CANADA-NEWFOUNDLAND
FLOOD DAMAGE REDUCTION PROGRAM

GLOVERTOWN

FLOOD STUDY REPORT

VOLUME 1: MAIN REPORT

Prepared by:

SHAWMONT NEWFOUNDLAND LIMITED
St. John's, Newfoundland

SMR-19-89 (Volume 1)

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ShawMont Newfoundland Limited

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Canada Newfoundland Flood Damage Reduction Program
c/o Department of Environment and Lands
Confederation Building Annex (Fourth Floor)
St. John's, Newfoundland

Attn: Mr. R. Picco, P. Eng.

Dear Mr. Picco:

Re: Glovertown Flood Study Report

We take pleasure in submitting fifty (50) copies of the final report on this interesting hydrotechnical study.

We trust the findings of the study will provide a sound basis for future municipal planning and will help reduce future losses from flooding in Glovertown.

We wish to express our appreciation of input provided by members of the Technical Committee.

Yours very truly,

A.D. Peach, P. Eng.
President

P.C. Helwig, P. Eng.
Study Manager

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EXECUTIVE SUMMARY

The main purpose of this study was to estimate the 1:20 and 1:100 year recurrence interval flood levels, determine the extent of flooding associated with each level and plot the corresponding flood risk contours on mapping provided by the Client.

Past experience with flooding at Glovertown indicates that flooding in this area is due to ice jams forming in the Terra Nova River. Accordingly, the methodology adopted in this study focused on an evaluation of ice jam induced flooding. The study program that was carried out included the following tasks:

i) Collection of documentary data on climate, hydrology and information on past floods.

ii) A field program to check existing cross-section data and obtain supplementary cross-section data. An interview survey to obtain information about past floods, was also undertaken as part of the field program.

iii) Ice studies to establish ice jam induced flood levels, as a function of flow and ice thickness and to investigate the effects of the tidal levels on flood water profiles.

iv) Hydrologic studies to estimate river flows and ice thicknesses concurrent with ice jam events and thereby to establish flood risk contours.

v) Preparation of a report summarizing the methods and findings of the study and suggesting possible remedial measures.

The study confirmed that flood events were due to ice jams forming in the river. Simulations with the ice model duplicated the sequences of ice jam formation observed during the 1984 and 1988 ice jam floods. Once the model was calibrated it was used to simulate flood conditions in the river for a wide range of flows and ice thicknesses and to compute maximum water levels at each section for each set of simulation data.

Using the results of the ice model simulations, in conjunction with estimated ice thickness and breakup flow probabilities, 1:20 year and 1:100 year recurrence interval flood risk contours were determined. These have been plotted on the flood risk map in the envelope pocket at the end of the main report.

The following recommendations are suggested to minimize the damage from future flooding in the study area.

Non-Structural Measures:

i) Glovertown Council should implement zoning regulations to control development in flood prone areas, as delineated on the flood risk map produced in this study.

ii) Monitoring of ice jam floods should be continued so as to improve the data base and confirm or adjust the findings of this study.

Structural Measures:

iii) Construction of an ice boom in the vicinity of Cross-Section 6.5 should be investigated. A boom would reduce the volume of ice in the lower river with minimal negative impact upstream of the Cross-Section 6.5 where the valley is well incised and the banks uninhabited. [A resident noted that ice jam problems were infrequent when the "old" log boom was in service at this location]. Further studies, using the ice model, are recommended to optimize the location and estimate loads on the boom.

iv) A combination of flood dyke and channel improvements to reduce water level rise and contain ice and water flows within the river channel. Further studies are recommended, using the ice model, with appropriate adjustments, to evaluate the effects of these measures.

v) Flood proofing of exposed existing structures and buildings.

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A field report containing data on past flooding and information collected in the field program is also available. Copies can be obtained by contacting the Canada-Newfoundland Flood Damage Program, c/o Dept. of Environment and Lands (Nfld.), St. John's (Nfld.).

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PART ONE

INTRODUCTION

1. INTRODUCTION

1.1 BACKGROUND

The lower reaches of Terra Nova River, in Glovertown are at risk from flooding due to ice jams. Two recent ice jam floods have occurred on the river in 1984 (Feb. 8-11) and 1988 (Feb. 28 - March 1). An ice jam also occurred in 1987 on the rapids section, but broke up without incident. Two earlier ice jam floods are reported but details are scarce.

In response to this problem the Governments of Canada and Newfoundland and Labrador commissioned a flood risk mapping study under the auspices of the Canada-Newfoundland Flood Damage Reduction Program.

The purpose of this study was to investigate the factors that cause flooding in Glovertown and to determine flood risk contours, showing the extent of flooding for floods having recurrence intervals of twenty (20) and one hundred (100) years. These contours would be plotted on detailed base mapping to provide information on flood risks to the Town Council of Glovertown.

1.2 AUTHORIZATION

In May 1988 a request for proposals was published giving the Terms of Reference for a flood risk mapping study in Glovertown. The proposal submitted by ShawMont Newfoundland Limited in association with LaSalle Hydraulic Laboratory Limited was selected. The study contract was subsequently awarded on behalf of the Canada-Newfoundland Flood Damage Reduction Program, by a letter from the Department of Environment and Lands (Newfoundland) signed by the Minister, the Hon., James Russell, and dated October 11, 1988.

1.3 ACKNOWLEDGEMENTS

The interest and cooperation of the Technical Committee: L. Langley - Environment Canada, Dr. W. Ullah, and R. Picco - Environment and Lands (Newfoundland) is greatly appreciated. Input from M. Goebel, Environment and Lands (Newfoundland) was also very helpful.

The principal members of the study team were:

from ShawMont Newfoundland Limited

P.C. Helwig - Study Manager, responsible for hydrology

H.J. Keats - Field Program

from LaSalle Hydraulic Laboratory Ltd.

G.K. Holder - Hydraulic and Ice Studies

PART TWO

METHODOLOGY

2.0 METHODOLOGY

2.1 LOCATION OF STUDY AREA

Glovertown is located about fifty-seven (57) km east of Gander (Newfoundland) on Alexander Bay, see Figure 2.1. The flood prone area is located near the outlet of Terra Nova River in the area known as Glovertown South. This portion of Glovertown lies along the low left bank of Terra Nova River and stretches inland about 800 metres from the coastal road. Land along the right bank which is higher, is not subject to flooding but is largely undeveloped. Glovertown South is, at present, only partly developed containing several homes surrounded by woods. Further details on the hydraulic features of the river are given in Section 3.2. The Terra Nova River is one of the largest rivers on the Island of Newfoundland, having a drainage area of 2000 km^2 at the Glovertown streamflow gauging station (02YS005) located just upstream of the community.

2.2 CLIMATE

The climate in Newfoundland can be described as a modified continental type of climate (1)*. Continental because the weather originates over the Continental North America land mass and modified due to the proximity of the ocean. The moderating influence of the ocean reduces the extremes of temperature associated with a continental climate regime. Another feature of the climate in the area is the relative frequency of periods of thaw during the winter period.

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* Refers to listing in the Reference Section.

2.2 CLIMATE (Cont'd)

Table 2.1, summarizes climate data collected at the Climatological Station at Gander International Airport. These climatic parameter values are typical for the area, although somewhat moderated at Glovertown due to the closer proximity to the ocean.

TABLE 2.1
Climatic Normals for Gander International Airport

MEAN OF TEMPERATURE, PRECIPITATION, HUMIDITY, PRESSURE, WIND AND SUNSHINE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
TEMPERATURE (C)													
MAXIMUM	-2.4	-2.6	0.4	4.5	11.0	17.3	21.9	20.3	15.9	9.8	5.0	-0.4	8.4
MINIMUM	-9.9	-10.9	-7.4	-2.7	1.3	6.2	11.2	10.8	6.9	2.2	-1.4	-7.1	-0.1
MEAN	-6.2	-6.8	-3.5	0.9	6.2	11.8	16.5	15.6	11.4	6.0	1.8	-3.8	4.2
EXTREME MAXIMUM	11.7	12.8	14.5	21.7	28.3	32.8	35.6	33.4	28.9	24.4	20.6	14.4	35.6
EXTREME MINIMUM	-27.2	-31.1	-25.6	-15.6	-8.9	-2.8	0.6	-1.1	-1.7	-6.3	-13.9	-26.1	-31.1
PRECIPITATION													
RAINFALL (MM)	33.0	23.6	37.3	42.6	55.5	77.3	69.0	97.3	81.1	91.3	74.8	38.8	721.6
EXTREME IN 24 HR	34.3	42.9	60.2	65.3	45.0	37.1	96.3	98.3	57.2	50.0	58.2	40.6	98.3
SNOWFALL (CM)	78.7	76.2	72.3	47.1	13.1	2.8	0.0	0.0	0.1	12.2	31.8	70.9	405.2
EXTREME IN 24 HR	36.2	47.8	41.4	37.8	16.5	21.8	T	T	5.1	20.8	43.8	45.7	47.8
TOTAL (MM)	109.1	99.7	110.1	93.2	70.0	80.3	69.0	97.3	81.2	104.7	107.3	108.2	1130.1
EXTREME IN 24 HR	35.1	57.9	60.2	65.3	45.0	37.1	96.3	98.3	57.2	50.0	58.2	45.7	98.3
HUMIDITY													
VAPOUR PRESSURE (KPA)	0.36	0.34	0.41	0.53	0.72	1.02	1.37	1.35	1.06	0.79	0.62	0.43	0.75
DEW POINT (C)	-8.8	-9.7	-6.6	-2.6	1.6	6.6	11.2	11.0	7.2	2.8	-0.8	-6.2	0.5
RELATIVE HUMIDITY (%)	81	80	80	81	77	75	75	78	78	81	84	83	79
PRESSURE													
SEA LEVEL (KPA)	100.7	100.8	100.9	101.1	101.3	101.3	101.4	101.3	101.4	101.3	101.2	100.9	101.1
WIND													
PREVAILING DIRECTION	W	W	W	NNW	W	SW	SW	WSW	W	WSW	W	W	W
SPEED (KM/H)	24.4	23.9	23.4	21.6	19.7	18.7	17.3	17.2	18.9	20.6	21.8	22.8	20.8
PEAK WIND (KM/H)	161	145	135	116	114	116	105	113	116	129	129	159	161
SUNSHINE													
BRIGHT SUNSHINE (H)	85.1	98.7	104.4	115.8	162.3	183.6	214.2	186.3	146.0	110.7	66.6	68.5	1542.2
% OF POSSIBLE	31.4	34.5	28.4	28.2	34.3	38.0	43.9	41.8	38.5	32.9	24.1	26.5	34.5

[from Reference 2]

2.3 HISTORY AND DESCRIPTION OF FLOODING

Extensive documentation is available on two recent floods in Glovertown, in 1984 and in 1988 floods. Both floods were caused by ice jams. Two earlier floods were reported but details are scarce and causes are not known with certainty.

In 1984, the flood was due to an ice jam that formed at the mouth of Terra Nova River and caused flooding in Glovertown South. Two houses were seriously damaged and two others suffered minor damages on this occasion. The 1988 flood was also due to an ice jam that formed about 1.0 km upstream from the river mouth. Some damage was reported from the 1988 flood, including erosion of road embankments and damage to the contents of a shed.

Further details on the effects of these floods are provided in the Field Report (3).

2.4 METHODOLOGY

The main purpose of this study, as outlined in the Terms of Reference, was "to provide estimates of the 1:20 and 1:100 year recurrence interval flood levels, determine the extent of flooding associated with each level and to plot these levels on base mapping provided (by the Client)". The Terms of Reference also required that the techniques employed in the study follow the guidelines established by Environment-Canada (4).

Past experience with flooding at Glovertown indicates that flooding in this area is due to ice jams forming in the river. Accordingly the methodology adopted in this study focused on an evaluation of ice jam induced flooding. The severity of open water flooding was nevertheless investigated to confirm whether this condition was a significant cause of flooding. The study program that was carried out included the following tasks:

i) Collection of documentary data on climate, hydrology and information on past floods.

ii) A field program to check existing cross-section data and obtain supplementary cross-section data. An interview survey to obtain information about past floods, was also undertaken as part of the field program.

iii) Ice studies to establish ice jam induced flood levels, as a function of flow and ice thickness and to investigate the effects of the tidal levels on flood water profiles.

iv) Hydrologic studies to estimate river flows and ice thicknesses concurrent with ice jam events and thereby to establish flood risk contours for the 1 in 20 year and 1 in 100 year recurrence interval flood levels.

v) Preparation of a report summarizing the methods and findings of the study and suggesting possible remedial measures.

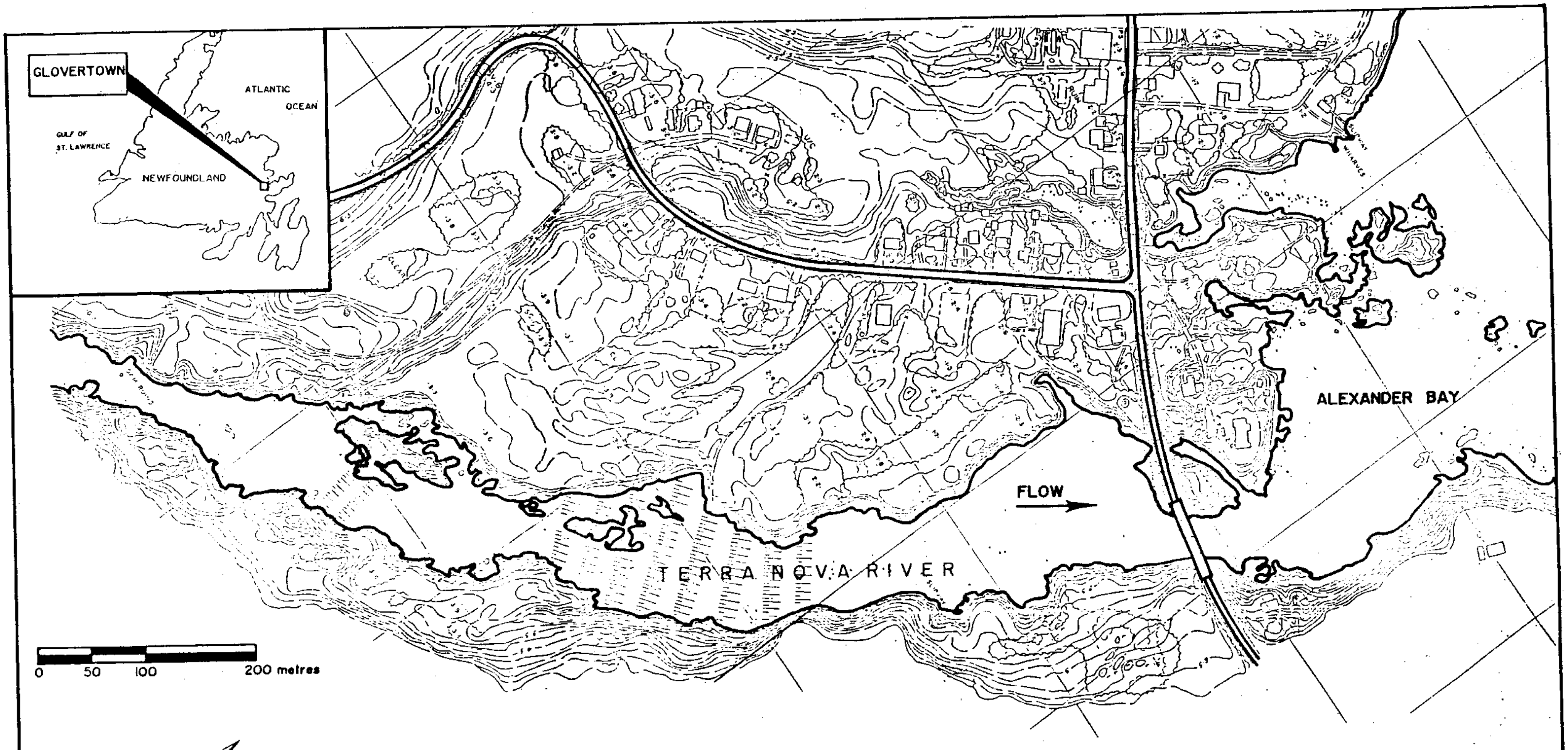

FIGURE 2.1

GLOVERTOWN FLOOD STUDY

- STUDY AREA MAP -

PART THREE
ICE STUDIES

3.0 ICE STUDIES

3.1 PREAMBLE

The purpose of this phase of the Glovertown flood study was to investigate the factors controlling ice jam flooding, in order to set up and calibrate a computer model based on the hydro-mechanical behaviour of fragmented ice covers in rivers. This model would then be used for computing flood levels resulting from selected flow and ice conditions. The relationships thereby established, when applied with statistics on flows and temperatures, from the hydrology study phase of the study, would be used to delineate flood risk contours.

3.2 FEATURES OF TERRA NOVA RIVER

The flood prone area is located near the outlet of the Terra Nova River, on Alexander Bay, in the area known as Glovertown South.

The outlet of the river as it enters Alexander Bay is approximately 150 m wide and is characterized by a series of small gravel bars that border the main channel. This was the site where the 1984 ice jam lodged. Two hundred and fifty metres upstream of the outlet, the river narrows to a width of 50 m and is crossed by a highway bridge. Upstream of the bridge, a tidal pool some 100 m wide by 300 m long extends to the foot of a series of rapids. In the 1988 flood an unstable jam initially formed in the rapids upstream of the tidal pool. This jam subsequently collapsed and reformed stably at the Tidal Pool. The rapids, which have an average width of 25 m extend upstream almost reaching to the Water Survey of Canada gauging station, some

3.2 FEATURES OF TERRA NOVA RIVER (Cont'd)

1000 m upstream of the tidal pool. Above the gauging station, the river width remains relatively constant and the flow returns to subcritical i.e., Froude No. <1.0. Further details on river geometry are given in the Field Report (3).

3.3 SETTING-UP THE ICE MODEL

3.3.1 Description of the Model

The ice model used for the Glovertown Study was developed at LaSalle Hydraulic Laboratory, hereafter LHL, based on studies done by Pariset and Hausser in the late 50's for the old Quebec Hydro Commission.

The results of these studies were the subject of two papers by Pariset and Hausser and Pariset, Hausser and Gagnon, references 5 and 6.

The calculation procedures developed by LHL were based almost entirely on the hydraulic/mechanical phenomena which take place as non-cohesive ice particles come down a river, meet an obstruction, and build up an ice cover. This approach implicitly assumes that an adequate supply of ice is available to satisfy the cover equilibrium criteria for whatever discharge is selected. In fact, this corresponds to calculating the highest level at each section; if more ice arrives, either the cover will progress in an upstream direction or the ice will be entrained underneath the downstream cover. The water level at a given section can only be exceeded if ice transported downstream creates an ice jam at a lower section whose backwater would drown-out that section.

3.3.1 Description of the Model (Cont'd)

During the freeze-up, a thin accumulation cover builds up as a mass of non-cohesive ice pieces, much of it in the form of frazil slush rather than as discrete, hard ice particles.

As winter progresses, cold from the surface penetrates the cover, gradually freezing the non-cohesive particles into the mass of the thermal cover down to the thickness determined by the degree-days of frost. In the spring, this whole cover is lifted and broken up by the rising discharge, furnishing a large supply of broken pieces of solid ice, that become available to form ice jams by the same ice accumulation processes as during freeze-up.

The mathematical model developed at LHL was used to simulate this pattern of ice formation, thermal thickening and breakup, and has been used with success on many projects in the past. These proven calculation techniques, were used to simulate the ice regime in the Terra Nova River.

As stated previously, ice formation in rivers is a function of flow velocity. In general, when the velocity is less than 0.6 m/s thermal sheet ice, such as found in a lake, forms. When flow velocities exceed this value, frazil or skim ice is generated. If a downstream obstacle is encountered ice particles can pile up against its upstream edge and form an accumulation cover or jam. The thickness of the accumulation cover is dependent on the velocity of flow; low velocities producing thin covers; high velocities thick ones.

Ice studies carried out at LHL revealed that rivers could be categorized as "wide" or "narrow" depending on the forces acting on the cover.

3.3.1 Description of the Model (Cont'd)

For the two cases, the leading edge of the cover progresses due to the accumulation of incoming floating ice with a thickness (t) given by the following relation for parameters defined in Figure 3.1.

$$\frac{V}{\sqrt{2gH}} = \sqrt{\frac{\rho - \rho^1}{\rho} \frac{t}{H} \left(1 - \frac{t}{H}\right)} \qquad (1)$$

In which : V = is the mean flow velocity upstream of the leading edge (m/s)
H = the mean depth defined by $H = A/B$ where A is the cross-section area and B the surface width (m);
ρ = the specific gravity of the water;
ρ^1 = the specific gravity of the ice.

As the cover lengthens, the increasing hydraulic forces on the cover must be balanced by the internal resistance created by the buoyancy of the accumulated ice and the reaction of the banks.

For "narrow rivers" the leading edge thickness provides sufficient strength to resist these added hydraulic forces, so in this case, the cover continues to grow upstream without further thickening.

For "wide rivers", external forces increase beyond the internal resistance of the leading edge, so the edge shoves thickening the cover and increasing its resistance until the cover becomes stable. This latter case is the usual one for ice jams in natural rivers.

3.3.1 Description of the Model (Cont'd)

Experiments, borne out by field observations, have revealed that an ice cover will remain stable if certain criteria are maintained. This condition is shown in the bell shaped curve in Figure 3.2. The ratio of ice thickness, t, divided by the depth, H, is shown as a function of:

$$\frac{Q^2}{C^2BH^4} \qquad (2)$$

where : Q = discharge (m3/s);
C = Chezy roughness coefficient
B = surface width (m);
H = depth of flow (m).

Providing points fall within the bell shaped curve the cover is stable for a range of ice thickness, depth and discharge values. However, when the edge of the bell is reached, an ice shove or increase or decrease in water level will occur to compensate for the new condition.

Application of these calculation methods is based on using the characteristic dimensions of each cross-section and the distances in between. A backwater curve can be established which can be adapted to link the cross-sections in the ice calculations, providing a strong degree of control on the calculation process.

When a stable accumulation cover has formed, it starts to thicken thermally from the surface at a rate proportional to the cumulative degree days of freezing, with a corresponding decrease in porosity from approximately 40% voids to solid ice. Over the winter period, water levels fall and the cover sags causing hinge cracks to form along the edges. These cracks and others formed by thermal contraction of the ice sheet fill with water which subsequently freezes. By the end of the winter period, the combination of these factors has produced an ice cover with cohesive strength, that has been found by experiment over the years, to be a function of the thermal ice thickness.

In the mathematical model, the thermal ice thickness can be entered as a measured value or calculated as a function of the cumulative freezing degree-days from the date of ice cover formation.

Ice cover breakup is generally caused by a combination of increased discharge and stage and thermal ice weakening and melting although either effect, by itself, may be enough to remove an ice sheet from a river.

During spring, a combination of warming air temperatures and increased solar radiation produce melting of the snow pack that cause river discharges to rise, signalling the start of breakup. The ensuing runoff causes water levels to increase, the ice cover to lift and shore leads to form.

As the discharge increases, a point is reached when the cover becomes hydro-mechanically unstable and the cover ruptures.

A breakup model incorporating the above logic has been developed at LHL. Using results obtained from the ice cover freeze-up/mid-winter programm, the same cross-sections and hydraulic parameters, the rupture of the ice cover during the spring breakup at each cross-section can be calculated with respect to discharge by equation (3):

$$\frac{Q^2}{B_{TOT}C^2} = \frac{[Kcoh\ (H_1)^2 + 0.094\ (H_1)^4\ (t_1/H_1)^2]\ (1 - 0.92\ t_1/H_1)^3}{1 + 0.92\ t_1/H_1} \qquad (3)$$

where : Q = mean daily discharge (m^3/s);
B_{TOT} = total surface width of section under the ice cover (m);
C = Chezy roughness coefficient ($m^{1/2}/s$);
H_1 = mean depth (m);
t_1 = thermal ice thickness (m);
Kcoh = cohesive shear strength factor (m^2).

If the right hand side of the equation is larger than the left, the cover is stable; otherwise, the cover is unstable (see Figure 3.2).

The cohesive shear strength factor (Kcoh) is given by the equation:

$$Kcoh = \frac{2\tau t_{th}}{\rho g} \qquad (4)$$

where : Kcoh = cohesive shear strength factor (m^2);
τ = ice shear stress of 2.2 kPa;
t_{th} = thermal ice thickness at break-up (m);
g = acceleration due to gravity, m/s/s;
ρ = density of water (Kg/m^3).

The above equation was derived from the original work done on the St. Lawrence River, where for a breakup thermal ice thickness of 0.6 m, an ice shear stress per metre (τt) of between 1.09 and 1.32 kN/m was found. These ice shear strength values have been applied in many studies, on rivers both large and small, and generally found to fit (this issue is further examined in Section 3.4).

3.3.1 Description of the Model (Cont'd)

Maximum breakup water levels are determined at each cross-section as a function of the maximum discharge that occurs at rupture. Broken ice debris from upstream piles against the upstream edge of the unbroken ice cover and if sufficient ice is available, a stable accumulation cover will develop in an upstream direction, the thickness being dependent on the river discharge.

3.3.2 Setting-Up, Open Water Conditions:

The eleven cross-sections surveyed by the Department of the Environment and Lands (Newfoundland) and checked by SNL, plus an additional cross-section (measured by SNL) across the tidal pool and designated Cross-Section 4.5, were used as model input data (Figure 3.3).

The model was calibrated for open water conditions using measured water elevations at each cross-section for the 1984 and 1988 (fall) open water flows. The discharges for the two events were 16 m^3/s and 45 m^3/s respectively.

Discrepancies were found between observed and calculated water levels at cross-section 6, 6.5 and 7, that necessitated adjustment to these sections. These discrepancies were probably due to the inaccurate field identification of the control section in this reach. Two options were considered for adjusting the data:

- introduction of a synthetic control section, or
- adjustment of each section by raising or lowering the section.

3.3.2 Setting-Up, Open Water Conditions: (Cont'd)

The second approach was used for adjusting sections 6, 6.5 and 7, since it was easier to apply that the first, albeit more physically correct, approach. Attempting a more elaborate adjustment, in this case, was considered unnecessary since ice jam flood levels are not significantly controlled by water levels in this sub-reach. Once this was done, good agreement for both profiles was obtained with a Manning "n" value of 0.035, as shown in Figure 3.4

Open water surface profiles for discharges of 100 to 700 m^3/s were then calculated for a range of tide elevations between -1.0 m and +1.0 m at the seaward limit (Cross-Section 1) approximately the tidal range in this area. Stage-discharge curves derived from these results are given for each cross-section in Figures 3.5 and 3.10 (Details on the computations are given in Volume 2 - Appendix I).

3.3.3 Setting-Up, Ice Conditions:

The next step was to simulate ice cover formation, rupture and ice cover accumulations (ice jam flood elevations) with the model. This involved checking ice cover stability over a range of discharges up to 400 m^3/s, and thermal ice cover thicknesses of 15, 30 and 45 cm, sufficient to include the expected design values. As the region's maritime climate is subject to periods of freezing and thawing during winter, it was reasoned that the ice cover cohesive strength would be low. A minimum cohesion value of τt = 1.09 KN/m was at first chosen. Later, the significance of this parameter on ice breakup elevations was investigated in a sensitivity analysis. A Chezy "C" value of 35, corresponding to a composite Manning "n" of 0.035, was selected as being appropriate to the reach under study. As greater water depths result in a more stable ice cover, simulations were first carried out for a high tide elevation of 1.0 m and followed by tidal elevations of 0.0 m and -1.0 m.

The results, given in Figures 3.6 to 3.8, show that the ice cover upstream of Cross-Section 9 remains stable for the full range of flows and hence will not contribute to the ice jams formed below the rapids. The photos and reports taken in 1984 and 1988 confirm that ice above Cross-Section 9 did in fact stay in place.

Below section 9, the ice cover rupture progresses in a downstream direction. (Cross-Sections 6.0, 6.5 and 8.0 are unstable at all flows and remain open all winter). Figure 3.6 shows the results obtained with a thermal ice covers 15 cm, thick and a high tide downstream elevation of 1.0 m. No change in the cover occurs until a discharge of 100 m^3/s is reached when the ice at Cross-Section 7.0 ruptures. At 175 m^3/s, Cross-Sections 5.5 and 4.0 fail, and so on, until the whole reach is ice free at a discharge of between 250 and 300 m^3/s.

Similar processes occur with ice thicknesses of 30 and 45 cm respectively. As expected, the thicker covers are more resistant and breakup occurs at progressively higher flows and water levels confirming that flood levels are dependant on ice cover thickness and discharge. [Printouts from the actual computer simulations are provided in Volume 2, Appendix 2 and give the water levels and discharge at each cross-section for the ice thicknesses selected].

3.3.4 Determination of Ice Jam Flood Levels

As stated earlier, the results from the ice rupture calculations showed that the cover upstream of Cross-Section 9 will remain stable for the full range of flows and thermal ice thicknesses considered. Hence the volumes of ice available to form ice jams would be limited to the volume available from those reaches that rupture downstream of Cross-Section 9. Potential ice jam locations (lodgement sites) were also identified from the results of the rupture calculations for each test flow used.

Since the amount of ice available for jam formation will be minimal, ice accumulation calculations assumed that all available ice would only pile up on the upstream edge of the intact cover and that ice jam water elevations would be governed by the critical ice formation level* at the lodgement site, see Figure 3.9. Above the lodgement site water levels would be determined by backwater calculations assuming open water conditions.

Figure 3.10 shows the stage-discharge curves plotted at each cross-section. Upstream of Cross-Section 5.5, water levels are unaffected by downstream jamming and follow an open water relationship. While below Cross-Section 5.5 water levels are affected by downstream ice jams.

* The "critical ice jam formation level" is the minimum stable ice jam water level for the given hydraulic conditions.

3.3.5 Verification of Model

The ice model was verified by comparing observed and computed water levels from the 1984 and 1988 flood events as below. On February 8th, 1984, an ice jam formed at the outlet of the Terra Nova River near Cross-Section 3 (see Figure 3.3). The discharge was estimated to be 262 m^3/s and the ice thickness 30 cm (report D. Hansen to M. Goebel of 1984/02/13). Referring to the stage-discharge curve given in Figure 3.10, a water elevation of 2.1 m is found at Cross-Section 3 for an ice cover thickness of 30 cm and discharge of 262 m^3/s. This value corresponds to the flood level of 2.09 m measured at House #1 - see Figure 3.3.

The site of the ice jam of February 29th to March 2nd 1988 event was near Cross-Section 5. The peak discharge measured at the Glovertown gauging station was found to be 172 m^3/s and the ice thickness was estimated to be 30 cm (observer's notes). From the stage-discharge curves, Figure 3.10, it can be seen that the water level at Cross-Section 5 was approximately 2.0 m. The corresponding flood elevation for this event, at House #2, was measured as 1.95 m which is close to the calculated value.*

The failure sequence and extent of stable and unstable ice cover simulated by the model generally correspond with field observations, recorded by video for the 1988 event, and reported for the 1984 event. This provides further, albeit qualitative, confirmation of the model set-up.

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* The printouts are provided in Volume 2, Appendix 5 and show how these water levels were obtained.

3.4 SENSITIVITY ANALYSES

The significance of assumptions on tide levels and the cohesive strength of ice were investigated by sensitivity analyses, as below.

3.4.1 Effects of Tide Level

As stated earlier, the above simulations were made with a downstream tidal elevation of +1.0 m. The significance of the tide elevation on ice jam flood levels was studied by repeating the above ice cover rupture and ice cover accumulation calculations at tidal elevations 0.0 and -1.0 m. [These results are presented in Volume 2 - Appendices 2 and 3]. Figures 3.11 and 3.12 give the breakup elevation discharge curves.

Figure 3.13 shows the influence the tide elevation has on the breakup elevations for an ice cover thickness of 30 cm. Ice covers are inherently more stable at a higher elevation for a given discharge and this is reflected on the graphs. As shown, the ice remains the most stable at tide elevation +1.0 m, resulting in the highest breakup levels. At tide elevations 0.0 and -1.0 m, ice rupture would occur at lower flows and produce lower breakup elevations.

3.4.2 Effects of Ice Cohesive Strength

The sensitivity of ice rupture and breakup elevations to values of cohesive strength of the ice cover was also investigated. A higher value of cohesion of τt (see equation 4) equal to 1.32 kN/m was used in the program and the simulations re-run. [The results are given in Volume 2 - Appendices 4 and 5 and Tables 25 to 48].

3.4.2 Effects of Ice Cohesive Strength (Cont'd)

Figure 3.14 shows the maximum breakup elevations at each section downstream of the rapids for the range of tide elevations and ice thickness simulated, with a lower and upper envelope of cohesive ice strength. The results show that a more resistant ice cover tends to withstand a greater flow and, in general, to produce higher breakup elevations.

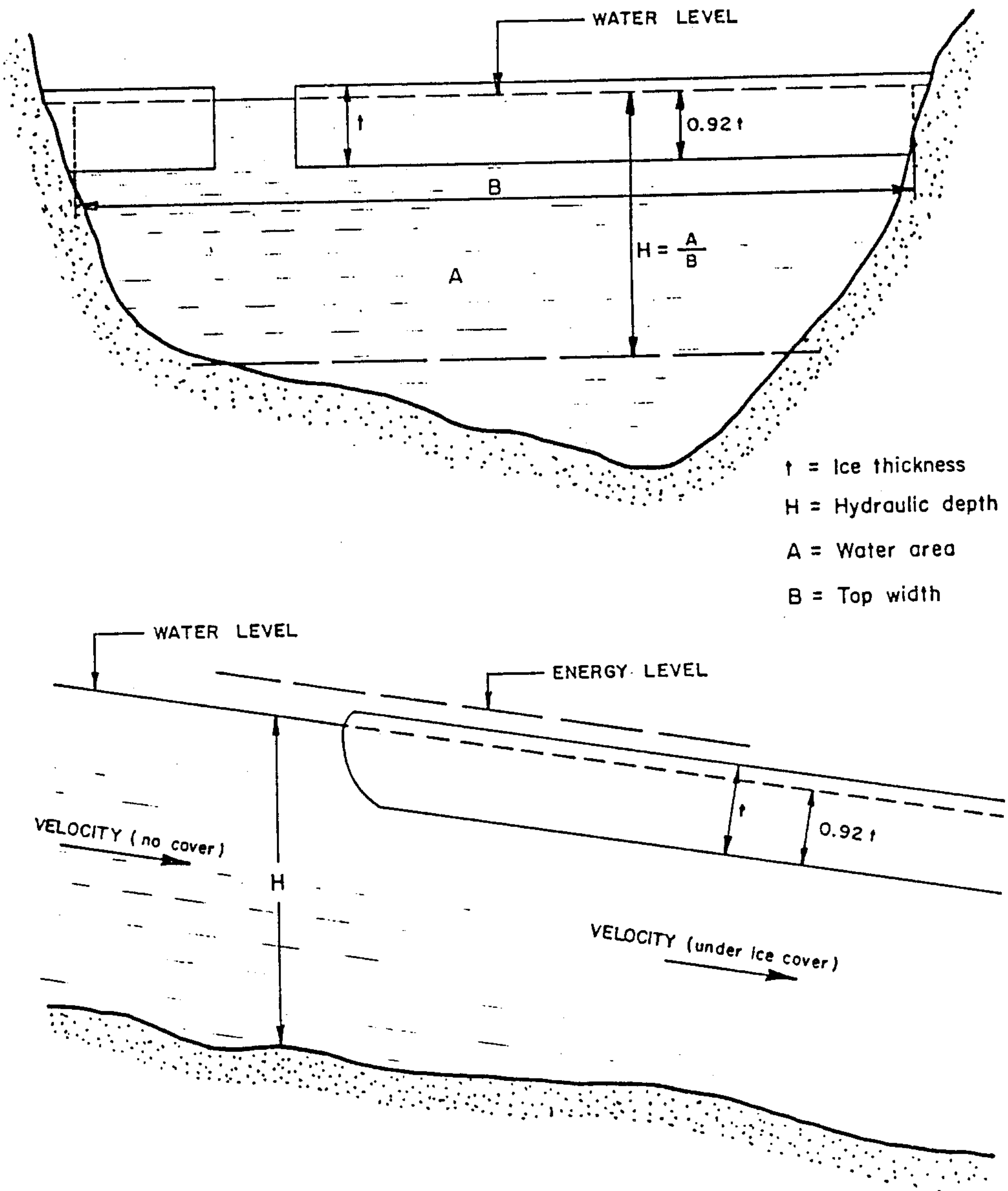
3.5 OPEN WATER FLOWS

The computer model was also run assuming no ice cover over a range of flows up to 700 m^3/s in order to determine head-discharge relationships for open water conditions. The results of these runs are show in Figures 3.5 and 3.10.

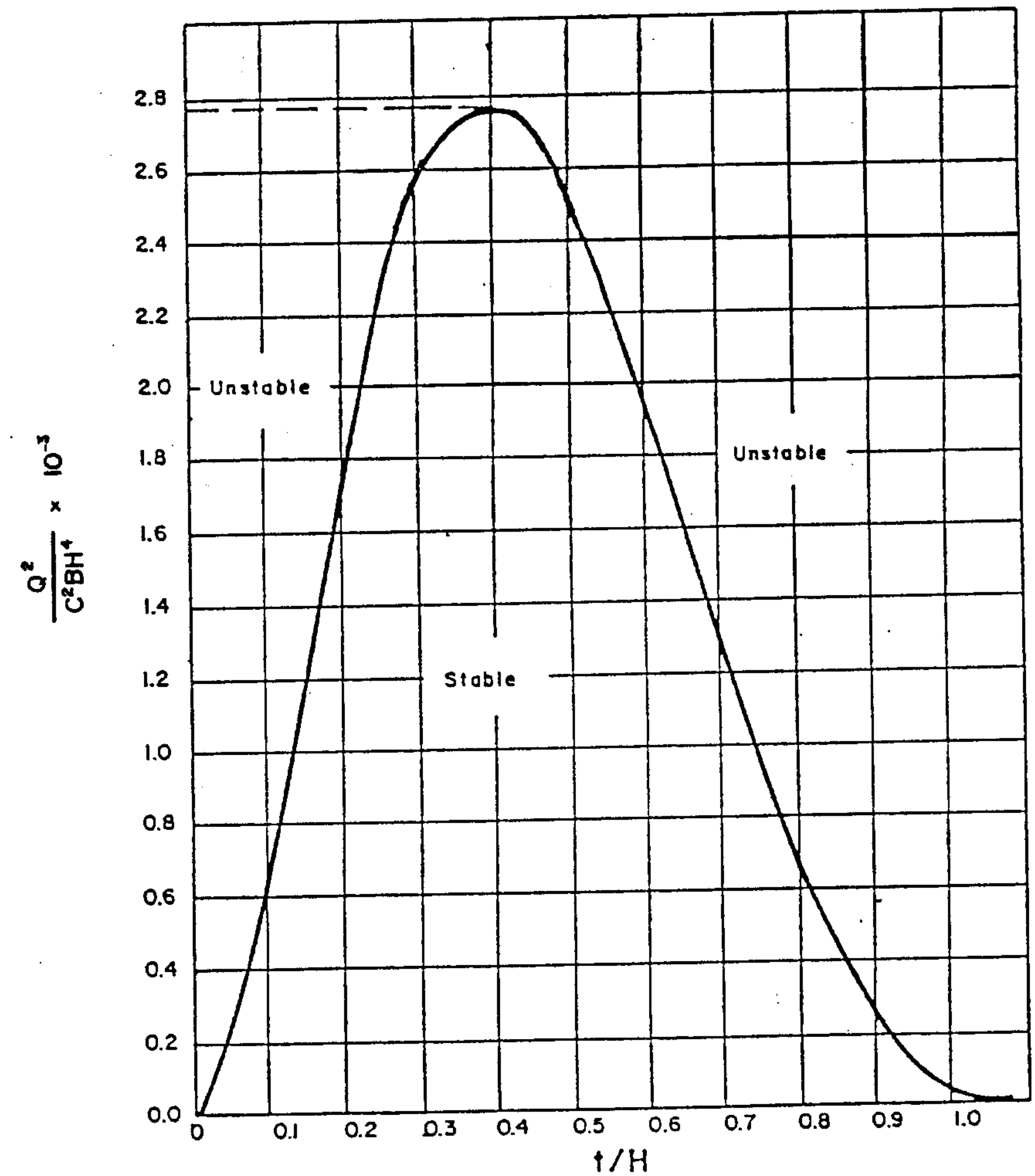
3.6 CONCLUDING COMMENTS

The ice model computer simulations identified the mechanics of ice cover rupture and gave open water and breakup water elevations in the Glovertown area. They showed that the ice cover upstream of the rapids will remain stable during breakup and will not contribute to ice jams formed below. Downstream of the rapids, the ice cover will rupture in a downstream direction as a function of the discharge. The results showed that the ice cover thickness at breakup, its cohesive strength and the downstream tide levels independently affect this process. High tide levels result in a more stable cover and thicker ice cover; while, stronger ice results in a more resistant ice cover and higher breakup elevations.

FIGURE 3.1



GLOVERTOWN FLOOD STUDY
HYDRAULIC AND SECTION PARAMETERS



GLOVERTOWN FLOOD STUDY
NON-COHESIVE ICE COVER
STABILITY CURVE

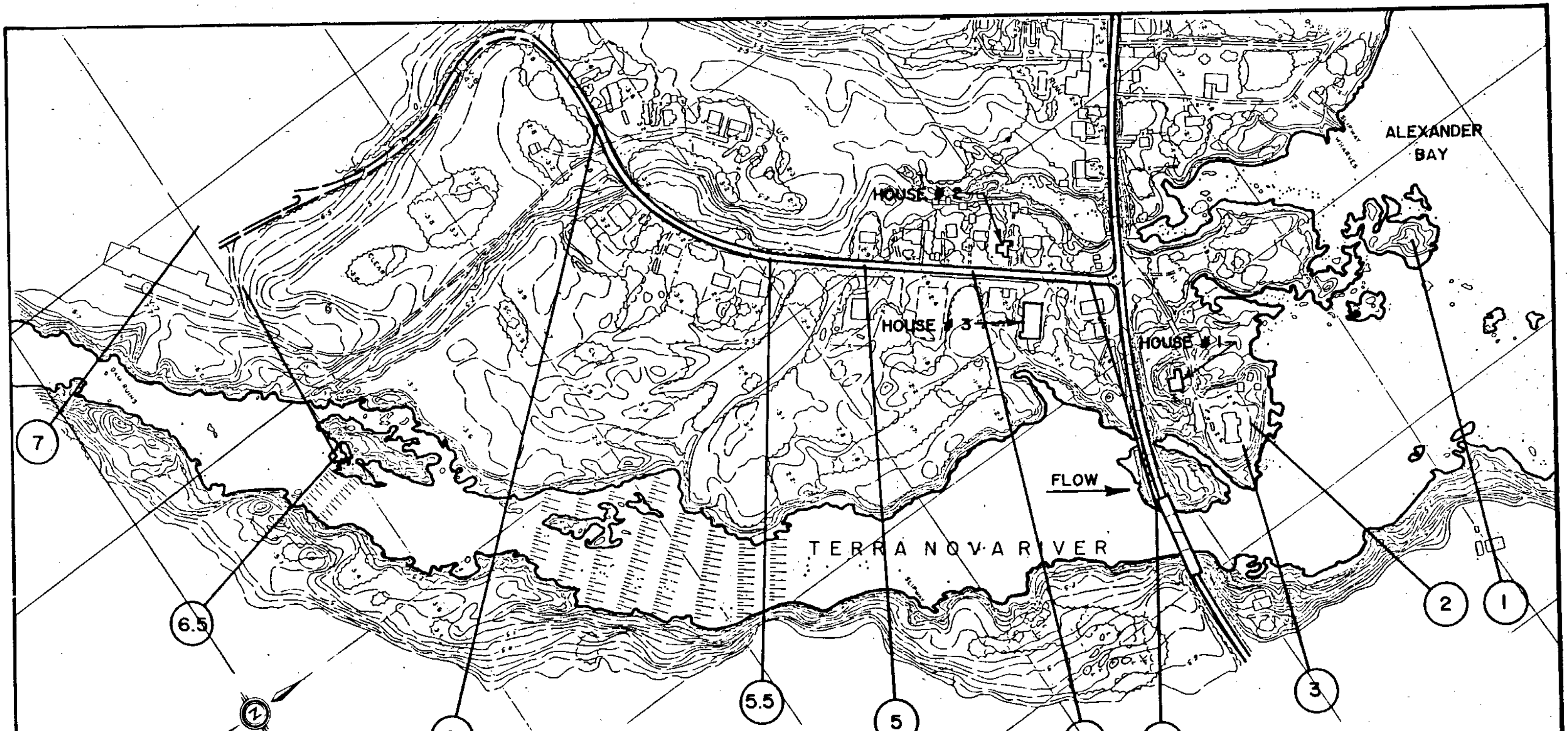


FIGURE 3.3

GLOVERTOWN FLOOD STUDY

- CROSS-SECTION LOCATIONS -

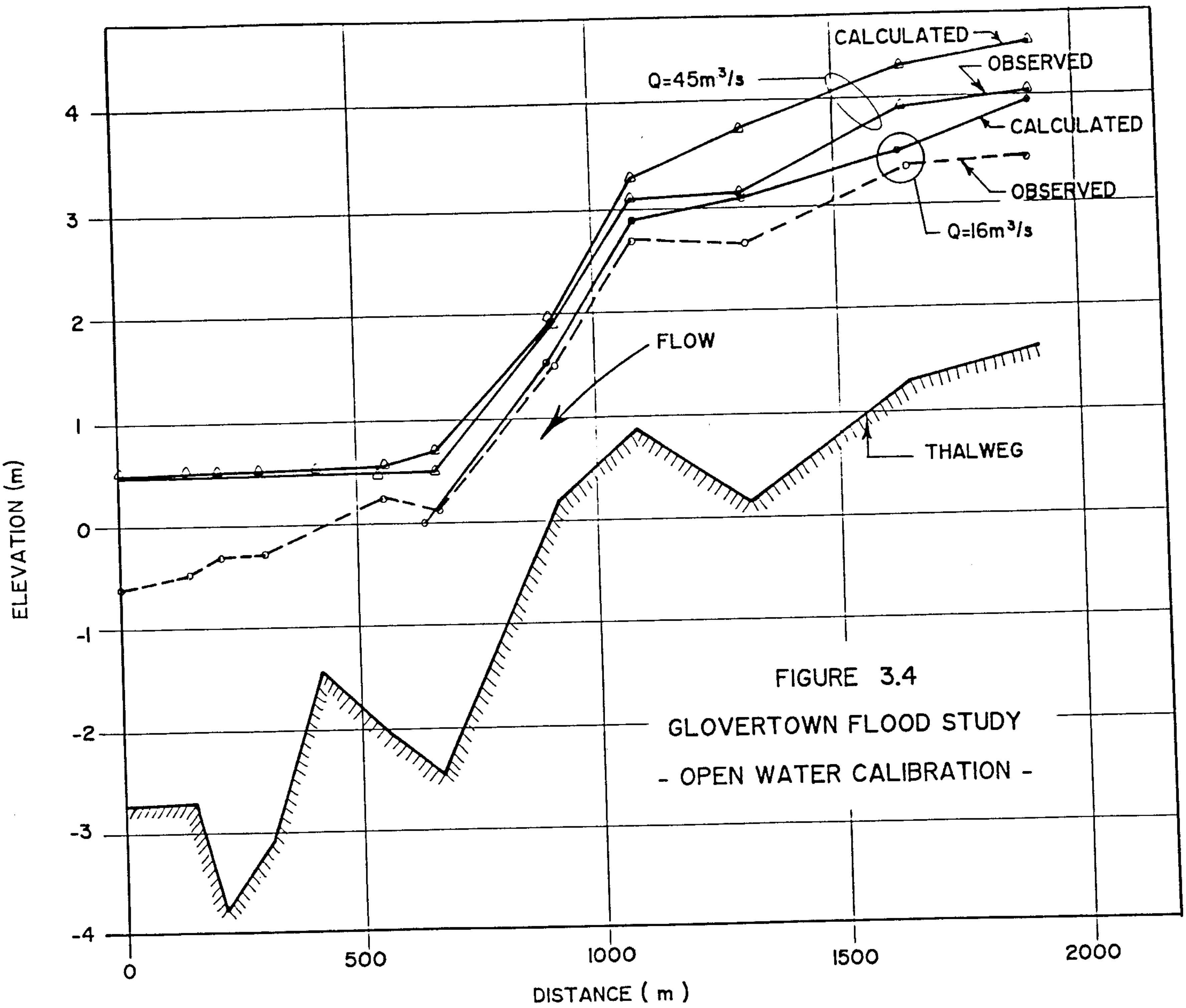
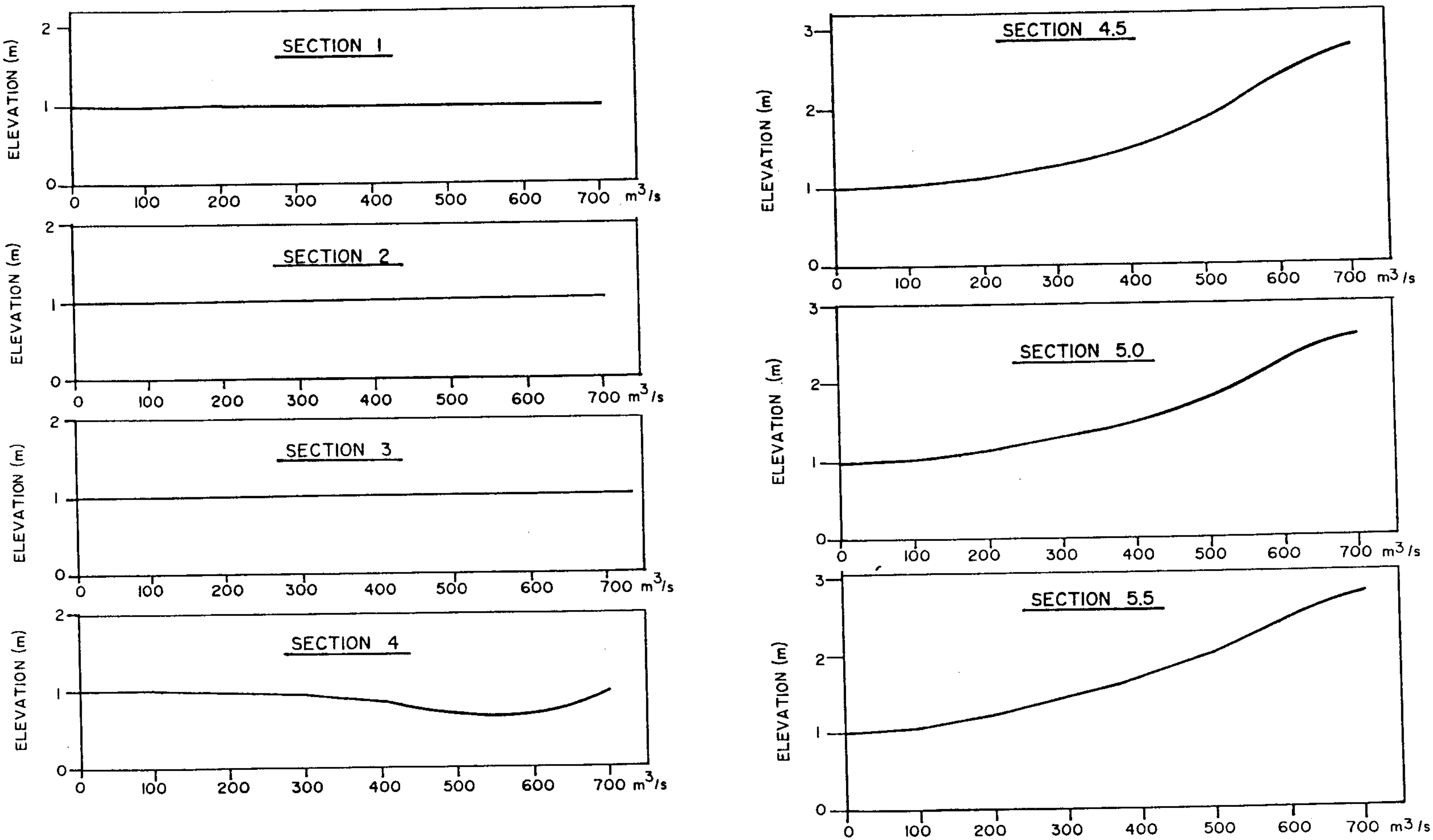


FIGURE 3.4
GLOVERTOWN FLOOD STUDY
- OPEN WATER CALIBRATION -



GLOVERTOWN FLOOD STUDY
OPEN WATER STAGE-DISCHARGE CURVES
SECTIONS 1 to 5.5
TIDAL ELEVATION = 1.0m

FIGURE 3.5

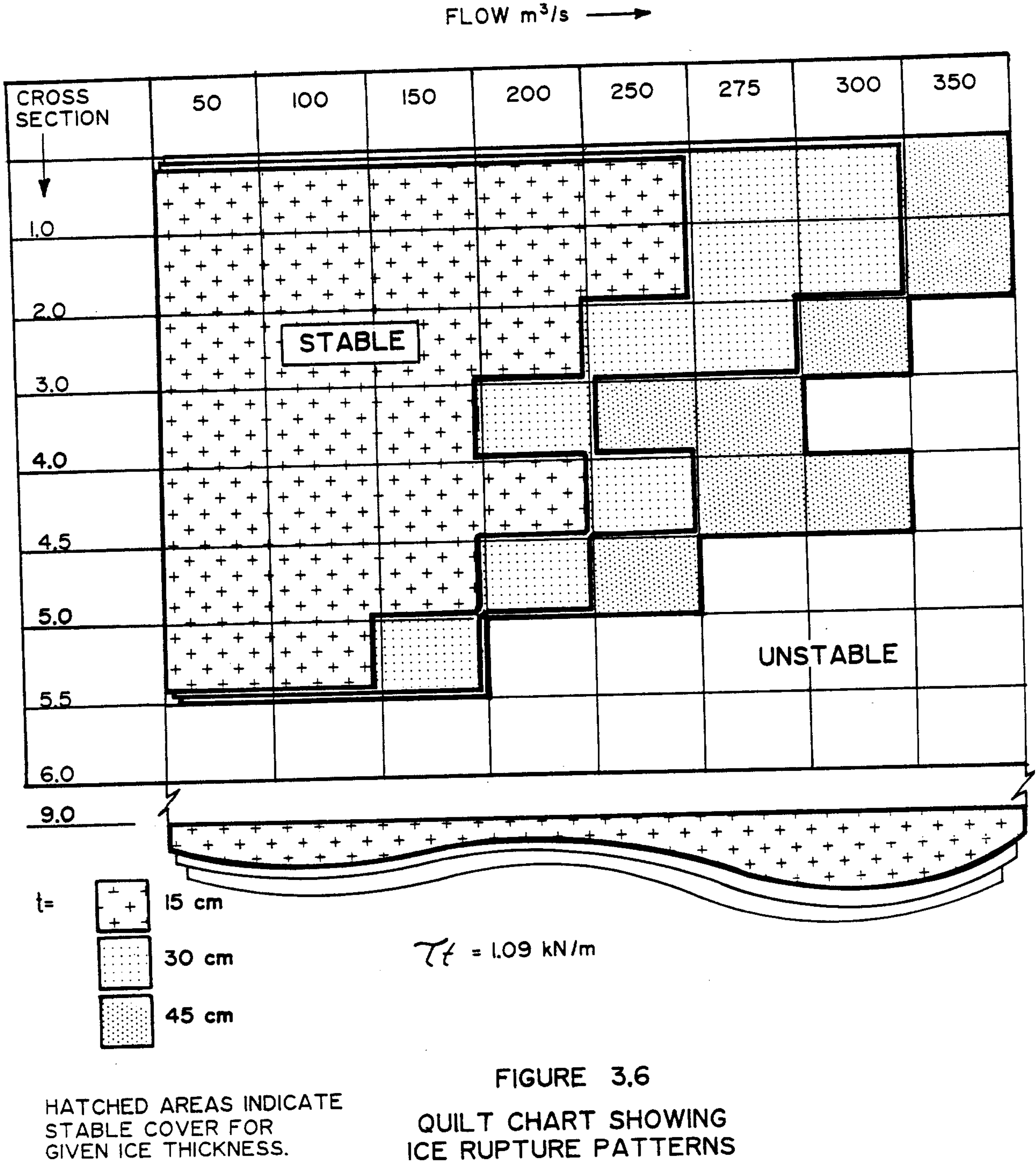
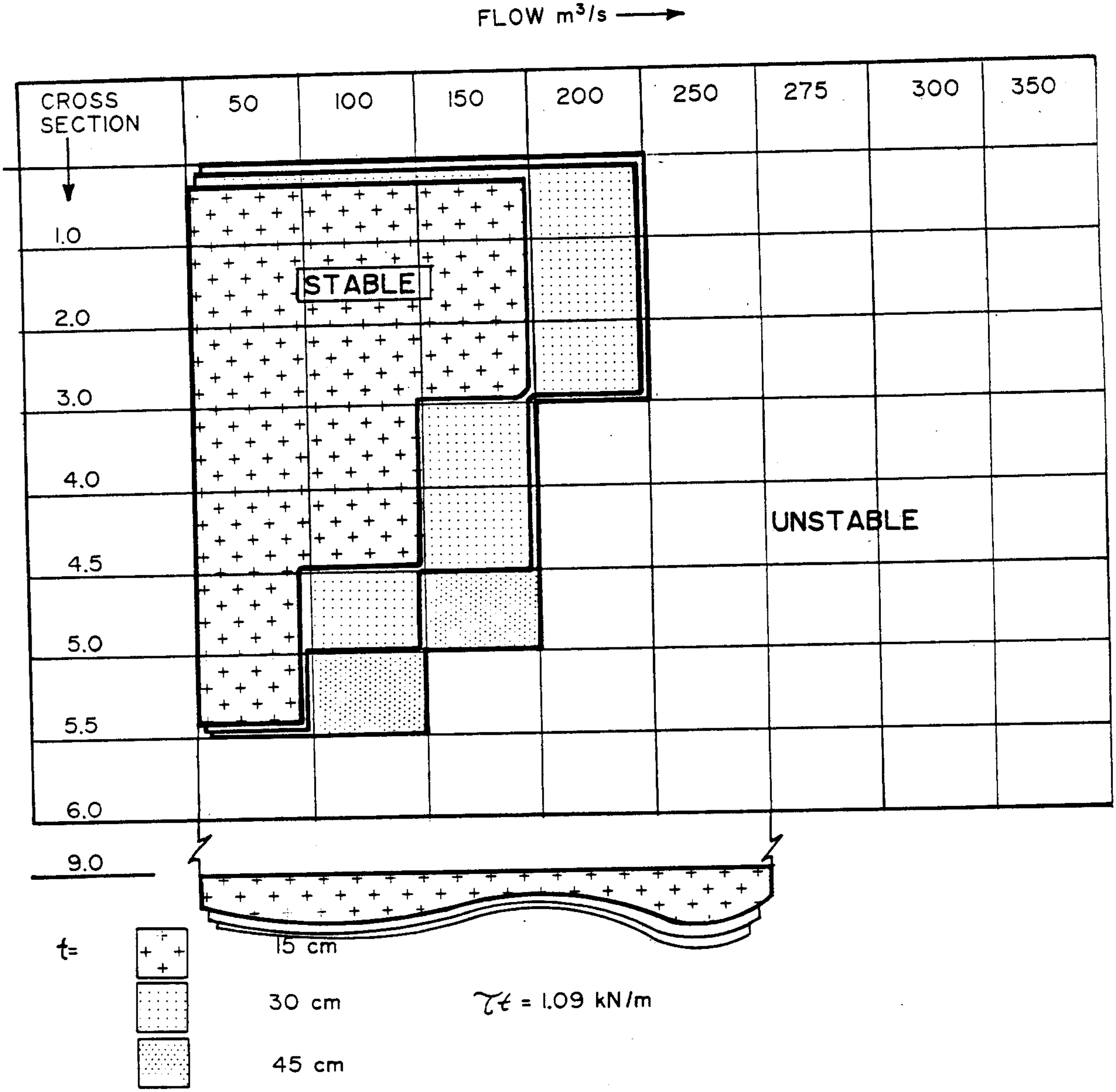


FIGURE 3.6

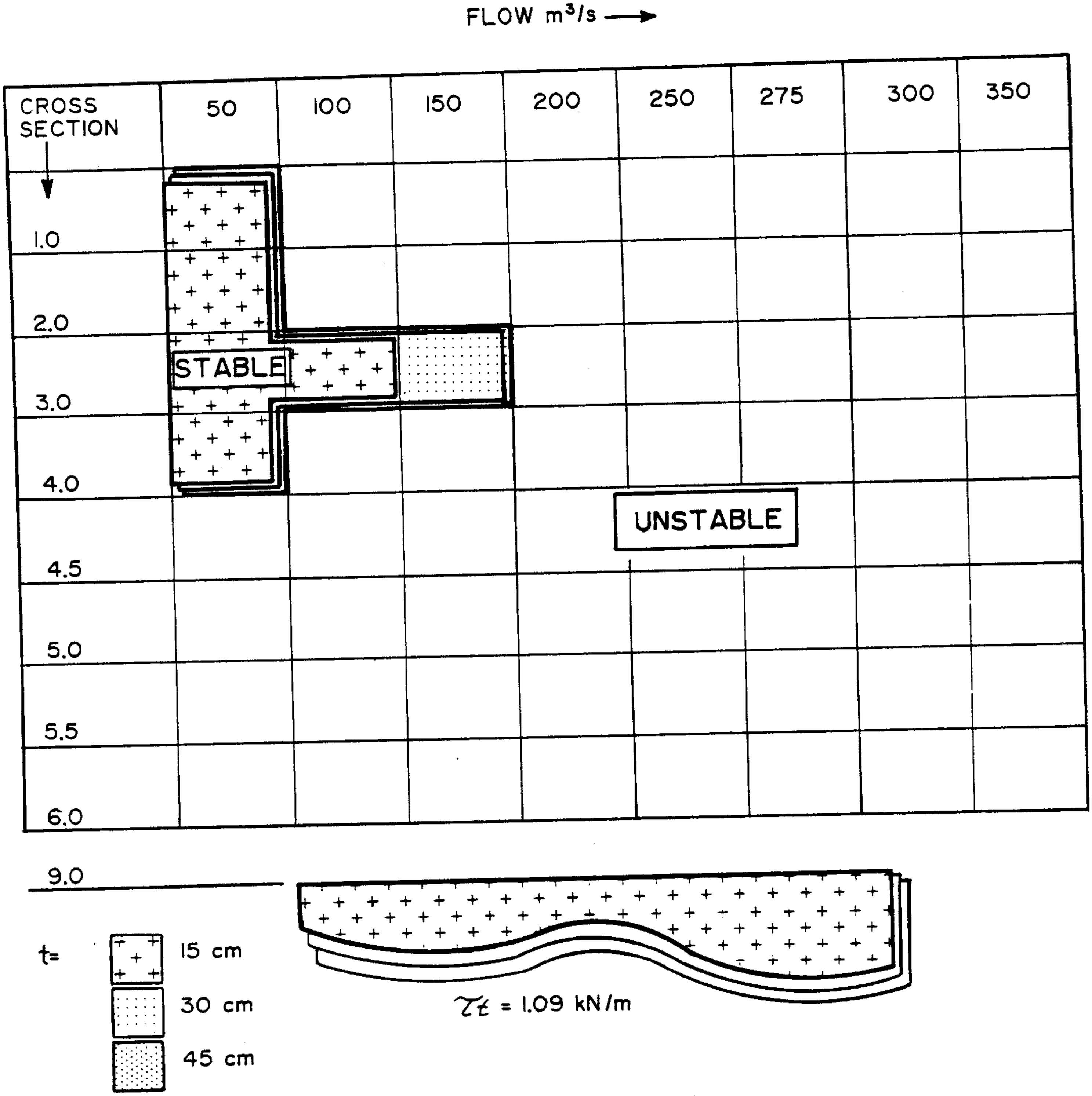
QUILT CHART SHOWING ICE RUPTURE PATTERNS FOR TIDAL LEVEL=1.0m



HATCHED AREAS INDICATE STABLE COVER FOR GIVEN ICE THICKNESSES.

FIGURE 3.7

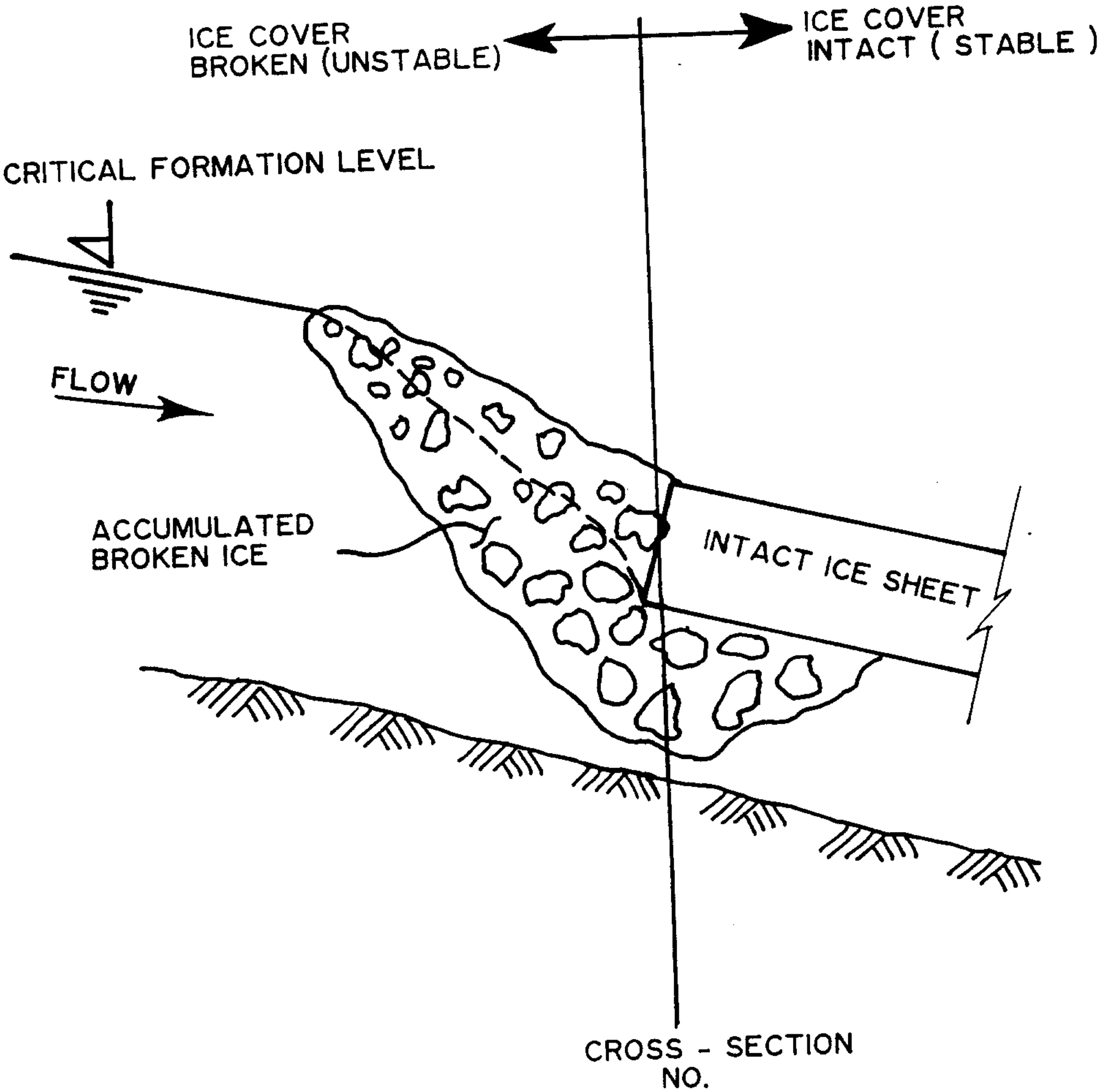
QUILT CHART SHOWING ICE RUPTURE PATTERNS FOR TIDAL LEVEL=0.0m



HATCHED AREAS INDICATE STABLE COVER FOR GIVEN ICE THICKNESSES.

FIGURE 3.8

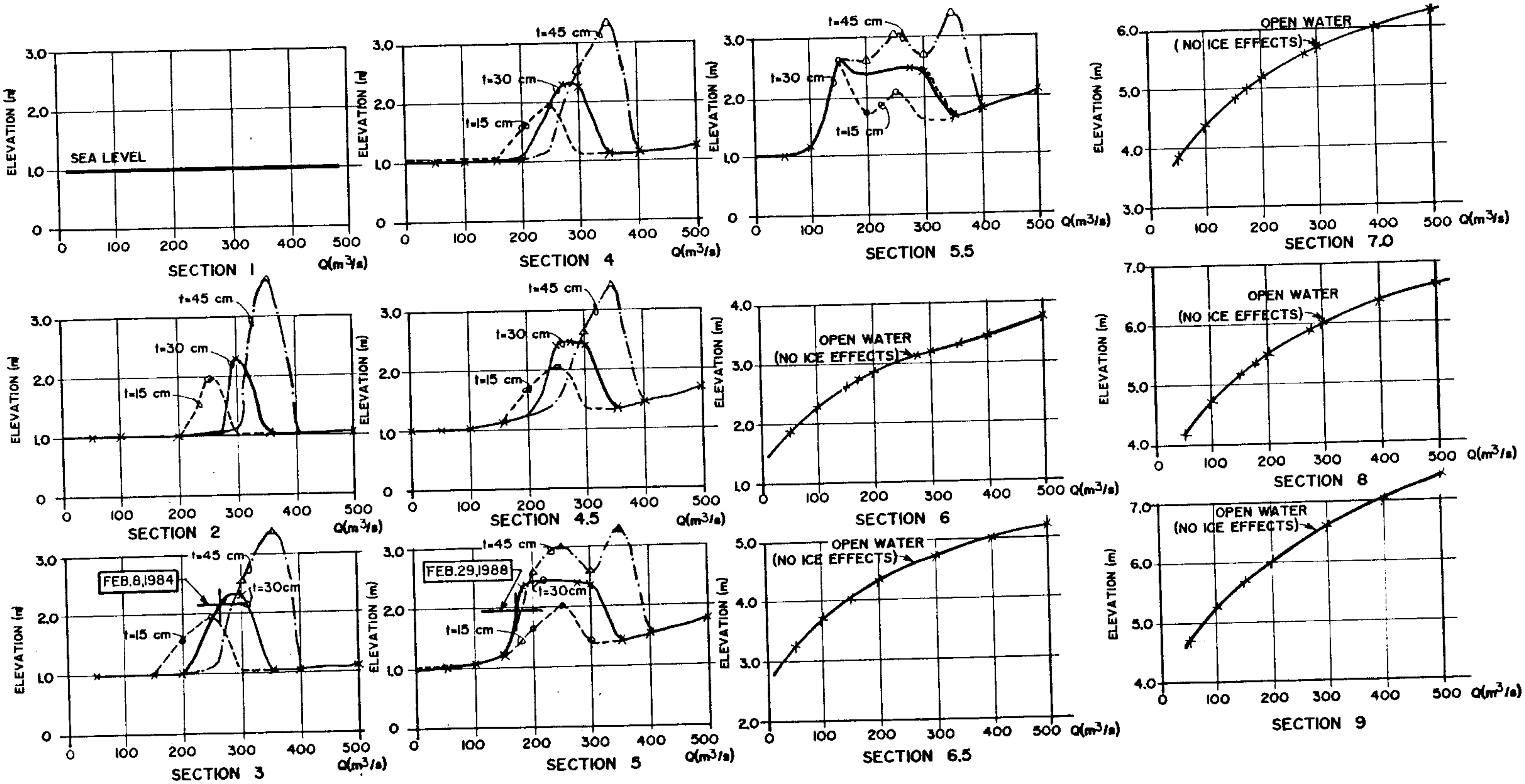
QUILT CHART SHOWING ICE RUPTURE PATTERNS FOR TIDAL LEVEL=-1.0m



GLOVERTOWN FLOOD STUDY

RELATION BETWEEN STABLE & UNSTABLE ICE COVER & CRITICAL FORMATION LEVEL

FIGURE 3.9



FEB. 8, 1984
t = 30cm
Q = 262m³/s

FEB. 29, 1988
t = 30cm
Q = 172m³/s

FIGURE 3.10

GLOVERTOWN FLOOD STUDY
STAGE DISCHARGE CURVES
TIDE AT +1.0 m

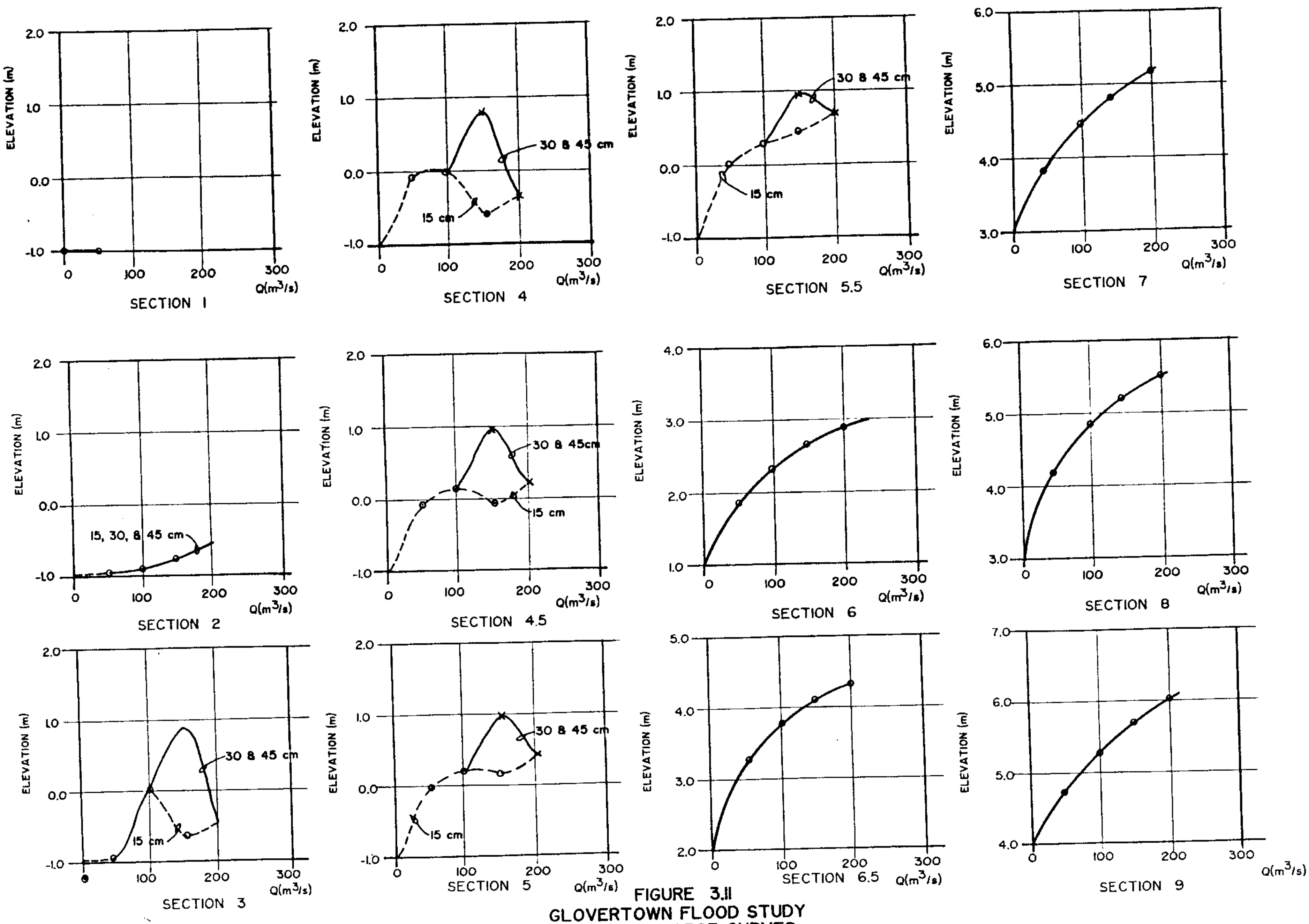


FIGURE 3.11
GLOVERTOWN FLOOD STUDY
STAGE DISCHARGE CURVES
TIDE AT -1.0m, I = 15,30, & 45cm

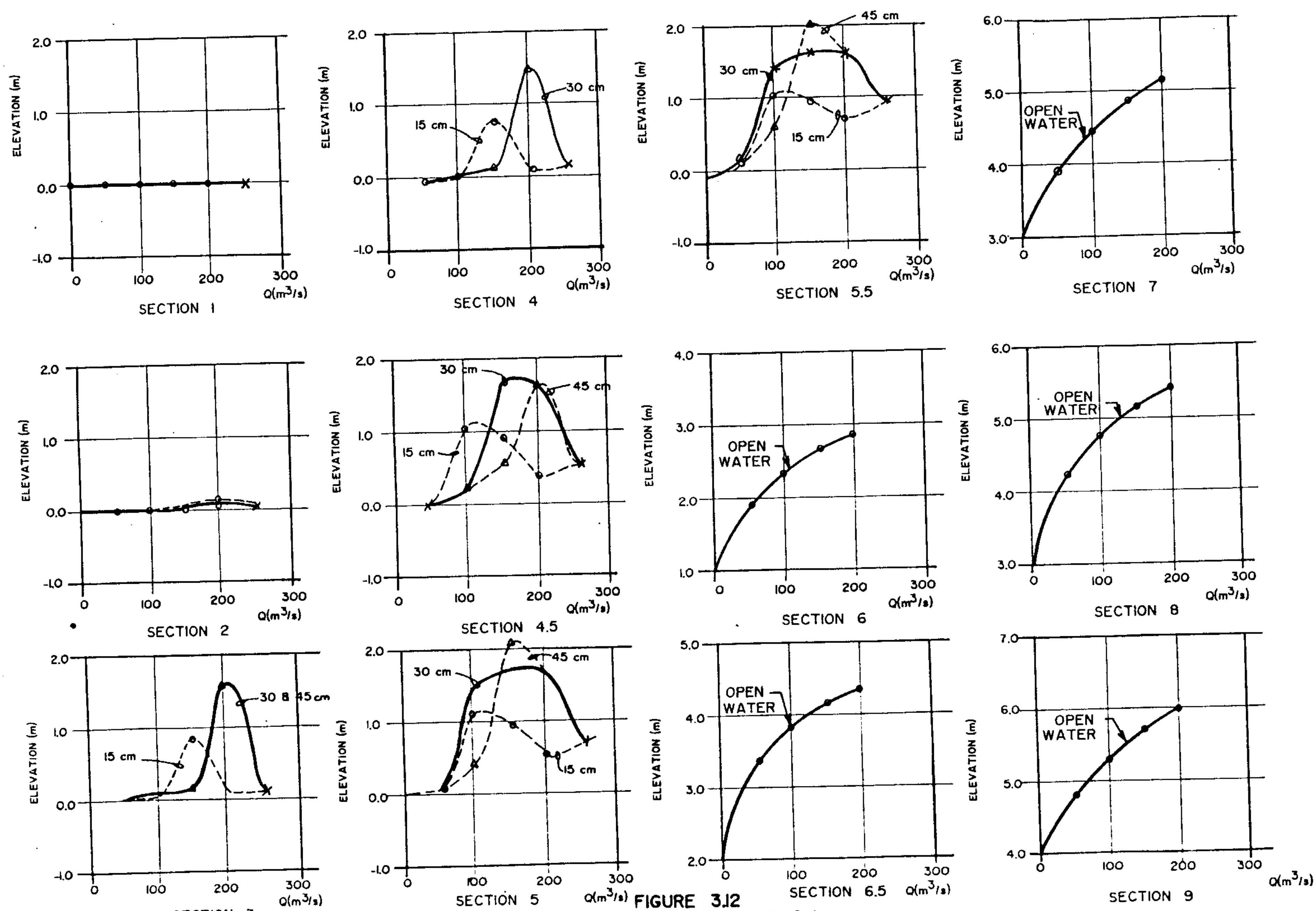


FIGURE 3.12
GLOVERTOWN FLOOD STUDY
STAGE DISCHARGE CURVES
TIDE AT 0.0 m, t = 15, 30, & 45 cm

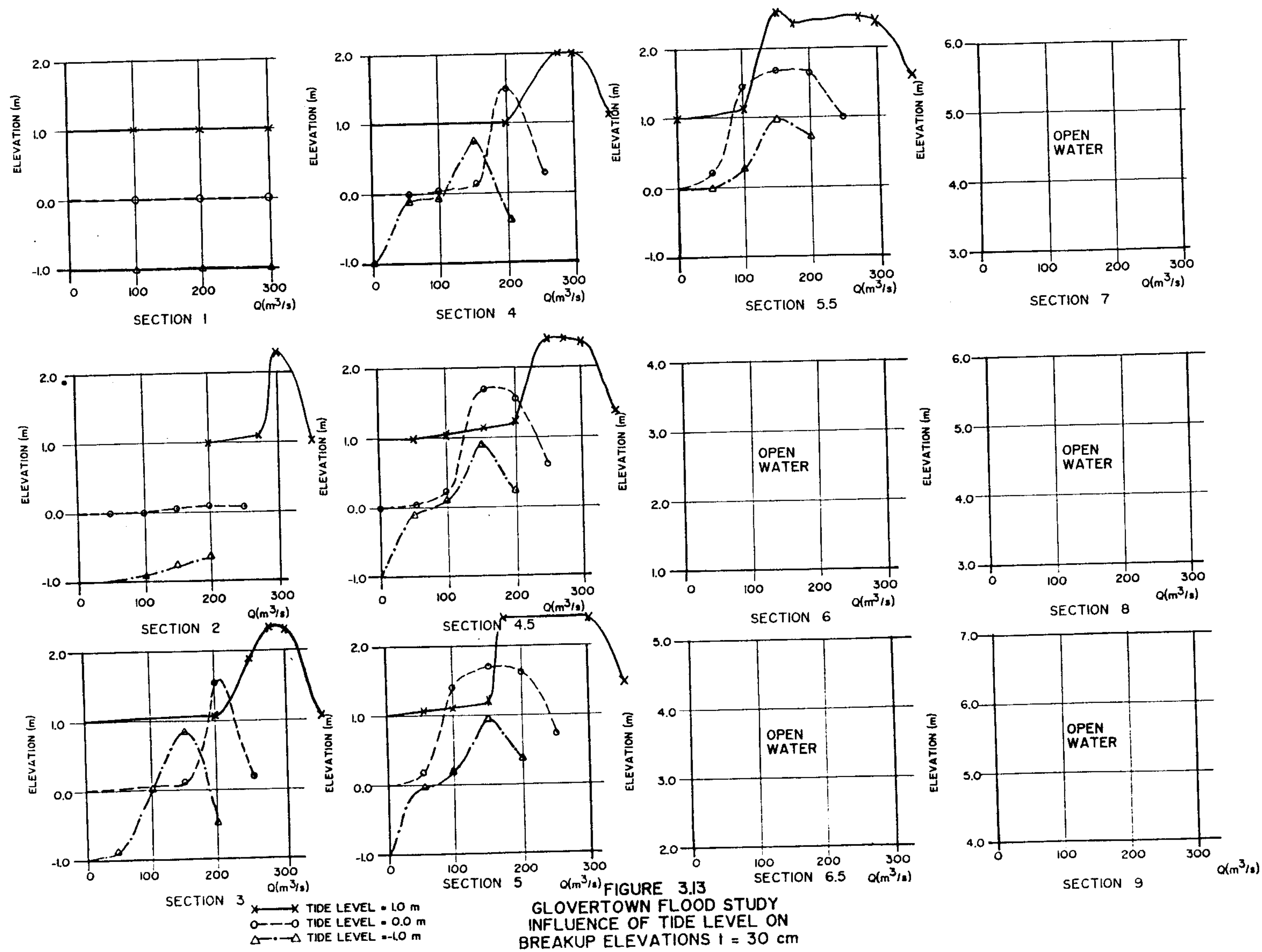


FIGURE 3.13
GLOVERTOWN FLOOD STUDY
INFLUENCE OF TIDE LEVEL ON
BREAKUP ELEVATIONS t = 30 cm

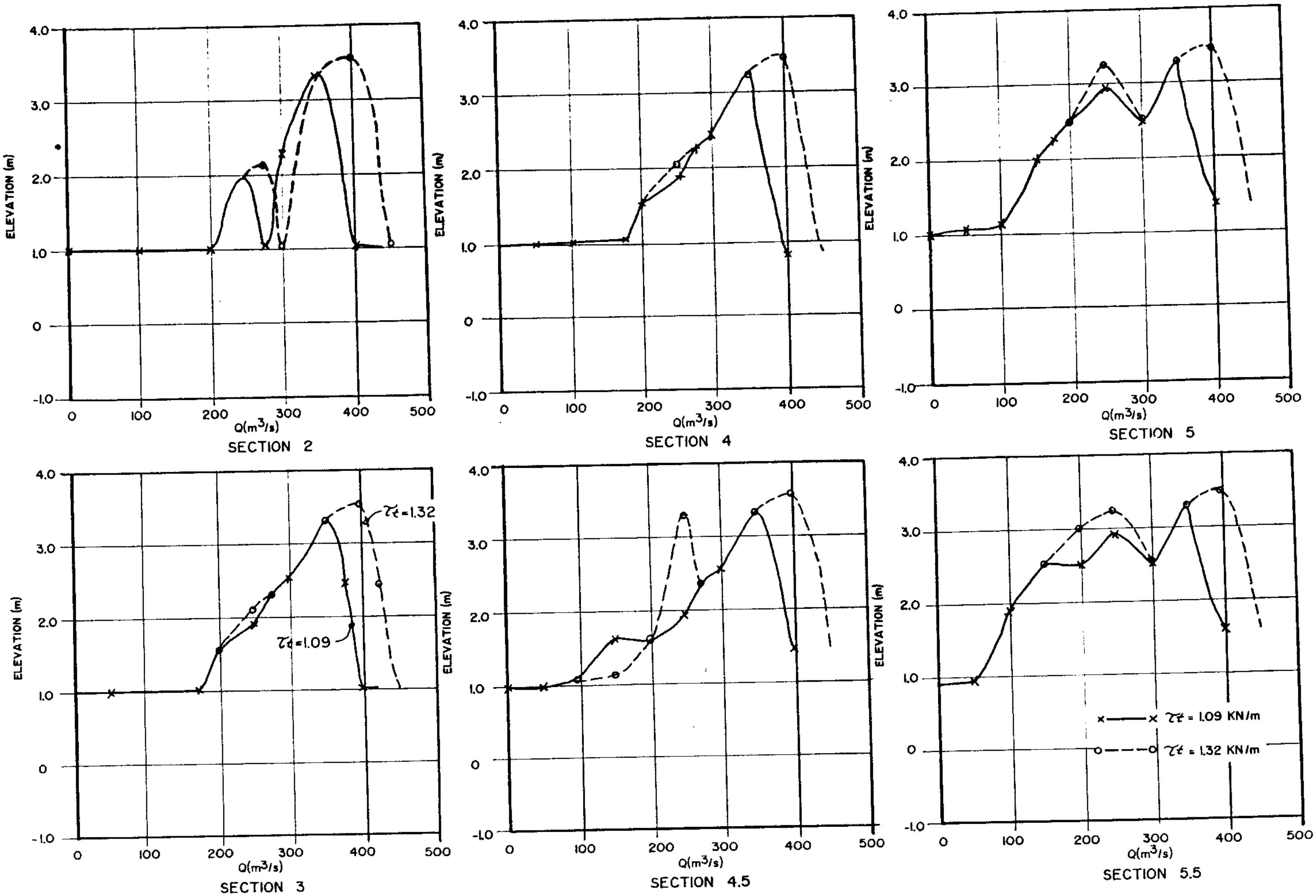


FIGURE 3.14
GLOVERTOWN FLOOD STUDY
MAXIMUM BREAKUP LEVELS VS ICE STRENGTH
(TIDE AT 1.0 m, t= 45cm τ_t = 1.09 KN/m ——, τ_t = 1.32 KN/m – – –)

PART FOUR

HYDROLOGY

4.0 HYDROLOGY

4.1 APPROACH

The ice studies described in Part 3 have produced relationships giving water levels at each cross-section as a function of flow and ice thickness. In the hydrology phase of the study these relationship were used, in combination with estimates for ice thickness and flood flows, to establish a nineteen year series of annual ice season water level maxima for input to probability analysis.

Since annual water level maxima could also be produced by open floods, probabilities of exceedance in river levels from this cause must be considered as well. From considerations of elementary probability theory the annual (total) probability of exceedance can be calculated, as below:

$$P_t = P_i + P_o - P_i . P_o \qquad (5)$$

where:

P_t = annual (total)probability of exceeding h

P_o = annual probability of exceeding h due to an open water flood

P_i = annual probability of exceeding h due to an ice season event

h = water level at a given cross-section

4.2 ESTIMATION OF FLOWS

Flow records are available on Terra Nova from 1951 to the present. For the period 1951 to 1984 these flows were measured at Eight Mile Bridges, near Terra Nova Village (drainage area =1290 km^2). In 1985 a new gauge was installed just upstream of Glovertown (drainage area = 2000 km^2) and the old gauge was discontinued. Unfortunately, there are no overlapping records for the two gauging stations.

In order to estimate flows on the Lower Terra Nova prior to 1985 it was necessary to determine a proration factor that would permit flows on the Lower Terra Nova (W.S.C. gauge at Glovertown) to be estimated from measurements taken on the Upper Terra Nova River [Water Survey of Canada gauge 02YS001, at Eight Mile Bridges]. In the absence of overlapping records, this factor was estimated by correlating peak flow data from the Upper Terra Nova and Lower Terra Nova gauges with records from a third river Middle Brook, as below:

$$\frac{Q_{TN,G'TOWN}}{Q_{MB}} = 9.17$$

$$\frac{Q_{TN,\ 8\ MI.\ BRIDGES}}{Q_{MB}} = 6.67$$

Whence:

$$F = \frac{Q_{TN,\ G'TOWN}}{Q_{TN\ 8\ MI.\ BRIDGES}} = \frac{9.17}{6.67} = 1.38$$

As a check the proration factor was also estimated as a function of the ratio of drainage areas, as below:

$$F = \left[\frac{D.A.\ G'TOWN}{D.A.\ 8\ MI\ BRIDGES}\right]^{0.76} *$$

$$\therefore\ F = \left[\frac{2000}{1290}\right]^{0.76} = 1.40$$

As shown above, both values for the proration factor, F, are in close agreement.

---

* From drainage area exponent in regional flood frequency analysis, Reference 9.

4.2 ESTIMATION OF FLOWS (Cont'd)

F = 1.38 was selected for estimating breakup and open season peak flows in this study.

Breakup flows were estimated from flows measured at the end of ice covered periods in the river. These periods were assessed from "backwater indications" shown in the flow records published by the Water Survey of Canada. Comparison of the occurrence and duration of such periods, as observed on the records of Lower Terra Nova, Middle Brook, Southwest Brook and Upper Terra Nova gauges, indicated that the records from Middle Brook provided the best index of conditions on the Lower Terra Nova, prior to 1985. Selection of the breakup flow also took into consideration the magnitude of the freeze-up flow. In general, breakup was not considered to occur unless the breakup flow was greater than the freeze-up flow. Open season maxima were also selected by examining the flow record through the open water season. Data are summarized in Tables 4.1 and 4.2 at the end of this section.

4.3 ESTIMATION OF ICE THICKNESS

Ice thickness was estimated as a function of cumulative degree days of frost using the following formula suggested by Frederking and Williams (7)

$$t = 3.5\alpha\sqrt{S} \qquad (6)$$

4.3 ESTIMATION OF ICE THICKNESS (Cont'd)

where:

t	=	ice thickness in cm	
α	=	0.8	windy lake with no snow
	=	0.5-0.7	average lake with snow
	=	0.4-0.5	average river with snow
	=	0.2-0.4	sheltered river with snow
s	=	Σ-T °C.days for ice covered period.	

α = 0.4 was selected as the most appropriate value for Glovertown, whence:

$$t = 1.4\sqrt{S} \quad \text{cm} \qquad (7)$$

Mean daily temperature data from the Gander Climatological station were used in applying this formula. Minimal data were available to check the accuracy of this formula. However, ice thickness in the vicinity of Cross-Section 3, was reported by M. Goebel, to be about 30 cm on Feb. 13, 1984. The estimated thickness at this time, based on a freezing degree day total of 429 °C.days, was 29 cm. This close agreement between observed and calculated was gratifying but not sufficient to provide solid confirmation. The significance of variations in the factor (=1.4) in equation 7, on determinations of t and flood levels, were investigated in a series of sensitivity analyses as discussed in Section 4.5.

4.4 PROBABILITY DETERMINATIONS

Annual water level maxima for ice and open water seasons were determined for each cross-section from flow maxima and ice thicknesses, computed as above, and head-discharge relationships form the ice study. Graphs showing the probabilities of exceedance versus water levels for ice season (P_i) and open water season (P_o) were then prepared. A typical pair of graphs is shown in Figure 4.1.

The "break" in the ice season graph reflects the two conditions which govern ice season levels: the flatter portion is produced by stable ice covers while the steeper portion arises from unstable covers and ice jams. Unfortunately there are too few points to adequately define the steep portion of the curve. This rules out the use of this approach for determining flood risk contours.

An alternative approach is to consider combinations of probabilities of ice thickness and breakup flows having the desired 1 in 20 year and 1 in 100 year return periods. These calculations are summarized in Tables 4.4 and 4.5 (at end of this section). Comparisons of the determinations based on shear strength factors, τt, having values of 1.09 kN/m and 1.32 kN/m and the best estimate of the 1984 flood levels are also shown. Ice thickness and breakup flow probabilities were taken from Figures 4.2 and 4.3.

The significance of increased shear strength of ice (τt = 1.09 and 1.32 kN/m) can be observed from examination of Tables 4.4 and 4.5. Small increases in water level, from 0.10 to 0.22 m, are found for conditions where ice covers are unstable and jamming occurs; elsewhere, the water levels remain the same. The shear strength factor accounts for the effects of cohesion between ice particles and is probably dependant on the internal ice temperature. Observations on the St. Lawrence indicate a range in value of 1.09 kN/m to 1.32 kN/m. Higher values have been observed on some northern rivers. It seems possible that the higher value, τt = 1.32 kN/m, could occur during mid winter jams on the Terra Nova: Accordingly, it is recommended that water level values based on τt = 1.32 kN/m be used for design.

4.5 OTHER SENSITIVITY ANALYSES

The significance of variations in other model parameters were investigated in selected sensitivity analyses as follows:

Figure 3.13 shows how tidal elevation effects ice jam flood levels in the river. Assumption of a starting tidal elevation of +1.0 m, is conservative and is recommended for design.

Effects of variation in estimates of ice thickness were assessed by considering changes in ice thickness of ± 33% of the value determined by equation (7). Applying this gave changes in water levels of 0.0 m to ± 0.25 m.

Effects of errors in flow estimates of ± 10% gave increases in flood levels in the order of ± 0.15 m to ± 0.30 m.

Also shown in Tables 4.4 and 4.5 are the estimates for the water levels produced in the 1984 ice jam flood. Water levels at Cross-Sections 3 and 5 are based on field observations while determinations at other cross-sections are based on computation.

4.5 OTHER SENSITIVITY ANALYSES (Cont'd)

These comparisons suggest that the 1984 event was somewhat more severe than a 1 in 20 year flood but less severe than a 1 in 100 year event.

4.6 CONCLUDING COMMENTS

Values of the parameters that affect ice jam flooding are not known with certainty, hence reasonable conservatism is prudent in the determination of the design 1 in 20 and 1 in 100 year flood contours. It should also be noted that the ice model is only an approximate representation of physical reality, especially on a relatively small river (8). Furthermore, the data base available for model verification is very limited.

"Design" flood elevations recommended in Tables 4.4 and 4.5 are based on a jam forming at high tide (elevation = 1.0 m) with a high ice strength, τt = 1.32 kN/m. Both assumptions are judged to be somewhat on the conservative side, but not overly so.

The recommended flood risk contours are shown on the flood risk map in the envelope pocket at the end of the report.

Table 4.1

Open Water Flow - Annual Instantaneous Maxima
Terra Nova River - Glovertown

Year	Maximum Open Water Flow (m^3/s)
1955	202
1956	319
1957	216
1958	110
1959	266
1960	344
1961	235
1962	352
1963	276
1964	352
1965	177
1966	217
1967	330
1968	189
1969	276
1970	206
1971	225
1972	190
1973	239
1974	184
1975	232
1976	214
1977	182
1978	174
1979	269
1980	313
1981	279
1982	276
1983	490
1984	142
1985	166
1986	311
1987	292
1988	225

Notes:

- Annual maxima for 1955-1983, except 1979 estimated from Terra Nova River at Eight Mile Bridges (2YS001).
- Annual maxima for 1979 estimated from Gander River at Big Chute (2YQ001).
- Annual maxima for 1984-1988 measured at Terra Nova River - Glovertown (2YS005).

Table 4.2

Ice Season - Annual Maxima
Terra Nova River - Glovertown

Year	Maximum Ice Water Flow (m^3/s)
1969	60
1970	39
1971	94
1972	38
1973	82
1974	38
1975	119
1976	64
1977	47
1978	117
1979	31
1980	25
1981	127
1982	20
1983	62
1984	269
1985	40
1986	28
1987	31
1988	80

Notes:

- Ice season maxima for 1969-1983 estimated from Terra Nova River at Eight Mile Bridges (2YS001).
- Ice season maxima for 1984-1988 measured at Terra Nova River - Glovertown (2YS005).
- In 1984 ice season maximum, Q = 269 m^3/s was also annual maximum flow.

Table 4.3

Annual Ice Thickness Maxima at Breakup

Winter Ending in Year	Maximum Ice Thickness (cm)
1969	10.1
1970	18.8
1971	19.1
1972	24.7
1973	33.7
1974	37.1
1975	41.0
1976	22.2
1977	24.6
1978	21.3
1979	26.9
1980	13.4
1981	22.8
1982	33.4
1983	29.0
1984	30.1
1985	22.4
1986	21.5

Note:

Ice thickness estimated as a function of accumulative degree days of freezing, see page 4-4.

Table 4.4

Probability Combinations - 1 in 20 year Recurrence Interval

Cross-Section	WATER LEVEL (m) t = 30 cm (0.26) Q = 110 m³/s (0.19) τt=1.09kN/m	τt=1.32kN/m	20 cm (0.77) 171 m³/s (0.065) τt=1.09kN/m	τt=1.32kN/m	15 cm (0.95) 186 m³/s (0.053) τt=1.09kN/m	τt=1.32kN/m	Open Water Levels (m)	1984 Flood Levels (m)	Design Level (m)	REMARKS
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	Tide
2	1.01	1.00	1.00	1.01	1.00	1.02	1.00	1.05	1.02	
3	1.01	1.01	1.02	1.11	1.02	1.40	1.01	2.20	1.40	Ice Jams Govern
4	1.01	1.02	1.05	1.14	1.40	1.42	0.85	2.20	1.42	
4.5	1.05	1.08	1.20	1.26	1.55	1.52	1.45	2.40	1.55	
5	1.10	1.10	2.20	1.90	2.10	2.12	1.46	2.40	2.20	
5.5	1.30	1.30	2.35	2.45	2.60	2.13	1.65	2.40	2.60	
6							3.45		3.45	
6.5							5.00		5.00	Open Water
7							5.95		5.95	
8							6.35		6.35	
9							7.00		7.00	

Notes:

1. Water levels for τt = 1.09 kN/m taken from Figure 3.10
2. Water levels for τt = 1.32 kN/m estimated from tables in Appendix 6, (Volume 2)
3. Open water levels for $Q_{20/open}$ = 390 m^3/s
4. Thickness probabilities shown in parenthesis after thickness, thus t = 30 cm (0.26)
5. P_t approximately equals P_i for probabilities of 0.01 to 0.05.

Table 4.5

Probability Combinations - 1 in 100 year Recurrence Interval

Cross-Section	WATER LEVEL (m) t = 30 cm (0.26) Q = 210 m³/s (0.04)		20 cm (0.77) 295 m³/s (0.013)		15 cm (0.95) 310 m³/s (0.011)		Open Water Levels (m)	1984 Flood Levels (m)	Design Level (m)	REMARKS
	τt=1.09kN/m	τt=1.32kN/m	τt=1.09kN/m	τt=1.32kN/m	τt=1.09kN/m	τt=1.32kN/m				
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	Tide
2	1.01	1.03	2.15	2.38	1.95	2.16	1.02	1.05	2.38	
3	1.10	1.05	2.20	2.36	1.95	2.20	1.04	2.20	2.38	
4	1.20	1.11	2.20	2.39	1.95	2.28	0.80	2.20	2.39	Ice Jam
4.5	1.35	1.80	2.25	2.46	2.05	2.24	1.65	2.40	2.46	
5	2.45	2.80	2.25	2.45	2.05	2.38	1.70	2.40	2.80	
5.5	2.60	2.81	2.35	2.47	2.10	2.35	1.80	2.40	2.81	
6							3.65		3.65	
6.5							5.20		5.20	
7							6.20		6.20	Open Water
8							6.60		6.60	
9							7.35		7.35	

Notes:

1. Water levels for τt = 1.09 kN/m taken from Figure 3.10.
2. Water levels for τt = 1.32 kN/m estimated from tables in Appendix 6, (Volume 2).
3. Open water level based on $Q_{100/open}$ = 470 m³/s
4. Thickness probabilities shown in parenthesis after thickness, thus t = 30 cm (0.26)
5. P_t approximately equals P_i for probabilities of 0.01 to 0.05.

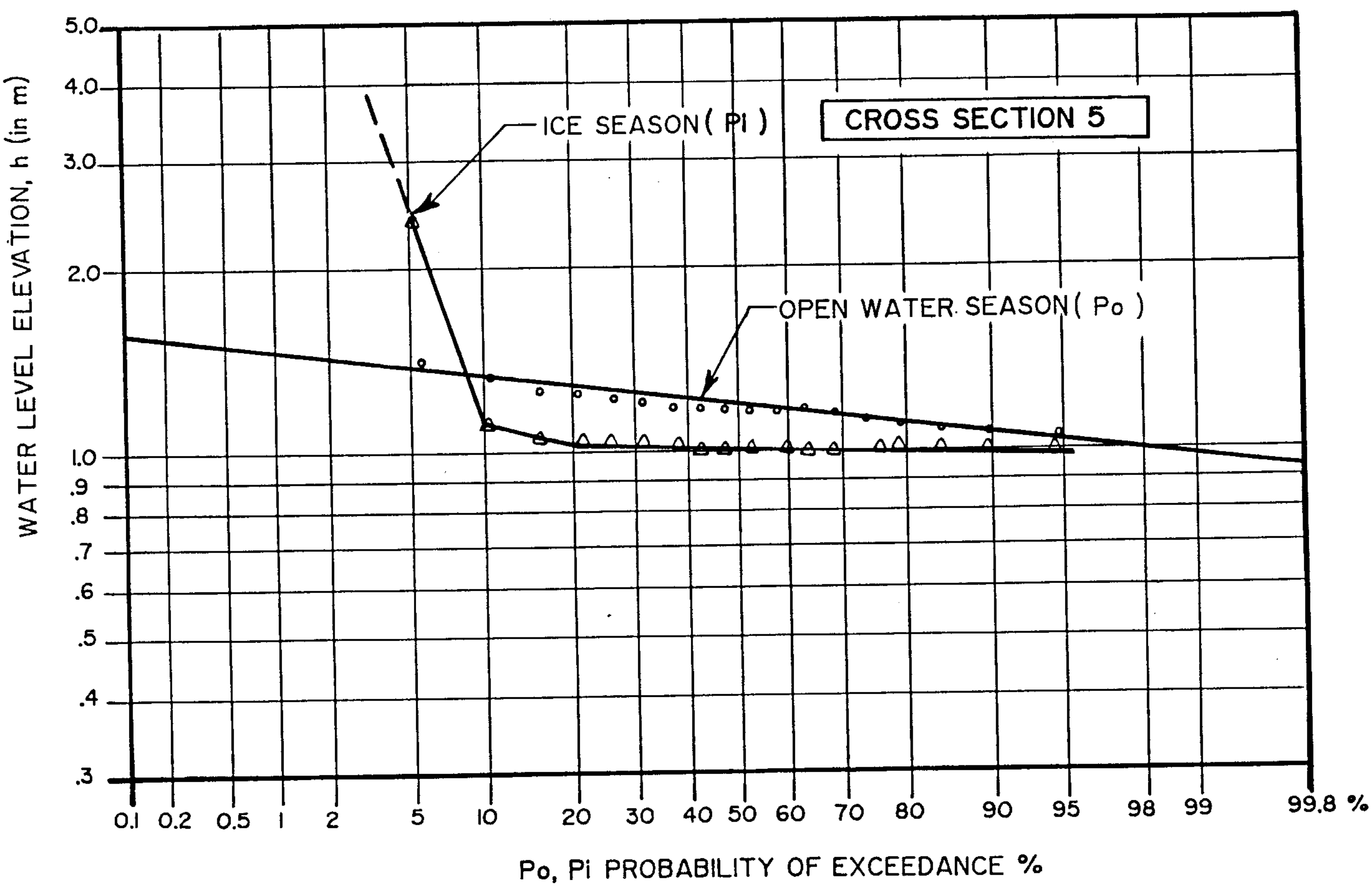


FIGURE 4.1

GLOVERTOWN FLOOD STUDY
TYPICAL PROBABILITY OF
EXCEEDANCE VERSUS
WATER LEVELS

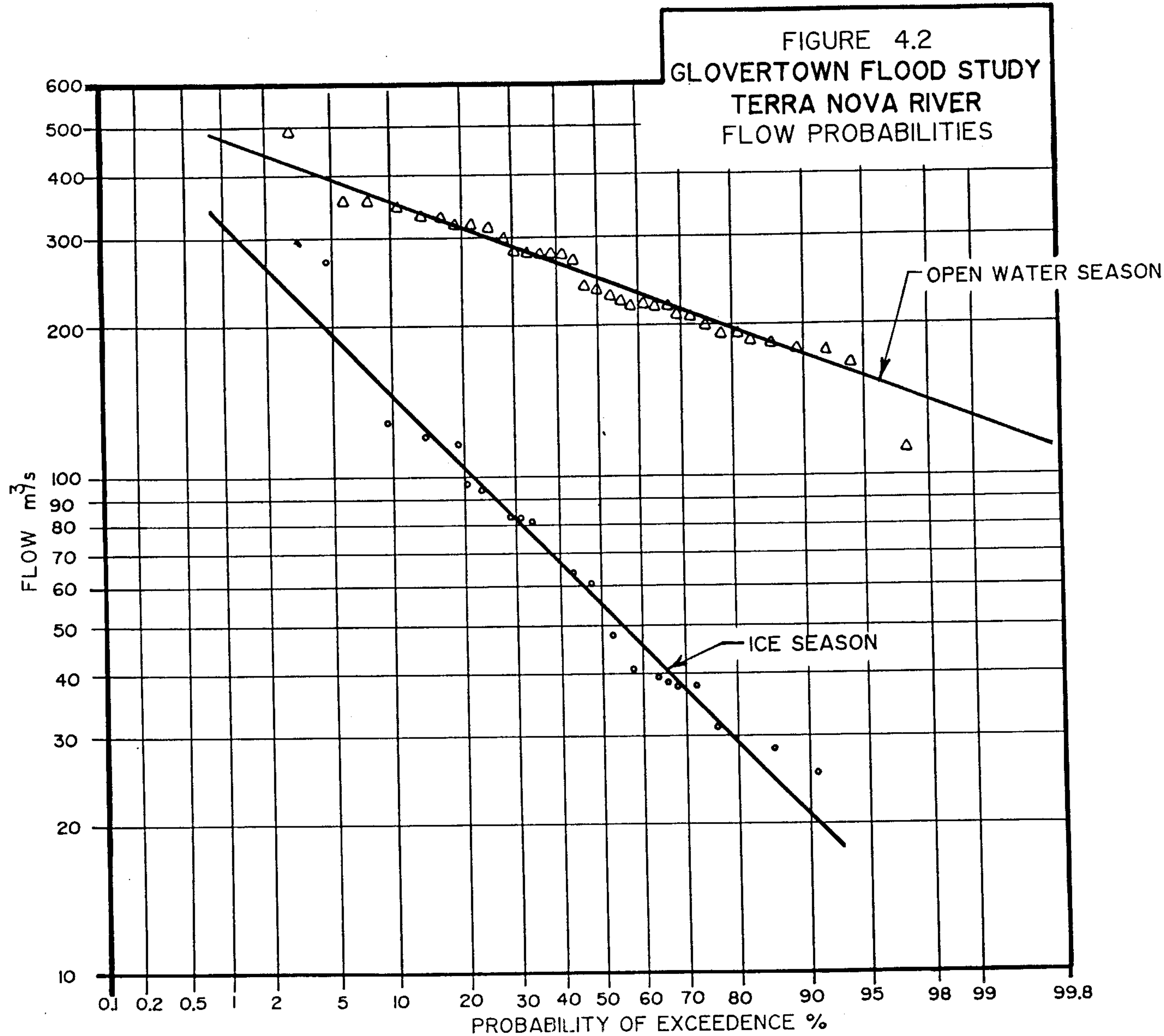
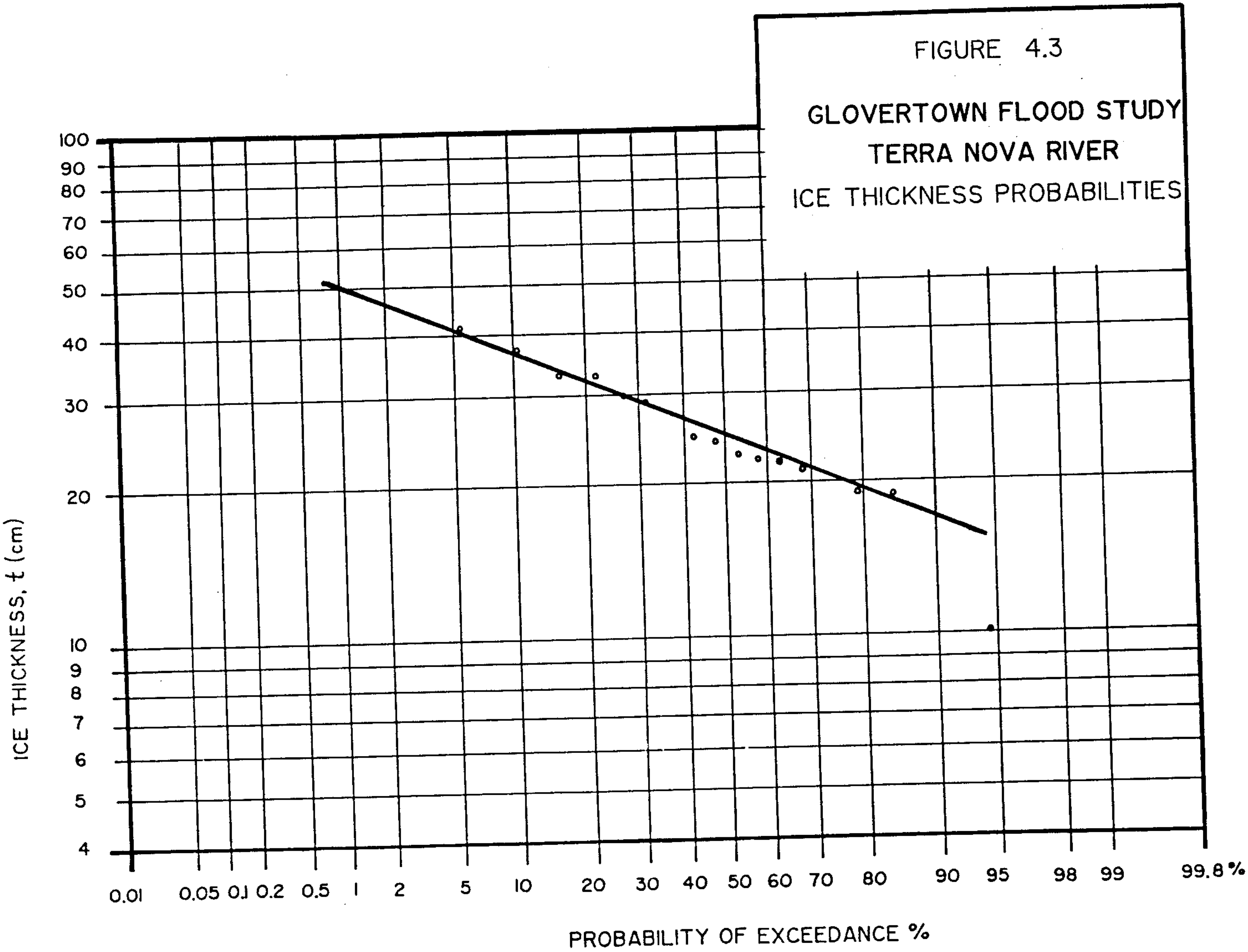


FIGURE 4.2
GLOVERTOWN FLOOD STUDY
TERRA NOVA RIVER
FLOW PROBABILITIES
OPEN WATER SEASON
ICE SEASON
FLOW m3/s
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
PROBABILITY OF EXCEEDENCE %
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8

FIGURE 4.3


GLOVERTOWN FLOOD STUDY
TERRA NOVA RIVER
ICE THICKNESS PROBABILITIES
ICE THICKNESS, t (cm)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
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 %
PROBABILITY OF EXCEEDANCE %

PART 5

RECOMMENDATIONS

5.0 RECOMMENDATIONS

The following recommendations are suggested to minimize damage from future flooding in the study area.

(a) Non-Structural Measures

i) Glovertown Council should implement zoning regulations to control development in flood prone areas as delineated on the flood risk map produced in this study.

ii) Monitoring of ice jam floods should be continued so as to improve the data base and confirm or adjust the findings of this study.

(b) Structural Measures

iii) Construction of an ice boom in the vicinity of Cross-Section 6.5 should be investigated. A boom would reduce the volume of ice in the lower river with minimal negative impacts, upstream of Cross-Section 6.5 where the valley is well incised and the banks uninhabited. [A resident of the area noted that ice jam problems were infrequent when the "old" log boom was in service at this location]. Further studies using the ice model are recommended to optimize the location and determine loads on the boom.

iv) A combination of flood dyke and channel improvements to reduce water level rise and contain ice and water flows in the river channel.

(b) Structural Measures (Cont'd)

Further studies are recommended using the ice model, with appropriate adjustments, to evaluate the effect of these measures.

v) Flood proofing of exposed existing structures and buildings.

REFERENCES

1. Hare, F.K. and Thomas, M.K. (1974)
"Climate Canada"
Wiley Publishers of Canada, Toronto

2. Environment Canada (1984)
"Principal Station Data - Gander"
Report PSD/DSP-46, Atmospheric Environment Service, Ottawa.

3. ShawMont Newfoundland Limited (1989)
"Flood Risk Mapping Studies: Glovertown Field Report"

4. Environment Canada, Water Planning and Management Branch (1976)
"Hydrologic and Hydraulic Procedures for Flood Plain Delineation".

5. Pariset, E. and Hausser, R. (1961)
"Formation and Evolution of Ice Covers on Rivers" - Transactions, Engineering Journal of Canada, Vol. 5 No. 1.

6. Pariset, E.; Hausser, R. and Gagnon, A. (1966)
"Formation of Ice Covers and Ice Jams in Rivers"
A.S.C.E. Proceedings, November 1966.

7. Frederking and Williams (1980)
"Forecasting Ice Phenomena in Rivers and Lakes"
National Research Council of Canada - Division of Building Research, Ottawa.

8. Cumming-Cockburn & Associates Limited, Willowdale, Ont. (1986)
"Ice Jams on Small Rivers: Remedial Measures and Monitoring"
for - Canada Centre for Inland Waters,
- Ministry of Natural Resources (Ontario),
- City of Mississauga,
and
- Credit Valley Conservation Authority.

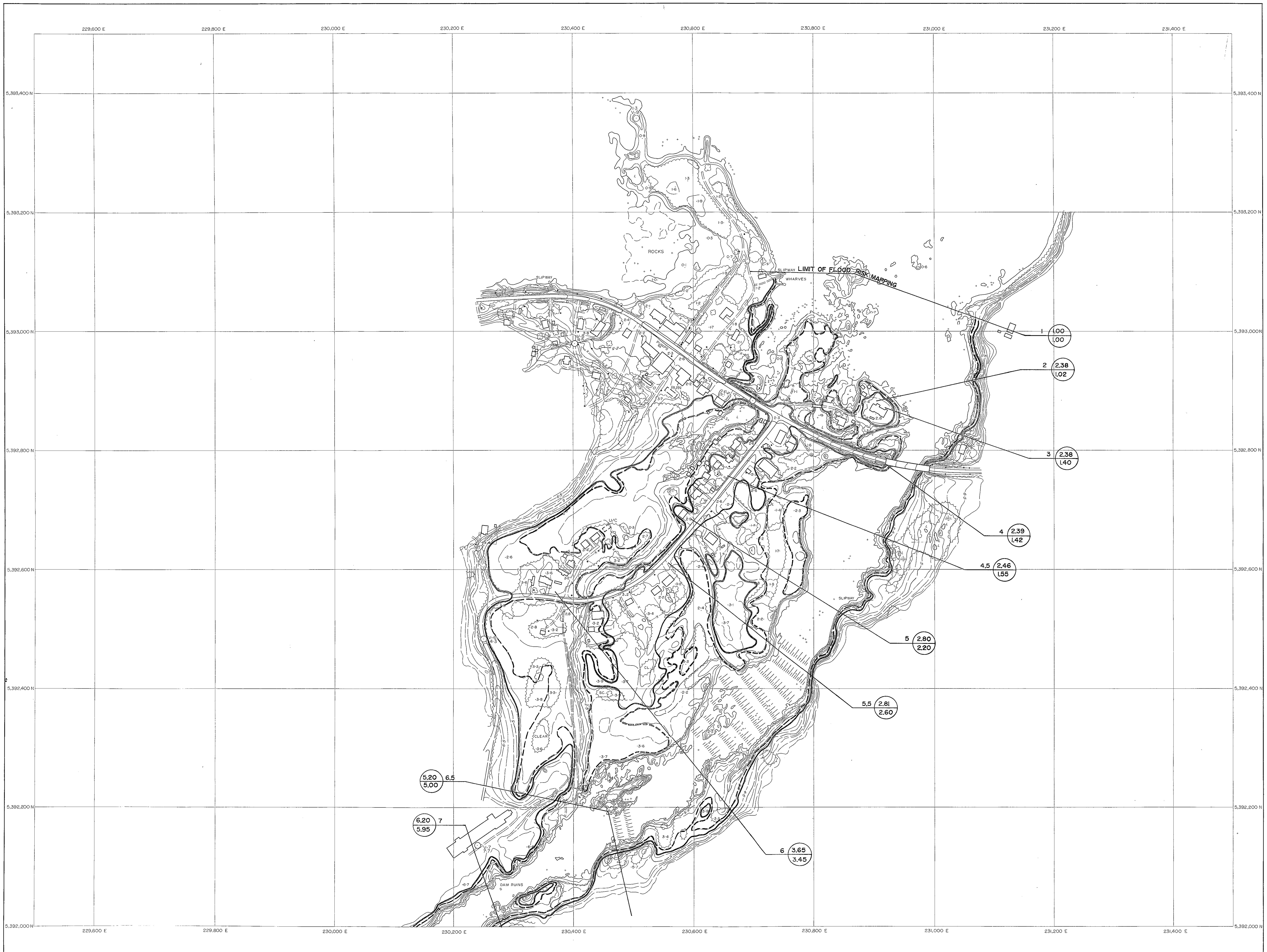
9. Panu, U.S. and Smith, D.A. (1986)
"Users Guide: Regional Flood Frequency Analysis for Island of Newfoundland" Canada-Newfoundland Flood Damage Reduction Program.

FLOOD RISK MAP
GLOVERTOWN, NEWFOUNDLAND
CARTE DU RISQUE D'INONDATION
GLOVERTOWN, TERRE-NEUVE

Environment Canada / Environnement Canada
Inland Waters / Eaux intérieures

Newfoundland Department of Environment / Ministère de L'Environnement de Terre-Neuve
Water Resources Division / Division des ressources en eaux

SHEET FR-GT-1 FEUILLE



LEGEND-LÉGENDE

SHORELINE AT TIME OF PHOTOGRAPHY
RIVES AU MOMENT DE LA PRISE DE VUES

FLOODWAY (1:20 YEAR PROBABILITY)
CANAL DE CRUE (PROBABILITÉ D'INONDATION: 1 FOIS TOUS LES 20 ANS)

FLOOD RISK AREA (1:100 YEAR PROBABILITY)
ZONE INONDABLE (PROBABILITÉ D'INONDATION: 1 FOIS TOUS LES 100 ANS)

1:100 YEAR FLOOD LINE
LIGNE DE LA ZONE INONDABLE (PROBABILITÉ: 1 FOIS TOUS LES 100 ANS)

CROSS-SECTION IDENTIFICATION
PROFILS TRANSVERSAUX ... 3 (2.38 / 1.40)

1:20 YEAR FLOOD LINE
LIGNE DE LA ZONE INONDABLE (PROBABILITÉ: 1 FOIS TOUS LES 20 ANS)

REFERENCE GRID

TWO HUNDRED METRE

NEWFOUNDLAND 3° MODIFIED

TRANSVERSE MERCATOR GRID

The Newfoundland 3° Modified Transverse Mercator Projection has a scale factor 0.9999 at the Central Meridian and a false easting of 304800 metres.

ZONE 1
Central Meridian
53° 00′ W

QUADRILLAGE DE RÉFÉRENCE

DEUX CENTS MÈTRES

QUADRILLAGE DE 3° DE LA PROJECTION TRANSVERSE

DE MERCATOR MODIFIÉE DE TERRE-NEUVE

La projection de 3° transverse de Mercator modifiée de Terre-Neuve a une altération linéaire de 0.9999 au méridien central et une abscisse conventionnelle de 304800 mètres.

ZONE 1
Méridien central
53° 00′ W

NOTE: Contours in heavy trees are approximate only.
Les courbes dans les zones boisées sont approximatives.

GENERAL INFORMATION

This map has been produced for the Inland Waters Directorate, Environment Canada and the Water Resources Division, Newfoundland Department of the Environment in association with Energy, Mines and Resources Canada. The mapping complies with the specifications of "Surveying and Mapping Procedures for Flood Plain Delineation" and "Hydrologic and Hydraulic Procedures for Flood Plain Delineation". Environment Canada, May 1976.

TOPOGRAPHIC MAP

This map was produced in 1988 by Kenting Earth Sciences International Ltd. from aerial photography flown in June, 1987.

FLOOD LINES

DISTRIBUTION

Copies may be obtained from the Department of Forest Resources and Lands, Mapping Division, Lands Branch, Howley Building, Higgins Line, St. John's, Newfoundland, A1C 5T7.

LEGEND-LÉGENDE

Control, integrated monument ... M-202 ... Monument de contrôle
vertical point ... V-430 569·2 ... Point altimétrique
Spot elevation, water level ... 565·1 ... EL 561·7± ... Point côté, élévation d'eau
Photo centre ... 60 ... Centre de photo
Railway, siding ... Chemin de fer et voie de service
Building, under construction, ruin ... U/C RUIN ... Bâtiment, en construction, ruine
Road paved, unpaved ... Route pavée, non-pavée
Bridge, footbridge, culvert ... Point, passerelle, ponceau
Cart track, trail ... Chemin de terre, sentier
Fence, hedge ... X ... H ... Clôture, haie
Guard rail ... Garde-fou
Retaining wall ... W ... W ... Mur de soutènement
Pylon, pole, light standard ... Pylône, poteau, lampadaire
Transmission line ... Ligne de transport d'énergie

FLOOD RISK MAP
GLOVERTOWN, NEWFOUNDLAND
CARTE DU RISQUE D'INONDATION
GLOVERTOWN, TERRE-NEUVE

SCALE 1:2 500 ÉCHELLE

METRES 50 0 50 100 150 200 250 MÈTRES

FEET 250 0 250 500 750 PIEDS

Contour interval 0.5 metre
Elevations in metres above Mean Sea Level
North American Datum 1927

Équidistance des courbes de niveau 0.5 mètre
Altitudes en mètres
Système de référence géodésique nord-américain, 1927

LEGEND-LÉGENDE

Quarry, cliff ... Carrière, falaise
Water course, definite ... Cours d'eau, défini
indefinite ... indéfini
Ditch ... D ... Fossé
Shoreline ... L ... Rive
Dam, falls, rapids ... DAM ... Barrage, chutes, rapides
Marsh, swamp ... Marais, marécage
Wooded area, scrub ... Région boisée, broussailles
Cemetery ... CEM ... Cimetière
Contour ... 565 ... Courbe de niveau
Depression contour ... 560 ... Courbe de cuvette
Indefinite contour ... 564 ... Courbe de niveau imprécise
Dyke or levee ... Digue

RENSEIGNEMENTS GÉNÉRAUX

Cette carte a été établie pour la Direction générale des Eaux intérieures, Environnement Canada et par la Division des ressources en eaux, ministère de l'Environnement de Terre-Neuve avec la participation d'Énergie, Mines et Ressources Canada. La cartographie se conforme aux spécifications énoncées dans les publications "Surveying and Mapping Procedures for Flood Plain Delineation" et "Hydrologic and Hydraulic Procedures for Flood Plain Delineation" publiées par Envrionnement Canada, mai 1976.

CARTE TOPOGRAPHIQUE

Carte établie en 1988 par Kenting Earth Sciences International Ltd. à partir de photographies aériennes prises en juin, 1987.

LIMITES DE LA CRUE

DISTRIBUTION

Des exemplaires de cette carte peuvent être obtenus en écrivant à l'adresse suivante: Department of Forest Resources and Lands, Mapping Division, Lands Branch, Howley Building, Higgins Line, St. John's, Terre-Neuve. A1C 5T7.

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GLOVERTOWN, TERRE-NEUVE