REVISED DRAFT

PAPER

on

MONTREAL ICE CONTROL STRUCTURE

for

EASTERN SNOW CONFERENCE

U.S. ARMY COLD REGIONS LABORATORY
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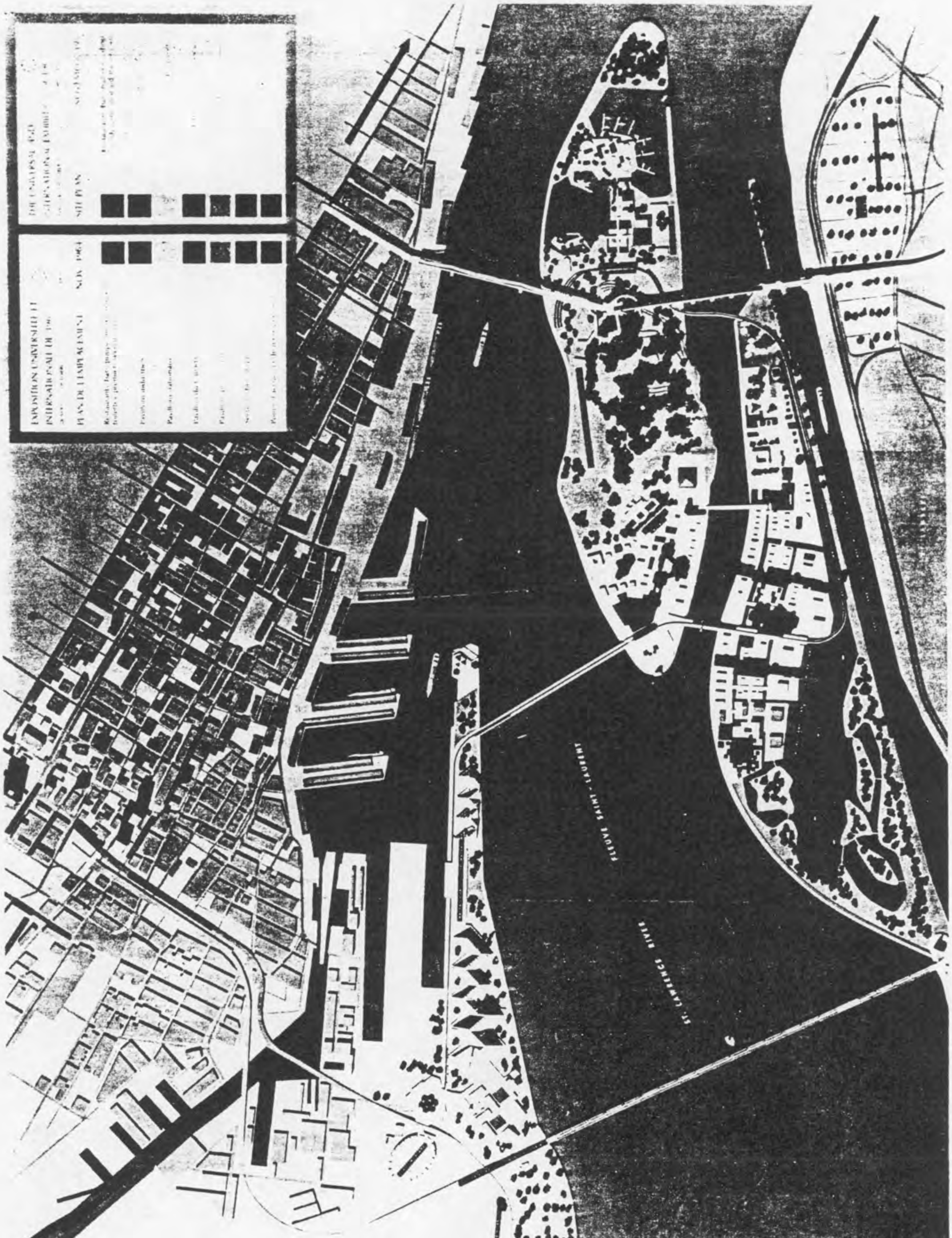


MONTREAL ICE CONTROL STRUCTURE

In 1967 the Canadian Universal and International Exhibition will be held in Montreal at a site in the middle of the St. Lawrence River created from existing and man-made islands.

I imagine you must wonder what a World's Fair has to do with a Snow Conference. I can assure you that, if there ever was a connection, we have the ingredients present around the site of the 1967 World's Fair. This location will be at times surrounded with snow and ice, which affects a very sensitive water level.

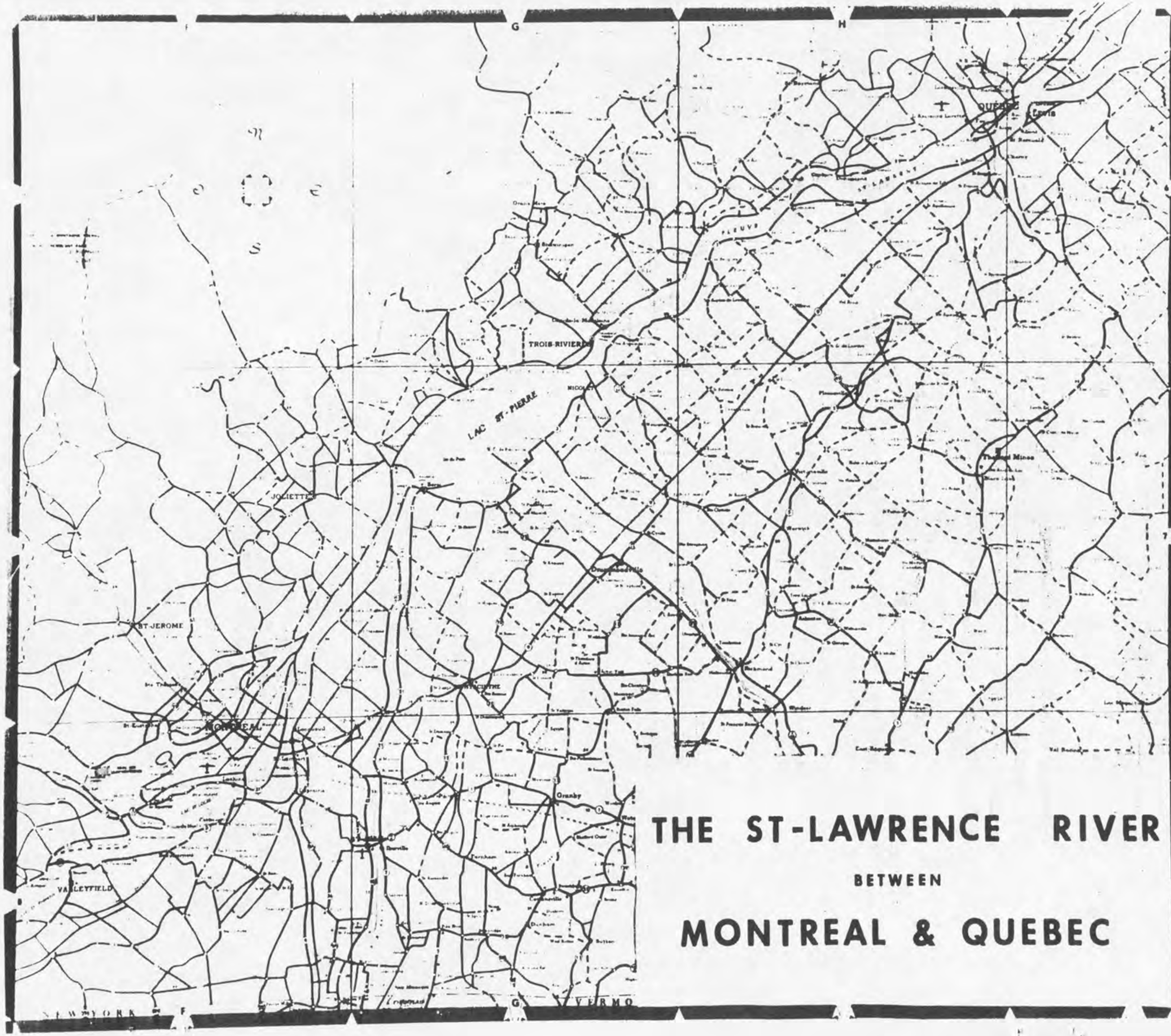
As can be seen on the screen, the actual site is divided into three main areas - the enlarged Ile St. Helene, the new Ile Notre Dame, and the McKay Pier section. The three areas comprised about 200 acres of land prior to the reclamation and filling projects, started in the summer of 1963. In their final state they will comprise about 600 acres. Obviously, the expanded land area in the middle of the river constitutes a restriction to the flow. We do not see this as a problem at all in the open navigation (water) season. However, when a good north country winter comes along and ice starts to flow in the river, the new restrictions could create quite a problem.

The federal government has been controlling ice and water level conditions in this area for a great number of years, through the use of icebreakers. With all the icebreaker experience to date, there can be no guarantee that the river will be kept open every year. Due to the restricting area at the Fair site, previous high water levels, caused by severe ice jams might well be exceeded. This led to the construction of the Ice Control Structure, providing, we hope, an additional safeguard:

a) to the Fair site itself;
b) to the maintenance of proper water levels in the Montreal harbour and the St. Lawrence Ship Channel;
c) against flooding and severe damage to the main St. Lawrence Seaway dyke, which starts adjacent to the Fair site;
d) against flooding in the lower lying areas of Longeuil, Verdun, and Lachine, important residential suburbs.

The City of Montreal, which is responsible for providing the actual Fair site, is sharing in the cost of the Control Structure, since they helped to create the problem. I won't give you the actual percentages applying to the shared cost, since the Mayor of Montreal, when confronted with the estimated costs of the structure, remarked that, while he had previously suggested sharing the cost equally, based on the use of a floating boom, he now felt that with the permanent dam we were providing a Cadillac whereas a Ford would do the job.

I understand there have been previous papers on both the theoretical and practical side of ice formation in the St. Lawrence River. While I know that these papers were prepared by persons who know much more about ice formation than I do, I believe a short review of the process is a necessary part of anything written about the Ice Dam.


THE ST-LAWRENCE RIVER
BETWEEN
MONTREAL & QUEBEC
QUEBEC
Levis
TROIS-RIVIERES
NICOLET
LAC ST-PIERRE
FLEUVE
JOLIETTE
ST JEROME
MONTREAL
VALLEYFIELD
Granby
Drummondville
G
H
F

FOLLOW GEOGRAPHICAL AREAS ON SCREEN

In the Montreal area, conditions are ideal for the generation of all three general categories of ice, i.e. sheet ice, frazil and anchor ice. The crystals, or frazil, form in Lake St. Louis and the Lachine Rapids and are then transformed into blocks and small rafts in the Laprairie Basin. The blocks then flow unhindered until they reach the calm water of Lake St. Peter, some 60 miles downstream from Montreal. With the colder temperatures of December, the initial freeze-over, or sheet, is formed at the lower end of Lake St. Peter. Once the total ice cover is formed, the new ice flowing downstream comes to rest against the ice bridge and starts an upstream progress of the cover. The backward progress goes on until it reaches an area where the current is too strong to permit its continuance. At this stage, one of two things happens: -

a) If the weather is very cold, the ice sheet will be relatively strong and the new flowing ice will plunge under the existing cover to start formation of an inverted or hanging dam. Under this condition, the water level will rise in front of the dam, the current will then drop, and normal progress of the ice sheet resume.

b) If the weather is mild, the ice sheet will not be strong enough to tolerate the increased pressure caused by the flowing ice rafts. The sheet will then buckle or telescope, again starting formation of a dam in restricted areas. Again, we have an increase in water level, hence a drop in the current velocity upstream, and normal progress of the ice sheet.

The foregoing occurs from Lake St. Peter upstream to the Fair site, where we reach the restriction which could cause an abnormal rise of water level around Montreal. For example, two weeks ago, with a cold snap, we had a 12-foot rise. In past years there have been occasions when the water went up to 18 feet in less than two weeks.

Obviously, severe temperatures, the volume of river flow, snowfall and precipitation all have a very serious and controlling effect on this whole situation. I am not going into this any further than to show a couple of slides depicting graphs on which these various factors are recorded. The actual relationship of one to the other is, I believe, a study in itself, and one, on which much remains to be done.

OBSERVATIONS OF TEMPERATURE RELATION TO WATER LEVEL

ALSO NOTE SHARP EFFECT OF ICEBREAKING

Selection of the actual dam site was limited by the geography of the region of two areas:

a) the lower section of Lake St. Louis; or
b) the lower section of Laprairie Basin.

At one time, we considered a dam on Laprairie and a separate boom on Lake St. Louis. It was decided to settle on a spot about 1,000 feet upstream from the Champlain Bridge and, hence, realize the storage capacity of practically the whole Laprairie Basin.

This decision resulted from the recommendations of a Committee of Federal Government, Chief Engineers, namely; Messrs. Gerald Millar, Walter Manning, Les Stratton and Lawrence Burpee of Department of Public Works, Transport, National Harbours Board and the St. Lawrence Seaway Authority, respectively.

The firm of Lalonde, Valois, Lamarre, Valois & Associates were retained as Consultants and very quickly took hold of the problem.

Extensive soil borings, model tests, and hydraulic studies followed. The model work was done at the LaSalle Hydraulic Laboratory. As usual, calibration to give similar characteristics to the prototype was difficult under the following variety of scales:

Vertical	1:150
Horizontal	1:600
Volumes	1:54,000,000
Velocities	1:12.25
Liquid Flow	1:1,102,000
Slopes	1:4
Ice Flow	1:137,500
Forces	1:13,500,000

The model covered about eight miles of the river. Ice was simulated, using polythene cubes, three to four millimeters base and height. They were fed into the model using separate funnels and control valves. Seventy-two piers, stoplogs, etc., were to scale and made of plexiglass and other plastics. Point gauges, reading to an accuracy of 1 m.m. - 0.5' in the field, were used.

When viewing the model in operation, from time to time, most of the amateurs in this field, thought we observed many phenomena which confirmed our own particular theories. I am going to review some seven specific points where the experts felt the results obtained in the model provided supporting data and answers to problems associated with construction and operation of the Control Dam.

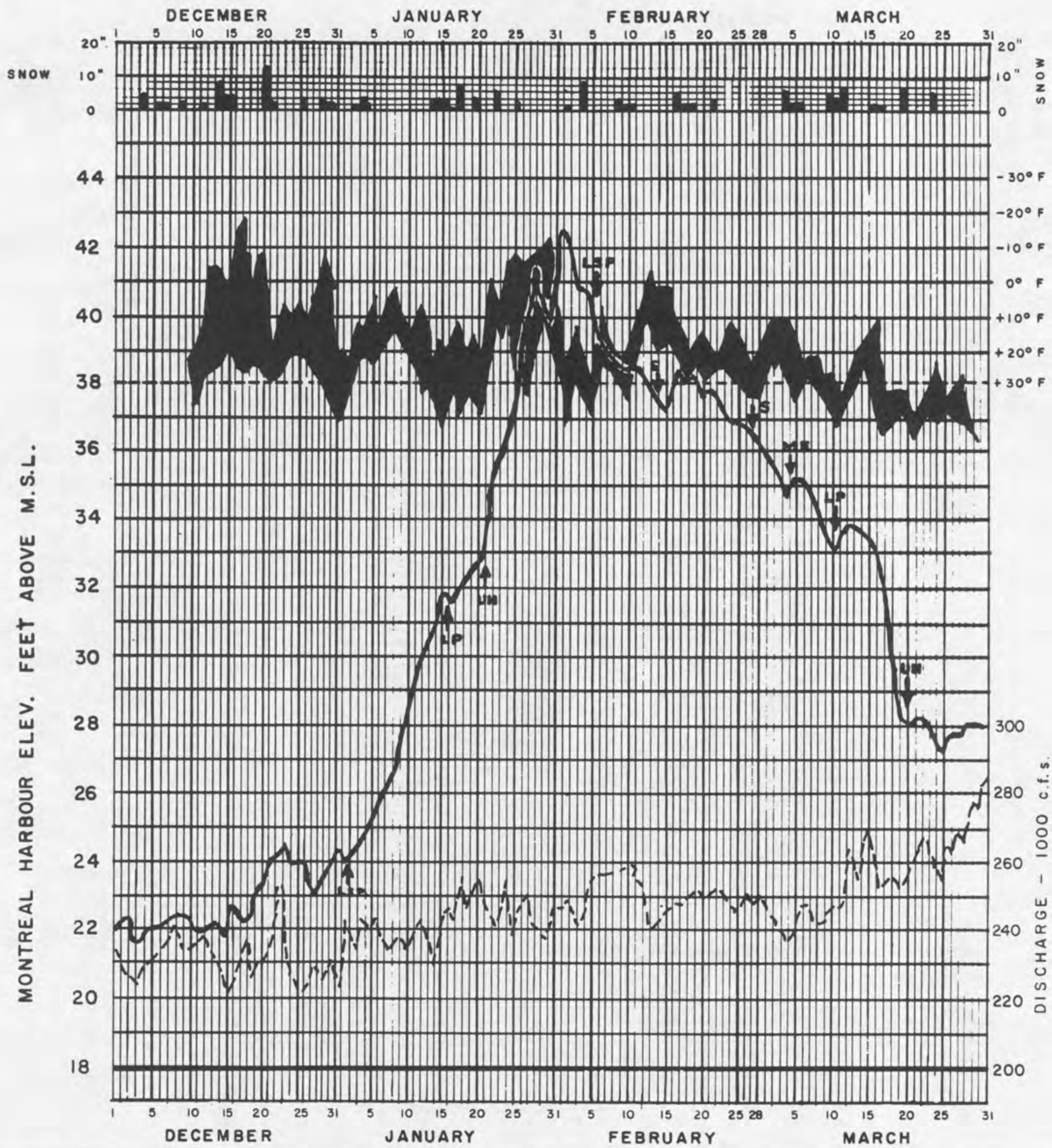
1. What is the minimum water level or reduced velocity at which ice will form in the Laprairie Basin?

   This was found to be Elevation 35. In the past this level was only reached after the ice cover had progressed upstream to the Montreal Harbour proper. Since, under ideal ice making conditions, it takes about one week to cover the 2 1/2 mile area between the harbour and the dam, we will be able to provoke a cover about a week earlier than usual.

2. What total amount of ice can be stored in Laprairie Basin?

   The LaSalle Lab people were aided considerably on this problem by previous studies made by Mr. D. W. McLachlan of the Joint Board of Engineers for the St. Lawrence River, and by Mr. Cousineau of Hydro-Quebec Commission.

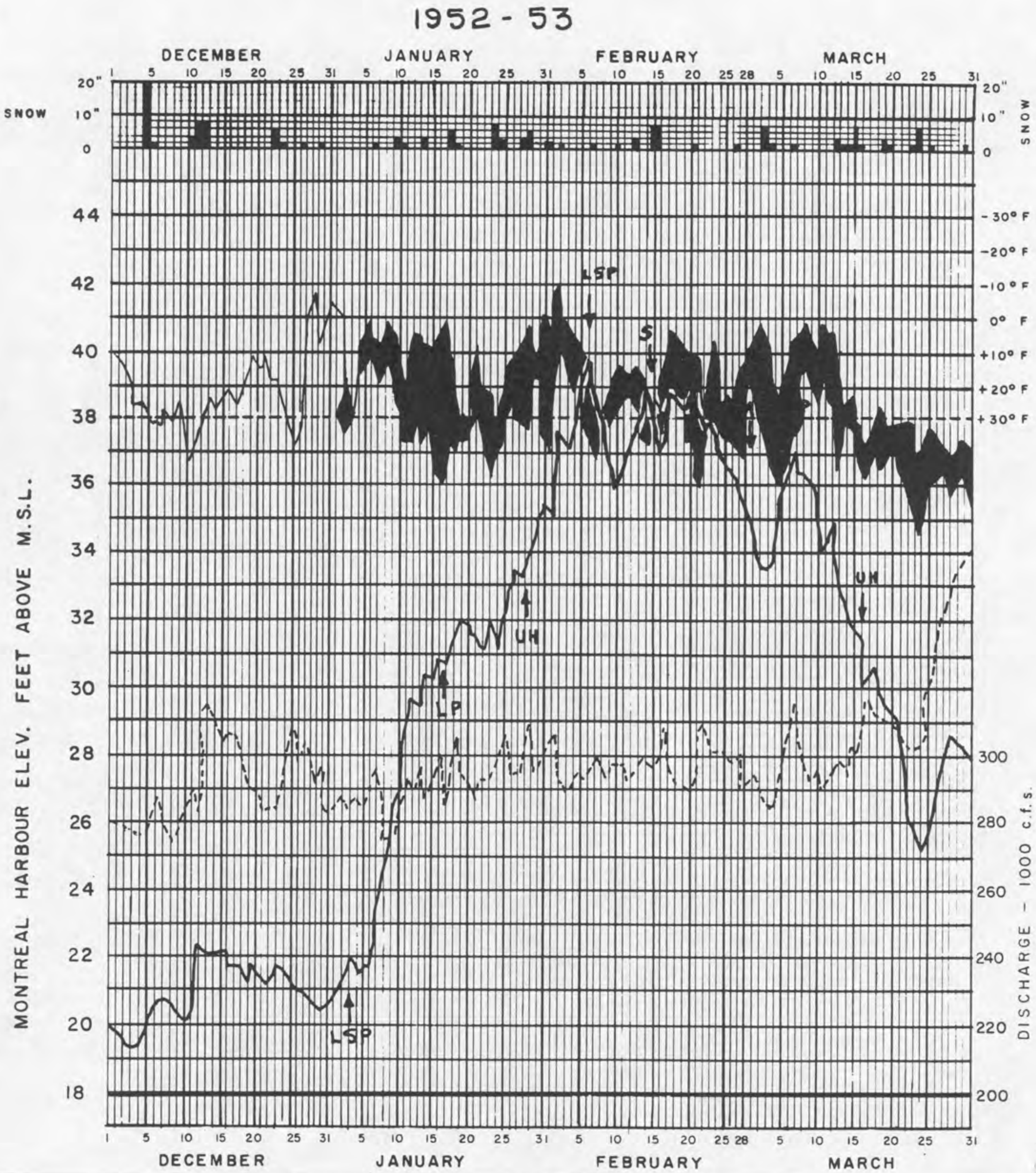
1951 - 52



MONTREAL, ICE CONTROL FACTORS— DAILY GRAPH
SCALES AS SHOWN

WATER LEVEL	PRECIPITATION
MAX.-MIN. TEMPERATURE	COMBINED DISCHARGE

	LAKE ST. PETER	SOREL	MONTREAL EAST	LONGUE POINT	UPPER HARBOUR
ICE COVER LOCATION	↑ LSP	↑ S	↑ ME	↑ LP	↑ UH
ICE BREAKER LOCATION	LSP ↓	S ↓	ME ↓	LP ↓	UH ↓



MONTREAL, ICE CONTROL FACTORS — DAILY GRAPH

SCALES AS SHOWN

WATER LEVEL

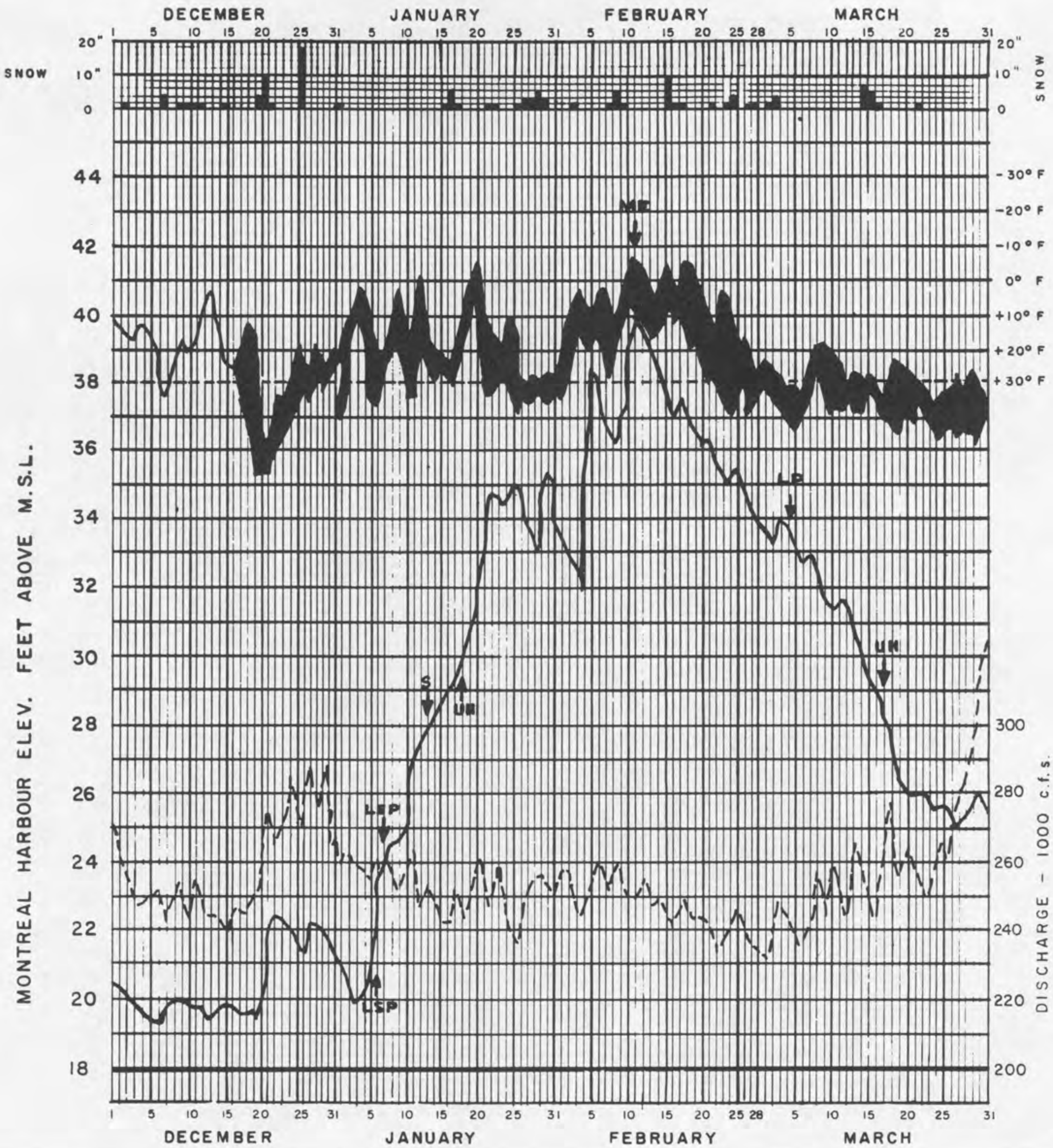
MAX.-MIN. TEMPERATURE

PRECIPITATION

COMBINED DISCHARGE

	LAKE ST. PETER	SOREL	MONTREAL EAST	LONGUE POINT	UPPER HARBOUR
ICE COVER LOCATION	↑ LSP	↑ S	↑ ME	↑ LP	↑ UH
ICE BREAKER LOCATION	LSP ↓	S ↓	ME ↓	LP ↓	UH ↓

1957 - 58



MONTREAL, ICE CONTROL FACTORS— DAILY GRAPH
SCALES AS SHOWN

WATER LEVEL

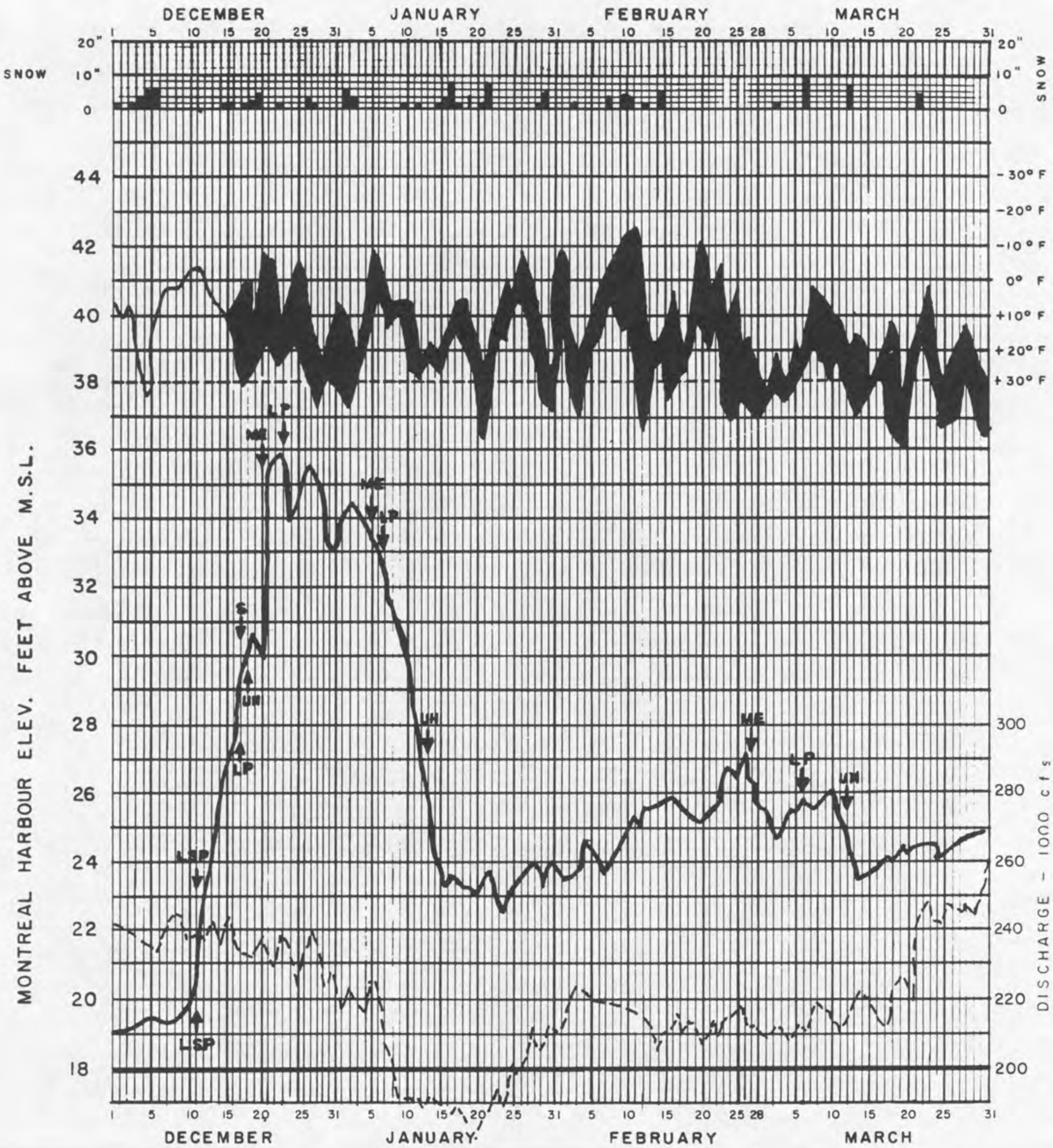
MAX.-MIN. TEMPERATURE

PRECIPITATION

COMBINED DISCHARGE

	LAKE ST. PETER	SOREL	MONTREAL EAST	LONGUE POINT	UPPER HARBOUR
ICE COVER LOCATION	↑ LSP	↑ S	↑ ME	↑ LP	↑ UH
ICE BREAKER LOCATION	LSF ↓	S ↓	ME ↓	LP ↓	UH ↓

1958 - 59

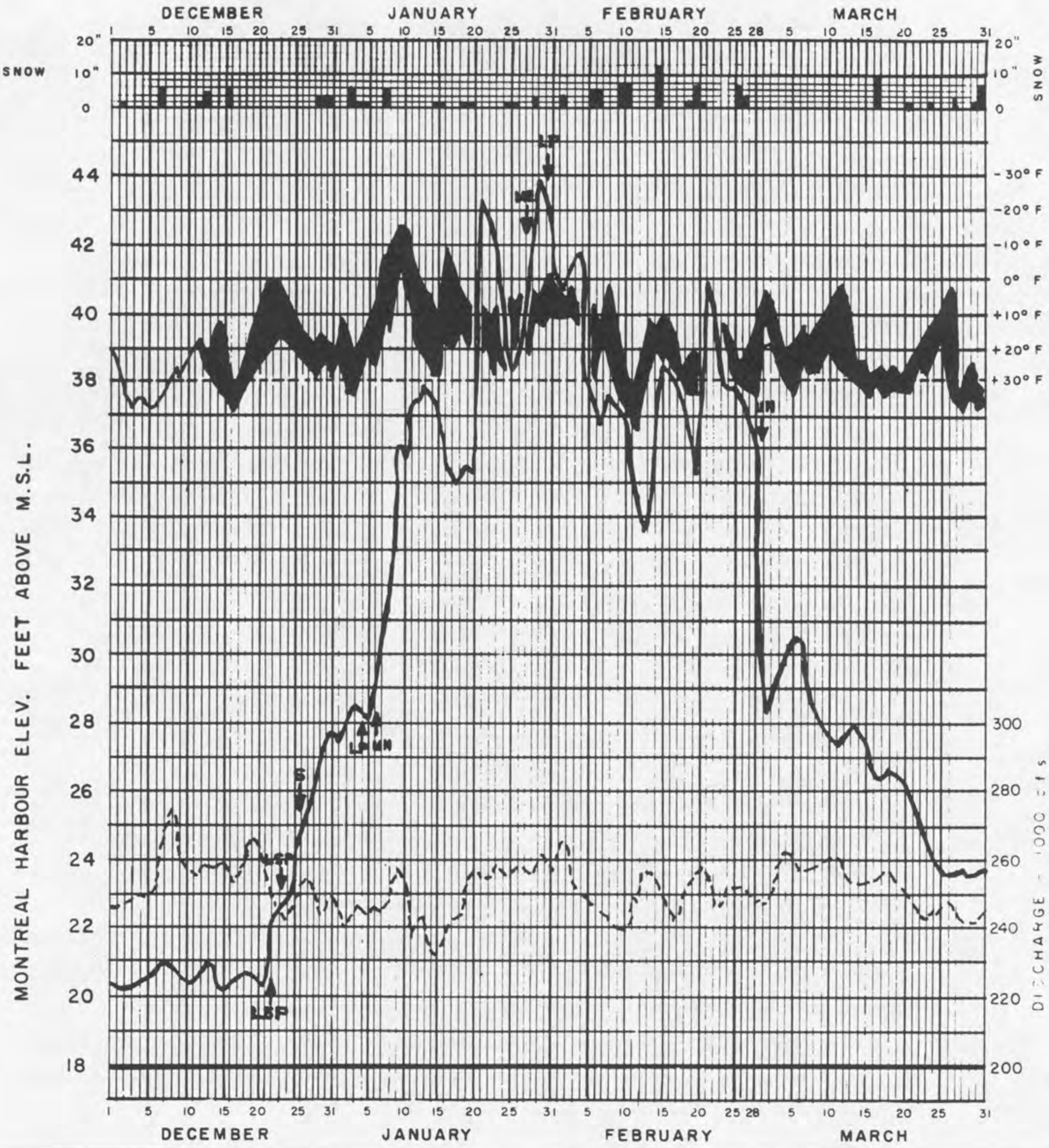


MONTREAL, ICE CONTROL FACTORS— DAILY GRAPH
SCALES AS SHOWN

WATER LEVEL
MAX.-MIN. TEMPERATURE
PRECIPITATION
COMBINED DISCHARGE

	LAKE ST. PETER	SOREL	MONTREAL EAST	LONGUE POINT	UPPER HARBOUR
ICE COVER LOCATION	↑ LSP	↑ S	↑ ME	↑ LP	↑ UH
ICE BREAKER LOCATION	LSP ↓	S ↓	ME ↓	LP ↓	UH ↓

1959 -60



MONTREAL, ICE CONTROL FACTORS— DAILY GRAPH

SCALES AS SHOWN

WATER LEVEL

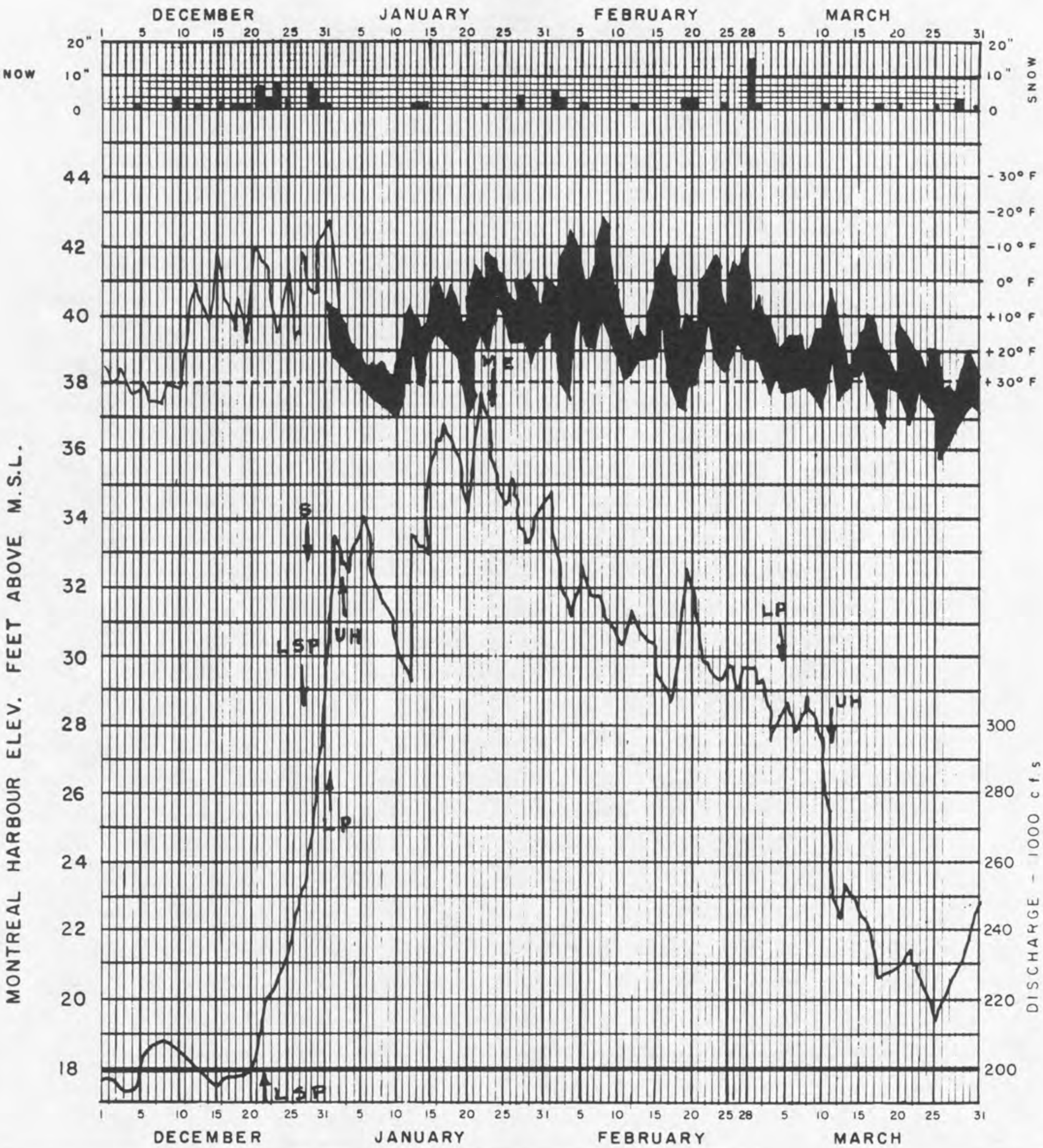
MAX.-MIN. TEMPERATURE

PRECIPITATION

COMBINED DISCHARGE

	LAKE ST. PETER	SOREL	MONTREAL EAST	LONGUE POINT	UPPER HARBOUR
ICE COVER LOCATION	↑ LSP	↑ S	↑ ME	↑ LP	↑ UH
ICE BREAKER LOCATION	LSP ↓	S ↓	ME ↓	LP ↓	UH ↓

1962- 63



MONTREAL, ICE CONTROL FACTORS — DAILY GRAPH

SCALES AS SHOWN

WATER LEVEL — MAX - MIN. TEMPERATURE — PRECIPITATION — COMBINED DISCHARGE

	LAKE ST. PETER	SOREL	MONTREAL EAST	LONGUE POINT	UPPER HARBOUR
ICE COVER LOCATION	↑ LSP	↑ S	↑ ME	↑ LP	↑ UH
ICE BREAKER LOCATION	LSP ↓	S ↓	ME ↓	LP ↓	UH ↓

Formulas relating the rate of ice production to the free area of water and the temperature difference between air and water have been evolved. In the model, ice production varied from 250 c.f.s. to 750 c.f.s., being equivalent to air temperatures of about 26° F. and 12°F. respectively. Ice storing below Elevation 35 was considered nil. For levels about 35, the sheet progresses upstream until it reaches the foot of Lachine Rapids, when it starts to flow under the existing sheet, partially forming dams, and a portion continuing downriver with the water level rise until it reaches the control structure. The ice will flow under the stoplogs, and an equilibrium is then reached where the new ice coming down equals the amount going under the logs. Elevation 44 is suggested as the maximum water level to be expected and, at that level, the stored ice quantity varied between 1.5×10^9 cu. ft. and 2.5×10^9 cu. ft., or 1.5 to 2.5 billion cubic feet.

3. What other effects would the structure have on the water levels in Montreal Harbour and vicinity?

   They found only better control of all ice conditions causing extreme levels, including flash releases of ice and run-off through a somewhat controlled waterway in the spring.

4. What effects would a large release of ice from Lake St. Louis have when an ice cover existed on Laprairie?

   In short, little, whether the ice control structure existed or not.
   A mass of ice would probably ground prior to building up against the existing cover. This happens since the water level downstream remains somewhat stable, having no cause to rise. This, of course, helped us to conclude that a separate ice boom on Lake St. Louis was not necessary.

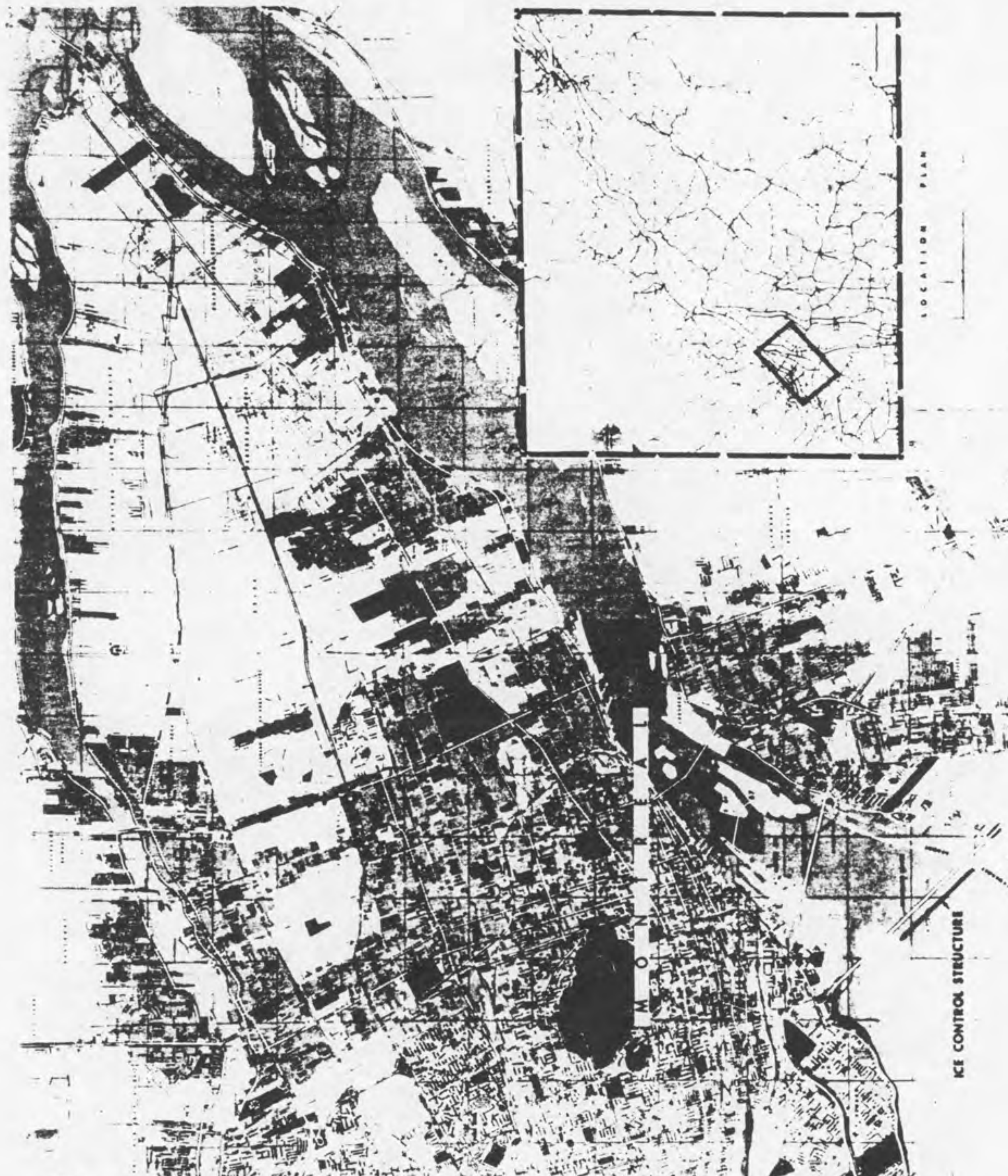
5. What ice thrusts should be expected against the stoplogs and piers?

   Both actual model testing and a theoretical approach was applied to this question. On the model, thrusts were evaluated at different water levels, using a suspended piece of wood resting against detector bands which were wired to a Sandborn recording gauge. Maximum recordings were reached just before the ice grounded. Theoretically, the works of Mr. Edwin Rose, in a 1946 A.S.C.E. publication, and also Timishenko's and Bryan's theory of thin plates were considered. These involved viewing the ice sheet as a thin plate, and taking into account the effects of wind and forces developed by the expansion of the ice sheet under solar radiation.

   In the final analysis, the piers were designed to resist a maximum load of 10 kips per lineal foot of structure -- the other elements, a design load of 5 kips per foot.

6. Where should a free water channel be located to assist the ice run-off?

   This was found in the vicinity of Pier 15, but in order to use the maximum depths of the river, the actual evacuating channel was moved out a little further and fixed between Piers 19 and 22.



SITE OF
ICE CONTROL STRUCTURE

7. What draft should obtain for the stoplogs?

The model indicated that a draft of more than four to six feet for the stoplogs would not improve the functioning of the control structure.

A few structural details should be of interest:-

There are 72 piers and two abutments, stretching from Nun's Island on the Montreal side to the Seaway dyke on the south shore. The piers are just over 88 feet on centres, with those in the free water channel area - that is Nos. 19 to 21, being just over 176 feet on centres.

Borings taken at the location of each pier showed solid rock lying from seven to 39 feet below the summer water level. The bottom elevation of the piers is set some five feet into the rock to ensure stability.

In order to obtain rapid pier construction, their base is being completely encased by a metal caisson. The caissons, and hence the bottoms of the piers, vary from 16 to 20 feet in width and from 55 to 67 feet in depth of length. The concrete for the pier base is poured up to eight feet below the water level, using a fixed tremie method. The rest of the base and all of the pier are then poured in the dry, using conventional methods, up to a top elevation of 72 feet.

The piers have a 4-foot recess on either side to receive the floating stoplogs which have overall dimensions of 6' x 5'7" x 82'1". They are built much in the same fashion as a ship. The ends of the logs will be equipped with guide rollers to transfer the thrust to the piers. The stoplogs will be trimmed, using concrete blocks as ballast in order to achieve, roughly, a four foot draft.

To prevent ice from adhering to the logs, permitting their removal when required, they will be heated, using infra-red lamps placed on the service platform. The roller bearings are assured of smooth functioning by separate heating of the notches in each pier. The whole structure will require power in the vicinity of 10,000 K V A.

A pre-stressed concrete deck is mounted on the top of the piers to provide access to the logs and electrical equipment. Workshops will be built in the area to maintain and operate the equipment. Two trucks, mounting specially designed winches, will remove and replace the stoplogs for periodic maintenance and for storing on top of the piers during summer months. The deck should not receive much use other than for the servicing of these logs, although it is conceivable that some scheme might be worked out whereby public recreational use might be made, at least at the extremities of the control structure.

Construction has been separated into three contracts: The first, for the piers, abutments, etc., was awarded to Dufresne Engineering at about $9.5 million. It is now over 50% finished. The second contract, that for the construction of the stoplogs, amounting to about $1.5 million, was awarded to Foresteel Products Ltd. last December. The third, which will include various ancillary facilities, and electrical and mechanical installations, is about to be tendered, with a contract award scheduled for this spring.

There are a couple of features to the main contract that are of interest from the Federal Public Works point of view. The bidders were required to supply complete Critical Path planned programs as a condition of tender and secondly we have a $10,000 a day penalty clause applying to completion dates.

This paper has been authored with tongue in cheek -- I would have preferred to wait a year or two and observe the structure in operation -- however, it is over 50% complete and, given the factor of safety in engineering judgments, we will take for granted it is going to work.

For such a novel type of structure, this $13 million job has been given relatively little publicity in Canada. There are a couple of obvious reasons: Firstly, it is a small remote part of the whole World's Fair complete - and secondly, the press do not seem to understand what it is all about. This, to me, may be a good thing, since like most insurance policies (and that is really what we have here), we hope it is never needed.

On the other hand, when one considers the value of what has to be protected in the general Montreal area, we believe the money is being well spent.