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Canada – Newfoundland
Flood Damage Reduction
Program

Hydrotechnical Study of the Badger and Rushy Pond Areas

MAIN REPORT

FENCO NEWFOUNDLAND LIMITED

Department of Environment

Environment Canada

Fenco Newfoundland

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July 17, 1985

Canada-Newfoundland Flood Damage
Reduction Program
c/o Department of Environment
P.O. Box 4750
St. John's, Newfoundland
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Attention: Mr. Robert Picco, P. Eng.
Project Engineer

Dear Mr. Picco,

BADGER AND RUSHY POND HYDROTECHNICAL STUDY

We are pleased to submit 50 copies of our final report on this hydrotechnical study of the Badger and Rushy Pond area.

The report summarizes the results of our field investigations, and our studies to identify flood prone areas of Badger and Rushy Pond, and damage reduction alternatives for Badger. The first chapter presents a concise summary of our findings and subsequent chapters provide the details.

It has been a pleasure for our staff to work with you and the other members of the Flood Risk Technical Committee in carrying out this study. We thank you for your assistance and constructive comments throughout its progress. We also acknowledge the help of the staff and residents of the Town of Badger, and the staff of the many other agencies who provided their assistance.

We look forward to being of service to you again in the near future.

Yours very truly,
Fenco Newfoundland Limited

Eric Gray.

Eric Gray, P. Eng.
PRESIDENT

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TABLE OF CONTENTS

TABLE OF CONTENTS (contd)

TABLE OF CONTENTS (contd)

TABLE OF CONTENTS (contd)

LIST OF TABLES

LIST OF TABLES (contd)

LIST OF TABLES (contd)

LIST OF FIGURES

LIST OF FIGURES (contd)

1.0 SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS OF STAGE I

1.1 Introduction

The Town of Badger and the Rushy Pond area have both experienced flooding in the past. Although the origin of flooding in both locations has been the Exploits River, the causes and effects of the flooding are different at each site. The sites are also separated by about 25 km, and for all intents and purposes, the evaluation of the flooding problem has entailed a separate study at each site. Common factors to both sites are summarized below and in the enclosed text. Similarly, factors of importance to each individual site have been assembled and summarized for each location on its own.

Since initiation of the project in January 1984, considerable effort has been focused on obtaining high quality field data at both sites during three extended periods in the winter season and in the open water season. Over 50 km of river were monitored throughout the winter of 1984 and 33 km were surveyed in the winter and summer months.

This data was then combined with that from many other local and provincial sources to provide accurate information for the analysis of past flooding problems. This in turn enabled projection of the 1:20 year and 1:100 year flood levels at both locations and evaluation of flood damage reduction alternatives at Badger.

1.2 Badger

1. It has been confirmed that open water flood levels do not reach the same flooding stage which is reached by winter ice conditions.

2. It has been determined that the winter flooding at Badger is caused by very rapid production of frazil slush which obstructs the flow on the Exploits River. This obstruction is thought to result from the mass of frazil slush combining with a collapse/shove of the ice cover, but no direct observation evidence is available to confirm this.

3. The conditions which lead to flooding have been simulated by a numerical, ice progression model prepared for use in the study and for the Technical Committee. The development of the ice cover on the Exploits River has been modelled over more than a 30 year time period and causal factors of this flooding (rate of ice progression) are clearly identified.

4. Frequency analysis of the annual series of ice progression rates at Badger have been conducted to give one estimate of the 1:20 and 1:100 year flood elevation in Badger.

5. Historical observations of flood levels have also been analysed to give another and confirming estimate of the 1:20 and 1:100 year level. The results of the two analyses are in close agreement and give a 1:20 year level of 99.48 metres and 1:100 year level of 100.36 metres at the centre of the Town of Badger. The area affected by the 100-year flood is shown in Figure 1.1.

6. The 1:100 year level is at an elevation which is approximately 0.4 metres higher than the 1983 level. The 1:100 year level will result in flood damage to 73 buildings in Badger as compared to about 40 for the 1983 event. The estimated direct damage resulting from the 1:100 year flood would be about $ 151,300 in 1984 dollars. Over the long term the average annual flood damage at Badger is projected to be $4,563.

1.3 Rushy Pond

1. It has usually been considered that flooding in the Rushy Pond area has been caused by high flow during open water conditions. This has been the case in some historical events that have been modelled using a validated backwater model.

2. The highest flooding level on record (1983), as well as the majority of other past floods took place when ice was present on the river. Flood levels during these events cannot be replicated under the assumption of open water flooding and it is concluded that ice blockages control flood levels at Rushy Pond as well as at Badger. Ice blockages have been noted in the study area and the reported location is generally given as the reach between the Red Cliff Overpass and the mouth of Sandy Brook (Figure 2.2).

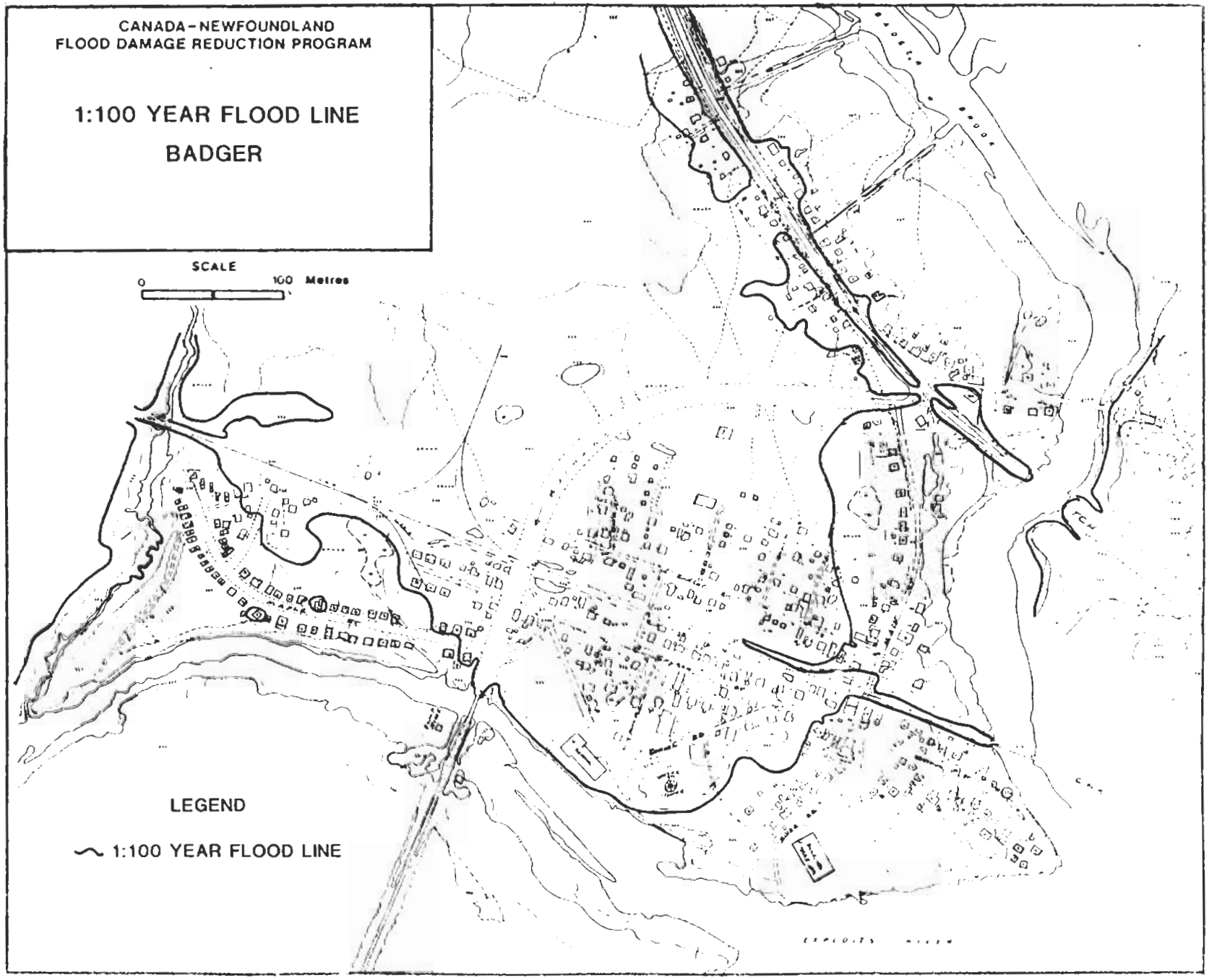

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
1:100 YEAR FLOOD LINE
BADGER
SCALE
0
100 Metres
LEGEND
1:100 YEAR FLOOD LINE

FIGURE 1.1

3. Ice jams/blockages in the Rushy Pond area cannot be accurately simulated by available mathematical models to enable projections of 1:20 and 1:100 year flood levels. The frequency of flood levels have, however, been analysed using historical information, and it is confirmed that the 1:100 year levels at the TCH as well as the 1:20 year level result from ice blockages.

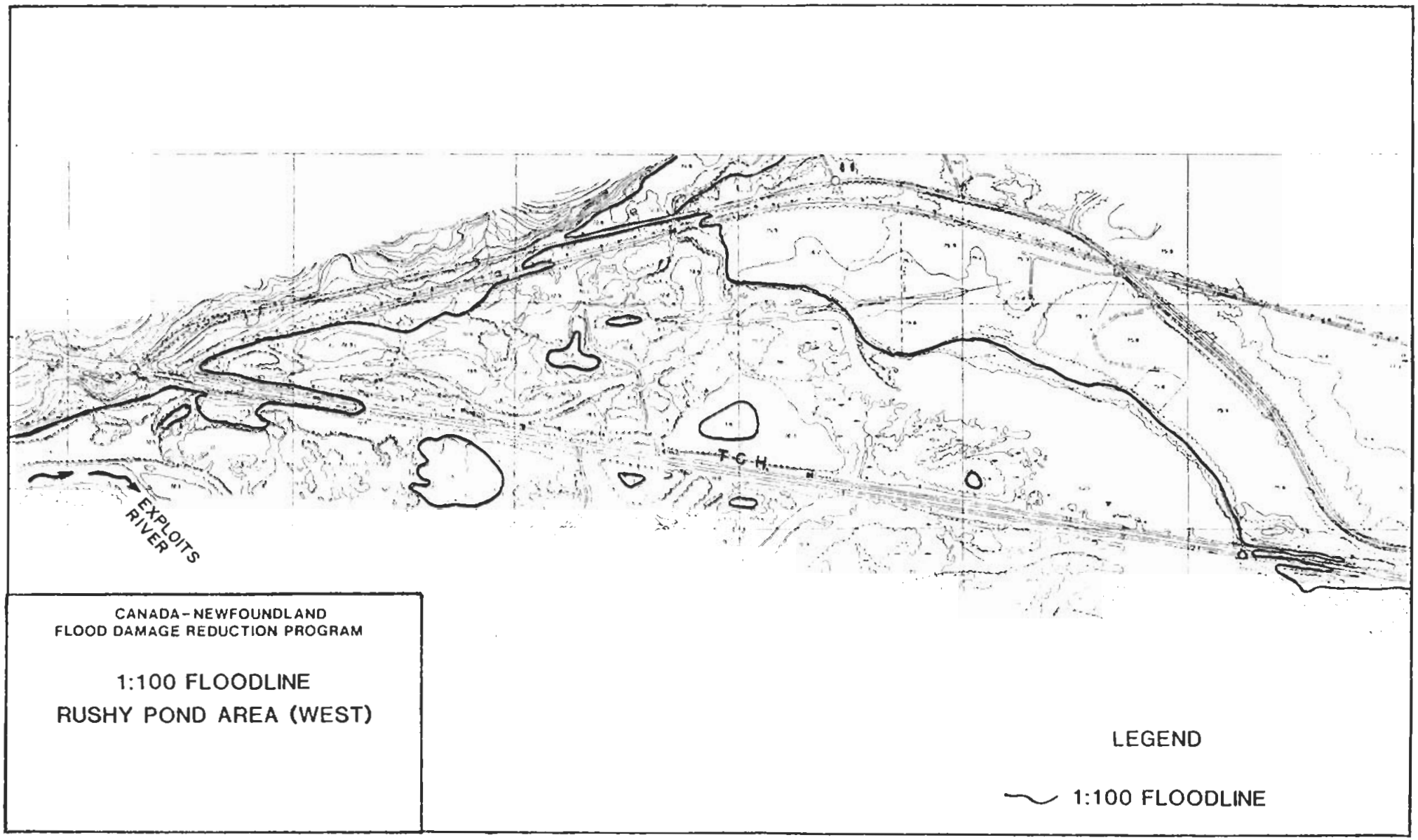
4. The 1:20 year level at the Trans Canada crossing of the Rushy Pond area is 72.4 metres and the 1:100 year level is 73.20 metres. The 1:100 year level is similar to that observed in the flood of January 1983 and is plotted in Figure 1.2 and Figure 1.3.

5. Flood damage estimates and possible remedial measures to alleviate flooding of the TCH are outside of the Terms of Reference for the Rushy Pond area.

1.4 Recommendations

1.4.1 Badger

1. As there are developable areas in Badger which are prone to flooding, it is recommended that the flood elevations advanced herein be adopted by to the town so that those areas can be zoned in the near future for special attention or design consideration (e.g. elevation on fill or piles).



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1:100 FLOODLINE
RUSHY POND AREA (WEST)

FIGURE 1.2

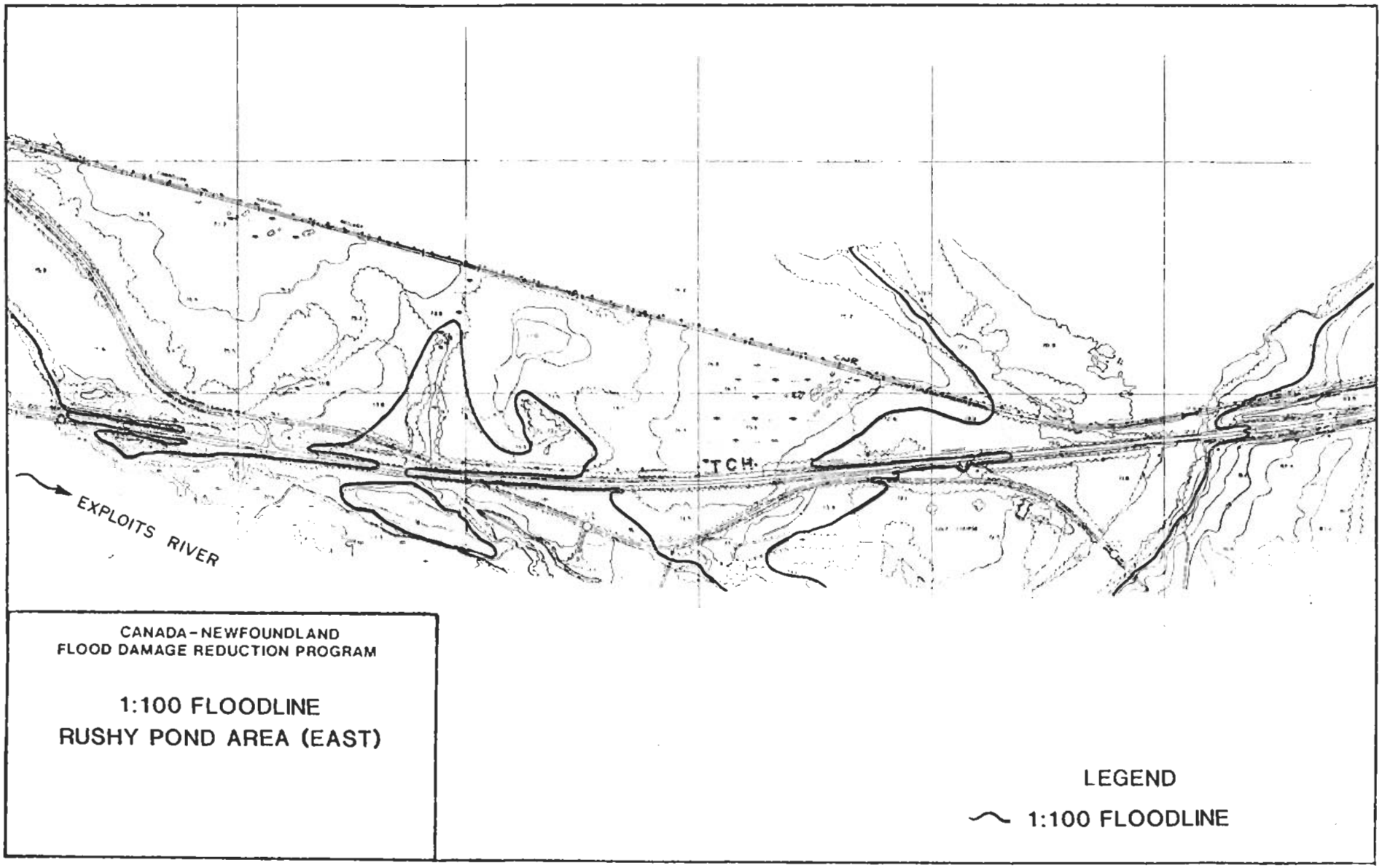

TCH
EXPLOITS RIVER
CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
1:100 FLOODLINE
RUSHY POND AREA (EAST)
LEGEND
1:100 FLOODLINE

FIGURE 1.3

2. It is recommended that the communication and flood warning system which was put in place after the 1977 flood be continued to ensure that it is adequate to warn of flooding situations in the upcoming year or two. Members of the Emergency Measures Organization should be included on the list of those receiving flood warnings, for example. Part of this warning system includes weather and flow monitoring by Newfoundland Environment which has proved most valuable in this study and will be needed in the future as well.

3. The ice progression model developed for this study provides a forecasting capability which has not been available until this time. It is recommended that this model (or a similar one) be set up for early warning of possible flood conditions during the coming winter.

4. A winter monitoring program for several years is also recommended. This program should include observations and/or measurements at a series of cross-sections to evaluate the severity of ice accumulations downstream of Badger and should include daily monitoring of ice levels. This monitoring provides even more forecasting capability; important documentation on ice conditions which may be required for alleviating flooding problems; and information relating to the choice of sites for long term water level monitoring.

1.4.1.1 Long Term Measures

1. The only cost-beneficial approach for reducing the cost of flooding at Badger is the status-quo situation - providing compensation for flood damages after floods have subsided. Although this approach does not provide flood protection, it is recommended because it is the only option with an acceptable benefit-cost ratio for minimizing the cost of flooding. All other approaches (such as dykes and dams) involve significanly greater expenditures of public funds than can be justified when compared to flood damages and the frequency of flooding.

2. If a long term, non-contingency approach is to be implemented for reasons other than a favourable benefit-cost ratio, it is recommended that the 73 flood-prone structures be flood proofed to an elevation above the 100-year flood level. Sections of several streets in the Town are low and should also be raised to ensure safe access during flood periods. This approach is less expensive than other permanent measures such as dyking or dyking with flood proofing (these were identified in the initial stages of study as being worthy of further investigation).

Overall, it is concluded that there are a number of actions which can be taken immediately to reduce the potential for flood damage at Badger in the coming winters. These involve: field monitoring and river modelling to give an improved forecast of possible flooding problems; and, preparedness for a fast and effective response if problems are forecast.

More permanent flood damage reduction strategies are also possible and these are presented in detail in Stage II of this study.

1.4.2 Rushy Pond

1. At the Rushy Pond Area, there is need for additional information on ice levels and ice conditions in the area of the Red Cliff Overpass. This will assist in identifying the location and severity of ice blockages and possible measures to reduce flooding. This area is relatively easy to access and benchmarks are now available to assist a modest field program.

2. There is also potential to reduce the level and duration of flooding at the Trans-Canada Highway in this area. Our mandate in the Terms of Reference precludes evaluation of these options at the present time; but because lives have been lost during TCH floods, we recommend this work be undertaken in the near future.

2.0 INTRODUCTION

2.1 General

While floods are a natural phenomenon, flood damages are a consequence of man's unwise development on flood plain lands - in the path of floods. These lands, adjacent to natural rivers and streams have in the past represented attractive centres for development. Today, floods no longer affect only those properties situated in the hazard areas; the additional loss of taxes, jobs and services may have a serious economic impact on residents of the community and region.

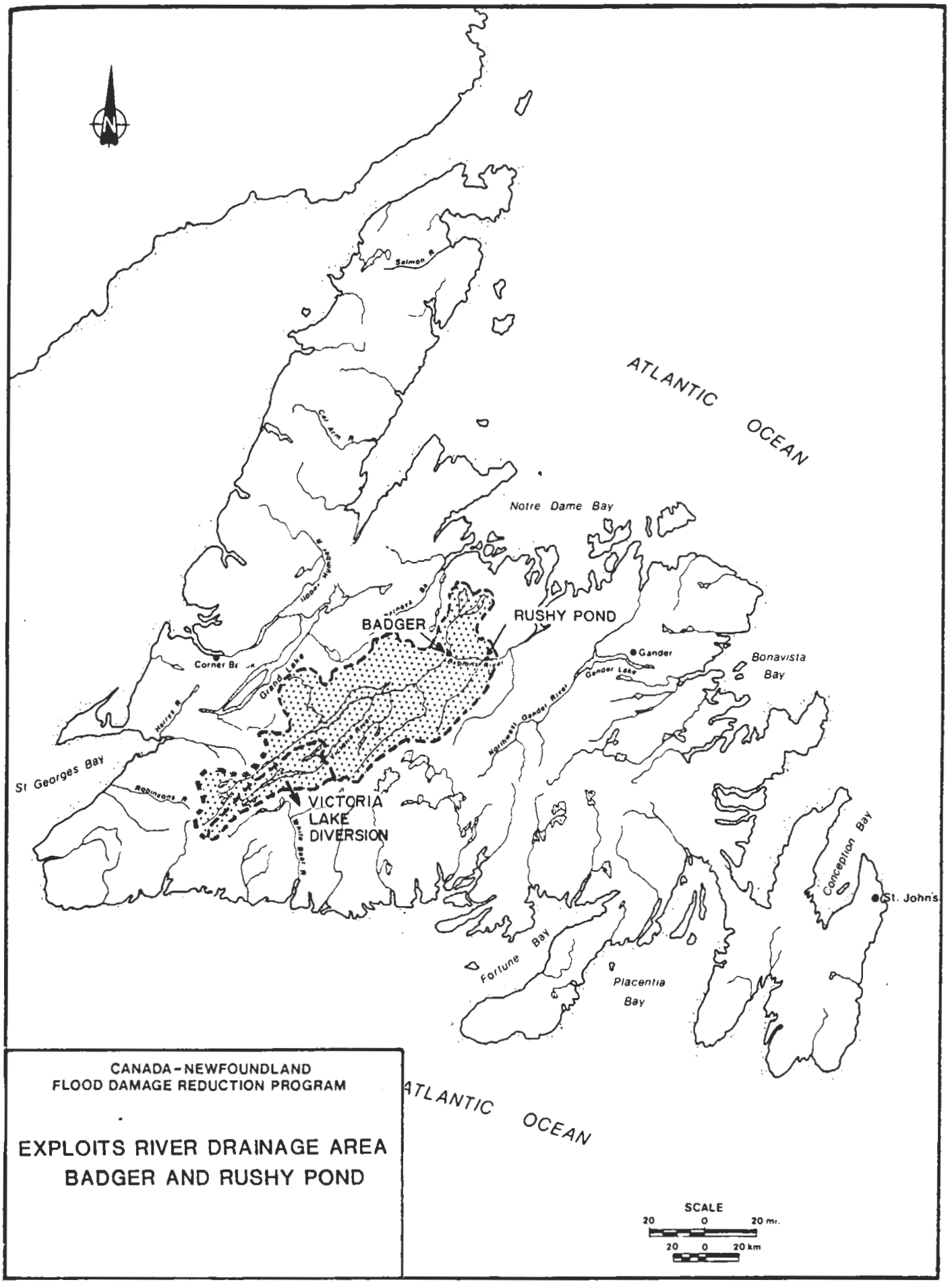
In view of the potential for loss of life and damages resulting from floods, the Province of Newfoundland and the Government of Canada entered into a "General Agreement Respecting Flood Damage Reduction" on May 22, 1981. The objective of this Agreement is to reduce the potential flood damages on flood plains along the shores of lakes, rivers and the sea. This Agreement also recognizes that the potential for flood damages can be reduced by control of the uses made of flood hazard areas. This involves the identification and delineation of flood prone areas and ultimately the designation of these areas wherein only certain conforming developments could take place. As part of this initiative, a flood risk mapping program is being undertaken in Newfoundland. The mapping of a flood risk area consists of four main components: hydrology, hydraulics, topographic mapping and public information. The main purpose of this investigation is to provide the hydrologic and hydraulic components for the identification of flood prone lands for the Exploits River at the Town of Badger and the Rushy Pond area.

The output from the hydrologic component, in the form of flood flows for specified probabilities, serves as the major input to the hydraulic component which will define the response of the river reaches under consideration to the hydrologic input and other relevant factors. The output from the hydraulic studies in the form of water surface profiles for the 1:20 and 1:100 year recurrence interval floods, is applied to specially prepared topographic maps to delineate the areal extent of these flood levels on the flood plain. The final component involves the development of maps, brochures and other interpretative information for the purpose of informing the public, government agencies, private companies, etc. of the flood hazard.

The study area is locted in the central part of Newfoundland, east of Corner Brook. Figure 2.1 outlines the drainage area of the Exploits River above Grand Falls and the portion of this area which has been diverted. The Town of Badger and the Rushy Pond area, which are upstream of Grand Falls, are marked on this figure. These two areas along the Exploits River have been subject to frequent flooding and are the topic of this study.

Figure 2.2 shows the study area in more detail. The Rushy Pond area is located within an old meander on the Exploits River just upstream of Grand Falls. The Trans-Canada Highway passes through this area and one past flood event led to the death of two motorists.

The Town of Badger is located at the confluence of two small brooks in the Exploits River. Flooding in the lower areas of the town adjacent to the Exploits River has not resulted in



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EXPLOITS RIVER DRAINAGE AREA
BADGER AND RUSHY POND

FIGURE 2.1

any deaths, but as recently as February 1983, caused an estimated $36,273 flood damage to private houses in the community (Department of Municipal Affairs, 1985). This and other references are provided in Chapter 12.

2.2 Study Objectives

The purpose of this study is to examine flooding problems at both:

1. The Town of Badger
2. The Rushy Pond area

The objectives of the study are three-fold, and are well summarized in the Terms of Reference:

(1) To identify the mechanics, physical processes and factors (physical, hydrometeorological, hydraulic) responsible for flooding in the Badger and the Rushy Pond areas.

(2) To provide estimates of the 1:20 and 1:100 year recurrence interval flood levels and the extent of flooding associated with each. Flooding at Badger is as a result of back-up of water caused by an ice constriction while in the Rushy Pond area, flooding is believed to be caused by high flows and ice.

(3) To evaluate suitable remedial and preventive measures for the Town of Badger to alleviate the flood damage problem, make appropriate recommendations and also assess any impact the recommended measures may have on upstream and/or downstream river reaches. This will

include the evaluation of the effectiveness of the use of explosives. Also to be included in this evaluation is the setting up of an ice monitoring facility to support a flood warning system.

The study consisted of: a thorough review of existing information, the selection of appropriate mathematical models, the identification of data voids, the collection and compilation of new data necessary for the study, the analysis/interpretation of the data, and derivation of the 1:20 and 1:100 year flood profiles.

Following this work, for Badger only, the study consisted of a thorough search for possible remedial measures, development of a stage-damage relationship and engineering, economic and environmental feasibility, and assessment of alternative remedial measures schemes.

2.3 Study Approach

The study was subdivided into two phases. The first focussed on identifying the causes and extent of flooding at Badger and Rushy Pond. The second focussed on the detailed development of flood damage reduction alternatives for Badger.

Phase I

(1) Following project initiation in early January 1984, a winter field program was immediately designed and the study area visited to observe ice conditions and collect important reports and documents relating to past flooding. The results of the data collection stage are com-

piled in Chapter 3, and the references and data sources are given in Chapter 12.

(2) The detailed winter field program was launched in mid-January. By that time, ice covered the river and it was possible to measure the thickness, ice elevation, and other parameters at key locations in both study areas. The survey program was expanded following review of the initial data and the work continued until 2 May 1984. The scope and results of the winter ice surveys are summarized in Chapter 4.

(3) The winter surveys were followed by another field program in July and August. This was required to provide detailed data on the topography of the ice-free channel and to provide accurate elevations in flood prone areas of Badger and Rushy Pond. The results of this work are contained in the latter part of Chapter 4.

(4) During these field surveys, streamflow data was being analysed to determine the 1:20 year and 1:100 year flood flows in the study areas. This was completed for the open-water season and the winter season to allow for separate analysis of both types of flood flows. The approach to this evaluation is described in Chapter 5.

(5) The results of the field investigations and hydrologic studies were combined in a computer backwater model to provide flood levels along the Exploits River from Goodyear's Dam to Badger, and on Badger Brook, Little Red Indian Brook and Rushy Pond Brook. The approach and results of this modelling for open-water seasons are

provided in Chapter 5. The results demonstrate that the highest historical floods at both Badger and Rushy Pond were the result of river ice conditions.

(6) Ice-effect flooding was then evaluated in detail at both sites (Chapter 7). Maximum use was made of historical ice level observations, and river ice conditions were simulated using our field observations, streamflow, and over 30 years of meteorological data. Ice effect flood levels for the 1:20 year and 1:100 year events were then determined and the extent of this flooding was mapped at Badger and the Rushy Pond area.

(7) As the flood levels in Badger showed that over 50 buildings would be flooded at the 1:100 year level, a flood damage analysis was then conducted to determine the damage which would result from a number of different flood levels. Flood damage data from previous floods (e.g. February 1983) were used to tailor the damage estimates to the Badger area as described in Chapter 8.

(8) A wide range of flood damage reduction alternatives were assembled, examined and compared for application at Badger (Chaper 9). These alternatives were reviewed and discussed with the Technical Committee at the conclusion of Phase I. Three of these alternatives were recommended for additional, detailed study.

Phase 2

(1) Detailed topographic mapping of Badger was completed by another firm in mid-January 1985. This was reviewed and

then employed for finalizing flood levels and the extent of flooding (Plates 1 and 2 inside the back cover of this report). It was subsequently used as base mapping for assessing the following flood damage reduction alternatives:

- full dyking around Badger
- dyking with floodproofing

A third flood damage reduction alternative:

- flood forecasting

was also examined in detail at this stage for use as an interim or long-term flood damage reduction approach.

The advantages, disadvantages, costs and benefits of these options (and sub-options) are discussed in detail in Chapter 10.

(2) Chapter 11 provides an implementation plan for scheduling the most advantageous flood damage reduction options, a final summary of benefits and costs, and the final recommendations of the Phase 2 study.

This volume (Volume 1) presents all of the major findings of the study and mapping of the flood prone areas of Badger and Rushy Pond. Volume 2, which is a compendium of technical notes, drawings and computer programs, is available to the interested reader from the Canada-Newfoundland Flood Damage Reduction Program office at Newfoundland Department of Environment, St. John's.

3.0 HISTORICAL FLOODING REVIEW

3.1 Background Data

The history of flooding on the Exploits River between Badger and Grand Falls has been drawn together from a variety of sources for this study. A comprehensive review is provided by Kindervater (1980) in his general report on flooding in Newfoundland and Labrador. The operating records of Abitibi-Price Inc. are also an excellent source of data, particularly because they document several minor floods or near-flood conditions not reported by Kindervater. The residents of Badger corroborate these records as well as provide additional insights, and the Newfoundland Department of the Environment has prepared several good summaries of past flooding.

Overall, there are at least twenty reports or documents which refer to past flood and river conditions of interest. These are listed in Chapter 12.0: Reference Data. Review of these reports shows that flooding or high water has occurred in the study area on sixteen occasions since the turn of the century:

Badger	Rushy Pond
1916-18	1903
1937	1934
1943	1965
1945-46	1971-72
1957	1975
1977	1975-76
1983	1979
	1980
	1983

In addition to these reports, there are also data from a number of other sources referenced in Chapter 12.0:

- photographs covering the 1977-1984 period during flood and non-flood events, taken from the ground and from helicopter

- air-photographs showing the study area at scale of about 1:15,000, over the reach from Grand Falls to Badger in 1975, 1976, 1978 and 1983

- LANDSAT satellite imagery 1973-1979 (1:18.5 million scale)

- drawings and plans giving original and revised profiles of the TCH at Rushy Pond as well as road bridges in the study area

- meteorological and streamflow information, covering the period from 1934 to the present.

These data and the documentation discussed above provide a great deal of information on past flooding events which are summarized in Table 3.1.

Of principal interest is that there has been no flooding at Badger during ice-free seasons, and the only flooding events without the presence of ice at Rushy Pond occurred in June 1965, early May 1975, and early May 1976.

TABLE 3.1

EXPLOITS RIVER
HISTORICAL SUMMARY OF FLOODING OR HIGH WATER
IN THE BADGER AND RUSHY POND AREAS

Date	Brief Summary of Reported Conditions*
Winter 1903 (est.)	· Rail line rerouting completed at Red Cliff; possibly initiated because of flooding earlier that year[1] (previous route had crossed Rushy Pond area between TCH and Old Badger Road).
Winter 1913	· Rail trestle at Leech Brook destroyed by ice[2] (good possibility that contributing ice was from Leech Brook itself).
Winter 1916-18	· A flood at Badger in this period approached intersection of Church Street and School Road and almost up to CNR tracks (at elev. 100.3 m - 329 ft.)**. Flooding generally similar to 1983 in its extent[3] to elevation 100.15 m (est.).
22 April 1934	· Ice jam at or below Rushy Pond Community (now abandoned)[1/2] flooded low land to depth of 7 feet (GSC elevation in range of 76 m) at Happy Vale farm (just east of Leech Brook).
	· Exploits discharge approximately 708 m^3/s (25 000 cfs) on 22 April rising to 988 m^3/s on 23 April and over 1325 m^3/s on 29 April.
	· Rail line also reported flooded near Rushy Pond Community and flooding continued for some time.
21 Feb. 1937	· Ice conditions at Badger reportedly raised levels to height similar to 1983[3] and higher than in 1977[4] (to elevation about 99.80 m).
	· Ice obstruction ("plug") was thought to be at Badger with water at houses[1].
Winter 1943 (est. Jan. 1943)	· Similar flooding in Badger as in 1977[2] and perhaps higher than 1983[5]. Although there no topographic records, the river banks at Badger are reported to have been reduced by 1 m due to logging work in floodplain some time prior to this flood. Flood elevation about 99.90 m.
1945/1946	· Winter ice conditions in Badger area raised levels to elevation similar to 1983 or lower[3], and lower than 1943. Flood elevation estimate 99.05 m.
	· River plugging noted on Jan 8, 1945[1] but location not given.

TABLE 3.1 (Cont'd)

Date	Brief Summary of Reported Conditions*
9-10 Mar. 1949	· Local flooding in Badger[2] from rainfall and snowmelt - not ice jamming on the Exploits).
	· Ice and wood jams on Exploits flooded Coach Road[2] - possibly in the Rushy Pond area.
15-16 Jan. 1951	· River plugged with ice at Badger Chute[1] but no flooding in Badger (elev. Exploits River assumed less than 97.5 m).
20 Jan. 1957	· High water reported at Badger[1] but no flooding. Exploits elevation assumed less than top of bank level and to approximately 97.80 m.
6 June 1965	· Heavy rain led to flooding of unfinished new TCH road bed about 460 m west of culvert. Water to depth of 25 cm over length of about 150 m[1/2/5].
	· Water level about 70.81 m (232.3 ft.) but receded by next day.
	· Peak flow estimated[1] at 1096 m^3/s.
30 Dec. 1971 - 4 Jan. 1972	· At Rushy Pond area, ice cover and heavy flow of slush ice raised water levels at TCH to road level[2] (elevation about 70.7 m (232 ft.)).
	· Exploits discharge about 170 m^3/s.
8 May 1975	· Water on shoulder of road at North Angle[1] (elevation est. 70.46 m (231.2 ft.)). This followed the raising of Goodyear's Dam by about 2 metres (221.1 ft to 228 ft.) during 1974-75. Work on new dam crest finished Jan. 1975.
	· Exploits discharge at Grand Falls 591 m^3/s.
24 Dec. 1975 - 8 Jan. 1976	· TCH at North Angle flooded to rainfall and thaw-induced increases in river flow (peak 646 m^3/s on 24th) and ice cover extending 3.2 km upstream[2/5/6].
	· Depth of flooding at low spot in TCH was about 60 cm to elevation 71.3 m (234 ft.).
4 April 1976	· Water reported to be running over highway[1] (flow est. 615 m^3/s).
	· Unknown flood elevation, but exceeded centreline elevation of 70.7 m (232 ft.)

TABLE 3.1 (Cont'd)

Date	Brief Summary of Reported Conditions*
4-6 May 1976	· TCH at North Angle again flooded due to high flow (instantaneous peak of 963 m^3/s on 6 May)[2].
	· Two people were drowned on 4 May when maximum daily discharge was about 716 m^3/s at Grand Falls.
	· Depth of road flooding unknown but exceeded elevation 70.7 m (232 ft. centreline elevation).
17-24 Jan. 1977	· Badger flooding worst since 1943[2/3/4] to elevation about 99.66 m (327 ft.) caused by blockage at Badger Rough waters[3]. Ice in Badger Bk. touched bottom of rail bridge[9] at 99.67 m.
	· River flow about 165 m^3/s at Badger[2].
	· 49 homes evacuated and flood damage to 28 structures reported to be $20,000[2] (details are appended[2]).
20-22 Mar. 1979	· Ice jam at North Angle near Goodyear's Dam raised levels at TCH and road was closed as a precautionary measure[2].
	· Daily discharge 504 m^3/s on 20 March[1] and flood level was below new/raised road grade 73.0 m (239.5 ft.).
7 Jan. 1980	· Water running through Goodyear's Pit at a time when the ice cover extended upstream to Aspen Brook[8]. This may indicate partial blockage of the Exploits River by ice.
	· Flood elevation unknown; river discharge about 155 m^3/s.
March 1980	· Badger ice conditions and Exploits River elevations were of concern, but there was no flooding. Maximum ice level was about 98.15 m.
13-14 Jan. 1983	· TCH flooded at Goodyear's Gravel Pit and Rushy Pond Brook due to high flood flows with ice.
	· The peak flow on 13th was 1067 m^3/s and the peak flow on the 14th at Grand Falls was about 1840 m^3/s[1].
	· Ice damaged CNR line about 0.8 km west of Leech Brook and road flooded east of Leech Brook on 13 Jan.
	· Depth of flow was 15-20 cm over TCH[5], or about elevation 73.2 m (240.1 ft.) on 14 Jan. over length of about 1.4 km. Ice pans were carried across the road[2] from the Exploits River at a point just east of Red Cliff Overpass[5]. This flood depth was the highest on record.

TABLE 3.1 (Cont'd)

Date	Brief Summary of Reported Conditions*
25 Feb. - 3 March 1983	· Slush accumulation at Badger on 23-24 Feb.[3].
	· Badger flooding from ice jam in Badger Rough Waters to an elevation 0.25 m higher than 1977 flood (about 99.91 m).
	· River flow approximately 160 m^3/s at Badger[2] (details appended)[7].
	· Homes evacuated and flood damage reported to be $89,000[7] excluding costs for ice blasting operations, etc.
January 1984	· No flooding at Badger. Ice level 97.0 m.
	· No flooding at Rushy Pond. Ice level 69.72 m.

* Principal Data Sources

1 Abitibi Price records from Nov. 1933; G.N. Cater personal communications.
2 Kindervater, 1980, "Flooding Events in Newfoundland and Labrador".
3 Badger residents, 1983, personal communications.
4 ShawMont, 1977, "Report on Badger Flood Investigations" (Draft).
5 G. Noseworthy, Department of Transportation and Communications, 1984, personal communications.
6 Nfld. DOE, 1976, Report on Flooding Trans-Canada Highway West of Grand Falls.
7 Terms of Reference - Badger Rushy Pond Hydrotechnical Study, 1983.
8 Nfld. DOE, 1980. River and Climate Observation Tables and Charts.
9 R. Sparkes, Terra Transport, personal communication.

** Elevations from topographic mapping prepared for Badger (Hunting Survey Corp. Ltd., 1963).

3.2 Causative Factors

3.2.1 Badger Overview

Flooding at Badger has only occurred during formation of the ice cover on the Exploits River in January (or February 1983 during reformation). River discharge during these events ranged from about 100 to 200 m^3/s (3600 to 6900 cfs) and averaged approximately 150 m^3/s (5300 cfs) at the Exploits Dam.

Evidence from 1983 photographs taken during field surveys suggests that flooding occurs at a time when the Exploits River ice cover is just reaching Badger. It is also clear from field surveys (and historical photographs) that this ice cover is mostly composed of frazil slush (slob) which accumulates to obstruct a large portion of the channel. The problematic accumulation point is reported to be the Badger Rough Waters.

Problematic floods in the past may have been caused by:

(a) a similar ice cover to that of 1984, but one which thickened and obstructed openings beneath the ice cover as a result of a heavier frazil run,

(b) a compression or "shove" in the Badger ice cover brought about by periods of relatively warm weather which weakens the ice cover,

(c) grounding or compression of the ice cover due to upstream flow changes.

The records of daily discharge at Exploits dam indicate that there have frequently been occasions when discharge has been completely curtailed or significantly increased (c) without creating a flooding condition at Badger. Work on points (a) and (b) above is discussed and described later in this report.

3.2.2 Rushy Pond Overview

Flooding at Rushy Pond has often occurred when discharge in the Exploits River has been much higher than the norm (e.g. 1983), and generally at a time when the discharge is about 560 m^3/s (20 000 cfs) at Grand Falls. It has also occurred, however, when river discharge was significantly lower and has occurred during the ice formation period (e.g. December 1975), during break-up (March to early May), or without the presence of ice (June 1965). Although ice was likely present at the beginning or throughout the majority of floods at Rushy Pond, its overall effect on flooding is not as clear from historical records as it is at Badger.

Ice data from the Rushy Pond area is less comprehensive than that at Badger because there are no long-term residents who have observed the river, and the river is too distant from the highway to easily permit observation during flood events.

Historical reports and field observations combined with interpretation from air photos, satellite imagery and topographic mapping yield the following information affecting flooding at Rushy Pond:

(1) Changes have taken place in the topography of the Rushy Pond area. Operations at Goodyear's Gravel Pit have reduced bank levels and cleared some overbank areas allowing flood waters to reach the TCH more readily.

(2) The TCH itself passes through the floodplain, and at high flows acts as a dyke. When overtopped or flanked by flood waters entering beneath Red Cliff Overpass, it acts as a dam retaining flood waters between it and the Old Badger Road.

(3) There is a transition in flow upstream of the Rushy Pond slob boom within the three kilometre reach below Red Cliff Overpass. The transitional area is shallow and narrow, is interspersed with bars and islands, and contains two bends. This area near Sandy Brook could well have been an ice jam site in the past - or at least have had flood effects modified by the presence of ice.

(4) Below this reach, the "Rushy Pulpwood Area" (containing the slob boom and three islands) represents another location which could be an ice jam site. Similarly, the narrows at Aspen Island or the bend below it may also obstruct ice movement.

Several pieces of data support consideration of ice effects at Rushy Pond:

(a) The 1934 flooding at Happy Vale farm was reportedly caused by an ice jam in the Rushy Pond area (flood elevation estimate 76.2 m). An ice scar at Rushy Pond community was surveyed at elevation 75.8 m (4 m above

1984 ice level); and throughout the study area, ice scar elevations are 2.5 to 3.0m above normal levels in the Rushy Pulpwood holding area.

(b) Although there is no ground-truth evidence of jamming, LANDSAT imagery shows that ice was present during two other floods at the Trans-Canada Highway:

- imagery of 13 December 1975 shows an ice cover extending well above the "North Angle" prior to late- December flooding (this ice, however, may have been swept downstream with rising flood waters and may not have influenced flooding).

- imagery of 24 March 1979 shows ice still present in the pulpwood holding area two days after the TCH flood threat on 20-22 March.

3.2.3 Historical Summary

In summary, the historical information indicates that the accumulation of river ice (frazil) during freeze-up is the most obvious factor influencing flooding at Badger.

At Rushy Pond, the most obvious factors contributing to flooding is high flow on the Exploits River. In addition, however, the presence of river ice may have been a contributing factor to some past floods. Hence, the effect of river discharge and ice conditions are both considered in the following sections of this report.

4.0 FIELD SURVEY PROGRAM

4.1 Introduction

Although past studies and the historical data base provide information which suggested various causes of flooding in the study area, there was almost no physical information describing the river hydraulics, the ice cover and the topography of the overbank areas. This information is required to isolate the causes of floods and develop flood level estimates and was gathered through a number of field surveys launched in early January 1984. Following break-up, a second series of surveys were carried out in the summer of 1984.

4.2 Winter Surveys

The objectives of the winter surveys were to:

- determine thickness and characteristics of the ice cover at several locations along the river
- observe, photograph and measure the changes which took place in the cover through time from freeze-up to break-up
- identify the location and progression of the ice cover as it moved upstream through Badger to Twelve Mile Falls
- establish survey bench marks along 32 km of the river and accurately measure the elevation of the ice surface throughout the winter

- establish staff and crest gauges, which in the event of an ice or flow-induced flood could be used to accurately determine the rate of rise of flood waters and their maximum level

- measure the elevation of ice scars in the study areas to provide information on the maximum ice elevation reached in previous years

- interview knowledgeable local residents and local agencies to obtain first hand information not available in historical reports

- observe the break-up or melt sequence and the location of open water as the cover gradually decayed in the spring.

Three monitoring sequences were undertaken:

- Freeze-up sequence. This was initiated by field observations which began on 10 January 1984 and extended for 26 days until 4 February 1984

- Mid-winter sequence. This program began on 21 February 1984 and continued for 17 days until 22 March 1984

- Break-up sequence. This began with the first signs of break-up on 23 March 1984 and continued (intermittently for 13 days) until the last observation on 2 May 1984

Overall, nineteen cross-sections defining the thickness and distribution of ice at nine river sections were provided in

the survey. Ice elevations were also obtained at twenty locations, with seventeen of these having more than one observation over the winter.

Figure 4.1 identifies the sites selected for winter observations of levels and ice thickness across the river and Table 4.1 summarizes the dates and observations recorded at each station.

4.2.1 Winter Survey Results

The observations, photographs, field notes and drawings of ice conditions on the river fill several large volumes which cannot be reproduced in this report. These are contained in Technical Appendices which are available at Newfoundland Department of Environment. Some of the key information is identified and discussed in several of the following chapters (e.g. ice elevations), and some is presented below.

Of particular relevance to the flooding problem at Badger is the change in the thickness of the ice cover through time. Figures 4.2, 4.3 and 4.4 show cross-sections of the ice cover at Section 4, which is just downstream of Badger at Junction Brook. The survey of 27 January (discharge about 152 m^3/s) shows a complete ice cover from bank to bank and a large accumulation of frazil slush obstructing about one-third of the channel on the southwest bank. A month later on 28 February, (discharge about 182m^3/s) the frazil slush obstruction had eroded at auger hole no. 10, for example, and the cover had decayed and opened up along the east bank of the river. By 21 March (discharge about 196 m^3/s), the frazil slush had eroded further. Despite progressive increases in the river discharge, the ice elevation which was highest in late January, dropped about 0.2 metres once the lead opened on the east bank, and another 0.1 m following additional decay of the cover in March.

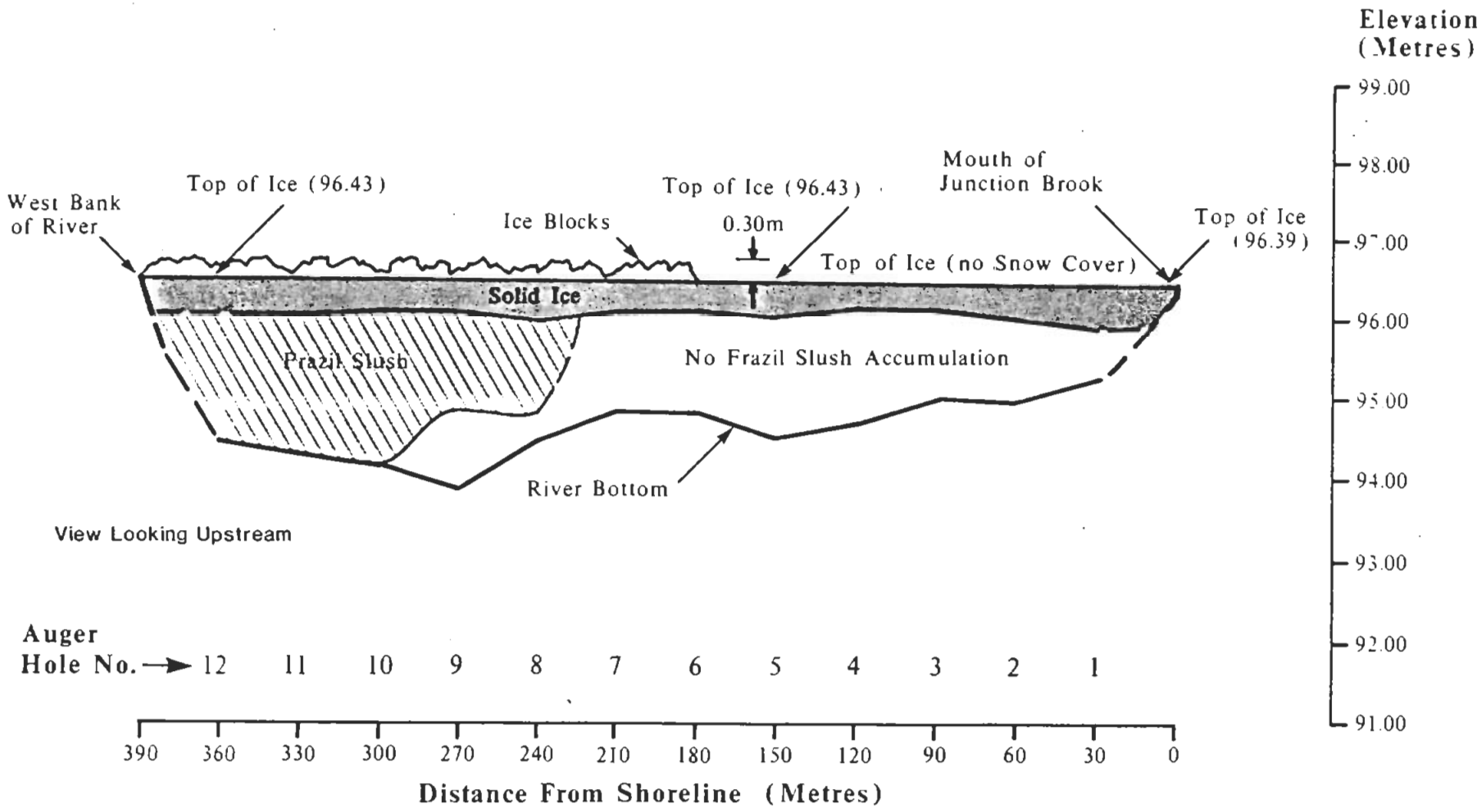
TABLE 4·1
EXPLOITS RIVER
SUMMARY OF WINTER FIELD MONITORING PROGRAM

SITE	A	B	C	D	E	F	G	G-I	H	H-I	I					BADGER BROOK BRIDGE	LITTLE RED INDIAN BROOK BRIDGE	RUSHY POND BROOK BRIDGE	LEECH BROOK BRIDGE	UP STREAM ICE EDGE
X-SECTION			4	3	2	1					5	6	7	31	32					
DATE																				
19/01/84			elev. obs.	elev. obs.																
20/01/84	elev. obs.	obs.																		
23/01/84							elev. obs.		elev. obs.							elev.	elev. obs.			
24/01/84					obs.	elev. obs.														
26/01/84																		elev. obs.	elev. obs.	
27/01/84			elev. obs. current																	
30/01/84				elev. obs. current	elev. obs. current															
31/01/84																				obs.
01/02/84																elev. obs.	elev. obs.			
02/02/84											elev. obs. current									
03/02/84						elev. obs. current	elev. obs.											elev.		
04/02/84	elev. obs.	elev. obs.																		obs.
22/02/84	elev. obs.	elev. obs.					elev. obs.						elev. obs. current							
23/02/84				elev. obs. current										elev. obs. current						
24/02/84												elev. obs. current			elev. obs. current	elev. obs.	elev. obs.	elev. obs.	elev. obs.	
27/02/84									elev. obs.	elev. obs. current	elev. obs.									obs.
28/02/84			elev. obs. current																	
29/02/84							elev. obs.													
05/03/84	elev. obs. current							elev. obs. current												obs
07/03/84					elev. obs.	elev. obs.										elev. obs.	elev. obs.	elev. obs	elev. obs.	
14/03/84																				
21/03/84	elev. obs. current		elev. obs. current				elev. obs.	elev. obs. current	elev.	elev. obs. current										
22/03/84									elev. obs. water temp							elev, obs. water temp	elev, obs water temp	elev, obs water temp	elev, obs.	obs.
04/04/84									obs.							elev, obs.	elev, obs.	elev, obs.	elev, obs	obs.
12/04/84																elev, obs.	elev, obs.	elev, obs.	elev., obs.	obs.
18/04/84																elev, obs.	elev, obs.	elev, obs.	elev., obs.	obs.
21/04/84									obs.							elev, obs	elev, obs.	elev, obs	elev., obs.	obs.
25/04/84																elev., obs.	elev., obs.	elev., obs.	elev., obs	
02/05/84																elev., obs.	elev., obs.	elev., obs.	elev., obs.	obs.

LEGEND:
obs = ICE/WATER CONDITIONS RECORDED
elev = ICE/WATER ELEVATION RECORDED
current = CURRENT READINGS TO DETERMINE FRAZIL ICE LOCATION RECORDED
water temp = WATER TEMPERATURE RECORDED

Cross-Section 4, Jan. 27, 1984

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

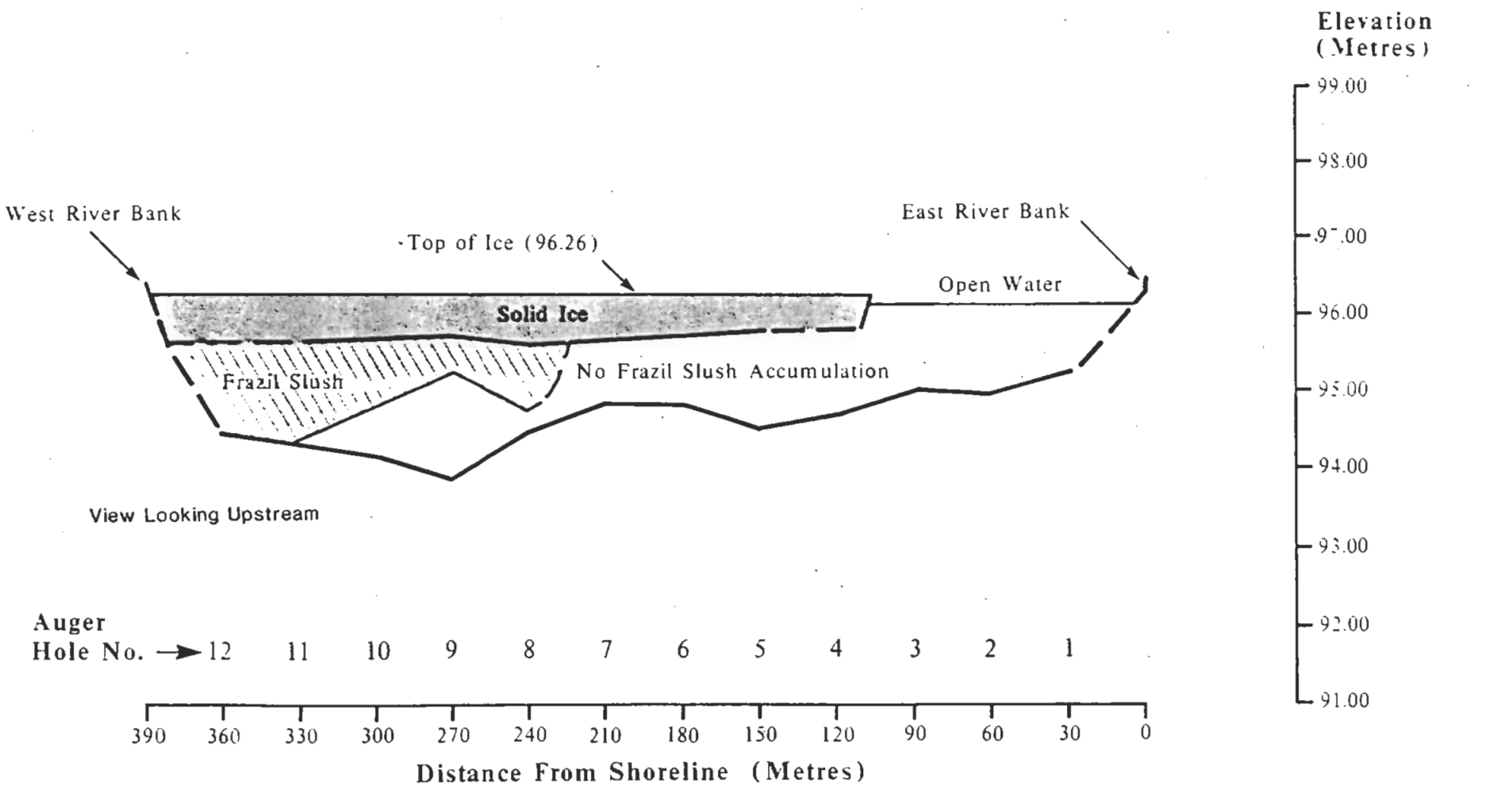


Notes: ~~ ice or bottom contour approximate

FIGURE 4.2

Cross-Section 4, Feb. 28, 1984

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

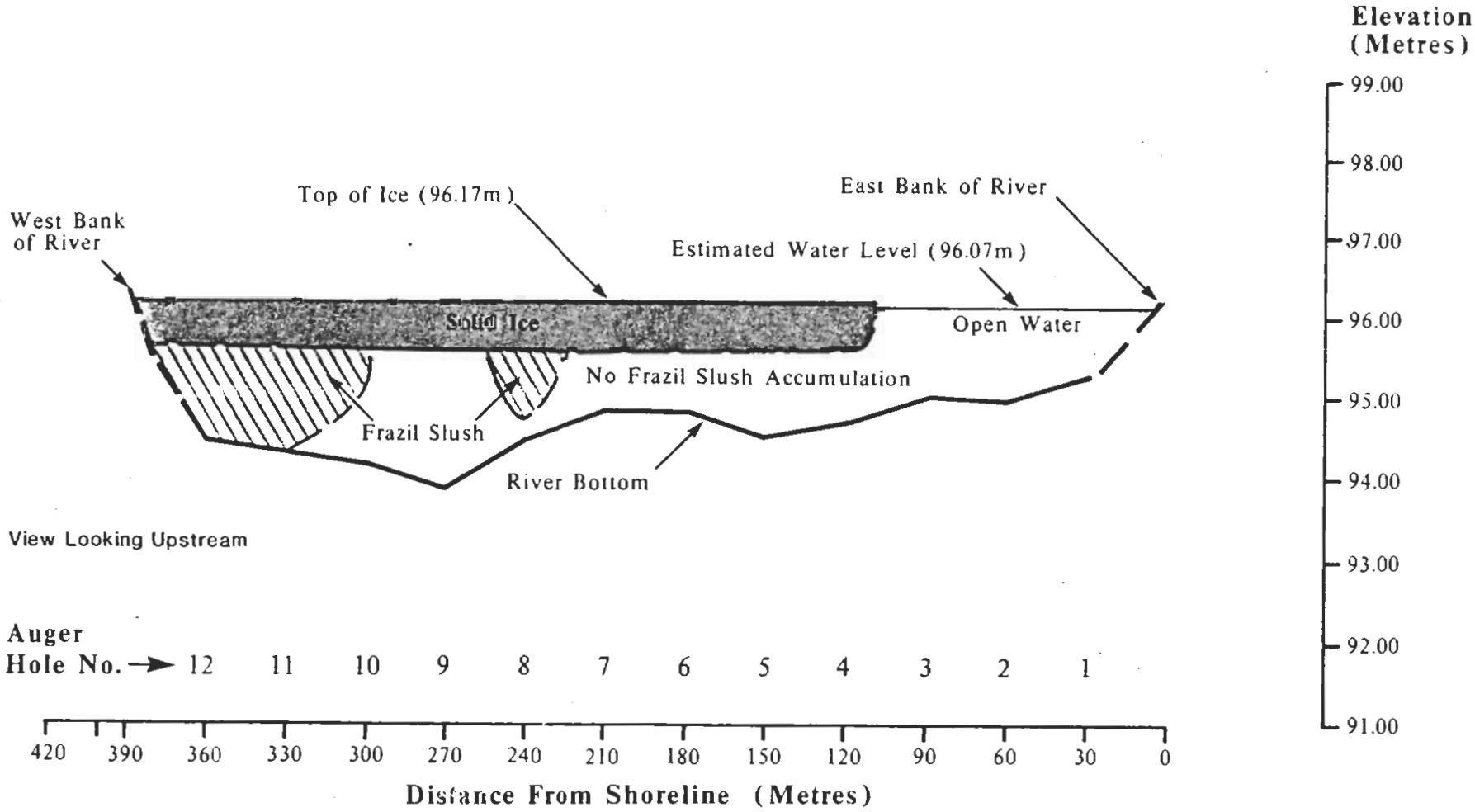


Notes: ~~ ice or bottom contour approximate

FIGURE 4.3

Cross-Section 4, March 21, 1984

CANADA–NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM



Notes: ~~~ ice or bottom contour approximate

FIGURE 4.4

Figures 4.5 and 4.6 show the same transition at Section 3, which is just below Badger Rough Waters. About two weeks after formation (30 January) the ice cover extended completely across the river and was still underlain by a thick accumulation of frazil slush. The slush at auger hole no. 2 had been eroded and, as seen in Figure 4.6, resulted in an open water lead along the east bank in late January. Of particular interest was that the ice level dropped 1.1 m as a result of erosion of the frazil slush and opening of the lead - rather than due to river discharge which was about 10 percent higher on 23 February.

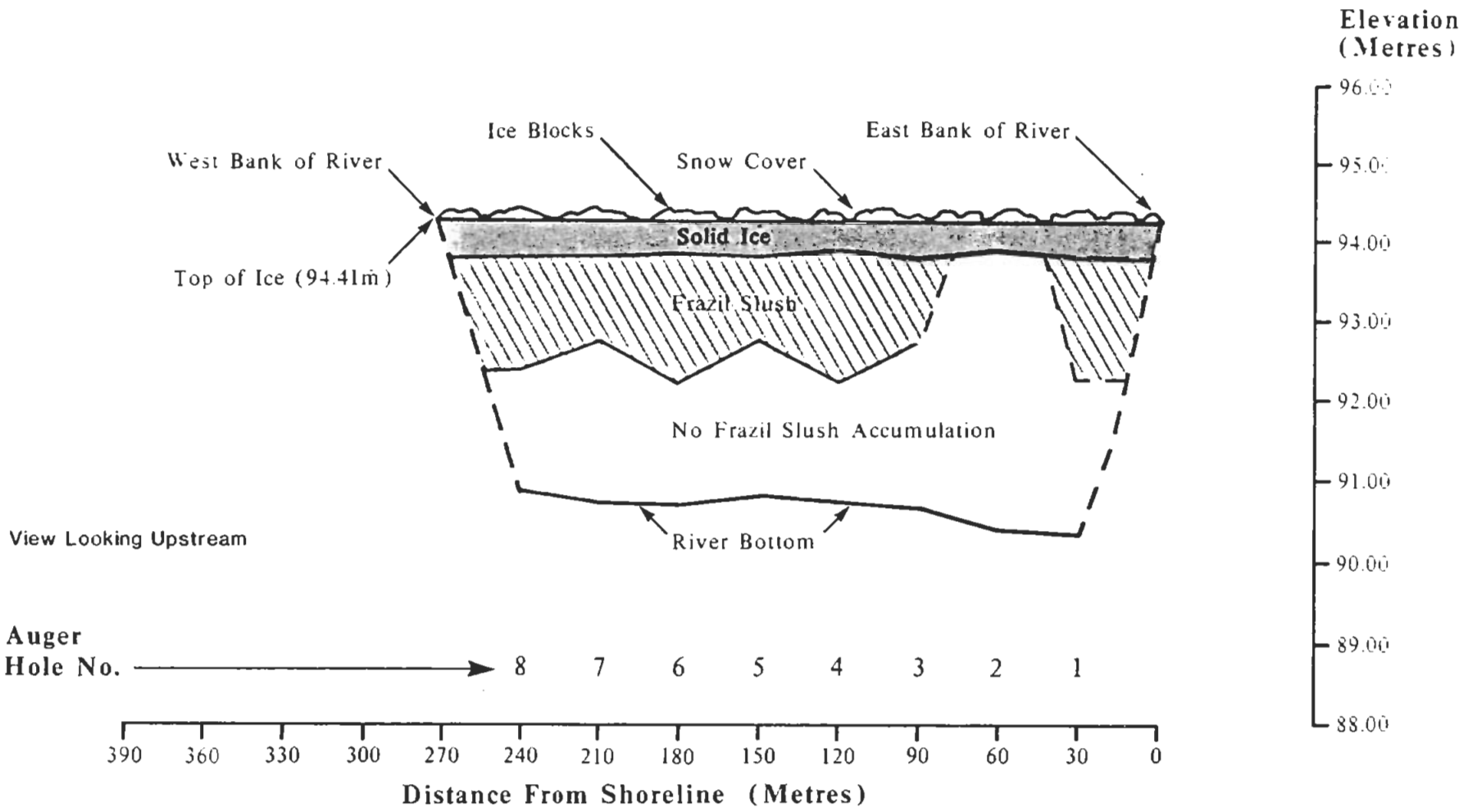
Figure 4.7 shows the mass of frazil slush which formed the ice cover at Section 2, which lies between Badger Chute and the Badger Rough Waters. The slush accumulation is 4 m thick from top to bottom. The top of the ice blocks (elevation 92.8 m) was also over 4 m above the open water elevation observed at the same site when summer flows were 25 percent higher.

Figure 4.8 shows a cross-section of the ice within Badger Rough Waters following erosion of the ice cover and opening of a lead along the east bank of the river. The top of the cover shows the effect of the slush beneath it resting on the main river bed. Earlier in the year (e.g. January) the ice extended completely across the river, and it is quite likely that the frazil slush beneath it filled the west bank section at auger hole no. 1 and extended further east past auger hole no. 3.

The 1984 field data and 1978 air photos show the location of leads within or below the ice covered river. These leads and

Cross-Section 3, Jan. 30, 1984

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

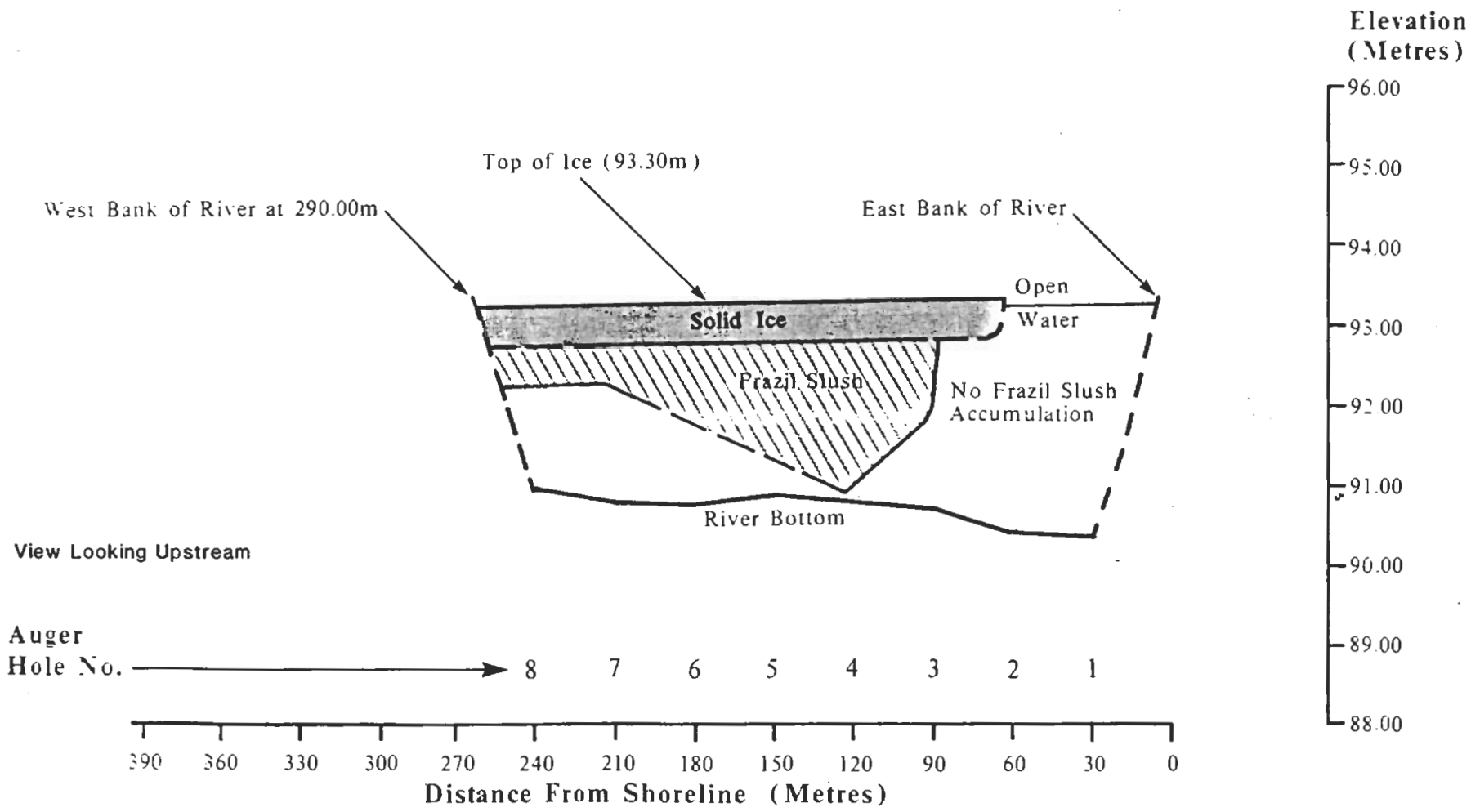


Notes: ~ ~ ~ ice or bottom contour approximate

FIGURE 4.5

Cross-Section 3, Feb. 23, 1984

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

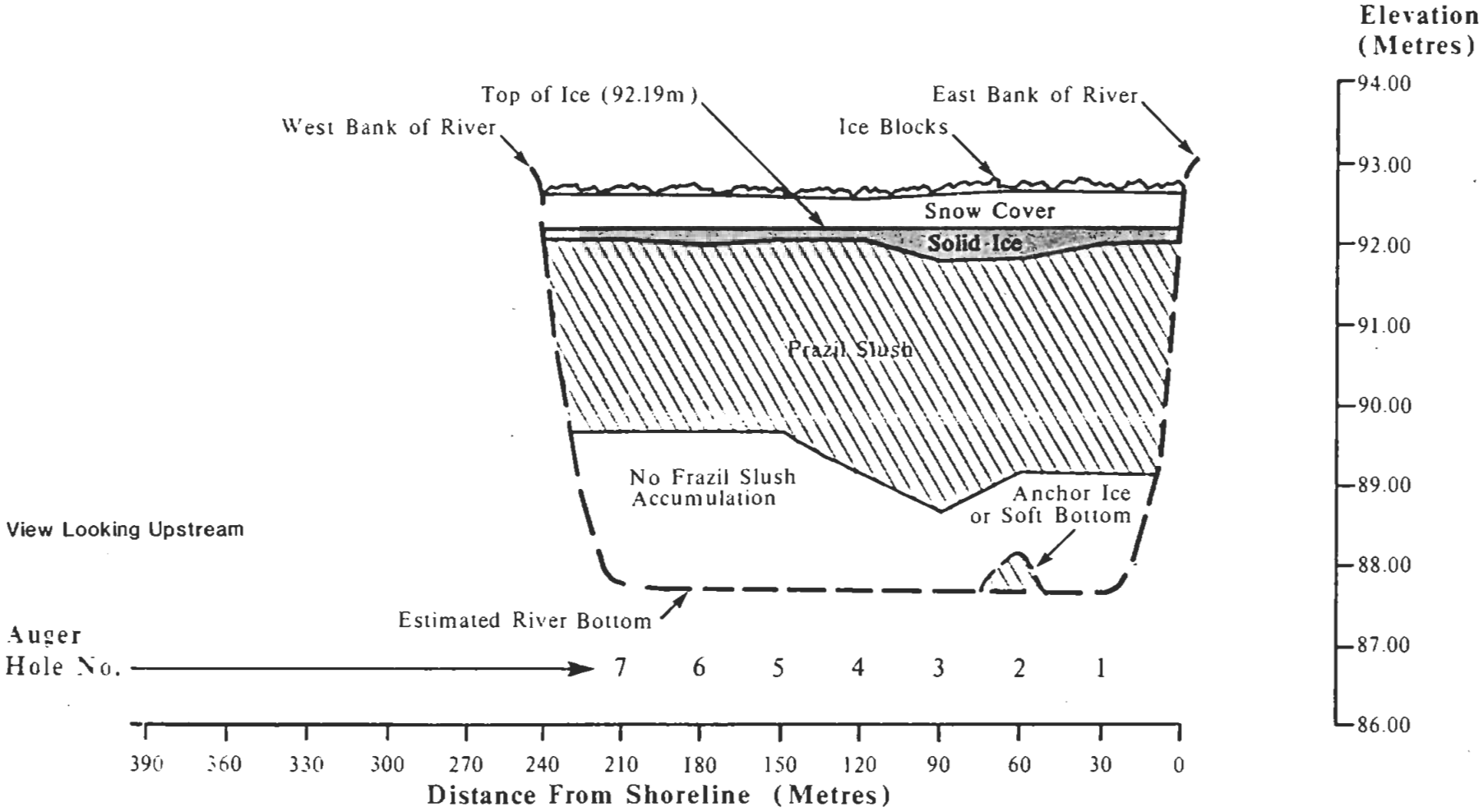


Notes: ~ ~ ~ ice or bottom contour approximate

FIGURE 4.6

Cross-Section 2, Jan. 30, 1984

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

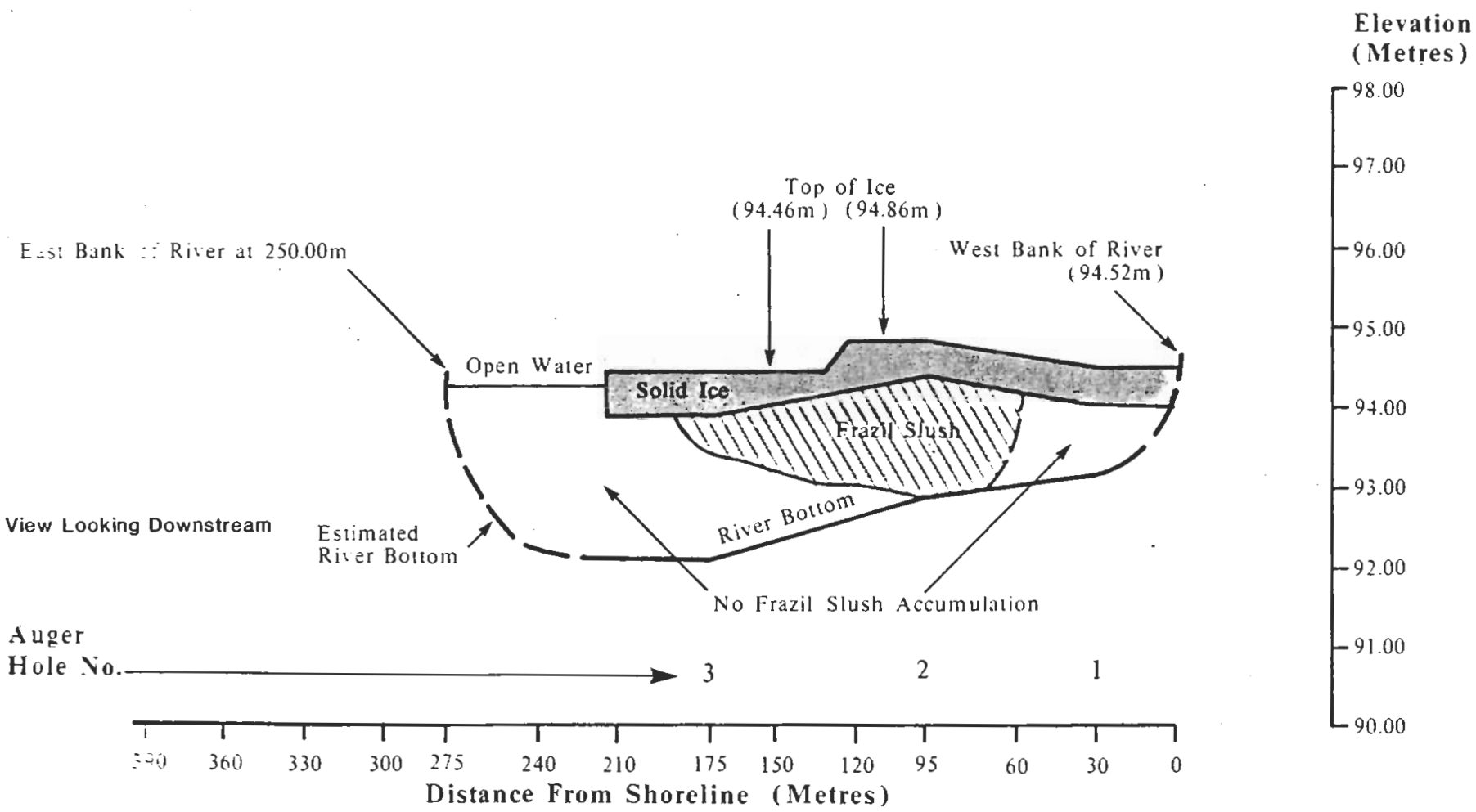


Notes: ~ ~ ~ ice or bottom contour approximate

FIGURE 4.7

Cross-Section 31, Feb. 23, 1984

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM



Notes: ~ ~ ~ ice or bottom contour approximate

FIGURE 4.8

channels are shown in 1977 and 1983 photographs as well and have been mapped in Figure 4.9. In all years of observation, the leads within the ice cover have been in almost the same location in the river.

This finding is of importance to the study as it will be of benefit in evaluating possible channel modifications or as a guide to ice blasting operations.

The results of these observations:

- indicate that a significant volume of frazil slush accumulates in the Badger area

- suggest that in flood years, this accumulation may contact the bottom (as in Figure 4.8) or shove into an accumulation of such thickness (e.g. Figure 4.7) that water elevations rise to flood elevations at Badger

- indicate why water levels recede in flood years (and non-flood years) as a result of natural erosion and opening of the ice cover through time at the leads

- are extremely valuable for hydraulic analysis and flood damage options described later in this report.

4.3 Summer Surveys

The objective of the summer survey program was to provide information on the channel geometry and depth which could not be easily completed in the winter months. The scope of this work included:

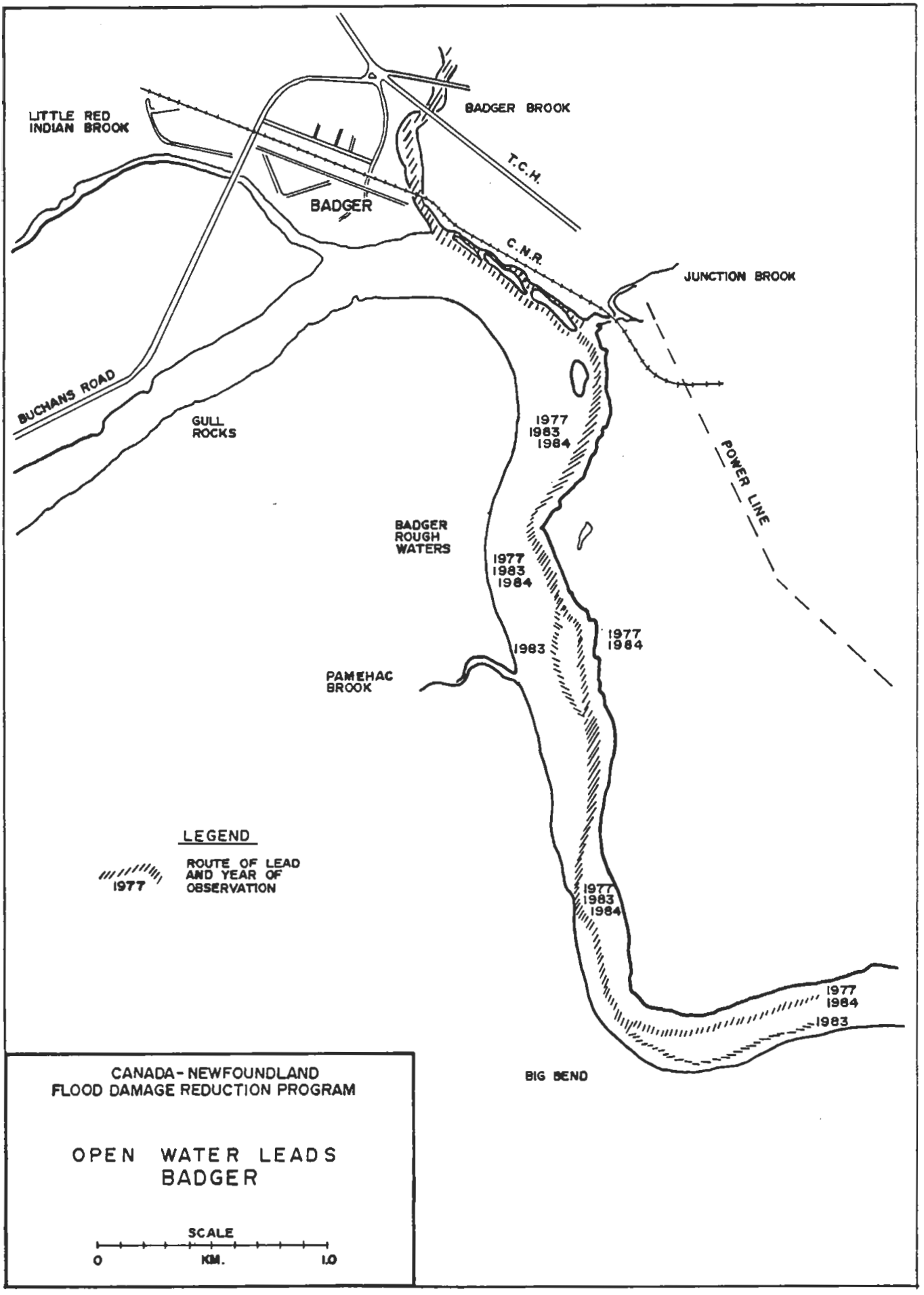

LITTLE RED INDIAN BROOK
BADGER BROOK
T.C.H.
BADGER
C.N.R.
JUNCTION BROOK
BUCHANS ROAD
GULL ROCKS
1977
1983
1984
POWER LINE
BADGER ROUGH WATERS
1977
1983
1984
1977
1984
1983
PAMEHAC BROOK
LEGEND
1977
ROUTE OF LEAD AND YEAR OF OBSERVATION
1977
1983
1984
1977
1984
1983
BIG BEND
CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
OPEN WATER LEADS
BADGER
SCALE
0
KM.
1.0

FIG. 4.9

- measurement of river depth, bottom elevation and surface elevation at all winter observation locations as well as other sites required for hydraulic modelling

- measurement of river bank and overbank elevations at each of these sections

- measure of all bridge structures on the river and its tributaries

- surveys of ground and flood elevations of buildings in Badger which have been or could be flooded by high water levels.

The summer program took place in two sequences:

- River Sequence. This was initiated on 9 July 1984 and extended over 33 days until 22 August 1984

- Badger Sequence. Building and topographic elevations were surveyed in the town in the 4-day period from 23 August to 28 August, 1984.

Overall, it was necessary to measure 31 cross-sections along the Exploits River, 6 sections on Badger Brook and 4 sections on Little Red Indian Brook, Rushy Pond Brook and Wigwam Brook, to ensure that proper coverage was obtained. In the Rushy Pond area, there is no detailed topographic mapping and considerable field effort was also required to identify controlling topography in the gravel pit.

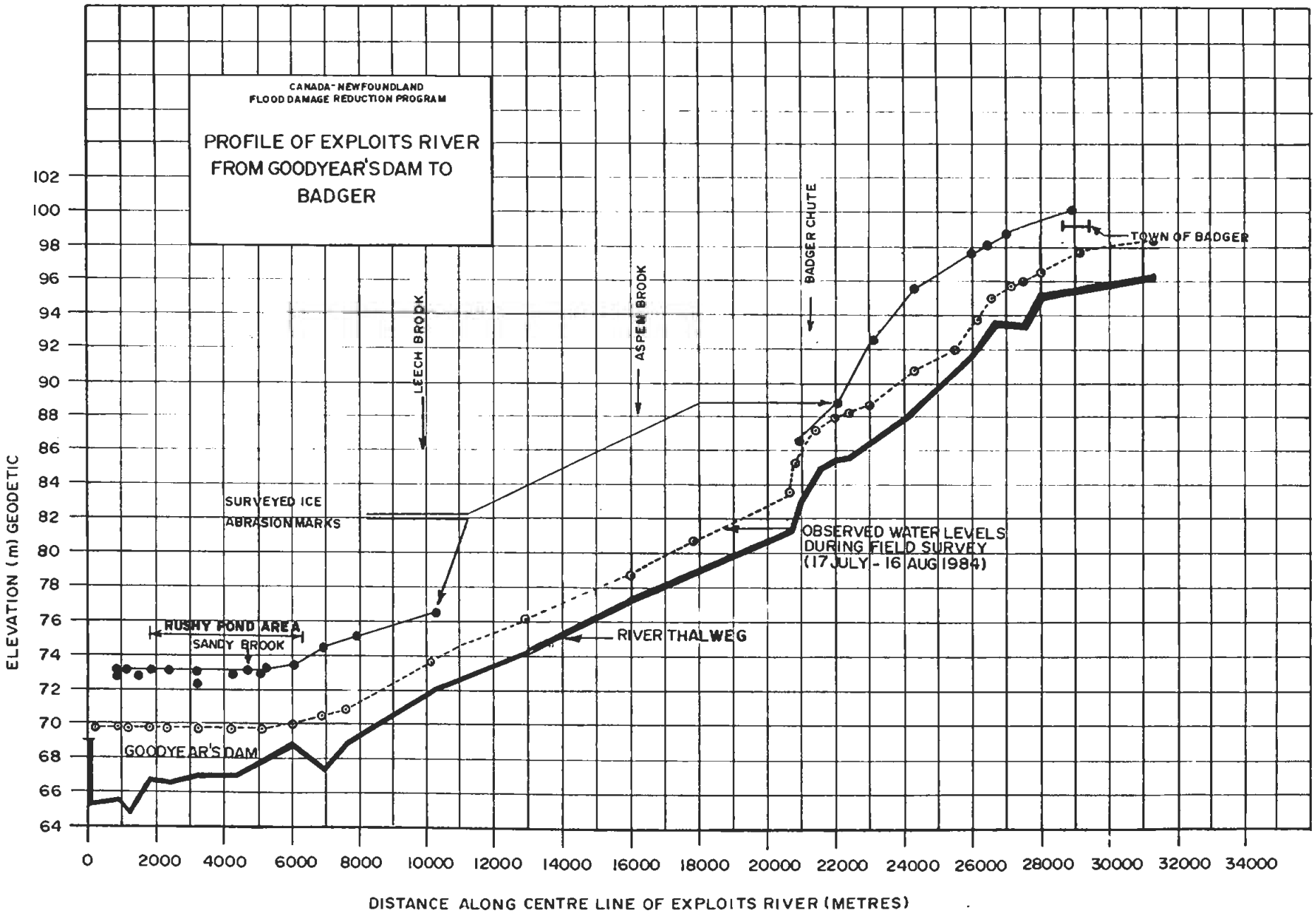

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
PROFILE OF EXPLOITS RIVER
FROM GOODYEAR'S DAM TO
BADGER
LEECH BROOK
ASPEN BROOK
BADGER CHUTE
TOWN OF BADGER
SURVEYED ICE
ABRASION MARKS
OBSERVED WATER LEVELS
DURING FIELD SURVEY
(17 JULY - 16 AUG 1984)
RUSHY POND AREA
SANDY BROOK
RIVER THALWEG
GOODYEAR'S DAM
ELEVATION (m) GEODETIC
102
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
68
66
64
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
24000
26000
28000
30000
32000
34000
DISTANCE ALONG CENTRE LINE OF EXPLOITS RIVER (METRES)

FIG. 4.15

In Badger, it was necessary to survey floor and ground elevations of 151 structures as well as 1,000 m of Maple Street and 400 m of Main Street. This was required to account for many new buildings and changes in the town that have taken place since the available 1963 mapping. Figure 4.10 indicates the locations of the field surveyed cross-sections on 1:50,000 scale mapping. Sections marked with an asterisk(*) were interpolated and are discussed in more detail in Chapter 6.

4.3.1 Summer Survey Results

The summer survey results have been drafted and are provided for each river cross-section in the Technical Appendix. For the most part, the results are of greatest value when coupled with the hydraulic modelling in Section 6.0. Several aspects of interest are shown by the cross-sections themselves.

Figure 4.11 shows an example of the results at Section 3250, which crosses the Goodyear's Gravel Pit, 3250 m upstream of Goodyear's Dam. The cross-section shows the main channel on the right and a height of land in the centre of the section separating the main channel from the TCH. The TCH is shown as the tall projection lying between the height of land and the east bank on the far left. Just to the right of the TCH, is the relatively low ditch/overbank area which has carried flood flows close to the TCH during some past floods. At the bottom of each cross-section plot, the Manning's roughness coefficient for the main channel and the left and right overbank is presented.

Section 5100, which is also through Goodyear's Pit is shown in Figure 4.12. It also shows the height of land separating

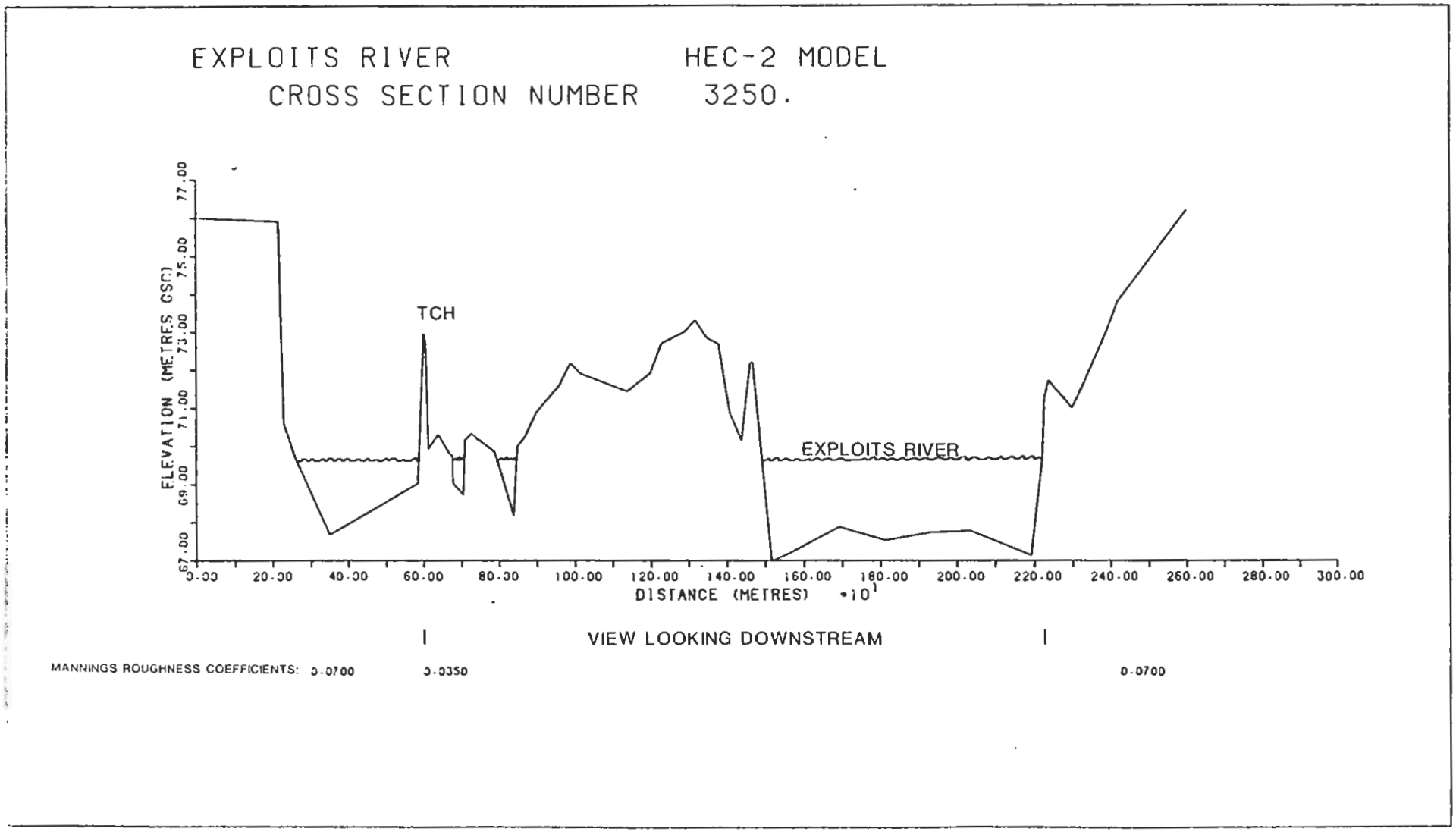


FIGURE 4.11

FIG 4.11

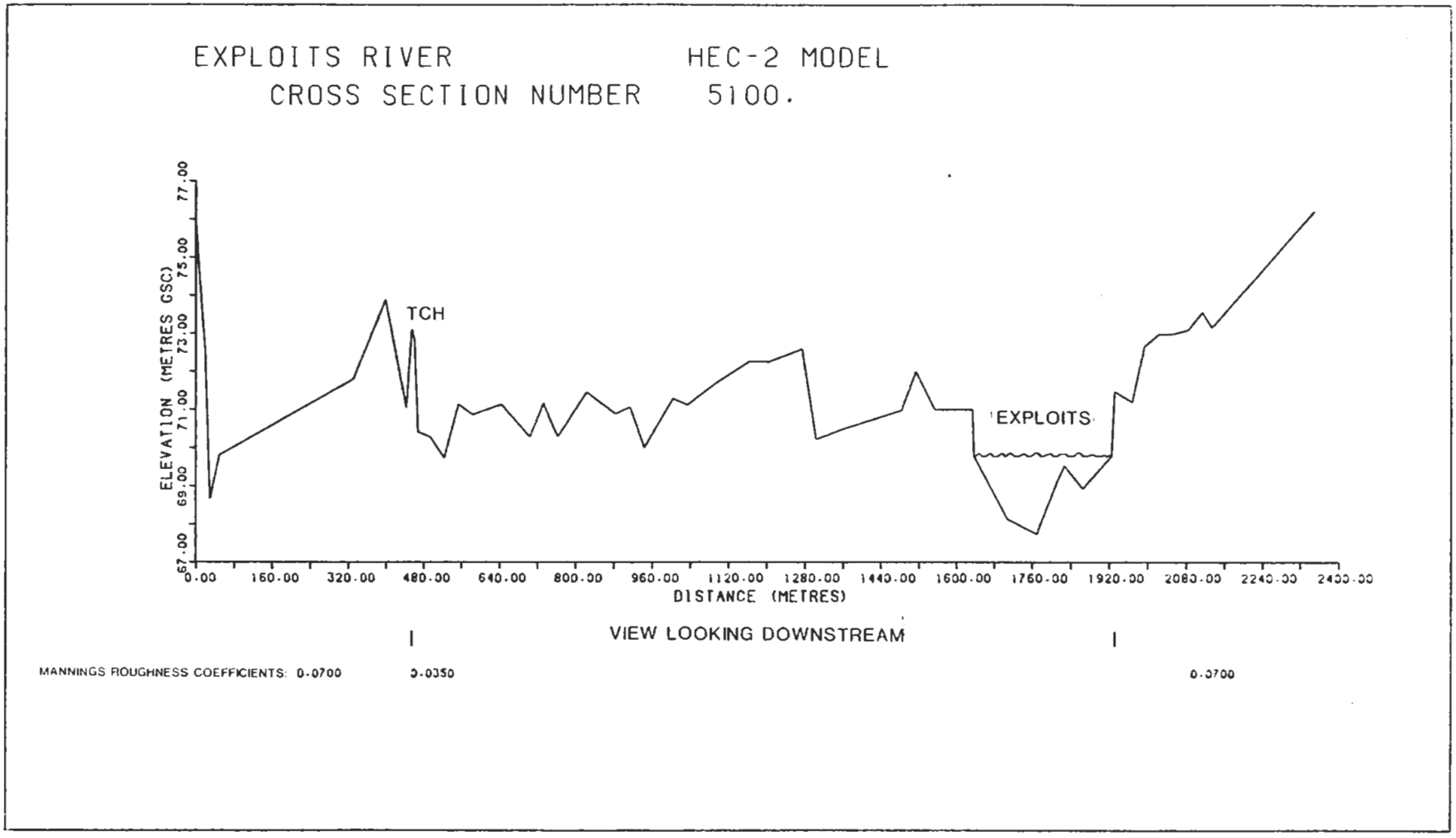


FIG 4.12

FIGURE 4.12

the main river from the TCH and the overbank area to the right of the TCH which has carried flood flows in past events.

Section 6050, which is just downstream of the Red Cliff Overpass (Figure 4.13) shows the main channel in the centre of the drawing, the TCH at the far left and a dyke which is approximately at the same elevation as river banks before gravel pit operations commenced in this area. The dyke is incomplete and completely missing in several areas upstream and downstream of this location. This allows flood flows to spill out of the channel and quickly move to the edge of the TCH at this section and at the downstreams sections described previously.

The results of these surveys in the Rushy Pond Area indicate that:

- there is an opportunity for flood water to leave the main channel of the Exploits River near the Red Cliff Overpass and flow along the length of the TCH from Red Cliff Overpass down to the "North Angle" Culvert

- the capacity of this overbank channel is relatively restricted, and in the event of ice blockage of the main channel, it would be expected that the TCH would be overtopped.

Section 27,090, which is at the upstream end of Badger Rough Waters, is shown in Figure 4.14. Of interest at this section (and others downstream through to Section 26790) is the presence of an overflow/diversion channel on the north (left) bank of the river through Badger Rough Waters. This diver

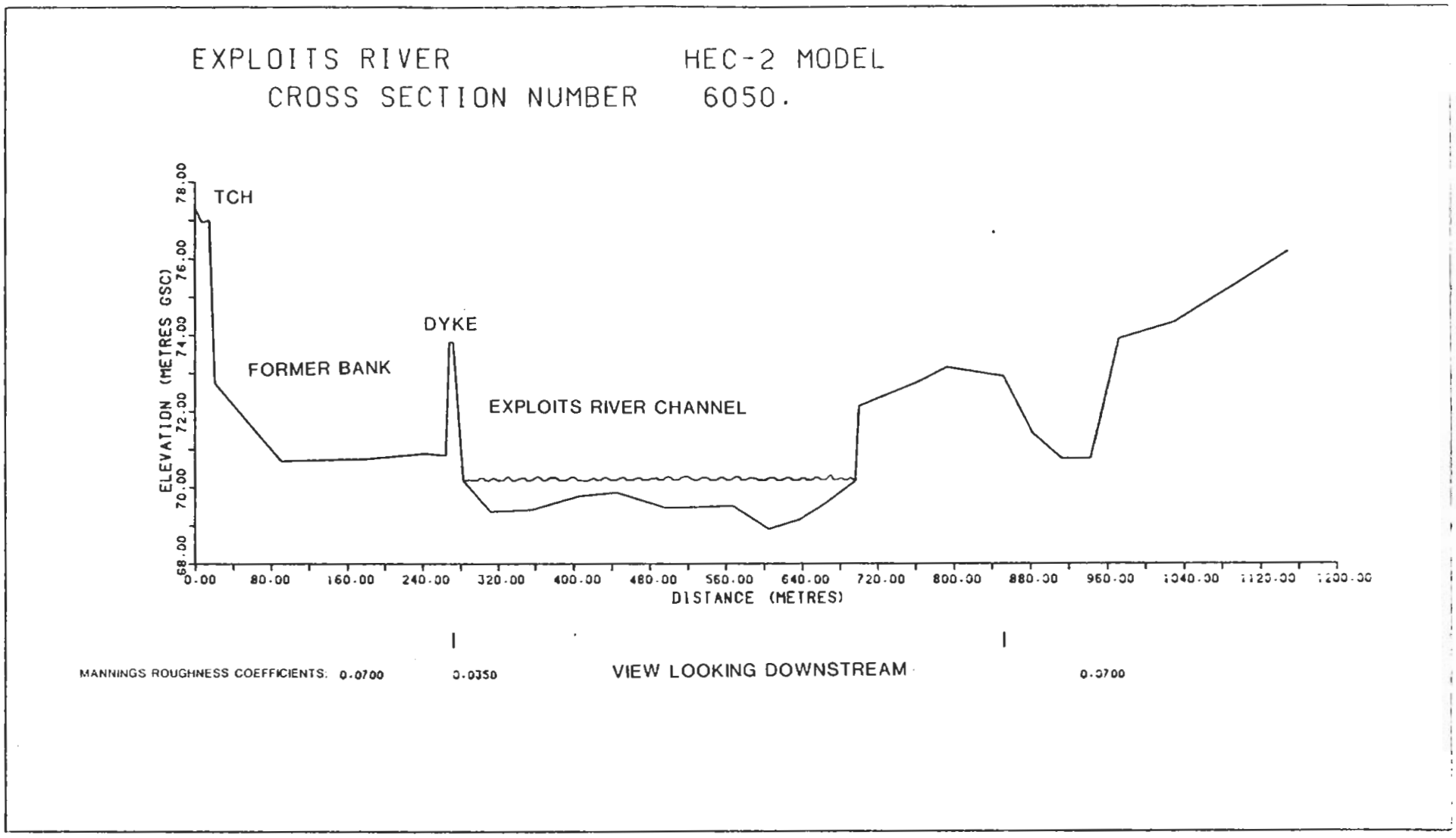


FIG. 4.13

FIGURE 4.13

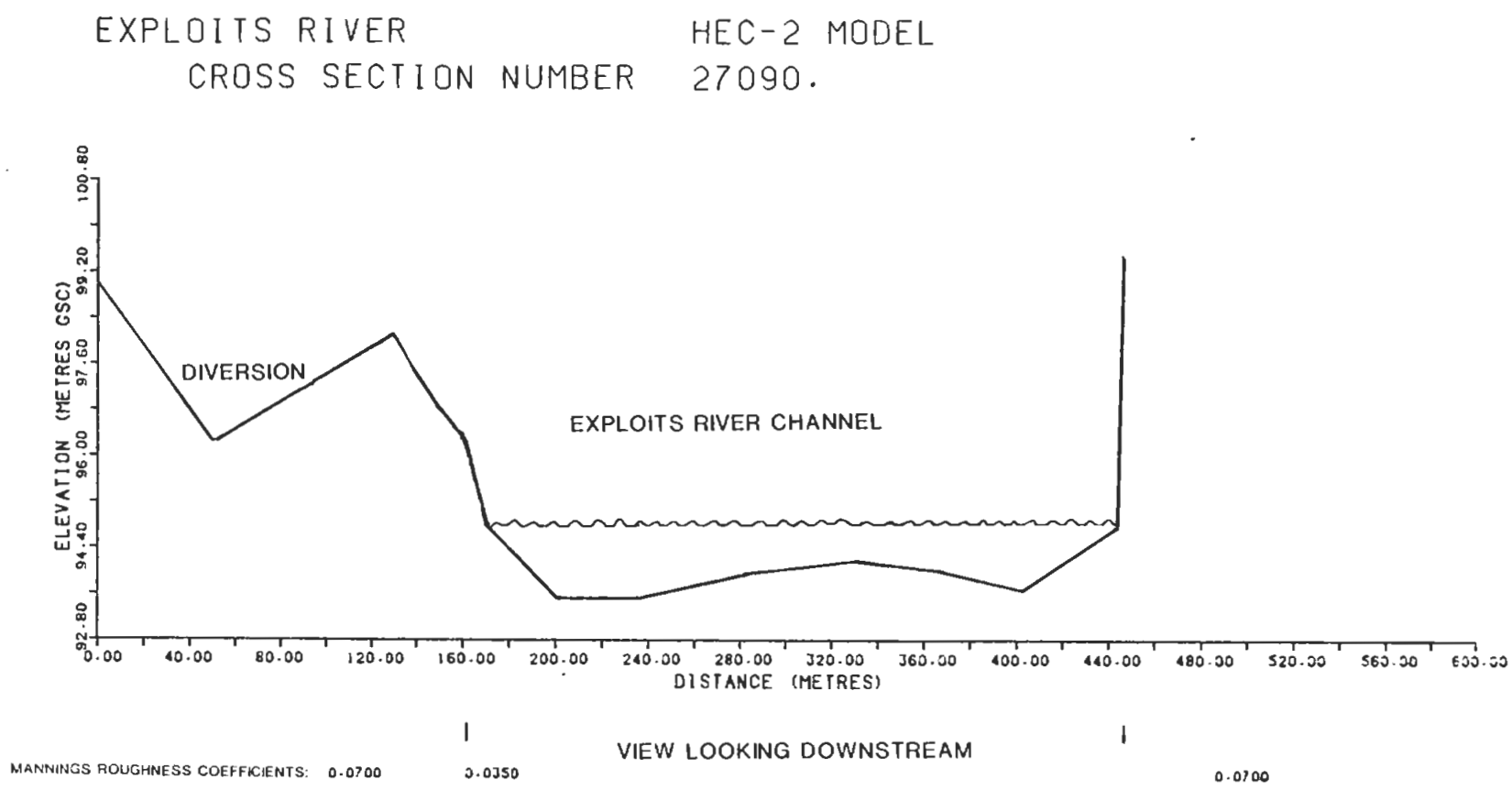


FIG 4.14

FIGURE 4.14

sion was observed to be carrying flood water around the ice jam at Badger Rough Waters during the February flood of Badger in 1983.

The overall results of the summer surveys in the Badger area confirm that:

- there are shallow areas (shown in Figure 4.8 for example), which could serve as locations which obstruct the flow of ice and water along the river below Badger

- there is a natural diversion which may be acting in flood years at Badger to limit flood elevations to a level similar to that of 1983.

The summer survey results are combined for both parts of the study area in the overview drawing, Figure 4.15. The river thalweg is shown from Goodyear's Dam to Badger along with a profile of the observed (1984) summer water levels and the elevations of ice abrasion marks along the river course. In the Rushy Pond area, these marks range between 2 and 4 metres above the summer level, and near Badger, they range between 4 and 5 metres above the summer level (at a discharge of about 208 m^3/s).

5.0 HYDROLOGIC ANALYSIS

5.1 Introduction

As indicated in the Terms of Reference for the Badger and Rushy Pond hydrotechnical study, flood profiles were required for the 1:20 and 1:100 year flows for open water conditions. In addition, flows were required as a basis for examining the impact of ice jams on water levels in the study area. The following sections discuss the derivation of these flows from the streamflow records available within the region.

In summary, the objectives of the hydrologic analysis were as follows:

i) to determine 1:20 and 1:100 year open water flood flows for the Exploits River for the purposes of backwater modelling at Badger and Rushy Pond

ii) to determine 1:20 and 1:100 year open water flood flows for Badger Brook and Little Red Indian Brook at Badger for backwater modelling purposes

iii) to provide winter flow estimates for use in evaluating ice effects.

5.2 Methodology

Flood flow estimates can be derived by various techniques including:

- Single station frequency analysis of flow records at the site of interest (or from a nearby site on the same stream by transposition)

- Regional frequency analysis of flow records within the general area of interest

- Computer simulation using a mathematical watershed model and long-term weather records.

The choice of method in a particular situation is governed by the availability and length of streamflow record at or near the point of interest. Table 5.1 indicates the hydrometric data of relevance to this particular study. Figure 5.1 shows the locations of the gauges with respect to the study area.

5.2.1 Methodology for Estimation of Flows on the Exploits River

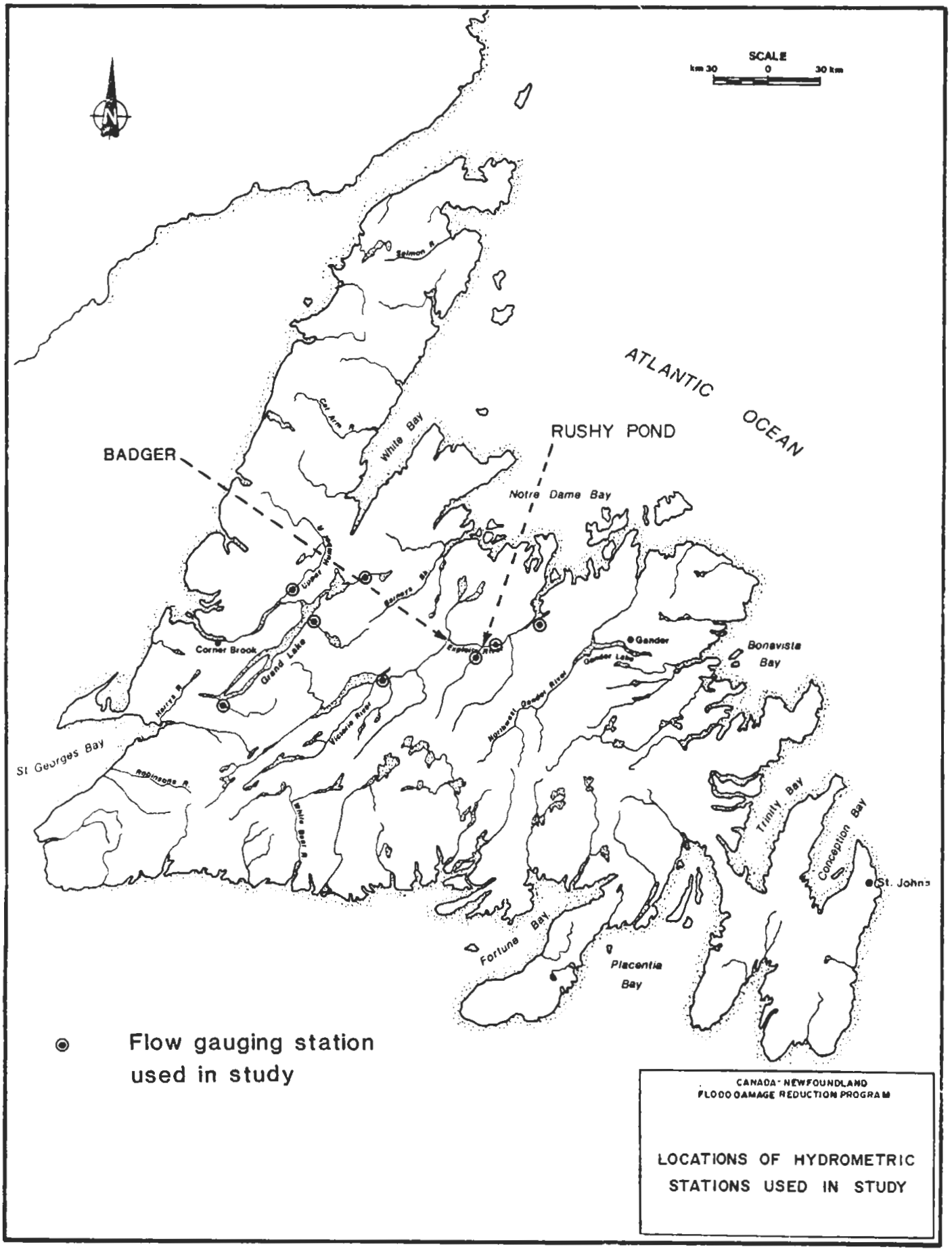
Clearly, the most important historical records with respect to flows on the Exploits River at Badger and Rushy Pond are those at the Exploits Dam, Grand Falls Dam and downstream of Stony Brook. As Figure 5.1 indicates, the Grand Falls Dam location is practically coincident with Rushy Pond with a difference of only 61.1 km^2 (0.7%) in drainage area between these two points. Hence a single station frequency analysis of the record at Grand Falls was selected as the appropriate method for estimation of flows at Rushy Pond. Since the records prior to 1934 were found to be approximate, only the period from 1934 to 1983 was utilized as a basis for this analysis. Section 5.3 describes how the data was prepared for this analysis.

TABLE 5.1

DATA AVAILABILITY

Location	Drainage Area (km^2)	Type of Data and Record	Period	Collecting Agencies	Comments
Exploits River at Exploits Dam	5092[1]	Water Level Gate Settings (Regulated)	1927-date	Abitibi	-abstracted from records maintained by Abitibi and converted to flow.
Exploits River at Grand Falls	8460[1]	Water Level Gate Settings (Regulated)	1914-1933	Abitibi	-approximate records
		Flow (Regulated)	1934-1961		-accurate records
		Flow (Regulated)	1962-date		-published by W.S.C.
Exploits R. below Stony Brook	8640[1]	Flow (Regulated)	1969-date	Water Survey of Canada (W.S.C.)	
Sandy Brook at Powerhouse	508	Flow (Regulated)	1965-date	N.L.P.C.	-published by W.S.C.
Rattling Brook at Powerhouse	378	Flow (Regulated)	1963-date	N.L.P.C.	-published by W.S.C.
Hinds Brook near Grand Lake	529	Flow (Natural)	1957-1979	W.S.C.	
Lewaseechjeech Brook at L. Grand Lake	343	Flow (Natural)	1953-date	W.S.C.	
Sheffield R. at Sheffield L.	362	Flow (Natural)	1956-1966	W.S.C.	
Sheffield R. at TransCanada Hwy.	391	Flow (Natural)	1973-date	W.S.C.	
Upper Humber R.	2110	Flow (Natural)	1929-date	W.S.C.	
Corner Brook at Powerhouse	127	Flow (Regulated)	1959-date	Bowater	-published by W.S.C.

[1]This drainage area excludes the portion of the watershed (1060 km^2) upstream of the Victoria Lake diversion.



CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

LOCATIONS OF HYDROMETRIC STATIONS USED IN STUDY

FIG. 5.1

As Figure 5.1 indicates, the Badger location is "bracketed" by the flow records at Exploits Dam and Grand Falls Dam. With a drainage area of 6653 km^2 just upstream of the confluence with Badger Brook, this location is approximately at the mid point of the two gauged locations. The method selected for estimation of design flows was therefore to utilize an area weighted average of the flows resulting from single station frequency analyses of the upstream and downstream records. Again, the period of record selected for analysis was from 1934 to 1983 inclusive.

In addition to obtaining 1:20 and 1:100 year peak annual flows, it was also necessary to estimate flows of various return periods for the winter months for use in the ice analysis section of this study. The same basic methodology as described above was adopted to carry out frequency analysis for the individual months from December to April inclusive.

5.2.2 Methodology for Estimation of Flows on Badger Brook and Little Red Indian Brook Tributaries

Historical reports have indicated that flooding in Badger results both from high water levels in the Exploits River and from overtopping of the banks of Badger Brook and Red Indian Brook. The latter is likely the result of a backup of water from the Exploits River rather than high flows on the two tributaries themselves. However, in defining the floodplain in this area it was important to confirm that this was the case. Hence 1:20 and 1:100 year flows were required for these two streams.

The drainage areas of Badger Brook and Little Red Indian Brook are 698.7 km^2 and 135.5 km^2 respectively. Since this is considerably different from the drainage area at the gauges on the Exploits River, it was not appropriate to base the flow estimates for the tributaries on these records. While it would have been feasible to utilize a hydrologic modelling approach, no flow records are available for either tributary on which to base model calibration. Hence a regional frequency analysis approach was adopted.

As Table 5.1 indicates, there are only seven sets of records within the general region of the Exploits River suitable for use in a regional analysis. In addition, a number of these records are at locations subject to regulation (although the impact of regulation is limited at high flows). However, it was decided that this data would provide an adequate basis for a regional analysis suitable to confirm the dominance of main stream water levels as design levels in the lower reaches.

5.3 Data Preparation

As previously indicated, the hydrometric record at the Exploits Dam and at Grand Falls Dam were not in ready-to-use form for the hydrologic analysis. Data preparation consisted of two phases:

i) abstraction of the data from the records maintained by Abitibi Price Inc., followed by conversion from water levels and gate settings to flows

ii) adjustment of the data to account for the effect of the implementation of the Victoria Lake diversion in late 1969/early 1970.

5.3.1 Abstraction of Data

i) Grand Falls Dam

As indicated in Table 5.1, records of mean daily flow at Grand Falls have been maintained by Abitibi Price Inc. for the 1934 to 1983 period selected for analysis in this study (the Technical Appendix provides details of the data collection). Hence data abstraction consisted of searching through the log sheets for these years and recording the maximum flow for each month in the period December to April and the maximum annual flow for each year. For the period 1969 to 1983, the maximum annual flow was available from Water Survey of Canada records obtained on magnetic tape. It should be noted that these data at Grand Falls Dam are mean daily flow values and an adjustment factor was applied after the frequency analysis to obtain instantaneous flow estimates.

ii) Exploits Dam

At this location, the records consisted of tables of daily readings of water level and changes in gate settings for the dam during each day. These records were scanned to locate the highest water level each month together with the greatest opening of the dam control structures. Through the use of the available rating curves[1], the flow at each time was computed. Daily flows were computed from December to April

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1 Provided in tabular form by Abitibi Price Inc.

and two or three flows per month were computed for the other months. From the monthly maxima, the annual maximum for each year was selected. It should be noted that these data are the best estimate of the instantaneous maxima since during high flow periods they are generally based upon selecting the highest value from a number of readings each day (Appendix A.5).

5.3.2 Adjustment for Victoria Lake Diversion

In the late 1960's, about 1060 km^2 of the Exploits River watershed was diverted from its normal north-easterly course to flow in a south-easterly direction into the Bay d'Espoir Hydro System. This was accomplished by construction of a dam at the former outlet of Victoria Lake, known as the Victoria Spillway, and diversion works to Burnt Pond, known as the Victoria Control. The impact of this diversion was to reduce the effective drainage area at the Exploits Dam from 6152 km^2 to 5092 km^2 and at Grand Fall Dam from 9520 km^2 to 8460 km^2. These are reductions of 17 and 11 per cent respectively. The diversion came "on-line" in late 1969 and has therefore been assumed to have affected all flows from 1970 to date inclusive.

An examination of records of water levels and outflows from Victoria Lake indicated that since its construction, spillage has never occurred from the Victoria Spillway into the Exploits River[1]. Even during the catastrophic event of January 1983, no spillage occurred and the reservoir reached only 63 per cent of its storage capacity (Buglar, 1983). It

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1 With the exception of brief periods when the operation of the outlet control works have been tested.

therefore appears that the diversion has effectively reduced the drainage areas as noted above and would therefore be expected to have considerably reduced peak flows at Exploits Dam and Grand Falls Dam.

In order to confirm the above, the statistics of the annual peak flows for the two records were compared for the periods 1934 to 1969 and 1970 to 1983. As Table 5.2 indicates, there are significant differences in the mean, standard deviation and skewness of the two samples for both locations. In addition, Mann-Whitney tests (Winkler and Hays, 1975) were performed to examine the homogeneity of the pre and post 1970 peak flow records. This non-parametric test uses the summed ranks of one sub-sample (i.e. the 1970 to 1983 period) from a ranked sample of the complete data set to determine whether the null hypothesis that the two parts of the data set have no significant difference can be rejected. As Table 5.2 shows, there appear to be significant differences in the Exploits Dam samples at the 1% level of significance and at about the 5 to 10% level for Grand Falls[1].

In order to examine the possibility that the differences observed were caused by some type of natural phenomena (e.g. climatic change), the same analysis as above was performed on the regionally available flow data indicated in Table 5.1. There is only one long term record unaffected by regulation covering the 1934 to 1983 period, i.e. the Upper Humber River at Reidville. Hence the tests were performed on the annual

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1 In other words, there is only a 1 in 100 chance that the differences in the sub-samples at Red Indian Lake are the result of random chance.

TABLE 5.2

STATISTICAL ANALYSIS OF PRE AND POST 1970 ANNUAL MAXIMA DATA

Location	Period	Condition of Data	Mean	Standard Deviation	Skewness	Mann-Whitney Statistic, U	Test Statistic, Z[1]
Exploits River at Exploits Dam	1934-1969	Observed[2]	728	277	0.14		
						110	-2.90
	1970-1983	Observed[2]	484	149	0.91		
						200	-0.86
	1934-1969	Adjusted[3]	594	230	0.25		
Exploits River at Grand Falls	1934-1969	Observed	886	308	0.07		
						190	-1.33
	1970-1983	Observed	760	328	1.65		
						227	-0.54
	1934-1969	Adjusted[3]	787	274	0.07		
Upper Humber at Reidville (test case)	1934-1969	Observed	567	112	0.30		
						253	1.93
	1970-1983	Observed	573	110	0.40		
Regional Average (test case)	1956-1969	Observed	0.18[4]	0.033	-0.92		
						268	3.23
	1970-1983	Observed	0.19	0.023	0.08		

1 The Mann-Whitney Statistic, U is not directly tested. Rather the derived test statistic, Z is utilized. Critical Z values are -2.326 for 1% level and -1.645 for 5% level of significance. Difference is significant if Z value is less than critical value.

2 Units are m^3/s

3 Adjusted by drainage area ratio to reflect the reduction in flows by the Victoria Lake diversion.

4 Units are $m^3/s/km^2$.

peak flows from this record. Several other records cover the period 1956 to 1983. The annual peak flows from these records were therefore divided by their respective drainage areas and were averaged to form a regionally averaged data set. The tests were then performed on the pre and post 1970 periods. As Table 5.2 indicates, there are no significant differences between the pre and post 1970 periods. Hence the differences observed at the Exploits and Grand Falls Dams must result from the Victoria Lake diversion and these records were therefore adjusted prior to frequency analysis.

Changes in the observed flow records could potentially have resulted from not only the diversion of part of the Exploits River watershed but also from changes in the operation of Red Indian Lake coincident with the diversion coming on line. However, an examination of operational procedures and water levels for Red Indian Lake indicated that procedures were essentially consistent for the pre and post 1970 periods. This probably results from the fact that there is relatively little storage at Red Indian Lake compared to the size of the upstream watershed. Hence an "excess" of inflow which existed prior to the diversion still remains despite a 17 per cent reduction in drainage area. Hence no operational changes have been required.

As previously noted, the diversion has effectively prevented all inflow from the area upstream of Victoria Lake. Hence a potential method of adjusting the flow records was to prorate flows by the appropriate drainage area factors. Since the "design" flows must reflect current conditions, the pre-diversion (i.e. pre 1970) flows were reduced to account for the reduced drainage areas. Although the non-homogeneity at Grand Falls was significant at only the 5 to 10% level, the adjustment was applied for consistency at both locations.

The following reduction factors were applied:

$$\text{Red Indian Lake factor} = \frac{5092}{6152} = 0.828$$

$$\text{Grand Falls factor} = \frac{8460}{9520} = 0.889$$

The statistical tests previously discussed were then applied to compare the pre and post 1970 records. As Table 5.2 shows, the Mann-Whitney test on the adjusted data now indicates no significant non-homogeneity of the samples. This adjusted data presented in Tables 5.3 and 5.4 was therefore accepted as suitable for use in frequency analysis.

5.4 Exploits River Frequency Analysis - Results

The adjusted annual and monthly maxima at the Exploits Dam and Grand Falls for the period 1934 to 1983 were subject to frequency analysis using the FDRPFFA computer program (Condie, Nix et al., 1977). After consideration of plots of the different distributions and examination of the sample statistics, it was determined that the Three Parameter Log Normal (3 PLN) distribution was preferable. Table 5.5 presents the results of these analyses indicating the 1:2, 1:20 and 1:100 year return period flows. Figures 5.2 and 5.3 present plots of the data and the fitted distributions for the annual maxima series.

As previously indicated, the flows at the Exploits Dam, as shown in Figure 5.3, are considered to be the best estimate of instantaneous flow maxima available. However, at Grand Falls Dam the values shown in Figure 5.2 are mean daily esti-

TABLE 5.3

EXPLOITS DAM, EXPLOITS RIVER (1934-1983)
MAXIMUM ANNUAL AND WINTER MONTHLY PEAK FLOWS[1]

Year	Maximum Annual	Maximum Daily Discharge per Month				
		January	February	March	April	December
	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
1934	853.1	157.0	153.2	155.2	835.1	167.2
1935	338.6	249.3	242.3	178.1	338.6	571.8
1936	743.2	134.9	133.5	578.8	342.1	245.6
1937	497.8	220.5	123.3	107.9	114.8	438.2
1938	327.4	130.6	116.2	171.1	168.9	110.1
1939	605.2	122.9	201.3	223.3	162.1	154.6
1940	740.0	147.6	121.6	191.0	173.0	99.3
1941	801.5	148.2	142.8	168.9	152.3	135.4
1942	607.8	130.0	227.9	267.1	226.4	169.4
1943	M	124.4	118.3	124.2	117.1	210.9
1944	687.4	147.1	99.3	126.9	153.2	189.1
1945	894.3	187.4	175.7	180.4	487.0	481.6
1946	853.3	146.9	124.2	183.4	853.3	89.1
1947	967.1	114.8	114.8	132.5	135.9	122.3
1948	1007.0	98.4	114.8	93.7	142.9	113.6
1949	488.6	169.9	138.5	346.8	373.9	249.0
1950	825.6	151.8	147.6	156.7	134.7	105.6
1951	910.5	105.5	108.1	115.1	910.5	277.1
1952	635.6	240.2	314.0	229.6	232.0	116.2
1953	638.7	152.3	251.9	149.9	639.2	133.5
1954	996.1	130.0	133.8	466.1	203.8	996.0
1955	281.7	291.7	160.5	166.8	147.8	124.2
1956	488.4	405.4	246.6	155.1	209.7	235.4
1957	337.4	202.9	181.6	148.1	130.0	337.4
1958	295.6	178.5	220.9	132.3	120.9	287.6
1959	407.8	156.7	145.7	140.1	171.5	407.7
1960	233.7	210.9	163.3	165.2	161.6	118.3
1961	498.9	123.0	126.5	70.2	96.0	93.7
1962	M	104.7	110.1	118.6	371.4	412.0
1963	334.0	340.1	333.9	218.4	200.3	281.2
1964	418.4	159.0	134.7	147.6	244.8	149.4
1965	568.9	151.5	133.5	245.3	250.2	127.4
1966	288.7	147.1	135.6	124.2	103.3	108.9
1967	501.9	229.2	155.7	121.9	107.7	327.6
1968	501.9	230.3	155.3	144.1	387.7	228.2
1969	608.4	161.6	439.0	198.8	155.6	544.0
1970	509.7	177.8	170.7	178.4	222.2	509.7
1971	527.8	191.9	147.5	264.0	525.8	196.9
1972	490.1	278.3	171.7	217.5	233.0	20.2
1973	325.6	195.3	144.1	263.3	223.7	146.9
1974	280.6	185.4	189.2	252.9	240.8	161.7
1975	365.2	177.4	192.1	84.9	102.7	133.0
1976	566.6	176.9	217.6	326.3	145.8	167.0
1977	555.8	168.4	188.3	187.5	250.5	375.9
1978	374.6	374.6	275.5	207.7	224.8	116.1
1979	336.9	132.0	162.8	336.9	186.8	152.9
1980	461.5	165.9	203.8	181.2	87.7	184.7
1981	841.8	186.8	178.9	173.5	286.0	257.1
1982	485.6	182.6	156.0	147.7	221.7	146.9
1983	666.7	177.2	170.0	157.9	666.7	151.2

[1] 1934-1969 values adjusted to reflect Victoria Lake Diversion.
M = Missing

TABLE 5.4

GRAND FALLS DAM, EXPLOITS RIVER (1934-1983)
MAXIMUM ANNUAL AND WINTER MONTHLY PEAK FLOWS[1]

Year	Maximum Annual	Maximum Daily Discharge per Month				
		January	February	March	April	December
	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
1934	1230.6	214.5	350.4	186.7	1230.6	288.6
1935	923.2	430.3	386.3	209.1	664.8	706.0
1936	895.1	196.3	198.6	911.5	480.8	606.6
1937	680.3	286.3	153.0	141.8	187.9	680.2
1938	471.4	242.6	264.7	190.0	341.7	152.8
1939	840.6	231.3	358.8	414.8	370.7	242.4
1940	944.3	192.1	140.4	245.9	411.4	414.1
1941	1005.5	185.9	210.7	188.1	342.2	164.0
1942	1018.6	207.3	287.7	339.5	469.8	229.8
1943	586 1	170.3	233.6	177.0	326.1	252.2
1944	788.6	213.2	162.4	152.9	196.8	248.8
1945	1052.0	239.6	279.2	235.6	544.5	337.0
1946	1045.0	254.3	201.2	172.9	1045.0	113.8
1947	1071.4	118.2	133.9	138.1	135.7	96.0
1948	1237.7	144.1	111.3	96.1	180.8	147.2
1949	517.0	563.3	168.4	611.1	492.9	344.3
1950	965.9	213.8	190.0	247.6	609.6	170.3
1951	1046.9	194.5	169.0	163.9	1046.9	353.7
1952	1029.9	331.7	54-.8	294.2	501.9	213.5
1953	757.4	364.2	567.1	188.0	757.4	213.0
1954	1335.3	156.5	537.5	713.1	357.4	1335.3
1955	411.5	456.1	314.2	341.9	233.3	212.1
1956	809.8	588.6	242.3	158.2	503.1	213.9
1957	418.6	203.0	184.1	169.9	216.6	380.5
1958	433.1	239.0	260.8	347.2	286.0	376.4
1959	436.5	146.5	109.9	110.7	307.9	436.5
1960	366.3	295.2	184.6	289.6	263.0	164.6
1961	502.0	131.3	122.0	180.8	193.8	173.7
1962	625 3	206.0	202.2	232.9	625.3	359.8
1963	566.2	400.2	384.0	305.0	380.2	391.0
1964	500.5	221.9	220.9	164.4	474.8	188.5
1965	974.3	233.4	244.8	355.1	278.1	162.8
1966	420.4	157.4	162.7	205.0	247.1	247.4
1967	770.3	172.2	168.2	152.9	114.0	329.1
1968	683.4	305.0	287.1	304.7	537.2	382.1
1969	986.7	223.1	761.9	256.4	265.4	923.7
1970	687.7	639.7	185.1	208.7	424.1	564.1
1971	919.4	193.9	243.2	255.5	919.4	276.3
1972	554.7	190.7	173.9	280.0	368.4	232.7
1973	474.5	208.2	187.0	157.9	474.5	339.5
1974	461.0	187.6	187.8	176.9	363.9	269.6
1975	610.2	170.8	162.0	188.7	524.6	610.2
1976	720.3	274.0	291.3	339.1	615.0	288.5
1977	846.7	301.0	282.0	232.7	517.5	846.7
1978	526.6	557.9	383.1	216.9	474.7	96.4
1979	573.8	331.9	261.7	573.8	337.1	232.8
1980	521.8	177.1	163.9	122.1	521.8	304.4
1981	1215.2	275.4	286.9	302.1	413.7	401.7
1982	912.2	280.3	249.8	216.2	769.8	224.9
1983	1622.8	1622.8	243.1	461.6	778.0	224.6

[1] 1934-1969 values adjusted to reflect Victoria Lake diversion.

TABLE 5.5

EXPLOITS DAM AND GRAND FALLS DAM
FREQUENCY ANALYSIS RESULTS FOR RED INDIAN LAKE AND GRAND FALLS DISCHARGES[1]

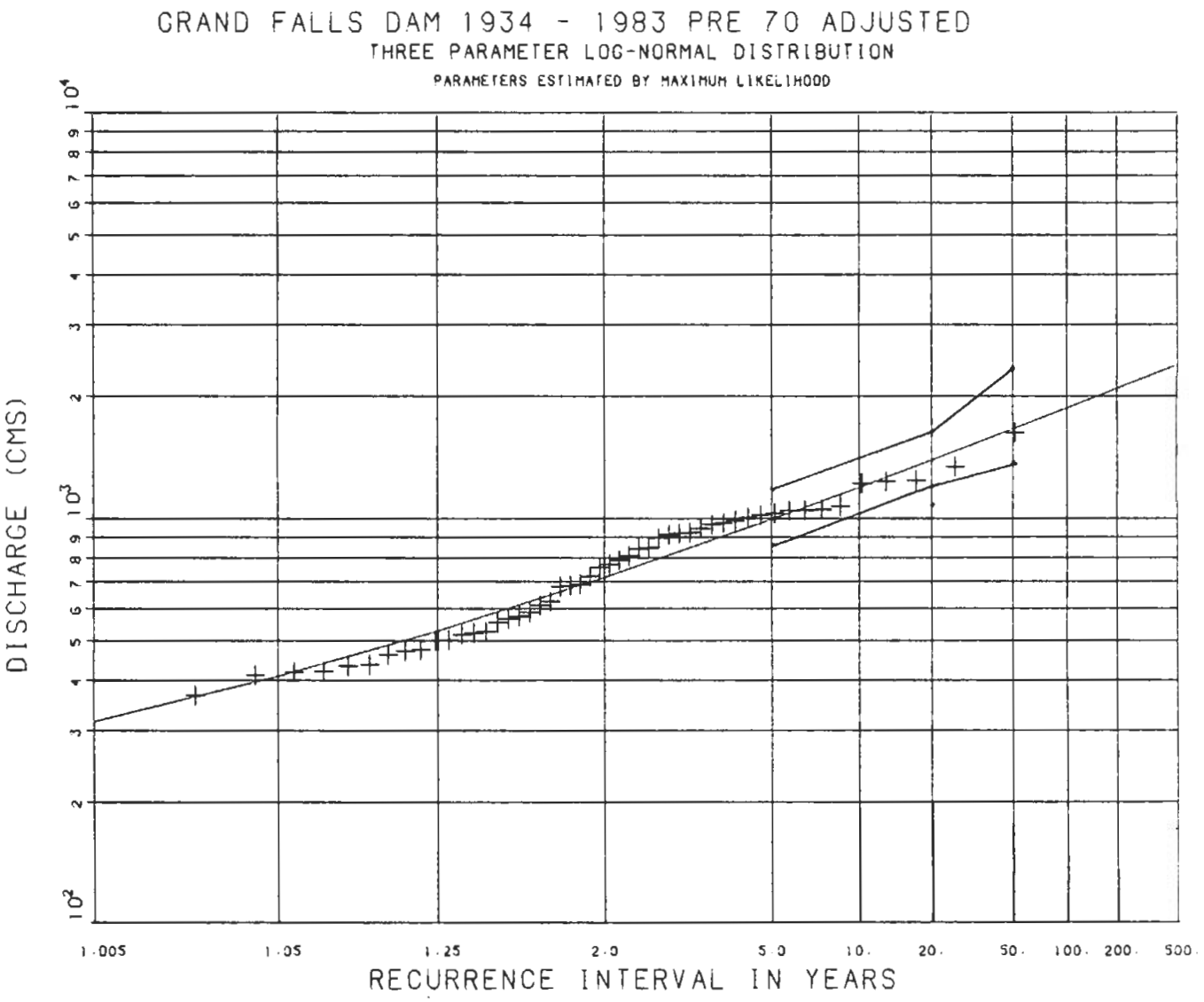
Location	Time Period	1:2 Year Flow (m^3/s)	1:20 Year Flow (m^3/s)	1:100 Year Flow (m^3/s)
Exploits Dam - Red Indian Lake	Annual[2]	520	1000	1320
	December[2]	195	530	792
	January[2]	166	304	411
	February[2]	157	300	425
	March[2]	166	333	454
	April[2]	198	683	1260
Grand Falls Dam - Grand Falls	Annual Daily[3]	716	1390	1870
	Annual[2] Instantaneous	745	1446	1945
	December[3]	281	774	1210
	January[3]	235	595	953
	February[3]	222	496	727
	March[3]	223	547	834
	April[3]	412	937	1300
	January to April[4]	411	877	1120

1 All values reflect diversion from the watershed at Victoria Lake.

2 Instantaneous flow estimates.

3 Daily flow estimates.

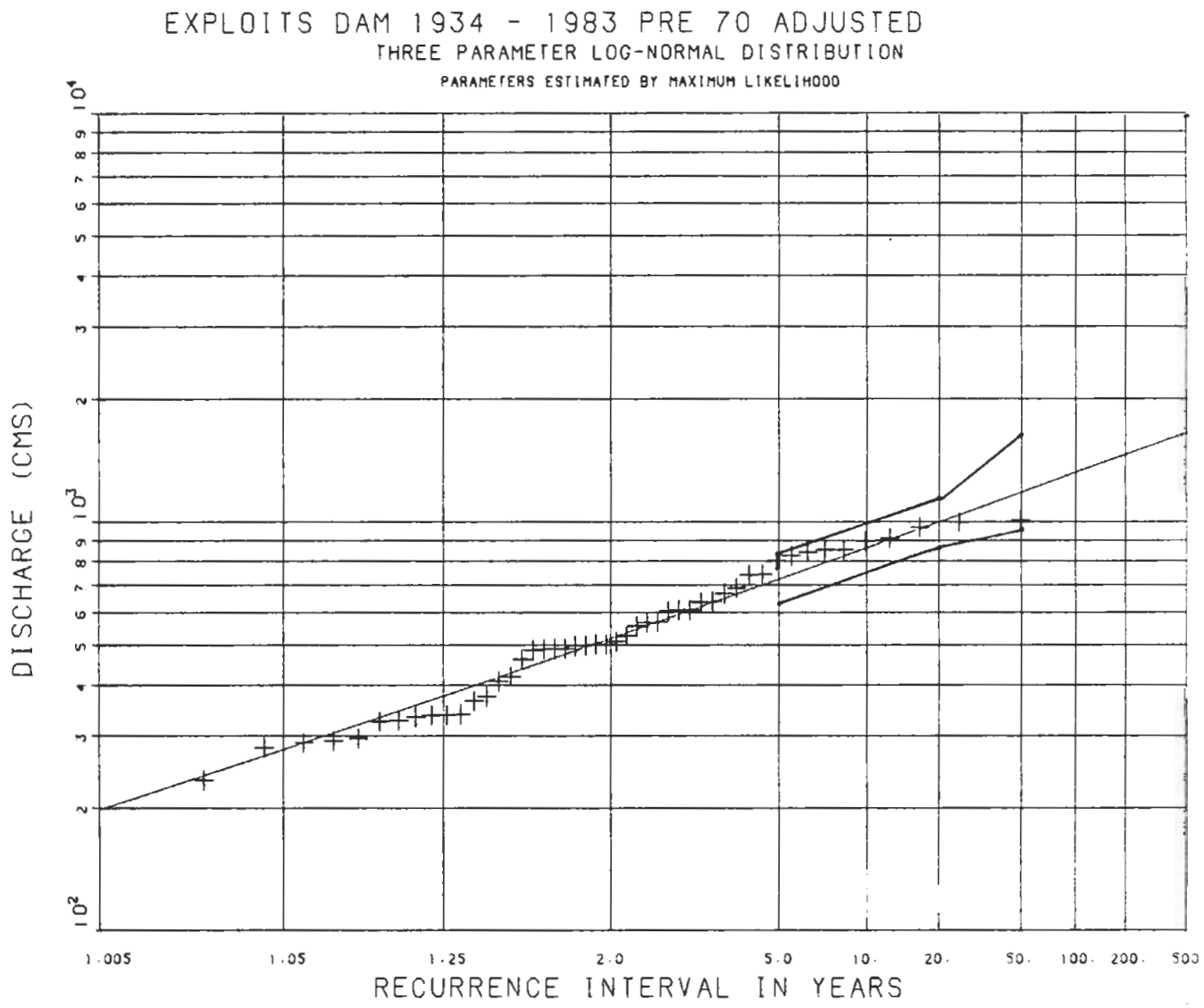
4 For the winter period when ice was present in the Exploits River in the lower reach near Grand Falls and Rushy Pond (LP3).



CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

FREQUENCY ANALYSIS OF MAXIMUM ANNUAL MEAN DAILY FLOW SERIES, GRAND FALLS, 1934 TO 1983

FIG. 5.2



CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

FREQUENCY ANALYSIS OF ANNUAL INSTANTANEOUS FLOW SERIES, EXPLOITS DAM, 1934 TO 1983

FIG. 5.3

mates and therefore required some adjustment to instantaneous values. Since no instantaneous measurements are available at Grand Falls for comparison with the daily values, the adjustment was based upon the Water Survey of Canada flow record just downstream of Grand Falls. This gauge is known as the Exploits River below Stony Brook. With a drainage area of 8640 km^2 it has only a 2 per cent difference in area from the Grand Falls gauge. Based upon the period 1969 to 1983 the average ratio between the maximum instantaneous and maximum daily flows is 1.04. Hence this factor was applied to the results of the Grand Falls frequency analysis to obtain the estimate of the 1:20 and 1:100 year instantaneous flows shown in Table 5.5.

The flow for the recent event of January 1983 (in which major flooding and damage occurred at Bishop's Falls) is shown in Figure 5.2 as the largest flow on record. Based upon the mean daily flow recorded at Grand Falls this would apparently correspond to a 1:50 year return period. However, when the estimated peak flow of 2269 m^3/s is compared to the adjusted frequency analysis for instantaneous maxima the return period is between 1:200 and 1:500 years.[1] This corresponds more closely to the severity of the event and its estimated return period at Bishop's Falls. The return period at Grand Falls would be expected to be lower than at Bishop's Falls since the flow upstream of Grand Falls was partially reduced by storage at Red Indian Lake.

The final step in calculating the design flows at Rushy Pond and Badger was to transpose the results from the Exploits and Grand Falls Dams to these locations. As previously indicated there is only a 0.7 per cent difference in drainage area

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1 Based on Water Survey of Canada estimate of 2400 m^3/s (maximum instantaneous flow estimate at the washed out Stony Brook gauge), adjusted to account for drainage area difference (3300-180)/3300 between the gauge and Grand Falls.

between Rushy Pond and Grand Falls Dam. Hence, with only this small reduction, the flow passing Grand Falls will be the flow which controls water levels on the Exploits River at Rushy Pond. Table 5.6 shows the final design flows at Rushy Pond.

The design flows at Badger were obtained as an areally weighted average of the flows at Exploits and Grand Falls Dams, as follows:

$$Q_B = Q_{RI} + \frac{(Q_{GF} - Q_{RI}) \cdot A_B}{A_{GF} - A_{RI}} \qquad (3\text{-}1)$$

where:

Q_B is the flow at Badger, m^3/s

Q_{RI} is the flow at Red Indian Lake, m^3/s

Q_{GF} is the flow at Grand Falls, m^3/s

A_B is the drainage area between Red Indian lake and Badger, km^2

A_{RI} is the drainage area at Red Indian Lake, km^2

A_{GF} is the drainage area at Grand Falls, km^2

This equation was applied both upstream and downstream of the confluence of Badger Brook. In the former case the drainage area A_B did not include Badger Brook. In the latter case Badger Brook was included. Table 5.6 presents the resulting open water design flows at these locations.

TABLE 5.6

OPEN WATER DESIGN FLOWS FOR STUDY AREA
FINAL 1:20 and 1:100 YEAR INSTANTANEOUS DISCHARGES

Location	Drainage Area	1:2 Year Flow	1:20 Year Flow	1:100 Year Flow
	(km^2)	(m^3/s)	(m^3/s)	(m^3/s)
Grand Falls, Exploits River	8640	745	1446	1945
Rushy Pond, Exploits River	8399	740	1436	1931
Badger d/s of Badger Brook, Exploits River	7352	671	1299	1739
Badger u/s of Badger Brook, Exploits River	6653	624	1206	1609
Badger Brook at Badger	698.7	-	212	249
Little Red Indian Brook at Badger	135.5	-	38.6	47.7

The same approach and areal reduction factors were employed to transpose the results of the winter frequency analyses in Table 5.5 to the Badger and Rushy Pond areas. Table 5.7 summarizes the flow for each month of the winter and the maximum flow during problematic ice periods is noted as the design flow.

At Rushy Pond, the historical dates of floods show that flooding with ice may take place in any of the winter months. Hence, Tables 5.5 and 5.7 include a seasonal analysis of peak flows occurring when ice was present in the Rushy Pond area. As this analysis encompasses the complete range of flows which can occur with ice, they have been selected as the design flows for winter analyses.

At Badger, past flooding has only occurred during the ice formation period (with only one exception in January). As the January flows correspond with the ice problem period, the peak flows for January have been selected as the "design" flows for use in winter analyses at Badger.

5.5 Little Red Indian Brook and Badger Brook

As previously indicated, the 1:20 and 1:100 year flows for the Little Red Indian Brook and Badger Brook tributaries were derived from a regional frequency analysis of streamflow records in the study region. Since this is only a partial regional analysis it has been designated a "sub-regional" analysis.

Single station frequency analyses were carried out using the FDRPFFA program for each of the seven streamflow records not on the main Exploits River shown in Table 5.1. From an

TABLE 5.7

WINTER DESIGN FLOWS - EXPLOITS RIVER STUDY AREAS

Location and Month		1:2 Year Flow[1]	1:20 Year Flow[1]	1:100 Year Flow[1]
		(m^3/s)	(m^3/s)	(m^3/s)
Exploits River Rushy Pond	December	290	799	1250
	January	243	614	984
	February	229	512	751
	March	230	565	861
	April	426	969	1343
	Jan. to April[2]	424	906*	1157*
Exploits River d/s of Badger Brook	December	260	715	1105
	January	218	515*	800*
	February	207	445	647
	March	210	491	731
	April	352	853	1321
	May[3]	291	-	-
Exploits River u/s of Badger Brook	December	240	657	1008
	January	202	450*	680*
	February	191	400	578
	March	197	442	645
	April	305	801	1302
	May[3]	263	-	-

1 Instantaneous flood flows.

2 Seasonal analysis when ice is present.

3 Mean monthly flow.

*4 Selected design flows.

examination of the resulting fits of the different distributions (Gumbel, Log Normal, 3 Parameter Log Normal and Log Pearson Type III), the 3 Parameter Log Normal distribution fit was selected for all cases except for Sheffield River at Sheffield Lake where the Log Pearson Type III was used. Estimates of 1:20 and 1:100 year return period maximum daily flows were obtained for each location. These are tabulated in Table 5.8.

Regression analysis was performed between the 1:20 year flow and drainage area and the 1:100 year flow and drainage area rather than relying on general empirical relationships. The latter generally give flows based on drainage area, A, raised to a coefficient less than 1.0, but for this region of study the resulting equations were as follows:

<u>1:20 Year</u>

$Q_{20} = 0.19\ A^{1.06}\ m^3/s$ with $R^2 = 0.97$, standard error = 18%

<u>1:100 Year</u>

$Q_{100} = 0.28\ A^{1.03}\ m^3/s$ with $R^2 = 0.95$, standard error = 21%

Given the limited number of points available for these regressions (i.e. the limited degrees of freedom) no other independent variables were examined.

The equations were applied to Badger Brook and Little Red Indian Brook to give estimates of the 1:20 year and 1:100 year flows at Badger. Since the sub-regional analysis had been based upon maximum daily flows, some adjustment was required to convert them to instantaneous values. Utilizing those records from the required data set for which both maximum instantaneous

TABLE 5.8

1:20 and 1:100 YEAR MAXIMUM DAILY FLOW ESTIMATES FOR WATERSHEDS WITHIN THE REGION OF THE EXPLOITS RIVER

Watershed	Drainage Area (km^2)	Type of Record	1:20 Year Flow (m^3/s)	1:100 Year Flow (m^3/s)
Sandy Brook at Powerhouse	508	Regulated	126	144
Rattling Brook at Powerhouse	378	Regulated	90.2	122
Hinds Brook near Grand Lake*	529	Natural	131	154
Lewaseechjeech Brook at Little Grand Lake*	470	Natural	156	198
Sheffield River at Sheffield Lake*	362	Natural	89.1	92.8
Upper Humber River* at Reidville	2110	Natural	757	851
Corner Brook at Powerhouse	127	Regulated	40.5	49.9

* Estimates of maximum instantaneous flows are available from Canada-Newfoundland Flood Damage Reduction Program.

and daily flows were available, a relationship between the ratio of instantaneous to daily flow and drainage area was developed. This was of the form:

$$Q_p/Q_D = 1.23\ A^{-0.023} \text{ with } R^2 = 0.21, \text{ standard error of } 0.04$$

where: Q_p is the maximum instantaneous flow, m^3/s

Q_D is the maximum daily flow, m^3/s

A is the drainage area, km^2

It should be noted that the ratios were all very close to 1.0 (ranging from 1.0 to 1.08). Therefore, despite the limited data set that this relationship was based upon and the relatively low strength of the correlation co-efficient, this uncertainty produces a very small variation in the flows derived from it.

The relationship was applied to the 1:20 year and 1:100 year daily flows derived for Badger Brook and Little Red Indian Brook to obtain 'design' flows shown in Table 5.6.

During the course of this study, a regional flooding frequency analysis of the Province of Newfoundland was completed under the Canada-Newfoundland Flood Damage Reduction Program (1984). The relationship for the northern region from that study was utilized to estimate the 1:20 and 1:100 year instantaneous flows for Little Red Indian Brook and Badger Brook. The resulting 1:20 and 1:100 year flows were 33.4 and 41.1 m^3/s for Red Indian Brook and 173.3 and 201.3 m^3/s for Badger Brook. These are between 13 and 19 percent lower than

the values obtained during the current study. This is to be expected since the full regional analysis covers a broader area of the province and a wider range of drainage areas than the localized analysis of the present study in which small drainage areas were specifically utilized. Inclusion of some regulated data in the sub-regional analysis and other physiographic differences account for these differences in the results.

6.0 OPEN WATER HYDRAULIC ANALYSIS

6.1 General

The purpose of the hydraulic investigation is to derive the 1:20 and 1:100 year open water surface profiles along the study reaches using the results of the field surveys and hydrologic information provided in Chapter 5.0.

To carry out the investigations, the HEC-2 (HEC, 1982) computer model was used. This model was selected for this study because it represents the state-of-the-art for the computation of water surface profiles for steady state conditions in open channels. It has been successfully used in similar applications in the U.S. and Canada; is well-documented; is parameter efficient for calibration; and is flexible in use.

The model was developed by the U.S. Corps of Engineers, Hydrologic Engineering Center to compute water surface profiles for natural or man-made channels, assuming that such flow is steady and gradually varied. The model estimates the change in water surface elevation between given river cross-sections with special computations accounting for bridge structures and other flow obstructions in the flood plain. The basic computational procedure used in the model is the solution of the one-dimensional energy equation with energy loss due to friction evaluated with Manning's equation.

Full details of the HEC-2 model and its underlying theory are given in the user's manual (HEC, 1982). The release used for this study was issued November 1976 updated April 1980 Error Correction 04, Modification 99.4.

A HEC-2 Ice Option program has also been developed to determine the backwater levels due to an ice cover. This option of the program was used in several simulations to model backwater levels due to ice cover conditions in Exploits River. These are discussed in Chapter 7.0.

6.2 Set-up of the HEC-2 Model

The HEC-2 model for the Exploits River and the other tributaries was set-up using river cross-sectional data obtained from field surveys.

The field surveys were undertaken from about the middle of July to the middle of August 1984. A total of 31 representative river valley cross-sections were surveyed along the Exploits River from the Goodyear Dam to approximately 2.5 km upstream from Badger Brook. The total distance surveyed along the river is about 32 km. Furthermore, six (6) cross-sections were surveyed for Badger Brook from the confluence with the Exploits River to about 800 m upstream of the old Badger Brook bridge and four (4) cross-sections for each of Little Red Indian Brook, Rushy Pond Brook and Wigwam Brook.

The surveyed cross-section also included three bridge structures across Badger Brook and Rushy Pond Brook and one bridge structure across Little Red Indian Brook and Wigwam Brook. The bridges were coded using the special bridge method because this method is capable of solving a wide range of flow problems that are applicable in this study.

At each cross-section, soundings of the channel below the water line were taken and the overbanks were surveyed beyond

observed historical flood levels. Water levels on the day of the survey for the calibration of the hydraulic model were measured as well as ice scars where visible. At each cross-section, photographs were also taken during the field surveys to assist in the selection of appropriate roughness coefficients (Manning's "n") for modelling purposes.

The study reach at the Rushy Pond area is relatively broad and placid from Goodyear's Dam to Goodyear's gravel pit (cross-section 5100). The slope of the river bed is fairly mild with an average gradient of 0.0005 m/m and an average roughness coefficient of 0.035. The river has a fairly large floodplain with an average roughness coefficient of 0.07.

From station 5100 to Badger Chute (cross-section 21305) the river becomes steeper and narrower. The average bed slope is about 0.0009 m/m and the average roughness ranges between 0.03 and 0.035.

The river reach from Badger Chute to the Town of Badger is much steeper having several rapids. The average slope is 0.00143 m/m and the roughness coefficient of the river varies from 0.035 to 0.040.

Within the Town of Badger the Exploits River has a much milder bed slope. The average gradient is 0.00043 m/m and the roughness coefficient is about 0.045.

Although 31 cross-sections for the Exploits River were surveyed, an additional fourteen (14) cross-sections were added upstream of Badger Chute to account for the rapids in this area. This approach was used since the changes in elevations

at the rapids were taken into account by adding a constant to the elevation of the surveyed cross-sections. In most cases the geometry of the cross-sections upstream and downstream of the rapids were found to be similar. The changes in depth were obtained from field observations and the width from air photos. A total of 45 cross-sections were consequently used to model the Exploits River. The location of the cross-sections are shown in Figure 4.10. The cross-section numbers also represent the total distance in metres along the Exploits River from Goodyear's Dam. All cross-sections were coded adopting the convention of looking downstream from left to right bank and all sections are referenced to Geodetic Survey of Canada (GSCD) datum.

A plot of all cross-sections and bridge structures for the Exploits River, Badger Brook and Little Red Indian Brook is presented in Technical Appendix 3.0.

A comparison of the cross-section numbers used in the HEC-2 model and those used during the 1984 field surveys are presented in Table 6.1.

6.3 Calibration of the HEC-2 Model

The HEC-2 model was calibrated using the water levels observed during the 17 July - 16 August, 1984 field surveys. Since the field surveys extended over one month, the water level at each section varied according to the flow which ranged from 184 m^3/s to 208 m^3/s at Grand Falls during that period. In order to avoid reach by reach model calibration based on the observed flow, the model was tested to assess its sensitivity to changes in flow. Two separate computer

TABLE 6.1

EXPLOITS RIVER CROSS-SECTION NUMBERS FOR FIELD SURVEYS UNDERTAKEN DURING WINTER AND SUMMER 1984

HEC-2 Cross-section No.	Cross-section Number from Summer '84 Field Survey	Cross-section Number from Winter '84 Field Survey
0	200	
950	225	
1200	250	
1850	5	5 (I)
2350	300	
3250	340	H
4250	400	
5100	440	
6050	460	
6900	500	
7610	520	H1
9960	600	
12660	700	
16260	800	
18260	900	G, G1
20910	990	
21305	1000	1 (F)
21945	1250	
22315	1500	
22835	1750	
23495	2000	2 (E)
24725	2500	
25850	3000	3 (D)
26510	3100	31
27090	3150	32
27650	4000	4 (C)
28175	6000	6
28675	7000	7
29975	8000	B
30951	8500	
31965	9000	A

runs were made starting with a flow of 184 m^3/s and 208 m^3/s at Goodyear's Dam and then reducing the flows at appropriate locations upstream. In comparing the results, it was found that the difference in water surface elevation for the runs was generally between 0.02-0.04 m. Since the above results indicate that the water level on the Exploits River is not very sensitive for the range of flows observed, an average flow of 198 m^3/s at the Goodyear's dam was used to calibrate the model. The flow was then reduced at appropriate locations reflecting tributary drainage area as shown in Table 6.2.

The starting water level conditions at Goodyear's Dam were computed manually in all cases and input to Cross-Section 0.0 of the HEC-2 model. This cross-section is located just upstream of Goodyear's Dam. A brief description of the procedure used to compute the starting water surface elevations at the dam is given in the Technical Appendix.

Estimates of Manning's "n" values were initially made for the channel and overbanks from the photographs taken during the survey based on experience obtained from previous studies and from other background sources (Barnes, 1967). In cases where islands were visible in the channel, NH cards were used to define different "n" values across the section. The calibration of the model was a relatively straight-forward procedure since there are no bridges on the Exploits River within the study reach. Trial simulation runs were made by making adjustment to the Manning's "n" values to fine-tune the model. After each run water surface profiles were plotted to compare the observed versus the simulated water levels. This procedure continued until the simulated water levels were in

TABLE 6.2

CALIBRATION OF EXPLOITS RIVER HEC-2 MODEL
FOR WATER LEVEL OBSERVATION DURING 17 JULY - 16 AUGUST 1984

Cross-section No.	Flow (m^3/s)	Observed Water Level (m - G.S.C.)	Simulated Water Level (m - G.S.C.)
0	198	69.69	69.69
950	198	69.69	69.70
1200	194	69.69	69.71
1850	194	69.70	69.72
2350	194	69.70	69.72
3250	194	69.70	69.73
4250	194	69.71	69.74
5100	194	69.79	69.78
6050	194	70.17	70.29
6900	194	70.59	70.60
7610	194	70.87	70.88
9960	194	73.60	73.48
12660	194	76.17	76.21
16260	194	78.74	78.81
18260	194	80.60	80.57
20910	191	83.46	83.41
21305	191	85.15	85.18
21945	191	87.14	87.19
22315	191	87.82	87.80
22835	191	88.18	88.26
23495	191	88.55	88.58
24725	191	90.60	90.50
25850	191	91.75	91.72
26510	191	93.63	93.52
27090	191	94.77	94.75
27650	191	95.50	95.46
28175	191	95.82	95.82
28675	186.5	96.33	96.31
29975	186.5	97.61	97.53
31965	186.5	98.19	98.20

close agreement with the observed. The results of the calibration are presented in Table 6.2 along with the observed water levels. Drawings of each cross-section are presented in Technical Appendix 3. For each cross-section, the "n" value used for the channel and left and right overbanks are presented below each plotted cross-section in the Appendix.

From a review of Table 6.2, it can be seen that the simulated water levels are in close agreement with the observed. As noted in Section 6.4, these results were confirmed by simulating two additional events for the Rushy Pond area.

6.4 Validation Study

Historic field observations during high flow conditions were used in order to confirm the model results which were based on low flow calibration. For the Rushy Pond area, two different open water events were used to confirm the model results. These events are: 6 June 1965, and 8 May 1975. In each case the calibrated HEC-2 model was used. Minor adjustments to the "n" values were then made to fine tune the model for the 1965 and 1975 events.

6 June 1965 Event

In 1965 the elevation of Goodyear's Dam was approximately 67.39 m. Based on this elevation and a flow of 1097 m^3/s, a starting water level of 69.6 m was input to the model. From historic observations near the TCH, water levels were estimated. The observed and simulated water levels at these locations are presented below:

Cross-section Number	Observed Peak Water Level (m)	Simulated Peak Water Level (m)
3250	70.35	70.42
5100	70.81	70.79

8 May 1975 Event

By May 1975, Goodyear's Dam had been raised to an elevation of about 69.0 m. The peak flow was estimated at about 591 m^3/s and the starting water level condition at the dam was estimated at about 70.40 m. Unfortunately there was only one field observation from historical sources.

Cross-section Number	Observed Peak Water Level (m)	Simulated Peak Water Level (m)
3250	70.46	70.56

Both the 1965 and 1975 open water events provided excellent confirmation of the capability of the model to accurately simulate water levels during high flow, open water conditions for the Rushy Pond area. The maximum difference between observed and simulated levels is 0.1 m (1975), which is well within the accuracy of the observation.

6.5 Rushy Pond: 1:20 Year and 1:100 Year Open Water Flood Levels

The calibrated and validated model for open water conditions at Rushy Pond was employed to simulate backwater conditions for the 1:20 year and 1:100 year flood flows. The 1:20 year flow at Goodyear's Dam is 1436 m^3/s and the starting water

level at this flow is about 71.65 m. Similarly, the 1:100 year flow at Goodyear's Dam is 1931 m^3/s and the starting water level at this flow is about 72.24 m. The computed water surface elevations and the pro-rated flows at various locations for the 1:20 year and 1:100 year flows are presented in Tables 6.3 and 6.4, respectively. Of importance is that the 1:100 year open water levels do not reach the same levels observed in the January 13-14, 1983 flood (Table 3.1) when ice was present in the study area.

6.6 Badger: 1:20 Year and 1:100 Year Open Water Flood Levels

The HEC-2 model for the Exploits River was carefully calibrated on the basis of the streamflows observed in July and August 1984 (Table 6.2). Since there have been no open water floods or high flow level measurements for the Badger area, confirmation of the HEC-2 model was attempted on the basis of water levels surveyed in June 1977 for Newfoundland and Labrador Hydro (Shawmont, 1977). The dates of the surveys were not provided in this month which had a significant reduction in flow from start to end. The surveyed water levels were also related to an assumed datum, rather than to geodetic.

Several simulations were conducted based on assumed flow conditions through the duration of the survey. Good agreement was obtained in some reaches but not in others which were surveyed on different days and flow rates. Overall, the 1977 data was too inconsistent to be used for validation; and as there were no high flows during the 1984 survey period, the calibrated model was used without validation for open

TABLE 6.3

1:20 YEAR COMPUTED WATER SURFACE ELEVATIONS
FOR THE EXPLOITS RIVER AT RUSHY POND AREA

Cross-section	1:20 Year Flow (m^3/s)	1:20 Year Water Surface Elevation (m - G.S.C.)
0	1436	71.65
950	1436	71.75
1200	1436	71.75
1850	1436	71.85
2350	1436	71.88
3250	1436	71.91
4250	1436	71.94
5100	1436	71.99
6050	1367	72.19
6900	1367	72.57
7610	1367	73.26
9960	1354	75.27
12660	1354	77.85

TABLE 6.4

1:100 YEAR COMPUTED WATER SURFACE ELEVATIONS
FOR THE EXPLOITS RIVER AT RUSHY POND AREA

Cross-section	1:100 Year Flow (m^3/s)	1:100 Year Water Surface Elevation (m - G.S.C.)
0	1931	72.24
950	1931	72.36
1200	1931	72.36
1850	1931	72.50
2350	1931	72.53
3250	1931	72.56
4250	1931	72.60
5100	1931	72.65
6050	1834	72.89
6900	1834	73.20
7610	1834	73.95
9960	1815	75.78
12660	1815	78.30

water simulations at Badger. Although some inaccuracy may result with model use for open water cases, the complete dominance of ice-effect conditions negates any concern arising from the absence of good data for validation. The large difference in flood levels with ice conditions ensures that any small changes in open water levels found in a validation exercise are completely accounted for in the overall flood picture at Badger.

The results of the open water 1:20 year and 1:100 year simulation for Badger are provided in Tables 6.5 and 6.6, respectively. A flood flow of 1739 m^3/s downstream of Badger and 1609 m^3/s upstream of Badger for the 1:100 year event and 1299 m^3/s and 1206 m^3/s, respectively, for the 1:20 year event were used in the HEC-2 model to compute the water surface elevations. The starting water level conditions at cross-section 26510 were obtained from the HEC-2 model calibration simulations for the reach between Rushy Pond and Badger. The computed 1:20 year and 1:100 year water surface elevations for the reach between cross-sections 12660 and 26510 are presented in Tables 6.7 and 6.8, respectively.

As would be expected, the 1:100 year level at Badger for open water conditions falls much below that observed in past floods which have been caused by ice jams in the Badger area. Flood levels from the 1:20 year event do not reach the top of the banks along the Exploits River, Badger Brook or Little Red Indian Brook. In the 100 year open water case, only a small area along the Exploits River just west of Beothuck Street and another west of River Road will contain some spill. No structures will be flooded in either the 1:20 year or 1:100 year case.

TABLE 6.5

1:20 YEAR COMPUTED WATER SURFACE ELEVATIONS
FOR THE EXPLOITS RIVER NEAR TOWN OF BADGER

Cross-section	1:20 Year Flow (m^3/s)	1:20 Year Water Surface Elevation (m - G.S.C.)
26510	1299	95.30
26790	1299	95.75
26810	1299	95.72
27090	1299	96.44
27180	1299	96.58
27650	1299	97.38
28175	1299	97.79
28675	1206	98.42
29975	1206	100.03
30951	1206	100.59
31965	1206	100.87

TABLE 6.6

1:100 YEAR COMPUTED WATER SURFACE ELEVATIONS
FOR THE EXPLOITS RIVER NEAR TOWN OF BADGER

Cross-section	1:100 Year Flow (m^3/s)	1:100 Year Water Surface Elevation (m - G.S.C.)
26510	1739	95.77
26790	1739	96.23
26810	1739	96.20
27090	1739	96.89
27180	1739	97.03
27650	1739	97.91
28175	1739	98.31
28675	1609	98.96
29975	1609	100.64
30951	1609	101.26
31965	1609	101.55

TABLE 6.7

1:20 YEAR COMPUTED WATER SURFACE ELEVATIONS FOR THE EXPLOITS RIVER FOR THE REACH BETWEEN RUSHY POND AND BADGER

Cross-section	1:20 Year Flow (m^3/s)	1:20 Year Water Surface Elevation (m - G.S.C.)
16260	1380	80.65
18260	1324	82.56
20910	1324	85.45
21235	1324	85.93
21255	1324	86.31
21305	1324	87.14
21705	1324	87.57
21845	1324	88.59
21945	1322	89.35
22195	1322	89.59
22315	1322	89.89
22475	1318	90.18
22835	1318	90.77
23495	1318	91.25
24475	1318	91.84
24495	1318	91.69
24725	1318	92.45
25850	1318	93.66
25860	1318	93.49

TABLE 6.8

1:100 YEAR COMPUTED WATER SURFACE ELEVATIONS FOR THE EXPLOITS RIVER FOR THE REACH BETWEEN RUSHY POND AND BADGER

Cross-section	1:100 Year Flow (m^3/s)	1:100 Year Water Surface Elevation (m - G.S.C.)
16260	1796	81.10
18260	1774	83.07
20910	1774	86.02
21235	1774	86.60
21255	1774	86.65
21305	1774	87.61
21705	1774	88.08
21845	1774	89.03
21945	1772	89.90
22195	1772	90.17
22315	1772	90.43
22475	1766	90.74
22835	1766	91.40
23495	1766	91.93
24475	1766	92.54
24495	1766	92.40
24725	1766	93.02
25850	1766	94.27
25860	1766	94.15

A sensitivity analysis was also carried out for the Exploits River. A brief description of the procedure used and of the results is presented in Technical Appendix 2.

6.7 Conclusions - Open Water Flood Levels

It is concluded from the calibration work and the validation results that the HEC-2 model prepared for open water conditions provides reliable estimates of flood levels on the Exploits River.

As noted above and as expected, high flows and open water conditions do not dictate flood conditions at Badger. The 1:100 year open water flood level at Badger (98.96 m) does not cause any flooding since it is lower than the non-damage elevation of 99.36 m in the Badger area. As noted previously, flooding in Badger is caused by ice blockages.

Information on ice conditions during break-up flooding is limited at Rushy Pond and it was previously assumed that flooding at Rushy Pond is caused by high flows rather than an ice constriction. This case was tested using the validated HEC-2 open water model. The 1:100 year open water level at Rushy Pond did not yield flood levels which would overtop the Trans Canada Highway (elevation 73.0 m) as observed in January 1983. Similarly, ice scar elevations shown in Figure 4-15 were not reached with the open water simulation.

Overall, it is concluded that flood levels at Rushy Pond as well as Badger are controlled by ice conditions. The problem conditions result from freeze-up slush accumulations at Badger whereas they result from break-up ice blockages at Rushy Pond.

7.0 ICE-EFFECT CONDITIONS

7.1 Introduction

One of the principal objectives of this study is to determine river stages during winter ice conditions, and link these stages to return periods to establish 1:20 year and 1:100 year winter levels. This has been completed for open water conditions in Chapter 6.0 by linking stage to return period by using the 1:20 and 1:100 year river flow to determine corresponding flood levels. On the Exploits River, however, this direct approach cannot be used with ice since it is possible to obtain different ice conditions and different water levels at the same site with little or no change in the discharge. As a result, the evaluation of ice effect river stages requires the use of different approaches which account for variable ice conditions as well as river flow, meteorology and channel morphology.

Three approaches have been identified as being useful for determining the ice-effect levels:

(1) The Perception Stage approach, which makes maximum use of historical data on ice levels to determine the frequency of occurrence of particular levels.

(2) Ice Progression Modelling approach, which identifies factors regulating ice conditions, and uses the frequency of occurrence of these factors and historical observations to determine the return period of a particular flood level.

(3) Backwater Modelling with Ice, which generates ice levels based on flow and ice stability criteria and determines the frequency of a particular level based on analysis of the full set of levels.

There are limitations to each approach and not all may be applicable to a given location. If there are no data on ice levels, for example, the first two approaches cannot be used. If there is an ice blockage, the third approach cannot be used successfully since the strength, duration and location of an ice blockage cannot be simulated. The approach(es) to be used at a particular site is a function of the available data and the type of ice problem, which are discussed below.

7.2 Badger Conditions

All of the past flooding in Badger has taken place in January or February. There have been no floods in the open water months since the turn of the century, and as shown in Chapter 6, the flooding potential in the open water months is low.

Past flooding problems at Badger have only occurred when discharge on the Exploits river has been at values close to 1:2 year winter rates (Table 7.1). At flood flows as low as about the 1:20 year winter range, the cover has been swept downstream without incident (e.g. March 1979); and at higher flow rates the ice cover has not been able to advance into the Badger area (e.g. January 1978). This structural inter-relationship between discharge and the ice cover suggests that flooding is related to the supply of ice entering the Badger area or arises from thick or obstructive ice accumulations which can only form in the low flow range. It

TABLE 7.1

COMPARISON OF EXPLOITS RIVER

DISCHARGE DURING FLOODING AND NON-FLOODING EVENTS[1]

Flows of High Water or Flooding Events		Flows at Non-Flooding years			Flows which Flush or Retard Ice Progression at Badger	
Year	Discharge (m^3/s	Discharge (m^3/s			Year	Discharge (m^3/s)
1937	191	196	146	189	1956	362
1943	142	156	188	157	1975	282
1945	176	204	163	128	1978	374
1946	178	188	164	187	1979	≤ 337
1957	193	226	183	149	1983	≤ 400
1977	161	192	192			
1980	176	189	126			
1983	164					
mean	173		175			≤ 351

1 for comparative purposes, January-February flood flow rates at Exploits Dam are: 1/2 yr = 166 m^3/s, 1/20 yr = 304 m^3/s, 1/100 yr = 425 m^3/s

certainly confirms that it is not possible to simply add an ice cover to the 1:100 or 1:20 year winter flow to simulate backwater levels corresponding to these return periods (Method 3, above).

The thick ice cover on the Exploits River at Badger contri butes to high water levels in the community, but field sur veys in 1984 show that the controlling problem is a blockage by frazil slush in the area of Badger Rough Waters (e.g. Figures 4.7 and 4.8). This contrasts with earlier supposi tion that blockages affecting Badger are located at Badger Chute. The former shows a significantly greater degree of blockage than the latter and the Badger Rough Waters area was reported as the problem location in more than one previous flood in Badger (e.g. 1983 and 1977).

The timing of Badger flood events is also of interest as it appears that icy floods nearly coincide with the appearance of the ice cover as it progresses upstream past the town. At that time, the subsurface channels which later erode this thick ice cover to form open water leads have not fully developed. The cover is at its thickest, and the full extent of any downstream blockages are felt.

A key factor which determines if flooding will occur in one year as compared to another is the volume of frazil slush joining and thickening the advancing ice cover on those days in which the cover is passing through the Badger area. A review of the meteorological data indicates that past flood ing has coincided with periods of significant frazil production. This production can be determined and linked to times

when the ice cover reached Badger and flood elevations in the town (Table 3.1).

The volume of frazil slush produced along the Exploits River is massive. The 50 kilometre reach above Badger contains all the elements of an "ice factory" and portions of the 30 km reach above Twelve Mile Falls remain as an open generator of frazil slush throughout each winter. The overall volume of ice produced by these river reaches can be estimated and used as a key factor for determining the frequency of occurrence of flood years (Method 2, above).

The problem is clearly linked to the volume of frazil slush which is generated above Badger and the rate of progression of the ice cover through the Badger area. There is sufficient data to simulate this condition (Method 2) and tie this causal factor to observed water levels. The record of water level observations is by itself quite good (Table 3.1) and can be used independently to generate a stage-frequency relationship for Badger (Method 1). The variability in ice conditions with similar discharge from year to year, combined with the likelihood of an ice blockage as a result of grounding of the ice cover on the river bed cast doubt on methods which attempt to simulate ice levels based on flow (Method 3). Hence for the Badger area, two methods are available for determining the 1:20 and 1:100 year flood levels with ice.

7.3 Rushy Pond Conditions

It has previously been considered that the principal cause of flooding at the Rushy Pond area has been high flow on the Exploits River combined with the removal of the banks in

portions of the Goodyear's Pit, construction of the TCH and changes in the elevation of Goodyear's Dam. These factors have certainly changed the hydraulic conditions in the Rushy Pond Area, but as shown in the open water analysis in Chapter 6, they do not fully account for high levels and flooding of the TCH.

Although high flows have accompanied many of the past floods in the Rushy Pond area, it is also clear from the timing of these floods that ice was present in the Exploits River at the initiation of most of these events and remained throughout at least one event (March 1979). It is also reported that an ice blockage accompanied the 1983 flood (Noseworthy, pc. 1984). The channel reach between Red Cliff Overpass and the mouth of Sandy Brook is a reach in which an ice blockage could form, and it is within this reach that ice accumulations are reported (Noseworthy, pc. 1984). Aside from this observation, there are no good on-site observations of the river during past flood conditions. These would be most useful for determining the severity, location and duration of ice blockages. As a result, this eliminates approaches which simulate ice processes or levels (Method 2 and 3, above).

Fortunately, however, there is a good long-term record of flood elevations covering the winter and break-up period at Rushy Pond. This record integrates the effects of ice conditions, channel geometry and flow, etc, and can be employed to determine the 1:20 and 1:100 year winter levels (Method 1).

7.4 Badger: Ice-Effect Levels

As it is most desirable to obtain estimates of river stage which can be identified with a return period, two methods have been undertaken to establish the 1:20 year and 1:100 year winter levels at Badger. The first draws on historical data from observations of river stage since 1915 (Method 1). The second draws on the results of 1984 field observations and the use of a river ice regime model (Method 2).

7.4.1 Probability Analysis of Historical Floods

The historical data base describing flood levels at Badger includes background information from local residents and Abitibi Price Inc., as well as data from past and recent field surveys (Table 3.1). This data can be employed to determine the probability distribution of winter flood levels using a subjective approach described by Gerard and Karpuk (1979).

The approach requires that a "perception stage," rank and record length be applied to each reported flood peak and level observation. The perception stage assigned to each source of data is defined as the stage above which the source would have provided information on the flood peak in any given year. The record length of a particular flood level is determined by the number of years at perception stages lower than that level. The rank of each flood levels is assigned by comparing that level to others having the same or lower perception stages. The approach is described below.

Current Residents

First hand information from local residents dates back to about 1915 at Badger. It is estimated that the residents who were interviewed would likely have recalled high or threatening flood levels associated with a perception stage elevation of about 98.30 metres (322.5 feet). At that level, flood waters would have just overtopped the banks at the confluence of Badger Brook and the Exploits River and would have been close to flooding the homes of several riverside residents.

The following table summarizes the the flood level data assigned as a result of recent interviews and topographic surveys in Badger.

Perception Stage m (ft)	Year of Flood	Flood Level Estimate Town Centre	Comment
98.30 m (322.5 ft)	1917	100.15 m	similar to 1983; below RR track (100.5m/330 ft)
98.30 m	1937	99.80 m	similar to 1983; above 1977; below 1943
98.30 m	1943	99.90 m	higher than 1977; above 1937, similar to 1983
98.30 m	1945	99.05 m	less than 1983; less than 1943, less than 1977
98.30 m	1977	99.66 m	above 1945, 0.25 m below 1983
98.30 m	1983	99.91 m	0.25 m above 1977; similar to many others in past

Abitibi Price Archives

Daily records of river discharge have been kept in log books since the winter of 1933-1934, and unusually high levels or flooding events are recorded as margin notes in these logs. Review of these records indicates that the perception stage of Abitibi personnel was much the same or slightly higher than that of the local residents from the 1930's to the 1950's. In the mid-1950's, however, Abitibi interest became more acute and their perception stage dropped to a point where their entries include river level information not mentioned by local residents. This is attributed to their considerable interest in winter conditions brought about by frazil slush accumulation at Grand Falls. As early attempts to reduce this ice problem included discharge control at the dam above Badger, it is considered likely that stage information on Badger would have been provided for flood levels above the bank-full stage of 97.5 metres (320 feet) in the lower area of the town near the mouth of Badger Brook.

The following table lists the Abitibi Price data which augments that of the local residents in Badger.

Perception Stage	Year of Level	Level Estimate at Town Centre	Comment
97.50 m (320 ft.)	1957	98.25 m	No flooding reported

Province of Newfoundland

The perception stage of Provincial Agencies is lower than either the local residents or Abitibi Price, and their care-

ful observations extend from the 1977 flood at Badger to the present. The perception stage associated with this source was placed at an elevation 97.25 metres (319 feet). At this elevation, flood encroachment would appear imminent at lower portions of the bank at Badger and hence be a cause for monitoring and concern.

Observed flood and high water levels are as follows:

Perception Stage	Year of High Level	Level Estimate at Town Centre	Comment
97.25 m (319 ft)	1977	99.66 m	• flood level photos
	1980	98.15 m	• photo reconnaissance initiated (no flooding)
	1983	99.91 m	• level observation and mapping

Hydrometric Surveys

Field surveys as part of this study cover the 1983-1984 winter season. This single year of record has a minimum recording level datum of zero. This perception stage is the minimum "gauge" reading that could be recorded for any given year, or about 96.0 metres at zero discharge. The ice level associated with this past winter was approximately 97.0 metres at the Exploits/Badger Brook confluence.

Perception Stage	Year of Recorded Level	Level Estimate at Town Centre	Comment
96.00 m (314.96 ft)	1984	97.40 m	field observation no flooding

Summary Diagrams

The flood level information from the above sources is summarized in Figure 7.1. Open horizontal bars denote the estimated perception stage for each source and these bars extend over all years the source was taken to be available to observe freeze-up events at Badger. Vertical bars extend from the perception stage for the source to the maximum ice stage observed. The summary diagram, Figure 7.2, blocks in the lowest perception bar across each year.

Record Length, Ranking and Probability Distribution

The rank and record length associated with each peak can be determined from the 70 years of data provided on the final summary diagram. The record length associated with each level is the sum of the years marked by a solid bar below that peak. The rank of a level is determined by summing the number of times that level has been equalled or exceeded in the group having perception stages lower than that level. Probability estimates for each level were calculated using the Blom plotting position formula;

$$P = (RANK-3/8)/(NYRS+1/4)$$

where P = probability of exceedence
RANK = rank of level
NYRS = record length assigned to each peak

The table below summarizes the calculation of cumulative probabilities for freeze-up stages at the town centre in Badger (Badger Arena).

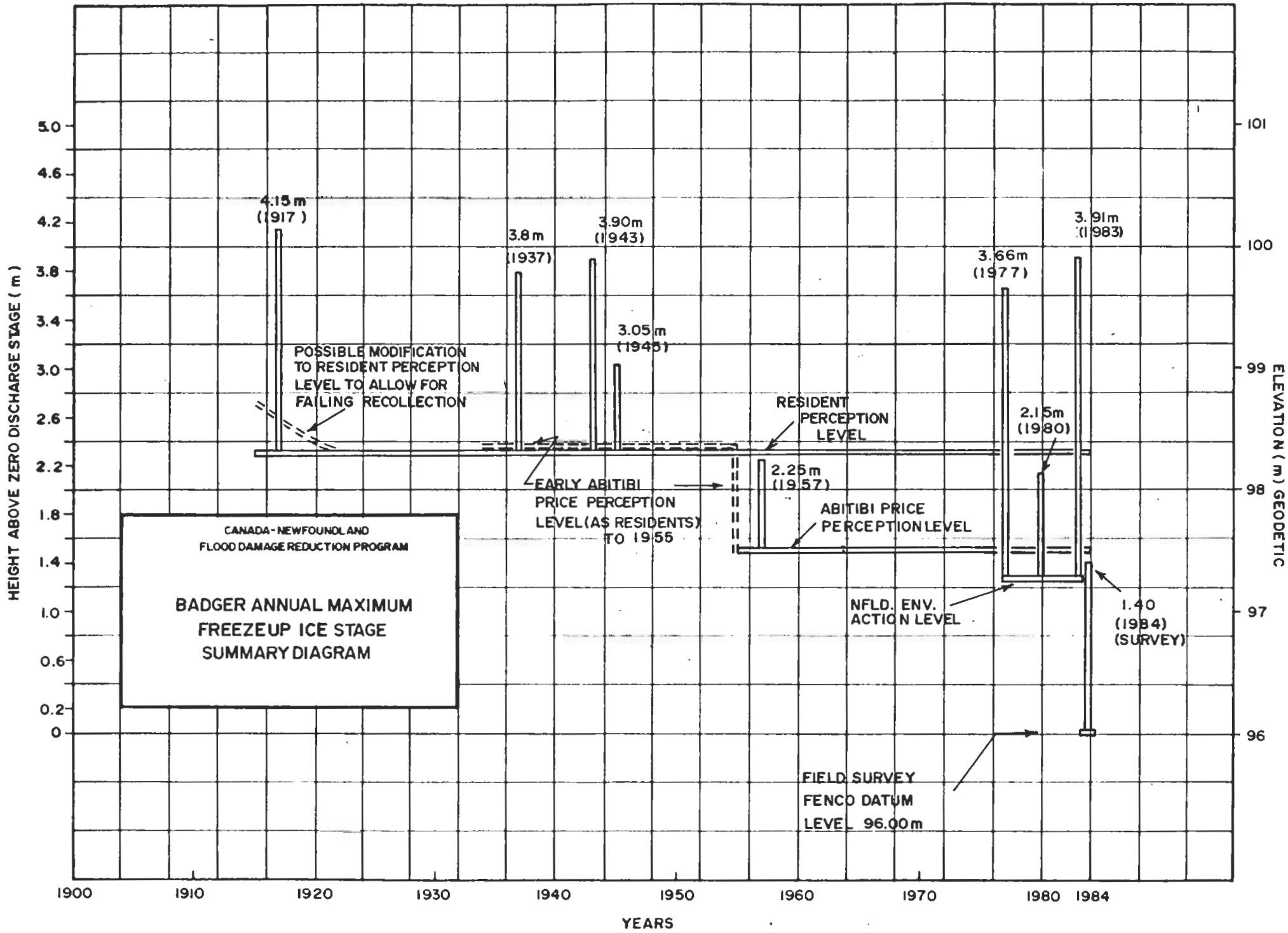

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
BADGER ANNUAL MAXIMUM
FREEZEUP ICE STAGE
SUMMARY DIAGRAM
HEIGHT ABOVE ZERO DISCHARGE STAGE (m)
ELEVATION (m) GEODETIC
YEARS
4.15 m (1917)
3.8 m (1937)
3.90 m (1943)
3.05 m (1945)
3.66 m (1977)
3.91 m (1983)
2.15 m (1980)
2.25 m (1957)
1.40 (1984) (SURVEY)
POSSIBLE MODIFICATION TO RESIDENT PERCEPTION LEVEL TO ALLOW FOR FAILING RECOLLECTION
RESIDENT PERCEPTION LEVEL
EARLY ABITIBI PRICE PERCEPTION LEVEL (AS RESIDENTS) TO 1955
ABITIBI PRICE PERCEPTION LEVEL
NFLD. ENV. ACTION LEVEL
FIELD SURVEY
FENCO DATUM
LEVEL 96.00 m

FIG. 7.1

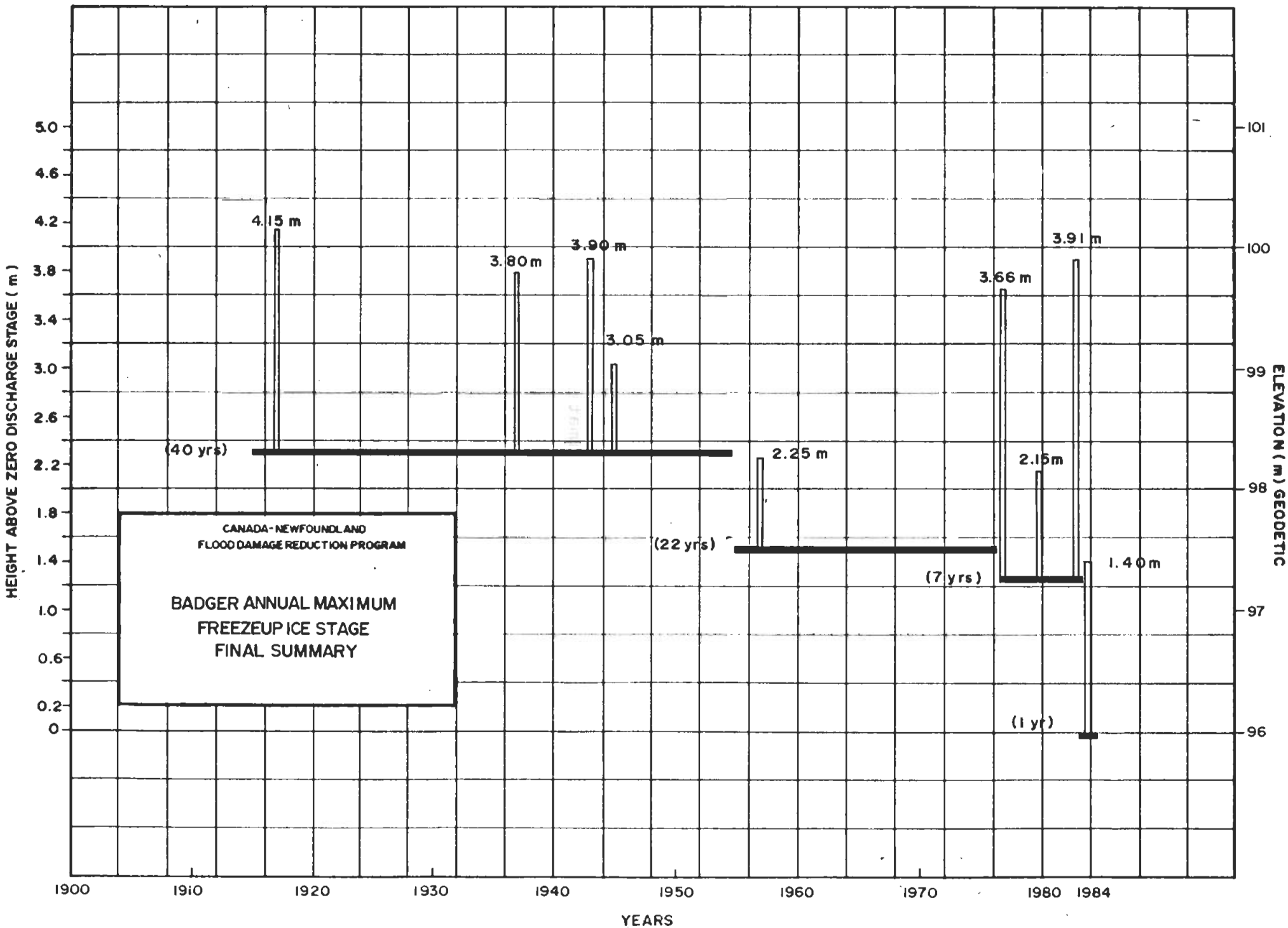

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
BADGER ANNUAL MAXIMUM
FREEZEUP ICE STAGE
FINAL SUMMARY
HEIGHT ABOVE ZERO DISCHARGE STAGE (m)
ELEVATION (m) GEODETIC
YEARS
5.0
4.6
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
1.0
0.6
0.2
0
101
100
99
98
97
96
1900
1910
1920
1930
1940
1950
1960
1970
1980
1984
4.15 m
3.80 m
3.90 m
3.05 m
2.25 m
3.66 m
2.15 m
3.91 m
1.40 m
(40 yrs)
(22 yrs)
(7 yrs)
(1 yr)

FIG. 7.2

Year	Datum Stage (m)	Rank	Years of Record	Exceedence Probability %
1917	4.15	1	70	0.9
1983	3.91	2	70	2.3
1943	3.90	3	70	3.7
1937	3.80	4	70	5.2
1977	3.66	5	70	6.6
1945	3.05	6	70	8.0
1980	2.15	4	30	12.0
1957	2.25	3	30	8.7
1984	1.40	4	8	43.9

Figure 7.3 shows the plotted points of cumulative probability for the maximum freeze-up stage, and includes a comparison with open water/non-ice stage-probability. Two conclusions are apparent;

1. Open water levels dominate the distribution of annual maximum river levels at Badger only for exceedence probabilities less than approximately 10% (1:10 year return periods). Otherwise, freeze-up water levels dominate.

2. There may be a physical limit on freeze-up ice levels at datum level of about 4.0 m (100.0 m GSCD). This may result from the presence of a natural diversion channel at Badger Rough Waters which was observed to be open during the flooding event of 1983. This diversion channel has an invert elevation of 96.6 metres (Figure 4.13).

7.4.2 Ice Progression Modelling

Recent observations of river ice conditions at Badger (notably the 1982-83 photographic record by Newfoundland

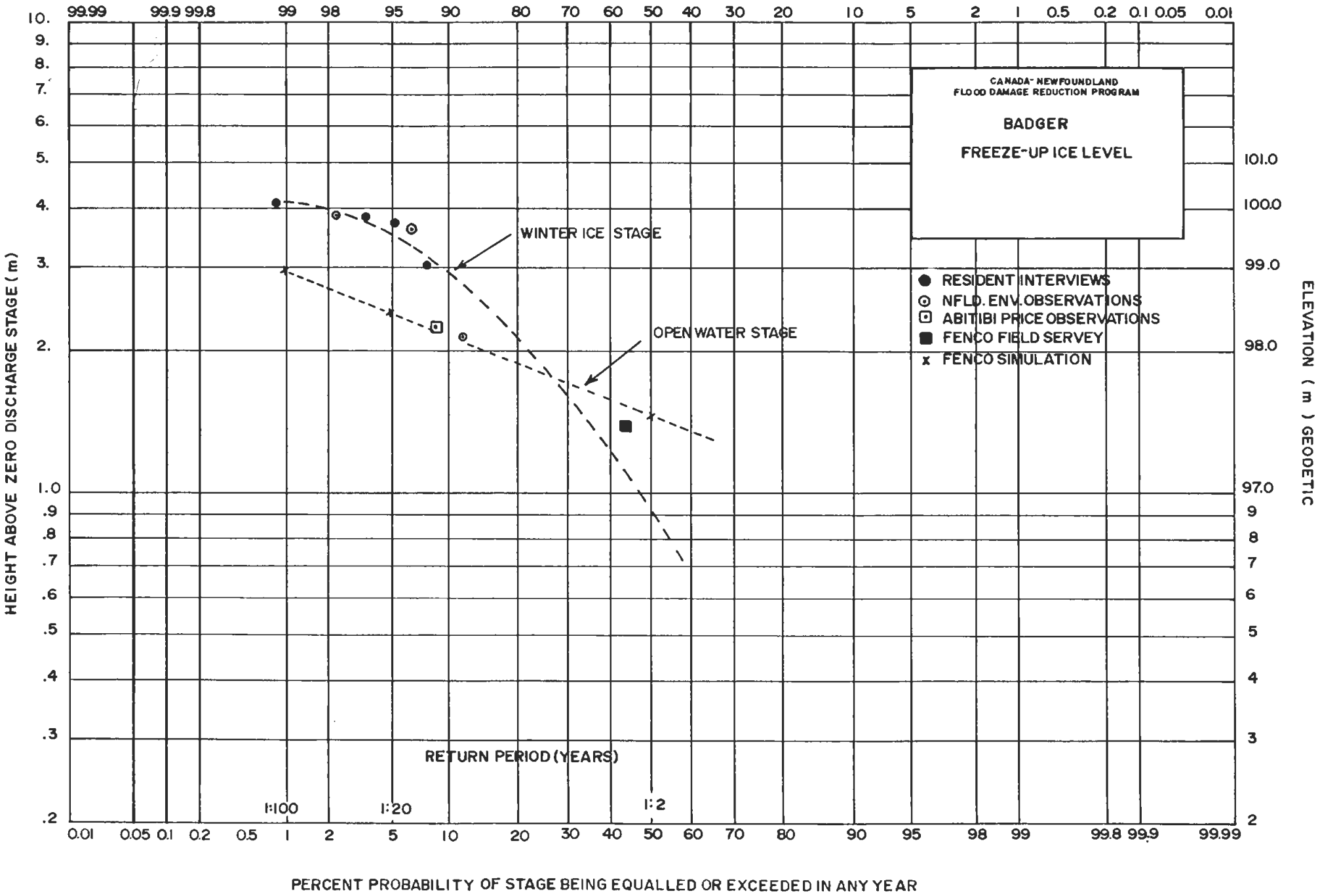

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
BADGER
FREEZE-UP ICE LEVEL
WINTER ICE STAGE
OPEN WATER STAGE
RESIDENT INTERVIEWS
NFLD. ENV. OBSERVATIONS
ABITIBI PRICE OBSERVATIONS
FENCO FIELD SERVEY
FENCO SIMULATION
HEIGHT ABOVE ZERO DISCHARGE STAGE (m)
ELEVATION (m) GEODETIC
RETURN PERIOD (YEARS)
1:100
1:20
1:2
PERCENT PROBABILITY OF STAGE BEING EQUALLED OR EXCEEDED IN ANY YEAR

FIG. 7.3

Environment and our 1983-84 survey), indicate that flooding conditions nearly coincide with the arrival of the ice cover in the Badger area. The ice cover progresses upstream through Badger without problem in some years, but in other years, causes a flood condition. In order to examine this condition in more detail and to provide information for determining flood levels, a model was prepared to simulate the upstream progression of the ice cover on the Exploits River.

Ice Progression Model

The model used to simulate ice conditions on the Exploits River combines a number of existing model approaches with the data obtained from the detailed winter survey of 1983-84. A detailed description of the model is provided in the Technical Appendices (Volume 2).

In summary, the model subdivides the river into 32 connected segments. The water temperature in each segment is initially simulated on the basis of meteorological data and discharge information from Environment Canada records and Abitibi Price files. When air and water temperatures in a segment fall to below freezing, frazil ice slush is generated in that segment, and combined with that of other segments and carried downstream. The slush passes over Goodyear's Dam until it is blocked by border ice growth at the dam or by the ice boom just upstream. Once the downstream progression is stopped, the slush from upstream segments begins to accumulate in segments upstream of Goodyear's Dam. Gradually (or rapidly), the ice cover grows upstream from the dam until it passes Badger and moves on up to Three Mile Island and beyond.

Model Calibration and Validation

Recent field observations and other historical reports describe the upstream progression of the ice cover from Goodyear's Dam toward Badger. Several years (such as 1983-84, 1982-83, 1981-82, 1955-56), contain three or more observations giving the location and date of the front of the ice cover. Aside from these few winters, there are no reported observations in two-thirds of the years since the early 1940's.

Two calibration and validation sequences were required for the ice progression model. The first sequence considered the current conditions on the Exploits River:

(1) The winter period between water years 1974-75 and 1983-84, when Goodyear's Dam had been raised by 2.0 m and when the ice boom in the Rushy Pond area was in place and effective in collecting frazil slush.

The second sequence examined:

(2) The winter years before Goodyear's Dam was raised (late 1974) and before the ice boom was placed in the Rushy Pond area (1955). Abitibi Price files indicate that the ice boom had little effect on ice cover formation in the 1955-74 period and was not effective until the dam was raised.

There is an abundance of calibration/validation information to reliably model the 1974-75 period to the present (Sequence

1). There is considerably less information describing the location of the ice cover in the earlier years (Sequence 2).

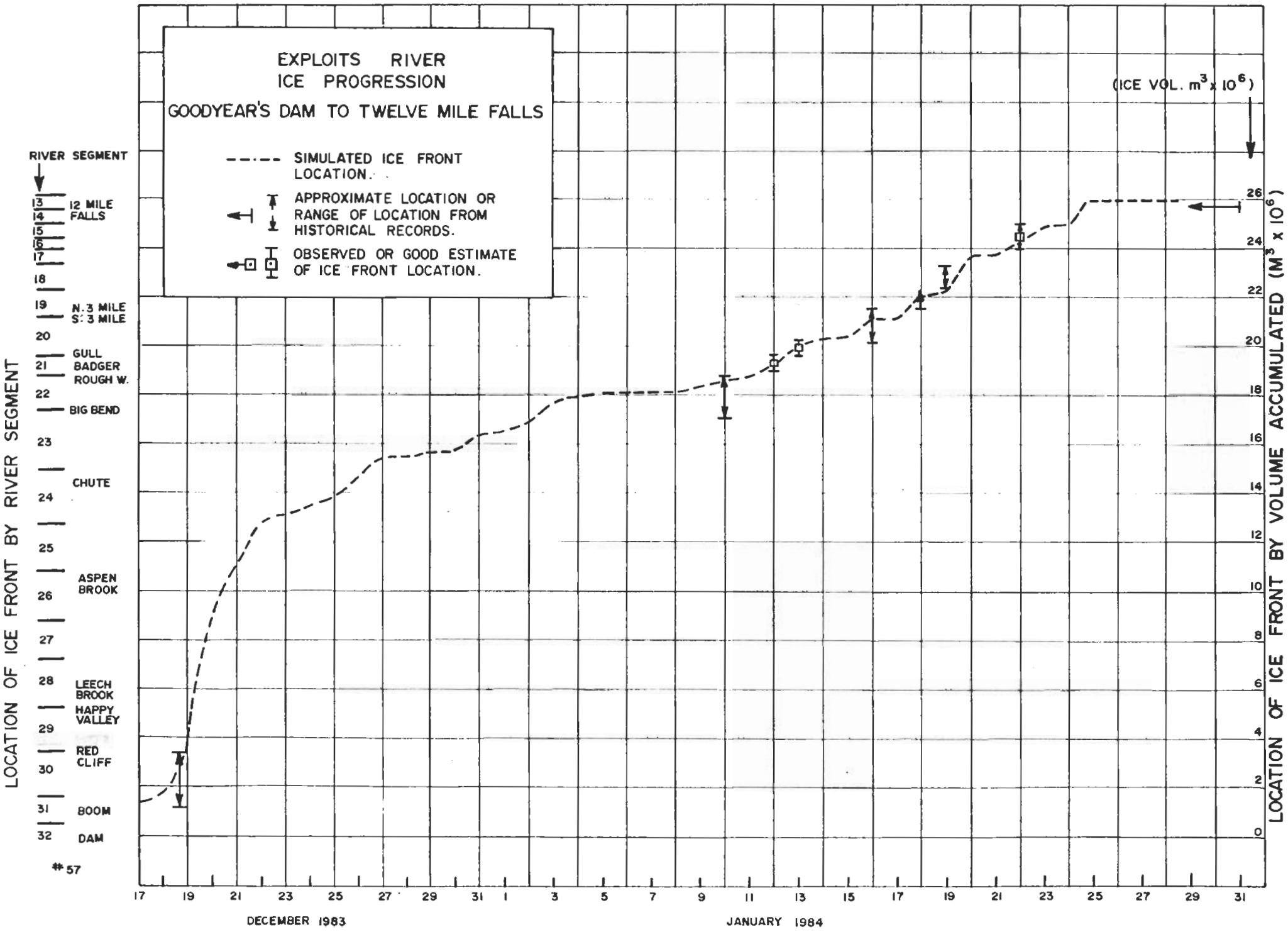
Sequence 1: 1974-75 to 1983-84

Model calibration was undertaken for the water year 1983-84; a year in which 9 ice progression observations were available from our field surveys and observations by Abitibi Price, Newfoundland Environment, and the residents of Badger. The results are shown in Figure 7.4. Validation runs were then conducted for 1982-83 (Figure 7.5), and 1981-82 (Figure 7.6).

Each of the validation runs provided excellent confirmation of the model which was then run for the remaining years between 1974-75 and 1983-84. Several of these years also contain an observation or two, which add to the model validation. Graphs for all years are presented in the Technical Appendices.

Sequence 2: 1973-74 and earlier

This period saw significant frazil volumes passing over Goodyear's Dam to create blockage problems at the Abitibi Price intake works at Grand Falls. In 1955, an ice boom was placed above Goodyear's Dam in an attempt to accumulate the frazil in an ice cover before it moved downstream. It was not a success and continued problems lead to the design and construction of the new dam at Goodyear's. Prior to 1955, there was no frazil ice collection boom.


EXPLOITS RIVER
ICE PROGRESSION
GOODYEAR'S DAM TO TWELVE MILE FALLS
SIMULATED ICE FRONT LOCATION.
APPROXIMATE LOCATION OR RANGE OF LOCATION FROM HISTORICAL RECORDS.
OBSERVED OR GOOD ESTIMATE OF ICE FRONT LOCATION.
(ICE VOL. m³ x 10⁶)
RIVER SEGMENT
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
12 MILE FALLS
N. 3 MILE
S. 3 MILE
GULL
BADGER
ROUGH W.
BIG BEND
CHUTE
ASPEN BROOK
LEECH BROOK
HAPPY VALLEY
RED CLIFF
BOOM
DAM
LOCATION OF ICE FRONT BY RIVER SEGMENT
LOCATION OF ICE FRONT BY VOLUME ACCUMULATED (M³ x 10⁶)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
17
19
21
23
25
27
29
31
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
DECEMBER 1983
JANUARY 1984
#57

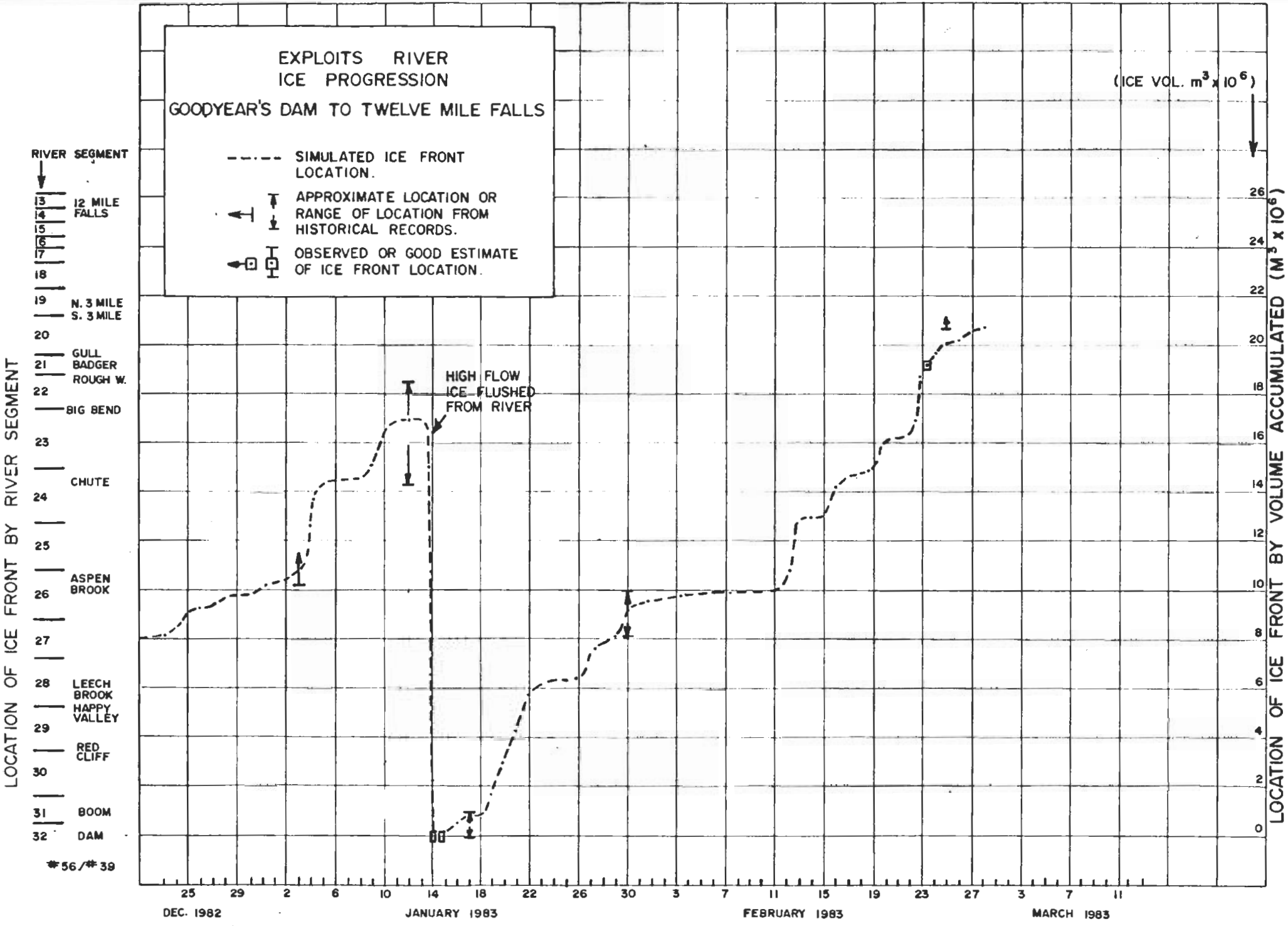

EXPLOITS RIVER
ICE PROGRESSION
GOODYEAR'S DAM TO TWELVE MILE FALLS
SIMULATED ICE FRONT LOCATION.
APPROXIMATE LOCATION OR RANGE OF LOCATION FROM HISTORICAL RECORDS.
OBSERVED OR GOOD ESTIMATE OF ICE FRONT LOCATION.
(ICE VOL. m³ x 10⁶)
RIVER SEGMENT
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
12 MILE FALLS
N. 3 MILE
S. 3 MILE
GULL
BADGER
ROUGH W.
BIG BEND
CHUTE
ASPEN BROOK
LEECH BROOK
HAPPY VALLEY
RED CLIFF
BOOM
DAM
#56/#39
LOCATION OF ICE FRONT BY RIVER SEGMENT
HIGH FLOW ICE FLUSHED FROM RIVER
LOCATION OF ICE FRONT BY VOLUME ACCUMULATED (M³ x 10⁶)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
25
29
2
6
10
14
18
22
26
30
3
7
11
15
19
23
27
3
7
11
DEC. 1982
JANUARY 1983
FEBRUARY 1983
MARCH 1983

FIG. 7.5

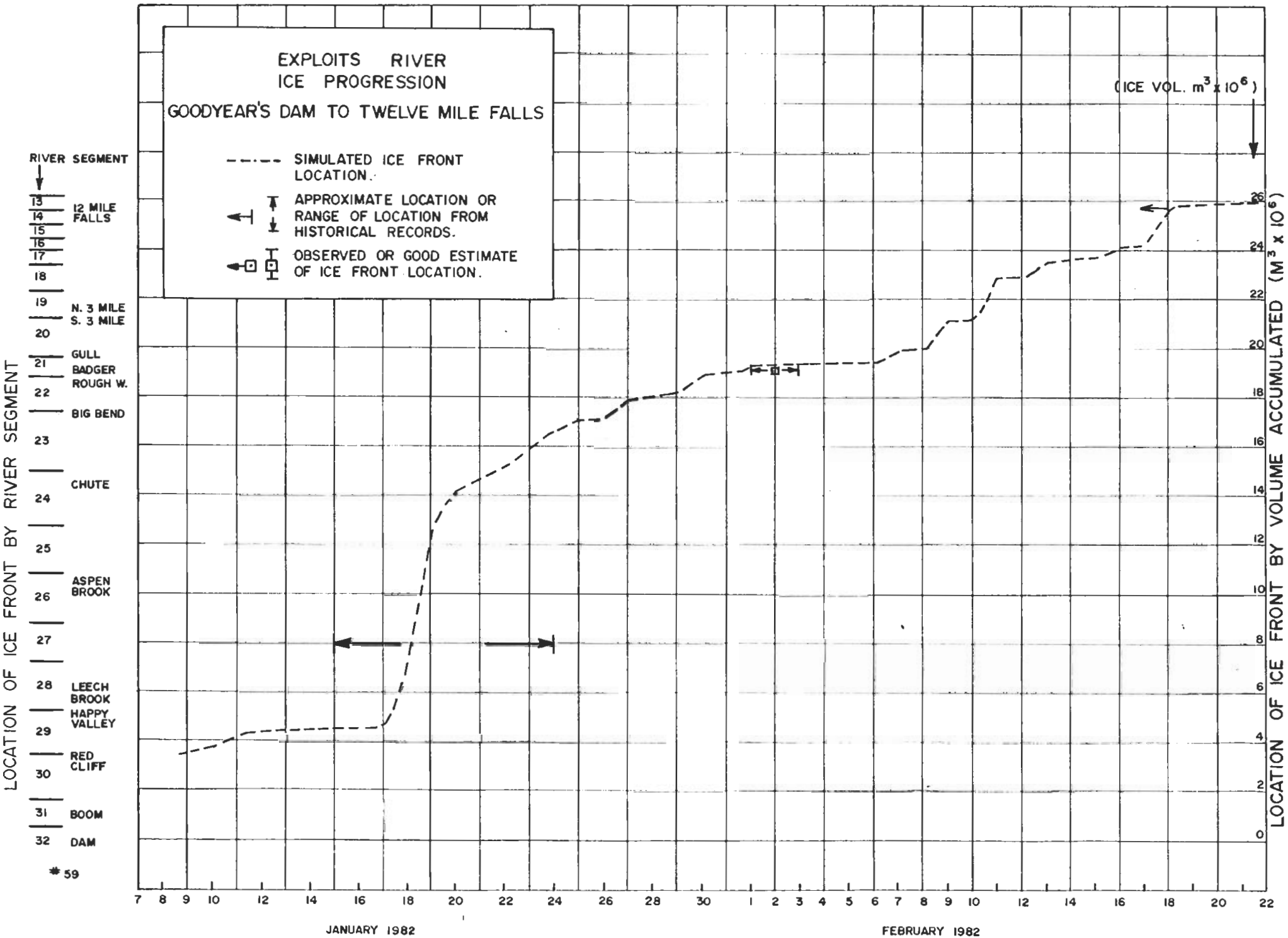

EXPLOITS RIVER
ICE PROGRESSION
GOODYEAR'S DAM TO TWELVE MILE FALLS
SIMULATED ICE FRONT LOCATION.
APPROXIMATE LOCATION OR RANGE OF LOCATION FROM HISTORICAL RECORDS.
OBSERVED OR GOOD ESTIMATE OF ICE FRONT LOCATION.
(ICE VOL. m³ x 10⁶)
RIVER SEGMENT
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
12 MILE FALLS
N. 3 MILE
S. 3 MILE
GULL
BADGER
ROUGH W.
BIG BEND
CHUTE
ASPEN BROOK
LEECH BROOK
HAPPY VALLEY
RED CLIFF
BOOM
DAM
LOCATION OF ICE FRONT BY RIVER SEGMENT
LOCATION OF ICE FRONT BY VOLUME ACCUMULATED (M³ x 10⁶)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
7 8 9 10 12 14 16 18 20 22 24 26 28 30 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22
JANUARY 1982
FEBRUARY 1982
#59

FIG. 7.6

Model calibration data is available through the winter of 1955-56 when attempts were first made to accumulate ice at a boom near Goodyear's Dam. Six ice observations were available from that year and Figure 7.7 shows the calibrated case.

Model validation was conducted in this second sequence on the basis of two observations made in the winter of 1950-51 and a single observation made in 1956-57. The validation simulations were again quite good and other years were simulated to fill out the full period (given in the Technical Appendices).

Ice Progression through Badger

Figure 7.8 summarizes the simulation results of the ice progression model in a single drawing to show the ice progression in a common time frame based on the date which the ice reached Badger. The day the cover reached Badger is day 0 (which in 1984, for example (Figure 7.4) represents January 12). The years in which there were no flood problems are marked by solid lines, and years with flooding or high water are marked by dashed lines. In all years, the stepwise progression of the ice cover shows plateaus of little or no advance followed by the rising slope of an advance period.

The clear difference between the flood and non-flood years is in the rate at which the ice cover approached Badger. Table 7.2 summarizes this progression rate for all years in which simulations were conducted. In 1983-84 (Figure 7.4) for example, the ice cover was stationary below Badger for several days before 8 January. Over a duration of 4 days

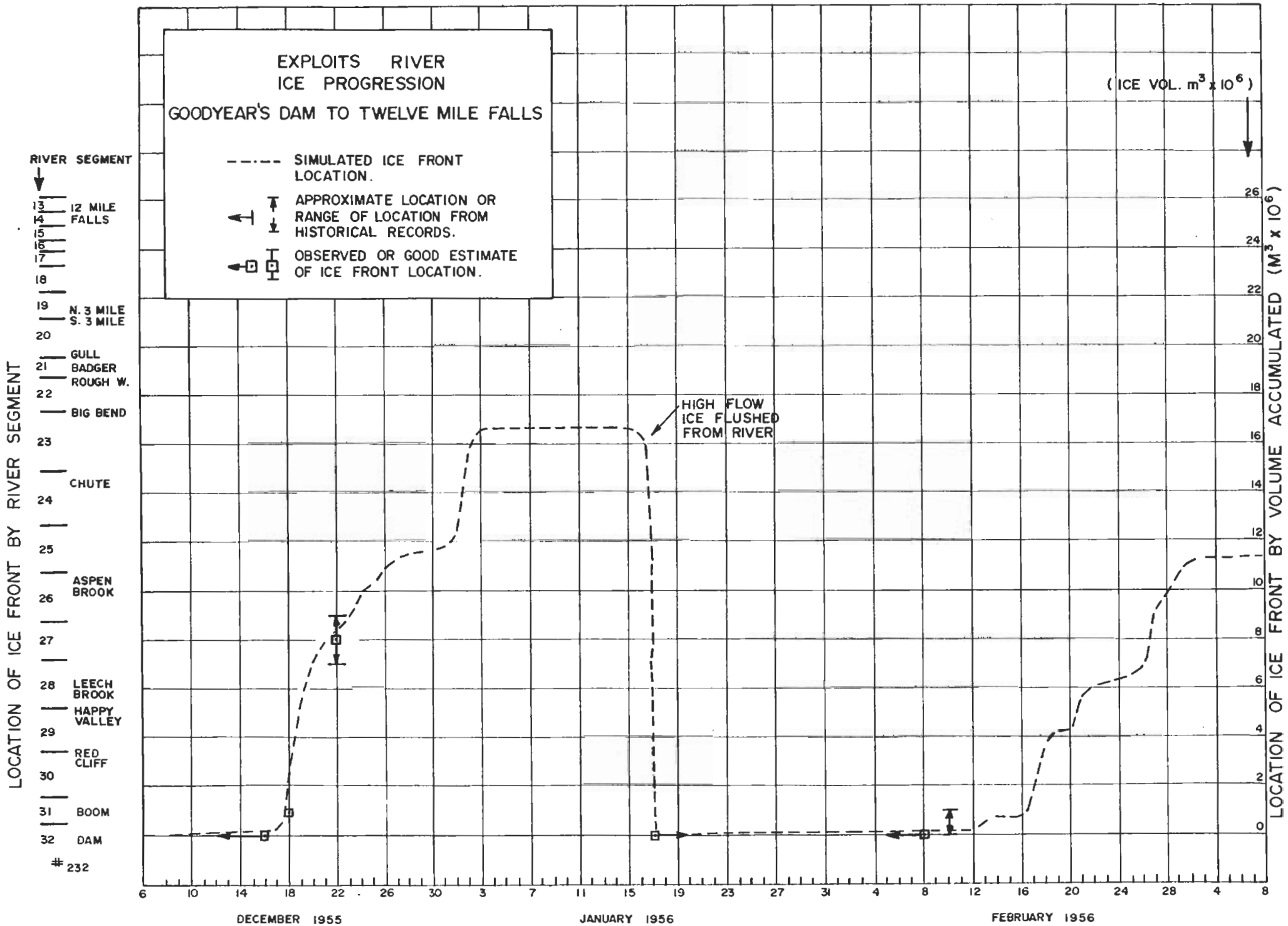

EXPLOITS RIVER
ICE PROGRESSION
GOODYEAR'S DAM TO TWELVE MILE FALLS
SIMULATED ICE FRONT LOCATION.
APPROXIMATE LOCATION OR RANGE OF LOCATION FROM HISTORICAL RECORDS.
OBSERVED OR GOOD ESTIMATE OF ICE FRONT LOCATION.
RIVER SEGMENT
12 MILE FALLS
N. 3 MILE
S. 3 MILE
GULL
BADGER
ROUGH W.
BIG BEND
CHUTE
ASPEN BROOK
LEECH BROOK
HAPPY VALLEY
RED CLIFF
BOOM
DAM
232
LOCATION OF ICE FRONT BY RIVER SEGMENT
(ICE VOL. m³ x 10⁶)
LOCATION OF ICE FRONT BY VOLUME ACCUMULATED (M³ x 10⁶)
HIGH FLOW ICE FLUSHED FROM RIVER
DECEMBER 1955
JANUARY 1956
FEBRUARY 1956

FIG. 7.7

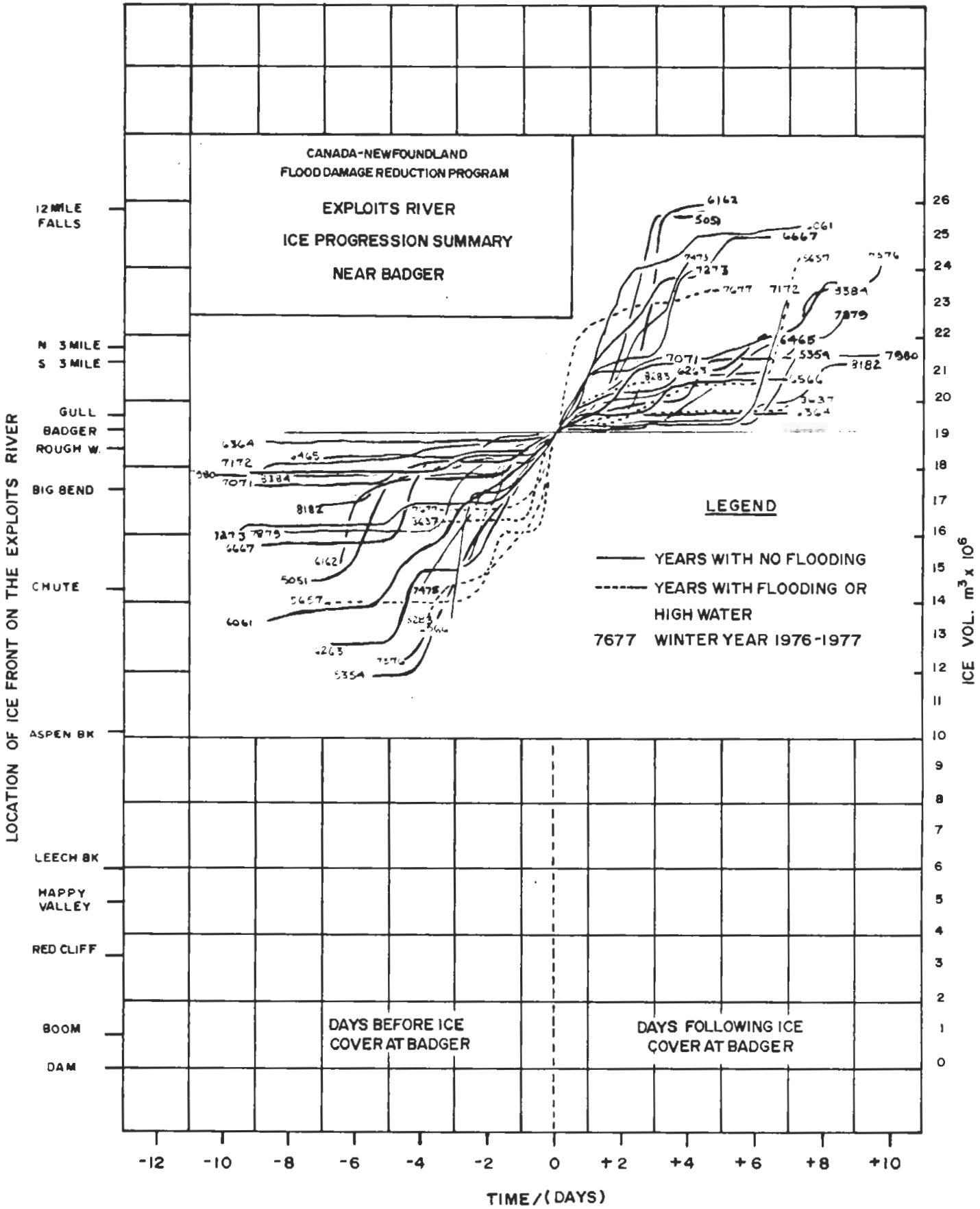

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
EXPLOITS RIVER
ICE PROGRESSION SUMMARY
NEAR BADGER
LEGEND
YEARS WITH NO FLOODING
YEARS WITH FLOODING OR HIGH WATER
7677 WINTER YEAR 1976-1977
12 MILE FALLS
N 3 MILE
S 3 MILE
GULL
BADGER
ROUGH W.
BIG BEND
CHUTE
ASPEN BK
LEECH BK
HAPPY VALLEY
RED CLIFF
BOOM
DAM
LOCATION OF ICE FRONT ON THE EXPLOITS RIVER
ICE VOL. m³ x 10⁶
DAYS BEFORE ICE COVER AT BADGER
DAYS FOLLOWING ICE COVER AT BADGER
TIME/(DAYS)

FIG. 7.8

Table7.2

EXPLOITS RIVER

SIMULATED HISTORICAL ICE GENERATION RATES THROUGH THE BADGER AREA

WATER YEAR	ICE VOLUME PASSING BADGER[1] ($m^3 \times 10^6$)	DURATION OF ICE PASSAGE[2] (days)	ICE VOLUME/DAY[3] ($m^3 \times 10^6$ day	Comment and Water Level Estimate[4]
1936-37	2.7	1.2	2.25	- ***flood (elev.99.8m est.)
42-43	missing key meteorological data		-	- ***flood (elev.99.9m est.)
44-45	1.2	2.0	0.6	- ice did not reach Badger
45-50	missing key meteorologcial data		-	- *** one flood (elev. 00.05m est.)
50-51	1.3	1.0	1.30	-
53-54	7.2	4.6	1.56	-
54-55	0.9	1.0	0.90	- ice did not reach Badger[5]
55-56	8.0	14.0	0.57	-
56-57	5.0	3.0	1.67	- *high/no flood (97.8m est.)
57-58	1.0	2.0	0.50	- ice did not reach Badger
58-59	5.2	5.0	1.04	-
59-60	1.0	1.0	1.00	-
60-61	5.2	5.8	0.90	-
61-62	1.3	1.75	0.74	-
62-63	6.4	5.2	1.23	-
63-64	0.3	1.0	0.30	-
64-65	0.6	1.2	0.50	-
65-66	1.8	1.6	1.13	-
66-67	0.9	0.9	1.00	-
67-68	0.9	2.0	0.45	- ice did not reach Badger
68-69	0.3	1.0	0.30	- ice did not reach Badger
69-70	2.0	4.0	0.50	- ice did not reach Badger
70-71	0.9	1.6	0.56	-
71-72	0.85	1.0	0.85	-
72-73	2.20	2.3	0.96	-
73-74	2.0	4.0	0.5	-
74-75	14.8	12.5	1.18	-
75-76	0.65	1.0	0.65	-
76-77	5.0	2.0	2.50	- *** flood (elev. 99.66 est.)
77-78	0.6	1.0	0.60	- ice did not reach Badger
78-79	3.0	4.0	0.75	-
79-80	0.8	1.0	0.80	- * no flood (98.15m est.)
80-81	1.2	1.0	1.20	- ice did not reach Badger
81-82	1.15	3.0	0.38	-
82-83	2.90	1.3	2.23	- *** flood (99.91m est.)
83-84	1.2	4.0	0.30	- * survey elevation 97.0m (formation elevation 97.4m)

1 total volume of frazil slush in accumulation reaching or passing Badger following a period of ice front stagnation for several days at a site below Badger.

2 total number of days between end of stagnation peirod below Badger and date on which ice front reaches Badger

3 ratio of ice volume passing Badger[1] to duration of ice passage[2]

4 *asterisks mark years when levels are known or can be estimated

5 values for years in which ice did not reach Badger are taken from the period in which the ice came closest to reaching Badger.

after this, the ice cover advanced to Badger accumulating an ice volume of 1.2×10^6 m^3. Hence the ice volume passing Badger per day is 0.3×10^6 m^3 during this period.

The flood years of 1982-83, 1976-77 and 1936-37, for examples, stand out from the rest because of the massive volume of ice forming the ice cover through the Badger area. Years in which high water levels were noted (e.g. 1956-57 or 1950-51), show somewhat higher rates of ice production than many, and years without flooding show a range of lesser rates.

This analysis strongly suggests that a major contribution to the cause of flooding at Badger is the rate of ice discharge coming into the Badger area when the ice cover is forming at the town. This mass of ice contributes to the formation of a very thick cover and obstruction of the flow which may be initiated by downstream shoving/plugging caused by temperature changes.

Years in which the ice cover did not reach Badger are not shown in Figure 7.8, but are included in Table 7.2 for reference. The values assigned to each of these years are taken from the period in those years in which the ice cover came closest to reaching Badger. Additional information on the derivation of Table 7.2 is included in Appendix 4.

7.4.3 Probability Analysis of Flood Levels

The rates of ice production given in Table 7.2 were the subject of a frequency analysis using the FDRPFFA program developed by Environment Canada (Condie and Nix, 1977). The

years in which the ice cover did not reach Badger were included in the analysis to provide an accurate representation of the annual series and return periods of flood years, but were set at a low value (0.1) to realistically represent their non-effect on flooding. These provides correct probability values for the production rates and an accurate representation of the distribution of the critical medium and high rates of production.

Figure 7.9 plots the raw data and the Three Parameter Log-normal distribution which provides a good fit to the data (Appendix 3). The 1:100 and 1:20 year return period ice production rates from this distribution are approximately 2.8 x 10^6 m^3/day and 2.02 x 10^6 m^3/day, respectively. The 1:100 year value is slightly higher than that projected for the 1982-83, 1976-77 and 1982-83 flood years. The 1:20 year value is slightly less than these flood years.

Figure 7.10 compares the volume of ice produced to the geodetic elevation at freeze-up for all the years in which levels are known or have been estimated. Scatter in the plotted positions is inevitable, and the only outlier results from the difficulty in estimating a flood level for the high water (but non-flood) event of 1956-57. As noted earlier, the water level for this year was derived from historical data and could be higher. Alternatively, the fitted curve could be convex and give a lower value for the 1:100 year level. As the former is possible, the linear and more conservative curve shown in Figure 7.10 is recommended.

The 1:100 year return period ice production rate (2.8 x 10^6 m^3/day) gives a flood level estimate of 100.36 m. The 1:20 year value (2.02 x 10^6 m^3/day) gives a flood level estimate of 99.48 m at the centre of Badger.

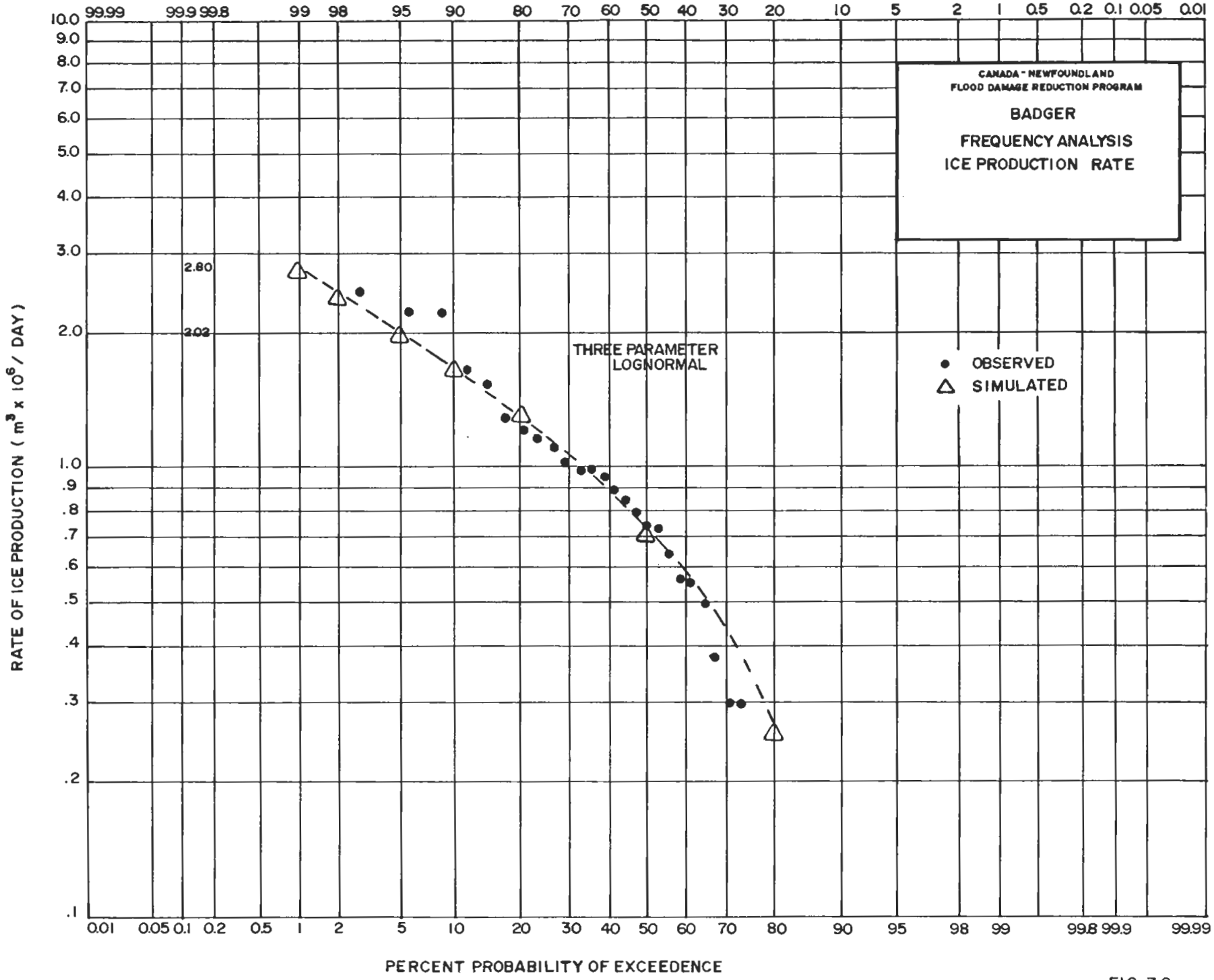

CANADA - NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
BADGER
FREQUENCY ANALYSIS
ICE PRODUCTION RATE
THREE PARAMETER
LOGNORMAL
OBSERVED
SIMULATED
2.80
2.02
RATE OF ICE PRODUCTION (m³ x 10⁶ / DAY)
PERCENT PROBABILITY OF EXCEEDENCE
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIG. 7.9

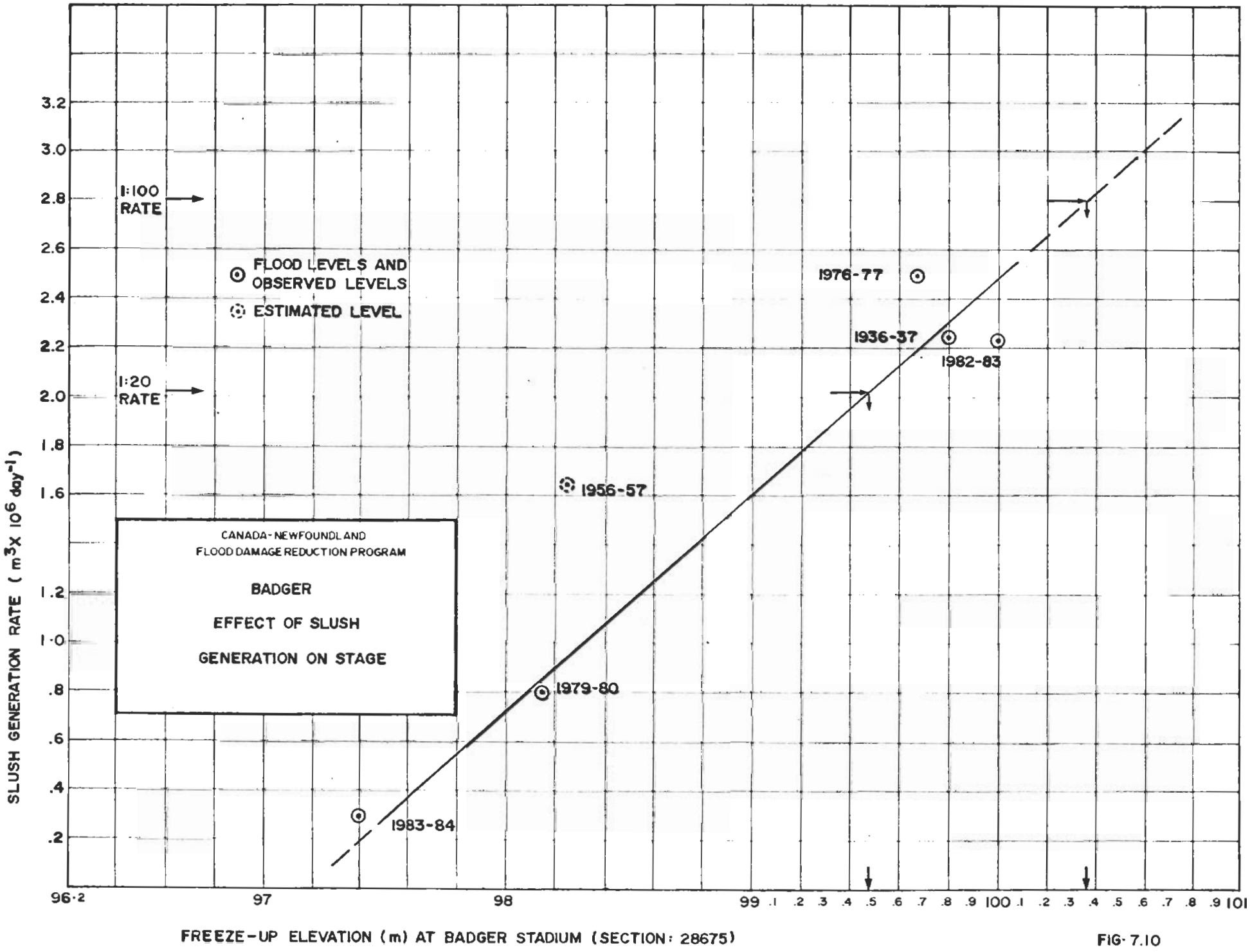

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
BADGER
EFFECT OF SLUSH
GENERATION ON STAGE
FLOOD LEVELS AND OBSERVED LEVELS
ESTIMATED LEVEL
1:100 RATE
1:20 RATE
1976-77
1936-37
1982-83
1956-57
1979-80
1983-84
SLUSH GENERATION RATE (m³ X 10⁶ day⁻¹)
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.2
1.0
.8
.6
.4
.2
96.2
97
98
99
.1
.2
.3
.4
.5
.6
.7
.8
.9
100
.1
.2
.3
.4
.5
.6
.7
.8
.9
101
FREEZE-UP ELEVATION (m) AT BADGER STADIUM (SECTION: 28675)

FIG. 7.10

The following table shows that the second method provides results which are comparable to the "perception" stage approach presented earlier (Figure 7.3, Section 7.4.1).

Return Period (yrs)	Perception Stage Estimate (m)	Ice Production Stage Estimate (m)
1:100	100.15	100.36
1:20	99.58	99.48

The results of the two methods are very close and would provide almost identical flood damage estimates.

The 1:100 year value provided by the perception stage approach incorporated results of the 1917, 1943 and 1945 floods which could not be included in the ice production approach because of meteorological constraints. These were flood years and likely associated with high rates of ice production and transport through Badger. If it were possible to include these values in the ice production method, it is likely that the probability curve (Figure 7.9) would be more negatively skewed and flatter at the upper end of the frequency analysis. This would reduce the 1:100 year estimate to less than 100.36 m.

Similarly, the ice production model includes estimates for significantly more non-flood years than the perception stage approach, and thus gives a more reasonable estimate of the 1:20 year flood level (and levels for lesser events, such as the 1:10 year return period).

In conclusion, the ice production model provides data allowing for a second approach to be used for confirming flood

stage at Badger. This approach confirms that the 1:100 year flood level at Badger is just above the 100.0 m elevation and that the 1:20 year level is about 99.5 m. Recommended estimates for each are 100.36 m (1:100 year) and 99.48 m (1:20 year). Figure 7.11 gives the final stage-frequency curve derived from the ice generation model for winter flood conditions at Badger. This figure also gives the open water relationship and the combined stage-frequency curve derived from both curves. The combined curve is derived from the relationship (Gerard and Calkins, 1984):

$$PA = PI + PO - (PI)(PO)$$

where:

PA is the probability that a flood stage will be equalled or exceeded by either ice related flooding or open water flooding

PI is the probability of the ice-related flood exceeding the given stage, and

PO is the probability of open water floods exceeding that stage.

As shown in the figure, the only influence of open water conditions on the combined curve is on the more frequent floods (10% probability of exceedence or greater). The ice-effect levels and combined levels are practically identical for the 1:100 year and 1:20 year return period floods (100.36m and 99.48m, respectively).

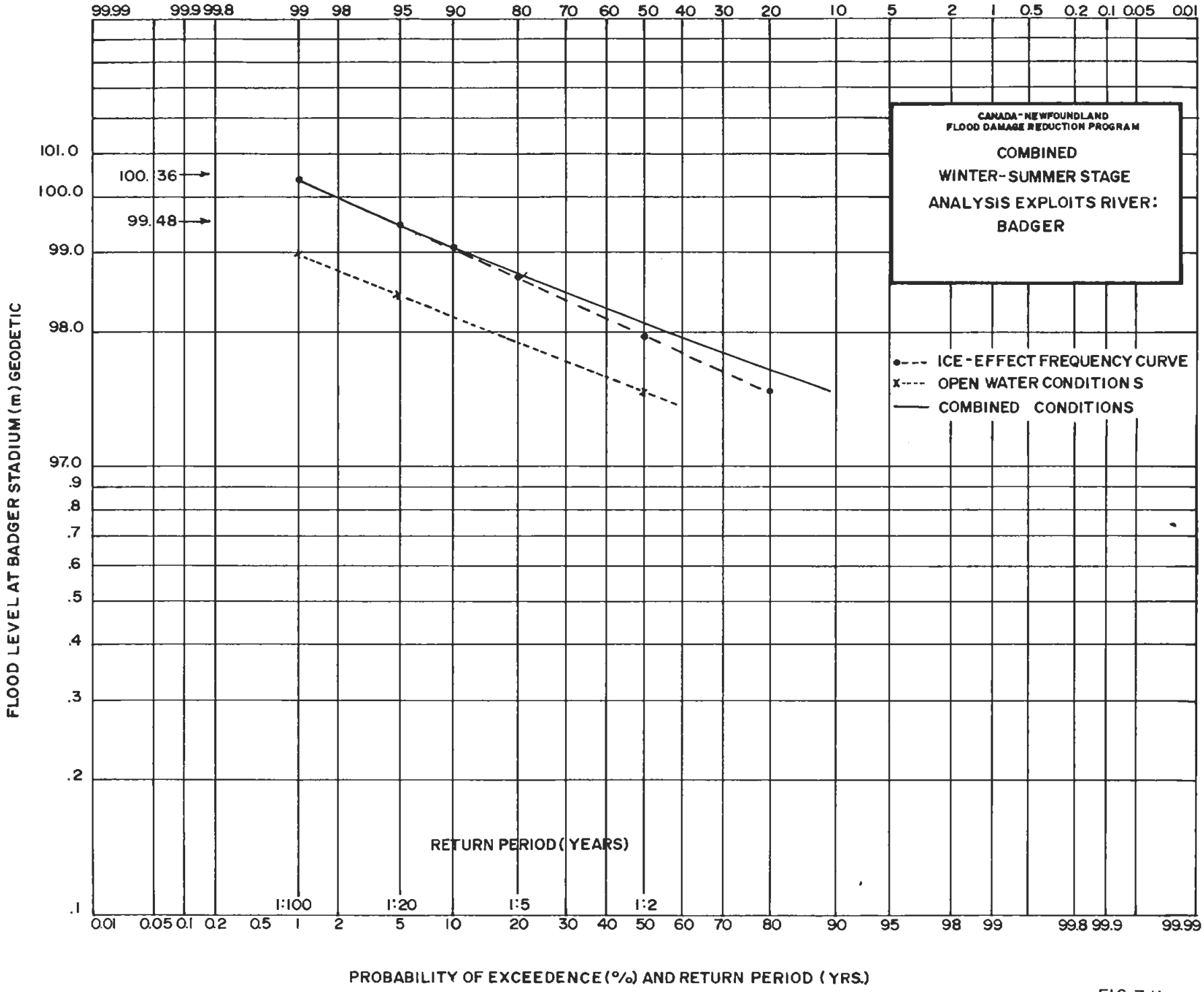

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
COMBINED
WINTER-SUMMER STAGE
ANALYSIS EXPLOITS RIVER:
BADGER
ICE-EFFECT FREQUENCY CURVE
OPEN WATER CONDITIONS
COMBINED CONDITIONS
FLOOD LEVEL AT BADGER STADIUM (m) GEODETIC
101.0
100.0
99.0
98.0
97.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
100.36
99.48
RETURN PERIOD (YEARS)
1:100
1:20
1:5
1:2
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
PROBABILITY OF EXCEEDENCE (%) AND RETURN PERIOD (YRS.)

FIG. 7.11

7.4.4 Backwater Modelling with Ice

The ice option of the HEC-2 model was employed in a third approach to determine if winter water levels could be linked to the discharge on the Exploits River. If such a simple and direct link exists, it would be possible to simulate historical ice levels and conduct frequency analyses of these to give the 1:100 year and 1:20 year flood level.

Figure 7.12 summarizes the observed ice levels at Badger during freeze-up in January 1984, and then following development of open leads in February. Also shown are the elevations of ice scars in the Badger area, and the location of several features in Badger. On the same figure are shown the elevations projected by the ice option of HEC-2 calibrated for freeze-up in 1984 (19 January). In this year without ice problems, the water level is 1.0 m above summer levels at Badger and 3.0 m above summer levels further downstream.

Figure 7.13 presents the same information as Figure 7.12 and ice levels simulated with the HEC-2 model for the flood of February 1983. In this flood period, the discharge on the Exploits River was larger than in January 1984, and the flood stage at Badger reached approximately 99.91 m. In the February 1983 simulation using HEC-2, it was necessary to increase the ice thickness just below Badger to provide a stable condition (Table 7.3). A significant increase in thickness was not required to achieve ice cover stability, and as a result the simulated flood levels reach only 97.8 m - or about 2.1 m below the observed flood stage for that discharge.

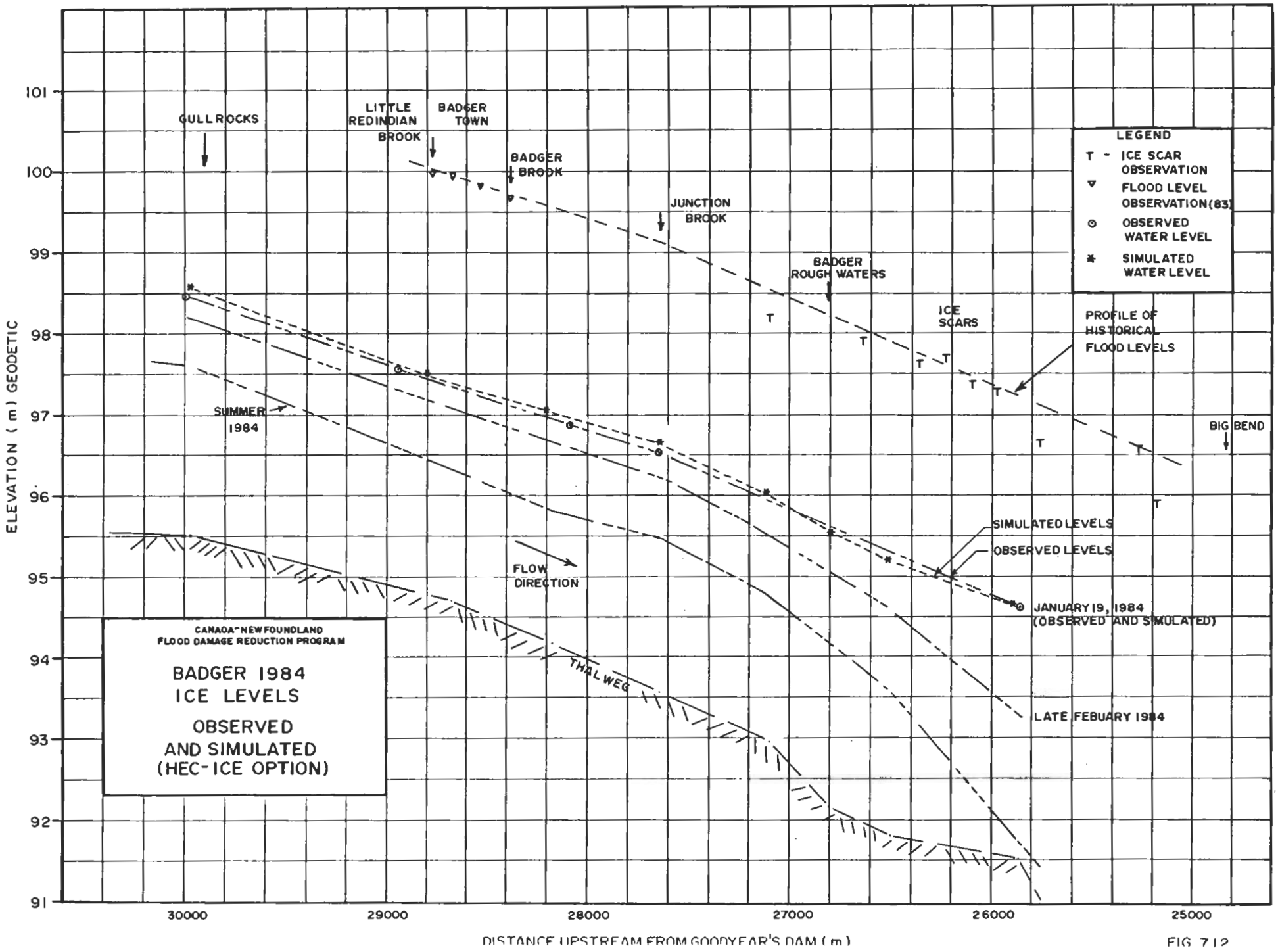

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
BADGER 1984
ICE LEVELS
OBSERVED
AND SIMULATED
(HEC-ICE OPTION)
LEGEND
T - ICE SCAR OBSERVATION
FLOOD LEVEL OBSERVATION (83)
OBSERVED WATER LEVEL
SIMULATED WATER LEVEL
GULL ROCKS
LITTLE REDINDIAN BROOK
BADGER TOWN
BADGER BROOK
JUNCTION BROOK
BADGER ROUGH WATERS
ICE SCARS
PROFILE OF HISTORICAL FLOOD LEVELS
BIG BEND
SUMMER 1984
SIMULATED LEVELS
OBSERVED LEVELS
FLOW DIRECTION
JANUARY 19, 1984 (OBSERVED AND SIMULATED)
THAL WEG
LATE FEBUARY 1984
ELEVATION (m) GEODETIC
101
100
99
98
97
96
95
94
93
92
91
30000
29000
28000
27000
26000
25000
DISTANCE UPSTREAM FROM GOODYEAR'S DAM (m)

FIG 7.12

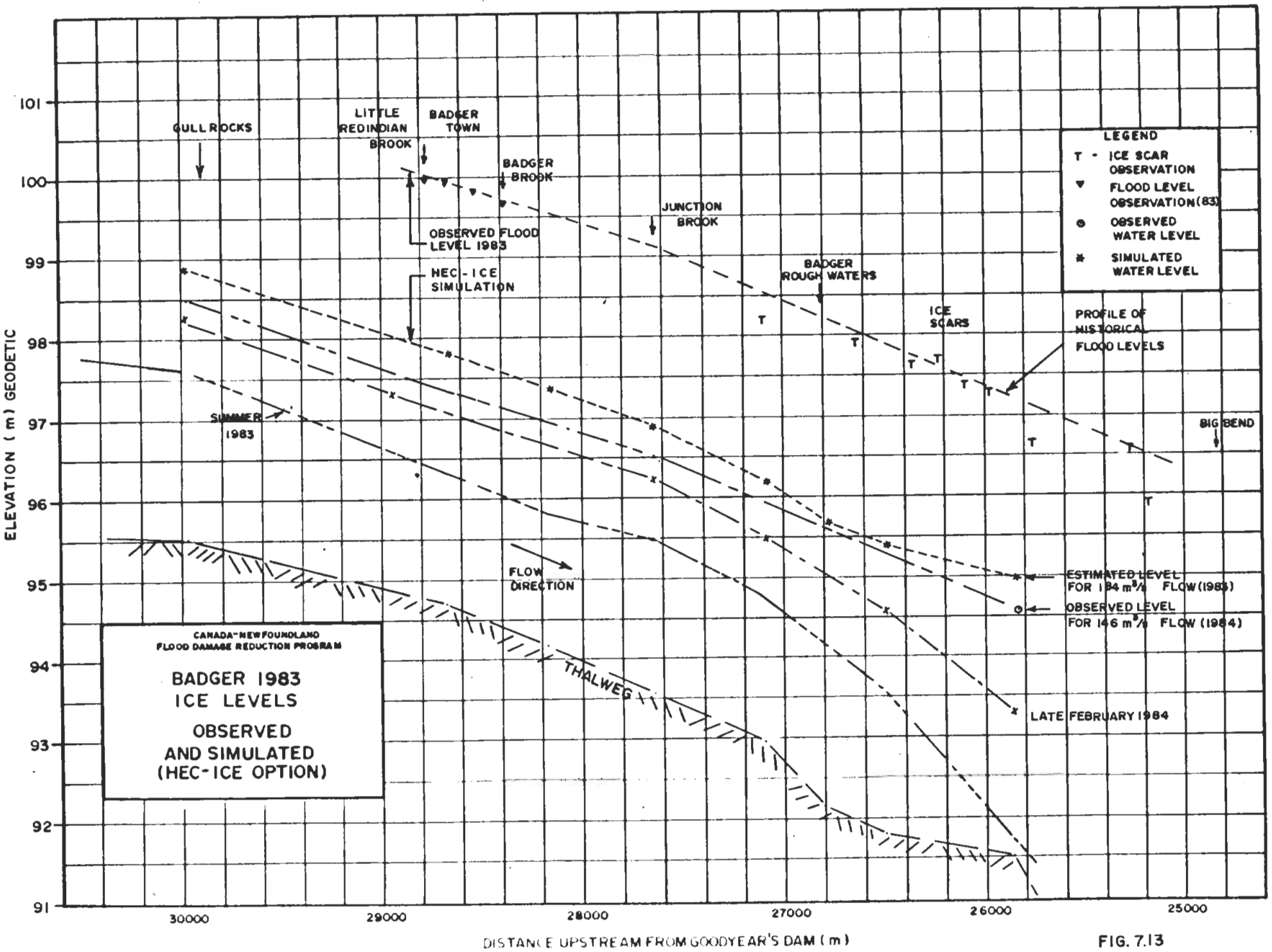

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
BADGER 1983
ICE LEVELS
OBSERVED
AND SIMULATED
(HEC-ICE OPTION)
LEGEND
T - ICE SCAR OBSERVATION
FLOOD LEVEL OBSERVATION (83)
OBSERVED WATER LEVEL
SIMULATED WATER LEVEL
GULL ROCKS
LITTLE REDINDIAN BROOK
BADGER TOWN
BADGER BROOK
JUNCTION BROOK
BADGER ROUGH WATERS
ICE SCARS
BIG BEND
OBSERVED FLOOD LEVEL 1983
HEC-ICE SIMULATION
SUMMER 1983
PROFILE OF HISTORICAL FLOOD LEVELS
FLOW DIRECTION
THALWEG
ESTIMATED LEVEL FOR 134 m³/s FLOW (1983)
OBSERVED LEVEL FOR 146 m³/s FLOW (1984)
LATE FEBRUARY 1984
ELEVATION (m) GEODETIC
101
100
99
98
97
96
95
94
93
92
91
30000
29000
28000
27000
26000
25000
DISTANCE UPSTREAM FROM GOODYEAR'S DAM (m)

FIG. 7.13

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TABLE 7.3

EXPLOITS RIVER AT BADGER
HEC-2 ICE OPTION SIMULATIONS
FOR JANUARY 1984 and FEBRUARY 1983

Cross-section Location	January 1984		February 1983	
	Thickness (m)	Elevation (m)	Thickness (m)	Elevation (m)
25850 (3000)	2.0	94.62	2.0	95.00
26510 (3100)	1.8	95.20	1.8	95.42
26790 (3125)	1.8	95.53	1.8	95.72
27090 (3150)	1.6	96.04	1.6	96.21
27650 (4000)	1.4	96.66	1.6*	96.90
28175 (6000)	1.4	97.05	1.6*	97.37
28675 (7000) Badger Stadium	1.4	97.48	1.4	97.77
Discharge	140 m^3/s above Badger 146 m^3/s below Badger		184.8 m^3/s above Badger 191.5 m^3/s below Badger	

* Required ice thickness for stability in 1983.

It is concluded from this test that a change in the discharge on the Exploits River does not by itself determine the winter flood stage at Badger. Although higher flood levels could have been achieved in the model by arbitrarily increasing the ice cover thickness or degree of blockage, the ice option of HEC-2 does not simulate these values and thus cannot be used with confidence on its own to simulate ice levels from year to year.

7.4.5 1:20 Year and 1:100 Year Levels at Badger

The Perception Stage approach and the Ice Progression Modelling approach for determining the 1:20 year and 1:100 year levels at Badger during winter ice conditions yield nearly identical results. As flood damages would also be nearly identical, it is recommended that the stage frequency curve presented in Figure 7.11 be used for this assessment. The recommended flood levels for this ice conditions are:

Return Period (years)	Flood Level at Town Centre (Section 28675)
1:20	99.48 m
1:100	100.36 m

7.4.6 Badger Flood Prone Areas

Detailed topographic mapping of the Town of Badger was completed in January 1985. This mapping provides considerably more accurate information on elevations and the location of structures in Badger than earlier mapping (1963), and serves as a good basis for evaluating flooding conditions and the size, extent and location of remedial works to reduce potential flooding.

The updated mapping provided an opportunity for detailed evaluation of the slope of the water surface during flooding at Badger. Analysis of our winter observations (1984), flood level observations by Newfoundland Environment (1983) and house and river surveys (1984) indicates that flood elevations along Little Red Indian Brook were slightly higher than those near Badger Arena. Elevations at the arena were in turn slightly higher than on Badger Brook. On both brooks there was no observed difference in elevation from the Exploits River to their upstream limits at Badger. The following table lists observed water surface slopes at Badger.

Observation Period	Winter Surface Slope (m/km)	Data Source
· 1983 flood profile	0.77	Newfoundland Env.
· 1984 freeze-up	0.82	Fenco field survey
· 1984 mid-winter	0.81	Fenco field survey
· 1984 summer	0.86	Fenco field survey

The slope during the 1984 freeze-up survey (0.82 m/km) was similar to the estimate derived from resident's recollections of 1983 levels and was selected for defining the 1:20 and 1:100 year flood level elevations in the Badger study area. Table 7.4 lists these flood elevation at key locations in Badger. The flood-prone areas corresponding to these levels are shown on Figure 1.1 (and Plate 1, Technical Appendices).

7.5 Rushy Pond Area: Ice-Effect Levels

As at Badger, it is desireable to obtain estimates of river stage which can be identified with probabilities of occurrence to establish the 1:20 and 1:100 year ice-effect levels at Rushy Pond. The perception stage approach is feasible at Rushy Pond, and can be completed by drawing on historical information of river stages in the area since 1903.

TABLE 7.4

BADGER: 1:20 AND 1:100 YEAR FLOOD LEVELS

Location in Badger	Flood Level (m)	
	1:20 Year	1:100 Year
Mouth of Badger Brook	99.18	100.06
Badger Brook above CNR Bridge	99.24	100.12
Town Hall	99.36	100.24
Arena (Sec. 28675)	99.48	100.36
Little Red Indian Brook	99.56	100.44

The ice progression modelling approach developed for freeze-up conditions at Badger is not appropriate for the Rushy Pond Area, and backwater modelling with ice is also inappropriate. This is because there is no firm information on the location or physical properties of ice blockages at Rushy Pond, and no information on the flows which initiated them or which they resisted before melting in place or being swept downstream. It is possible to simulate the effects of an individual ice jam or ice cover (e.g. Badger, January 1984, Figure 7.12) but not possible to reliably simulate other years for developing a stage frequency analysis (e.g. Badger, February 1983, Figure 7.13).

7.5.1 Probability Analysis of Historical Floods

The historical data base describing winter floods in the Rushy Pond Area includes information from the Department of Transportation and Communication, Newfoundland Environment, CN Rail and from our 1984 surveys. Additional data describing flood conditions upstream of the study area (e.g. Leech Brook) is also available but not appropriate for use in the Rushy Pond area. Overall, eight years of information can be employed to determine the probability distribution of ice-effect flood levels using the perception stage approach of Gerard and Karpuk (1979).

Department of Transportation and Communication

Several winter floods have taken place since completion of the TCH, which was initially flooded during construction in 1965. Water levels are noted at a stage when a shoulder of the road is reached, and this elevation represents the perception stage at which information on flood levels would have been provided by this source.

The perception stage for this source has changed with time, corresponding to changes in the elevation of the TCH through the study area. The perception level at the shoulder of the original TCH is set at 70.45 m. The current level, 72.75 metres, corresponds to the shoulder of the newly elevated road. Prior to completion of the TCH, the Old Badger Road was in regular use and the perception stage for this road has also been taken to be the shoulder elevation, 73.3 m.

The following table summarizes the winter flood level assignments resulting from the observations of this agency:

Perception Stage	Year of Record	Flood Level Estimate at TCH Culvert	Comment
70.45 m	1972	70.70 m	Water to road level
70.45 m	1976	71.30 m	Flood at TCH low spot
72.75 m	1979	72.90 m	Road closed as a precautionary measure
72.75 m	1983	73.20 m	High flow and ice

Newfoundland Environment

As well as being on the site for several of the floods described above, photos were taken of the study area in 1977. These show flooding in Goodyear's Pit near the TCH. In January 1980, flooding of Goodyear's Pit was also recorded in the climate and flow records kept by this source. The record indicates that ice was moving through the Goodyear's Pit at that time.

The perception stage for these two records was set at the unflooded ground elevation in Goodyear's Pit near the TCH (69.8 m), the water level for both years was set at 72.0 metres - sufficient to cause water to enter the area and to

show evidence of flooding and ice movement, yet below the perception stage at which the DOT would have become concerned.

Perception Stage	Year of Record	Flood Level Estimate at TCH Culvert	Comment
69.80 m	1977	73.00	No TCH flooding
69.80 m	1980	73.00	No TCH flooding

CN Rail

In 1903, the railway line from Red Cliff Overpass to 2.5 km east of the Overpass was raised and moved northward to its present route from a route which cut directly through the study area. The move was prompted by flooding in the study area which reached a level between the old rail bed (71.5 m) but below the current rail bed (72.5 m). The perception level for this source appears to be the same elevation as the rail bed at which flood damage would occur. Given that the 1903 route was also exposed to erosion and ice action during flooding, a flood level estimate of 71.5 m is selected for this event.

Perception Stage	Year of Record	Flood Level Estimate at TCH Culvert	Comment
71.5 m	1903	71.5	CNR flooded
72.5 m	post 1903	-	No flood reports

Hydrometric Survey

Field surveys as part of this study cover the 1983-84 winter season which has a perception stage level (or minimum "gauge" reading at zero flow) of 69.0 m. The ice level associated with this past winter was 69.72 m at the Rushy Pond ice boom.

Perception Stage	Year of Record	Flood Level Estimate at TCH Culvert	Comment
69.0 m	1984	69.72	No flooding

Summary Diagrams and Probability Distribution

The flood level information from the above sources is summarized in Figures 7.14 and 7.15. The horizontal bars denote the estimated perception stage and the vertical bars extend up from the perception stage to the maximum ice stage observed.

The rank and record length associated with each peak is determined from Figure 7.15 and summarized in the following table:

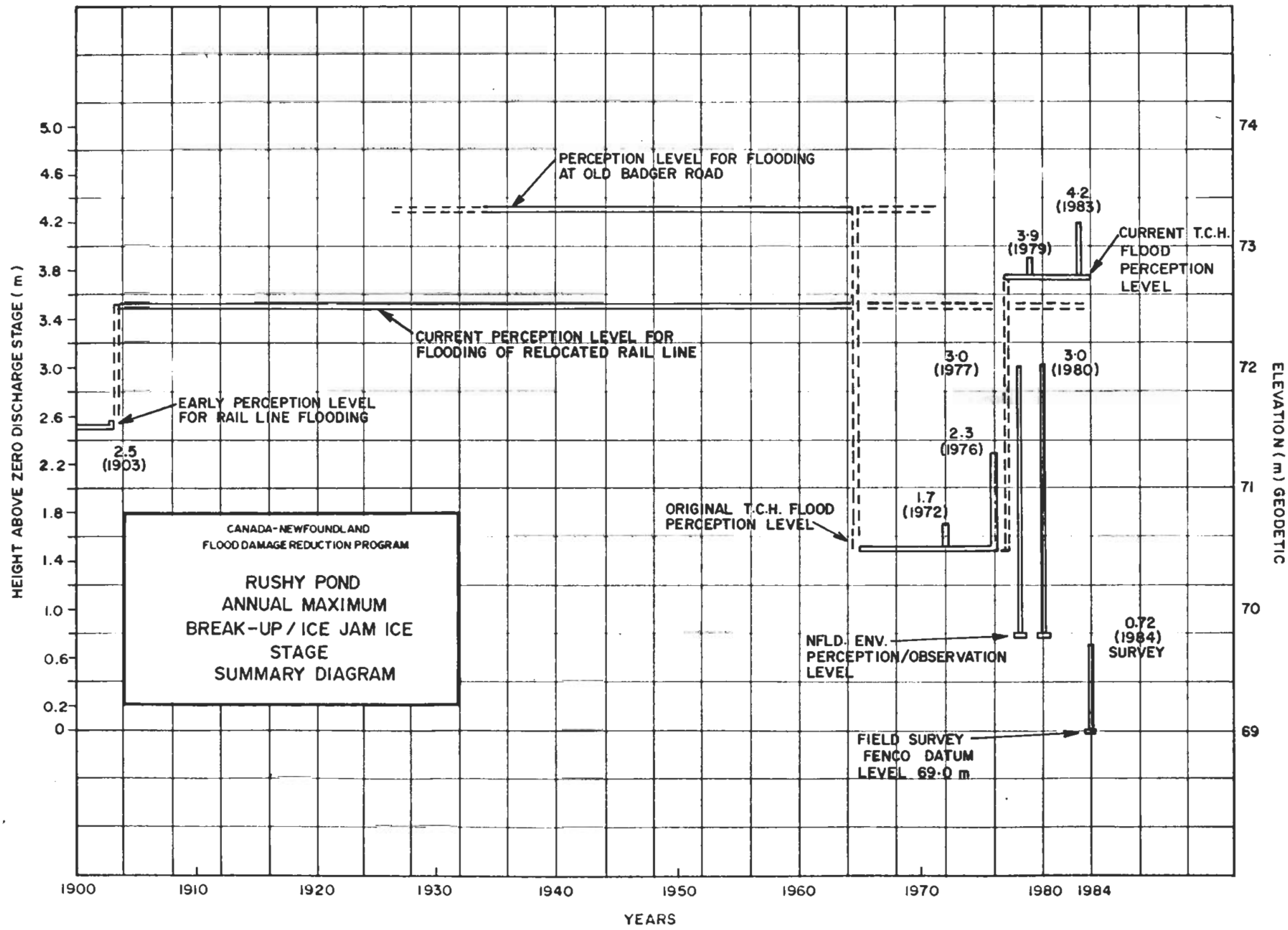

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
RUSHY POND
ANNUAL MAXIMUM
BREAK-UP / ICE JAM ICE
STAGE
SUMMARY DIAGRAM
PERCEPTION LEVEL FOR FLOODING
AT OLD BADGER ROAD
CURRENT PERCEPTION LEVEL FOR
FLOODING OF RELOCATED RAIL LINE
EARLY PERCEPTION LEVEL
FOR RAIL LINE FLOODING
2.5
(1903)
ORIGINAL T.C.H. FLOOD
PERCEPTION LEVEL
1.7
(1972)
2.3
(1976)
3.0
(1977)
3.9
(1979)
4.2
(1983)
CURRENT T.C.H.
FLOOD
PERCEPTION
LEVEL
3.0
(1980)
NFLD. ENV.
PERCEPTION/OBSERVATION
LEVEL
0.72
(1984)
SURVEY
FIELD SURVEY
FENCO DATUM
LEVEL 69.0 m
HEIGHT ABOVE ZERO DISCHARGE STAGE (m)
5.0
4.6
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
1.0
0.6
0.2
0
ELEVATION (m) GEODETIC
74
73
72
71
70
69
1900
1910
1920
1930
1940
1950
1960
1970
1980
1984
YEARS

FIG. 7.14

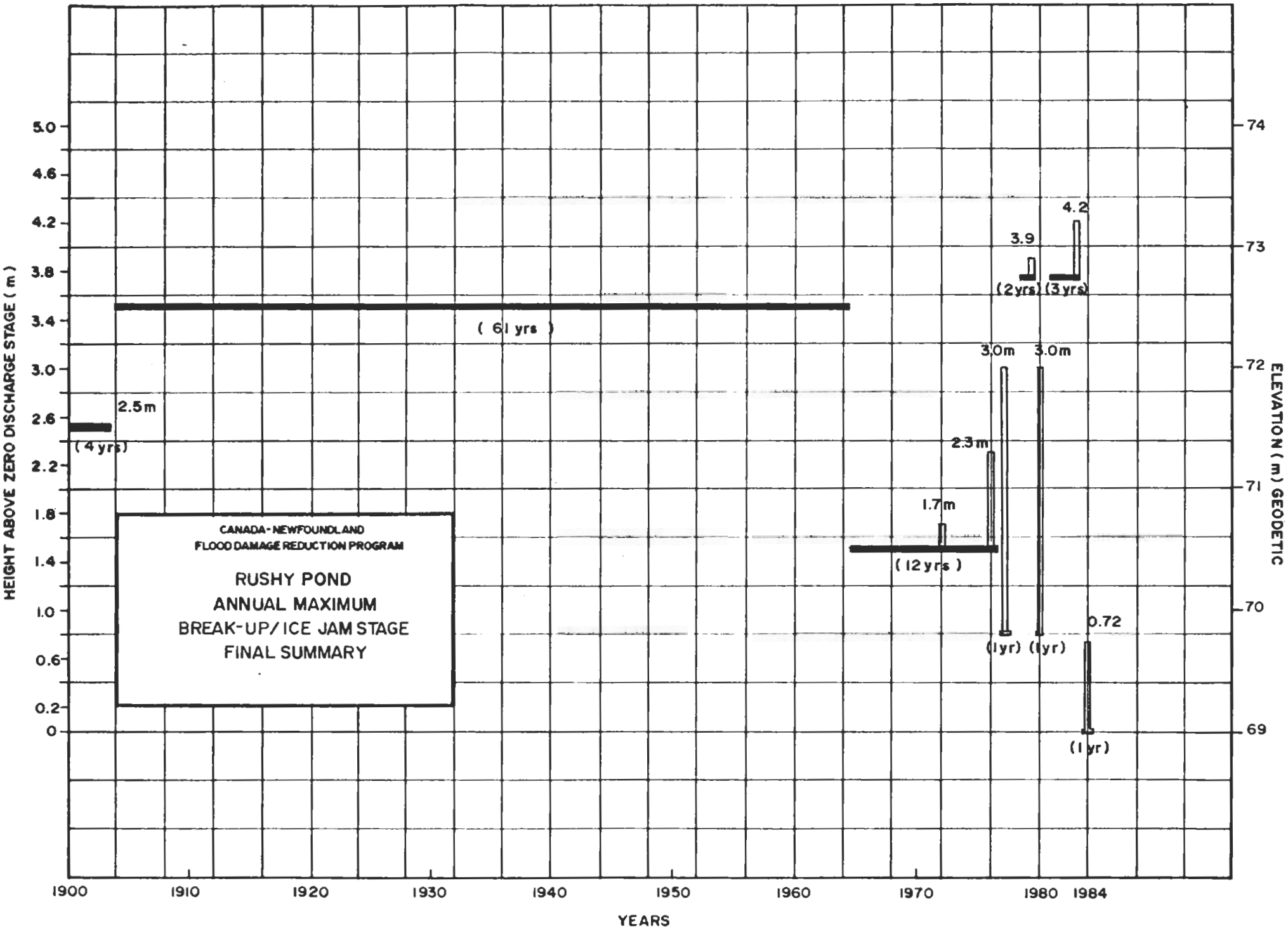

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
RUSHY POND
ANNUAL MAXIMUM
BREAK-UP/ICE JAM STAGE
FINAL SUMMARY
HEIGHT ABOVE ZERO DISCHARGE STAGE (m)
ELEVATION (m) GEODETIC
YEARS
5.0
4.6
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
1.0
0.6
0.2
0
74
73
72
71
70
69
1900
1910
1920
1930
1940
1950
1960
1970
1980
1984
2.5m
(4 yrs)
(61 yrs)
1.7m
2.3m
(12 yrs)
3.0m
(1yr)
3.0m
(1yr)
3.9
(2yrs)
4.2
(3yrs)
0.72
(1yr)

FIG. 7.15

Year	Datum Stage	Rank	Years of Record	Exceedence Probability %
1983	4.20	1	85	0.7
1979	3.90	2	85	1.9
1903	2.50	3	19	13.6
1977	3.00	2	19	8.4
1980	3.00	2	19	8.4
1976	2.30	3	15	17.2
1972	1.70	4	15	23.8
1984	0.72	1	1	50.0

Figure 7.16 shows the plotted points of cumulative probability for the winter ice stage and for the open water, ice-free condition. It is concluded that:

(1) Winter ice causes higher flood stages than high flows during open water conditions for return periods beyond the 1:7 year return period

(2) The 1:20 year and 1:100 year ice-effect levels are 72.4 m and 73.20 m, respectively.

7.5.2 1:20 and 1:100 Year Levels at the Rushy Pond Study Area

The perception stage approach for the Rushy Pond area gives winter flood levels which are approximately 0.5 m higher than open water flood levels for the 1:20 and 1:100 year return periods. This difference progressively decreases and the open water stage is higher than the ice stage for return periods more frequent than the 1:7 year case.

The 1:100 winter level is almost the same as the 1983 flood level along the highway in the Rushy Pond area. As levels

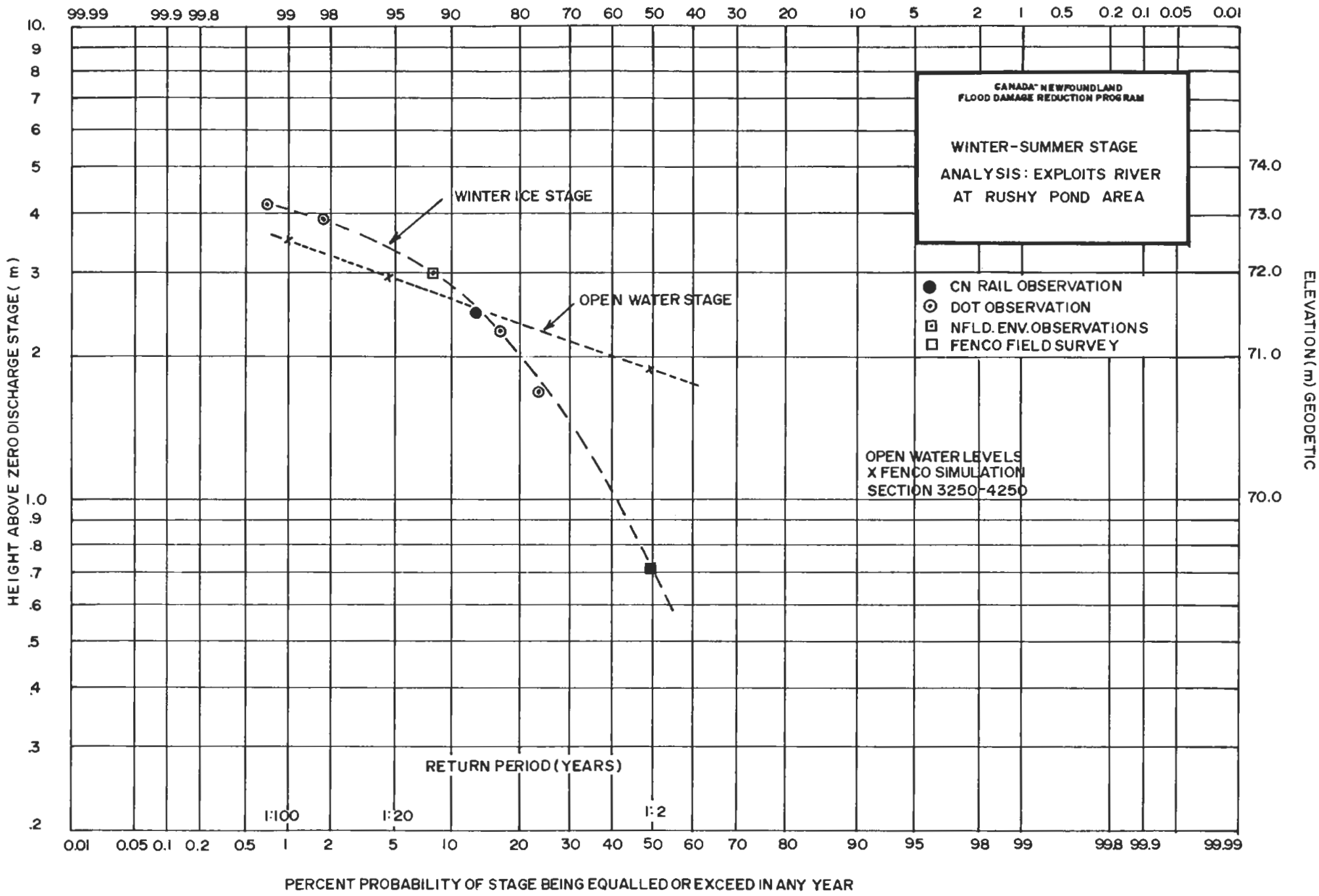

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
WINTER-SUMMER STAGE
ANALYSIS: EXPLOITS RIVER
AT RUSHY POND AREA
CN RAIL OBSERVATION
DOT OBSERVATION
NFLD. ENV. OBSERVATIONS
FENCO FIELD SURVEY
WINTER ICE STAGE
OPEN WATER STAGE
OPEN WATER LEVELS
X FENCO SIMULATION
SECTION 3250-4250
RETURN PERIOD (YEARS)
1:100
1:20
1:2
HEIGHT ABOVE ZERO DISCHARGE STAGE (m)
ELEVATION (m) GEODETIC
PERCENT PROBABILITY OF STAGE BEING EQUALLED OR EXCEED IN ANY YEAR
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
10. 9 8 7 6 5 4 3 2 1.0 .9 .8 .7 .6 .5 .4 .3 .2
74.0 73.0 72.0 71.0 70.0

FIG. 7.16

are known throughout most of the study area from the 1983 flood, it is recommended that this flood be used as a general guide for defining the 1:100 year flood levels. The recommended flood levels for the study area are as follows:

Return Period (Years)	Flood Level at North Angle Culvert (Section 3250)
1:20	72.40 m
1:100	73.20 m

Figure 7.17 gives the combined winter and open water stage-frequency diagram recommended for the Rushy Pond area. The figure is derived in the same manner as outlined for Badger (section 7.4.3), and like Badger the ice-effect levels are the same as the combined levels for the 1:100 year and 1:20 year return period floods (73.2m and 72.4m respectively).

7.5.3 Rushy Pond Flood Prone Area

In December 1984, topographic mapping was completed for the study area at a scale of 1:5000. This mapping provided much needed information for finalizing flood levels throughout the study area and for plotting them on detailed mapping (Figures 1.2 and 1.3, and Plate 2 in Technical Appendices).

As shown in Figure 4.15, much of the study area is dominated by the backwater from Goodyear's Dam. Both the water level and ice scar information show that the level of past floods has been uniform from Goodyear's Dam to above Sandy Brook (Section 5100). Upstream of Sandy Brook (at Section 6050), the river is shallower and narrower, and ice scars and observed water levels show that levels at Red Cliff Overpass are slightly higher than those observed downstream:

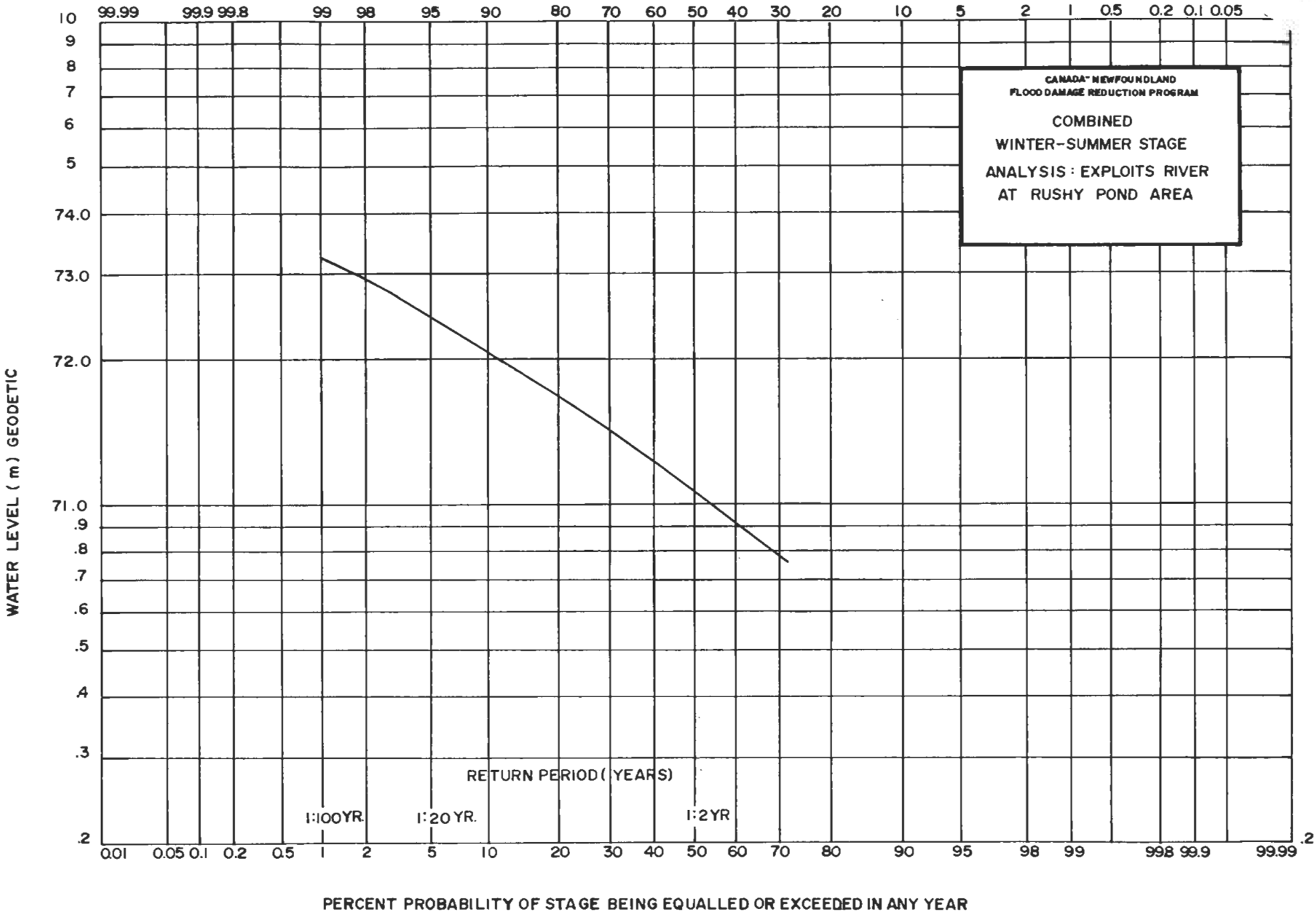

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
COMBINED
WINTER-SUMMER STAGE
ANALYSIS: EXPLOITS RIVER
AT RUSHY POND AREA
WATER LEVEL (m) GEODETIC
10
9
8
7
6
5
74.0
73.0
72.0
71.0
.9
.8
.7
.6
.5
.4
.3
.2
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
RETURN PERIOD (YEARS)
1:100YR.
1:20YR.
1:2YR
PERCENT PROBABILITY OF STAGE BEING EQUALLED OR EXCEEDED IN ANY YEAR

FIG. 7.17

Observed Data	Rushy Pond Area	Red Cliff Overpass	Increase in Water Level at Red Cliff
Summer water levels (1984	69.69	70.3	0.61
Ice scar levels	73.2	73.75	0.55

Until such time as additional ice observations are undertaken in the area of Red Cliff Overpass, it is recommended that design flood levels be taken to be 0.6 m higher at this site than throughout the downstream reach. Table 7.5 gives the recommended flood levels for the Rushy Pond area.

TABLE 7.5

RUSHY POND AREA - 1:20 YEAR AND 1:100 YEAR FLOOD LEVELS

Location	Flood Level (m) 1:20 Year	1:100 year
Rushy Pond Brook	72.4	73.2
"North Angle" Culvert	72.4	73.2
Trans-Canada Highway	72.4	73.2
Red Cliff Overpass	73.0	73.8

8.0 FLOOD DAMAGE ANALYSIS - BADGER

8.1 Introduction

The Town of Badger has been flooded on several past occasions with the most recent being 1977 and 1983 (Table 3.1). In 1977, about 28 structures were damaged by flood waters with an estimated damage of about $20,000. In 1983, about 41 structures were flooded with an estimated damage of $45,269.

Due to the repeated nature of flood damages in the Badger area, it is necessary to develop a damage-frequency relationship to obtain a better assessment of the magnitude of the problem.

8.2 General Approach

In order to determine the dollar damages due to flooding, a field survey of the structures within the floodplain was conducted at the end of August 1984. Structures were surveyed to determine the ground elevation and elevation of the first floor. The number of structures surveyed and location are as follows: Maple Street, 61; River Road, 14; Beothuck Street, 33; Main Street, 25 and TCH, 19. A photographic inventory of each structure was also undertaken to allow building use and type classification for determining flood damages.

The approach to determine general flood damage estimates for Badger followed a methodology through which the damage was initially related to the type of structure (Acres 1968). Dollar damages were then determined on the basis of recent work which links flood damage to flood level (Paragon, 1984).

Values were then updated to 1984 dollars and then adjusted to local conditions at Badger on the basis of historical flood damage estimates. A damage-flood frequency curve was then prepared and an average annual damage estimate was computed for Badger.

8.3 Derivation of Composite Depth-Damage Curves

8.3.1 Depth-Damage Curves

The depth-damage data used for this study is based on a study undertaken for the Ontario Ministry of Natural Resources (Paragon Engineering, 1984). In this study estimation techniques relating to flood damages were reviewed and then the most appropriate depth-damage data was recommended. For residential structures, the study recommended the use of the Glengowan data which is a composite curve consisting of the U.S. Federal Insurance Administration (FIA) curve and the Acres curve. Since the Glengowan curves represent the most up-to- date damage data available and are recommended for use by the Ontario Ministry of Natural Resources, they were used in this study.

The damage data presented in the Paragon reports is in 1979 dollars. To update to 1984 dollars, the comsumer price index information available from Statistics Canada was used. Consultation with Statistics Canada indicated that a reasonable estimate in 1984 dollars would be obtained by multiplying 1979 dollar values by 1.55.

8.3.2 Calibration of Depth-Damage Curves

Where possible, it is desirable to develop depth-damage curves for site specific, locations. However, since this is not possible for this study, the depth-damage relationships discussed above can be "calibrated" using historical damage data to better reflect local conditions. Historical damage data is available for the 1977 and 1983 floods in Badger.

1977 Flood Damage

- about $20,000 (1977) flood damage claims, rent, assessment and miscellaneous expenses
- estimated 28 structures flooded
- of the 28 structures, four (4) were badly flooded, four (4) had some first floor flooding and about twenty (20) structures had basement flooding only. Source: (Kindervater, 1980)

1983 Flood Damage

The Department of Municipal Affairs provided the following cost breakdown for the 1983 damages:

	Item	$1983
(1)	Personal property claims	$36,273
(2)	Rent paid to displaced persons	1,085
(3)	Property assessment cost	684
(4)	Miscellaneous expenses (paid to Town Council	7,227
	Total Direct Damages (Item 1) and Indirect Flood Damages (Item 2,3,4)	$45,269

A total of 41 people received personal property assistance as a result of the 1983 flood.

In order to calibrate the standard depth-damage curves, it was first necessary to check the historical data with that obtained from the field survey of Badger. It was determined that the number of structures affected by floods in 1977 and 1983 were in close agreement with the number counted from the field survey. Based on a flood elevation of 99.66 m in 1977, our investigation indicated that there were 29 structures which suffered flood damages. Of these structures, four homes had the first floor flooded to a depth of 0.27 m to 0.7 m; four other homes were flooded from a depth of 0.08 m to 0.18 m; three commercial/recreational structures were partially flooded; and the remaining 18 structures had flooding to basements.

Similarly, based on a flood level of 99.91 m in 1983, it was determined that 43 structures suffered flood damages as compared to 41 families who received personal property assistance. Of the 43 structures, 18 homes had basement flooding; 18 had first floor flooding; one had both the first floor and basement flooded; and 6 commercial/public buildings were partially flooded.

Initially, the standard depth-damage curves were used to determine flood damage to the 18 structures having first floor flooding in 1983. The direct damage computed with the standard curves for these structures was estimated at $41,100 ($ 1983). This exceeds the total flood estimate (first floor plus basements) for that year and demonstrates that the standard curves over-estimate first floor flood damages at Badger.

The same approach was then employed to estimate 1977 flood damages. From the cost breakdown presented above for the 1983 flood damages, it is seen that the indirect damages (items 2, 3 and 4) were 25% of the direct damages (Item 1). The same proportion of indirect damages (25% of direct property claims) recorded in 1983 was assumed to be the case in 1977. This gives the following breakdown of cost estimates for the 1977 damages:

Item	$ 1977
(1) personal property claims	16,000
(2),(3),(4) rent, property assessment and miscellaneous expenses	4,000
Total Direct and Indirect Damage Claims	$20,000

The standard depth-damage relationships were then used to generate first floor flood damage estimates for the 1977 event, and these relationships gave a damage estimate of $13,030 ($ 1977). This leaves only $2,970 to cover all the costs of basement flood damages to eighteen structures, or about $165 per structure. This estimate for basement damages is too low and supports the earlier conclusion that the standard flood damage curVes overestimate first floor flood damages in Badger.

Our field survey in Badger indicates that flood damage to basements in the previously flooded portions of the town would average approximately $500 ($ 1984) per structure. For the 1983 flood, the following estimates apply:

Item	$ 1983	$ 1984
(1) total property damage claims minus	36,273	38,812
basement damage estimate (18)	8,411	9,000
. resultant first flood damage calibrated to Badger	27,862	29,812
. standard depth-damage estimate for first floor damage	41,100	43,977
. ratio of calibrated to standard first floor damage estimates	.68	.68

The first floor damages calibrated to conditions at Badger (eg., $27,862 in 1983 dollars) are 68% of those obtained using the standard depth-damage relationships developed for several other areas of the country (eg., $41,100 in 1983 dollars). Hence a reduction of 32% to the values derived from the standard depth-damage relationships is appropriate for estimating first floor flood damages in Badger.

Taking this 32% reduction to be applicable to the first floor damages estimated by the standard relationships for the 1977 flood ($13,030 in 1977 dollars), reduced this damage estimate to a calibrated value of $8,860. Inclusion of basement flood damages and rent and miscellaneous expenses gives the following flood damage estimate in 1977 and 1984 dollars;

1977 Items	$ 1977	$ 1984
(1) Personal Property Claims		
. basements (18)	5,172	9,000
. first floor damage	8,860	15,416
(2),(3),(4) rent, assessment, misc.	4,000	6,960
Total Direct and Indirect Damages	$18,032	$31,375

The $18,032 calibrated value compares favourably to the approximate total of $20,000 quoted in the literature (Kindervater, 1980). Given that the $20,000 value is an approximation and does not appear to be as rigorously documented as the 1983 damage estimates, it is concluded that the 32% reduction factor is reasonable for use as a flood damage calibration factor for Badger.

8.3.3 Computation of 1:50 and 1:100 Year Flood Damages

The 1983 peak flood level has been estimated at 99.91 m in the Badger area. Since this flood level is nearly equivalent to a 1:50 year event, the direct flood damage for this return period has already been accurately estimated by the Department of Municipal Affairs for Badger. In 1984 dollars the direct flood damage is approximately $38,800.

The direct flood damages for the 1:100 year event were developed in several steps. First, the standard depth damage relationships were used to estimate first floor flood damages. Next they were reduced by 32% to bring them into line with the calibration for Badger. Basement flood damages were then added to this total at $500 for each basement which was flooded previously. Basements which were not previously flooded were assigned damage values based on the standard relationships less 32%. Overall, this approach gives a direct flood damage estimate (personal claims) at the 1:100 year flood level of $151,325 ($ 1984). Additional details outlining the development of this damage estimate are provided in Appendix 4.0.

As noted earlier, there are also indirect damages associated with flooding. Indirect damages include costs incurred in response to the flood and as a result of flood damages such

as lost wages, interruption to transportation routes, etc. As outlined in Section 8.3.2, some of the indirect flood damages (items 2 to 4) were evaluated in the 1983 flood and their total was 25% of the direct damage estimate. However, these damages did not include all of the indirect cost items listed above (e.g. lost wages). To account for these items, an additional 5% of the direct damage was added to the indirect damages.

Including this additional 5% to the 1977 and 1983 flood estimates brings the grand total damage estimate to the following ($ 1984):

Item	Flood Year	
	1977	1983
(1) Personal property claims	24,416	38,812
(2,3,4) Indirect costs	6,960	9,626
(5) Other indirect (5%)	1,221	1,941
Total Flood Damage	$32,597	$50,379

Direct damages/personal claims for the 100 year event are estimated to be $151,325 ($ 1984). Assuming that the ratio of indirect to direct damages would be similar to the 1983 case (ie. items 2,3,4 are 25% of item 1) and adding 5% to account for other undocumented, indirect damages (item 5) brings the total indirect damages to 30% of the direct/ property claims. The total flood damage estimate for the 100-year event becomes $196,723 ($151,325 + $45,398 dollars 1984).

The total flood damage estimates for these three events are summarized in the following table with the return period associated with each:

Flood Year	Return Period	Total Damage Estimate ($ 1984)
1977	approx. 1:40 yr	32,597
1983	approx. 1:50 yr	50,379
	1:100 yr	196,723

Given also that the non-damage flood level for the Badger area is about 99.36, the above values can be used to prepare a water level-damage curve for the Badger. This curve is presented in Figure 8.1.

8.4 Damage-Frequency Curves and Average Annual Damages

A damage-frequency curve was plotted to compute the expected average annual value for the Badger flood prone area. This curve was developed by combining the information from the water level-frequency curves of Figure 7.11 with the damage-water level curves of Figure 8.1. From these two curves one may select a water level and then find both the average return period of that level and the expected resulting damage value. This was done over a range of water levels to obtain several pairs of points relating an expected damage value to a return period. The inverse of each return period was determined to allow each damage value to be associated with a probability of exceedence. The damage-frequency curve for the Town of Badger is shown in Figure 8.2.

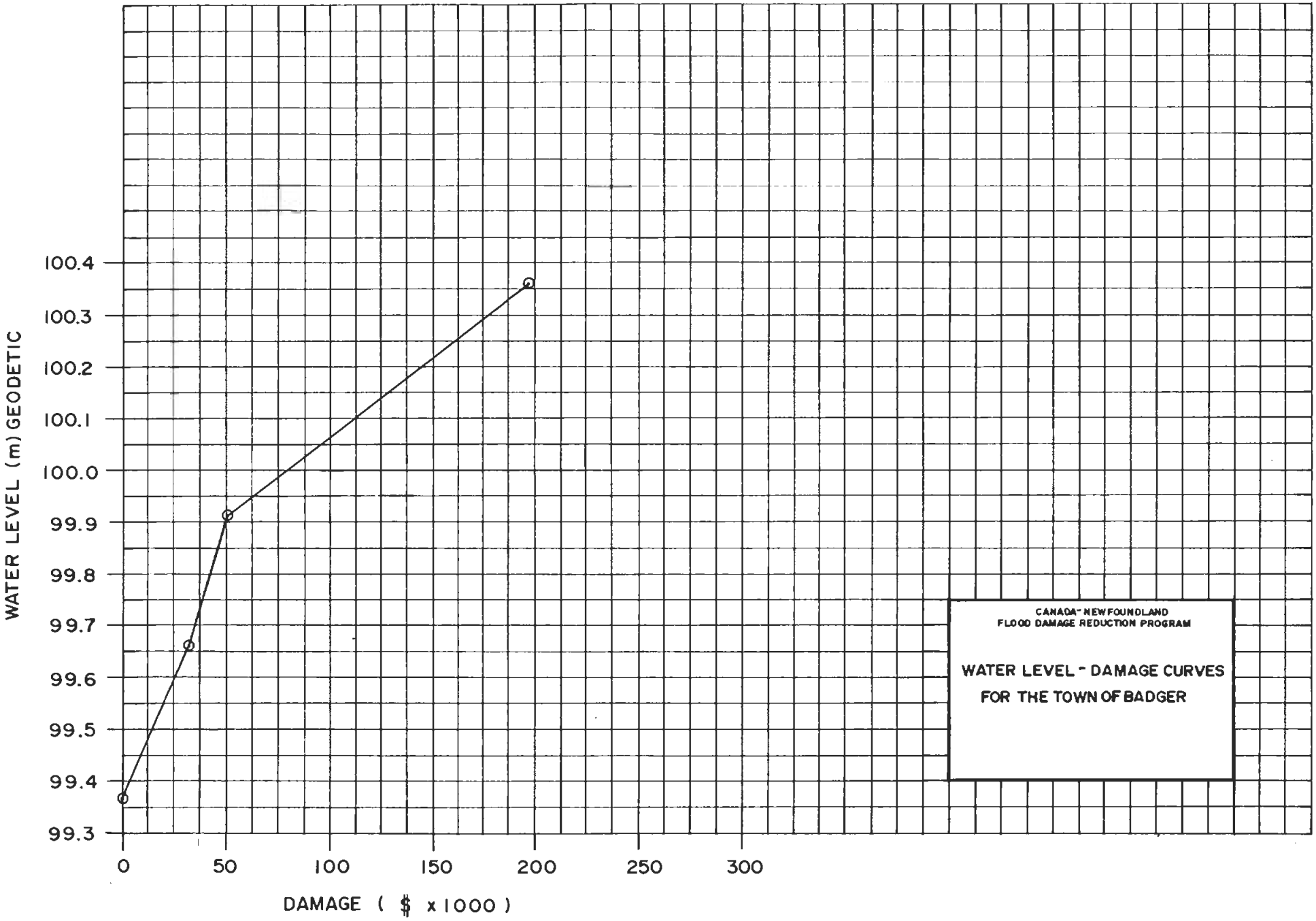

WATER LEVEL (m) GEODETIC
100.4
100.3
100.2
100.1
100.0
99.9
99.8
99.7
99.6
99.5
99.4
99.3
0
50
100
150
200
250
300
DAMAGE ($ x 1000)
CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
WATER LEVEL - DAMAGE CURVES
FOR THE TOWN OF BADGER

FIG. 8.1

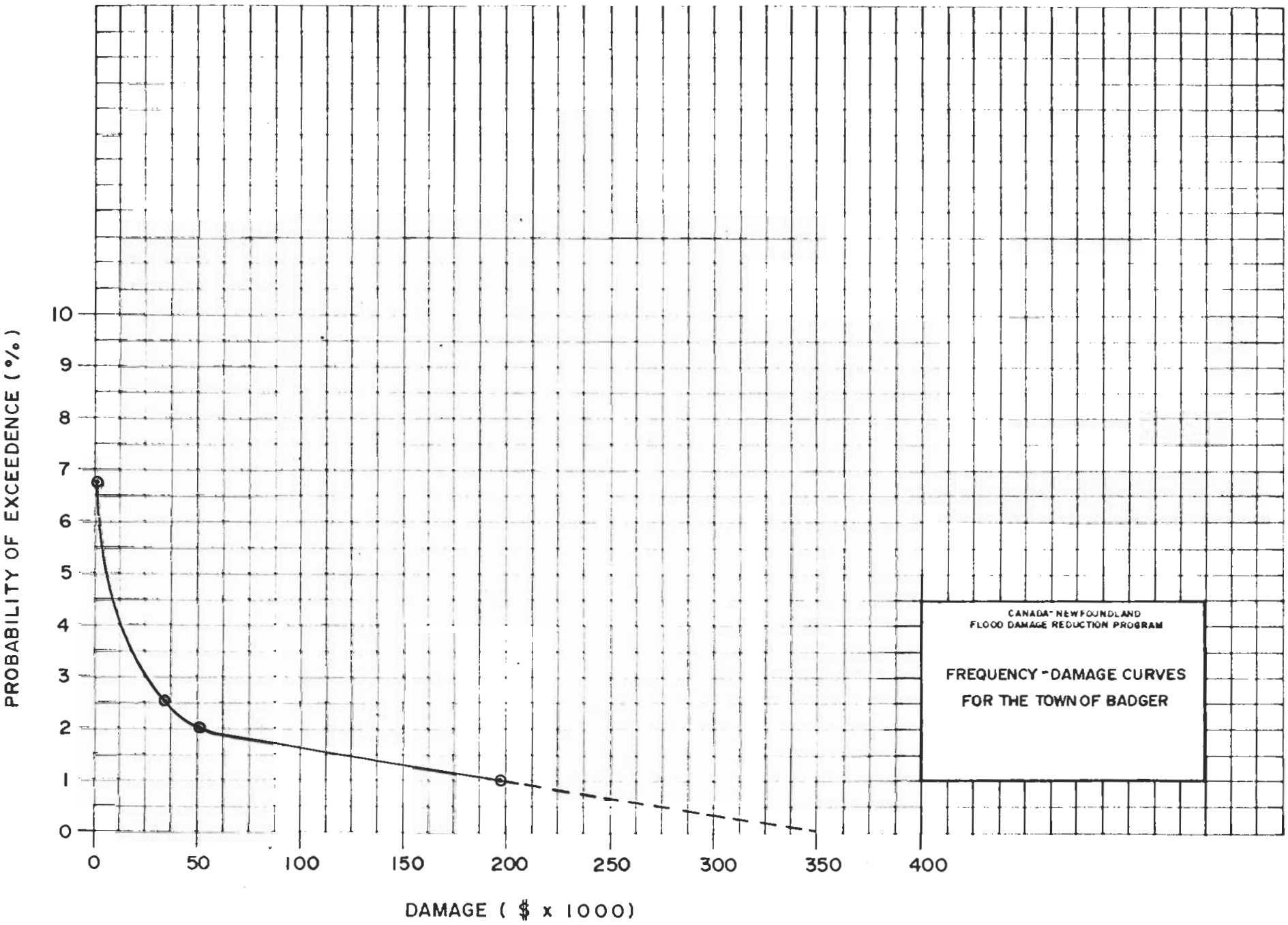

PROBABILITY OF EXCEEDENCE (%)
10
9
8
7
6
5
4
3
2
1
0
0
50
100
150
200
250
300
350
400
DAMAGE ($ x 1000)
CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
FREQUENCY-DAMAGE CURVES
FOR THE TOWN OF BADGER

FIG. 8.2

To compute the average annual damage, the damage corresponding to each water level is weighted by the probability of its occurrence. Damage caused by frequent events is weighted more heavily than damage caused by more rare events. The sum of the weighted damages represents the expected annual flood damage. This computation was performed using a computerized method with the HEC-AAD model (Corps of Engineers, 1977). The average annual flood damage for Badger is approximately $4,563.

8.5 Benefit Cost Approach

The reduction or elimination of the above-mentioned flooding cost is the benefit derived from expenditures to reduce flood damages. The costs of alternatives to achieve these benefits can be compared in terms of benefit/cost ratios, which if greater than unity (i.e. 1.00) indicate that the benefits derived from a project are greater than the costs associated with project implementation. As a benefit/cost ratio increases, a project becomes more economically feasible.

To allow for the accumulation of benefits through time (i.e. accumulated average annual reduction in flood damages), discount rates must be used to convert benefits into present values. These values may then be compared to the present costs of the damage reduction alternatives.

The interest rate, or real social discount rate, recommended by Environment Canada (1984) for benefit-cost analysis in evaluations of public projects is 10%.

A common time frame (50 years) was necessarily adopted in this monetary analysis to permit a meaningful comparison of the costs of construction projects and the flood damage reduction benefits that may accrue over a long period of time.

Using the average annual damage of $4,563 estimated in Section 8.4, a present worth of benefits of $45,240 is obtained. Using a range of discount rates of 5% and 15% for sensitivity yields present worth of benefits of $ 83,300 and $30,390 respectively.

The following chapter employs the 10% discount rate value and present worth of $45,240 in evaluating the comparative costs of various flood damage reduction options.

9.0 REMEDIAL MEASURES

The final step of this Phase I report calls for examination and screening of flood damage reduction alternatives which could be employed in the Badger area. Proven ways to reduce flood damages can be broadly categorized into either of two groups:

1. The first group contains structural and non-structural alternatives which recognize that ice problems can arise, and these alternatives mitigate against the effects of the resulting high water. Alternatives identified as possible solutions for reducing flood damages in this category include:

   a) floodplain zoning and acquisition
   b) flood warning
   c) flood proofing
   d) dyking

2. The second group contains alternatives which modify or reduce the flooding/ice accumulation problem which causes the high water levels. Alternatives for consideration in this category include those which modify the ice or river hydraulics:

   a) channelization
   b) ice retention structures (ice boom or ice dam)
   c) ice removal/blasting
   d) thermal/flow regulation

Each alternative has been examined in more detail in the following sections as to its particular application to the

Exploits River and the resultant reduction in flood damages in Badger. The hydrotechnical effectiveness and approximate cost of various alternatives in these groups are discussed and they are ranked on the basis of effectiveness, environmental effects and cost.

Certain of the alternatives are illustrated on the best available mapping of the town (1963). This mapping is quite out of date, however, and despite supplementary field measurements in 1984 it remains inadequate to allow for full development of some of the following alternatives (principally dyking).

One alternative not mentioned up to this point is the option of accepting flood damages as they occur and providing damage assistance as required. This alternative involves no remedial works and, due to its characteristics, is considered as the "status quo" alternative. It provides a practical base for comparison purposes considering the possibility of maintaining current conditions.

9.1 Screening of Flood Damage Reduction Alternatives

9.1.1 Floodplain Zoning and Acquisition

A total of 73 residential dwellings, institutional and commercial buildings currently fall within flood-prone areas of the Exploits River at Badger. Although most of the area of the town in the flood-prone zone is now developed, there still remain some flood-prone areas which might otherwise be considered as desirable river-side locations (e.g. Maple Street west of current developed areas; west side of Main Street between CNR and TCH bridges).

An alternative available to reduce the potential for future damage to these areas is to acquire the undeveloped lands and properties and included them in the designated floodplain.

A second alternative, zoning to prevent development in these areas, is also possible as part of the town's development strategy. Both of the above (acquisition or zoning) could effect protection in the undeveloped areas.

The final and recommended option for immediate consideration for the undeveloped flood-prone areas would involve zoning to control the design and type of structure located there in the future to insure no adverse effects to new structures or to upstream or downstream residents. As noted in Table 9.1 (which compares all of the alternatives discussed in this section), the comparative cost of this option is low but the flood damage reduction benefits for future development in these areas is high.

The option of overall acquisition of all existing properties in the flood hazard zone does not appear immediately feasible since the cost (estimated in excess of $1.5 million) and social disruption would be excessive (Table 9.1). It may be advantageous, however, to gradually acquire some of the most damage-prone structures as they come on the market or when they have sustained severe flood damages.

9.1.2 Flood Warning

The success of a flood warning system is based on the efficient collection and use of meteorological, streamflow and ice data to predict the timing and severity of potential flood

TABLE 9.1

COMPARISON OF FLOOD DAMAGE REDUCTION ALTERNATIVES FOR THE 1:100 YEAR PROTECTION LEVEL: BADGER***

Alternative Type	Total Cost* Estimate ($)	Environmental Effects	Social Effects	Benefit-Cost** Ratio	Comment
1. Status Quo	45,240	- some water pollution	- significant short and long term disruption	-	- undesirable
2. Zoning Future Development	low	- natural environment could be enhanced by riverside park	- positive for future development	high for future	- provides no relief benefit to current development
3. Property Acquisition	+1,500,000	- low	- very disruptive due to relocation	0.03	- politically difficult to implement
4. Flood warning monitoring	70,000	-	- positive but not wholly satisfactory	0.4-0.2	- provides incomplete protection but enhances the protection provided by other options
5. Flood Proofing (Elevation) Alone	+ .500,000	-	- temporary displacement	≤ 0.09	- indirect damages due to flooding are not eliminated
5(a)Flood Proofing (Berm and Elevation)	400,000	-	- temporary displacement	0.11	- indirect damages due to flooding not completely eliminated
6. Full Dyking	+350,000	- affects some streamside vegetation	- relocation of 3-4 homes	0.13	- some flood warning required
7. Dyking/Flood proofing	+250,000	- affects some streamside vegetation	- possible relocation of 1 home	0.18	- some flood warning required
8. Channelization	+600,000	- significant river & riverside affects	-	≤ 0.08	- costs may be significantly higher and success is not ensured
9. Ice Retention Dam	3,800,000	- significant river effects	-	0.01	- potential for power production but at greater cost
10. Ice Removal (Blasting with flood warning)	478,675	- some aquatic impact	- potentially significant safety hazard	0-0.09	- may not provide any protection

* Costs involving dykes and berms are approximate. Engineering, maintenance and environmental assessment costs are not included, and real rate of return of 10% is used.

** Total (direct plus indirect) flood damages have been used to compute the benefit-cost ratios.

*** All figures are preliminary and more refined values of costs and benefit-cost ratios are provided in Chapter 10 and Appendix 5.0.

conditions. Given warning, appropriate action may be taken to reduce flood damages through contingency plans involving elevation or removal of contents above expected flood levels, final closure of controlled outlets through dykes or final flood proofing measures.

All flood warning systems require close co-operation of all involved, and in this regard, the system of communication and close co-operation which was established for Badger following the 1977 flood should be maintained as a high priority. The on-going climatological monitoring by Newfoundland Environment should also be maintained as it has, and will, remain as a valuable source of data.

At present, flood forecasting for the Badger area is conducted by Newfoundland Environment using daily discharge records at Grand Falls. During the winter, these records show reductions in discharge at Grand Falls which cannot be explained by flow reductions at Exploits Dam. These "losses" represent channel storage made available by upstream ice production and water level increases caused by the presence of the ice cover. When the losses become a large portion of the streamflow and/or extend over a long period, a team is sent into the field to evaluate the seriousness of the problem and the potential for flooding (e.g. 1980).

Two flood forecasting components are recommended for addition to the present systems. The first involves use of ice progression modelling developed for this study (or similar modelling). The current model provides good estimates of the ice front location on the Exploits River and can be adjusted to events of a particular year on the basis of climate and

discharge monitoring conducted by Newfoundland Environment. Five-day forecasts offered by the Atmospheric Environment Service of Environment Canada could be input to the model on a regular basis and used to forecast the significance of the ice accumulation at Badger using Figure 7.15. If the forecast combined with Newfoundland Department of Environment observations of flow reductions at Grand Falls suggests a flood threat, mobilization could commence to minimize potential flood damages.

The second component to this annual ice forecasting - and one which is strongly recommended for future years - is a program of ice monitoring similar to that conducted in the Badger area during this past winter. For the coming year, at least, river ice conditions should be surveyed from formation through to partial erosion of the cover at several stations. An important part of this program would be monitoring of ice levels which can now be rapidly determined from the benchmarks established by our survey team in the 1984 survey. This monitoring of levels would enhance the forecasts made by the model and the flow observations; would provide more information on blockage sites, and, would provide confirmation of developing problems before the ice cover reaches the town.

In subsequent years, the model may be used on its own or better yet replaced by observations from regular field reconnaisance in the winter. As the ultimate objective of the field reconnaisance would be to measure levels in a river reach which is difficult to access, it may be desirable to establish a permanent monitoring site in the area. Equipment may be established at the site to provide a record of water level readings which can be read by a telephone call to the monitoring station rather than by a trip to the site. The

advantage of the former is that levels could be remotely monitored by the minute, day and night; whereas a site visit to obtain a single reading could take over half a day - which could be a critical time delay in some flood years.

The cost of a remote forecasting option employing level sensors and telephone link are presented in Table 9.1. Although desirable, a flood warning system on its own would not totally eliminate flood damages at Badger. Many actions can be taken with a warning to reduce the effects of flooding but some of the contents of some buildings and the structures themselves would still be subject to flooding.

In combination with flood proofing, dyking or blasting, however, flood warning provides important lead time to: mobilize work crews; close and seal structures which are floodproofed; close drainage openings in dykes; set up drainage pumps; or, begin blasting operations. These aspects are discussed in the following sections.

9.1.3 Flood Proofing

Flood proofing encompasses a wide variety of adjustments, additions, and alterations to structures to their immediate environment which attempt to reduce or eliminate the potential for damages that can result from flood waters. These measures may include:

- installation of permanent or temporary closures at openings in structures

- raising structures on fill, columns or piers

- construction of floodwalls or low berms around structures.

Permanent closure, as its name implies, involves permanently closing and sealing all possible openings in a structure through which flood waters could enter. This requires, for example, sealing basements and basement windows and usually involves strengthening of walls and basement slabs. It also becomes difficult to flood proof by closure at locations where the flood waters are projected to be deep, because this could involve permanent closure of outside doors to residences. Hence, flood proofing by permanent closure is often limited to large institutional structures such as Badger Arena, or structures on the outer fringe of flood prone area where flood depths are less than about 0.3 m.

The second approach, elevation of building to levels above flood levels is used in areas where permanent closure is difficult or impossible. A number of homes in Badger have already included this approch in their design or may have been modified in recent years. As with permanent closure, no human intervention or flood warning is required with elevation to make the flood proofing effective.

Some homes in Badger would require only minimal elevation changes while others would have to be raised by over one metre. Both cases involve initial costs related to raising the structure with the costs increasing with the amount of fill or height of foundations required to support the structure.

The flood hazard zone in Badger encompasses 73 buildings. Although the cost of flood proofing for individual structures varies widely with the building and its location, over $0.5 million would be required to effect the structural changes if all of these buildings were flood proofed. Related costs associated with roadway flood proofing, for example, would increase this total.

Flood proofing also entails combinations of closure and/or elevation of certain structures, with berming around groups of other structures. The group of structures in the Maple Street area are a good example of a development which could be protected by a low berm. With this alternative, those 58 flood-prone structures in the main portion of the town and along the Main Street and the TCH could be floodproofed by elevation. Figure 9.1 shows the general location of this option on the map of the town, and the option is costed in Table 9.1. The cost estimate is based on relatively impervious native soils acting as a foundation for the berm.

Although the structures are protected by flood proofing, there will still be certain:

- residential damage due to the cost of road clearing and cleaning of private properties and the sewer system

- indirect damage due to loss of business, disruption of communication

- municipal involvement to ensure proper stormwater drainage is maintained at local drainage courses

- need for flood warning to ensure closure and drainage considerations are acted upon in time.

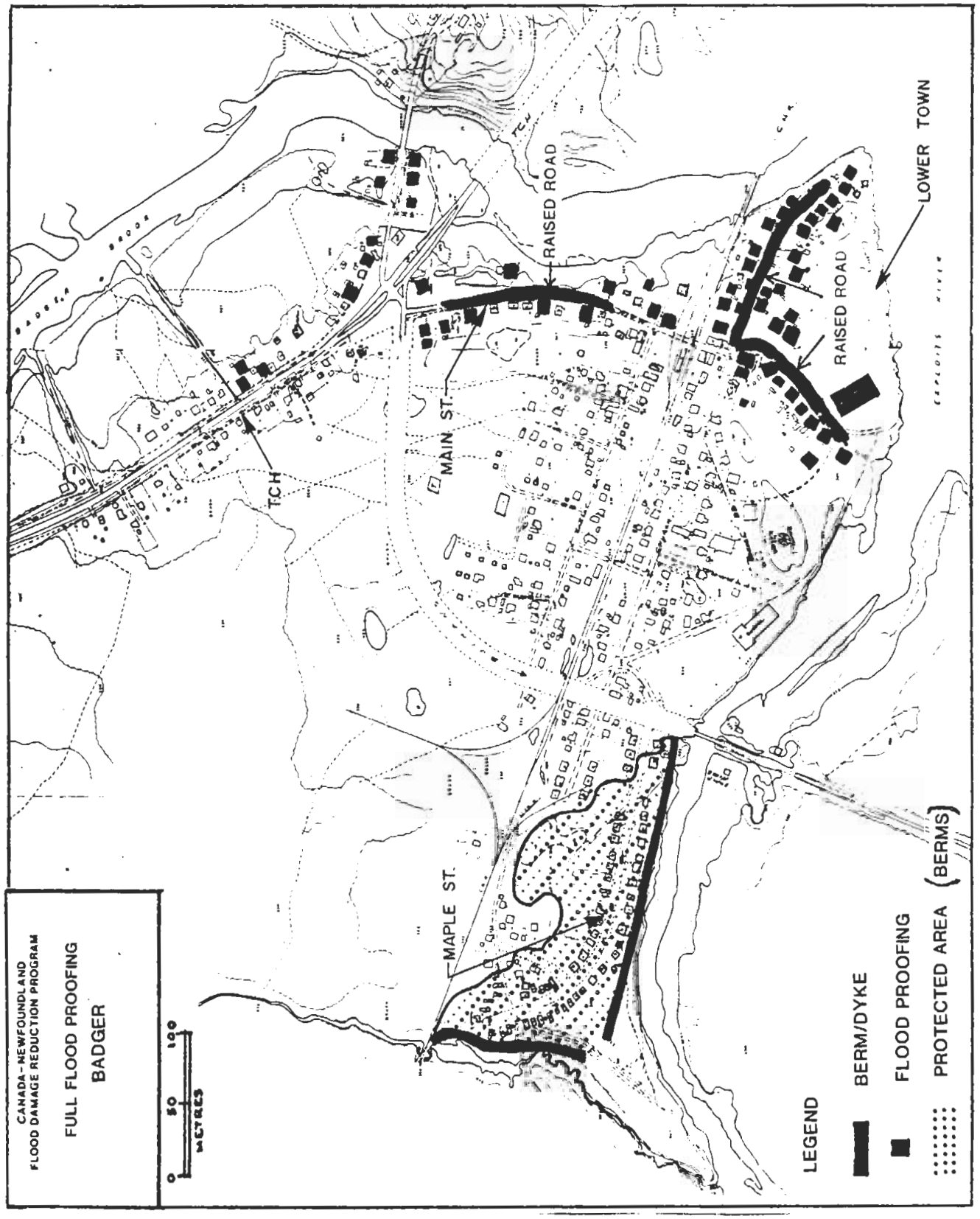

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
FULL FLOOD PROOFING
BADGER
0
50
100
METRES
MAPLE ST.
MAIN ST.
T.C.H.
RAISED ROAD
RAISED ROAD
LOWER TOWN
LEGEND
BERM/DYKE
FLOOD PROOFING
PROTECTED AREA (BERMS)

FIGURE 9.1

9.1.4 Dyking

Dykes provide protection against flooding by confining flood waters to the river channel, and at Badger would be an effective remedial measure on their own. Flooding to the 1:100 year level at the town can be prevented by a series of very low dykes/berms which would not alter the flow of ice or flood water past the town.

Full protection to the town would entail construction of about 2,500 metres of dyke as shown in Figure 9.2. As part of this option, it would be necessary to relocate 4 structures and several garages, elevate a portion of Old Badger Road just east of the TCH, and evaluate the imperviousness of the native soils.

The following points must be noted in regard to dyke construction at Badger:

- the view of the river at some riverside properties will be altered
- some riverside vegetation will be disturbed
- municipal involvement will be required to ensure proper storm drainage and closure of reverse flow/flap gates at local drainage courses
- flood warning would be necessary to ensure drainage considerations are acted upon in time.

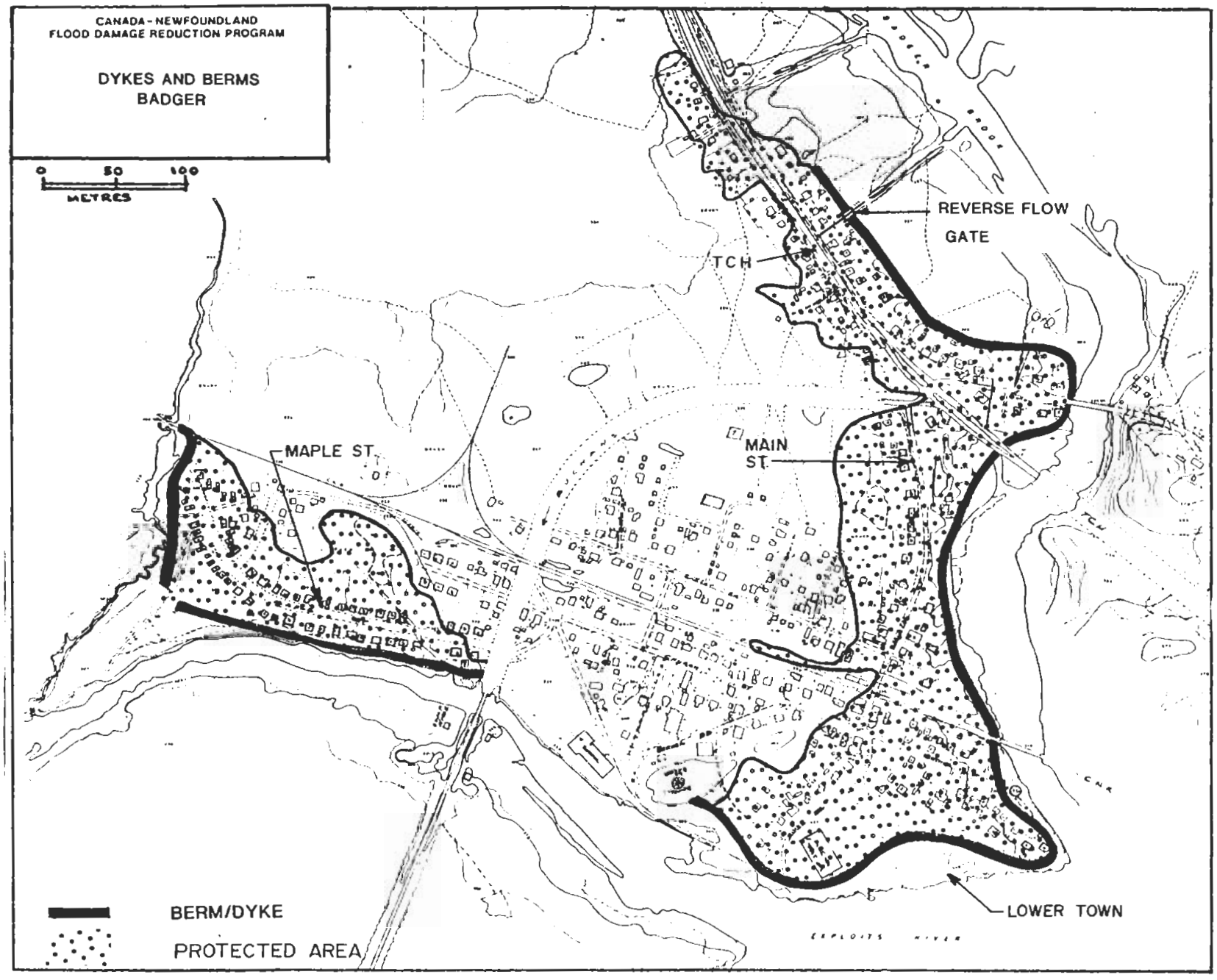

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
DYKES AND BERMS
BADGER
0 50 100
METRES
REVERSE FLOW
GATE
TCH
MAPLE ST.
MAIN
ST.
LOWER TOWN
BERM/DYKE
PROTECTED AREA

FIGURE 9.2

The cost and several points on this option are summarized in Table 9.1. Relatively impervious native soils have been considered for this cost comparison.

9.1.5 Dyking with Floodproofing

The dyking option is complicated near the Old Badger Bridge. In that area, a considerable length of dyke and reconstruction of the road could be replaced by flood proofing 9 structures (Figure 9.3).

As part of this option only one structure remains too close to the river bank to enable completion of the project and relocation or construction of the flood wall would be necessary. The constraints relating to effects on aesthetics, municipal involvement and flood warning (Section 9.1.4) still apply, but as shown in Table 9.1, a considerable cost saving can be realized.

In terms of those methods which mitigate against the effects of high water levels at Badger, this option which combines dyking and flood proofing appears to be the optimum choice.

9.1.6 Channelization

Channelization is commonly used at open water flood locations to increase the hydraulic capacity of a river reach and lower water levels. Typically, a rock ledge or other debris which regulates upstream levels is removed or a portion of the channel is deepened and widened through the flood prone area.

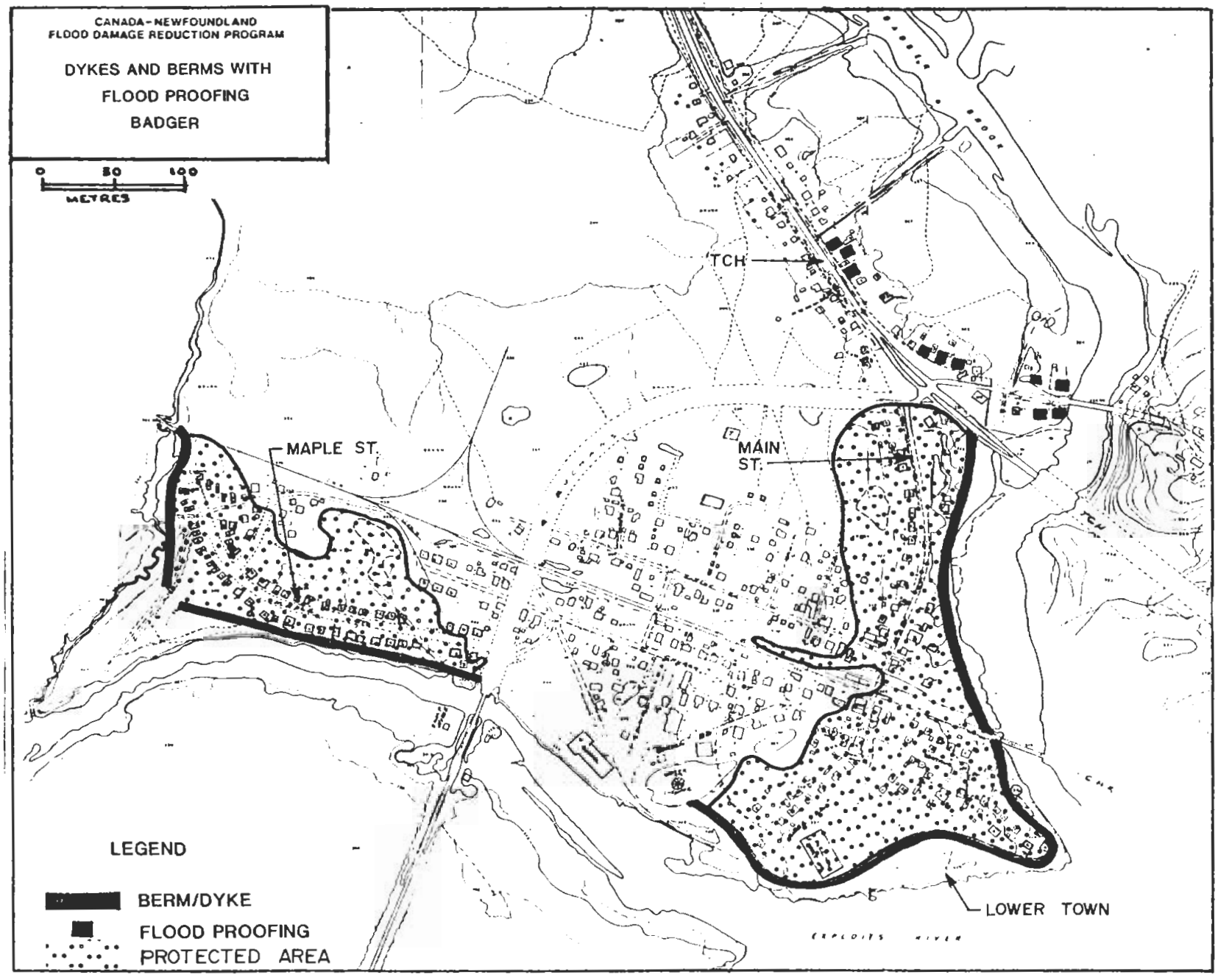

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
DYKES AND BERMS WITH
FLOOD PROOFING
BADGER
0 50 100
METRES
TCH
MAPLE ST.
MAIN ST.
LOWER TOWN
LEGEND
BERM/DYKE
FLOOD PROOFING
PROTECTED AREA

FIGURE 9.3

When ice is the causitive factor in the flooding, channelization also promotes the passage of ice by removing obstructions (such as the shallows at Badger Rough Waters) which may impede its progress. It may also be undertaken to assist the formation of a stable cover or reduce the level in an ice field.

Downstream of the Badger area, there are several shallow reaches where rock ledges may be providing a point of contact during shoves in the ice field. Although it is reported that the shallows in the Badger Rough Waters have been the location of recent blockages, there is also evidence from ice scar data, historical observations and the ice progression model that blockage sites which have caused flooding at Badger may extend to the Big Bend (2.5 km downstream of Badger Rough Waters) or 1.5 km further downstream to the shallows at Section 22835. As a result, channelization in one area may not constitute a solution to the ice problem. In terms of overall protection, channelization is consequently required: in the shallows at the Badger Rough Waters (7 ledges in a reach which is 600 metres long and 300 metres wide); at the shallows at the Big Bend (5 ledges over a reach which is 1,000 metres long and 200 metres wide); and about 1.5 km further downstream where there are another 7 ledges.

The cost of channelization in the first two areas has been estimated in Table 9.1 for cost-comparison purposes. The final cost is dependent on geotechnical conditions which are largely unknown and river conditions which could significantly effect the rate and approach to the work.

In addition to being extremely expensive, the work will result in:

- significant disruption to the aquatic environment at the site and further downstream

- shoreline disruption resulting from disposal operations

9.1.7 Ice Retention

The general objective of ice retention works is to encourage formation of an ice accumulation in an area which is not prone to flood damage. The most appropriate site in the Badger area is upstream of the town where ice retention would speed the formation of an ice cover up to Twelve Mile Falls; reduce the volume of frazil slush generated in that reach and passing downstream; reduce the volume of slush forming the ice cover in the Badger area; and subsequently reduce the river ice level at Badger (Figure 7.15). Engineering options to produce a stable ice cover in this reach include: weirs and booms or ice retention dams.

Both options could provide a relatively quiescent pool leading to the formation of an ice cover and a means to hold the cover in place when the upstream ice field is initially forming. The same approach was used to eliminate frazil problems at Grand Falls through construction of Goodyear's Dam and the ice boom at Rushy Pond.

The river reach above the study area is too steep to attempt to regulate in its entirety since several retention dams would be required. A single structure, however, would be

adequate to provide a pool and initiate the cover, and the river narrows at Gull Rocks presents a good site. The required structure would span about 150 metres across the river; be approximately 4 metres high and have a boom upstream of the weir to hold the ice in place. Since it is in such close proximity to the town, a secure concrete structure is considered appropriate and the cost is given in Table 9.1.

A similar structure was previously evaluated at this site, (ShawMont, 1977) for possible multi-use for power generation (2-3 MW). Although additional costs in the range of $2.5 million would be required for the generation facilities, the potential income from power production would help to retire part of the cost of the structure.

9.1.8 Ice Removal: Blasting

Removal of ice by explosives is undertaken at blockage sites in some rivers during spring breakup, or as part of preemptive river ice clearing operations prior to breakup. In the latter situation, trenching machines or ice cutters are sometimes used to divide the ice cover into smsll sections before explosives free them to move downstream. This free access of ice from a blockage site into a downstream reach is essential, for without it the ice which is loosened by blasting will not leave the problem area. At some locations, a downstream reach of open water forms naturally, but at other locations, it must be opened by other methods (ice breakers, tugs, hovercraft, additional blasting, etc.).

The situation at Badger is different than the usual case involving the use of explosives. The blockage takes place at freezeup not breakup and is composed of a thick mass of frazil slush instead of solid floes. The blockage site is not as clearly defined as is often the case at breakup sites, and there may be more than one blockage site below Badger which has caused past floods. Of considerable importance is that there are no open water areas below Badger (during the initial days of the ice cover) which can be used to convey the ice out of the area if it is dislodged by blasting. In summary, the principal constraints on blasting are:

i) no open water area downstream during initial freezeup

ii) considerable uncertainty as to the location of the ice blockage(s)

iii) an ice cover which is thick and porous and resistant to destruction

iv) an ice cover which does not provide a secure platform for ice removal operations

Each of these constraints are examined below as to their significance on blasting and their effect on the cost of blasting operations.

During freezeup in ice jam years, it is possible that the ice cover near Badger Rough Waters will be similar but more obstructive than that shown in Figures 4.2, 4.5 and 4.7. At freezeup, the cover spans the full river width and extends downstream past Badger Chute before any open water leads are

encountered. Given that there are no open water leads to convey ice from blockage sites and that it will be impossible to blast an opening along the full length of river from Badger Chute to Badger, some other means of conveying ice from blockage areas must be found.

Figure 4.5 shows that there are thinner sections of ice (near auger hole number 2) which carry most of the river flow and which eventually open to form the lead shown in Figure 4.6. If such thin sections are present in ice jam years (and it appears from Figure 4-9 that they are) then the only hope for ice clearing operations is to blast along the route of these thin sections to artifically develop an open reach. In this work, flow velocities beneath the cover must be relied upon at some point (the starting point of blasting) to safely carry the broken ice beneath the cover and downstream.

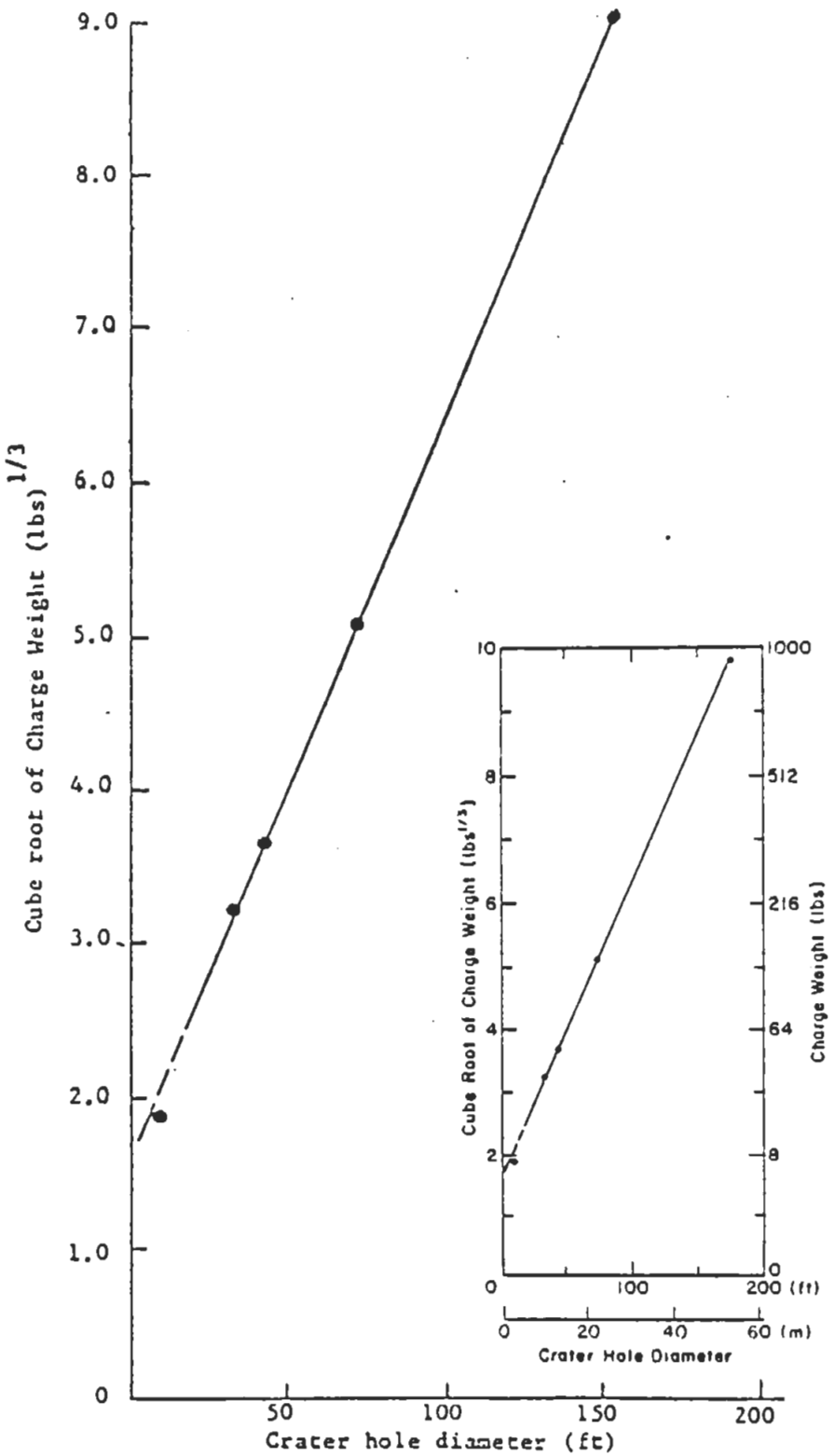
Flow velocities under the ice cover were examined to determine if ice would carry safely beneath the cover along the route of these subsurface channels, or if the ice would block these channels or simply remain in place after blasting. This assessment indicates that the ice would remain at the blasting site unless blasting began below Badger Rough Waters and progressed upstream. Moreover, the range of velocities which must be exceeded to avoid a blockage in these subsurface channels is 0.6 m/s to 0.9 m/s, and 1.3 m/s is considered a safe upper limit. Velocities downstream of Badger Rough Waters (0.8 to 1.2 m/s) are in the upper end of this critical range but lie below the safe upper limit. Hence it cannot be guaranteed that ice from blasting will move freely downstream, and it is quite possible that the broken cover from the blasting site could form another blockage.

The thickness and porosity of the ice cover are also significant constraints. For success in any blasting operation, the charges must be placed beneath the ice to blow a crater through it. Figure 9.4 outlines the charge weight versus the crater hole diameter for solid ice covers. The slush cover at Badger will require more explosives to achieve the same effect.

More important is that the ice surface is reported to be weak during flood conditions and is a poor (or impossible) working surface for drilling and placing charges. Thus surface access is likely to be slow and hazardous and cannot be conducted at the required rate of speed without expensive helicopter support.

The speed of operations is critical and would have to begin as soon as the potential for possible ice problems is recognized. In 1983 there were three days from the time when the ice situation appeared problematic and the start of flooding (Appendix 1.0). At best, one day is required for mobilization (assuming materials are stored near Badger), leaving just two days to complete the blasting. If the blockage point can be identified and if it is less than 900 m in length, then a thirteen-man blasting crew would have time.

If the blockage covers a longer reach of river or cannot be located, then there would not be sufficient time to prevent flooding.



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"CHARGE WEIGHT VERSUS CRATER HOLE DIAMETER"

FIGURE 9.4

Overall, blasting operations for flood damage reduction at Badger is fraught with problems. Primarily it cannot be guaranteed that broken ice from a blasting site will not jam again downstream. In addition, there is little time allowance for mobilization, finding the blockage site(s), and conducting the operation. The ice surface at Badger is also an unsafe platform for this work which compounds the hazard associated with explosives handling.

Despite these clear limitations, the approximate cost of blasting operations has been prepared for cost comparison purposes in Table 9.1. Commercial rates have been used for equipment, personnel, and disbursements considering:

- a 13-man blasting team with support from two helicopters

- blasting operations during 50% of all years (considers training, preemptive blasting, false alarms)

- inclusion of flood warning to provide maximum lead time for mobilization.

The benefit-cost ratio in Table 9.1 is shown to range from zero to 0.09. The zero indicated that the problems with blasting are so significant that there may never be any success or benefits derived. The higher value considers the remote possibility that all of the above-described problems can be overcome. Until tested and proven effective in a situation similar to Badger, however, the benefit-cost ratio must be taken as zero.

9.1.9 Thermal/Flow Regulation: Exploits Dam

The operations of Exploits Dam during the early winter months calls for a regular gradual release of about 150 m^3/sec. In most years, the reservoir is not at a high level through the winter months and the rule curve for operations essentially "rations" the limited storage at Red Indian Lake by supplying just enough flow to meet the power production needs at Grand Falls Dam. For the most part, the discharge at the dam is from the surface layer of the lake.

One of the advantages of a large upstream lake or reservoir near a downstream site is that the relatively warm water below the ice cover can be considered a source of heat. On the Exploits River, however, the dam is about 50 km above the town and the reach between the dam and the town is shallow and turbulent. Any benefit which could be derived by the use of submerged gates or by a change in the reservoir rule to increase the discharge temperature is marginal and would be lost by surface heat exchange between the dam site and Badger. In the flooding periods at Badger, high wind and cold temperatures lead to such rapid heat loss, cooling and ice production that any change in temperature would not be felt much further than 10-20 km below the dam. Hence no change in the withdrawal level or rule curve is recommended.

Meteorological conditions and volume of ice production is the cause of ice problems at Badger rather than changes in the discharge. River discharge during past flood periods has been relatively constant, which in retrospect was a wise decision. Any increases in discharge could well have aggravated flooding at Badger or caused an ice jam and flooding in

the downstream reaches (e.g. Rushy Pond). In addition, Red Indian Lake cannot be relied upon to have sufficient storage to supply large flow increases. Alternatively, decreases in discharge may have aggravated grounding and reduced the rate at which the ice cover eroded channels in the cover. Until such time as future observations pin down the exact location of the blockage or the ice cover configuration at the time of freeze-up through Badger, no change in the rate of discharge is recommended during flood or non-flood years.

9.2 Recommendations for Phase II

Based upon the results of Phase I of this study, as summarized in Table 9.1, it appears that none of the options considered would control flooding to the 1:100 year design level in an economically justifiable manner. Since economic factors are not necessarily the only considerations in implementing flood control measures, it appears that the following alternatives are worthy of further study in Phase II:

i) Dyking combined with flood proofing by elevation and berms will control flooding to the 1:100 year design level and beyond. Further investigation using recent topographic mapping is required, however, to refine the cost of this option.

ii) Dyking on its own will also control the flooding to the 1:100 year design level at a cost which is similar to that of the dyking/flood proofing combination. Its cost is only higher than the previous option because of the difficulty associated with possible relocation of 3 to 4 houses and/or the construction cost of flood walls to include those structures in the dyking plan. Updated mapping would assist in this appraisal as well.

iii) Establishing a flood forecasting system in the field and the associated development of an ice monitoring plan for the coming winter are important for the success of dyking, berms, and flood proofing. Additional discussions relating to costing, siting, and equipment selection for a permanent site are suggested for Phase II.

10.0 PHASE 2: BADGER FLOOD DAMAGE REDUCTION ALTERNATIVES

10.1 Introduction

The Stage 1 recommendations were reviewed by the Technical Committee of the Canada-Newfoundland Flood Damage Reduction Program in November and December 1984. Following review and discussion with the Consultant, the Technical Committee recommended that the three flood damage reduction options suggested at the conclusion of Phase 1 be developed in more detail during Phase 2. These options were:

i) dyking

ii) dyking with flood proofing

iii) flood forecasting

It was noted in the Terms of Reference that the object of this second stage was to develop these options in sufficient detail to enable selection of a final course of action. Detailed designs and drafting of contingency plans or regulations were not required beyond that sufficient to permit budgetting of time and funds to implement these measures.

In addition, the final segment of this stage required that sensitivity analyses be conducted to determine the sensitivity of flood level estimates and cost estimates to variations in streamflow, river bed roughness and other parameters evaluated and selected during the course of the study.

The following sections describe the further development of the above-mentioned flood damage reduction options. Final

comparisons, recommendations and sensitivity analysis are presented in Section 10.6 and the Technical Appendices (Vol. 2).

10.2 Badger Flood Prone Areas

As shown in the Plate 1, flood waters can now enter the town at four locations, which will be referred to as the Maple Street section, the lower town section, the Main Street section and the TCH section.

Maple Street

The flood prone area along Maple Street extends from the Buchans Road bridge to the CNR culvert along Little Red Indian Brook. The lowest portion of this section is about 75 m west of the bridge and flood waters entering this area fill a broad, low basin lying between Maple Street and the CNR line to the north. Almost all of the homes along this bank are located above the 99.5 m contour and many are above the 100 m contour.

The 1:20 year flood level affects only one home in this area, although a number of garages and sheds along Little Red Indian Brook would be partially flooded.

The 1:100 year flood would affect almost every property along the brook and place about 50 homes in the flood prone area. Flood waters at the low spot on Maple Street (near the bridge) would be almost one metre deep.

Lower Town

This area extends from the water tower hill along the banks of the Exploits River to the CNR bridge over Badger Brook. Most of this area is below elevation 99.5 m with the lowest section being at the foot of Beothuck Street. Flooding in this area would begin at this low point and rapidly spread to River Road and beyond.

The 1:20 year flood level would surround about 20 homes and public buildings in this area and cause flood damage at four of them. The 1:100 year flood would damage basements and the first floor of 38 homes and public buildings.

Main Street

This section along Badger Brook runs from the CNR bridge to the new Trans-Canada Highway Bridge. The majority of buildings on this section along Main Street are located above the 99.5 m contour, but none are above the 100 m ground contour. Over 200 m of road along this reach is below 99.2 m which allows flood waters to spill over the street and into the low lying area just west of Main Street.

The 1:20 year flood will spill over Main Street and surround one home and one commercial structure. First floor flooding would take place at 2 structures.

The 1:100 year flood would surround 25 buildings; flooding the first floor of 10 and the basements of three.

Trans-Canada Highway (TCH)

This flood prone section extends from the new TCH bridge along Badger Brook to the northern limit of the Town. The majority of homes on the east side of the TCH are on the 99.5 m ground contour, and those on the west are mostly above the 100 m contour. Near the old TCH bridge, several homes are near the 99.0 m contour. High water levels in this area would first be detected at these homes, and then later behind most of the structures on the east side of the TCH. Homes along the west side of the TCH would be affected by back flows up the drainage culverts crossing the highway.

The 1:20 year flood will reach the TCH through drainage ditches which extend to Badger Brook. Near the old TCH bridge, 3 homes would be surrounded, but only 1 basement and 1 first floor would be flooded.

The 1:100 year flood would surround 41 structures, and extend to the west side of the TCH (through drainage ditches and across the TCH at the junction of the old and new highways. Only 2 basements would be flooded, but 9 buildings would incur first floor flooding.

Table 10.1 summarizes the extent of flooding in each flood prone area in Badger. The extent of flooding in the lower town area is significantly greater than other areas at both the 1:20 and 1:100 year levels. At the 1:100 year level, flood damages at Maple Street, Main Street and the TCH are very similar, but their combined total is less than than expected for the lower town.

TABLE 10.1

BADGER FLOOD PRONE STRUCTURES

Maple Street Building Number	River Road Building Number	Beothuk St. Building Number		Main St. Building Number	TCH Building Number
45	Area	32	14	6	1
49	1	U.C. Hall	15	8	2
53	2	Town Hall	16	9	3
57	3	4	17	10	9
65	6	5	18	13	11
73	7	6	19	15	12
79	8	7	21	18	14
81	9	8	24	18(a)	15
83	10	8A	25	19	16
85		9	26	21	17
60		12	27	23	18
58		13	28	24	
44		STP	29	25	
		#*	31		
13	8		28	13	11

* house number uncertain (building just SE of Town Hall)

A flood damage analysis was also undertaken for each area identified above. The average annual flood damage for Maple Street and Main Street is about $633 (1984$) each. For the TCH, it is $668 and for the lower town it is about $ 2,629. The present worth of the flood damages of each area is presented in Table 10.2 using discount rates of 5%, 10% and 15% and a project life of 50 years.

10.3 Dyking

10.3.1 Soils

At this second stage, a detailed review of all readily available soil information was conducted as part of the assessment of the dyking option. Whereas Stage 1 data had suggested the presence of silty clay within the overburden, more detailed information indicates a predominence of dense sand, gravel and boulders (Geocon, 1964; Warnock Hersey, 1968). Aside from this qualitative information, however, no factual data is provided in these reports on the sand grading or its permeability.

Flooding in February 1983, lasted for about six days; and although it is possible to provide an estimate of seepage through the native material for such an event, the problem with a sandy base for a dyke goes beyond just inflow seepage considerations. Sandy deposits are rarely uniform and the risk of concentrated seepage (piping) leading to erosion and rapid failure of a dyke is ever present with this material. Such an event would pose a clear safety hazard as well as cause significant flood damage.

At present, the uniformity of the overburden is not known and field investigations would be required at the site to enable

TABLE 10.2

FLOOD DAMAGE SUMMARY FOR THE FOUR
FLOOD PRONE AREAS IN THE TOWN OF BADGER

Location	Average Annual Flood Damage ($ 1984)	Discount Rate (%)	Present Worth ($)
Maple Street	633	5	11,564
		10	6,280
		15	4,219
Lower Town	2,629	5	47,990
		10	26,064
		15	17,509
Main Street	633	5	11,564
		10	6,280
		15	4,219
TCH	668	5	12,182
		10	6,616
		15	4,443
TOTAL	4,563		

an assessment of the piping potential. The program to complete this assessment would likely entail two stages involving a large number of boreholes at each stage. In the first stage, about 40 holes would be required to gain an impression of the sand stratum variability. A second stage involving more holes would be required if the material is found variable. The results of even this work may also be inconclusive.

In view of the potential consequences of dyke failure as a result of piping, a positive approach which designs against this possibility is considered appropriate at this phase in the project. The approach may be termed "active" or "passive."

"Active" approaches are those which use drainage methods to control and capture seepage as it enters. Examples are toe drains and rows of relief wells, which when combined with a network of pumps and internal drainage channels, collect and pass the seepage inflow back into the river. Special filter media and design considerations are generally required with this approach. The potential for power outages, pump failure or blockage would be a concern and sufficient safeguards (eg. standby pumping) would be necessary to provide a high level of protection against all potential seepage hazards.

A more positive design against piping would be through provision of a "passive" system designed to keep the water out. Methods commonly used include:

- cutoff trenches
- thin sloping membranes
- grout curtains

- sheet pile walls
- thin cutoff walls
- impermeable upstream walls

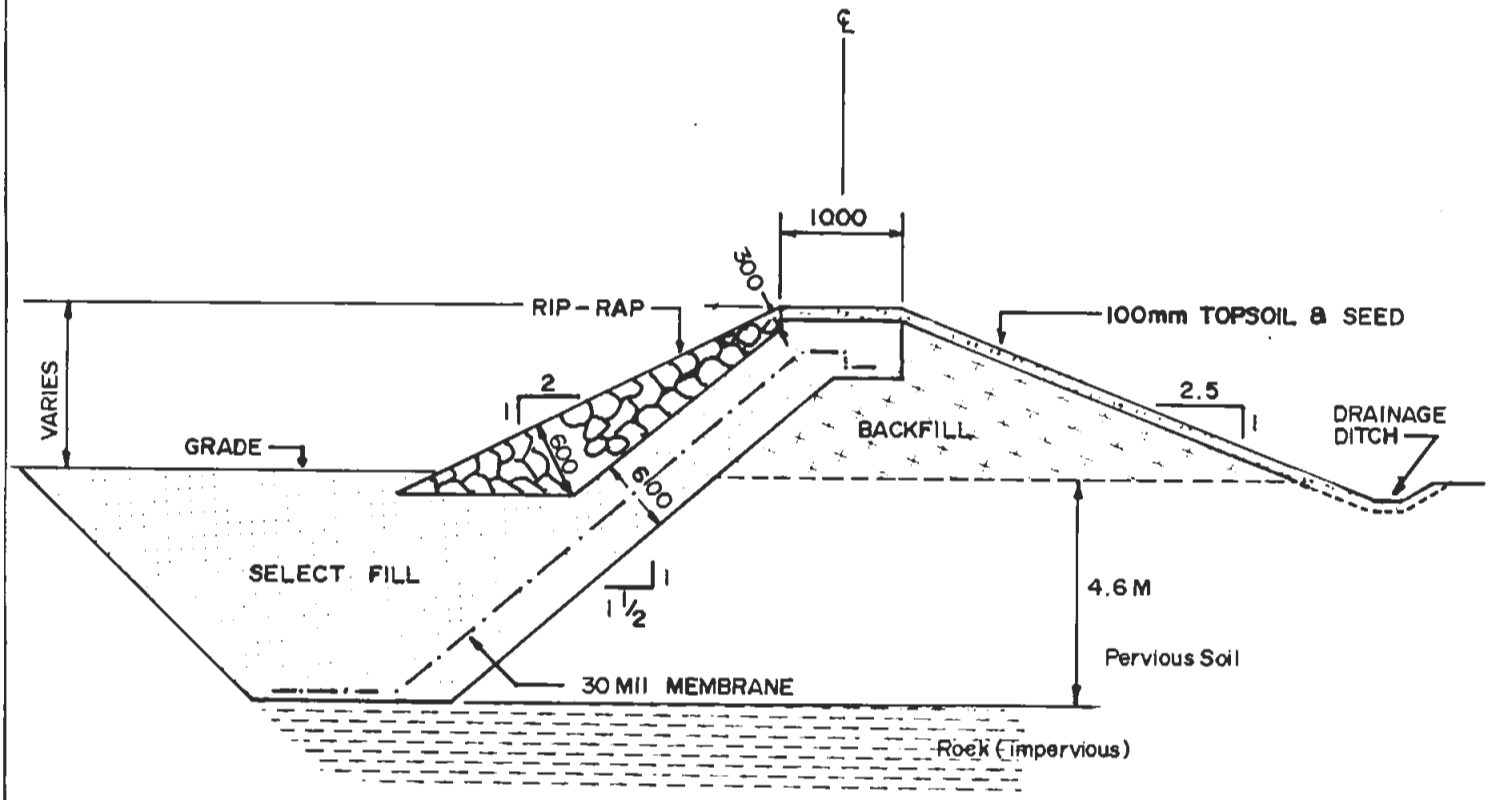
The presence of boulders in the overburden and the desire for a secure system limits the alternatives to:

- cutoff trenches
- thin sloping membranes

The cutoff trench offers a means for completely controlling seepage if the cutoff penetrates the pervious strata to bedrock. Throughout most of Badger the impervious material (bedrock) appears to lie about 5 m below the surface. Once a trench is excavated, the cutoff is formed by filling the trench with a compacted barrier of impervious soil (such as a silty clay) which is also used for the dyke itself.

A thin, highly impervious sloping membrane (eg. 30-40 mil PVC) may also be employed on the upstream/river side of the dyke when ample supplies of impermeable soils are not available. Such membranes are often used in tailings disposal dykes and an option employing this approach is shown in Figure 10.1.

Both of the "passive" systems outlined above will require: significant excavation, dewatering provisions, placement of an impervious barrier, rip rap facing along the Exploits River portions of the dyke, and provisions for collection and disposal of incidental seepage and storm/melt water runoff which may gather inside the dykes during a flood. The latter will pass through a set of gated culverts (flap gates) except during flood conditions on the Exploits River. In flood events, the gates will remain closed and temporary pumping



TYPICAL DYKE DETAIL

N.T.S.

CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

TYPICAL DYKE DETAIL
BADGER

FIG. 10.1

may be necessary. Figure 10.1 shows a typical dyke cross-section and Figures 10.2 shows details of a flap gate.

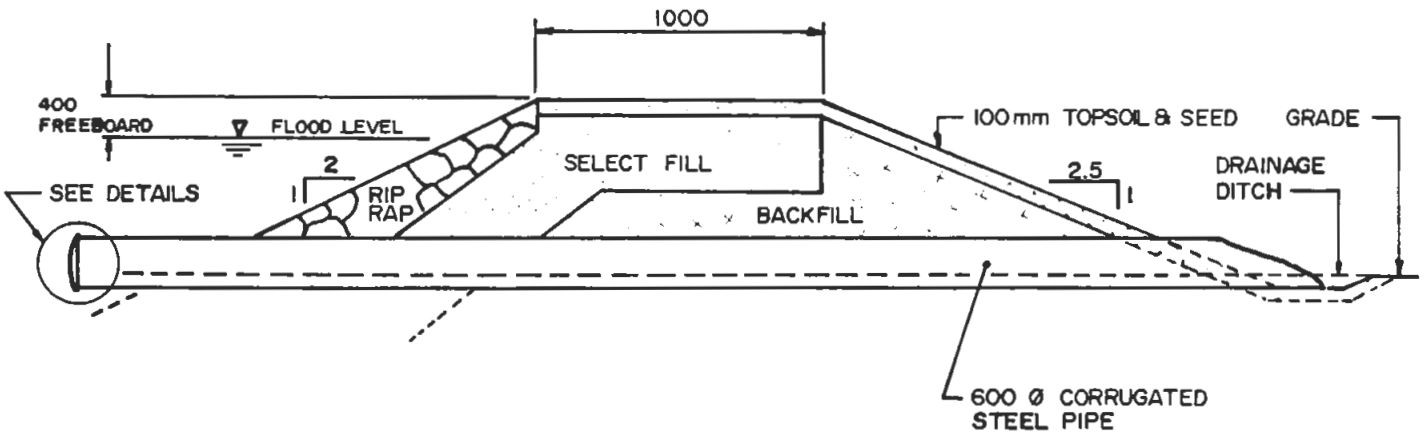
10.3.2 Dyking Arrangement

Dyking is an effective means of protecting a large number of flood prone structures. However (as indicated in Section 10.3.1), the soils in the Badger area are not impervious and the simple dykes would be undermined unless special construction precautions were undertaken to prevent the water from seeping under the dykes. There are not large quantities of impervious soil in the Badger area (Dept. of Highways, 1985) and the impervious sloping membrane outlined in Section 10.3.1 and shown in Figure 10.1 is the only practical construction technique for use with the dyking option. This procedure is relatively expensive and has made the dyking option substantially more costly in comparison with the other flood remedial works. The costs associated with the various dyking segments in the Town of Badger are described in this section and are based on the cost variables presented in Table 10.3.

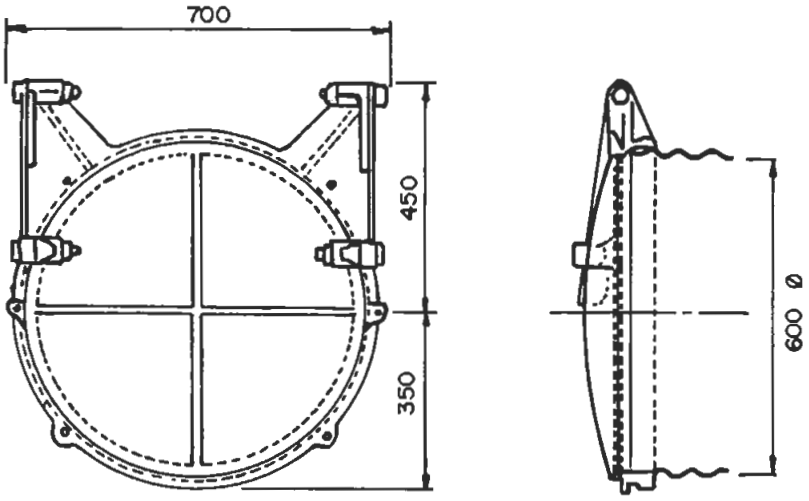
The dyking arrangement used to protect each flood prone area identified in Section 10.2 is presented below. Full dyking has been considered for all flood prone structures subject to flooding from both the 1:20 and 1:100 year floods.

Maple Street

To protect the Maple Street area from 1:100 year flood damages, a continuous dyke would extend from Buchans Road bridge to the CNR culvert across Little Red Indian Brook. The dyke would be located on the north bank of the Exploits



TYPICAL CULVERT DETAIL



FLAP GATE DETAILS N.T.S.

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CULVERT DETAILS
BADGER

FIG. 10.2

TABLE 10.3

DYKING COST VARIABLES

ACTIVITY	RATE FOR COSTING PURPOSES
- Clearing & Grubbing/Stripping	$ 2,200.00/ha
- Excavation/Disposal	5.25/m^3
- Riprap	61.21/m^3
- Culverts	100.00/m
- Flap Gates	690.00/ea.
- Portable Diesel Pumps for Emergency Flood Drainage	1,936.70/mo.
- Drainage Ditches on Inside of Dyke	6.00/m^3
- Imported Dyke Material (Local Sand/Till)	9.00/m^3
- 30-40 Mil PVC Liner Membrane	7.36/m^2
- Line Grade & Seed/Topsoil	1.75/m^2
- Concrete Wall (with piling)	26,110.00/L.S.
- Concrete Wall (with gate)	3,807.00/L.S.
- Sheet Piling	157.00/m^2

River and east bank of Little Red Indian Brook as indicated in Figure 10.3. The length of the dyke is approximately 650 m and the height varies from 0.8 m to 2.8 m. The 1:100 year flood level in this area is 100.44 m. Allowing a minimum 0.30 metres freeboard, the minimum top of dyke elevation is about 100.74 m. Additional details describing the development of this and other cost estimates are given in tables provided in Appendix 5.0. The construction of the dyking would involve the relocation of about 5 sheds/garages and the cost of the dyke is about $ 531,000.

The 1:20 year dyke is about 1.8 m high and extends about 120 m west from the Buchans Road bridge. The 1:20 year flood level in the Maple Street area is about 99.56 m. Allowing for 0.3 m freeboard, the minimum top of dyke elevation is 99.86 m. The extent of the 1:20 year dyke is presented in Figure 10.7 and the cost is about $ 61,000 (Appendix 5.0). For both the 1:20 and 1:100 year dykes, a flap gate is required at the low point just west of Buchans Road to drain off storm/melt water accumulated behind the dyke.

Lower Town

The proposed 1:100 year dyke for this area extends from the water tower hill along the banks of the Exploits River to the CNR bridge over Badger Brook. However, at the sewage treatment plant, it is not possible to build a dyke because of space constraints. Consequently a concrete flood wall is required to provide complete flood protection. The concrete flood wall with sheet pile foundation would be about 15 m long and 1.7 m high. The length of the dyke is about 825 m and the height varies from 1.7 m to 2.8 m. The top of dyke elevation is 100.70 m. Two flap gates would be required. One would be near the CNR line to prevent water from Badger Brook from backing up through an existing culvert during high

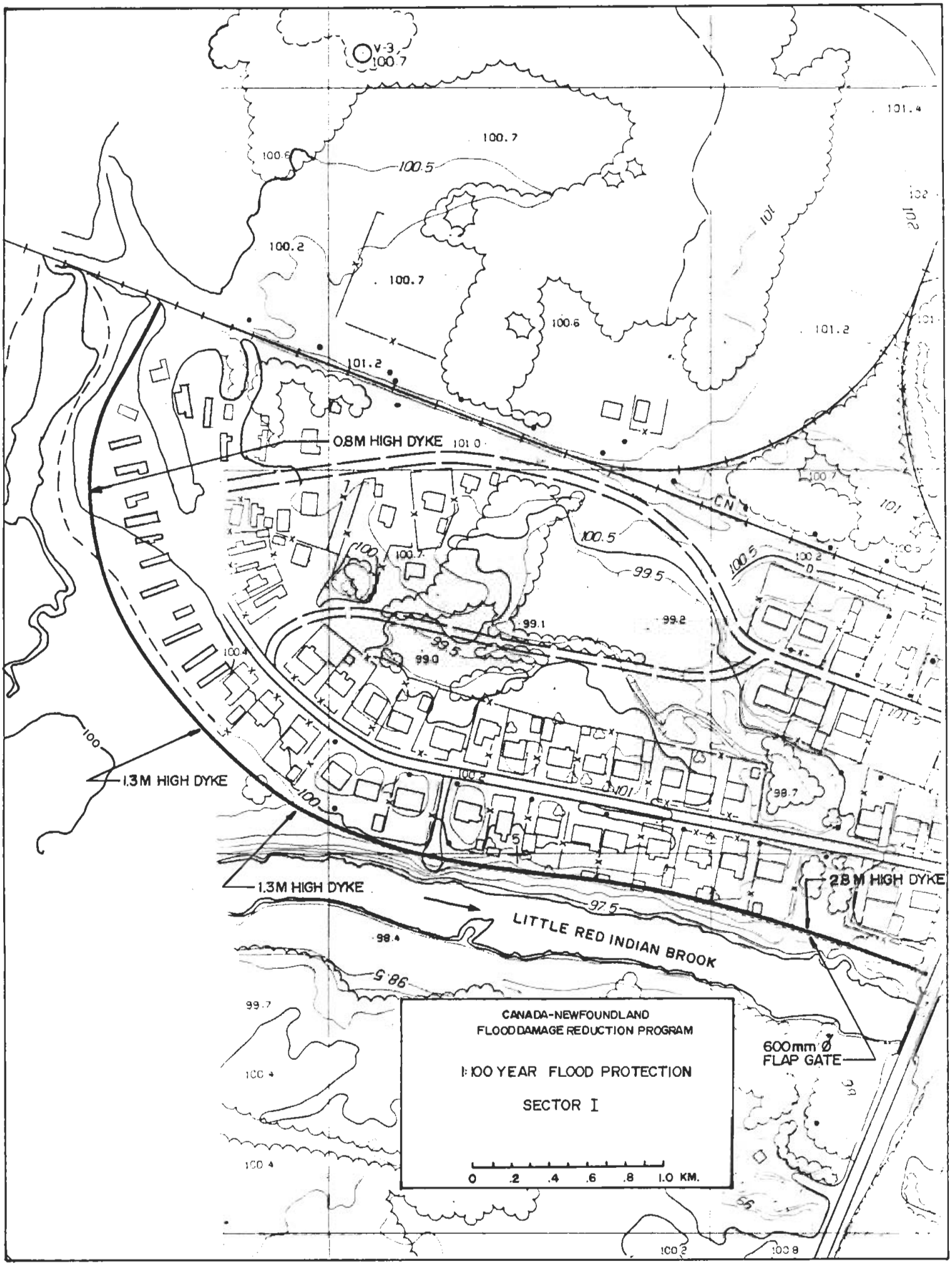
0.8M HIGH DYKE
1.3M HIGH DYKE
1.3M HIGH DYKE
2.8M HIGH DYKE
600mm Ø FLAP GATE
LITTLE RED INDIAN BROOK
CN
CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
1:100 YEAR FLOOD PROTECTION
SECTOR I
0 .2 .4 .6 .8 1.0 KM.

FIG. 10.3

flows and the other towards the end of Beothuk Street to drain off surface runoff from the local area.

The location of the 1:100 year dyke is presented in Figure 10.4. The cost of the dyke, including the flood wall, is about $754,000 (Appendix 5.0).

During the 1:20 year flood, the arena, the sewage treatment plant (STP) control building, and a residential structure near the STP are flooded. Since the flood damages are localized in these two areas a continuous dyke is not warranted. Local berming is, therefore, considered appropriate to protect the above structures. For the arena a berm 0.5 m high and about 270 m long is required. For the control building and the structure near the STP, a combined berm of 170 m long and 1.1 m high is required. The STP cannot be easily protected by a berm because of space restrictions, and because it would not be damaged it is not protected in this option. The top of dyke elevation in this area is a minimum of 99.8 m with a freeboard of 0.3 metres.

The cost of the 1:20 year dyke for the lower town area is about $150,000. The dyking arrangement is shown in Figure 10.7.

Main Street

The proposed 1:100 year dyke for the Main Street area extends from the CNR bridge to the new Trans-Canada Highway Bridge as shown in Figure 10.5. The dyke is about 400 m long and the height varies from 1.8 m to 2.0 m. The top of dyke elevation in this area is a minimum of 100.45 m. Two flap gates are

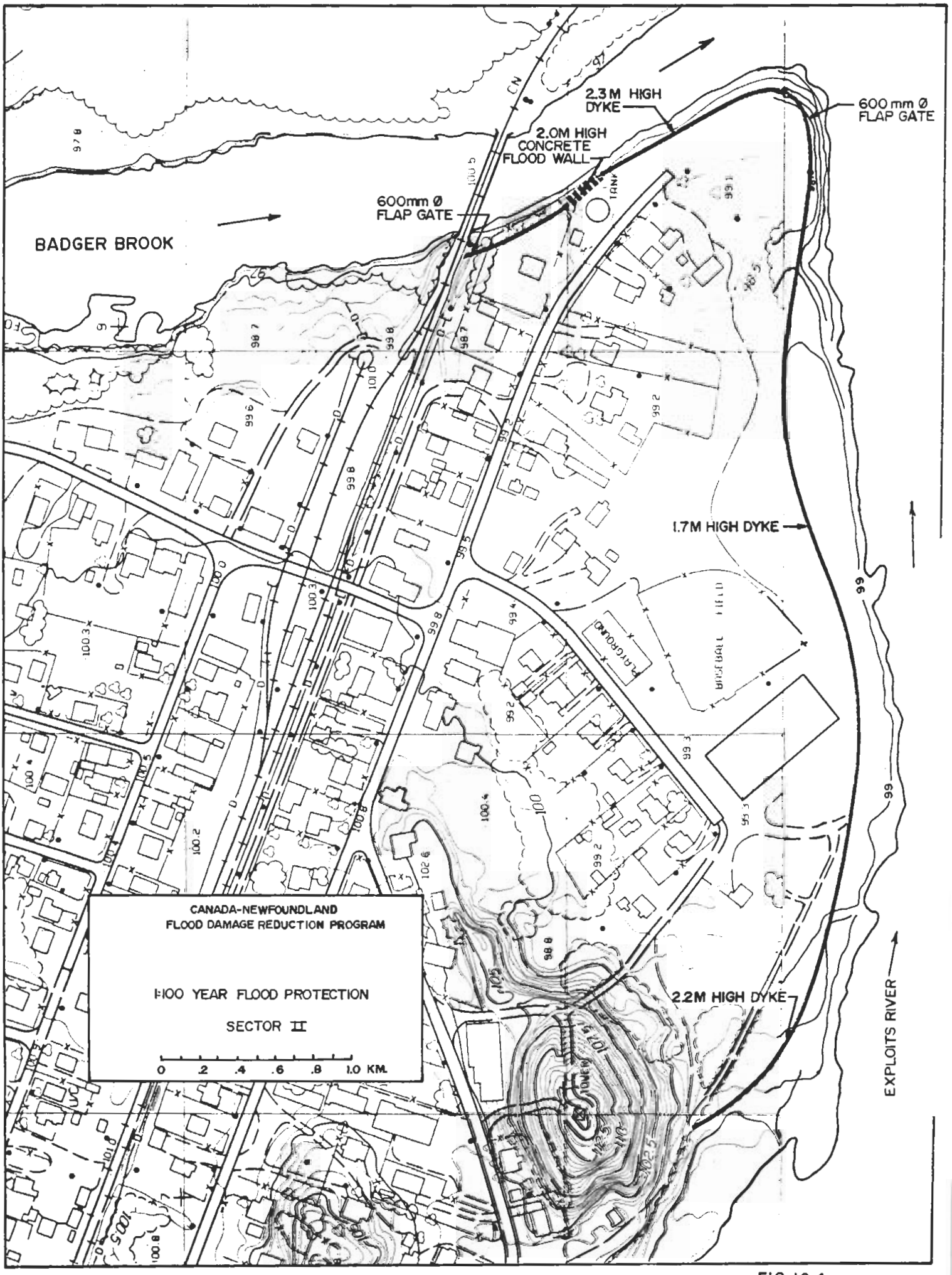
2.3 M HIGH DYKE
600 mm Ø FLAP GATE
2.0M HIGH CONCRETE FLOOD WALL
600mm Ø FLAP GATE
BADGER BROOK
1.7M HIGH DYKE
2.2M HIGH DYKE
EXPLOITS RIVER
CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
1:100 YEAR FLOOD PROTECTION
SECTOR II
0 .2 .4 .6 .8 1.0 KM.

FIG. 10.4

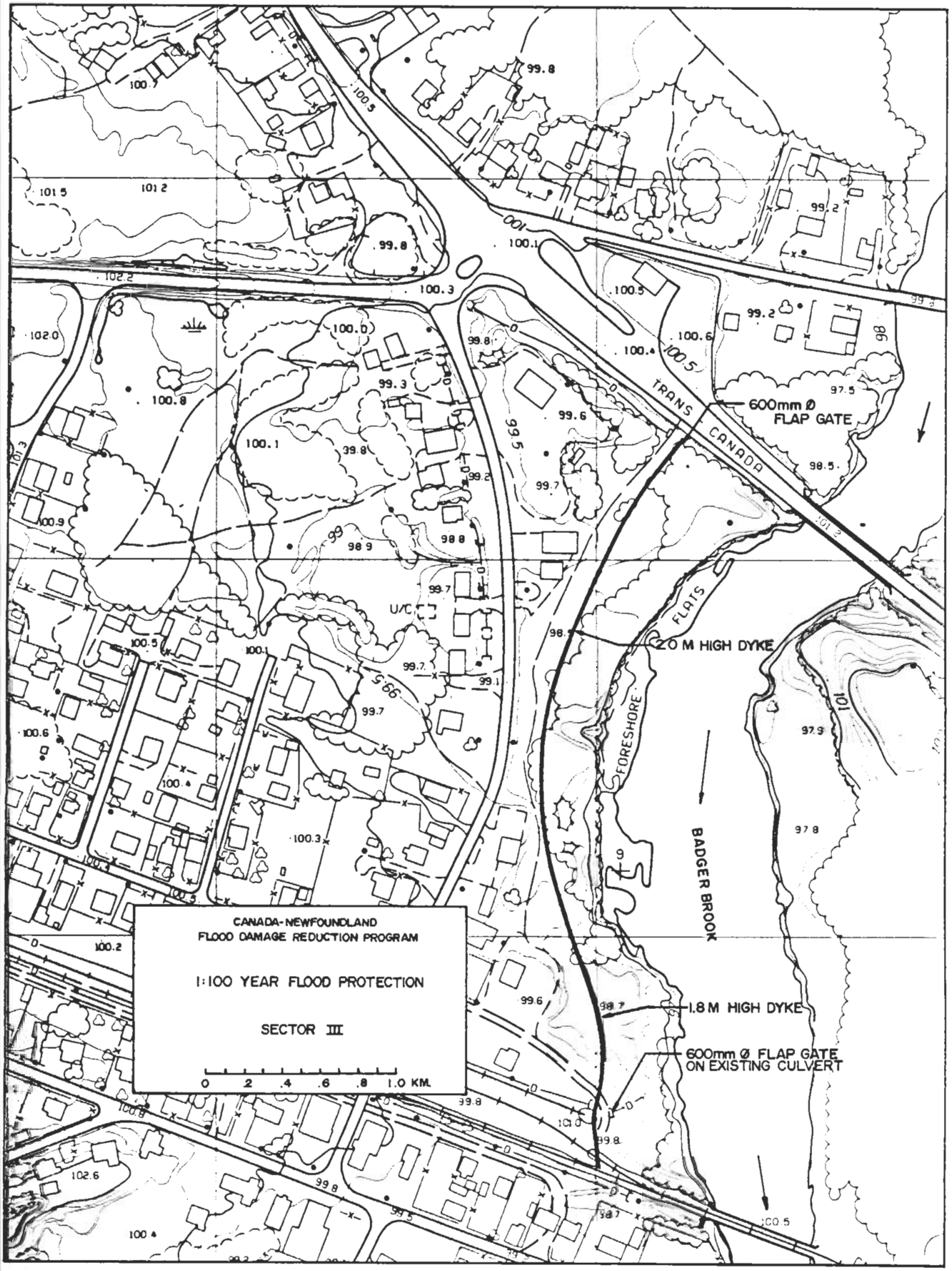
CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
1:100 YEAR FLOOD PROTECTION
SECTOR III
0 .2 .4 .6 .8 1.0 KM.
600mm Ø
FLAP GATE
TRANS CANADA
2.0 M HIGH DYKE
FLATS
FORESHORE
BADGER BROOK
1.8 M HIGH DYKE
600mm Ø FLAP GATE
ON EXISTING CULVERT
U/C

FIG. 10.5

required for this area to prevent the water from Badger Brook from backing up through two existing culverts.

The cost of the 1:100 year dyke is about $370,000. The 1:20 year flood causes damages to two residential structures near Main Street. A berm can be used to protect these two structures as shown in Figure 10.7. The berm is about 130 m long and about 0.5 m high. The minimum top berm elevation is 99.60 m for the 1:20 year flood. The cost of this berm is about $49,000.

Trans Canada Highway (TCH)

The 1:100 year dyke for the TCH area extends from the TCH bridge along Badger Brook to the northern limits of the Town as indicated in Figure 10.6. The dyke is about 670 m long and the height varies from 0.7 m to 3.0 high. The 1:100 year flood level in this area is about 100.12 m but the elevation at the old TCH bridge across Badger Brook is approxiamtely 99.8 m. In order to provide complete protection a 0.7 m high concrete flood wall and steel gate is required across the old TCH road. The gate would normally be open to allow pedestrian access but would be closed during potential flood threats.

Three flap gates are required in conjunction with the dyking. One flap gate is required to prevent the water from Badger Brook from backing up through an open ditch and the other two to drain surface runoff accumulated behind the dykes.

The minimum top of dyke elevation in this area is about 100.45 m. The cost associated with the construction of this dyke along with the flood wall and steel gates is approxi-

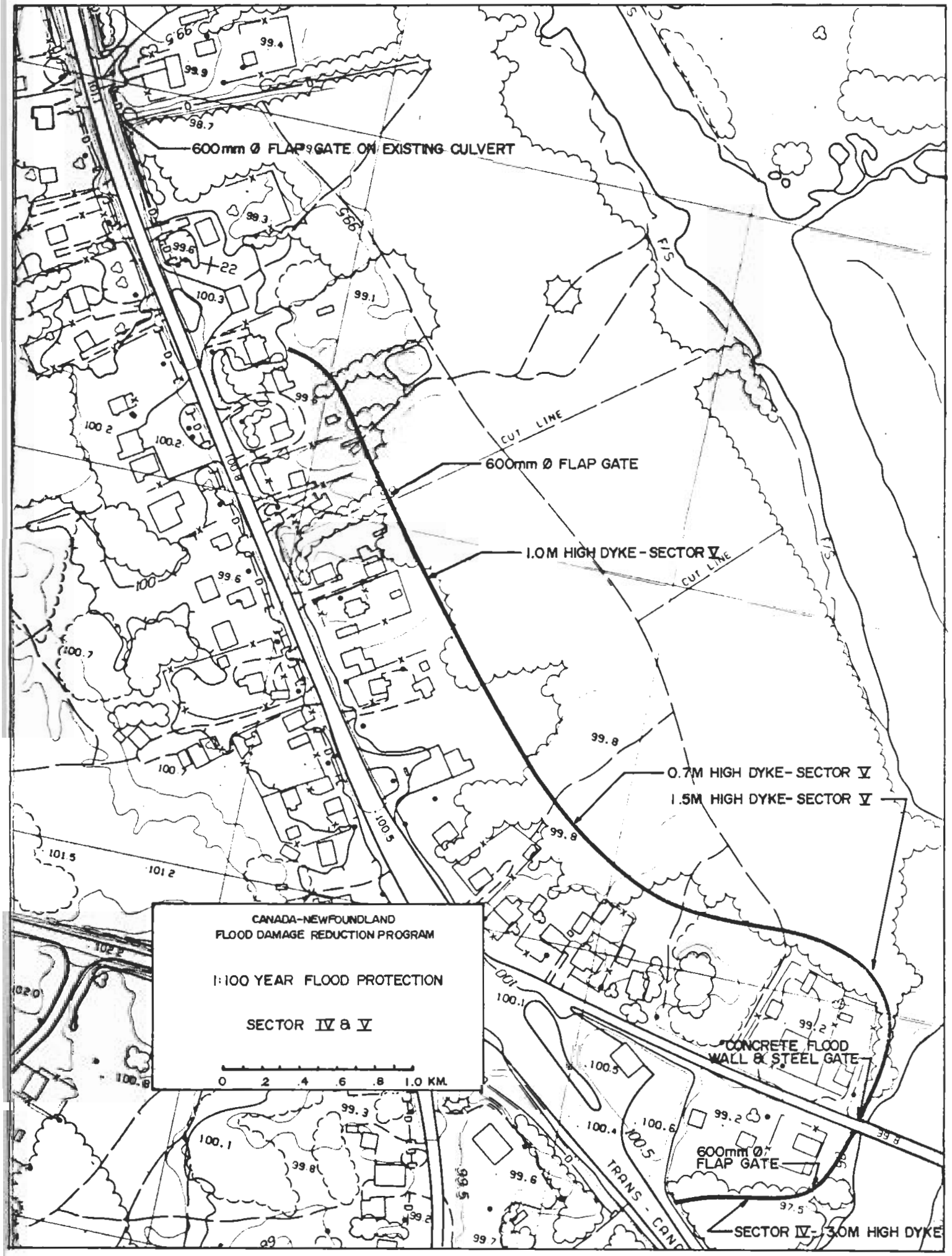
600mm Ø FLAP GATE ON EXISTING CULVERT
600mm Ø FLAP GATE
1.0M HIGH DYKE - SECTOR V
0.7M HIGH DYKE - SECTOR V
1.5M HIGH DYKE - SECTOR V
CUT LINE
CUT LINE
CONCRETE FLOOD WALL & STEEL GATE
600mm Ø FLAP GATE
SECTOR IV - 3.0M HIGH DYKE
TRANS - CAN
CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
1:100 YEAR FLOOD PROTECTION
SECTOR IV & V
0 .2 .4 .6 .8 1.0 KM.

FIG. 10.6

mately $468,000. Two sheds would have to be relocated to construct the dykes.

The residential structures subject to flooding from the 1:20 year flow are located near the old TCH bridge and Badger Brook as shown in Figure 10.7. The dyke required for this area is 310 m long and varies in height between 0.5 m and 2.0 m. The minimum top of dyke elevation in this area is 99.60 m.

Two flap gates would be required to drain off surface runoff accumulated behind the dykes and the cost of the 1:20 year dyke is about $140,000.

10.3.3 Temporary Pumping Sites

Although there are a number of flap gates provided with the various dyke arrangements outlined in Section 10.3.2, these flap gates would not be very effective during prolonged periods of high flows from the Exploits River. The flap gates would prevent water outside the dyke from backing up through existing culverts/ditches. However, they would not allow surface runoff accumulated behind the dyke to be released when the river flow is high.

In conjunction with the proposed dyke arrangements, temporary pumping sites would be required. These sites would be located at low points behind the dykes where water would tend to collect. Two portable pumps and one stand-by would be required to pump the water from behind the dyke on a regular basis.

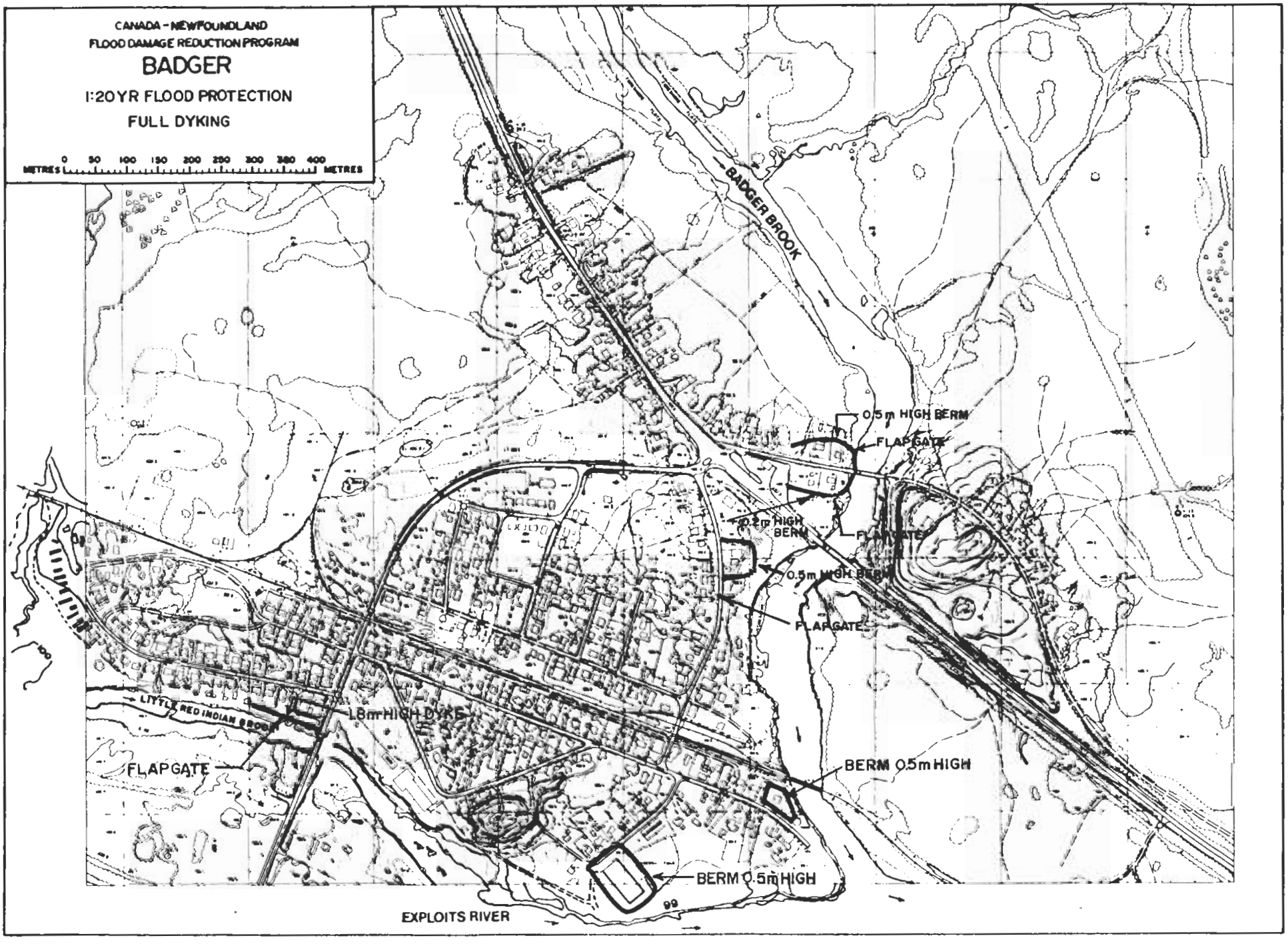
CANADA - NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
BADGER
1:20YR FLOOD PROTECTION
FULL DYKING
0 50 100 150 200 250 300 350 400
METRES METRES
BADGER BROOK
0.5m HIGH BERM
FLAPGATE
0.2m HIGH BERM
FLAPGATE
0.5m HIGH BERM
FLAPGATE
LITTLE RED INDIAN BROOK
1.8m HIGH DYKE
FLAPGATE
BERM 0.5m HIGH
BERM 0.5m HIGH
EXPLOITS RIVER

FIG. 10.7

10.3.4 Dyking Cost Summary

A cost summary of the various dyke arrangements considered in Section 10.3.2 for both the 1:100 and 1:20 year floods is presented in Table 10.4. The total dyking cost to provide protection for the 1:20 year level is $ 400,000. The cost of dyking protection for the 1:100 year level is $2,123,000. Although these costs are based on considerably more site information than was available for developing the earlier estimates in Phase 1 (Table 9.1), there are still many geotechnical unknowns to be resolved at the site (through analysis of test pit results, for example) before dyking cost estimates can be completely finalized.

10.4 Flood Proofing

The option of flood proofing was examined in Stage 1 (Section 9.1.3) considering:

- elevation
- closure and seals
- berms and floodwalls

The advantage of the latter is that it is often capable of providing flood protection to groups of structures at less cost than closure or elevation of the individual buildings in the same group. The advantage of elevation is that it is "permanent" and requires no intervention to be effective. Closure and seals are generally more economical but are "contingent" in that some lead time (warning) is needed to put closures and seals in place. These basic methods used in "dry" flood-proofing (ie. keeping a building and its contents completely dry) are used at existing structures and new structures alike.

TABLE 10.4

COST SUMMARY OF DYKING OPTION FOR
THE 1:20 YEAR AND 1:100 YEAR PROTECTION LEVEL FOR
THE TOWN OF BADGER*

Location	Cost of Dyking for 1:20 Year ($)	Cost of Full Dyking for 1:100 Year ($)
Maple Street (Segment I)	61,000	531,000
Lower Town (Segment II)	150,000	754,000
Main Street (Segment III)	49,000	370,000
TCH (Segment IV)	140,000	468,000
TOTAL COST:	400,000	$2,123,000

* Appendix 5.0 provides additional details for each cost estimate presented here.

"Dry" flood proofing by elevation is the preferred approach for new structures. Construction of new buildings on fill, columns (posts, piles, piers or walls) are the alternatives and each can be completed for new homes outside of the 1:20 year flood risk area at an additional building cost of 2-8% (MacLaren, 1978). As well as being inexpensive, elevation has the advantage that the design of the basic structure need not be significantly altered. Elevation is also advantageous if the design flood elevation is exceeded by unusually high flood waters, because damage would only be a function of the difference between the design elevation and the flood level rather than the full depth of the flood itself.

A major advantage of elevation on columns is related to the effect of flood plain encroachment. Columns, unlike fill, do not displace flood plain storage and raise the flood water level. A drawback is that basement cannot be incorporated in this type of flood proofing and much of the economy can be lost through the need to erect a larger structure.

Overall, the ease and flexibility afforded by elevation on fill makes this option appealing for any new construction considered for most areas of Badger. The lower town (River Road and Beothuk Street) provides only limited flood plain storage, and if new construction is contemplated in this area it would be more appropriate to consider elevation on piles, piers or columns.

Dry flood proofing by closures and seals has not received the same level of regulatory support as elevation. The reasons are fairly straightforward. Bulk-heads on doors and windows are a contingency measure requiring intervention to be effective. Should there be no flood warning or intervention there would be no flood proofing and a home could be flooded to the same depth as the flood level outside. In addition, damage would be much higher than if the design flood elevation was exceeded at a building raised on fill. Hence, this

flood proofing approach is not recommended for any new construction in the flood prone areas of Badger.

Despite these considerations for new structures, it must be noted that closures and seals are viable and economical for shallow flooding depths, and are often the only option available for flood proofing existing structures.

Flood walls and berms have the greatest appeal for flood proofing existing structures. Floodwalls or berms around a building are closely related to closures - and are in fact external closures. Their main advantage is that any structure or small groups of structures in any condition can be protected if space around the buildings is available.

The disadvantages are similar to those discussed under closures and seals and this method is not recommended for new construction in Badger.

A further disadvantage is the high cost of drainage control required with this method in areas where sub-surface infiltration is high. This is expected to be the case in Badger, and hence the cost of this approach (compared to the value of a building) is expected to be significantly higher than the 11% to 30% range which would apply for impervious soil conditions.

A second basic option for flood proofing is called "wet" flood proofing. It is employed in certain situations where other techniques to keep the interior of a structure completely dry are not feasible. Water resistant carpets and finishes, interior vents and drains, and locating damage-susceptible materials (eg. circuit boxes) above design flood levels are some of the methods in this option. Although it is not recommended as the general solution for the Badger

area, it has been retained as a last alternative for existing structures that cannot be dry flood proofed by other methods.

The following section provides the details of flood proofing approaches for existing structures in Badger. Priority has been placed on dry flood proofing by elevation. In certain cases where the feasibility is in doubt or the cost would be excessive (eg. Badger Arena), closures and seals have been taken as the next best approach. External closure by berms and floodwalls has been dropped because of the cost for drainage control would bring this option well above that of the above-mentioned approaches. Wet flood proofing has not been considered except as a last resort option for cost comparison purposes.

Structures flood proofed to the 1:100 year and 1:20 year protection level are shown in Figures 10.8 and 10.9, respectively.

10.4.1 Maple Street Area

This section of Badger contains 3 trailer homes which would sustain first floor flooding in the 100-year event and 10 permanent homes with basement flooding potential. None of the latter will have first floor flooding at the 100-year level.

Where infiltration can not be reasonably controlled, the basements of existing homes can be reinforced and sealed to effect a strong water tight foundation. The foundation becomes a strong impervious structure which requires no subsurface drainage. The costs of this "undrained" system

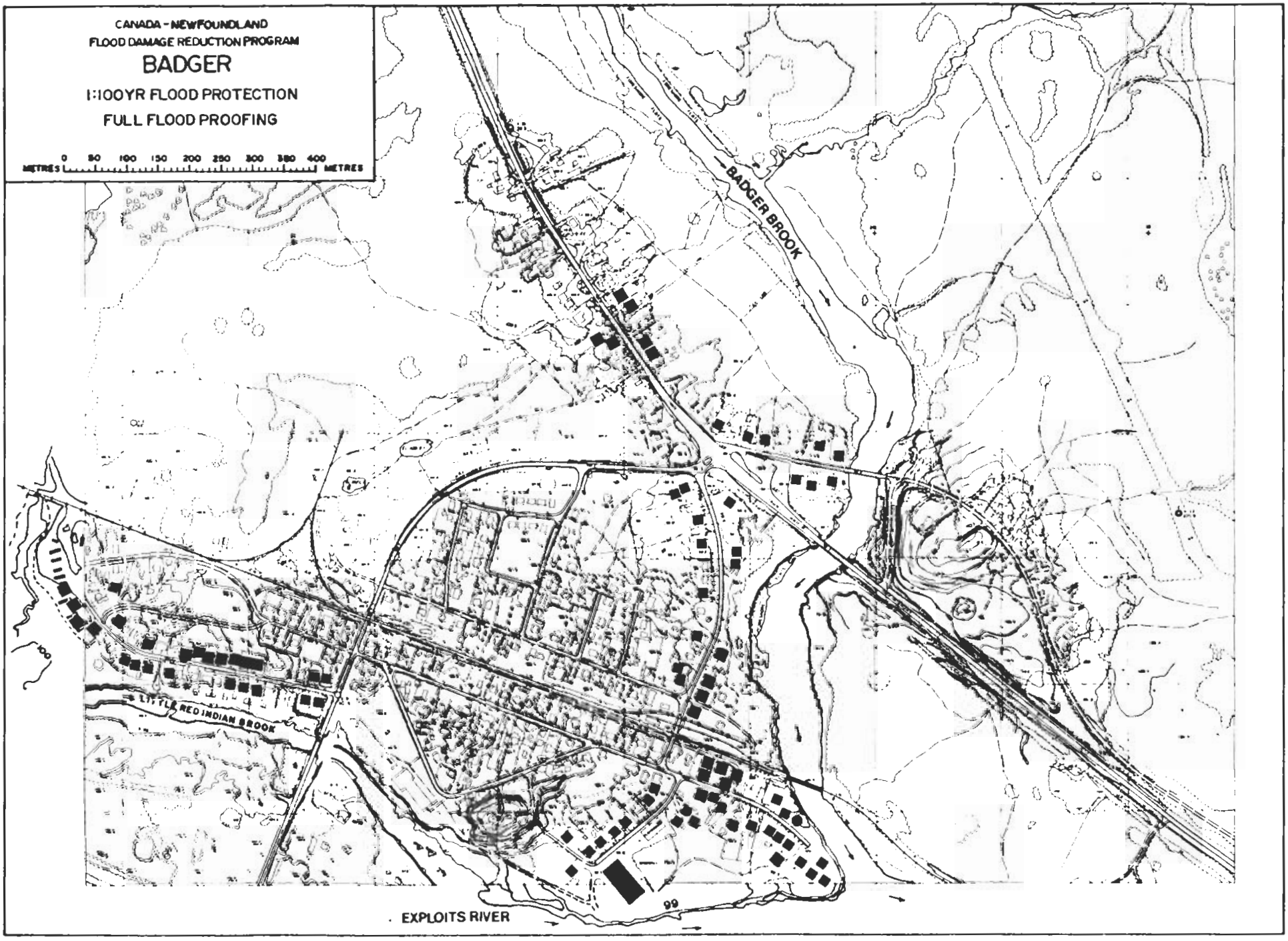
CANADA - NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
BADGER
1:100YR FLOOD PROTECTION
FULL FLOOD PROOFING
0 50 100 150 200 250 300 350 400
METRES METRES
BADGER BROOK
LITTLE RED INDIAN BROOK
EXPLOITS RIVER
99

FIG. 10.8

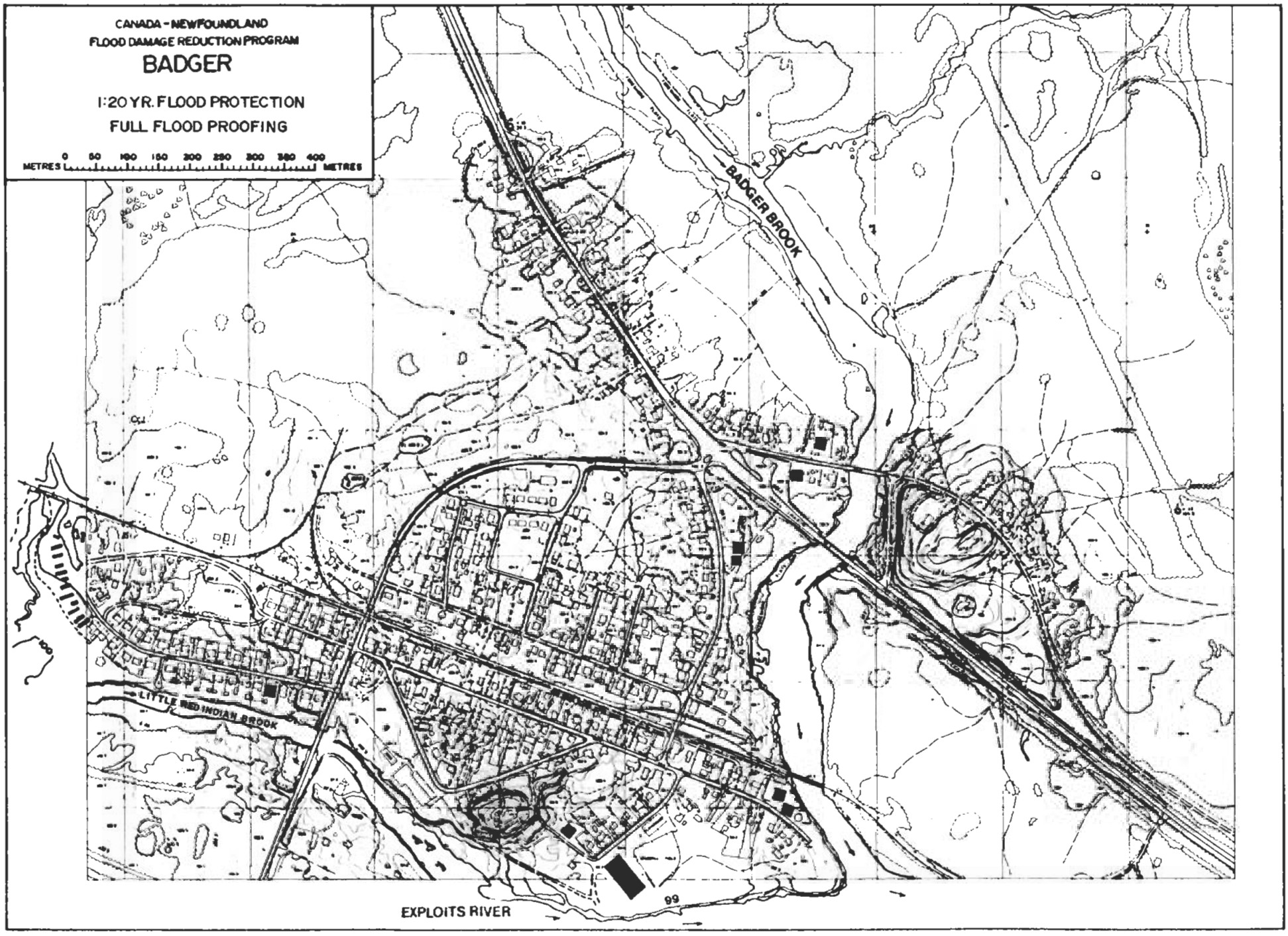
CANADA - NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM
BADGER
1:20 YR. FLOOD PROTECTION
FULL FLOOD PROOFING
METRES 0 50 100 150 200 250 300 350 400 METRES
BADGER BROOK
LITTLE RED INDIAN BROOK
EXPLOITS RIVER
99

FIG. 10.9

are higher for existing buildings than that involved for new basements because the existing walls must be replaced under difficult working conditions. The work is labour intensive and basement contents must be moved and stored, utilities and services adjusted, supporting columns changed, walls and partitions removed and replaced, etc. Costs are also highly dependent on the structure and soil conditions.
The work can be completed by:

- segmental reconstruction of the wall and slab
- elevating the structure to allow full scale reconstruction below it.

The cost for this work is estimated to range from $10,000 to $24,000 (1984) per structure (MacLaren, 1978). Alternatively an existing foundation could be left in an unflood-proofed form so long as the contents are relocated. There would not be sufficient room in most homes to allow for this type of relocation and it could only be handled by constructing an addition to the home to replace the lost area of the basement. The range of cost for this option is a function of the current floor area and use of the basement and is estimated to range from $15,000 to $40,000 (A.E. Lepage, 1985). This cost excludes the loss of use of the land required for the addition or any new land requirements. As it is overall slightly more expensive than basement reconstruction, the preceding approach was adopted here for cost evaluation.

The cost of Maple Street flood proofing to the 100-year level is outlined in detail in Appendix 5.0 and will total about $165,000. Flood proofing to bring the first floor of all structures to an elevation above the 100-year level will only cost about $6,000, with the remainder of the total going to basement flood proofing.

10.4.2 Lower Town - River Road and Beothuk Street

There are 38 homes and public buildings susceptible to damage within the 100-year flood plain in this area of the town. Unlike the situation an Maple Street, 33 of these would sustain first floor flooding (this includes 3 with basement flooding as well), 2 more would have only basement flooding, and 3 are on the fringe of the flood plain and would require first floor protection as a precautionary measure. The vast majority of structures in the lower town can be protected by elevation, and those with basements can be floodproofed by the "undrained" system. The Arena and Town Hall deserve special mention.

It would be prohibitvely expensive to attempt to flood proof the Arena by elevation, and for similar structures on impervious soil the usual approach is closure and seals, or a surrounding flood wall or berm. The pervious soils at Badger make the latter approaches extremely expensive as well. Closure and seals would require removal of the steel cladding, segment-by-segment removal of the wall to expose the slab, channeling the slab to provide a groove to contain a water proofing membrane, application of the membrane to the surface, and replacement of the wall and the cladding. This cost has not been estimated but is considered in the range in the cost of a flood wall (ie. approximately $85,000).

Given that these latter approaches are excessive, a combination of closure and seals with wet flood proofing is considered appropriate. This would entail provision of steel flood doors and shields, check valves and plugs, and application of sealants to reduce the flow of surface water entering

the building. Subsurface entry between the walls of the slab may be controlled by retrofitting an internal drainage network and providing sump pumps. Without certain knowledge of the success of this approach, however, it would be appropriate to 'wet' flood proof the principal electrical/mechanical systems as well by elevating them above the design flood level. The cost of this partical closure/wet flood proofing approach is estimated at $17,000, but a detailed structural and geotechnical analysis would be necessary to arrive at a refined figure.

The Town Hall is the second largest flood prone structure in Badger, and there appear to have been several additions to the original structure over the years. These, and the limited crawl space, add to the difficulty of flood proofing by elevation. Alternatively, the majority of the structure could be flood proofed by closure and seals (concrete slab tied to external and internal walls with flood doors). Both this and elevation are estimated to cost about $20,000, but the selection and final cost estimate should again follow a detailed structural review.

Overall, the flood proofing cost for the lower town is estimated to total $324,000 of which $263,000 is required to provide first floor flood protection. Excluding flood proofing of the arena, the cost estimate drops to about $307,000 of which $246,000 would be required to bring the first floor elevation of the remaining structures to non-damaging elevations. The development of these and other flood proofing cost are provided in Appendix 5.0.

10.4.3 Main Street

This area contains 10 buildings which would have first floor flooding at the 100-year level and three which would have only basement flooding. The bulk of these flood prone structures can be flood proofed by elevation, and those with basements can be made imperivous. The only buildings requiring special consideration are the Post Office and the warehouse/office on the southeast corner of the Trans Canada Highway and Main Street.

The Post Office structure is too substantial to raise. It appears to be structurally sound, however, and since the 100-year flood level is only 0.3 m above the first floor level it is amenable to flood proofing by closures and seals. This could be accomplished by the addition of a 0.5 metre brick wall across the window space and a sliding steel door at the front entry.

The warehouse/office appears similar to the Arena in that elevation and complete closure would be prohibitively expensive. As an alternative, closure has been assumed with provision of a high capacity sump pump combined with elevation of all internal shelves, electrical units, etc., to an elevation of 0.3 m above the first floor level.

The total cost of flood proofing for this section of the town is estimated to be $102,000. Partial flood proofing to achieve first floor flood damage reduction will be about $48,000.

10.4.4 Trans Canada Highway (TCH)

This area includes 11 flood prone structures of which nine would have first floor flood damage and two would have just

basement flooding during the 100-year event. There appear to be no structures requiring special consideration (such as closure and seals or wet flood proofing) and all could be flood proofed by elevation or by basement reconstruction.

The cost for complete protection to the 100-year level is estimated at $93,000 with partial protection to ensure flood damage reduction to the first floor level accounting for about $63,000 of this total.

10.4.5 Flood Proofing Cost Summary

Table 10.5 summarizes the flood proofing costs for various segments of the town. The breakdown of the total cost is as follows:

$684,000	provides complete 'dry' flood proofing of all structures except the arena which would be closed and sealed with further provisions for 'wet' flood proofing
$667,000	provides complete 'dry' flood proofing of all structures except the arena, which would not be flood-proofed
$380,000	complete flood protection for all structures to the first floor level. The arena would be closed/sealed and wet floor-proofed. Basements would not be flood-proofed with this partial protection approach, however.

TABLE 10.5

BADGER: FLOOD PROOFING OF STRUCTURES AND ROADWAYS FOR 1:100 YEAR

FLOOD DAMAGE REDUCTION

Location	No. of Structures	Total Floodproofing Cost Estimate	1st Floor/Partial Protection Estimate
Maple Street	13	165,000	6,000
River Road and Beothuk Street	38	324,000 (307,000)*	263,000 (246,000)*
Main Street	13	102,000	48,000
TCH	11	93,000	63,000
Total Structures	75	684,000 (667,000)*	380,000 (363,000)*

Roadways	Floodproofing Cost Estimate
Maple Street	12,000
River Road and Beothuk Street	37,500
Main Street	17,000
TCH	7,500
Total Roadways	74,000

* excludes Arena flood proofing

$363,000 complete flood protection for all structures to the first floor level. The arena and basements would not be flood proofed with this partial protection option.

As shown in the Table, the cost is highest in the Lower Town (River Road and Beothuk Street) because of the number of structures involved. Maple Street, Main Street, and the TCH have a similar number of structures requiring flood proofing (11-13 buildings). However, the ratio of basements to first floor flooding is much higher on Maple Street than the other two areas which accounts for the higher cost for flood proofing protection on Maple Street.

The cost of flood proofing protection for first floors only is highest in the River Road and Beothuk area. This is because flood waters are deeper and more extensive work would be required. The cost along Main Street is somwehat lower because flood depths are low and buildings such as the Post Office can be flood proofed at reasonably low cost.

10.5 Dyking with Flood Proofing

During the Stage 1 studies it was considered most appropriate to combine flood proofing in some portions of the town with dyking in other portions. Specifically:

- flood proofing by a low berm at Maple Street
- flood proofing by elevation along the TCH
- dyking of the lower portion of the town along River Road, Beothuk Street and Main Street

This combination provided the least cost alternative in Stage 1 as it avoided the cost of extensive dyking to protect only a few dwellings which could be more economically flood proofed (eg. those by the old TCH bridge), and covered large areas by comparatively inexpensive dyking (eg. Beothuk Street).

The detailed mapping and soils data has enabled the dyking cost to be updated for a number of options in the four flood prone sections of Badger (ie. Maple Street, the lower town, Main Street and the TCH section). Similarly, structure-by-structure flood proofing estimates have been completed. These two flood damage reduction approaches have been compared in the following section to determine if greater economy can be achieved through a combination of flood proofing with dyking.

10.5.1 Maple Street

The inflow of flood waters from Little Red Indian Brook/ Exploits River can take place over a broad area extending from the Buchans Road Bridge to the CNR bridge just west of the town. Hence, there is only one berming/dyking option for sector-wide coverage for 100-year flood damage reduction. That is a 650 m berm from the CNR bridge to the Red Indian Brook Bridge (Figure 10.3). The cost of this option was discussed earlier, and as shown in Appendix 5 will total approximately $531,000.

Alternatively, each of the 13 structures can be flood proofed at a total cost of $165,000 (Table 10.3). As noted in Section 10.2, this entails elevation of three trailer homes and basement flood proofing of 10 other homes.

The flood proofing option is $336,000 less than the dyking option and hence deserves strong consideration. In addition, a freeboard elevation of 0.3 m would be provided at each of the 13 flood proofed structures to offer additional protection in the event of a flood level above the 100-year event.

The berm/dyke system includes a similar freeboard, and if the dyke is maintained at the design level it offers similar above-the-100-year protection to a total of about 18 structures - five more than the individual flood proofing case. Although this provides an additional benefit for the dyking/-berming case, the possibility of the design levels being exceeded counters this benefit. If the berm is overtopped, for example, all 18 structures would receive the same flood damage as if the berm was not there. If the flood proofing design level is exceeded, the elevated structures (3) would receive less damage.

Overall the benefits from each option are about equal, and the economy of elevation flood proofing supports its selection for Maple Street.

10.5.2 Lower Town - River Road - Beothuk Street

Flood waters from the Exploits River enter this area along the full length of the river banks. The only section-wide option for dyking is a 2 metre dyke and flood wall running 825 m along the river from the water tower hill to the CNR bridge over Badger Brook (Figure 10.4). The cost of this option is approximately $754,000.

The alternative of flood proofing the 38 structures in this area would cost $324,000 (Table 10.5), or $430,000 less than

the dyking option. In addition to being less expensive, all structures except the Arena and Town Hall are dry flood proofed by elevation - a significant advantage if future flood levels ever exceed the design level.

The principal disadvantage of flood proofing just the structures is that the water level on the streets would exceed 0.6 m at the 1:50 year flood level. This would limit vehicle access. During the period when flood levels reach the 100-year elevation, the water depth over the area would be about 1.2 m and restrict pedestrian access. Both forms of access could be maintained by elevating Beothuk and River Road by about 0.6 m at a cost of approximately $37,500. This reduces the cost differential between the two options to about $393,000. Inclusion of driveway regrading, additional culverts to permit post-flood drainage and adjustment to services would further reduce this difference.

Overall, flood proofing is significantly less expensive than dyking. As flood proofing by elevation has the secondary advantage of providing protection if design flood levels are exceeded, it is recommended for the lower town.

10.5.3 Main Street

Flood flows from the Exploits River and Badger Brook gain access to this area along Badger Brook and carry over Main Street to flood the low lying areas of the west. The most appropriate dyking option is a 2 metre high structure extending 400 metres from the CNR line to the Trans Canada Highway. The cost of this option is approximately $370,000 (Figure 10.5).

The flood proofing alternative costs $102,000 (Table 10.5) which is $268,000 less expensive. This is reduced to a $251,000 difference by the addition of 0.3 m to the surface of Main Street to allow for pedestrian and road access during flooding events. With this inclusion, the level of protection offered by both options is practically the same. Inclusion of freeboard on the dyke may offer marginal protection to four more structures than the 13 which would be flood proofed, but this is countered by the increased protection which flood proofing offers in the event of a flood above the design level.

Overall, the cost advantage offered by flood proofing makes it the recommended choice for this section of Badger.

10.5.4 Trans Canada Highway (TCH)

Flood waters from the Exploits River and Badger Brook enter this area over the banks of Badger Brooks, and gain access to low areas west of the TCH through the culverts which pass beneath it. There are four dyking and flood proofing combinations for this area in addition to the basic two options of full dyking or flood proofing.

Full dyking would require 670 m of dyke and berm construction, combined with flood wall construction at the old TCH bridge. The required dyke would be 3 metres high in some places but but would generally average about 1 metre above existing ground. The cost of this alternative is approximately $468,000 (Figure 10.6).

The cost of flood proofing (11 structures) is approximately $93,000, to which an additional $7,500 must be added to

ensure vehicle access to the homes closest to the old highway bridge. The dyking option provides marginal (freeboard) protection to 9 buildings not covered by flood proofing, but as mentioned previously this benefit is countered by the benefit which flood proofing provides if design levels are exceeded.

The combination of flood proofing with dyking does not result in alternatives which are less expensive than flood proofing on its own. For example, the five structures closest to the old TCH bridge could be flood proofed to eliminate about 200 m of the required dyking. This would reduce the protection cost but it would still total about $363,000.

Another option for combining flood proofing with dyking would include flood proofing of the 3 northernmost buildings (as well as those around the old Badger Brook bridge). This substantially reduces the length of dyking and reduces the overall protection cost to about $182,000.

Overall, however, the inclusion of dyking in these schemes raises the cost above that of flood proofing on its own ($93,000). As the flood proofing option is less expensive than complete dyking, it is recommended on this basis.

10.5.5 Dyking with Flood Proofing - Cost Summary

Table 10.6 provides a summary comparison of the detailed costs of dyking and flood proofing for 1:100 year protection. In each section of the town, the dyking cost is substantially greater than the cost of flood proofing. Along the TCH,

TABLE 10.6

EVALUATION OF REMEDIAL WORK OPTIONS FOR
1:100 YEAR FLOOD PROTECTION FOR THE TOWN OF BADGER

Location	Remedial Works Option		Cost* ($)
Maple Street	i	full dyking	531,000
(Sector I)	ii	full flood proofing	177,000
River Road/	i	full dyking	754,000
Beothuck Street	ii	full flood proofing	361,500
(Section II)			
Main Street	i	full dyking	370,000
(Sector III)	ii	full flood proofing	119,000
TCH	i	full dyking	468,000
(Sectors IV)	ii	full flood proofing	100,500
"	iii	partial dyking with flood proofing	182,000
Total Cost	i	full dyking	2,123,000
	ii	full flood proofing	758,000
	iii	partial dyking with flood proofing	839,500

* floodproofing costs include the cost of road elevation for vehicle access

where combinations of dyking with flood proofing could be considered most feasible, the cost of the dyking raises the combined cost above that of flood proofing alone. Hence, flood proofing is recommended if complete protection to the 100 year level is desired.

Table 10.7 compares the cost of dyking with flood proofing for the limited number of structures affected by the 1:20 year flooding. As is the case for 100-year flood protection, the dyking option is substantially more expensive than flood proofing in each section of Badger. Overall, flood proofing is recommended if partial protection to the 20-year level is desired.

10.6 Flood Warning System

The purpose of a flood warning system is to provide prior estimates of future hydrological conditions so that appropriate actions may be taken to reduce or eliminate the losses caused by flooding. For the Badger area, it is felt that a flood warning system could enhance the ability of the local inhabitants to be better prepared for a flood. In conjunction with the ice simulation model, monitoring the rise in water level due to ice blockages in the Exploits River downstream of Badger makes it possible to predict the incidence of flooding in Badger. From preliminary analysis of observed ice scars and computed water surface profiles due to ice blockages, a suitable monitoring location has been found about 3 km downstream of Badger (Section 25860). A water level monitoring station at this location could be installed to automatically transmit water levels to Badger where assessment of potential flooding would be made.

Water level data can be transmitted from remote stations using three modes of communication. These are: satellite, telephone landline and radio. Satellite transmission was not

TABLE 10.7

EVALUATION OF REMEDIAL WORK OPTIONS FOR
1:20 YEAR FLOOD PROTECTION FOR THE TOWN OF BADGER

Location	Remedial Work Option	Cost ($)*
Maple Street (Sector I)	i) dyking (Figure 10.7)	61,000
	ii) flood proofing (Figure 10.9)	13,000
River Road/ Beothuck Street (Sector II)	i) dyking	150,000
	ii) flood proofing	42,000
Main Street (Sector III)	i) dyking	49,000
	ii) flood proofing	6,000
TCH (Sector IV)	i) dyking	140,000
	ii) flood proofing	25,000
Total Cost	i) dyking	400,000
	ii) flood proofing	86,000

* roadway flood proofing is not required.

considered for this study because it was found impractical for the short distance (less than 4 km) from the remote station to Badger. A telephone landline system was initially considered (in Phase 1). However, after more detailed information was obtained from Terra Nova Telephone and Newfoundland Light and Power Co. Limited, it was estimated that to service the water level monitoring station with telephone and hydro could cost over $30,000. Because of the high cost involved in installing telephone and hydro lines, a radio transmission system was considered next. Radio is ideally suited for applications where power and telephone is not available but information is required on a regular basis. The radio system consists of a transmitter and a receiver. The transmitter will collect the water level data and transmit it at pre-determined time intervals and the receiver, located in Badger, will receive the data and then print it onto paper via a small printer or could send it to a small computer for storage or further data manipulation.

The instrumentation at the remote station for water level monitoring and radio transmission would be housed in a shelter which would be removed from the flood plain and away from potential damage by ice floes. The water level would be monitored by means of a pressure transducer which measures the water pressure and then converts to water level. The cable from the transducer to the shelter would be buried to prevent it from being damaged by the ice.

10.6.1 Flood Warning System Cost Summary

A breakdown of the costs for installing a radio transmission system is presented in Table 10.8. As can be seen the approximate cost of the whole system is about $24,000. This cost includes shipping and taxes.

TABLE 10.8

COST BREAKDOWN FOR INSTALLATION OF A RADIO TRANSMISSION SYSTEM

Item	Cost (1984 $)
1. Instrumentation	
· Remote Radio Transmitter, VHF Antenna and Pressure Transducer at Remote Station	6,500
· Receiver and Printer at Central Station in Badger	9,000
2. Shelter and Associated Material	3,000
3. Installation	4,000
4. Testing	1,500
Total Cost:	$24,000

As far as flooding in Badger is concerned, it is only required to monitor the water level in the Exploits River during the freeze-up period (which may be more than once each year). The internal battery contained in most radio transmitters would be sufficient for use up to 60 days, and 3-4 months operation would be provided by the addition of an external battery.

However, if this station is to be used for other reasons in a year round operation, a solar panel and battery pack may well be required. The cost of the solar panels and battery pack is about an additional $3,000.

In addition to the capital cost of the equipment and its installation, there are also additional costs related to maintenance, monitoring, forecasting and equipment replacement. The annual maintenance and monitoring costs are estimated to be about $500 and $2000 respectively. The latter cost considers regular monitoring and data recording for 14 days each year. Manipulation of the data to develop rule curves or to simulate ice conditions with a mathematical model is estimated to cost about $3,000/year, although it should be possible to reduce this investment once more experience has been gained with these tools for Badger.

The present worth of the annual maintenance, monitoring, and forecasting costs over a fifty (50) year period at a 10% discount rate is $54,531 ($ 1984). Adding equipment replacement in about 25 years (having a present worth of $2,215) and the capital cost of the initial installation brings the final present worth cost for forecasting to a total of $80,746.

10.7 Screening of Flood Damage Reduction Alternatives - Phase II

The detailed analysis of flood proofing, dyking, dyking with flood proofing, and flood warning support the conclusion that options involving dyking are too expensive to be pursued any further. This leaves:

- flood proofing, and
- flood warning

as the remaining viable options for flood damage reduction in Badger.

The flood warning option is the least expensive alternative for reducing flood damages. As noted earlier, however, it only provides additional lead time for contingency activities such as blasting or placing the contents of basements, etc., above the design flood level. This reduces the flood damage but does not eliminate damages to floors, walls, and the contents which are not moved.

Flood proofing provides this protection without requiring a flood warning. Some advanced notice is desirable, however, so that cars, trucks and outside furniture, etc. can be moved (and flood doors put in place at the Arena, for example). As previous floods in the town have developed over several days, it is conceivable that this would give sufficient lead time to enable flood proofing to stand on its own without a flood warning system - once all of the flood proofing is completed. Until that time, however, a warning system would be advantageous. This is discussed in the following sections.

11.0 IMPLEMENTATION PLAN

11.1 Flood Proofing Priorities

The majority of flood prone structures in Badger are single story homes having living and sleeping quarters, and most valuable furnishings on the first floor. As first floor flooding poses a potential safety hazard and the largest contributor to flood damages, it assumes a priority position over basement flood proofing for flood damage reduction. Several structures which would be flooded to the first floor level also have basements (eg. #9 River Road). For these, it would be more efficient to flood proof the basement/substructure during the process of first floor flood proofing. The following lists this first priority for flood proofing:

First Floor Flood Proofing

Location Section	Number of Buildings	Cost of First Floor Flood Proofing ($ 1984)
Maple St.	3	$ 6,000
Lower Town	35	$ 280,000 (includes 3 basements)
Main Street	10	$ 48,000
TCH	9	$ 63,000
		$ 397,000

The second schedule of flood proofing operations would involve the remaining structures having basement flooding. This priorization is based on the fact that the majority of these basements have recently been flooded, and the asumptions that: most valuable contents have been relocated to the first floor level; and, that these substructures are unlikely to be sleeping quarters. The cost and location of this work is summarized below:

Basement Flood Proofing

Location Section	Number of Structures	Cost of Basement Flood Proofing
Maple Street	10	$ 159,000
Lower Town	2	$ 27,000
Main Street	3	$ 54,000
TCH	2	$ 30,000
		$ 270,000

The only remaining structure is the Arena. It has been given the lowest priority since it is not a dwelling and likely has been partially flood proofed as a result of the last two floods.

Arena Flood Proofing

Location Section	Number of Structures	Cost of "Wet"/Closure Flood Proofing
Lower Town	1	$ 17,000

As noted earlier, it is prohibitively expensive to "dry" flood proof this structure, and hence wet flood proofing provisions combined with closures and seals are appropriate. This work is estimated to cost $17,000, but as is the case for all structures, it would require a structural inspection before implementation.

The final work is that involved in flood proofing the streets to ensure pedestrian and vehicle access during flooding conditions. The cost estimate for this work is as follows:

Roadway Flood Proofing

Location Section	Road/ Street	Cost of Road Elevation
Maple St.	Maple St.	$ 12,000
Lower Town	River/Beothuk	$ 37,500
Main	Main Street	$ 17,000
TCH	TCH	$ 7,500
		$ 74,000

11.2 Flood Proofing Schedule

As the probability of damaging floods in Badger is close to 1 in 20 years, it has been assumed for scheduling purposes that the structural flood proofing work need not be totally completed within several months or a single year. Although there is some risk involved with extending the work, this extension would allow one or two local contractors to complete the work with ever increasing efficiency and at a "bulk" rate which could be lower than the unit costs given here. The schedule provided in Table 11.1 provides an overview of the timing of flood proofing expenditures following final engineering and contract awards.

The average annual damage associated with each section of Badger is provided in Table 10.2 which has been used as a guide for determining a final priority for flood proofing activities in the town. Table 11.2 summarizes the overall schedule of flood proofing work.

TABLE 11.1

FLOOD PROOFING SCHEDULE

1:100 YR FLOOD DAMAGE REDUCTION - BADGER

Year	Flood Proofing Activity	Capital Cost ($1984)
Year 1	· install flood warning system	$ 24,000
	· initiate first floor flood proofing (with some basements)	200,000
		$224,000
Year 2	· complete first floor flood proofing	$197,000
	· initiate basement flood proofing	35,000
		$232,000
Year 3	· complete basement flood proofing	$235,000
		$235,000
Year 4	· complete Arena flood proofing	$ 17,000
	· complete road elevations	74,000
		$ 91,000

TABLE 11.2

SCHEDULE OF FLOOD PROOFING PRIORITIES
1:100 YEAR FLOOD DAMAGE REDUCTION: BADGER

Activity	Location Ranking
1. First Floor Flood Proofing	1. Lower Town
	2. Trans Canada Highway
	3. Maple Street
	4. Main Street
2. Basement Flood Proofing	1. Maple Street
	2. Main Street
	3. Trans Canada Highway
	4. Lower Town
3. Arena Flood Proofing	
4. Roadway Flood Proofing	

11.3 Flood Proofing with Flood Warning

Until flood proofing is completed in Badger, it will be important to have advanced warning of rising flood waters. This is particularly desirable until first flood flood proofing is completed. It would also be most desirable until basement flood proofing is finished to give the maximum lead time for moving contents to higher elevations.

The ideal flood warning approach outlined in Section 10.6 is a remote station giving water level conditions on demand. The installation and maintenance costs (Section 10.6) for this operation over a 5 year period total $44,850.

Assuming this monitoring with flood proofing brings the total cost of this combined option to about $802,850.

11.4 Flood Warning with Blasting

One of the disadvantages of using explosives to destroy ice blockages near Badger is the time requirement. Time is needed to identify problem conditions, check the ice cover, mobilize the blasting team and conduct the blasting operation. Lead time is very short at Badger, and if blasting is considered it must be combined with a warning system to give the longest possible lead time.

It was noted in Section 9.1.8 that there are also other serious limitations on blasting operations in addition to the shortage of time. These are:

- no open water areas downstream of blockages to carry the broken ice away from the blockage

- the distinct possibility that broken ice from blasting could block channels beneath the ice cover causing additional blockages. In this event, precious time would be lost in attempts to locate and destroy these blockages as well

- considerable uncertainty as to the location of the initial ice blockage(s)

- an ice cover which is porous, resistant to blasting, and a hazardous platform for conducting an inherently dangerous task.

It is considered most likely that these limitations are too severe to be overcome successfully. Since past usage near Badger failed to quickly reduce flood levels, blasting cannot be recommended as an option for protecting Badger from floods.

The cost of blasting operations with flood warning is estimated to have a present worth cost of $478,675 (10% real rate of return - Appendix 5). This assumes that false alarms, training and preventative blasting will total 25 occasions in the next 50 years. This may not be sufficient to cover all false alarm occasions (ie., when warning indicates a possible problem and blasting operations must be initiated just to ensure that all is in readiness if problems continue). The frequency and cost of these situations cannot be estimated, but would clearly increase the cost total to above $478,675.

11.5 Status Quo Alternative

There are currently no structural or non-structural works (such as dykes or flood level sensors) established in Badger for flood damage reduction. If flooding occurs, compensation is paid by the province for reasonable damage claims.

Flooding does not occur each year and when the probability of flooding is combined with the damages that can occur it is shown in Section 8.5 that the average annual damage is $4,563. In other words, an annual allocation of this amount by the province for flood damage reduction would be sufficient to pay damage claims in Badger for existing buildings. The present worth of this allocation at 5%,10% or 15% discount rates is $83,300, $45,240 or $30,390 respectively.

Once the flood prone sections of Badger (shown in Figure 1.1) are officially designated as flood risk areas, one of the first steps in cutting the cost of flooding is to ensure that the pattern of future development is undertaken in a way that won't increase flood damages. Hence, future houses built in the designated floodway would not receive flood damage compensation from either the federal or provincial government.

11.6 Benefit-Cost Analysis - Phase 2

A final benefit-cost analysis was carried out for the alternatives presented below:

i dyking
ii flood proofing
iii flood proofing with partial dyking
iv flood proofing with flood warning for the first 5 years while flood proofing is being implemented
v flood warning system
vi flood warning system with blasting
vii status quo

The results are summarized in Table 11.3 and described below. To establish the benefit-cost ratios for alternatives (i), (ii) and (iii), the costs presented in Table 10.6 were compared to the present worth of flood damage reduction benefits. These were estimated in Section 8.5 to total $45,240.

The cost of the flood warning system (v) was based on a capital cost of $24,000 for the instrumentation/installation, $5,500 annual operation/maintenance/forecasting cost for a 50-year period and replacement of equipment after 25 years.

The benefits of the flood warning system were based on the reduction in flood damages which would occur if it was possible to predict a flood occurrence one day earlier than at present.

Normally, damage to the contents of flooded structures is about 30% of the structural damage (Acres, 1968). It was determined in Section 8.3.2 that personal property claims

TABLE 11.3

COMPARISON OF FLOOD DAMAGE REDUCTION ALTERNATIVES FOR 1:100 YEAR PROTECTION LEVEL: BADGER PHASE II

Permanent/Non-contingency Alternatives	Cost* ($1984)	Benefit-Cost Ratio *
i Dyking	2,123,000	0.021
ii Flood Proofing	758,000	0.060
iii Flood Proofing with Partial Dyking (TCH)	839,500	0.054
iv Flood Proofing with Flood Warning	802,850	+0.057
Contingency Alternatives		
v Flood Warning	80,746	+0.039
vi Flood Warning with Blasting	478,675	0 to 0.09
vii Status Quo	45,240	1.00

* Net present values at 10% real rate of return.

Benefit-cost ratios at 5% and 15% rates of return are presented in Table A.2.2 of the Technical Appendices.

were 70% of the total damage estimate for floods in Badger (or 30% of the total flood damage was indirect costs such as rent, lost wages, etc.). As a result the present Worth of flood damage reduction benefits to contents is $45,240 x 70% x 30% = $9,500 ($ 1984).

It is difficult to estimate how much of the flood damage to contents could be alleviated by providing additional time to move contents to neighbouring buildings (which are higher) or to attics or upper floors. Assuming that 1/3 of the contents could be protected in such a manner given extra time provided by a flood warning system, the benefit of the warning system is 1/3 x $9,500 = $3,167 and the benefit-cost ratio is 0.039. This ratio does not include the benefit which would result from earlier implementation of sandbagging, snow bank dyking, etc. As these benefits are difficult to estimate, their effect on icreaseing the benefit cost ratio has been noted by a "+" symbol.

Flood warning could be considered appropriate with flood proofing (iv) during the five years when flood proofing is being implemented. In this period, the benefit provided by the warning system would be about $ 319 per year ($ 4563 average annual damage X .7 X .3 X 1/3) or only about $ 1210 over the five year period. Costs for this warning system would also be reduced to total $ 44,850 - principally because operation/maintenance/forecasting costs would only be required during a five year period. The equipment replacement costs would not be required as well.

The cost of blasting operations with flood warning (vi) over the next 50 years was estimated to have a present worth of $478,675. This assumes that blasting would be undertaken 25 times in the next 50 years, but as noted in Section 11.4 this frequency and cost may well be exceeded.

It is very doubtful that there will be any benefit derived from this expenditure. Past operations at Badger have not been successful in reducing levels at the rate required for flood damage reduction. If future operations were more successful than those of the past at dislodging/ breaking the ice at the blockage, analysis of ice and hydraulic conditions indicates that the ice may remain in place or block again nearby. These secondary blockages may well be more severe than the original blockage and lead to even worse flooding than the original case. Hence, as no benefit can be projected, the benefit-cost ratio for this option is zero.

Overall, none of the alternatives involving permanent, non-contingency actions for flood damage reduction is economically attractive. The least unattractive benefit-cost ratio for permanent, non-contingency flood damage reduction is flood proofing. The benefit-cost ratio for this option is 0.06, which translates into a cost of about $17 for every $1 benefit.

In terms of contingency flood damage reduction, flood warning or flood warning with blasting is even less desirable. Although the costs are less than permanent options, the benefits are also significantly lower and reduced to a point where they are small to non-existent. The status quo option of paying compensation for flood damage claims stands alone as the only option with an acceptable benefit-cost ratio. The ratio is 1.0 because the costs are exactly matched by the benefits. The costs are also significantly lower than all of the other options providing permanent or similar contingency protection.

11.7 Final Recommendations - Phase 2

1. The results of the detailed cost estimates prepared in this phase confirm the Phase 1 finding that none of the options for complete 1:20 year or 1:100 year flood protection are economically justifiable. It is noted in the text that certain assumptions have been made in estimating the benefits, flood damages and option costs (eg. pervious soil conditions). Although these assumptions introduce some uncertainty into the presentation of the benefit-cost ratios for each option, it appears that none can be recommended for economic reasons.

2. If a structurally oriented solution to minimizing flood damages is to be implemented for reasons other than a favourable benefit-cost relationship, then flood proofing is recommended at all 73 flood-prone buildings in Badger.

   The major advantages of this option are that:

   (a) no intervention or flood warning is required for it to be effective for most buildings (the Arena, warehouse/office at the TCH-Main Street intersection, and the Post Office are the exceptions and require some advance warning to put flood doors in place)

   (b) the work may be staged over several years

   (c) the work may be staged to address the most damage-prone areas of Badger and most damage-prone parts of structures (ie. first floors)

3. If for economic or other reasons a flood proofing approach is not implemented, the "status quo" approach is recommended. This alternative provides full compensation for damage at existing buildings in the event of flooding at Badger. Although this option offers no flood protection for the town, it is the only option with an acceptable and attractive benefit cost ratio for minimizing the cost of flooding. All other approaches involve too much expenditure of public funds to be financially justifiable.

4. It is recommended that the flood contingency program put in place by the town in 1977 be continued in the future. It has provided flood warning and assistance in past floods, and to provide the greatest possible likelihood of success it is recommended that:

   (a) a downstream, water level recorder be installed with a radio transmitter so that maximum lead time of potential flooding conditions can be obtained

   (b) the Department of Environment monitoring of ice and river flow conditions be continued, and be augmented by the use of ice progression model developed for this study (or a similar model)

   (c) field monitoring of freeze-up, ice thickness and breakup be conducted over the next few winters to provide additional data to assist in forecasting and identifying problematic ice conditions.

5. Regardless of the choice of solution for minimizing the cost of flooding to existing buildings in Badger, it is recommended that municipal by-laws be modified to control development in all areas within the 1:100 year flood lines shown in Figure 1.1. Criteria for flood proofing of any new development should include the following minimum elevations:

Maple Street	100.74 m
River Road/Beothuk	100.66 m
Main Street	100.42 m
Trans-Canada Highway	100.42 m

Enforcement of this type of zoning will prevent any increase in the potential flood damage in the flood plain.

12.0 REFERENCE DATA AND SOURCES

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12.2 Photographs

1977 - documented set of colour photographs of Badger and the Exploits River during flooding event in January (Prov. Nfld.)

1977 - undocumented black and white photographs of Rushy Pond area showing ice conditions of the Exploits River (Prov. Nfld.)

1977 - documented set of colour photographs of Exploits River from Grand Falls to Badger, 10 March 1977 (Env. Canada)

1977 - undocumented photos (3) of winter-spring ice conditions Exploits River

1980 - documented, mounted set of colour photographs of Badger area March 2,3 1980 (Prov. Nfld.)

1983 - undocumented colour photographs of Rushy Pond area following January flooding (Prov. Nfld.)

1983 - undocumented colour slides (80) of Exploits River from Rushy Pond to Badger area during February-March flood (Prov. Nfld.)

1984 - undocumented colour photographs of Exploits from Grand Falls to Exploits Dam (January 10-12) (Fenco and Prov. Nfld.)

1984 - field photographic record file, Exploits River Rushy Pond to 12 Mile Falls (January-March 1984) (Fenco)

1984 - undocumented colour photographs, Exploits from Grand Falls to Noel Pauls Brook (overflight of 22 Feb.) (Prov. Nfld.)

1984 - field photographic record file, Exploits River Goodyear's Dam to Three Mile Island (July-August 1984) (Fenco)

1984 - photographic record file, Badger structures

12.3 Air Photographs

18 Jul 1946	- Rushy Pond area	(B and W)
08 Sep 1964	- Rushy Pond area	(B and W)
Aug 1975	- Study area	(colour)
Sep 1975	- Study area	(colour)
14 Jun 1976	- Rushy Pond area	(B and W)
Aug 1976	- Study area	(colour)
Mar 1978	- GF to Chute	(B and W)
20 May 1983	- Study Area	(B and W)

12.4 Drawings and Plans

Department of Municipal Affairs Provincial Planning Division, 1963. "Badger-Newfoundland", Hunting Survey Corp., Montreal (scale: 200 feet to 1 inch. Contour Interval - 5 feet)

ibid, containing overlay of 1983 flood contours prepared by Newfoundland Environment

Dept. Transportation and Communication, March 1975, "Plan & Profile Proposed TCH Reconstruction in Rushy Pond Area" (showing proposed elevation increase of about six feet)

Dept. of Highways, 1964, "Plans for New TCH Bridge Badger Brook"

Dept. of Highways, 1968, "Plans for New Buchans Road Bridge Red Indian Brook"

Dept. of Highways, 1964, "Plans for New TCH Bridge Rushy Pond Brook"

Unavailable Data: Old TCH Bridge Badger Brook (circa 1936)
Old TCH Bridge Rushy Pond (circa 1936)
CNR Bridges and Grade in the Study Area

Department of Energy Mines and Resources, Topographic Mapping, Newfoundland, (Scales 1:50,000 and 1:250,000)

12.5 Contacts and Agencies

Badger Area

Burt Hayden (Mayor)
Ed Lawlor
Bill Mayne (Deputy Mayor)
Reg White
Ron Power
Hubert Gilbert
Joe Roberts
Clyde Loader
George Hayden
John Loader, Jr.
Sullivan Hurley
Max Drover
Jim Patey

Abitibi Price

G.N. Cater

Charlie Janes

Dept. of Transport

Roy Noseworthy

Kevin Langdon

Calvin Squires

Terra Transport (CN)

Rendell Sparkes

12.6 Meteorological and Streamflow Data

Meteorology

Canada Climate Centre, Downsview, Ontario

Station	Data
840 0700 Buchans A	date
840 0301 Badger (AUT)	air temperature (max., min., mean)
840 1700 Gander	dew point temperature (daily mean)
	precipitation (total daily)
	rainfall (total daily)
	snowfall (total daily)
	wind speed (mean daily speed, prevailing direction)
	daily sunshine (total hours - Gander)

870 1550 Exploits Dam	date air temperature (daily max., min., mean) precipitation (total daily) rainfall (total daily) snowfall (total daily)

Streamflow

Abitibi Price Inc., 1934 - Feb. 1984, "Exploits Dam Water Readings" - records of daily lake elevation & stoplog operation at Exploits Dam; daily records of mean discharge at Grand Falls Dam.

Abitibi Price Inc., 1969 edition, "Discharge in C.F.S. Exploits Dam"

- A and C Gates
- B Gate
- Submerged Gates
- Log Sluice

Abitibi Price Inc., 1970, "Exploits Dam Storage" (area, volume, elevation and rule curve)

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Exploits River below Stony Brook
Sandy Brook at Powerhouse
Rattling Brook at Powerhouse
Hinds Brook near Grand Lake
Lewaseechjeech Brook at Grand Lake
Sheffield River at Sheffield Lake
Sheffield River at Trans Canada Hwy.
Lloyds River below King George IV Lake

12.7 Support Documentation

Acres Limited, 1968, "Guidelines for Analysis: Streamflows, Flood Damages, Secondary Flood Control Benefits," Joint Task Force on Water Conservation Projects in Southern Ontario

Ashton, G.D. 1980. "Freshwater Ice Growth, Motion, and Decay" in Dynamics of Snow and Ice Masses (ed. Colbeck), Academic Press Inc., New York.

Barnes, H.H., Roughness Characteristics of Natural Channels, Geological Survey Water Supply Paper 1849, Washington, D.C., 1967

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Edinger, J.E., Brady, D.K., and J.C. Geyer, 1974. "Heat Exchange and Transport in the Environment," EPRI Pub. 74-049-00-3, Report No. 14, Palo Alto, California.

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Fountain, A.G., 1984. "Yukon River Breakup: The 82-Year Record," Northern Engineer, Vol. 16, No. 1.

Gerard, R. and E.W. Karpuk, 1979. "Probability Analysis of Historical Flood Data." ASCE J. Hyd. Div., Vol. 105, No. HY9.

Ingeldow, T. and Associates Ltd., 1970 Hydrometric Network Plan for the Province of Newfoundland, New Brunswick, Nova Scotia and Prince Edward Island, for Dept. Energy Mines and Resources

Inland Waters Directorate, 1979 "Guidelines for the Benefit Cost Analysis of Flood Damage Reduction Projects, Environment Canada, Ottawa

Insurance Bureau of Canada, Home Evaluation Calculator, 1982 Edition.

Kivisild, H.R., 1959. "Hydrodynamics of Ice Floods," Proc. IAHR Eighth Congress, Montreal, Quebec.

Kivisild, H.R., 1959. "Hanging Ice Dams," Proc. IAHR Eighth Congress, Vol. III, Montreal, Quebec.

Paragon Engineering, 1984, "Flood Damages, Volume 2, A Review of Estimation Techniques," for Canada-Ontario Flood Damage Reduction Program, Kitchener, Ontario.

Paragon Engineering, 1984, "Flood Damages, Volume 2, Guidelines for Estimation," for Canada-Ontario Flood Damage Reduction Program, Kitchener, Ontario.

U.S. Army Corps of Engineers, 1977, "Expected Annual Flood Damage Computation," Davis, California.

U.S. Army Corps of Engineers, Hydrology Engineering Centre. HEC-2 Water Surface Profiles - Users Manual, Corps of Engineers, U.S. Army, Davis, California, Sept. 1982

U.S. Army Corps of Engineers, 1981. "Engineering and Design Ice Engineering", Eng. Circ. No. 1110-2-220, Hanover, N.H.

Vanderbilt University, 1971. "Effect of Geographical Location on Cooling Pond Requirements and Performance" for U.S. EPA, Proj. No. 16130 FDQ, Nashville, Tennessee

Winkler, R. L. and W. C. Hays, 1975. "Statistics: Probibility, Inference and Decision," Holt, Reinhart and Winston, New York.

APPENDIX 1.0

SUMMARY OF 1977 and 1983 FLOOD EVENTS, BADGER

FLOOD OF JANUARY 17-24, 1977 (from Kindervater, 1980)

Cause: One half mile (0.8km) long ice jam, Exploits River at Badger Chute [some four miles (6.4km) downstream of Badger]

Description:

The Exploits River, Badger Brook and Red Indian Brook overflowed into the community of Badger, as a result of water backup caused by an ice jam. On January 20th, provincial authorities declared a "state of emergency".

The sequence of events were reported to be as follows: 1) on January 18th, a water level rise was noticed on the Exploits River; 2) the Exploits River overflowed its banks; 3) on the 20th, water levels were rising at a rate of about 1.5 inches (3.8 cm) per hour and five to six families were evacuated; 4) on the 21st, the Town Hall, fire hall and stadium were flooded and more families were evacuated and at least two streets were closed; 5) water levels remained steady throughout most of the 22nd, however, the levels began to recede by the evening and, 6) on the 23rd, water levels dropped eight inches (20 cm) in the morning and 14 inches (36 cm) by evening.

During the flood, 49 families involving slightly more than 200 people had to be evacuated from their homes. Only eight of the evacuated houses had several inches of water over the main floor and about 20 houses had flooded basements. The remaining houses were evacuated as a precautionary measure.

The Town's water supply was reported to be contaminated when sewers backed up, however, another report stated that "extra chlorine was being added to the water supply to combat possible pollution from surface water".

Magnitude:

At the height of the flooding, water was said to be up to four feet (1.2 metres) deep in some streets of the Town. Badger also received about 30 centimeters (11.8 inches) of snowfall on January 20th, which was accompanied by high winds. The floodwaters were reported to have reached the doorstep of the Roman Catholic Church and the sewage treatment plant was surrounded by as much as six feet (1.8 metres) of water.

Several of the houses affected during the flood are described as follows:

1. Residence of Mr. Hugh Day - seven inches (0.2 metres) of water in the basement porch.

2. Residence of Mr. Sullivan Hurley - no water in the house but it was surrounded. His neighbours up the street had carpet ruined, tile peeled off and other damages (Beothuck Street area). Neighbours across the street had about 18 inches (0.46 metres) of water in their porch.

3. Residence of Mr. Reg White - eight to ten inches (0.20 - 0.25 metres) of water in his home damaging floors and wallboard.

4. Residence of Mr. Max Drover - garage and shed floors were flooded to a depth of three or four feet (0.9 to 1.2 metres).

5. Residence of Mr. Jim Patey (near fire hall) - surrounded by water which seeped in over the floor.

It was also reported that similar flooding but of a lesser extent had occurred at the same point on the river practically every spring but had not reached such proportions since 1943.

Damages:

No estimates of damage were presented in the newspaper accounts; however, in response to a questionnaire, damages to private homes and contents was estimated to be about $ 20,000. Radio station CJCN, Grand Falls, launched a fund raising appeal to help the flood victims.

THE 1983 FLOOD: (from Canada-Newfoundland Flood Damage Reduction Program 1983)

Since the 1977 flood the Nfld. Dept. of Environment has monitored flow conditions on the Exploits River as well as temperature and precipitation data in order to provide a flood warning. The monitoring is done on a daily basis from December to breakup in the spring. The first indication of an ice constriction in the river is a reduction in flows reaching the Abitibi Price power plant in Grand Falls. The sequence of events leading to the 1983 flooding was as follows: Persistent cold weather following the break up of the ice cover on January 17-18 caused the ice cover to reform on the river. Based on this monitoring, the town was notified of the worsening situation on February 23.

(1) February 25 - water level was rising with some fluctuations

(2) February 26 - water level rose, flooding sections of the Town, evacuation of houses begun, snowstorm hits the area

(3) February 27 - water level continued to rise, more houses are evacuated

(4) February 28 - water level stable, state of emergency declared, a total of 38 homes evacuated, schools closed, temperatures drop to minus 27°C.

(5) March 1 - water level stable, blasting team arrived and started operation, water level flucuated slightly.

(6) March 2 - blasting continued, plans made to evacuate the whole town, forecasted milder temperatures and heavy rain did not materialize.

(7) March 3 - water level started receding, temperature above freezing, blasting continued.

(8) March 4 - water level continues to recede, state of emergency lifted, clean up began.

The damage to approximately 40 houses affected by the flooding was generally confined to basements and some first floor areas.

The amount of damage due to the flood is estimated to be $ 89,000. This does not include indirect costs such as the blasting operations and other government services.

APPENDIX 2.0

A.2 ICE PROGRESSION DATA BASE

The analysis of ice conditions and ice-induced floods draws on: the results of 1984 field work; the hydrologic analyses completed to date; and the ice data which has been collected and studied.

A.2.1 Ice Formation and Progression

Table A.1 summarizes the available data defining the first appearance of ice on the Exploits River, and Table A.2 summarizes the upstream progression of the ice cover.

In January 1975, work on raising the weir crest (2 metres) at Goodyear's Dam was completed to enable the "slob" boom in the Rushy Pulpwood Holding Area to function as an ice retention structure. Prior to that time, much frazil slush passed over Goodyear's Dam and downstream to the trash racks at the Mill Pond and beyond. In these years, a major run of frazil slush extending for over one week was required to form an ice cover at the Mill Pond. It then took about a week for the cover to grow from Goodyear's Dam to Badger Chute (Cater, p.c.), and about 3 weeks for the first ice to reach Badger - or at a progression rate of about 1.3 km/day.

Since 1975, the ice cover first forms above Goodyear's Dam and Table A.3 summarized the rate of upstream progression of the ice cover in recent years. This data provides calibration and validation data for modelling the progression of the ice cover and volume of frazil ice generated by the river.

TABLE A.1

ICE FORMATION - EXPLOITS RIVER
GRAND FALLS TO BADGER

Water Year	Formation Data
1933-34	Dec. 14 river frozen
34-35	river plugged early Dec.
36-37	Dec. 4, 7-21, Jan. 1-2 much frazil slush
38-39	-
40-41	-
42-43	pre-Dec. 18 ice on Mill Pond
43-44	Dec. 11 - first frazil. Dec. 24 ice left river
45-46	Dec. 17- frazil observed. Jan. 8 - river plugged
46-47	Dec. 3- frazil observed
48-49	Jan. 20- ice "plug" in Gorge
49-50	-
50-51	Jan. 6- much frazil slush
52-53	Jan. 14- river "plugged"
54-55	Dec. 3- frazil observed, Jan. 7 sheet ice, and frazil until 29th
55-56	Dec. 5- frazil observed, Dec 18- much frazil slush
56-57	Dec. 4- frazil observed but large quantities in late Dec.
57-58	-
58-59	Dec. 4 - frazil observed
59-60	Dec. 12 - frazil observed and Mill Pond freezes
61-62	Dec. 13- frazil observed
62-63	Dec. 15 to Jan. 3- frazil slush observed
63-64	Dec. 13- frazil slush observed
65-66	Dec. 1 - frazil slush observed
66-67	Dec. 5 - frazil observed, pond freezes late Dec.
67-68	Dec. 13- frazil observed
69-70	Dec. 25- frazil observed
70-71	Dec. 14- frazil observed
71-72	-
72-73	Dec. 5- frazil slush observed
73-74	Dec. 30- frazil slush observed
74-75*	Dec. 26- frazil slush observed
75-76	Nov. 21 - frazil slush observed
76-77	-
77-78	-
78-79	Nov. 25- first ice on Mill Pond
79-80	-
80-81	-
81-82	-
82-83	-
83-84	Dec. 19- frazil slush accumulating at "North Angle"/Ice Boom

* Goodyear's Dam raised in winter of 1974-75. Work completed January 1975.

TABLE A.2

ICE PROGRESSION- EXPLOITS RIVER
GRAND FALLS TO BADGER

Water Year	Progression Data
1933-34	-
34-35	-
35-36	-
36-37	Jan. 21 - Badger flood (20 days after last frazil slush at Grand Falls)
37-38	
38-39	
40-41	
41-42	
42-43	
43-44	
44-45	Jan. 8- Badger flood (24 days from first observation of frazil slush)
45-46	
46-47	
47-49	
48-49	
50-51	Jan. 15 - ice in Badger Chute (10 days after observation of slush at Grand Falls)
51-52	
52-53	
54-55	
55-56*	Dec. 22- ice progressed 7 miles up from slob boom (in 4 days from Dec. 19)
56-57	Jan. 20- high water Badger (about 25 days after slush at Grand Falls)
57-58	
59-60	
61-62	
63-64	
64-65	
66-67	
67-68	
68-69	

* Slob boom first use, but not considered effective until 1975.

TABLE A.2 (cont'd)

ICE PROGRESSION- EXPLOITS RIVER
GRAND FALLS TO BADGER

Water Year	Progression Data
1969-70	
70-71	
71-72	
72-73	Jan. 10 ice at "slob boom" (11 days after observation of slush at Grand Falls) Feb. 15 and Mar. 10 LANDSAT show no ice above Leech Brook that year
74-75*	Mar. 18- ice at Twelve Mile Falls (unknown progression rate)
75-76	Dec. 13- ice at Aspen Bk. (23 days after trace frazil observed at Grand Falls)
76-77	Jan. 17- Badger flood (unknown progression rate) Jan. 20- ice to Three Mile Island (3 days after Badger Flood, ± 1 mile/day)
77-78	Feb. 8- ice at Badger Chute (unknown progression rate)
78-79	Dec. 8- ice at Badger Chute (14 days after ice on Mill Pond) Mar. 3- ice at Twelve Mile Falls (unknown progression rate)
79-80	Jan 7- ice at Aspen Bk. (unknown progression rate)
80-81	Mar. 2- ice near Three Mile Island
81-82	Jan. 24 - ice at Leech Brook Feb. 2- Badger high water (10 days after ice at Leech) Feb. 18 - ice at Twelve Mile Falls (15 days after ice at Badger)
82-83	Jan 14 - ice up to region of Badger Chute then swept away by flood flows Jan 30 - ice to Leech Brook (about 10 days after ice reforming Feb. 23- ice at Badger (24 days after Leech Brook area) Feb. 25 -ice 2 km above Three Mile Island (3 days after Badger)
1983-84	Jan. 10- ice at "Big Bend" (19 km from "North Angle" in 23 days) Jan. 12- ice at Junction Bk. (4 km from Big Bend in 2 days) Jan. 18- ice above Three Mile Island (6 km in 6 days) Jan. 31- ice at Twelve Mile Falls (15 km in 13 days) Feb. 4 - ice at Twelve Mile Falls (no upstream growth beyond Twelve Mile Falls).

* Goodyear's Dam raised in winter of 1974-75, work completed Jan. 1975

TABLE A.3

RATE OF ICE PROGRESSION- EXPLOITS RIVER
GRAND FALLS TO BADGER

Water Year	Progression Rate and Timing	
1975-76	Nov 21-Dec 13 - Goodyear's to Aspen Bk.	- 17 km/23 days = 0.7 km/day
1976-77	Jan 17-Jan 20 - Badger to Three Mile Island	- 4 km/3 days = 1.33 km/day
1978-79	Nov 25-Dec 08 - Goodyear's to Chute	- 21 km/14 days = 1.50 km/day
1981-82	Jan 24-Feb 02 - Leech to Badger	- 12-18 km/10 days = 1.2-1.8 km/day
	Feb 02-Feb 18 - Badger to Twelve Mile Falls	- 19 km/15 days = 1.3 km/day
	Jan 20-Jan 30 - Goodyear's to Leech Bk.	- 11 km/10 days = 1.1 km/day
1982-83	Jan 30-Feb 23 - Leech to Badger	- 18 km/24 days = .75 km/day
	Feb 23-Feb 25 - Badger to Three Mile Island	- 6 km/3 days = 2.0 km/day
1983-84	Dec 19-Jan 10 - North Angle to Big Bend	- 19 km/23 days = .8 km/day
	Jan 10-Jan 12 - Big Bend to Junction Bk.	- 4 km/2 days = 2.0 km/day
	Jan 12-Jan 18 - Badger to Three Mile Island	- +6 km/6 days = +1.0 km/day
	Jan 18-Jan 31 - 3 Mile to Twelve Mile Falls	- 15 km/13 days = 1.2 km/day

APPENDIX 3.0

SLUSH RATE FREQUENCY ANALYSIS

EXPLOITS R. SLUSH RATE FREQ. ANALYSIS

SAMPLE STATISTICS

MEAN = 810.426 S.D. = 656.246 C.S. = 0.9896 C.K. = 3.8686

SAMPLE STATISTICS (LOGS)

MEAN = 6.2672 S.D. = 1.0633 C.S. = -0.5466 C.K. = 2.3101

SAMPLE MIN = 100.10 SAMPLE MAX = 2500.00 N = 34

PARAMETERS FOR GUMBEL I A = 0.002085 U = 519.01
CHI-SQUARE= 3.89 KOLMOGOROV-SMIRNOV= 0.1438 # OF CLASSES= 7 DEG. OF FREEDOM= 4

PARAMETERS FOR LOGNORMAL M = 6.2672 S = 1.0633
CHI-SQUARE= 11.45 KOLMOGOROV-SMIRNOV= 0.1754 # OF CLASSES= 7 DEG. OF FREEDOM= 4

NO MAXIMUM LIKELIHOOD SOLUTION FOR THREE PARAMETER LOGNORMAL

PARAMETERS FOR THREE PARAMETER LOG NORMAL BY MOMENTS A = -0.1247E+04 M = 7.5806 S = 0.3113

STATISTICS OF LOG(X-A)

MEAN = 7.5836 S.D. = 0.3013 C.S. = 0.3930 C.K. = 2.7074
CHI-SQUARE= 3.79 KOLMOGOROV-SMIRNOV= 0.1209 # OF CLASSES= 7 DEG. OF FREEDOM= 3

PARAMETERS FOR LOG PEARSON III BY MOMENTS A =-0.2906 B =0.1339E+02 LOG(M) =10.1578 M = 0.2579E+05
CHI-SQUARE= 6.58 KOLMOGOROV-SMIRNOV= 0.1641 # OF CLASSES= 7 DEG. OF FREEDOM= 3

PARAMETERS FOR LOG PEARSON III BY MAXIMUM LIKELIHOOD A =-0.7125 B =0.2478E+01 LOG(M) = 8.0330 M = 0.3081E+04

DISTRIBUTION STATISTICS MEAN = 6.2672 S.D. = 1.1217 C.S. =-1.2704
CHI-SQUARE= 5.86 KOLMOGOROV-SMIRNOV= 0.1509 # OF CLASSES= 7 DEG. OF FREEDOM= 3

	GUMBEL I		LOGNORMAL		THREE 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	-281.00		34.10		-368.00		7.90		19.70	
1.050	-14.40		91.70		-72.30		61.70		79.00	
1.250	291.00		215.00		261.00		236.00		224.00	
2.000	695.00		527.00		713.00		661.00		580.00	
5.000	1240.00	12.00	1290.00	21.20	1300.00	12.60	1350.00	0.00	1310.00	18.10
10.000	1600.00	11.90	2060.00	24.60	1670.00	13.00	1750.00	0.00	1900.00	19.30
20.000	1940.00	12.00	3030.00	28.00	2020.00	15.30	2060.00	0.00	2530.00	23.30
50.000	2390.00	12.10	4660.00	32.20	2470.00	19.60	2400.00	0.00	3400.00	31.40
100.000	2730.00	12.20	6250.00	35.10	2800.00	23.00	2590.00	0.00	4080.00	38.50
200.000	3080.00	12.30	8150.00	37.90	3120.00	26.40	2730.00	0.00	4770.00	46.00
500.000	3500.00	12.40	11300.00	41.00	3560.00	30.90	2860.00	0.00	5700.00	56.20

$\times 10^3 m^3 day^{-1}$

EXPLOITS W. SLUSH RATE FREQ. ANALYSIS

YEAR	DATA	ORDERED	RANK	PROB.	RET. PERIOD
3637	2250.00	2500.00	1	0.029	35.000
4445	100.10	2250.00	2	0.057	17.500
4647	800.00	2230.00	3	0.086	11.667
5051	1300.00	1670.00	4	0.114	8.750
5354	1560.00	1560.00	5	0.143	7.000
5455	100.20	1300.00	6	0.171	5.833
5556	570.00	1230.00	7	0.200	5.000
5657	1670.00	1180.00	8	0.229	4.375
5758	100.30	1130.00	9	0.257	3.889
5859	1040.00	1040.00	10	0.286	3.500
5960	1000.00	1000.00	11	0.314	3.182
6061	900.00	999.90	12	0.343	2.917
6162	740.00	960.00	13	0.371	2.692
6263	1230.00	900.00	14	0.400	2.500
6364	299.00	850.00	15	0.429	2.333
6465	500.00	800.00	16	0.457	2.188
6566	1130.00	750.00	17	0.486	2.059
6667	999.90	740.00	18	0.514	1.944
6768	100.40	650.00	19	0.543	1.842
6869	100.50	570.00	20	0.571	1.750
6970	100.60	560.00	21	0.600	1.667
7071	560.00	500.00	22	0.629	1.591
7172	650.00	401.00	23	0.657	1.522
7273	960.00	380.00	24	0.686	1.458
7374	401.00	301.00	25	0.714	1.400
7475	1180.00	299.00	26	0.743	1.346
7576	650.00	100.80	27	0.771	1.296
7677	2500.00	100.70	28	0.800	1.250
7778	100.70	100.60	29	0.829	1.207
7879	750.00	100.50	30	0.857	1.167
8081	100.80	100.40	31	0.886	1.129
8182	380.00	100.30	32	0.914	1.094
8283	2230.00	100.20	33	0.943	1.061
8384	301.00	100.10	34	0.971	1.029

APPENDIX 4.0

4.0 1:100 YEAR FLOOD DAMAGE ESTIMATE: BADGER

Table 10.1 lists the structures in Badger which are prone to flood damage from the 1:100 year event. The principal subsections of the town (eg., Maple Street, River Road, etc.) are identified and the house numbers are listed for each subsection.

The standard depth-damage relationships (tables) for estimating flood damages (Paragon Engineering, 1984) are given in the following pages as Tables A.4-1 to A.4-7. For a given type of structure (eg., CW residential), the expected flood damage can be read directly from the tables by determining the flood depth relative to the first floor. It should be noted that the damage estimates are given in 1979 dollars and are converted to 1984 dollars by multiplying by 1.55.

The first floor flood damages in Badger were initially estimated using these tables and the flood depths given on Plate 1 and Table 7.4. These values were then marked up to 1984 dollars and then reduced by 32% to reflect the damage calibration for the Badger area (Section 8.3.2). Basements in the flood prone area which were previously flooded in 1977 and 1983 were assigned a $500 damage ($ 1984). Basements which were not flooded in those years were assigned the higher flood damages shown in the tables to reflect usage based on resident perception that the basements were "high and dry". As a final step, the latter basement costs were converted to 1984 dollars and reduced by 32% to reflect local conditions.

Table A.4-8 summarizes the 1:100 year direct flood damage estimate which totals $151,325.

TABLE 10.1

BADGER FLOOD PRONE STRUCTURES

Maple Street Building Number	River Road Building Number	Beothuk St. Building Number		Main St. Building Number	TCH Building Number
45	Arena	32	14	6	1
49	1	U.C. Hall	15	8	2
53	2	Town Hall	16	9	3
57	3	4	17	10	9
65	6	5	18	13	11
73	7	6	19	15	12
79	8	7	21	18	14
81	9	8	24	18(a)	15
83	10	8A	25	19	16
85		9	26	21	17
60		12	27	23	18
58		13	28	24	
44		STP	29	25	
		#*	31		
13	8	28		13	11

* house number uncertain (building just SE of Town Hall)

TABLE A.4.3.

DEPTH DAMAGE TO RESIDENTIAL STRUCTURES AND CONTENTS
(in 1979 dollars)

TWO STOREY WITH BASEMENT *

Depth Relative to First Floor	Type of Residential Structure					
	AB $	BB $	CB $	AW $	BW $	CW $
- 7.5	2,059	570	156	1,783	1,110	822
- 7	2,573	570	289	2,274	1,110	827
- 6	2,981	612	594	2,690	1,198	946
- 5	3,248	851	768	2,934	1,289	1,051
- 4	3,539	1,184	992	3,200	1,386	1,167
- 3	3,856	1,648	1,283	3,490	1,491	1,296
- 2	4,202	2,292	1,658	3,807	1,604	1,439
- 1	5,603	3,056	2,210	5,076	2,137	1,919
0	6,403	3,438	2,487	5,711	2,404	2,159
1	9,806	5,347	3,868	8,884	3,739	3,358
2	14,008	7,639	5,526	12,691	5,342	4,797
3	18,911	10,313	7,460	17,133	7,212	6,476
4	24,514	13,368	9,671	22,209	9,349	8,395
5	29,417	16,042	11,605	26,651	11,218	10,074
6	31,518	17,183	12,433	28,555	12,019	10,793
7	34,320	18,716	13,539	31,093	13,088	11,753

* Calibrated FIA Curve (4); Contents damage - 30% of structural damage.

TABLE A.4.4.

DEPTH DAMAGE TO RESIDENTIAL STRUCTURE AND CONTENTS
(in 1979 Dollars)

MOBILE HOME ON FOUNDATION *

Depth of Flooding Relative to First Floor	Mobile Homes on Foundation $
0 feet	897
1 foot	5,125
2 feet	7,407
3 feet	8,616
4 feet	9,223
5 feet	9,396
6 feet	9,504
7 feet	9,645

* Average price range of new mobile homes (based on size of 14' x 68') is approximately $23,000 - $25,000. Coves Area homes valued at $10,000 - $12,000 maximum, as most of these are older than 8 - 10 years. Market value obtained from "Trailer Centre" dealer (London); referred by Thomas, Williams and Rowell Insurance Adjusters, London, Ontario. Contents were valued at 30% of structure.

TABLE A.4.1 RESIDENTIAL CLASSIFICATIONS

Class	Department of Municipal Affairs Designation	General Criteria
1. Wooden (or Stucco)		
AW	D-7 to D-10	Solid, architect-designed wooden structure. May be ultra-modern or older two-storey. High quality solid construction and materials.
BW	D-4 to D-6	Double wall frame home. Typical average quality housing developments. Most wooden homes fall into this class.
CW	D-1 to D-3	Rough frame structure, thin walls. May have stucco or imitation brick coating.
2. Brick (or Stone)		
AB	C-8 to C-10	Mansion-like or ultra-modern appearance. Very high quality in construction and materials
BB	C-6 to C-7	Typical mass-produced ranch-style or two-storey home.
CB	C-4 to C-5	Cheap brick or concrete block bungalow.

TABLE A.4.2.

DEPTH DAMAGE TO RESIDENTIAL STRUCTURES AND CONTENTS
(in 1979 dollars) *

ONE STOREY WITH BASEMENT **

Depth Relative to First Floor	Type of Residential Structure					
	AB $	BB $	CB $	AW $	BW $	CW $
- 7.5	2,059	570	156	1,783	1,110	822
- 7	2,573	570	289	2,274	1,110	827
- 6	2,981	612	594	2,690	1,198	946
- 5	3,072	805	725	2,775	1,219	994
- 4	3,166	1,059	886	2,862	1,239	1,043
- 3	3,262	1,393	1,082	2,953	1,260	1,096
- 2	3,362	1,833	1,321	3,046	1,282	1,151
- 1	5,043	2,750	1,989	4,569	1,923	1,727
0	6,724	3,667	2,652	6,092	2,564	2,303
1	11,767	6,417	4,642	10,660	4,487	4,029
2	14,008	7,639	5,526	12,691	5,342	4,797
3	16,249	8,861	6,410	14,722	6,197	5,565
4	19,611	10,695	7,736	17,767	7,479	6,716
5	22,973	12,528	9,063	20,813	8,761	7,867
6	26,335	14,361	10,389	23,859	10,043	9,018
7	29,137	15,889	11,494	26,397	11,111	9,978

* The Consumer Price Index set to a base of 1971 = 100 was used as the basis to translate 1980 values to 1979 dollars. The 1980 figures were multiplied by a factor of .90104, based on the relationship between CPI Index values of 191.2 and 212.2 for 1979 and 1980, respectively.

** Calibrated FIA Curve (2): Contents Damage - 30% of structural damage

TABLE A.4.5.

DEPTH DAMAGE TO COMMERCIAL CONTENTS
(in 1979 Dollars)
(Dollars/square foot)

Type of Commercial Structure	Depth Relative to First Floor						
	0-1/2	1	2	3	4	5	6
Food/Variety	1.50	6.00	8.00	10.25	12.50	13.50	13.75
Automotive Sales and Service	6.25	12.50	19.25	25.25	30.25	37.50	42.00
Hardware and Home Furnishings	2.00	4.25	4.25	4.25	8.25	8.25	8.25
Other Retail	4.25	20.25	39.75	45.50	50.75	52.25	52.50
Amusement Recreation Service	(Use Structural Data Only)						
Office and Personnel Services	13.25	23.50	30.25	35.25	36.50	38.25	39.50

TABLE A.4.6.

DEPTH DAMATE TO COMMERCIAL STRUCTURES
(in 1979 Dollars)
(Dollars/square foot)

Type of Commercial Structure	Depth Relative to First Floor						
	0-1/2	1	2	3	4	5	6
Food/Variety	0.75	1.50	2.25	3.00	3.25	4.00	4.75
Automotive Sales and Service	0.75	1.50	2.00	3.00	3.50	4.00	4.25
Hardware and Home Furnishings	1.00	1.50	2.25	2.75	3.50	4.25	4.50
Other Retail	1.00	1.50	2.00	3.00	3.50	4.00	4.50
Amusement Recreation Service	1.00	1.50	2.25	3.00	3.50	4.00	4.50
Office and Personnel Services	0.75	1.25	2.25	3.00	3.25	4.00	4.50

TABLE A.4.7

DEPTH DAMAGE TO COMMERCIAL STRUCTURES AND CONTENTS
(in 1979 Dollars)
(Dollars/square foot)

Type of Commercial Structure	Depth Relative to First Floor						
	0-1/2	1	2	3	4	5	6
Food/Variety	2.25	7.50	10.25	13.25	15.75	17.50	18.25
Automotive Sales and Service	7.00	14.00	21.25	28.25	33.75	41.50	46.25
Hardware and Home Furnishings	3.00	5.75	6.50	7.00	11.75	12.50	12.75
Other Retail	5.25	21.75	41.75	48.50	54.25	56.25	57.00
Amusement Recreation Service	1.00	1.50	2.25	3.00	3.50	4.00	4.50
Office and Personnel Services	14.00	24.75	32.50	38.25	39.75	42.25	44.00

TABLE A.4-8

BADGER: 1:100 YEAR DIRECT FLOOD DAMAGE ESTIMATE

Location	Direct Damage ($ 1984)
Maple Street	20,519
River Road	22,763
Beothuk Street	63,018
Main Street	23,579
T.C.H.	21,446
TOTAL	$151,325

APPENDIX 5.0

A.5 Flood Damage Reduction Cost Estimates

Table	Description
A5.1	1/100 Year Dyking: Maple Street
A5.2	1/20 Year Dyking: Maple Street
A5.3	1/100 Year Dyking: Lower Town
A5.4	1/20 Year Dyking: Lower Town
A5.5	1/100 Year Dyking: Main Street
A5.6	1/20 Year Dyking: Main Street
A5.7	1/100 Year Dyking: TCH
A5.8	1/20 Year Dyking: TCH
A5.9	Flood Proofing Cost Summary for Maple Street (1/20 and 1/100 Year)
A5.10	Flood Proofing Cost Summary for Lower Town (1/20 and 1/100 Year)
A5.11	Flood Proofing for Main Street (1/20 and 1/100 Year)
A5.12	Flood Proofing for Trans Canada Highway (1/20 and 1/100 Year)
A5.13	Flood Warning with Blasting: Cost Estimate

Table A5.1

1/100 YEAR DYKING: MAPLE STREET

Item	Quantity	Unit	Unit Cost $	Total Cost
1. Clearing and Grubbing	nil	ha	2,200.00	nil
2. 600 mm dia. C.S.P.	13	m	100.00	1,300.00
3. 600 mm dia. Flap Gate	1	ea	690.00	690.00
4. Topsoil and Seed	2,858	m^2	1.75	5,001.50
5. Backfill (Previously Excavated)	16,426	m^3	7.00	114,982.00
6. Backfill - Select	15,125	m^3	9.00	136,125.00
7. Rip - Rap	805	m^3	61.21	49,274.05
8. Membrane - P.V.C.	8,663	m^2	7.36	63,759.68
9. Dyke Excavation	29,317	m^3	5.25	153,914.25
10. Concrete Flood Wall with Piling	n/a	n/a	n/a	nil
11. Ditching along Dyke	326	m^3	5.00	1,630.00
12. Wall and Gate	n/a	L.S.	n/a	nil
13. Dewatering	1	L.S.	4,000.00	4,000.00
				530,676.48
			say	531,000.00

Table A5.2

1/20 YEAR DYKING: MAPLE STREET

Item	Quantity	Unit	Unit Cost $	Total Cost
1. Clearing and Grubbing	0.1	ha	2,200.00	220.00
2. 600 mm dia. C.S.P.	12	m	100.00	1,200.00
3. 600 mm dia. Flap Gate	1	ea	690.00	690.00
4. Topsoil and Seed	600	m^2	1.75	1,050.00
5. Backfill (Previously Excavated)	1,500	m^3	7.00	10,550.00
6. Backfill - Select	1,500	m^3	9.00	13,500.00
7. Rip - Rap	177	m^3	61.21	10,834.17
8. Membrane - P.V.C.	822	m^2	8.00	6,576.00
9. Dyke Excavation	2,933	m^3	5.25	15,398.25
10. Piles	nil	m^2	157.00	nil
11. Ditching along Dyke	30	m^3	6.00	180.00
12. Dewatering	1	L.S.	1,000.00	1,000.00
				61,148.42
			say	61,000.00

Table A5.3

1/100 YEAR DYKING: LOWER TOWN

Item	Quantity	Unit	Unit Cost $	Total Cost
1. Clearing and Grubbing	nil	ha	2,200.00	nil
2. 600 mm dia. C.S.P.	27	m	100.00	2,700.00
3. 600 mm dia. Flap Gate	2	ea	690.00	1,380.00
4. Topsoil and Seed	5,750	m^2	1.75	10,062.50
5. Backfill (Previously Excavated)	25,011	m^3	7.00	175,077.00
6. Backfill - Select	18,149	m^3	9.00	163,341.00
7. Rip - Rap	1,905	m^3	61.21	116,605.05
8. Membrane - P.V.C.	9,988	m^2	7.36	73,511.68
9. Dyke Excavation	34,158	m^3	5.25	179,329.50
10. Concrete Flood Wall with Piling	1	L.S.	26,110.00	26,110.00
11. Ditching along Dyke	390	m^3	5.00	1,950.00
12. Wall and Gate	n/a	L.S.	n/a	nil
13. Dewatering	1	L.S.	4,000.00	4,000.00
				754,066.73
			say	754,000.00

Table A5.4

1/20 YEAR DYKING: LOWER TOWN

Item	Quantity	Unit	Unit Cost $	Total Cost
1. Clearing and Grubbing	0.06	ha	2,200.00	132.00
2. 600 mm dia. C.S.P.	nil	m	100.00	nil
3. 600 mm dia. Flap Gate	nil	ea	690.00	nil
4. Topsoil and Seed	1,125	m^2	1.75	1,968.75
5. Backfill (Previously Excavated)	nil	m^3	7.00	nil
6. Backfill - Select	530	m^3	9.00	4,770.00
7. Rip - Rap	nil	m^3	61.21	nil
8. Membrane - P.V.C.	nil	m^2	8.00	nil
9. Dyke Excavation	nil	m^3	5.25	nil
10. Piles	910	m^2	157.00	142,870.00
11. Ditching along Dyke	nil	m^3	6.00	nil
12. Dewatering	n/a	L.S.	n/a	nil
				149,740.75
			say	150,000.00

Table A5.5

1/100 YEAR DYKING: MAIN STREET

Item	Quantity	Unit	Unit Cost $	Total Cost
1. Clearing and Grubbing	1.05	ha	2,200.00	2,310.00
2. 600 mm dia. C.S.P.	12	m	100.00	1,200.00
3. 600 mm dia. Flap Gate	3	ea	690.00	2,070.00
4. Topsoil and Seed	2,632	m^2	1.75	4,606.00
5. Backfill (Previously Excavated)	11,958	m^3	7.00	83,706.00
6. Backfill - Select	9,518	m^3	9.00	85,662.00
7. Rip - Rap	823	m^3	61.21	50,375.83
8. Membrane - P.V.C.	5,237	m^2	7.36	38,544.32
9. Dyke Excavation	18,190	m^3	5.25	95,497.50
10. Concrete Flood Wall with Piling	nil	L.S.	n/a	nil
11. Ditching along Dyke	204	m^3	5.00	1,020.00
12. Wall and Gate	n/a	L.S.	n/a	nil
13. Dewatering	n/a	L.S.	5,000.00	5,000.00
				369,991.65
			say	370,000.00

Table A5.6

1/20 YEAR DYKING: MAIN STREET

Item	Quantity	Unit	Unit Cost $	Total Cost
1. Clearing and Grubbing	0.02	ha	2,200.00	44.00
2. 600 mm dia. C.S.P.	nil	m	100.00	nil
3. 600 mm dia. Flap Gate	1	ea	690.00	690.00
4. Topsoil and Seed	215	m^2	1.75	376.25
5. Backfill (Previously Excavated)	nil	m^3	7.00	nil
6. Backfill - Select	66	m^3	9.00	594.00
7. Rip - Rap	nil	m^3	61.21	nil
8. Membrane - P.V.C.	nil	m^2	8.00	nil
9. Dyke Excavation	nil	m^3	5.25	nil
10. Piles	300	m^3	157.00	47,100.00
11. Ditching along Dyke	nil	m^3	6.00	nil
12. Dewatering	nil	L.S.	n/a	nil
				48,804.25
			say	49,000.00

Table A5.7

1/100 YEAR DYKING: TRANS CANADA HIGHWAY

Item	Quantity	Unit	Unit Cost $	Total Cost
1. Clearing and Grubbing	1.1	ha	2,200.00	2,420.00
2. 600 mm dia. C.S.P.	38	m	100.00	3,800.00
3. 600 mm dia. Flap Gate	3	ea	690.00	2,070.00
4. Topsoil and Seed	2,489	m	1.75	4,355.75
5. Backfill (Previously Excavated)	13,702	m^3	7.00	95,914.00
6. Backfill - Select	11,652	m^3	9.00	104,868.00
7. Rip - Rap	759	m^3	61.21	46,458.39
8. Membrane - P.V.C.	5,744	m^2	7.36	42,275.84
9. Dyke Excavation	29,761	m^3	5.25	156,245.25
10. Concrete Flood Wall with Piling	nil	L.S.	n/a	nil
11. Ditching along Dyke	330	m^3	5.00	1,650.00
12. Wall and Gate	1	L.S.	3,807.00	3,807.00
13. Dewatering	1	L.S.	4,000.00	4,000.00
				467,864.23
			say	468,000.00

Table A5.8

1/20 YEAR DYKING: TRANS CANADA HIGHWAY

Item	Quantity	Unit	Unit Cost $	Total Cost
1. Clearing and Grubbing	0.09	ha	2,200.00	198.00
2. 600 mm dia. C.S.P.	22	m	100.00	2,200.00
3. 600 mm dia. Flap Gate	2	ea	690.00	1,380.00
4. Topsoil and Seed	959	m^2	1.75	1,678.25
5. Backfill (Previously Excavated)	nil	m^3	7.00	nil
6. Backfill - Select	660	m^3	9.00	5,940.00
7. Rip - Rap	nil	m^3	61.21	nil
8. Membrane - P.V.C.	nil	m^2	8.00	nil
9. Dyke Excavation	nil	m^3	5.25	nil
10. Piles	821	m^2	157.00	128,897.00
11. Ditching along Dyke	nil	m^3	6.00	nil
12. Dewatering	nil	L.S.	n/a	nil
				140,293.25
			say	140,000.00

TABLE A5.9

FLOOD PROOFING COST SUMMARY FOR: Maple Street

Floodproofing for Event: 1/20yr. 1:100yr.

Structure Building No.	Approach and Inclusions		Summary Cost Est. (\$ 1984)	Summary Cost Est. (\$ 1984)
	First Floor			
45	· engineering assess		—	1800-
49	· disconnect / extend /		—	2000-
53	reconnect services		—	2200-
	· elevate / move			
	· fill / conc. pad porch		First Floor	6000-
	· elev. fuel tank (as req'd)			
	· insulation			
	· skirt replacement			
	· steps replacement			
	· landscaping			
	Substructures			
57	· engineering assess		—	13500-
65	· disconnect / extend /		—	15200-
73	reconnect services		—	15300-
79	· raise / support		—	14800-
81	superstructure		—	8200-
83	· remove existing		—	22000-
85	foundation (walls, slab)		13000-	13000-
60	sequentially or whole		—	19800-
58	· reconstruct reinforced		—	15200-
44	"undrained" foundation		—	22000-
	· backfill, sump pump		—	
	steps, landscape, exterior finishes	Substruct	13000-	159000-
	· replace stored contents			
	Roadways			
Maple	· clear, fill, top off		—	12000-
	Special Structures			
	· none for special attention		—	—
	Total Cost		13000-	177000-

	Initials	Date
Prepared By		
Approved By		

TABLE A5.10

FLOOD PROOFING COST SUMMARY FOR: LOWER TOWN

Floodproofing for Event: 1/20 yr. 1:100 yr.

	Structure Building No.	Approach and Inclusions	Summary Cost Est. ($ 1984)	Summary Cost Est. ($ 1984)
1	River Rd.	First Floor		
2	1	· engineering assess	—	9500 -
3	2	· disconnect / extend /	—	1500 -
4	3	reconnect services	—	6700 -
5	6	· elevate / move	—	3300 -
6	7	· fill / conc. pad porch	—	14800 -
7	8	· elev. fuel tank (elev'd)	—	4200 -
8	9	· insulation	2000 -	3000 -
9	10	· skirt replacement	—	5000 -
10	Beothuk	· steps replacement	—	—
11	U.C	· landscaping	—	9700 -
12	Town Hall		—	20300 -
13	4		—	4000 -
14	5		—	5000 -
15	6		—	5000 -
16	7		—	9800 -
17	8		—	15200 -
18	8A		—	2000 -
19	9		—	4000 -
20	12		12000	15000 -
21	13		2000	3000 -
22	STP		2000	3000 -
23	#		—	3000
24	14		—	4900 -
25	15		—	4900 -
26	16		—	4000 -
27	17		—	7200 -
28	18		—	5900 -
29	19		—	4100 -
30	21		—	14800 -
31	22		—	10300 -
32	24		—	5000 -
33	25		—	5000 -
34	26		—	5000 -
35	28		—	8000 -
36	29		—	11700
37	31		—	8200 -
38		First Floor Only	18000	246000
39				
40	6	Substructures with	—	12000 -
41	9	First Floor	10000	12000 -
42	24		—	10000 -
43			10000	34000 -
44				
45		TOTAL	28000	280000 -
46				

	Initials	Date
Prepared By		
Approved By		

		1	2	3	4
TABLE A5.10 (con't)			1:20	1:100	
	Substructures				
32	· engineering assess			12000 -	
27	· disconnect / extend / reconnect services			15000 -	
	· raise / support superstructure	TOTAL	—	27000 -	
	· remove existing foundation (walls, slab) sequentially or whole	(only substructures)			
	· reconstruct reinforced "undrained" foundation				
	· backfill, sump pump steps, landscape, exterior finishes				
	· replace stored contents				
	Roadways				
	· clear, fill, top off		—	37500 -	
	Special Structures				
	Arena (sumps, shields, seals, valves membrane, wetproof, HVAC)		14000 -	17000 -	
	Totals		42000 -	361500 -	

	Initials	Date
Prepared By		
Approved By		

TABLE A5.11

FLOOD PROOFING COST SUMMARY FOR: MAIN STREET

Floodproofing for Event: 1/20yr. 1:100yr.

Structure Building No.	Approach and Inclusions	1	2 Summary Cost Est. ($ 1984)	3 Summary Cost Est. ($ 1984)	4
	First Floor				
6	· engineering assess			8000 -	
8	· disconnect / extend /			5000 -	
9	reconnect services			500 -	
10	· elevate / move			2500 -	
13 (P.O.)	· fill / conc. pad porch			2000 -	
18	· elev. fuel tank (as req'd)		3000 -	5000 -	
18A	· insulation		3000 -	5000 -	
19 (ware H.)	· skirt replacement			10000 -	
23	· steps replacement			5000 -	
25	· landscaping			5000 -	
			6000 -	48000 -	
	Substructures				
15	· engineering assess			22000 -	
21	· disconnect / extend /			22000 -	
24	reconnect services			10000 -	
	· raise / support			54000 -	
	superstructure				
	· remove existing				
	foundation (walls, slab)				
	sequentially or whole				
	· reconstruct reinforced				
	"undrained" foundation				
	· backfill, sump pump				
	steps, landscape,				
	exterior finishes				
	· replace stored contents				
	Roadways				
Main St	· clear, fill, top off		—	17000 -	
	Special Structures				
	· no major constraints				
	TOTAL		6000 -	119000 -	

TABLE A5:12

FLOOD PROOFING COST SUMMARY FOR: TRANS CAN. HWY

	Initials	Date
Prepared By		
Approved By		

Floodproofing for Event: 1/20 yr. 1:100 yr.

Structure Building No.	Approach and Inclusions	1	2 Summary Cost Est. (\$ 1984)	3 Summary Cost Est. (\$ 1984)	4
	First Floor				
1	· engineering assess			3800 -	
2	· disconnect / extend /			5200 -	
3	reconnect services			6000 -	
9	· elevate / move			8000 -	
11	· fill / conc. pad porch			9500 -	
12	· elev. fuel tank (as req'd)			15500 -	
15	· insulation			6000 -	
16	· skirt replacement			4000 -	
18	· steps replacement			5000 -	
	· landscaping				
				63000 -	
	Substructures				
14	· engineering assess		8000 -	10000 -	
17	· disconnect / extend /		17000 -	20000 -	
	reconnect services				
	· raise / support			30000 -	
	superstructure				
	· remove existing				
	foundation (walls, slab)				
	sequentially or whole				
	· reconstruct reinforced				
	"undrained" foundation				
	· backfill, sump pump				
	steps, landscape,				
	exterior finishes				
	· replace stored contents				
	Roadways				
	pavement (top off with		—	7500	
	additional asphalt)				
	Special Structures				
	TOTAL		25000 -	100500 -	

Table A5.13
Flood Warning with Blasting:
Cost Estimate

Blasting Mobilization (Day 1)

	Labour	Expenses
13 man crew (2 - EMO, 2 - Explosives Supplier, 5 - Badger Team, 4 - Military)		
1 observer (Dept. Environment+pilot)		
14 men, 102 man-hours @ $15/hr	$1,530	$ 500
Total Day 1	$ 2,030	

Blasting (Day 2)

Bell Jet Ranger helicopter (6 hr @ $400/hr)		$ 2,400
"Labrador" helicopter (6 hr @ $3500/hr)		$21,000
Explosives (10,000 lbs/day as in 1983)		$10,000
Misc. expenses		$ 1,600
14 man, 150 man-hours @ $15/hr	$2,250	
Total Day 2	$37,250	

Blasting (Day 3)

Operations as Day 2	Total Day 3	$37,250

Blasting Demobilize (Day 4)

Bell Jet Ranger final recon. (3 hr @ $400/hr)		$ 1,200
EMO, Supplier, Env. travel		$ 200
10 men, 122 man-hours @ $15/hr (clean-up operations, prepare reports)	$1,830	$ 500
Total Day 4	$ 3,730	
TOTAL OPERATION	$80,260	

Present Cost of Blasting Operations with Flood Warning

Assuming blasting undertaken 25 times in next 50 years (at a frequency of once every two years) the present cost for a range of discount rates is:

Discount Rate	Compount Interest Factor	Present Cost
5%	9.128	$732,613
10%	4.958	$397,929
15%	3.331	$267,346

To provide the maximum possible lead time, a flood warning system is also required as part of this operation. The cost of this system is discussed in Section 10.6.1 and will involve an initial installation cost of $24000, replacement in 25 years, and annual maintenance monitoring/analysis costs of $5500 per year. The present worth cost of this activity is noted below and is added to the blasting operations to arrive at a total present worth cost for this option.

Discount Rate	Flood Warning	Blasting Operation	Total Present Worth Cost ($ 1984)
5%	$131,495	$732,613	$864,108
10%	$ 80,746	$397,929	$478,675
15%	$ 61,366	$267,346	$328,712

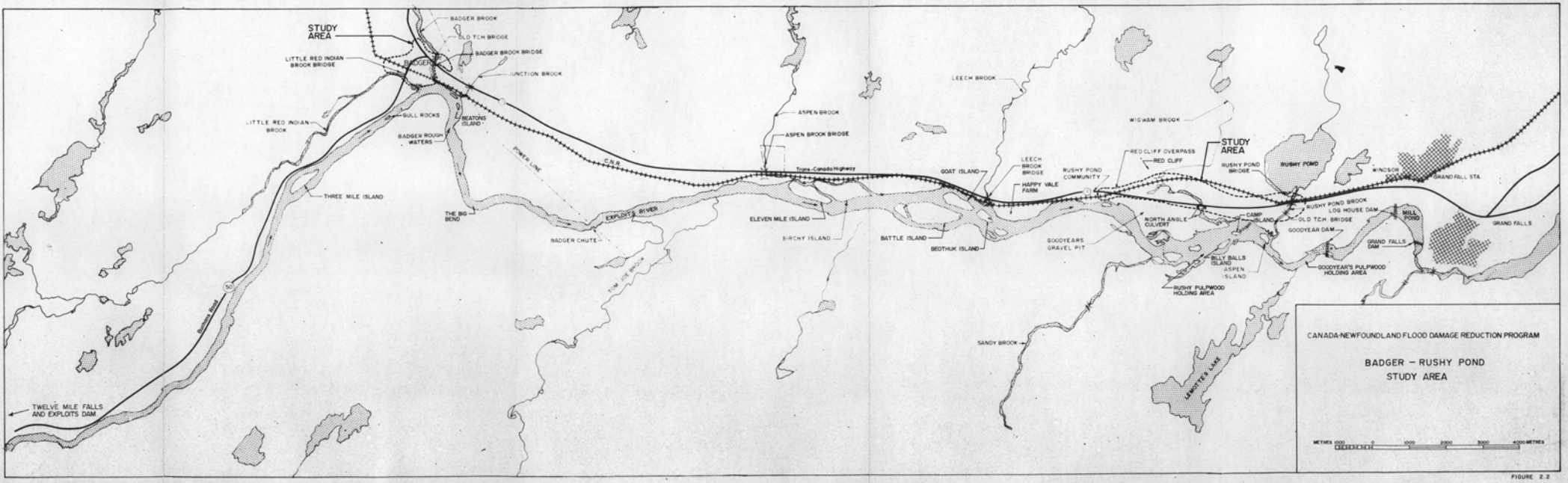
STUDY AREA
BADGER BROOK
OLD TCH BRIDGE
BADGER BROOK BRIDGE
LITTLE RED INDIAN BROOK BRIDGE
BADGER
JUNCTION BROOK
LITTLE RED INDIAN BROOK
BULL ROCKS
BEATONS ISLAND
BADGER ROUGH WATERS
THREE MILE ISLAND
THE BIG BEND
POWER LINE
C.N.R.
EXPLOITS RIVER
BADGER CHUTE
TOM JOE BROOK
Exploits Road
TWELVE MILE FALLS AND EXPLOITS DAM
ASPEN BROOK
ASPEN BROOK BRIDGE
Trans-Canada Highway
ELEVEN MILE ISLAND
BIRCHY ISLAND
BATTLE ISLAND
BEOTHUK ISLAND
GOAT ISLAND
LEECH BROOK
LEECH BROOK BRIDGE
HAPPY VALE FARM
RUSHY POND COMMUNITY
GOODYEARS GRAVEL PIT
NORTH ANGLE CULVERT
WIGWAM BROOK
RED CLIFF OVERPASS
RED CLIFF
STUDY AREA
RUSHY POND BRIDGE
RUSHY POND
CAMP ISLAND
BILLY BALLS ISLAND
ASPEN ISLAND
RUSHY PULPWOOD HOLDING AREA
SANDY BROOK
LEMOITE'S LAKE
RUSHY POND BROOK
LOG HOUSE DAM
OLD T.C.H. BRIDGE
GOODYEAR DAM
GOODYEAR'S PULPWOOD HOLDING AREA
GRAND FALLS DAM
MILL POND
WINDSOR
GRAND FALL STA.
GRAND FALLS
CANADA-NEWFOUNDLAND FLOOD DAMAGE REDUCTION PROGRAM
BADGER – RUSHY POND
STUDY AREA
METRES 1000 0 1000 2000 3000 4000 METRES

FIGURE 2.2

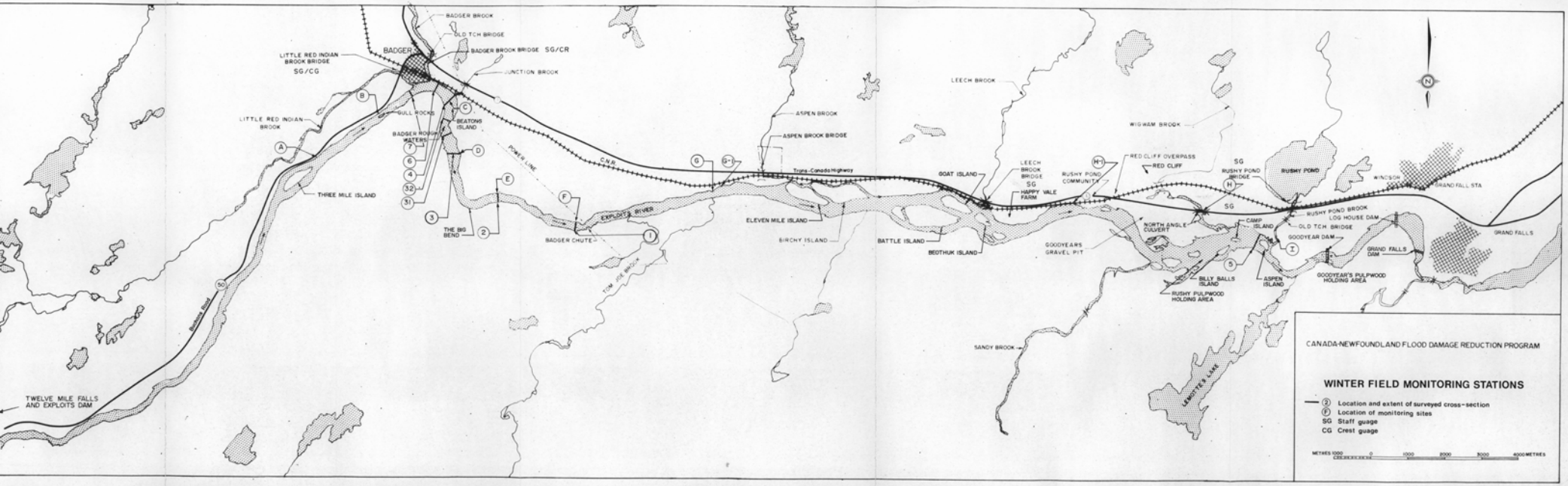
BADGER BROOK
OLD TCH BRIDGE
BADGER
BADGER BROOK BRIDGE SG/CR
LITTLE RED INDIAN BROOK BRIDGE SG/CG
JUNCTION BROOK
LITTLE RED INDIAN BROOK
BULL ROCKS
BEATONS ISLAND
BADGER HOUSE WATERS
THREE MILE ISLAND
THE BIG BEND
POWER LINE
C.N.R.
EXPLOITS RIVER
BADGER CHUTE
TIM JOE BROOK
ASPEN BROOK
ASPEN BROOK BRIDGE
Trans-Canada Highway
ELEVEN MILE ISLAND
BIRCHY ISLAND
BATTLE ISLAND
BEOTHUK ISLAND
GOAT ISLAND
LEECH BROOK
LEECH BROOK BRIDGE SG
HAPPY VALE FARM
RUSHY POND COMMUNITY
RED CLIFF OVERPASS
RED CLIFF
WIGWAM BROOK
SG
RUSHY POND BRIDGE
RUSHY POND
WINDSOR
GRAND FALL STA
GRAND FALLS
NORTH ANGLE CULVERT
GOODYEARS GRAVEL PIT
CAMP ISLAND
RUSHY POND BROOK
LOG HOUSE DAM
OLD TCH BRIDGE
GOODYEAR DAM
GRAND FALLS DAM
GOODYEAR'S PULPWOOD HOLDING AREA
BILLY BALLS ISLAND
RUSHY PULPWOOD HOLDING AREA
ASPEN ISLAND
SANDY BROOK
LEMOTY'S LAKE
Exploits River
TWELVE MILE FALLS AND EXPLOITS DAM
N
CANADA-NEWFOUNDLAND FLOOD DAMAGE REDUCTION PROGRAM
WINTER FIELD MONITORING STATIONS
(2) Location and extent of surveyed cross-section
(F) Location of monitoring sites
SG Staff guage
CG Crest guage
METRES 1000 0 1000 2000 3000 4000 METRES

FIG. 41

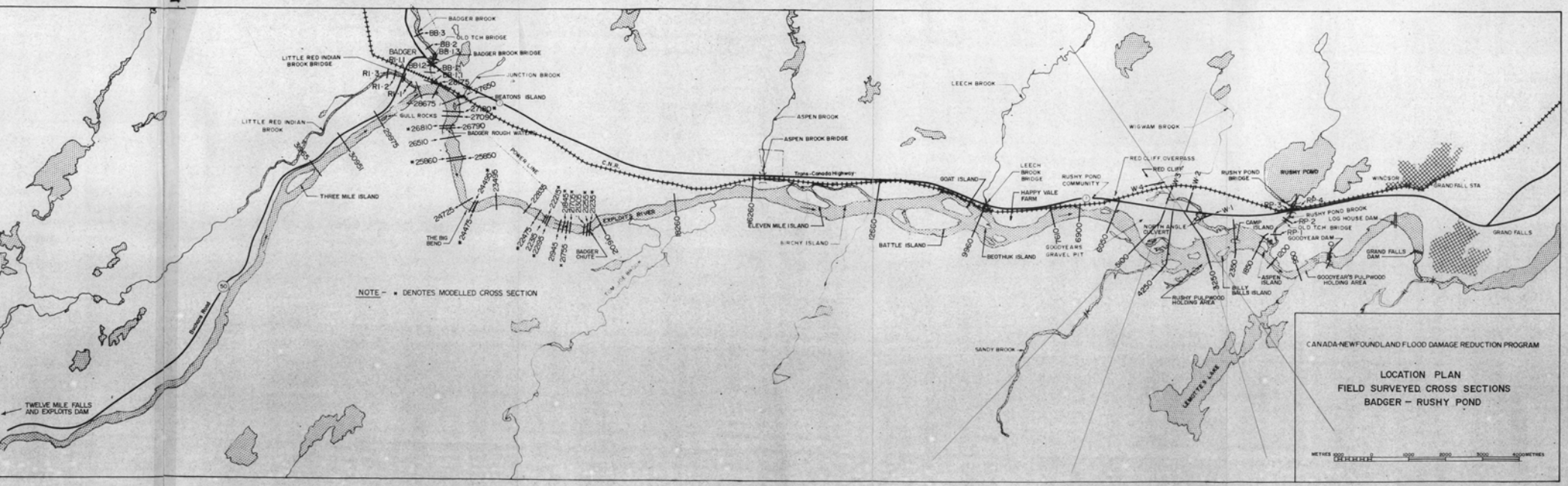
CANADA-NEWFOUNDLAND FLOOD DAMAGE REDUCTION PROGRAM
LOCATION PLAN
FIELD SURVEYED CROSS SECTIONS
BADGER – RUSHY POND
NOTE – * DENOTES MODELLED CROSS SECTION
METRES 1000 0 1000 2000 3000 4000 METRES
BADGER BROOK
OLD TCH BRIDGE
BADGER BROOK BRIDGE
LITTLE RED INDIAN BROOK BRIDGE
JUNCTION BROOK
BEATONS ISLAND
LITTLE RED INDIAN BROOK
GULL ROCKS
BADGER ROUGH WATER
POWER LINE
C.N.R.
THREE MILE ISLAND
THE BIG BEND
EXPLOITS RIVER
BADGER CHUTE
TWELVE MILE FALLS AND EXPLOITS DAM
Bowring Road
ASPEN BROOK
ASPEN BROOK BRIDGE
Trans-Canada Highway
ELEVEN MILE ISLAND
BIRCHY ISLAND
BATTLE ISLAND
GOAT ISLAND
BEOTHUK ISLAND
GOODYEARS GRAVEL PIT
LEECH BROOK
LEECH BROOK BRIDGE
HAPPY VALE FARM
RUSHY POND COMMUNITY
WIGWAM BROOK
RED CLIFF OVERPASS
RED CLIFF
NORTH ANGLE CULVERT
RUSHY PULPWOOD HOLDING AREA
SANDY BROOK
LEMOTTE'S LAKE
RUSHY POND BRIDGE
RUSHY POND
CAMP ISLAND
ASPEN ISLAND
BILLY BALLS ISLAND
RUSHY POND BROOK
LOG HOUSE DAM
OLD TCH BRIDGE
GOODYEAR DAM
GOODYEAR'S PULPWOOD HOLDING AREA
GRAND FALLS DAM
GRAND FALLS
WINDSOR
GRAND FALL STA

FIG. 4.10