as follows:

$$WP_n = \frac{(P_1 * W_1 + P_2 * W_2 + ---- P_n * W_n)}{n} \quad (B.1)$$

Where P_1, P_2 --- P_n = Period precipitation amounts at Stations 1, 2, ...n respectively, in inches

W_1, W_2 --- W_n = Weights applied to the station precipitation

n = Total number of stations; a maximum of 30 stations

WP_n = Weighted period Net Watershed Precipitation inches

Basically, there are two general options for the calculation of snowmelt, namely: (1) the temperature index method; and (2) the use of generalized equations of snowmelt as determined by the thermal budget of heat loss and gain to the snowpack. The temperature index method is usually used for daily forecasting applications, whereas the detailed energy budget approach is more appropriate for design flood calculations when extensive watershed data is available. By either method, daily or period values of effective snowmelt runoff values are computed as a time series, as a function of appropriate meteorological values.

The second equation has the advantage of being more precise and detailed, but also has the disadvantage of requiring some data which is available at only a very limited number of stations. Examples of such data are;

- Difference between air temperature measured at 10 feet above the snow surface and snow surface temperature in degrees Fahrenheit (°F). The snow surface temperature is assumed to be 32°F
- Difference between the dewpoint temperature measured 10 feet above the surface of the snow and the temperature of the snow surface (32°F)

- Above the surface of the snow and the temperature of the snow surface (32°F)
- Wind velocity at 50 feet above the snow, in miles per hour
- Solar radiation on a horizontal surface, in langleys
- Average snow surface albedo
- Basin shortwave radiation melt factor
- Average forest canopy cover
- Convection-condensation melt factor

A detailed discussion of the various snowmelt options and their application to the Humber River is presented in Section B.2.

In addition to the two options of snowmelt equations available to the user, two additional options for the simulation of snow cover are also available;

i) Snow Cover Depletion
ii) Snow Band Option.

With the snow cover depletion option, snow cover is diminished in thickness, and in surface area during the snowmelt season. However, two disadvantages of Option i) are that snowfall during the calculation period is not added to the existing snow cover and secondly, it is necessary to enter at the beginning of the period of calculation, the quantity of snow which will effectively run off after the melt. However, this option has been shown to be useful in the flood forecasting model and may be useful in this context at a later date. The snow band option allows the user to separate the subwatershed into different "bands" according to elevation with the temperatures being lowered systematically with increased elevations.

Soil Moisture Index (SMI) - The soil moisture index used in the SSARR model represents a weighted mean basin value of the water stored in the soil mantle that can be removed by plant roots through transpiration and also by natural evaporation. It does not include the part of the soil moisture content that exists at the permanent wilting point. The computation of the changes of soil moisture index values are based on the increases resulting from rainfall or snowmelt, and the decreases by the evapotranspiration process. Increases in the soil moisture index values result in a "permanent" loss to runoff in the water balance for the basin as a whole. The upper limit of the soil moisture index is considered to be its field capacity, which is equivalent to the capillary moisture holding capacity, or the total amount of water which can be held under the force of gravity under natural conditions. Thus, the soil moisture index is a continuously varying parameter that may range from a value of zero when the soil moisture has been reduced to the "wilting point" by the evapotranspiration process, to a maximum value represented by the field capacity of the soil for the basin as a whole. Section C.2 presents a detailed discussion of SMI relationships applied to the Humber River watershed.

Evapotranspiration Index (ETI) - The evapotranspiration index (ETI) used in the SSARR model is a weighted basin mean daily value of the water lost to the atmosphere by the evapotranspiration process. Transpiration, soil evaporation and evaporation of free water from the plant or forest cover are considered to act together to produce the losses by evapotranspiration. Since the evapotranspiration loss is physically the result of change of state of water from the liquid to vapour phase, the process of evapotranspiration requires energy for the transformation, and is, therefore, dependent upon a source of energy from the atmosphere.

In the model, the potential evapotranspiration may be computed by either of two basic methods, namely: (i) mean daily amounts based on mean monthly values which are typical for a given hydrologic regime; or (ii) mean daily air temperature or dew point temperatures, or daily solar radiation amounts. The daily computed amounts are adjusted in either case by a function to account for daily or period rainfall which would reduce the potential rate of evapotranspiration. In the application of the SSARR model, the mean daily amounts computed through use of mean monthly amounts are most commonly used.

Section B.2 presents a detailed discussion of the Evapotranspiration rates applied to the Humber River.

Baseflow Infiltration Index (BII) - The Baseflow Infiltration Index used in the SSARR watershed model provides a means for computing the relative proportion of the water available in the surface layers of the soil mantle that enters the groundwater aquifers as deep percolation. Under the principle of "generated runoff", as defined above, all water which is not lost to the atmosphere by evapotranspiration, or the permanent loss by soil moisture increase, is available to runoff as a time delay function. Conceptually, the model considers the time delay to occur in three zones, namely surface, sub-surface and baseflow. The long time delay caused by base flow infiltration represents that portion of the water which is in transitory storage for several months (or possibly years under certain circumstances).

Section B.2 presents a detailed discussion of the BII relationships applied to the Humber River.

Surface - Sub-surface Flow Index S-SS) - In the model, the surface-sub-surface (S-SS) flow separation index deals with the water excess which is generated from the residual after soil moisture and transpiration losses and base flow infiltration have been satisfied. Normally, the "direct" runoff is considered to be the result of the percolation of "free" water through the upper layers of the soil mantle (say, in the zone up to a maximum of depth of 50 cm below the ground surface) termed as sub-surface flow. When the water input rate exceeds the capacity of the sub-surface zone to transmit water under gravitational force, the residual water excess amount is considered to occur directly on the ground surface or the upper few centimetres of the soil mantle. The surface-sub-surface (S-SS) flow separation is a means for defining the relative portion of the direct runoff that contributes to each portion, as a function of input rate.

The S-SS function is usually specified as a nonlinear function, whereby the lower rates of input provide water excess primarily in sub-surface zone, while high input rates are predominantly on the surface runoff. The time delay functions for routing surface and sub-surface flow are specified to represent the difference in storage times for each of the two zones. Section B.2 presents a detailed discussion of the S-SS relationships applied to the Humber River.

Watershed outflow transformation by polyphase routing for each flow component input (NP, TS) - The water excess values computed for each time period in each of the three flow components (surface, sub-surface and baseflow) must be transformed from values computed as input rates to time-distributed values of streamflow. In the SSARR model, this transformation is accomplished by polyphase routing, whereby the input rates expressed as cm per period are converted to equivalent values of steady-state outflow, expressed as cubic metres per second for the particular drainage area. The routing is performed through the use of the flow continuity equations set forth in the SSARR users manual (57).

The use of polyphase routing for this type of transformation has several advantages for computerized simulation of streamflow from watersheds. These include: (i) simplicity of computation; (ii) ease of application in trial and error reconstitution studies for determining basin runoff characteristics; (iii) the relatively small amount of information required to store in the computer, in order to represent the basin runoff characteristics; (iv) the completely flexible means for representing time delays to runoff either for short term flood runoff on relatively small tributaries, or for long-term base flow on groundwater discharge for large river system; (v) the convenient means for preserving the continuity of flow at any specified point in time, for "stop action" or "instant replay" capabilities, particularly in its use for day-to-day streamflow forecasting; (vi) the flexibility of providing virtually any desired shape of runoff characteristics (as, for example, a unit distribution of known characteristics), (vii) the assured preservation of continuity of flow for any computed runoff excess and (viii) the ability to represent non-linear response for runoff from a watershed. Section B.2

presents a summary of the relevant polyphase routing parameters applied to the Humber River.

B.1.4 Methodology for Model Calibration and Validation

In general, the optimization of the various parameters is normally accomplished by trial-and-error reconstitution studies of historical streamflow data. Such studies are generally performed for several years of historical data, whereby the various parameters are tested to achieve the best fit of computed and observed streamflow. It is normally assumed that the physical factors affecting runoff are non-changing over a period of years, so that the parameters and functions used in the model are fixed as a given set of values for the entire study period. The degree of fit between computed and historical streamflow is determined either visually by inspection of graphical plots of the data or by graphical or statistical methods. The principal objective is to achieve consistency over a wide range of hydrologic conditions to eliminate bias between high and low periods of streamflow and to achieve relatively uniform consistency for the years being studied.

The overall water balance for particular study areas should represent as closely as possible the known or expected values of precipitation, evapotranspiration, soil moisture and groundwater condition that are characteristic for the climatological and hydrological regime of the area. The main objective of reconstitution studies is first to achieve a water balance by adjusting the following parameters: (i) precipitation weighting for estimating basin precipitation from index station values; (ii) SMI function, in terms of total soil moisture index values and the shape of the SMI function; (iii) ETI values, based on observed or estimated amounts which properly reflect the seasonal or daily variation; and (iv) BII function, representing the portion of water input which contributes to base flow. When the overall water balance is achieved, the refinements in timing can be taken into account by adjusting the polyphase routing parameters for each component's flow (surface, subsurface, and base flow), and by adjusting the S-SS flow separation function.

The simulated flow series obtained in this manner is compared with the measured hydrograph at the gauging station and the difference between the two are interpreted in the following fashion:

a) If the discharge calculated is systematically higher (or lower) than the measured discharge and the difference more pronounced as a function of time, the estimate for evaporation is systematically too low (or too high). It is necessary then to reduce (or increase) the slope of the curve SMI;

b) If the slope of the calculated hydrograph recession curve is greater than that of the measured hydrograph, the base flow is too low. It is necessary then to reduce the slope of the curve BII;

c) If the maximum reconstituted discharge is clearly greater than the recorded maximum discharges and if the runoff volumes are little different (that is to say, if the curve SMI is good), the surface runoff is too large with respect to the sub-surface flow. It is necessary then to reduce the slope of the curve S-SS;

d) If the calculated discharges are clearly greater than the measured discharge following the first light rainfall in the period, the initial value of SMI must be diminished;

e) If the shape of the calculated hydrograph, following the first light rainfall, is clearly sharper than the shape of the measured hydrograph, the maximum for the curve BII is too low.

With respect to calibrating the model to snowmelt periods, the differences between calculated and observed flows are interpreted as follows:

a) If the upward slope of the synthetic hydrograph is too mild, the rate of melt must be increased;

b) If the calculated flood begins later than the measured flood, the base temperature must be decreased;

c) If the volume of the flood is too large, it is necessary to modify the weighting of the snow course stations in a fashion to decrease the initial snow thickness;

While the above description is only a very brief description of the methods used for adjusting and optimizing parameters, it provides the principles by which the model is used in undertaking streamflow simulations. When used in the forecasting mode over a number of years, model re-calibration should be frequently undertaken.

B.1.5 Preparation of Input Data

Input data to the SSARR program are prepared on specialized "card image" formats. A specific group of card columns on a specific card format is set aside for each of the data words required by the program. Within the group of columns (called a "field"), the data word must be properly positioned to match the scaling expected by the program. (Additional details are provided in the Users Manual (57).)

For instance, a river station number may be a maximum of nine decimal digits in length. The "6D" card format must contain a river station number in card columns 5-13, right adjusted (The "6D" refers to the identifying punches in card columns one and two, called the "card code"). Station number 10000 would be entered in this field as "000010000". (The zeroes need not be punched. Blank card columns are assumed to be zero by the program in all numeric fields.)

In most card formats, the decimal point position in fields designed for fractional values is fixed by the program. For instance, an elevation of 2.35 feet would be entered in the first elevation field of the "6D" card format (card columns 25-31) as "0000235" (the decimal point must not be input into the card. It's position is fixed by the program.)

A set of data preparation forms, upon which data can be recorded, has been included in the SSARR manual. These forms relieve the user from the need to memorize the card field locations for the various data words. Once the cards have been input with the required data, they must be placed in a specified order for processing by the SSARR program.

The computer program requires that input cards be in a precise sequence. Many out-of-sequence conditions can be detected by the program but some cannot, and computations will proceed with erroneous data. The following major groups of cards must be in sequence, and the cards within each group have a specific sequence which is required.

The card groupings are as follows:

1. Run control ("J" card)
2. Tables, and Hydromet and River Station characteristics ("C" cards)
3. Configuration control ("P" cards)
4. Time control ("T" cards)
5. "H" Card - Optional
6. Initial conditions specification and time dependent data (card codes 1, 2, 3, 4, 5 and 6)
7. Plot and Optional output control cards (PL, PQ, PE, PS, PM, PH, PR, PT, and X formats)
8. End of run control (END card)

The "J" card is the first card of a user's run deck. There can only be one "J" card at the beginning of the deck.

Table B.1 presents a summary of the organization of the SSARR input data file and a brief description of specific card groups for the more frequently used cards.

B.1.6 Application to Flood Forecasting

Applying the SSARR model to a watershed for the purposes of flood forecasting is similar to its use in the long-term simulation mode. However, there are several unique aspects of flood forecasting which require different model capabilities and operating procedures.

The usefulness and practicality of a flood forecasting model is dependent on both the accuracy and timing of a given forecast prediction. The value of a perfect forecast significantly reduces with time until its value is near zero at the time of the event. Therefore, an important feature of a flood forecasting system is the ability to minimize the time of forecast preparation and maximize the warning time.

In a flood forecasting mode, the computations are restarted daily or more frequently under rapidly changing conditions. This fact places a great importance on the model to compensate for the effects of initial conditions and to adjust the antecedent computations to the observed initial conditions.

On a current basis, the data available to evaluate hydrologic conditions in the watershed are at a minimum. Therefore, the model must minimize the effect of a deviation due to use of incomplete and inaccurate precipitation, runoff, and temperature data. As the runoff computation is extended into the future, the hydrologic input is composed of forecast values of meteorologic conditions which are subject to known limitations. This places great responsibility on the forecaster and the model to be realistic about the compromise between theoretically desirable complexity and computational detail in light of the validity of the hydrologic data available as input.

Since the Humber River system includes reservoirs which exert significant control over the river flows, another level of complexity is added to the forecasting problem and the resulting model requirements. The interdependence of the forecast of runoff and the regulation of the reservoir makes manual specification of reservoir operations to the model impractical, if not impossible. Therefore, an ideal model should have the ability to "regulate" reservoirs automatically on the basis of criteria for reservoir elevation and outflow as well as discharges and stages at points downstream from the reservoir. Justification for decisions in design of the model for operational forecasting, in the choice of the options used, and in methods used in applying the model will generally be on the basis of one or more of the above unique aspects of operational river forecasting.

Additional details for operating the SSARR Model in a flood forecasting mode can be found in the SSARR manual (57).

Section B.2.5 provides a summary of the additional data requirements for applying the SSARR model to the Humber River.

B.2 Application of the SSARR Model to the Humber River

The objective of applying the SSARR model to the Humber River is to produce 1:20 year and 1:100 year recurrence interval flow rates for the study reach. In order to attain that objective, it was necessary to utilize as much historic data (hydrometric, meteorologic and reservoir regulation data) as is practical. Physical characteristics of the watershed (drainage areas, reservoir volumes, etc.) were also obtained from a number of sources including available topographic and soils maps and physical surveys. The model parameters were then calibrated and validated to historic data to ensure that an accurate representation of the hydrologic response of the Humber River watershed has been obtained.

B.2.1 Meteorologic Input Data

As discussed in Section 3.0 of the main text, there are a number of meteorologic stations situated in or in close proximity to the Humber River watershed. However, a number of stations were eliminated for the following reasons:

- too much missing data
- period of record imcompatible with period of record for the hydrometric stations
- zone of influence of the meteorologic station outside of the drainage basin (based on Thiessen Polygons)

The stations in close proximity to the watershed were initially selected by Thiessen Polygons, as were initial weighting factors for the individual subwatersheds (see Figure B.1). The stations selected for application in this study are as follows:

- Badger
- Buchans
- Burnt Pond
- Corner Brook
- Deer Lake
- Rocky Harbour
- Stephenville

However, the Badger meteorologic station is equipped with an automatic gauge which has not produced daily precipitation amounts since 1973. Furthermore, discussions with staff at Atmospheric Environment Service (Ms. A. Hoeller) indicated that the available data for this station is somewhat questionable and as such, should be used with extreme caution. Therefore, the Badger meteorologic data was not used for the purposes of hydrologic model calibration and validation.

The overall effect of neglecting the Badger meteorologic data is assumed to be insignificant as it is located a considerable distance from the watershed and as such, only influences the Hinds Brook and Sheffield Brook subwatersheds to a limited degree.

The SSARR Hydrologic Model requires that all meteorologic stations be referenced by an identifying number. The reference number for meteorologic stations must be 4 digits in length and was selected by assigning the last 4 digits from the number used by Atmospheric Environment Service. In some cases, more than one meteorologic station at the same location was combined to yield a longer period of record for that location. The numbers assigned to the various meteorologic stations are as follows:

Buchans	0700
Burnt Pond	0812
Corner Brook	1300
Deer Lake	1500
Rocky Harbour	3096
Stephenville A	3800

As previously mentioned, initial weighting factors were determined by Thiessen polygons. However, most of these stations are situated in communities located near the sea and are, therefore, at relatively low elevations. As such, modifications to the precipitation weighting factors were undertaken based on a review of published maps (27, 49) which account for variations in precipitation and runoff amounts for the highland areas. Temperature weighting factors were not modified to account for variations in subwatershed elevations as this is done automatically by the SSARR Model (see Section B.1) by utilizing a temperature/elevation lapse rate. Tables B.2 to B.12 present the precipitation weighting coefficients used for the subwatersheds modelled in the Humber River model.

B.2.2 Hydrologic Parameters

As previously discussed, the SSARR Model is basically made up of 3 main groups of cards which perform different functions. Most of the hydrologic parameters are defined within the permanent characteristics of the model which include the CT, CB, C3, CR, CL, CC, C1 and P cards. The hydrologic parameters, such as the characteristic tables (S-SS, BII, SMI, etc.) and the polyphase routing parameters, are determined during the model calibration stage . However, a number of parameters such as drainage areas and altitude-area relationships were calculated from existing 1:50,000 scale mapping. The calculated hydrologic parameters are presented in Tables B.2 to B.12 for the subwatersheds modelled by the SSARR model for the Humber River.

Due to the size and hydrometeorologic characteristics of the Humber River watershed, together with a review of available hydrometric data, flooding conditions are generally a result of spring snowmelt conditions.

For application of the SSARR model to the Humber River, the temperature index snowmelt option was selected for use in this study. The temperature index equation (see Section B.1.3) uses readily available data (mean daily temperature and precipitation) and also offers a precision and detail acceptable for the needs and scope of this study.

In conjunction with the temperature index method, the elevation band options were also selected for use. The elevation band option was selected as it represents the only practical technique for ensuring that precipitation falling as snow is systematically added to the accumulated snowpack, and the precision obtained with this option is about the same as the snow cover depletion method (46) and because freshly fallen snow is automatically added to the snow cover.

For application of the SSARR model to the Steady Brook watershed, the mean daily evapotranspiration amounts were based on mean monthly values. The mean monthly evapotranspiration amounts were obtained from isohyetal maps prepared by A.E.S. (60), and ranged between 0.01 in/day (.25 mm/day) and 0.13 in/day (3.3 mm/day) with an average of 0.05 in/day (1.4 mm/day). The daily computed amounts were adjusted as per the SSARR manual by a function to account for daily rainfall which would reduce potential evapotranspiration rates.

B.2.3 **Model Calibration and Validation**

i) General

The ultimate goal of any model calibration/validation is to ensure that the model accurately simulates the hydrologic response of a watershed and produces realistic flow estimates at a given location. Utilizing the available meteorologic and hydrometric data, calibration of the SSARR model was accomplished as follows:

- calibrate all subwatersheds for which sufficient hydrometric data exists
- calibrate all ungauged subwatersheds draining into Grand Lake by utilizing historic water level data available for Grand Lake
- transfer hydrologic parameters from gauged subwatersheds to ungauged subwatersheds located downstream of Grand Lake by comparing physiographic parameters
- verify results of the calibrated model at the study area (downstream of Deer Lake) by comparison to discharges recorded at a short term hydrometric gauge (02YL003) and to historic water levels recorded in Deer Lake.

The calibration and validation of the model was accomplished by carrying out a number of steps in the following order:

- determination of sub-watershed physical characteristics such as area and elevation/area relationships
- determination of routing parameters for the individual subbasins
- determination of monthly evaporation rates and meteorologic weighting factors
- determination of the runoff parameters by simulating summer/autumn flow series
- determination of the snowmelt parameters by simulating winter/spring flow series
- verification of the validity of the parameters by independent simulation of additional hydrologic flow series.

It is advantageous to begin initial calibration simulations on a summer/fall flow series for the following reasons:

- the runoff conditions are independent of snowmelt
- it is relatively easy to veryify the weighting of meteorologic stations
- the natural hydrograph shape during this period is usually more representative of the subwatershed unit hydrograph shape due to short nature of summer/fall runoff events

During the continuous simulation of a summer/fall flow series, the discharge is a function of:

- measured rainfall at applicable meteorologic stations and assigned precipitation weighting factors
- initial antecedent conditions of SMI and BII
- the estimated curves for SMI, BII and S-SS
- the routing coefficients NP and TS determined for each subwatershed.

Once the SSARR model yielded good continuous simulation results for a summer/fall flow series, all previously computed parameters are used in the model, and a winter/spring flow series was simulated to determine the various snowmelt parameters. At this stage, the only parameters for which estimates must be used are:

- rain freeze temperature
- base temperature
- lapse rate
- melt rate (for degree day method)

Calibration simulations were undertaken for the 5 gauged subwatersheds by simulating a time series which includes a complete summer/fall/winter/spring cycle. This time series was selected for the following reasons:

- antecedent initial conditions during dry weather periods (July) are more easily estimated
- early winter (December) snowfall is accumulated for melt during the next spring
- antecedent conditions prior to snowfall are calculated by model.

Additional flow series were simulated for split-sample validation purposes to ensure that the model accurately simulates the hydrologic response of the gauged subcatchments within the Humber River watershed. In this case, an additional spring/summer/fall/winter period of meteorologic data was simulated with the computed hydrographs compared to those observed at the gauge location. It was evident from the validation simulations that a good level of accuracy was achieved.

In summary, a total of approximately 90 months of simulated flows was undertaken for each gauged subwatershed. Figures B.2 to B.6 present a comparison of typical calibration and validation spring freshet observed versus computed hydrographs for the 5 gauged subwatersheds. The spring freshet portion of the flow series was selected for presentation as it usually represents the maximum discharges simulated during a given year.

It can be seen that the simulated hydrographs closely resembled the observed hydrographs with respect to magnitude and timing of the peak discharges and also with respect to runoff volume. The fact that computed runoff volumes are similar to observed indicates that the precipitation inputs and moisture/runoff relationships are adequately represented. This also includes parameters which reflect the snow accumulation within the watershed. Coincident magnitude and timing of peak discharges indicates that subwatershed routing parameters are accurately represented.

Although visual appreciation is a useful tool in determining the precision of any calibration simulation, it can be somewhat subjective. Therefore, calibration analyses were undertaken by using the following graphical comparisons:

- cumulative mass curves of computed and observed flow volumes
- comparisons of simulated and observed mean daily peak flows by means of a partial duration flood frequency analysis.

Comparison of cumulative mass curves indicate the ability of the model to accurately reproduce flow volumes. The ability of the model to accurately reproduce peak discharges is measured by a comparison of observed and simulated partial duration flood frequency analyses. The results of this analyses (presented in Figures B.7 to B.11) illustrate that the model gives good simulations (within an average of 6% for runoff volumes) with respect to computed runoff volumes and peak discharge estimates.

Therefore, based on the continuous simulations and the split sample testing (over a period of approximately 90 months for each gauged subwatershed), it was concluded that the SSARR Model adequately represents the hydrologic regime of the 5 gauged subwatersheds within the Humber River watershed.

As a further check, historic water levels in Grand Lake were used in conjunction with observed discharges to determine hydrologic runoff parameters for the 4 ungauged subwatersheds draining to Grand Lake. Similar to the calibration of the gauged subwatersheds, a total of 14 months of meteorologic and hydrometric data was used for calibration purposes. Figure B.11 presents a comparison of the observed and computed Grand Lake water levels for the spring freshet period. This portion of the flow series was selected for presentation as it represents the period of time when runoff is highest. It is evident from the annual fluctuations in water level that the SSARR model adequately simulates the seasonal variations in runoff from the various sub-watersheds, an additional flow series of 14 months was undertaken for validation purposes. The results of these simulations indicate a similar level of accuracy was obtained for the validation simulations, indicating that the model is a reasonable representation of the hydrologic regime.

As discussed in the main report, hydrologic parameters for the 2 ungauged subwatersheds located downstream of Grand Lake were determined by transferring parameters derived for similar calibrated subwatersheds at other locations.

This was accomplished by developing a similarity index in order to compare the homogeneity of ground cover and soil types of the ungauged subwatersheds within the Humber River watershed. Data was taken from the Canada Land Inventory: Soil Capabilities for Agriculture (1:1,000,000 series) and the Newfoundland Forest Type Maps (1:30,000 series) for the Humber Valley. Each subwatershed was given a score for the soil class, limitations for agriculture and vegetation type present. An accumulated score was calculated so that a comparison between gauged and ungauged watersheds could be made. (A summary of soil characteristics and forest cover variations, etc.. is given in Figures 2.3 and 2.4 of the main report.)

Tables B.2 to B.12 summarize the hydrologic characteristics of all subwatersheds utilized in the SSARR model.

ii) Simulation of Outflow From Grand Lake

When calibrating the model to observed data, several attempts were made to simulate outflows from Grand Lake. The simulated flows were based on the calculated inflow to Grand Lake and utilizing the observed lake levels taken by the Bowater Power Company as an actual rule curve. Unfortunately, it was found that although a relatively accurate representation of the Grand Lake inflows was utilized (due to extensive calibration to upstream gauges) the resulting simulated outflows downstream of Grand Lake were highly erratic in magnitude and not representative of flow conditions when compared to observed flows. It was also found that on several occasions, unrealistic simulated flows were obtained by the model (negative flows).

The phenomena of negative flows is discussed in the SSARR manual (57) and is attributed to time periods when inadequate inflows are available to reach the "target" elevation specified in the reservoir rule curve. In other words, the model computes negative outflows to meet the reservoir elevation specified by the user. It can, therefore, be concluded that negative outflows are attributed to errors associated with the following:

- simulated reservoir inflows
- inaccurately defined reservoir stage/storage curve
- observed reservoir water levels used as target elevations.

When applying the SSARR model to the Humber River, extensive calibration to historic data was undertaken to ensure that an accurate representation of the hydrologic conditions was obtained and, hence, a good correlation between observed and simulated streamflow rates and volumes exists. It is evident from previous discussions that despite the limitations of the meteorological input data, the model gives an adequate (i.e. relatively accurate) temporal simulation of inflows to the Grand Lake Reservoir. It is, therefore, concluded that although a number of input data deficiencies may exist, the model accurately represents the hydrologic response of the Humber River.

The stage/storage curve available for Grand Lake was derived by the Bowater Power Company (revised in 1977) and has been verified in the course of these investigations.

The following is a list of some of the factors which could influence observed lake levels and hence contribute to observed lake level measurement errors:

- measurement errors (i.e. observer errors would likely be in excess of .025 ft (0.76 cm)
- wind set up
- barometric pressure variations on Grand Lake
- wave influences

As previously discussed, the observed reservoir water levels were obtained from records collected by the Bowater Power Company. Upon review of the data, it is evident that the data is recorded to the closest 0.05 ft.(1.52 cm), and is only recorded at one location (i.e. at the main control dam). With this level of accuracy, it is possible to incur a daily round-off error of 0.025 ft.(0.76 cm) Due to the extensive surface area of Grand Lake, an elevation error of this magnitude constitutes a storage error of approximately 130 million cubic feet (3.7×10^6 m^3). Because the SSARR model meets the specified target elevation on a daily basis, the associated volume of water discharged from Grand Lake on a daily basis could also be in error by approximately 130 mcf. This volume error constitutes a mean daily flow of approximately 1500 cfs or 30% of the mean annual discharge from Grand Lake.

In summary, it can be seen that a lake level measurement error of less than 3 cm results in a discharge error at the outlet of Grand Lake similar in magnitude to the mean annual discharge. It can, therefore, be concluded that very small errors in lake level measurements result in relatively large discharge variations downstream of Grand Lake.

In addition to the observed lake level round-off error previously discussed, it is very likely that a number of other factors affect the stage/storage/discharge relationship, and hence the simulation accuracy (i.e. if measured levels are used as the rule curve).

Wind set-up can be defined as the vertical rise in the still water level on the downwind side of a body of water caused by wind stresses on the surface of the water. Such vertical rises in water level are a function of many variables (wind velocity, wind direction, lake depth, fetch length, etc.) and can be as much as several feet in magnitude.

Barometric pressure variations can also contribute to variations in lake levels. When dealing with a body of water the size of Grand Lake, it is also possible that areal barometric pressure variations could exist, resulting in vertical differences in water level along the lake. For example, a 2 lb/in^2 (.14 atm) variation in barometric pressure results in a variation in water level of approximately 0.15 ft. (4.6 cm).

In conclusion, due to the complexity and "errors" associated with discharge de-regulation, the use of the SSARR model in this mode for historical simulation is not recommended. The installation and monitoring of additional water level recording stations along Grand Lake would be useful in the future in order to refine the model for the flood forecasting mode.

iii) Simulation of Outflow from Deer Lake

Outflows from the Upper Humber River and Grand Lake are subsequently routed through Deer Lake. Deer Lake is a natural reservoir which operates under free flow outlet conditions. Therefore, it is of primary concern to accurately represent the stage/discharge/storage curve for the outlet of Deer Lake as flows within the study area are directly proportional to this relationship.

Unfortunately, all the long-term hydrometric gauges are located upstream of the study area and cannot be used to calibrate the SSARR model outflows from Deer Lake. However, a new hydrometric gauge was recently installed near the outlet of Deer Lake at the Humber Village Bridge for which sufficient data exists for validation purposes. In addition to the short term hydrometric gauge located downstream of Deer Lake, the Bowater Power Company records water levels near the tailrace of the hydroelectric plant, which is located at the upstream end of Deer Lake.

As discussed in the main text, it was necessary to adjust the water levels recorded by the Bowater Power Company to account for the head losses through Deer Lake. This was accomplished by utilizing historic stage information on the Humber River at Governors Point. This gauge was apparently operated for 18 years (1929 to 1946) by the Bowater Power Company. The results of this analysis indicate that water levels on a given day at the outlet of Deer Lake are lower than that recorded by the Bowater Power Company at the tailrace of the hydroelectric plant. Differences in excess of 1 ft. (30 cm) were frequently observed throughout the period of record with an average of 0.7 ft. (21 cm) lower at the outlet of Deer Lake compared to measurements at the tailrace.

B.2.4 Peak Flow Estimates

i) Effects of Upstream Diversions and Power Regulation

An analysis was undertaken to examine the effect of changes to the hydrologic regime of the Grand Lake watershed due to:

A - Indian Brook diversion

B - Hinds Lake Power Development

C - Revised rule curve for Grand Lake power production

The Hinds Lake Power station and the revised rule curves for Grand Lake represent recent changes to the hydrologic regime of Grand Lake, and as such, insufficient data exists to statistically test for variations to the hydrometric record. However, the SSARR model was utilized in the single event mode to model the effects of these changes during peak runoff events.

A. Indian Brook Diversion

Starting in October, 1962 to date, a watershed area of approximately 238 km^2 was diverted from Indian Brook to Birchy Lake with minor return flow to Indian Brook. Cumulative mass curves were developed for the period of record before and after the diversion. It was evident from a comparison of these mass curves that the runoff volumes from Grand Lake have increased approximately 4% since the implementation of the diversion. This percentage increase is approximately equal to the increase in drainage area and is also consistent with other previous investigations (50). However, a frequency analysis of peak discharge was undertaken comparing the two periods of record and it was found that annual peak discharges downstream of Grand Lake have been reduced slightly since the diversion. It was, therefore, concluded that changes to the hydrologic regime due to the diversion of Indian Brook would have a negligible effect on peak flows within the study area.

B. Hinds Lake Power Development

The Hinds Lake Power Development Project entered into storage adjustments in 1980. The reservoir was increased in size and regulated and some minor diversions were introduced to increase the drainage area by approximately 120 km^2. Virtually all of the increase in drainage area was a result of diversions from surrounding lands which naturally drained to Grand Lake. The result of the Hinds Lake power development project was found to increase the peak discharge associated with an approximate 1:100 year runoff (a rainfall plus snowmelt design event was input) by about 2% downstream of Deer Lake.

C. Grand Lake Rule Curve

Since 1981, a revised reservoir rule curve has been in effect for the operation of Grand Lake. The former rule curve resulted in Grand Lake being drawn down to a minimum level approximately 2 feet lower than the present rule curve. Furthermore, Grand Lake is filled approximately one month sooner than with the previous rule curve.

Utilizing the SSARR Model in the single event mode, a 1:100 year rainfall plus snowmelt design event (approximate) was simulated to compare the effects of rule curve changes. The former rule curve results in a reduction in peak discharges of about 5% for the 1:100 year event just downstream of Deer Lake when compared to the present rule curve. However, this comparison is dependent on the month in which the event is assumed to start (i.e. for some months, the existing rule curve results in a reduction of peak flows when compared to the former rule curve.

Summary

The change in peak flows downstream of Deer Lake was found to be insignificant due to significant contributions from the Upper Humber River and the effects of routing through Deer Lake. It was, therefore, concluded that no adjustments to the hydrometric record from

Grand Lake were deemed necessary to account for the Indian and Hinds Brooks Diversions or due to change in the Grand Lake operating curve.

ii) Long Term Flow Sequence

It was evident from the flow simulations that due to the routing problems associated with Grand Lake, a long-term sequence of historical discharges within the study area could not be accurately simulated by utilizing the theoretical rule curve. Therefore, in order to derive peak flow estimates within the study area, it was concluded that the extensive period of record at the outlet of Grand Lake and the Upper Humber River could be used as input to the SSARR model to simulate a long-term hydrometric record in the study area. The model was also used to simulate inflow to Deer Lake from subwatersheds for which no hydrometric data exists, in addition to using its reservoir routing capabilities through Deer Lake, and its channel routing capabilities through the study reach. A flood frequency analysis of the simulated long-term flow sequence was undertaken on annual peak discharges (see main report).

Utilizing the SSARR model, 39 years of hydrometric and meteorologic record were combined to simulate a long-term hydrometric record for the study reach. Based on the 39 years of simulated data, an annual flood series was obtained for both the upstream and downstream ends of the study reach (i.e. immediately upstream of Deer Lake and the Community of Steady Brook respectively).

The OUTLIER program (61) was utilized to identify high and low outliers in each of the peak flow data series previously discussed. The tests for outliers follow the procedures adopted by the U.S. Water Resource Council and indicate that no high or low outliers exist in the data sets.

Statistical frequency analysis assumes that the sample to be analysed is a reliable set of measurements of independent random events from a homogeneous population. The validity of this assumption can be verified using statistical significance tests for each data sample, with the results of the tests assessed individually and on a regional basis. For the present study, testing of the available sample series was undertaken using the following tests:

1) Spearman rank order serial correlation test for independence
2) Spearman rank order correlation coefficient test for trend
3) Mann-Whitney split sample test for homogeneity
4) Wald-Wolfowitz split sample test for homogeneity
5) Runs above and below the median for general randomness.

The above mentioned tests were undertaken using a statistical computer program (30) developed by Environment Canada. Results of these analy ses indicate that the data samples can be regarded as independent, homogeneous and free of trend at both the 1% and 5% level of significance.

Several distributions were fitted to the available data sets for comparison purposes, including Gumbel 2, Log Normal (LN), Three Parameter Log Normal (3PLN) and Log Pearson Type III (LP3). The computer program FDRPFFA (22), provided by the Water Planning and Management Branch, Envionment Canada, was utilized for this purpose and for computing the 1:20 and 1:100 year flood peaks and the corresponding 95% confidence limits. Tables B.13 and B.14 present a summary of the different distributions and the corresponding standard errors for the upstream and downstream reaches of the study area respectively.

In flood frequency analysis, it is not possible to pre-determine which frequency distribution should be used. The selection of the appropriate distribution for use in this investigation was based on comparisons of the computed "T" year flood using the methods as outlined in the FDRPFFA program (22), and summarized as follows:

- comparison of various fitting techniques to other statistical estimates using available regional techniques
- comparison of the theoretical statistics of skew and kurtosis to those estimated from the station data

- visual comparison of the degree of fit of each distribution to the available data set

Based on a comparison of theoretical and calculated statistics, the 3PLN distribution was selected for use in this analysis. Figures B.14 and B.15 present the flood frequency plots for the upstream and downstream study reach respectively. The flow estimates calculated for the study area using the procedures described herein are also presented in Table 3.1 of Section 3.0 in the main report.

B.2.5 Flood Forecasting

It was evident from undertaking historic simulations that additional data requirements would be useful for applying the SSARR model to the Humber River in a flood forecasting mode. The additional data requirements can be subdivided into meteorologic, hydrometric (both streamflow and water levels) and snow course stations and are described as follows:

Proposed Automatic Meteorological Stations (Precip. Temp.):

- Western End of Grand Lake near T.C.H.
- Near Battle Pond
- Near Red Indian Lake
- North Side of Grand Lake near Glover Island
- At Hinds Brook Power Station
- Near Sheffield Lake at T.C.H.
- Near Birchy Lake

Proposed Streamflow Station:

- Indian Brook Diversion (to Birchy Lake)
  (i.e reinstate W.S.C. gauge)
- Continuation of existing gauges

Proposed Water Level Recorders (telemetred):

- Outlet of Deer Lake
- West end of Grand Lake

- Outlet of Grand Lake
- Sandy Lake
- Inlet of Deer Lake

Proposed Snow Course Stations:

- Near Gros Morne National Park) all Upper
- Near Adies Pond) Humber -
- Near Birchy Lake) telemetred
- Upgrade other stations with regard to frequency and data collection methods, etc.

The location of these stations is presented on Figure B.16.

In addition to the aforementioned data requirements, satellite photos are also available (at a nominal charge) to estimate snow covered areas on a weekly basis.

TABLE B.1

File Organization of SSARR Input Data

	Cards	Description
	J	run characteristics
	CP	characteristics of the meteorological stations
	CT	tables of variation of basin parameters
Permanent	CB	basin characteristics
characteristics	C3	altitude-area curve
of the model	CR	reach characteristics
	CL	lakes and reservoir characteristics
	C1	reservoir storage curves
	CC	node characteristics
	P	network configuration
	T	specification for the duration of the adjustment
	2B	initial conditions of the basins
Initial	2R	initial conditions of the reaches
conditions and	3B	revision of initial basin conditions
input data	4D	meteorological data (observed and forecast)
	5	temporal distribution of rain and temperature
	6	hydrometric data
Control of	PR	printing of the numerical value of the results
print-out	PQ	printing of graphs
of results	END	end of file

TABLE B.2

Characteristics of Basin: Leweseechjeech Brook
No: 1100

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 181 mi^2
Gauge Number - 02YK002
Period of Record - 1952 - date

b) Applicable Meteorologic Station

Temperature			Precipitation		
SSARR No.	Name	Weighting Coefficient	SSARR No.	Name	Weighting Coefficient
0812	Burnt Pond	102	0812	Burnt Pond	135
1300	Corner Brook	190	1300	Corner Brook	252
3800	Stephenville	8	3800	Stephenville	10

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	3	2	2
TS	15	40	300

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
475	0	1500	82.7
500	3.2	1750	93.0
750	7.2	2000	97.2
1000	20.6	9999.99	99.9
1250	55.9		

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.0900

Base Temperature (°F) - 32.0

Freezing Temperature (°F) - 30.0
(of rain)

Lapse Rate (°F/1000 ft) - 3.00

TABLE B.3

Characteristics of Basin: Hinds Brook
No: 1101

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 204 mi^2
Gauge Number - 02YK004
Period of Record - 1956 - date

b) Applicable Meteorologic Station

Temperature			Precipitation		
SSARR No.	Name	Weighting Coefficient	SSARR No.	Name	Weighting Coefficient
0700	Buchans	183	0700	Buchans	248
1500	Deer Lake	17	1500	Deer Lake	24

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	3	5	2
TS	20	50	450

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
650	0	1750	85.1
750	0.5	2000	98.0
1000	24.8	2100	99.1
1250	42.2	9999.99	99.9
1500	64.3		

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.0900

Base Temperature (°F) - 30.0

Freezing Temperature (°F) - 32.0
(of rain)

Lapse Rate (°F/1000 ft) - 3.00

TABLE B.4

Characteristics of Basin: Sheffield Brook
No: 1102

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 151 mi^2
Gauge Number - 02YK003
Period of Record - 1955 - date

b) Applicable Meteorologic Station

Temperature			Precipitation		
SSARR No.	Name	Weighting Coefficient	SSARR No.	Name	Weighting Coefficient
0700	Buchans	100	0700	Buchans	125

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	3	5	2
TS	20	50	450

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
325	0	1250	73.4
500	9.4	1500	90.8
750	30.1	1750	99.0
1000	49.3	9999.99	99.9

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.0700
Base Temperature (°F) - 28.0
Freezing Temperature (°F) - 35.0
(of rain)
Lapse Rate (°F/1000 ft) - 3.00

TABLE B.5

Characteristics of Basin: Indian Brook Diversion
No: 1103

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 92 mi^2
Gauge Number - 02YM002
Period of Record - 1963 - 1978

b) Applicable Meteorologic Station

Temperature SSARR No.	Name	Weighting Coefficient	Precipitation SSARR No.	Name	Weighting Coefficient
1500	Deer Lake	100	1500	Deer Lake	100

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	4	3	2
TS	15	20	200

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
400	0	1200	99.0
500	1.0	9999.99	99.9
750	24.7		
1000	93.7		

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.050

Base Temperature (°F) - 28.0

Freezing Temperature (°F) - 35.0
(of rain)

Lapse Rate (°F/1000 ft) - 3.00

TABLE B.6

Characteristics of Basin: Upper Humber River
No: 1104

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 814 mi^2
Gauge Number - 02YL001
Period of Record - 1928 - date

b) Applicable Meteorologic Station

Temperature			Precipitation		
SSARR No.	Name	Weighting Coefficient	SSARR No.	Name	Weighting Coefficient
1500	Deer Lake	106	1500	Deer Lake	162
3096	Rocky Harbour	84	3096	Rocky Harbour	118

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	4	3	2
TS	15	20	200

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
50	0	1250	59.7
250	10.0	1500	70.8
500	30.6	1750	84.4
750	38.5	2000	94.3
1000	46.8	2250	99.4
		9999.99	99.9

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.070

Base Temperature (°F) - 32.0

Freezing Temperature (°F) - 35.0
(of rain)

Lapse Rate (°F/1000 ft) - 3.00

TABLE B.7

Characteristics of Basin: Grand Lake West
No: 2100

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 501 mi^2
Gauge Number - N/A
Period of Record - N/A

b) Applicable Meteorologic Station

Temperature			Precipitation		
SSARR No.	Name	Weighting Coefficient	SSARR No.	Name	Weighting Coefficient
0700	Buchans	6	0700	Buchans	3
1300	Corner Brook	344	1300	Corner Brook	507
1500	Deer Lake	34	1500	Deer Lake	50
3800	Stephenville	17	3800	Stephenville	25

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	3	3	2
TS	15	20	200

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
233	0	1250	51.4
254	13.2	1500	84.5
500	24.3	1750	90.4
750	32.4	9999.99	99.9
1000	37.9		

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.050
Base Temperature (°F) - 28.0
Freezing Temperature (°F) - 35.0
(of rain)
Lapse Rate (°F/1000 ft) - 3.00

TABLE B.8

Characteristics of Basin: Grand Lake Central
No: 2101

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 276 mi^2
Gauge Number - N/A
Period of Record - N/A

b) Applicable Meteorologic Station

Temperature			Precipitation		
SSARR No.	Name	Weighting Coefficient	SSARR No.	Name	Weighting Coefficient
0700	Buchans	10	0700	Buchans	12
1500	Deer Lake	190	1500	Deer Lake	229

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	3	3	2
TS	15	20	200

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
233	0	1250	71.7
234	27.2	1500	79.7
500	42.6	1750	85.1
750	51.0	2000	97.0
1000	64.2	9999.99	99.9

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.050

Base Temperature (°F) - 28.0

Freezing Temperature (°F) - 35.0
(of rain)

Lapse Rate (°F/1000 ft) - 3.00

TABLE B.9

Characteristics of Basin: Grand Lake East
No: 2102

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 456 mi^2
Gauge Number - N/A
Period of Record - N/A

b) Applicable Meteorologic Station

Temperature SSARR No.	Temperature Name	Temperature Weighting Coefficient	Precipitation SSARR No.	Precipitation Name	Precipitation Weighting Coefficient
0700	Buchans	78	0700	Buchans	74
1500	Deer Lake	122	1500	Deer Lake	115

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	3	3	2
TS	15	20	200

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
283	0	1250	69.2
284	11.6	1500	82.4
500	31.2	1750	97.4
750	43.6	9999.99	99.9
1000	55.2		

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.050

Base Temperature (°F) - 28.0

Freezing Temperature (°F) - 35.0
(of rain)

Lapse Rate (°F/1000 ft) - 3.00

TABLE B.10

Characteristics of Basin: D/S Grand Lake
No: 2104

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 77 mi^2
Gauge Number - N/A
Period of Record - N/A

b) Applicable Meteorologic Station

Temperature			Precipitation		
SSARR No.	Name	Weighting Coefficient	SSARR No.	Name	Weighting Coefficient
1500	Deer Lake	100	1500	Deer Lake	107

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	3	2	2
TS	10	20	200

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
250	0	1000	95.2
500	28.6	1200	99.0
750	59.2	9999.99	99.9

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.050
Base Temperature (°F) - 28.0
Freezing Temperature (°F) - 35.0
(of rain)
Lapse Rate (°F/1000 ft) - 3.00

TABLE B.11

Characteristics of Basin: Local Inflow to Deer Lake
No: 2105

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 640 km^2
Gauge Number - N/A
Period of Record - N/A

b) Applicable Meteorologic Station

Temperature			Precipitation		
SSARR No.	Name	Weighting Coefficient	SSARR No.	Name	Weighting Coefficient
1300	Corner Brook	24	1300	Corner Brook	28
1500	Deer Lake	176	1500	Deer Lake	208

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	3	3	2
TS	15	20	200

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
16	0	1000	86.9
17	10.6	1250	95.9
250	33.2	1500	99.3
500	50.9	1750	99.7
750	71.4	99999	99.9

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.06

Base Temperature (°F) - 28.0

Freezing Temperature (°F) - 35.0
(of rain)

Lapse Rate (°F/1000 ft) - 3.0

TABLE B.12

Characteristics of Basin: Local Inflow to Corner Brook
No: 2106

a) Characteristic of Hydrometric Station

Quality of Discharge - Natural
Area of Sub-watershed - 146 km^2
Gauge Number - N/A
Period of Record - N/A

b) Applicable Meteorologic Station

Temperature SSARR No.	Name	Weighting Coefficient	Precipitation SSARR No.	Name	Weighting Coefficient
1300	Corner Brook	100	1300	Corner Brook	145

c) Sub-watershed Characteristics

i) Routing Coefficients

Coefficient	Surface	Subsurface	Baseflow
NP	3	3	2
TS	10	15	100

ii) Altitude - Area Relationship

Altitude (ft)	Area Below (%)	Altitude (ft)	Area Below (%)
0	0	1000	40.1
250	13.7	1250	55.9
500	18.2	1500	79.6
750	27.1	1750	95.2

iii) Snow Melt Coefficients

Melt Rate (in/°F days) - 0.06

Base Temperature (°F) - 28.0

Freezing Temperature (°F) - 35.0
(of rain)

Lapse Rate (°F/1000 ft) - 3.0

TABLE B.13

Estimates and Standard Errors for Various Distributions Tested -Upstream Study Reach

Maximum Instantaneous Discharge Data

U/S Steady Brook Study Area

Year	Data	Ordered	Rank	Prob.	Ret. Period
1938	431.	949.	1	0.019	51.974
1939	612.	926.	2	0.045	22.443
1940	564	903.	3	0.070	14.312
1941	671.	890.	4	0.095	10.505
1944	592.	887.	5	0.121	8.298
1945	802.	875.	6	0.146	6.858
1946	756.	802.	7	0.171	5.841
1947	618.	756.	8	0.196	5.090
1948	875.	745.	9	0.222	4.509
1949	558.	734.	10	0.247	4.047
1954	640.	734.	11	0.272	3.671
1955	459.	714.	12	0.298	3.359
1956	595.	708.	13	0.323	3.096
1957	462.	680.	14	0.348	2.871
1958	445.	671.	15	0.374	2.676
1959	513.	649.	16	0.399	2.506
1960	521.	640.	17	0.424	2.357
1961	572.	618.	18	0.450	2.224
1962	714.	612.	19	0.475	2.106
1963	926.	606.	20	0.500	1.999
1964	613.	595.	21	0.526	1.903
1965	589.	592.	22	0.551	1.815
1966	649.	589.	23	0.576	1.736
1967	484.	581.	24	0.602	1.662
1968	445.	572.	25	0.627	1.595
1969	949.	564.	26	0.652	1.533
1970	532.	558.	27	0.677	1.476
1971	708.	532.	28	0.703	1.423
1972	903.	530.	29	0.720	1.373
1973	606.	521.	30	0.753	1.327
1974	530.	513.	31	0.779	1.284
1975	581.	513.	32	0.804	1.244
1976	887.	484.	33	0.829	1.206
1977	734.	462.	34	0.855	1.170
1978	745.	459.	35	0.880	1.136
1979	428.	445.	36	0.905	1.105
1980	680.	445.	37	0.931	1.075
1981	390.	431.	39	0.956	1.046
1982	734.	428.	39	0.981	1.019

Statistics

Sample Statistics

Mean = 639. S.D. = 150.4 C.S. = 0.5556 C.K. = 2.6134

Sample Statistics (logs)

Mean = 6.4333 S.D. = 0.2310 C.S. = 0.1912 C.K. = 2.3733

Sample Min = 428. Sample Max = 949. N = 39

Parameters for Gumbel I A = 0.008359 U = 569.

Parameters for Lognormal M = 6.4333 S = 0.2310

Parameters for Three Parameter Lognormal A = 278. M = 5.8015 S = 0.4292

Statistics of Log (X-A)

Mean = 5.8016 S.D. = 0.4292 C.S. = -0.1341 C.K. = 2.4180

Parameters for Log Pearson III by Moments A = 0.0221 B = 0.1094E+03 LOG(M) = 4.0171 M = 0.5554E+02

Parameters for Log Pearson III by Maximum Likelihood A = 0.0698 B = 0.1113E+02 LOG(M) = 5.6563 M = 0.2861E+03

Distribution Statistics Mean = 6.4333 S.D. = 0.2329 C.S. = 0.5995

Flood Frequency Distributions

	Gumbel I		Lognormal		3-Parameter Lognormal		Log Pearson III Max. Likelihood		Log Pearson III Moments	
Return Period	Flood Estimate	St.Error Percent	Flood Estimate	St.Error Percent	Flood Estimate	St.Error Percent	Flood Estimate	St.Error Percent	Flood Estimate	St.Error Percent
1.005	369.		343.		387.		388.		358.	
1.050	436.		426.		441.		443.		431.	
1.250	512.		512.		508.		510.		511.	
2.000	613.		622.		609.		608.		618.	
5.000	748.	4.61	756.	4.31	753.	5.04	749.	5.01	754.	4.54
10.000	838.	5.28	837.	4.99	851.	6.43	848.	6.44	840.	5.53
20.000	924.	5.86	910.	5.67	948.	8.12	945.	8.24	921.	6.93
50.000	1040.	6.51	1000.	6.52	1080.	10.60	1080.	11.00	1020.	9.19
100.000	1120.	6.92	1060.	7.12	1180.	12.60	1160.	13.20	1100.	11.10
200.000	1200.	7.28	1130.	7.69	1280.	14.50	1290.	15.50	1180.	13.10
500.000	1310.	7.69	1210.	8.39	1420.	17.20	1450.	18.70	1280.	15.90

TABLE B.14

Estimates and Standard Errors for Various Distributions Tested -Downstream Study Reach

Maximum Instantaneous Discharge Data

D/S Steady Brook Study Area

Year	Data	Ordered	Rank	Prob.	Ret. Period
1938	439.	977.	1	0.019	51.974
1939	512.	921.	2	0.045	22.443
1940	534	907.	3	0.070	14.312
1941	694	901.	4	0.095	10.505
1944	589.	892.	5	0.121	8.299
1945	816.	890.	6	0.146	6.858
1946	776.	816.	7	0.171	5.843
1947	654.	776.	8	0.196	5.090
1948	907.	754.	9	0.222	4.509
1949	598.	745.	10	0.247	4.047
1954	654.	731.	11	0.272	3.671
1955	459.	731.	12	0.298	3.359
1956	603.	722.	13	0.323	3.096
1957	497.	694.	14	0.348	2.871
1958	450.	680.	15	0.374	2.676
1959	518.	657.	16	0.399	2.506
1960	521.	654.	17	0.424	2.357
1961	569.	654.	18	0.450	2.224
1962	722.	618.	19	0.475	2.106
1963	921.	612.	20	0.500	1.999
1964	516.	603.	21	0.526	1.903
1965	589.	598.	22	0.551	1.815
1966	657.	589.	23	0.576	1.736
1967	497.	589.	24	0.602	1.662
1968	450.	584.	25	0.627	1.595
1969	977.	584.	26	0.652	1.533
1970	535.	569.	27	0.677	1.476
1971	731.	555.	28	0.703	1.423
1972	892.	535.	29	0.728	1.373
1973	618.	521.	30	0.753	1.327
1974	555.	518.	31	0.779	1.284
1975	584.	516.	32	0.804	1.244
1976	901.	497.	33	0.829	1.206
1977	731.	497.	34	0.855	1.170
1978	754.	459.	35	0.880	1.136
1979	433.	450.	36	0.905	1.105
1980	680.	450.	37	0.931	1.075
1981	890.	439.	38	0.956	1.046
1982	745.	433.	39	0.981	1.019

Statistics

Sample Statistics

Mean = 649. S.D. 151.8 C.S. = 0.5305 C.K. = 2.6125

Sample Statistics (logs)

Mean = 6.4489 S.D. = 0.2303 C.S. 0.1628 C.K. = 2.3700

Sample Min = 433. Sample Max = 977. N = 39

Parameters for Gumbel I A = 0.008221 U = 578.

Parameters for Lognormal M = 6.4489 S 0.2303

Parameters for Three Parameter Lognormal A = 266. M = 5.8672 S = 0.4079

Statistics of Log (X-A)

Mean 5.8672 S.D. = 0.4079 C.S. = -0.1284 C.K. 2.4083

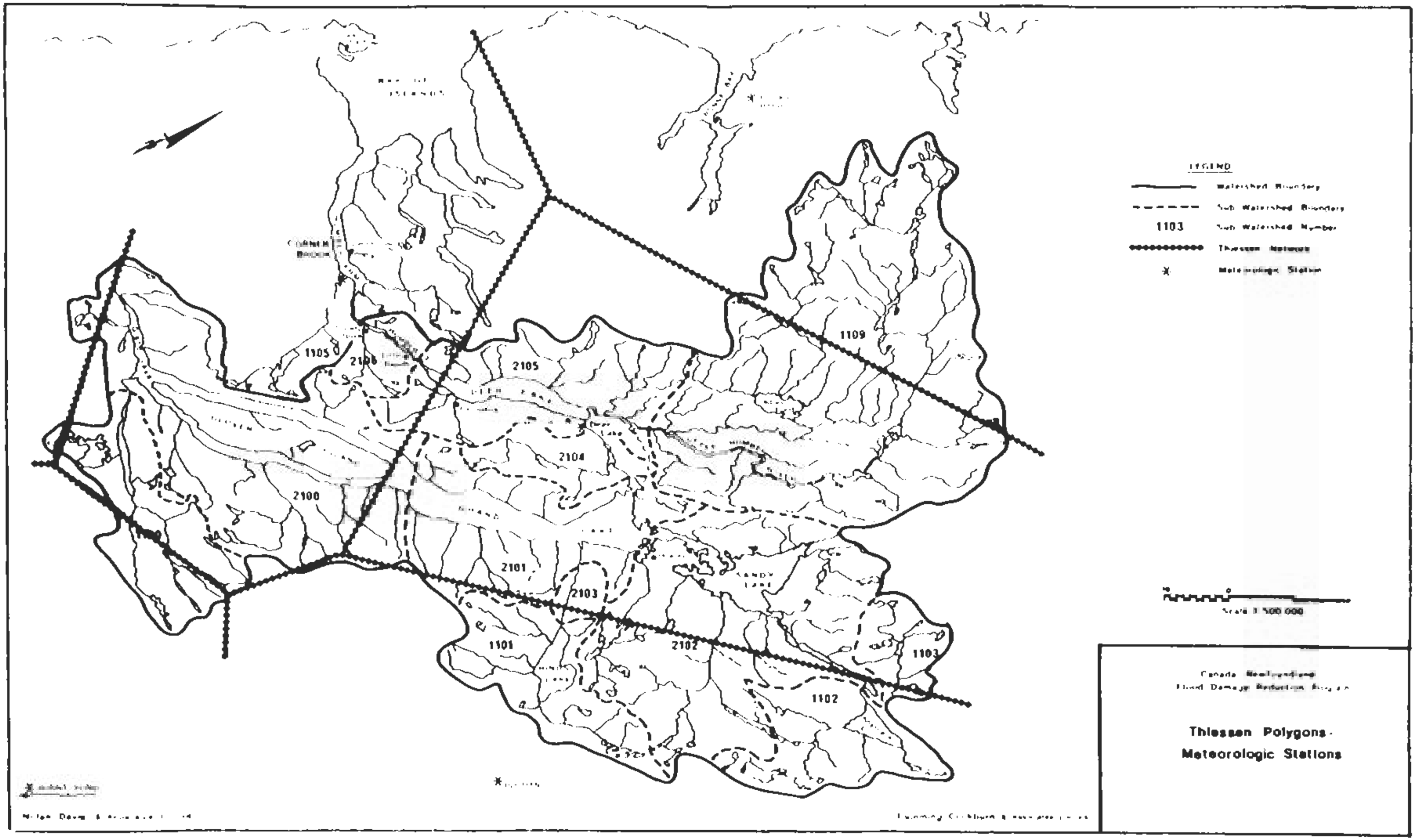
Parameters for Log Pearson III by Moments A = 0.0187 B = 0.1509E+03 LOG(M) = 3.6193 M 0.3733E+02

Parameters for Log Pearson III by Maximum Likelihood A = 0.0596 B = -0.1500E+02 LOG(M) = 5.5546 M = 0.2584E+03

Distribution Statistics Mean = 6.4489 S.D. = 0.2309 C.S. = 0.5164

Flood Frequency Distributions

	Gumbel I		Lognormal		3-Parameter Lognormal		Log Pearson III Max. Likelihood		Log Pearson III Moments	
Return Period	Flood Estimate	St.Error Percent	Flood Estimate	St.Error Percent	Flood Estimate	St.Error Percent	Flood Estimate	St.Error Percent	Flood Estimate	St.Error Percent
1.005	375.		349.		390.		389.		362.	
1.050	443.		433.		447.		448.		437.	
1.250	520.		521.		517.		519.		520.	
2.000	623.		632.		620.		620.		628.	
5.000	760.	4.62	767.	4.29	764.	4.95	761.	4.80	766.	4.50
10.000	852.	5.29	849.	4.98	862.	6.26	858.	6.22	852.	5.44
20.000	939.	5.87	923.	5.66	957.	7.89	953.	7.92	933.	6.80
50.000	1050.	6.51	1010.	6.50	1080.	10.30	1080.	10.50	1030.	9.00
100.000	1140.	6.92	1080.	7.10	1180.	12.20	1180.	12.70	1110.	10.80
200.000	1220.	7.28	1140.	7.66	1280.	14.10	1280.	14.90	1180.	12.80
500.000	1330.	7.70	1230.	8.37	1410.	16.60	1420.	18.00	1280.	15.50


LEGEND
Watershed Boundary
Sub Watershed Boundary
1103 Sub Watershed Number
Thiessen Network
Meteorologic Station
1109
2105
2106
1105
2104
2100
2101
2103
2102
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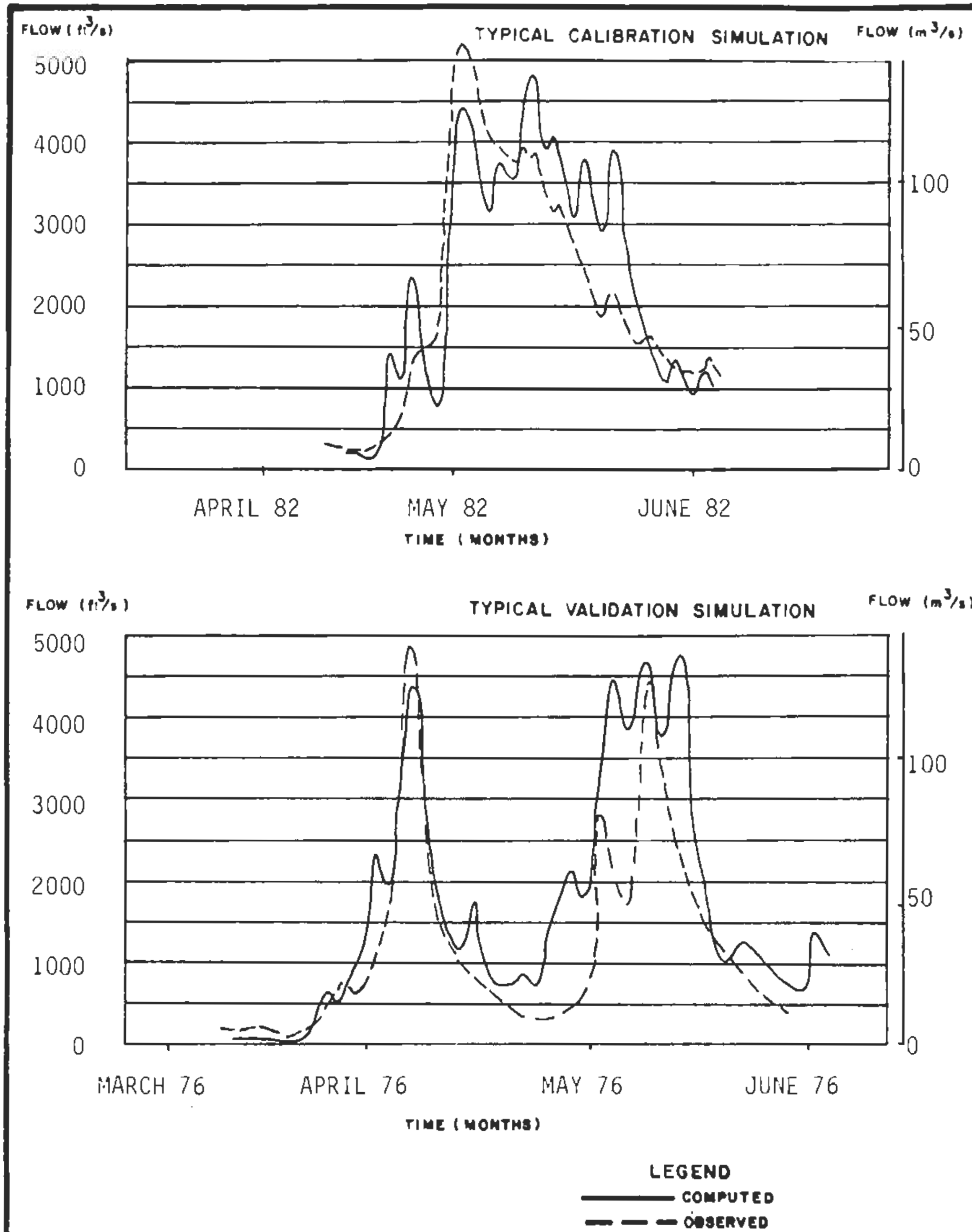
Corner Brook
Sandy Lake
Canada Newfoundland
Flood Damage Reduction Program
Thiessen Polygons -
Meteorologic Stations

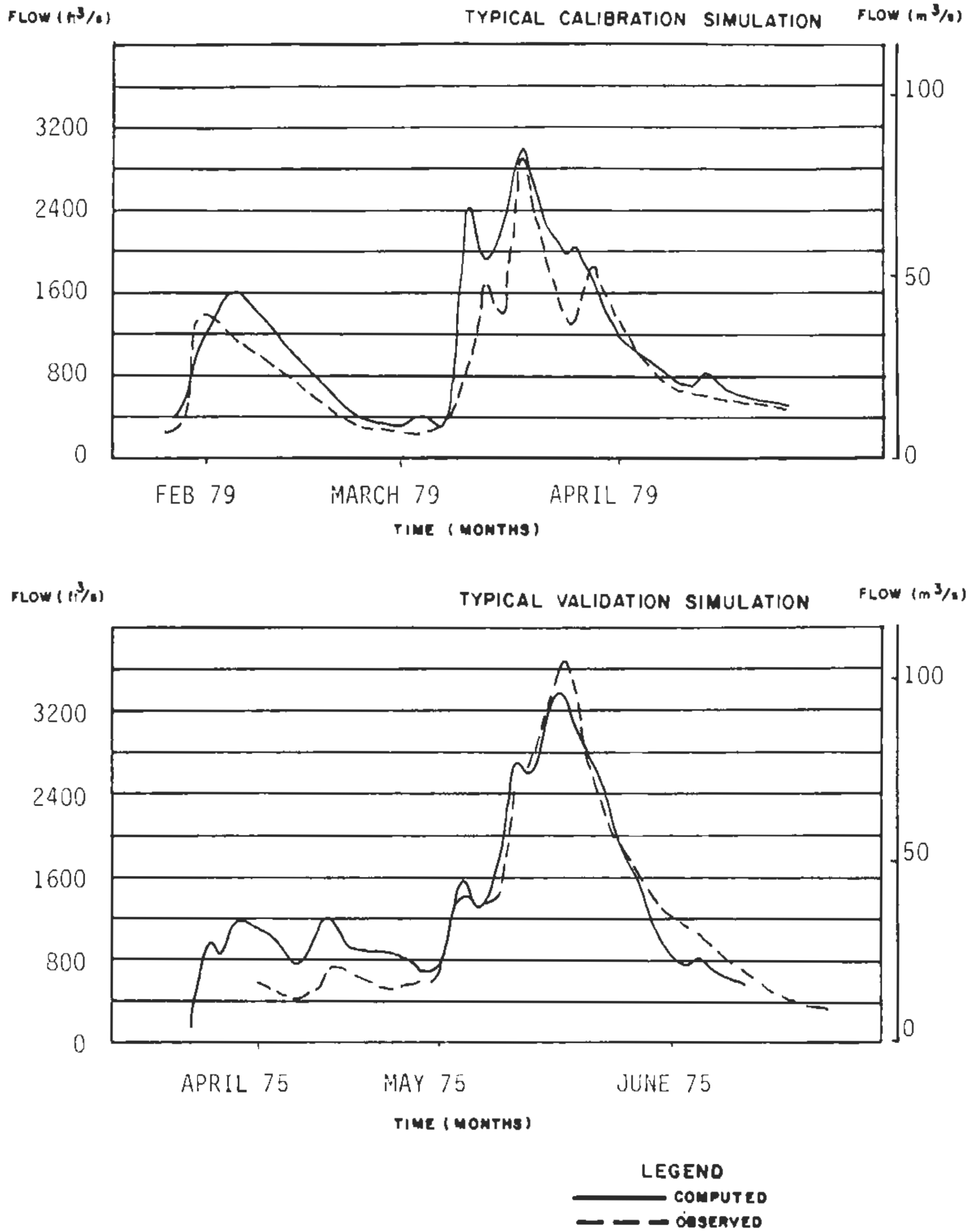
Figure B-1



Observed vs Computed Hydrographs - Lewaseechjeech Brook

CUMMING-COCKBURN & ASSOCIATES LIMITED

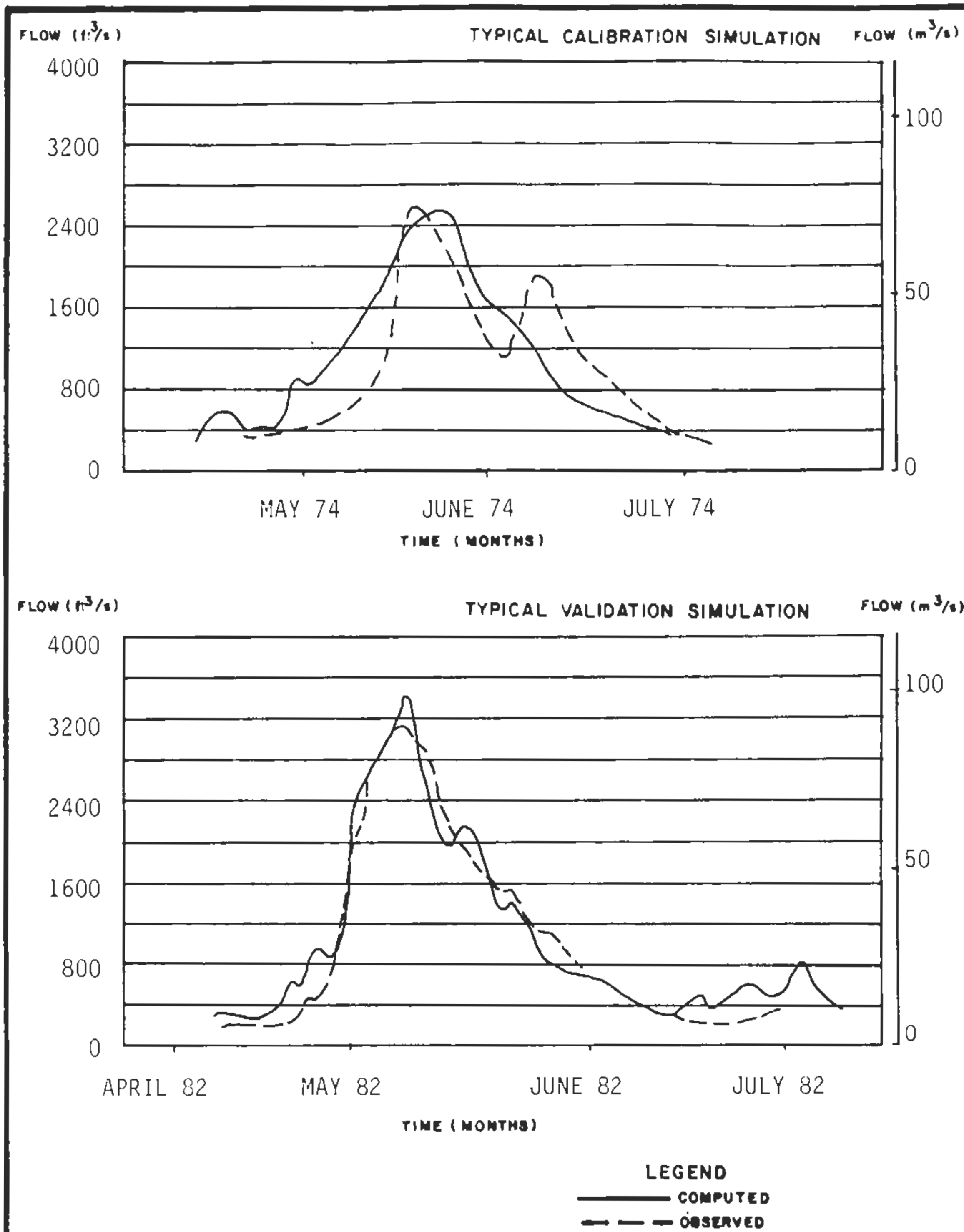
Figure B·2



Observed vs Computed Hydrographs - Hinds Brook

CUMMING-COCKBURN
& ASSOCIATES LIMITED

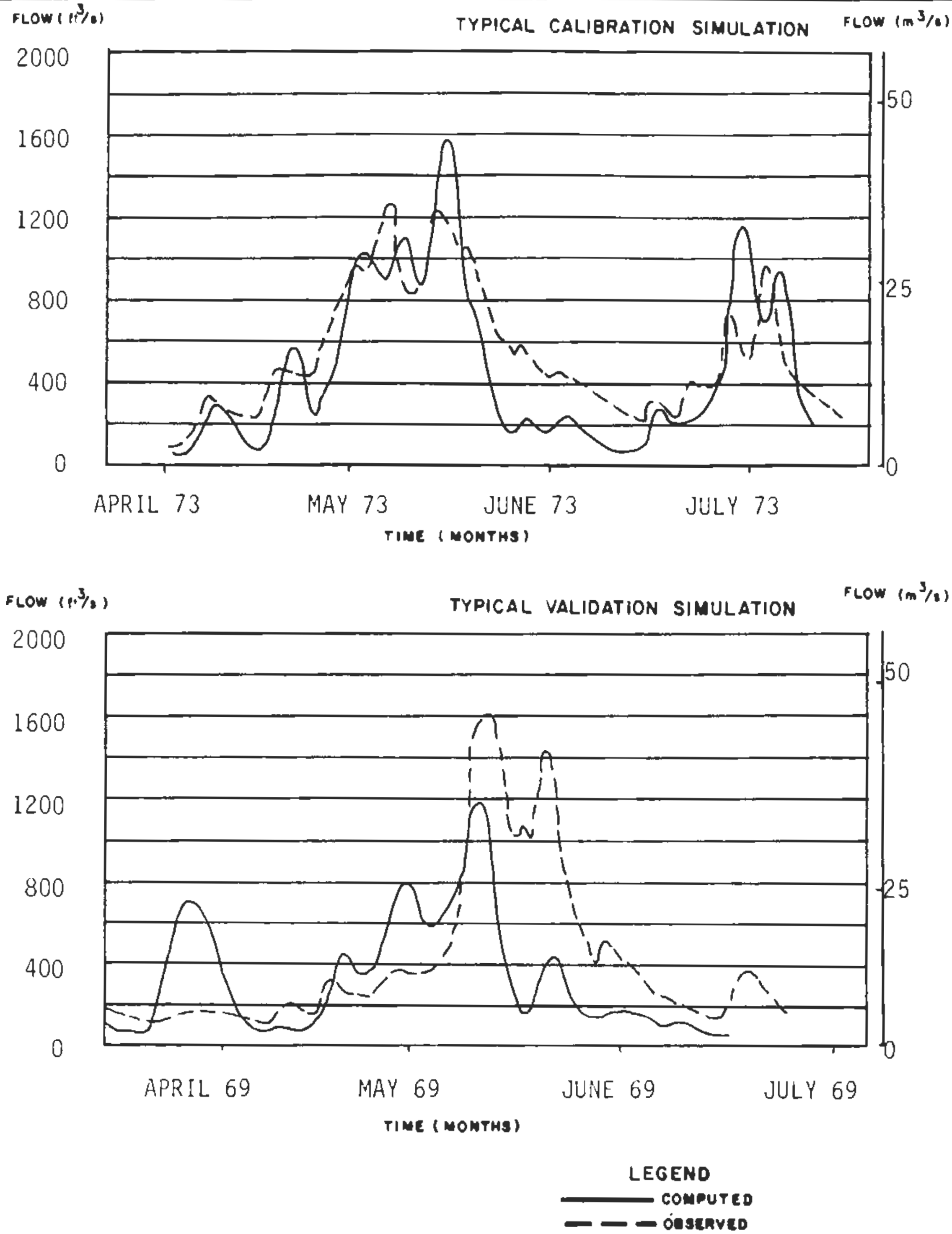
Figure B·3



Observed vs Computed Hydrographs - Sheffield Brook

CUMMING-COCKBURN & ASSOCIATES LIMITED

Figure B·4



Observed vs Computed Hydrographs - Indian Brook

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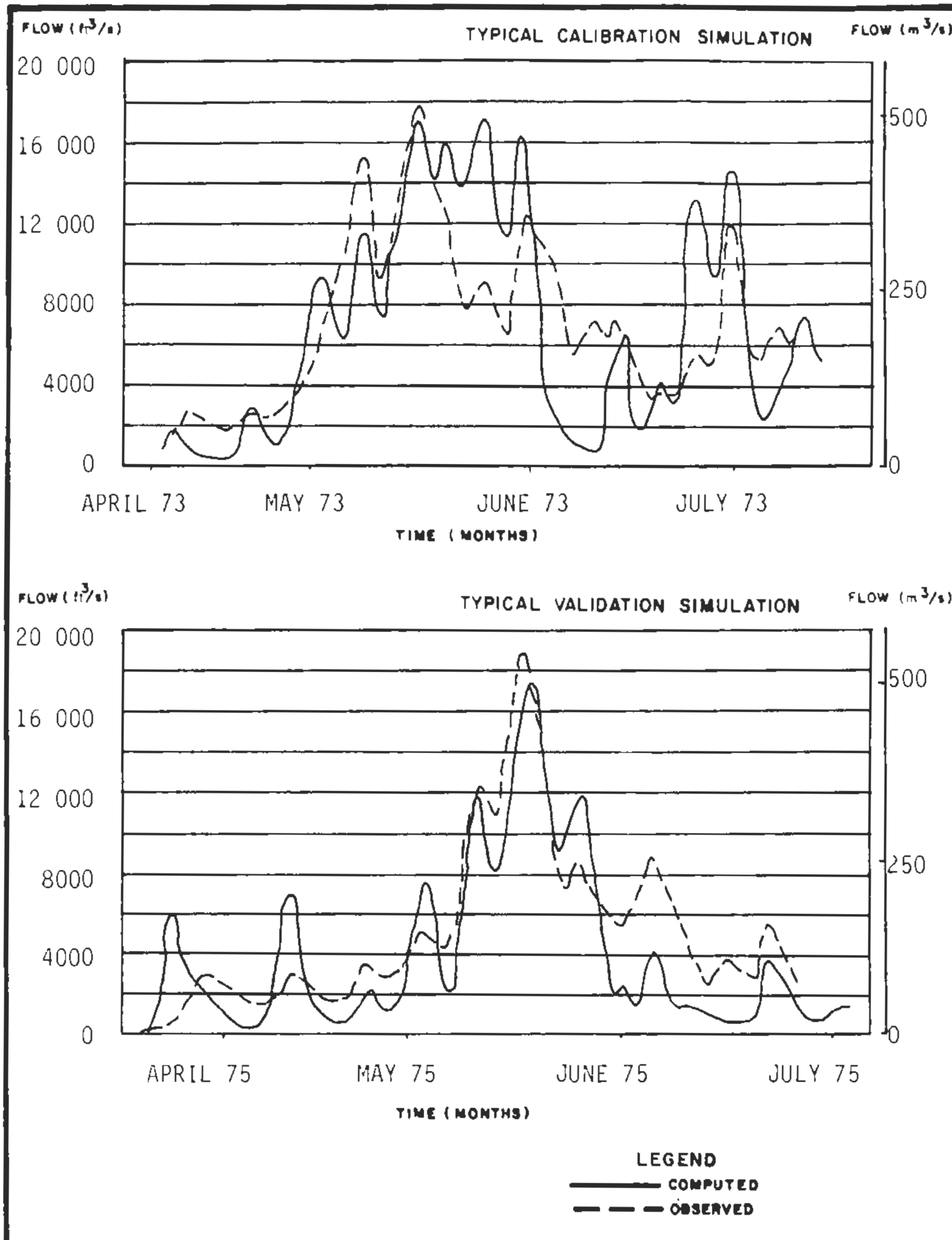
Figure B-5



Observed vs Computed Hydrographs - Upper Humber River

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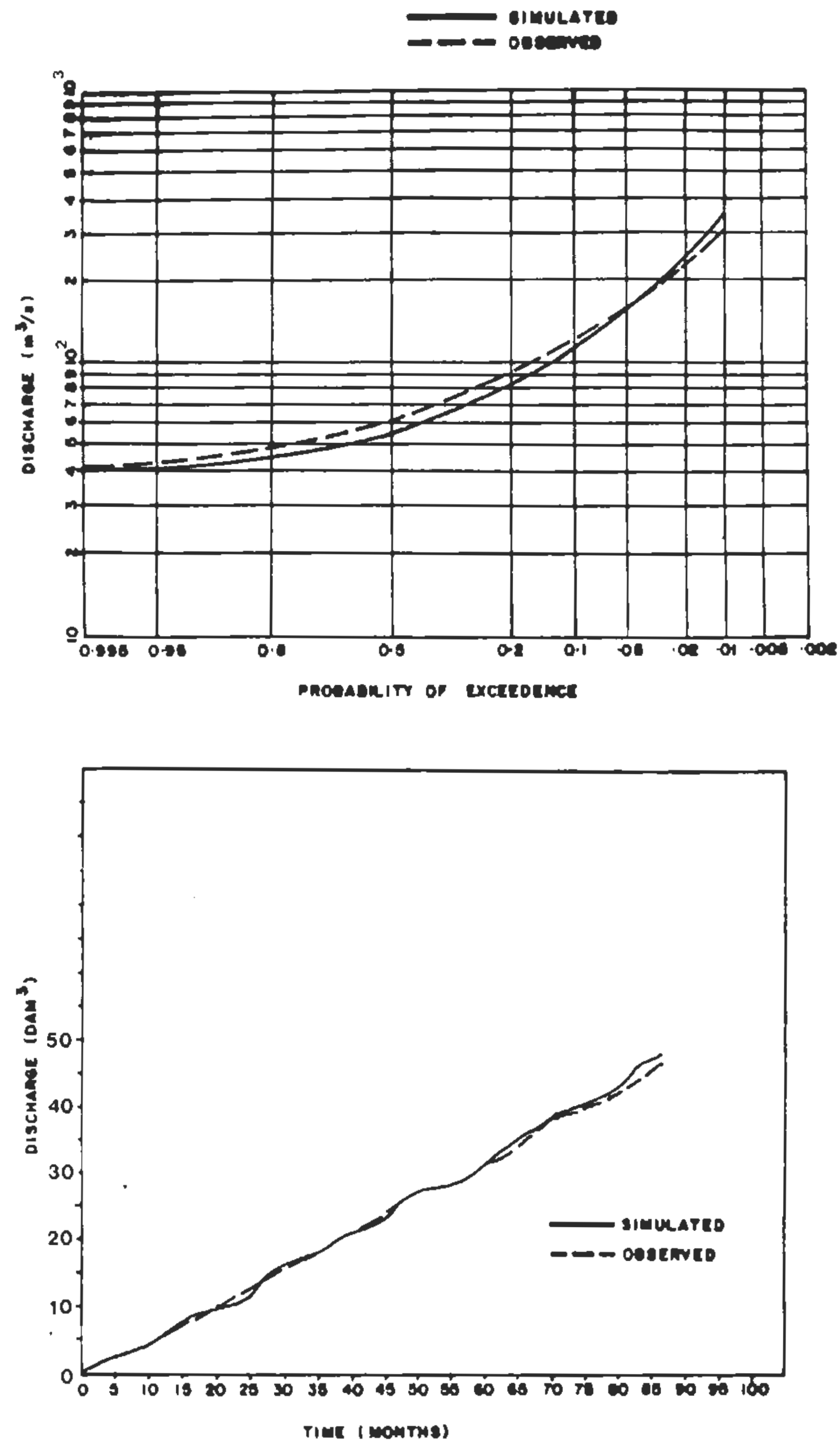
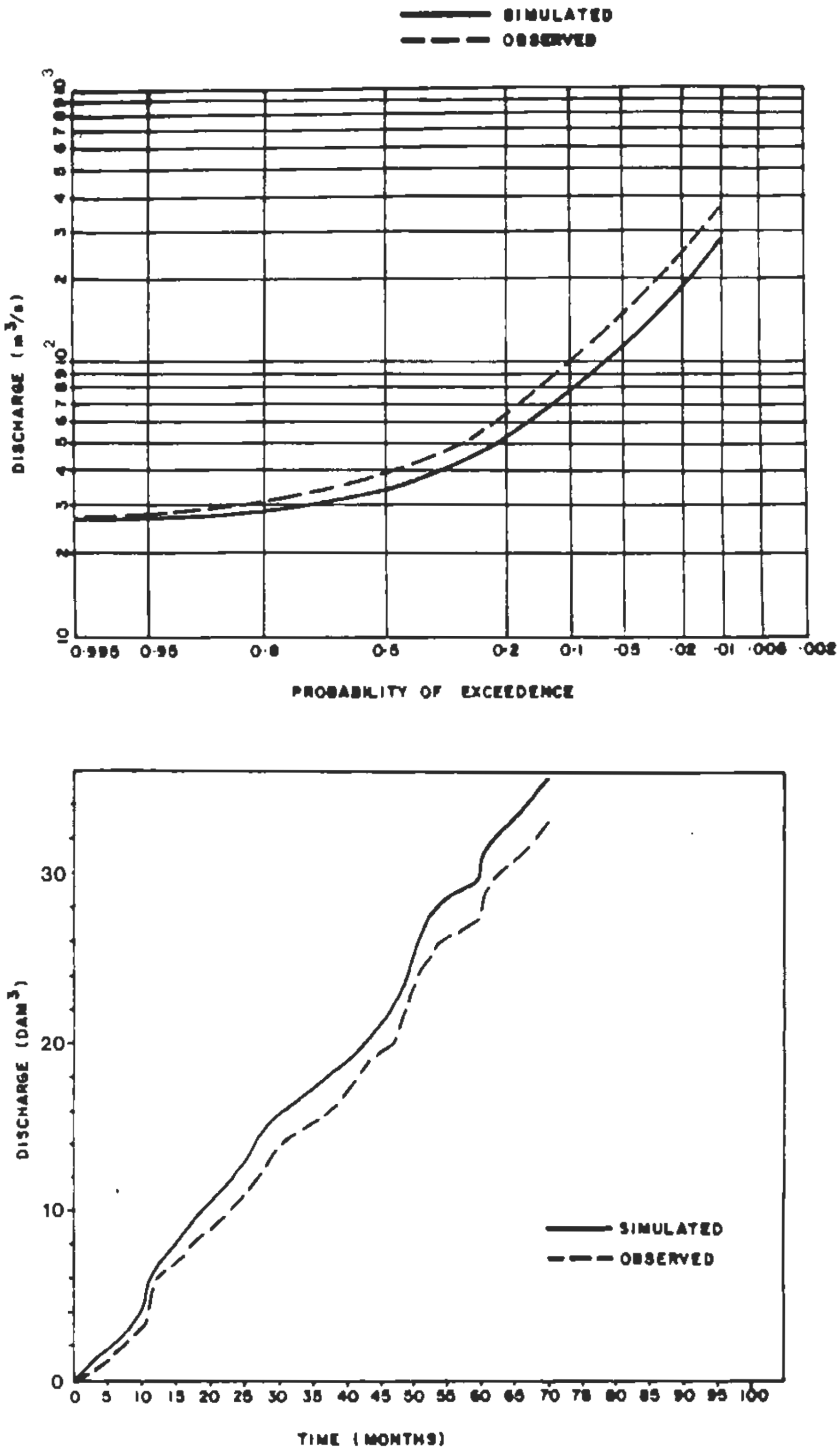
Figure B-6



Partial Duration Series and Cumulative Mass Curves - Lewaseechjeech Bk.

CUMMING-COCKBURN & ASSOCIATES LIMITED

Figure B-7



Partial Duration Series and Cumulative Mass Curves - Hinds Brook

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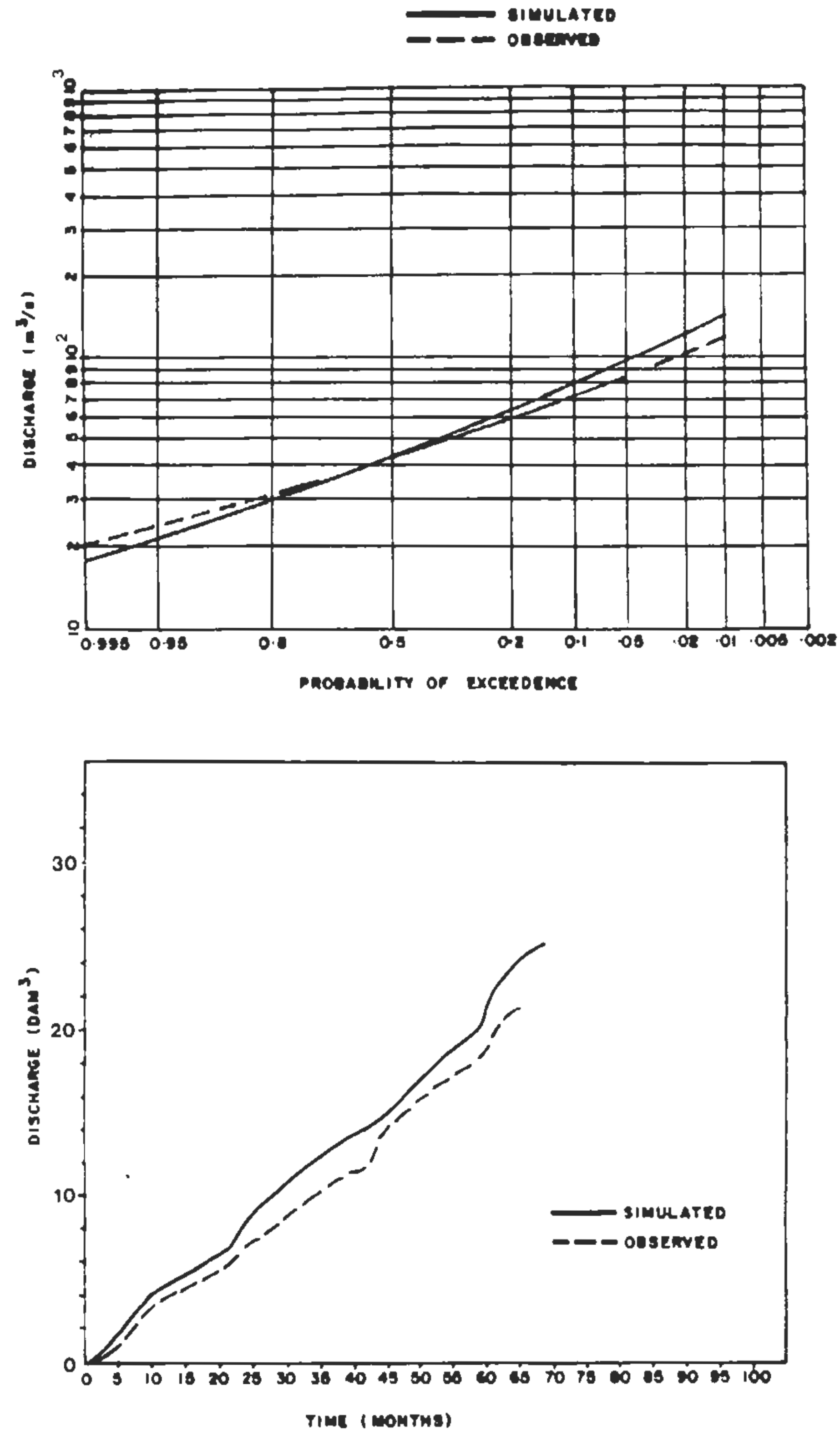
& ASSOCIATES LIMITED

Figure B·8



Partial Duration Series and Cumulative Mass Curves - Sheffield Brook

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& ASSOCIATES LIMITED

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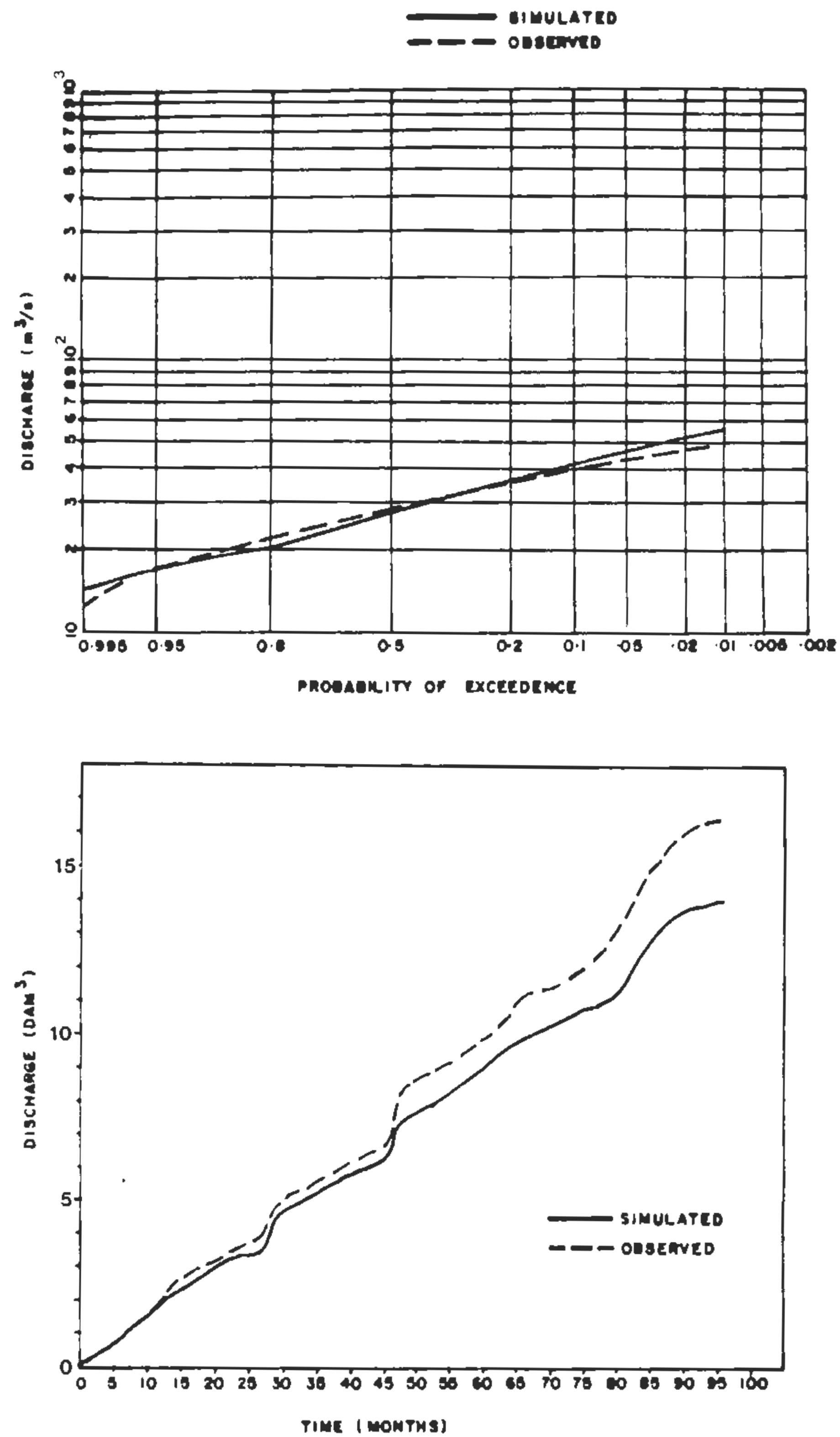
Figure B·9



Partial Duration Series and Cumulative Mass Curves - Indian Brook

CUMMING - COCKBURN
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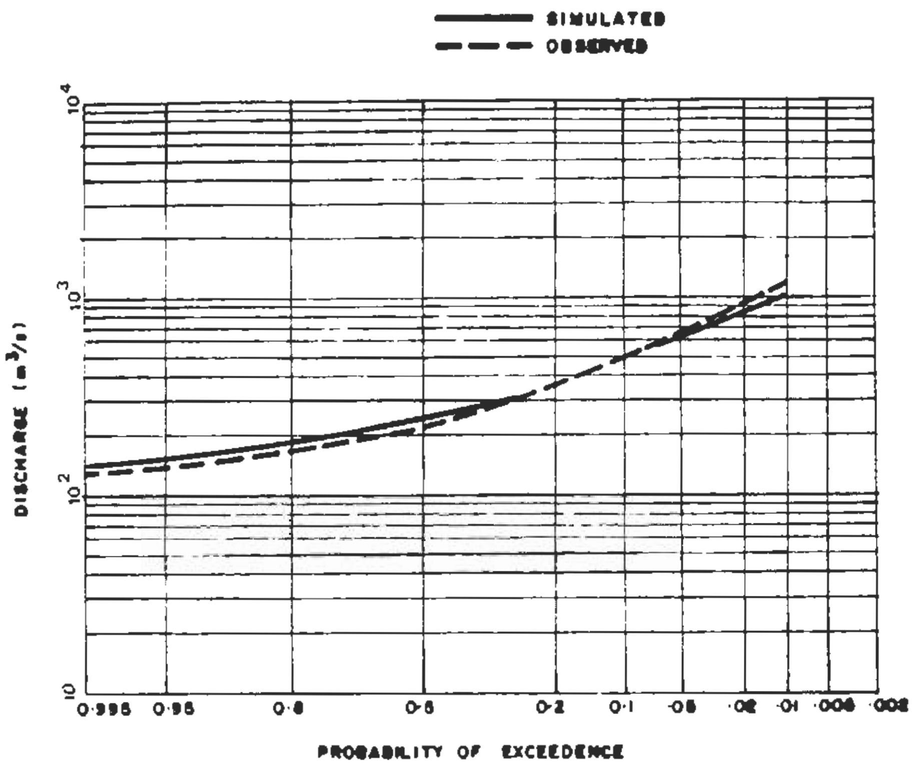
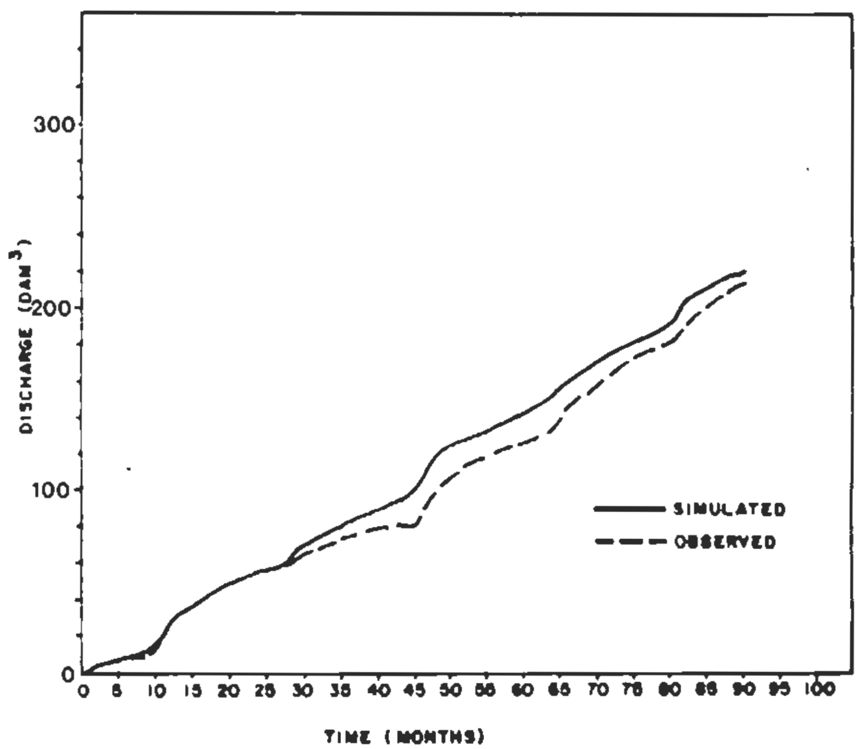
Figure B-10

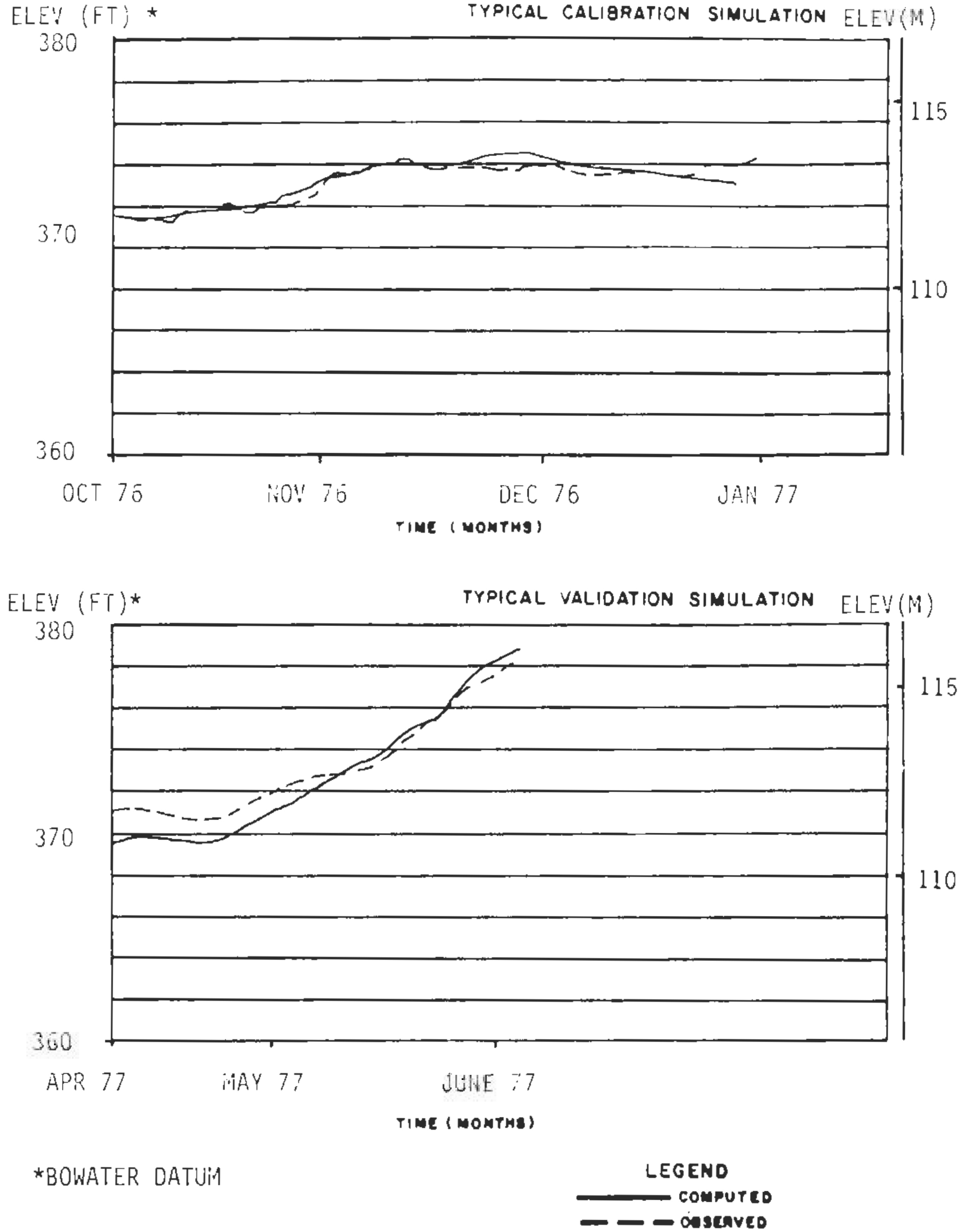




Partial Duration Series and Cumulative Mass Curves - Upper Humber

CUMMING-COCKBURN & ASSOCIATES LIMITED

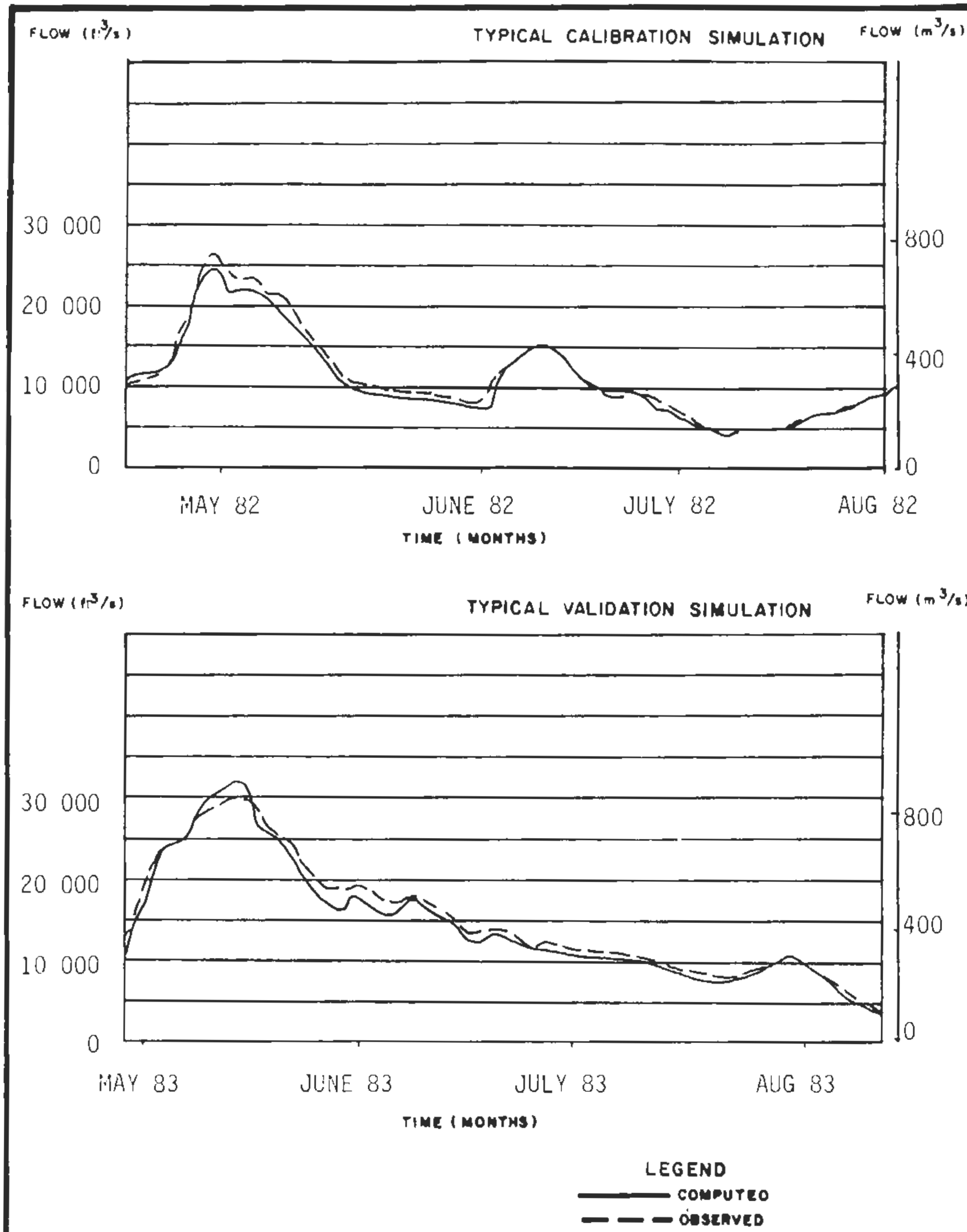
Figure B-11



Observed vs Computed Waterlevels- Grand Lake

CUMMING-COCKBURN & ASSOCIATES LIMITED

Figure B-12



Observed vs Computed Hydrographs - d/s Deer Lake

CUMMING-COCKBURN & ASSOCIATES LIMITED

Figure B-13

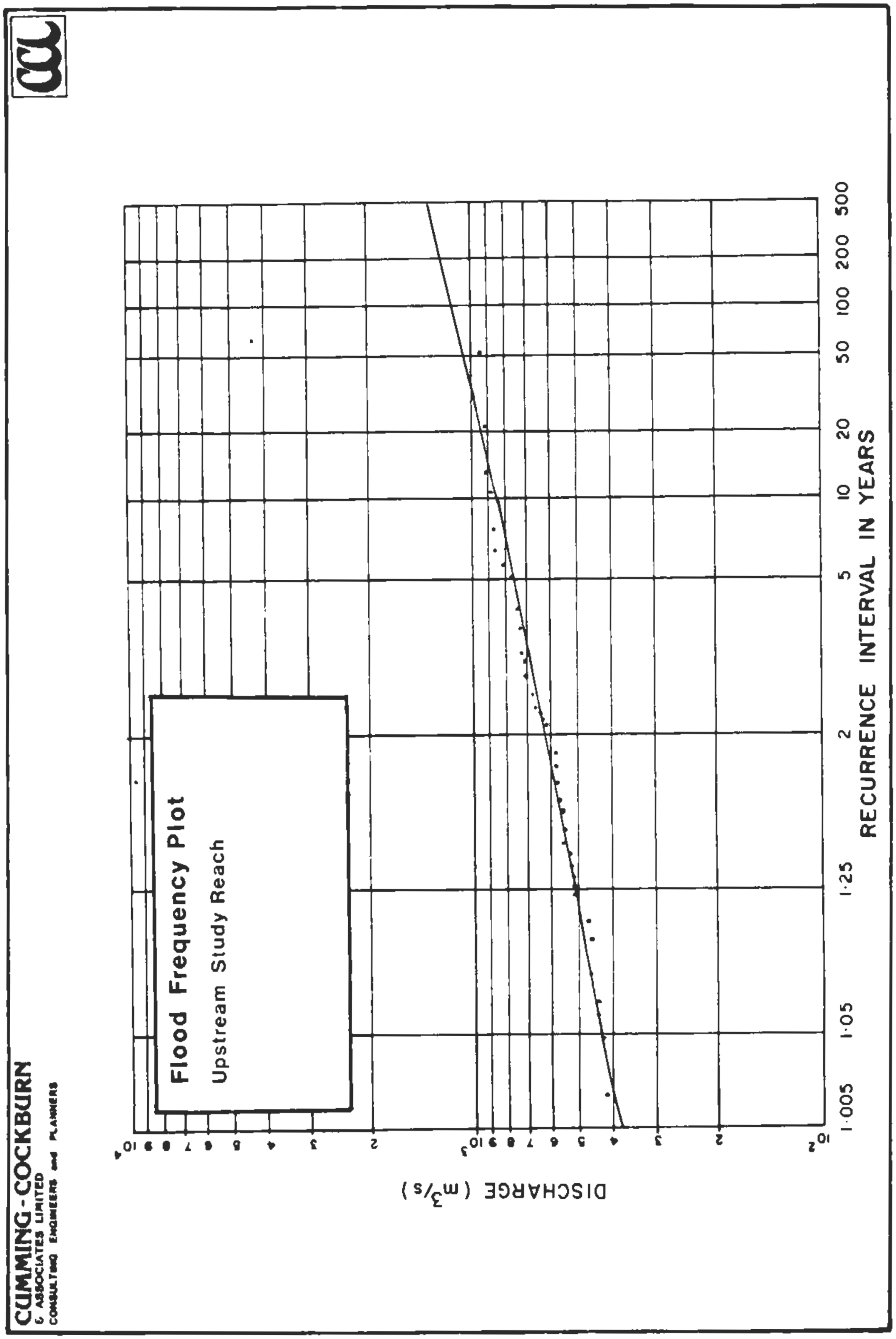

CUMMING-COCKBURN
& ASSOCIATES LIMITED
CONSULTING ENGINEERS and PLANNERS
Flood Frequency Plot
Upstream Study Reach
DISCHARGE (m^3/s)
RECURRENCE INTERVAL IN YEARS
1·005
1·05
1·25
2
5
10
20
50
100
200
500

Figure B.14

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& ASSOCIATES LIMITED
CONSULTING ENGINEERS and PLANNERS

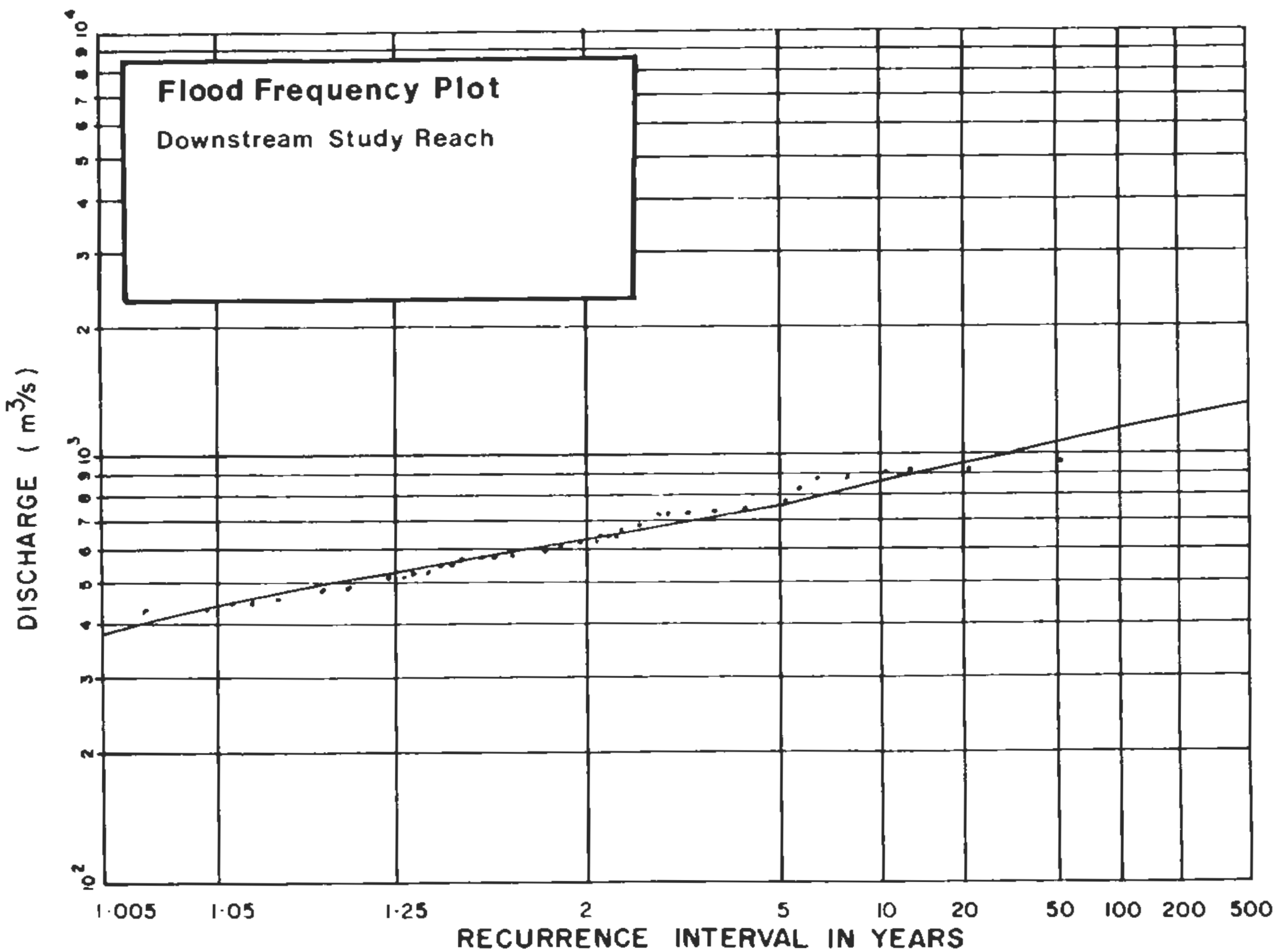

Figure B.15

APPENDIX C

COMPARATIVE PEAK FLOW ESTIMATES

APPENDIX C

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C.1 Regional Flood Frequency Analysis

The Inland Waters Directorate of Environment Canada, in association with the Water Resources Division of the Newfoundland Department of Environment, have recently completed a regional flood frequency analysis for the Island of Newfoundland (27). The details of the prediction equations are given in Tables C.1, C.2 and C.3.

These regional equations were based on recorded natural streamflow data at 21 long-term (greater than 10 years of record) hydrometric stations located throughout the Island. The parameters incorporated into these equations are defined in Table C.4. Also in Table C.4 are the ranges for each parameter over which the equation is valid.

Flood flow estimates at seven locations, assuming natural flow conditions, are listed in Table C.5 using these procedures. Instantaneous flood flows and their associated upper and lower 95% confidence limits are given for recurrence intervals of 1:2, 1:20 and 1:100 years. The average confidence limits for the 1:20 and 1:100 year peak flows were found to be approximately ±42% and ±48% respectively.

The values of each parameter, used in determining the flows, are listed in Table C.6. It should be noted that the values for SHAPE for each of the five sites in the Humber River slightly exceed the parameter range. This has probably not introduced much error. More important is the fact that the drainage areas to these five locations greatly exceed the upper limit of 4400 km^2.

Daily discharge records for the hydrometric stations in the Upper Humber River near Reidville (02YL001) from 1929 to date, and the Humber River at the outlet of Grand Lake (02YK001) from 1926 to date were examined. The mean of the annual maximum daily mean discharges (regulated) recorded at the outlet of Grand Lake for the 57 years of record is approximately 340 m^3/s. The mean of the annual maximum mean daily discharges recorded on the Upper Humber River is approximately 560 m^3/s. Given the facts; that the total drainage area to these sites is some 7130 km^2 and hence about 89% of the drainage area to the Humber River at Humber Arm; that the annual maximum flows from these sites do not often occur on the same day; that the Humber River to Grand Lake is heavily regulated; that some attenuation will occur downstream of these points; and that instantaneous flows will probably be slightly higher than daily mean flows, it can be concluded that the estimate of 852 m^3/s for the two year recurrence interval flood flow (QP_2) downstream of Deer Lake is reasonable.

The peak daily mean flow recorded on the Humber River at Humber Village Bridge (02YL003) since the establishment of the hydrometric station during 1982 was 851 m^3/s (manual gauge with two readings per day) recorded in May 1982. Apparently water levels, and hence flows of the magnitude experienced in 1982 have been exceeded a number of times in the past with the 1981 and 1969 events perhaps being among the largest.

Combining for each year the annual maximum daily mean flows for the hydrometric station in the Upper Humber near Reidville with those for the Humber River at the outlet of Grand Lake, and ignoring the fact that the dates, let alone the months, do not coincide, indicates that the estimated 100 year flood flow (QP_{100}) of 1410 m^3/s at Humber Arm has probably never been experienced in the period of record from 1929 to date. The maximum daily mean discharge obtained in this manner was 1340 m^3/s on May 23, 1969 (the dates coincided in that extreme case).

For these reasons, it was concluded that the estimated instantaneous flood flows as given in Table C.5 are reasonable, assuming that the effect of artificial regulation of Grand Lake can be neglected.

C.2 Frequency Analysis of Deer Lake Water Levels

Table C.7 summarizes maximum observed water levels at the hydroelectric plant tailrace in Deer Lake for the period 1930 to 1982, as obtained from records maintained by the Bowater Power Company.

A frequency analysis of the maximum water levels was undertaken by means of the FDRPFFA flood frequency analysis program (22). It was found that the mean annual flood level in Deer Lake at the tailrace is about 7.21 m (23.66 ft GSC). The 1:2, 1:20 and 1:100 year water levels at the same location were estimated by means of the Three Parameter Log Normal Distribution and were found to be 7.16 m, 8.24 m, and 8.79 m respectively. Figure C.1 presents a frequency plot of Deer Lake levels at the tailrace location.

In addition to historic water levels measured at the hydroelectric plant tailrace, the Bowater Power Company also maintained a stage gauge between 1929 and 1946 at the outlet of Deer Lake (Governors Point). Therefore, the concurrent historic water level measurements at these two locations in Deer Lake were compared in order to determine the head losses between the power plant (long term historic levels), and the outlet of the Lake.

The results of this analysis indicate that there exists an elevation difference in Deer Lake of approximately 0.7 ft. (21 cm) between the tailrace of the power plant and the outlet near Governors Point. This elevation difference was applied to the recurrence interval water levels calculated at the tailrace to obtain equivalent recurrence interval water levels at the outlet of Grand Lake.

At the present time, the Bowater Power Company utilize a rating curve at the outlet of Deer Lake as presented in Figure C.2. This rating curve (BOWATER) relates Deer Lake water levels to peak discharge measured at a location near the outlet of Deer Lake. The BOWATER rating curve was defined in relation to Bowater's datum, which can be converted to geodetic datum using the relationship indicated on Figure C.2.

In order to validate the BOWATER rating curve, the HEC-2 model was utilized to analyse open water and log boom conditions. Figure C.2 compares the results of this analysis with the BOWATER rating curve. It is evident from this figure that for the low flow portion of the curve, the HEC-2 model assuming a log boom closely follows the BOWATER curve. Conversely, for the higher flows, the HEC-2 model (with no logs) is more representative of the BOWATER curve.

We assume that the data points used to derive the BOWATER curve are likely a mixture of log boom and open water conditions at the outlet of the lake. Therefore, because the BOWATER rating curve is based on historic data, and was validated by the HEC-2 model, it is considered to be the best available and adequate for the purposes of this investigation (it was also adopted in the SSARR Model routing through Deer Lake.

However, in order to approximate the estimating error associated with use of the BOWATER rating curve (i.e. a fairly high degree of scatter in the points is evident by reference to Figure C.2), a linear regression of Deer Lake water level versus discharge at the outlet was also undertaken. This relationship for estimating discharge from Deer Lake water level was found to have a standard error of estimate of about 112 m^3/s. (The linear rating curve was only used for comparison purposes and was <u>not</u> further utilized in the investigations.)

The 1:2, 1:20 and 1:100 year water levels computed at the tailrace were adjusted to the outlet of Deer Lake and then converted to discharge amounts using the BOWATER rating curve. The 1:2, 1:20 and 1:100 year peak flows at the outlet of Deer Lake were found to be approximately 632, 1020 and 1246 m^3/s respectively.

C.3 SSARR Single Event Simulation

As discussed in the main text, a secondary flow estimate was also undertaken utilizing the SSARR Model in the single event mode.

The snowmelt analysis was undertaken using an algorithm derived from an energy budget method developed by the U.S. Army Corps of Engineers for forested areas. This algorithm uses recorded meteoroligic data to compute snowmelt amounts for selected recurrence intervals. It is preferred to use recorded meteorologic data because major spring run-off events are usually a combination of rainfall plus snowmelt conditions. Because the meteorologic inputs to such events (rainfall, temperature, snowpack, etc.) are not mutually exclusive (i.e. are somewhat dependent upon each other), their combined probability is not easily calculated.

Therefore, the rainfall plus snowmelt was established by analysis of available data for the meteorologic stations applicable to the Humber River. This analysis was undertaken by staff of AES and uses historical meteorologic data to obtain the 1 to 10 day melt plus rainfall totals available for runoff.

In order to account for the areal distribution pertaining to the snowmelt plus rainfall inputs, the point values at each meteorologic station must be reduced. Unfortunately, no areal reduction factors presently exist and the development of this relationship is beyond the scope of this study. Therefore, areal reduction factors developed for rainfall events (35) were applied to the snowmelt events. The resultant 1:100 year and 1:20 year peak flow estimates are calculated to be 954 m^3/s and 1317 m^3/s respectively. It should be noted that these are somewhat on the high side when compared to SSARR long term simulations. This is as one would intuitively expect, as the single event flow simulation assumes that certain recurrence interval meteorologic events are occurring simultaneously over the entire watershed at all meteorologic stations.

TABLE C.1

Step-Wise Regression Results for $\log_{10} QP_2$ (Island of Newfoundland)

$$\log_{10} QP_2 = k + a \log_{10} DA + b \log_{10} MAR + c \log_{10} ACLS + d \log_{10} SHAPE$$

Regression Parameter Coefficient

Step Number	k	a	b	c	d	SE	Multiple R
1	0.1424	0.7380	0	0	0	0.26	0.90
2	-6.3102	0.8230	2.0363	0	0	0.14	0.97
3	-2.5295	0.7934	1.6307	-1.2654	0	0.11	0.98
4	-2.5824	0.8310	1.7260	-1.3269	-0.7894	0.10	0.99

NOTES:

1. F = 4.5
2. SE = Standard Error of Estimate

TABLE C.2

Step-Wise Regression Results for Log $_{10}QP_{20}$ (Island of Newfoundland)

$$\log_{10}QP_{20} = k + a \log_{10}DA + b \log_{10}MAR + c \log_{10}ACLS + d \log_{10}SHAPE$$

Regression Parameter Coefficient

Step Number	k	a	b	c	d	SE	Multiple R
1	0.4679	0.6916	0	0	0	0.29	0.86
2	-7.0661	0.7909	2.3776	0	0	0.14	0.97
3	-2.8270	0.7576	1.9228	-1.4188	0	0.11	0.99
4	-2.8741	0.7911	2.0077	-1.4736	-0.7031	0.09	0.99

NOTES:

1. F = 4.5
2. SE = Standard Error of Estimate

TABLE C.3

Step-Wise Regression Results for Log $_{10}QP_{100}$ (Island of Newfoundland)

$$\log_{10}QP_{100} = k + a \log_{10}DA + b \log_{10}MAR + c \log_{10}ACLS + d \log_{10}SHAPE$$

Regression Parameter Coefficient

Step Number	k	a	b	c	d	SE	Multiple R
1	0.6300	0.6623	0	0	0	0.31	0.84
2	-7.4743	0.7691	2.5576	0	0	0.15	0.97
3	-3.1059	0.7348	2.0889	-1.4621	0	0.11	0.98
4*	-3.1500	0.7662	2.1684	-1.5134	-0.6581	0.10	0.99

NOTES:

1. F = 4.4
2. SE = Standard Error of Estimate
3. * Lowered F from 4.5 to 4.4 to include SHAPE in equation

TABLE C.4

Parameter Definitions and Ranges

Parameter	Range Within Which the Regression Equations are Applicable
DA	3.9 to 4400 km^2
MAR	788 to 2124 mm
ACLS	55 to 100%
SHAPE	1.24 to 2.45

DA = Drainage area (km^2)

MAR = Mean Annual Runoff (mm)

ACLS = Percentage of Drainage Area Controlled by Lakes or Swamp (from 1:50,000 scale maps)

SHAPE* = $\frac{0.28 \times \text{Basin Perimeter (km) from 1:50,000 NTS maps}}{\sqrt{DA}}$

* SHAPE parameter is taken from Chow's Handbook of Hydrology

TABLE C.5

Estimated Instantaneous Natural Flood Flows

Location	Drainage Area (km²)	QP_2 (m^3/s) -95%	QP_2 (m^3/s)	QP_2 (m^3/s) +95%	QP_{20} (m^3/s) -95%	QP_{20} (m^3/s)	QP_{20} (m^3/s) +95%	QP_{100} (m^3/s) -95%	QP_{100} (m^3/s)	QP_{100} (m^3/s) +95%
Humber River at Humber Arm	7990	524	873	1310	771	1240	1830	811	1410	2170
Humber River downstream of Steady Brook	7980	523	871	1310	769	1240	1820	810	1410	2170
Humber River upstream of Steady Brook	7900	511	852	1280	750	1210	1780	793	1380	2130
Humber River at Humber Village Bridge (Lundrigan's Bridge) WSC Stn. #02YL003	7860	511	852	1280	750	1210	1780	793	1380	2130
Humber River at outlet of Deer Lake	7830	511	852	1280	750	1210	1780	793	1380	2130
Steady Brook at confluence with Humber River	81.4	35.6	59.4	89.2	65.2	105	155	76.8	134	206
Steady Brook at Water Supply Pump House	76.5	32.3	53.9	80.9	58.8	94.9	140	69.2	171	186

TABLE C.6

Watershed Parameters Determined for Selected Sites

Location	DA (km^2)	MAR (mm)	ACLS %	SHAPE (-)
Humber River at Humber Arm	7990	1110	99	2.60
Humber River downstream of Steady Brook	7980	1110	99	2.60
Humber River upstream of Steady Brook	7900	1110	99	2.64
Humber River at Humber Village Bridge	7860 WSC	1110	100	2.61
Humber River at outlet of Deer Lake	7830	1110	100	2.59
Steady Brook at confluence with Humber River	81.4	1100	57	1.56
Steady Brook at Water Supply Pump House	76.5	1100	60	1.52

TABLE C.7

Annual Maximum Deer Lake Elevations*

Year	Maximum (ft.)	Lake Level (m)	Year	Maximum (ft.)	Lake Level (m)
1930	116.0	35.4	1957	112.1	34.2
1931	112.6	34.3	1958	112.0	34.1
1932	112.9	34.4	1959	111.7	34.0
1933	115.0	35.0	1960	113.4	34.6
1934	119.4	36.4	1961	113.6	34.6
1935	111.9	34.1	1962	115.8	35.3
1936	116.9	35.6	1963	117.5	35.8
1937	114.6	34.9	1964	113.0	34.4
1938	111.7	34.0	1965	113.6	34.6
1939	114.0	34.7	1966	114.2	34.8
1940	113.9	34.7	1967	112.7	34.3
1941	115.2	35.1	1968	112.2	34.2
1942	114.9	35.0	1969	118.5	36.1
1943	112.6	34.3	1970	114.0	34.7
1944	113.5	34.6	1971	116.0	35.4
1945	116.5	35.5	1972	116.5	35.5
1946	115.5	35.2	1973	114.3	34.8
1947	114.8	35.0	1974	113.2	34.5
1948	117.4	35.8	1975	114.0	34.7
1949	114.2	34.8	1976	115.9	35.3
1950	113.7	34.6	1977	115.4	35.2
1951	110.7	33.7	1978	113.3	34.5
1952	113.5	34.6	1979	112.6	34.3
1953	112.8	34.4	1980	114.0	34.7
1954	114.0	34.7	1981	116.9	35.6
1955	111.1	33.9	1982	116.4	35.5
1956	113.6	34.6			

Source : The Bowater Power Company Limited

* Bowater Datum

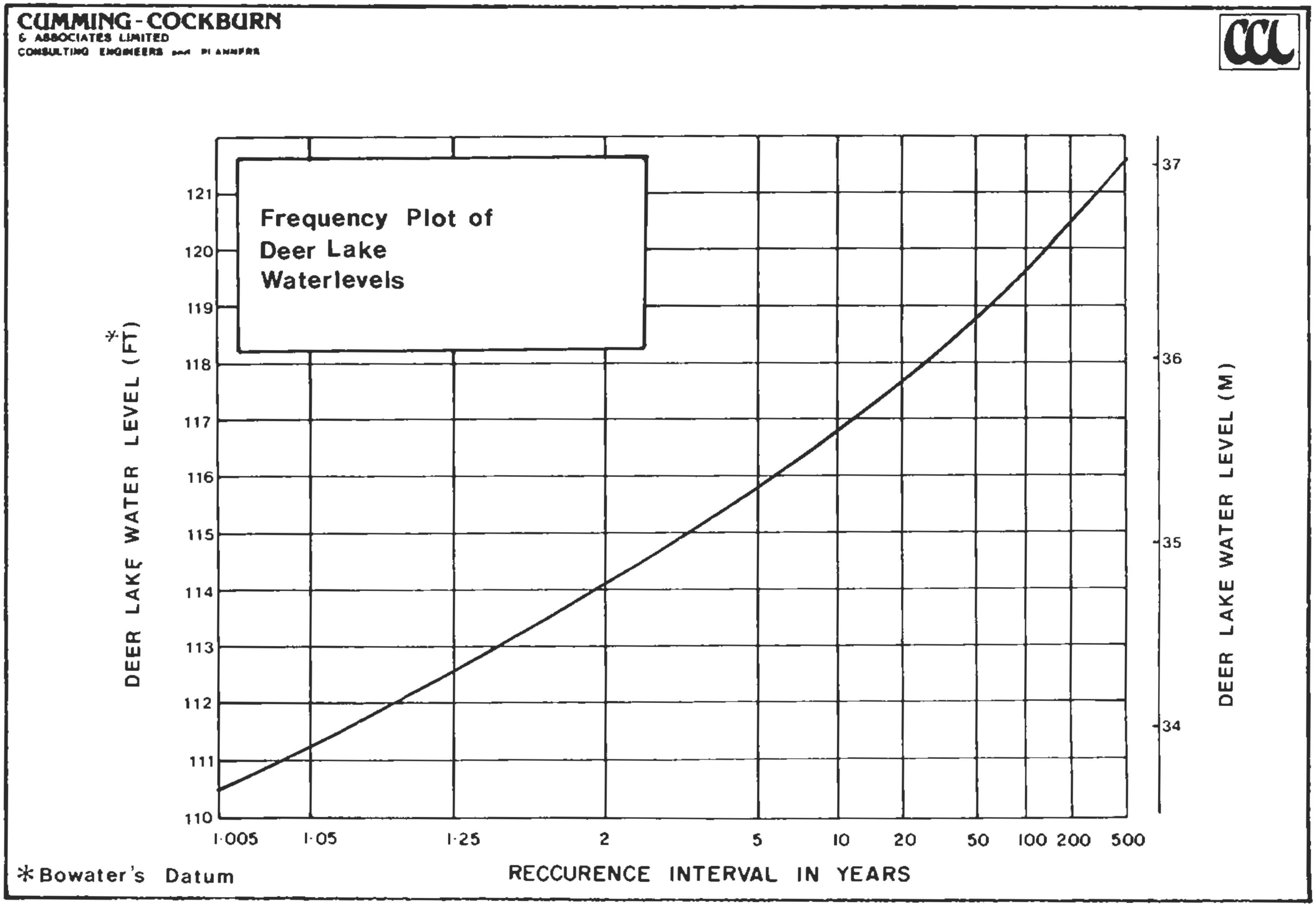
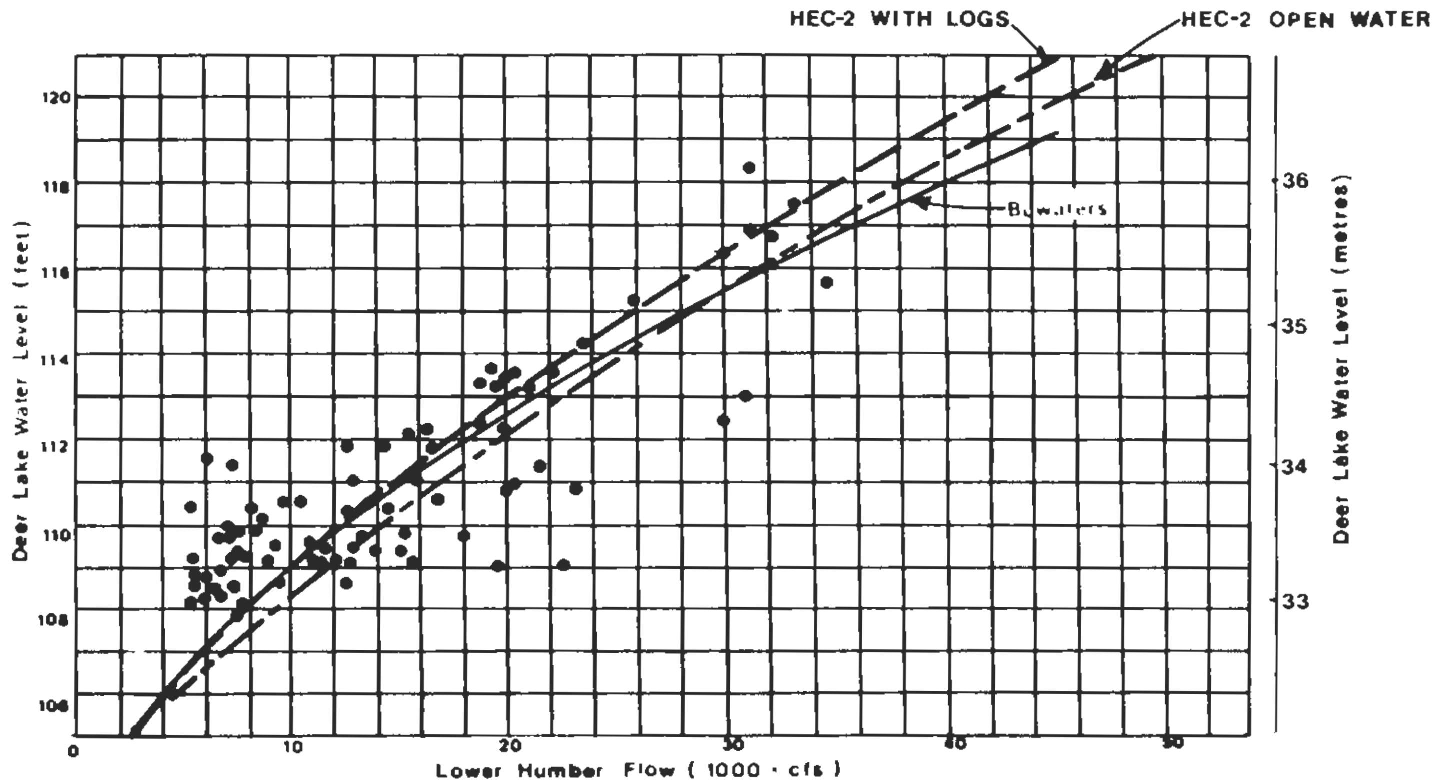

CUMMING-COCKBURN
& ASSOCIATES LIMITED
CONSULTING ENGINEERS and PLANNERS
Frequency Plot of
Deer Lake
Waterlevels
DEER LAKE WATER LEVEL (FT)*
121
120
119
118
117
116
115
114
113
112
111
110
1·005
1·05
1·25
2
5
10
20
50
100
200
500
RECCURENCE INTERVAL IN YEARS
37
36
35
34
DEER LAKE WATER LEVEL (M)
*Bowater's Datum

Figure C.1



Note: Deer Lake water levels referenced to Bowater datum
Subtract 90.6 feet for geodetic elevation.

Source Bowater Power Company Ltd.

Canada-Newfoundland
Flood Damage Reduction Program

Deer Lake
Stage - Discharge Curve

Nolan Davis
& Associates Ltd

Cumming Cockburn
& Associates Limited

Figure C.2

APPENDIX D

DETERMINISTIC HYDROLOGIC ANALYSES

STEADY BROOK

APPENDIX D

DETERMINISTIC HYDROLOGIC ANALYSIS - STEADY BROOK

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APPENDIX D

HYDROLOGIC ANALYSIS - STEADY BROOK

D.1 General

The HYMO model is a single event model and is capable of taking into account the following factors:

1. Can model time characteristics of unit hydrographs.
2. Can account for variations within the watershed in soil types and land use characteristics.
3. Can account for antecedent soil moisture conditions.
4. Can provide peak flow estimates based on rainfall and snowmelt inputs.

In addition, this model has previously proven capabilities for simulating peak flows in a number of other practical applications for various watersheds with hydrologic characteristics similar to Steady Brook (e.g. see Ref. 13, 14).

The input requirements for this model include both meteorological (rainfall/snowmelt) data and physiographic characteristics (land use, time to peak values, constituent soil characteristics, etc.) of the study area.

The following sections describe the hydrologic procedures used in the development and application of the HYMO model in the determination of secondary flow estimates for the Steady Brook watershed.

D.2 HYMO Model Structure

In order to transform the meteorological input into runoff hydrographs, the HYMO program uses a synthetic unit hydrograph technique and the U.S. Soil Conservation Service rainfall-runoff relationships (51).

The program generates a hydrograph for each selected sub-drainage area of the watershed. The hydrographs, beginning at the upstream end of the basin, are added together and routed downstream until the storm event hydrograph at the outlet of the entire watershed is obtained.

It can be seen from Figure 1.2 that the study reach only includes the extreme downstream portion of Steady Brook. As such, the HYMO model required to simulate the response of the Steady Brook watershed only requires one subcatchment in order to determine peak flow estimates for that reach of Steady Brook within the study area.

The watershed boundary (see Figure 3.6) was determined through examination and interpretation of existing 1:50,000 scale mapping of the study area. This mapping was used to measure the drainage area, slopes and land-use characteristics, etc. The watershed area was found to be 81.4 km^2 to the confluence of the Brook with the Humber River in the Community of Steady Brook.

D.3 Meteorologic Input Data

High runoff and flow conditions in the watershed are primarily generated as a result of rainfall, snowmelt and/or rain on snow conditions. However, severe rainstorm events can also occur resulting in extreme flow conditions.

The design storm pattern used in the deterministic computer model was based on an analysis of recorded events at two meteorologic stations in the Province (St. John's and Gander, Newfoundland) (4). The temporal distribution derived by the Atmospheric Environment Service interpretation of 6-12 hr. rainstorms was also compared in a previous study (14) with an analysis of severe recorded events which have occurred in the vicinity of the study area (9). It was found that the AES temporal distribution derived for Gander and St. John's gave close agreement to that derived from recorded historical events, with the former analysis resulting in slightly higher peak flows. Therefore, it is recommended that the AES temporal distribution should be used in this study.

For the purposes of this analysis, no areal reduction factors were applied to the rainfall amounts due to the relatively small size of the Steady Brook watershed. This was based on a review of historical storms which occurred in the area and was substantiated by previously computed relationships between drainage area and rainfall reduction factors.

The 12-hour temporal distribution was used based on an analysis of the time of concentration of the Steady Brook watershed. From empirical equations, it was determined that the time of concentration for the Steady Brook watershed at the outlet is approximately 5 hours. Peak flow simulations using 6-hour and 24-hour storm distributions resulted in insignificantly lower peak discharge values which also confirms the use of a 12-hour storm distribution.

A comparison of the 12-hour design storm pattern can be found in Table D.1.

The total point rainfall was obtained from Rainfall-Intensity-Duration Frequency (RIDF) curves derived from the meteorologic station at Deer Lake Airport. The resulting total rainfall for the 1:100 and 1:20 year 12-hour storms was found to be 67.1 mm and 56.3 mm respectively, with associated standard errors within ±10% at the 50% confidence levels (based on 16 years of data).

D.4 Hydrologic Input Parameters

D.4.1 Time to Peak and Recession Constant

In order to simulate the response of a specific watershed to a rainfall event using the HYMO procedures, two unit hydrograph parameters must first be established. They are the time to peak and the recession constant for the unit hydrograph. The following describes the various methods used to develop these parameters:

a) The assessment of the time to peak parameter, T_p, for the subwatershed involved the application of the following equation developed for HYMO (54):

$$T_p = 4.63\ DA^{0.422}\ SLP^{-0.46}\ (L/W)^{0.133} \qquad (D.1)$$

where : DA = area of watershed (mi^2)
SLP = slope of watershed (ft/mi)
L = length of watershed (mi)
W = width of watershed (mi)

b) The initial determination of the hydrograph recession constant, K, involved the application of the following equation as given in the publication on the program HYMO (54):

$$K = 27.0\ DA^{0.231}\ SLP^{-0.777}\ (L/W)^{0.124} \qquad (D.2)$$

where DA = watershed area (mi^2)
L = watercourse length (mi)
SLP = slope of watercourse (ft/mi)
W = width of watershed (mi)

NOTE: The above equations were originally (empirically) developed using the English system of units.

D.4.2 Soil Cover Complex Number

A runoff index factor combining the hydrologic soil group and land use characteristics is referred to as a hydrologic soil cover complex number, CN. Simulated runoff volumes are proportional to the complex number according to the following rainfall-runoff relationship:

$$Q = \frac{(P - 0.2s)^2}{P + 0.8s} \qquad (D.3)$$

where P = precipitation amount (inches)

$s = \frac{1000}{CN} - 10$

Q = amount of runoff (inches)

(Equation D.3 was originally developed in English units. To convert the amount of runoff to millimetres, multiply by 25.4).

Using the available land use information (as interpreted from 1:50,000 scale maps), and soils information, as interpreted from surficial geology maps (scale 1:30,000) available from the Newfoundland Department of Mines and Energy (19), the average soil cover complex number was determined for the watershed (refer to Table D.2 for typical soil cover complex numbers). The average soil cover complex number of the Steady Brook watershed is 76 and 89 for AMC II and AMC III respectively (the relationship of AMC II to AMC III condition is given in Table D.3).

As mentioned in Section 3.3 of the Main Report, insufficient data exists for estimating the antecedent soil moisture conditions for a number of historical peak flow events. However, previous analyses (14) on nearby, similar watersheds have indicated that AMC III is somewhat more representative of the soil conditions in this area of Newfoundland. (AMC III represents saturated soil conditions.)

D.5 Sensitivity Analysis

The peak flow rate for the dimensionless unit hydrograph is estimated by the following equation (51, 53):

$$q_p = \frac{b \cdot DA \cdot Q}{T_p} \qquad (D.4)$$

where b = watershed unit hydrograph parameter estimated as a function of K and T_p

DA = drainage area (mi^2)

Q = volume of runoff (inches)

T_p = time to peak (hrs)

q_p = unit hydrograph peak flow rate (ft^3/s)

(To convert q_p to m^3/s divide by 35.31)

The model sensitivity to variations in input parameters was tested by varying the estimated parameters within prescribed ranges. Previous work in similar watersheds (14) has indicated that the available model procedures can accurately estimate the time to peak of the unit hydrograph. Therefore, for simplicity, this parameter was kept constant throughout the sensitivity analyses.

One parameter which has a direct influence on the peak magnitude of the unit hydrograph is the "b" value. (The "b" value is a function of K and T_p.) This parameter is reflective of the "peakiness" of a unit hydrograph. To check the parameter sensitivity, the "b value" for the Steady Brook watershed was adjusted ±20%, which is a realistic variation based on experience in other applications (14). It was evident from the results of the simulations that the peak discharges for the 1:100 year event at the watershed outlet vary approximately +5% and -8% corresponding to ±20% changes to the b values.

The effect of changing the antecedent soil moisture condition on estimated peak flows was also analysed. Saturated conditions (AMC III) were originally selected based on historical flood events on nearby watersheds. It was found that the peak flows for a 1:100 year rainstorm event are reduced by an average of 56% when an AMC II condition (representative of drier soil conditions) is assumed.

TABLE D.1
Rainfall Distribution Comparison
for the 12-hour Design Storms (a)

Time (hours)	(b) Design Storm Distribution Estimated by Analysis of Historical Events (%)	(c) AES 12-hour Design Storm Distribution (%)
0 - 1	3	5
1 - 2	11	8
2 - 3	8	8
3 - 4	6	10
4 - 5	11	10
5 - 6	13	14
6 - 7	9	13
7 - 8	13	8
8 - 9	10	10
9 - 10	9	8
10 - 11	6	4
11 - 12	1	2
	100	100

Notes:

(a) Percent of total rainfall over 12-hour period.
Distribution given reflects the percentage of the total rainfall that falls over the period

(b) Source - Analysis of historical rainfall events by CCL, 1983

(c) Source - Analysis by Environment Canada (2)

TABLE D.2

Summary of Typical Runoff Curve Numbers

Land Use	Hydrologic Soil Group*				
	B	BC	C	CD	D
Residential	85	88	90	91	92
Row Crop	71	74	78	79	81
Forest	66	71	77	80	83
Pasture	69	74	79	82	84

* Based on Antecedent Moisture Condition II

Source: Reference (51)

TABLE D.3

Relationship Between AMC II and AMC III

CN for AMC II	Corresponding CN for AMC III
100	100
95	98
90	96
85	94
80	91
75	88
70	85
65	82
60	78
55	74
50	70
45	65
40	60
35	55
30	50
25	43
20	37
15	30
10	22
5	13

AMC II The average condition
AMC III Highest runoff potential. Soils in the watershed are saturated from antecedent rains

Source: Reference (51)

APPENDIX E

SUMMARY OF COMPUTED

WATER SURFACE ELEVATIONS

APPENDIX E

SUMMARY OF COMPUTED WATER SURFACE ELEVATIONS

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APPENDIX E

SUMMARY OF COMPUTED WATER SURFACE ELEVATIONS

Tables E.1 and E.2 present a tabular summary of the 1:20 and 1:100 year flood elevations for the Humber River and Steady Brook respectively. Refer to Figures 4.3 and 4.4 for approximate cross-section locations for the Humber River and Steady Brook respectively, and to Figures 4.8 and 4.9 for the corresponding hydraulic profiles.

The areal extent of the flood prone areas are delineated on 1:2500 scale topographic maps for the study area.

APPENDIX E

TABLE E.1

Summary of Computed Water Surface Elevations

- Humber River -

Section No.	Location/ Description	1:20 Yr.Water Level (m) Free Flow Condition	1:100 Yr.Water Level (m) Free Flow Condition	Using Upper 95 C.L. Discharge
119.0	D/S Study limit	5.6	6.3	7.2
120.0		5.7	6.4	7.3
121.0		5.7	6.5	7.4
122.0	Mitchell Property - Gauge Site #8 (Humber River /Steady Bk. Conflu.)	5.8	6.5	7.4
123.0		5.8	6.5	7.4
221.0	Thistle Property - Gauge Site #7	5.9	6.7	7.6
222.0		6.0	6.8	7.6
223.0		6.0	6.8	7.7
224.0		6.0	6.8	7.7
225.0		6.0	6.8	7.7
226.0	Lundrigan Property - Gauge Site #6	6.0	6.8	7.7
227.0		6.0	6.8	7.7
228.0		6.1	6.8	7.7
229.0		6.1	6.9	7.7
2210.0		6.1	6.9	7.8
2211.0		6.1	6.9	7.8
2212.0		6.1	6.9	7.8
2213.0		6.2	6.9	7.8
2214.0	Humber Village Bridge (approx. WSC gauge location)	6.2	6.9	7.8
2214.1		6.2	6.9	8.0
2215.0		6.4	7.1	8.2
2216.0		6.4	7.2	8.2
2218.0		6.4	7.2	8.3

TABLE E.1 (cont'd)

Section No.	Location/ Description	1:20 Yr.Water Level (m) Free Flow Condition	1:100 Yr.Water Level (m) Free Flow Condition	Using Upper 95 C.L. Discharge
2219.0	Humber Village Bridge (approx. WSC Gauge Location)	6.5	7.2	8.3
2220.0		6.5	7.2	8.3
2221.0		6.5	7.2	8.3
2222.0		6.5	7.3	8.3
2223.0		6.5	7.4	8.4
2224.0		6.7	7.4	8.4
2225.0		6.8	7.5	8.6
2226.0		6.8	7.5	8.6
2227.0	Strawberry Hill - Gauge Site #5	6.8	7.6	8.6
2229.0		7.1	7.8	8.8
2230.0		7.4	8.1	9.0
2231.0		7.7	8.4	9.2
2232.0		7.9	8.6	9.5
2233.0		8.0	8.6	9.6
2235.0	Deer Lake Outlet	8.1	8.8	9.8
2236.0		8.1	8.8	9.8
2237.0	Boom Siding Wharf - Gauge Site #4	8.1	8.8	9.8

TABLE E.2

Summary of Computed Water Surface Elevations

- Steady Brook -

Section No.	Location/ Description	1:20 Yr.Water Level (m) Free Flow Condition	1:100 Yr.Water Level (m) Free Flow Condition	Using Upper 95 C.L. Discharge
-121.0	Steady Brook Outlet at Humber River	5.7	6.5	7.4
302.0		5.7	6.5	7.4
303.0	Gauge Site #9 Near Falls Ave.	5.8	6.5	7.4
304.0		6.0	6.6	7.4
305.0	C.N.R. Trestle	6.4	6.6	7.4
305.1		6.7	6.9	7.4
306.0		7.0	7.3	7.9
307.0		8.6	8.8	9.1
308.0		11.6	11.8	12.3
309.0	Trans-Canada Highway	12.3	12.6	13.2
309.1		12.4	12.6	13.2
310.0		12.4	12.7	13.2
311.0		15.3	15.5	16.0
312.1	Old Trans-Canada Hwy.	16.4	16.8	17.5
312.2		17.0	17.4	18.1
312.0	U/S Study Limit at Pumphouse	17.5	17.9	18.8