SNOW-MELT AS A FACTOR IN QUEBEC STREAM-FLOW

by

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INDEX

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The Province of Quebec, together with Labrador, covers an area of 600,000 square miles and extends from the northern boundaries of Vermont and New York to Hudson Strait, a distance of some 1,200 miles. (See Page35)

As one might expect, considerable variety of climate is found within Quebec's territorial limits. For example, the mean annual temperature and precipitation at Montreal are +43°F. and 41", respectively, as compared with corresponding figures of +18°F. and 13" at the northern tip of Ungava Bay; and, in the average Winter, the snowfall ranges from a total of 112" at Montreal to 50" at the northern extremity of the Province.

Almost all of Quebec's population and industrial activity are concentrated within the St. Lawrence drainage and, speaking very generally, one can say that the topography, hydrology and climate of this region are remarkably similar to those of the northern New England States. The industrial development has been quite different, however, from that of New England; and one of the most striking differences may be found in the field of hydro-electric power.

Hydro-electric development in Quebec is close to 7,000,000 horsepower, 80% of which is concentrated along a comparatively few large rivers which drain into the St. Lawrence from the north, between Montreal and Tadoussac. All these streams have the same general watershed characteristics and are regulated to a high degree through the operation of large storages which, for the most part, have been built by The Quebec Streams Commission, a Provincial Government Agency charged with the management of all running streams in the Province. Typical of the rivers in this group, and outstanding among them, is the St. Maurice, whose watershed of 16,000 square miles approaches the combined areas of New Hampshire and Vermont. (See Page 37). Its primary flow of close to 75% of the mean run-off makes it one of the best regulated rivers in the world and its potentiality of more than 2,000,000 horsepower, of which upwards of 1,500,000 horsepower already have been developed by The Shawinigan Water and Power Company, is attributable to the operation of 7 reservoirs having a combined capacity of 8,000,000 acre-feet. Six of these reservoirs have an aggregate capacity of 1,500,000 acre-feet with drainage areas sufficiently large to permit yearly use operation and, consequently, they represent no problem.

The remaining storage has a maximum capacity of 6,500,000 acre-feet and is controlled by the Gouin Dam with a watershed of some 3,400 square miles. Since its capacity in relation to its drainage is sufficiently large to permit storage reserves to be carried over from year to year, this reservoir is the backbone of the storage system and it is evident that, in dealing with a river as closely regulated as is the St. Maurice, the ability to forecast the occurence of storable water would be of vital importance to the Company's operations.

Since, on the average, almost half of the annual run-off to the Gouin reservoir is represented by the Spring freshet, an obvious approach to a solution of the problem is on the basis of snow-cover measurement and, in this connection, Shawinigan has been carrying out annual snow-surveys since 1928. Measurements which originally were confined to four snow-courses have been extended to nine whose locations are governed largely by accessibility, as transportation is a vital consideration (See Page39). The survey is carried out about mid-March since, after that time, serious snow-melt is apt to occur at the more southerly observation posts.

Predictions based on these surveys have been generally unreliable and have led to a re-examination of the problem in the light of experience. As a first step, figures relating to snow depth measurements made in the vicinity of the Gouin Dam, together with pertinent precipitation and other data, have been compiled for each of the 24 years that have elapsed since the snow surveys were initiated (See Page41).

STATISTICAL

The Spring freshet in the vicinity of the Gouin Dam starts between March 18 and April 29, with a mean date of April 13. It is completed; on the average, by June 18, but may be prolonged until July 31 or finished as early as May 12. Its duration averages 66 days, but may be as little as 26 days or as great as 116 days; and the inflow during this period ranges from 700,000 to 3,300,000 acre-feet, with an average value of 1,750,000 acre-feet, which is equivalent to a depth of 9.70 inches on the drainage area.

The water content of the snow-cover at the beginning of the Spring flood has a mean value of 9.53", with a maximum of 13.99" and a minimum of

5.62", and the precipitation which occurs during the melting period varies between 1.76" and 14.93", with a mean value of 7.14"; while the total depth of water supplied to the catchment area before and during the melting period amounts to an average of 16.62", with extremes of 9.28" and 24.97", which represent limiting yields of 32% and 76% with a mean value of 58%.

PATTERN OF RESULTS

Pages 43 and 45 show, in absolute figures and as percentages of mean, the Spring inflow to the Gouin reservoir in relation to the water content of the snow-cover, as measured and as adjusted to reflect precipitation between the date of snow measurement and the time when the freshet period begins; also in comparison to the precipitation occuring during the freshet period and to the total water available for run-off. The rough envelope of each set of comparisons has been delineated for purposes of clarification.

An inspection of these comparisons reveals little in the way of a definite relationship between Spring run-off and the water content of the snow-cover existing just prior to the beginning of the melting period. It is considered significant that the inclusion of the precipitation occurring between the date of snow measurement and the beginning of the Spring freshet adds nothing to the strength of the figure, nor does it alter the slope of the envelope axis.

The comparison between Spring run-off and the precipitation occurring during the freshet period shows a somewhat irregular pattern with a definite general slope, indicating that there is a strong relationship between such precipitation and the volume of the Spring freshet.

The relationship between the volume of the Spring flood and the applicable total of the water contained in the snow-cover and occurring during the flood-period likewise shows a more or less definite slope, with an axis at about 45° having a horizontal cut-off of perhaps 6 inches. Speaking in the broadest possible terms, it would appear from these characteristics that an accumulation of approximately 6 inches of water might occur before the Spring freshet is initiated.

If all practical experience in the field of hydrology is ignored, a strictly mathematical consideration of the observed data might lead to the general conclusions that, at least in the geographical region of the Gouin reservoir, the water content of the snow-cover has little effect on the characteristics of the spring freshet and the dominant influence appears to be the rainfall occurring during the melting period. Supporting examples would be found in the experiences of 1934, when a snow-cover of near-record depth, followed by s sub-normal rainfall, resulted in a very low Spring run-off; and in that of 1936, when an unusually light snow-cover combined with a very heavy Spring rainfall to produce a flood some 50% above the normal figure.

Despite the foregoing, it seems unreasonable to suppose that the apparent effect of the water contained in the snow-cover on the characteristics of the Spring flood should be so limited, and it is logical to believe that there are additional factors which have a substantial influence. Some of the contributary causes can be deduced from reasonable assumptions based on experience, and these are considered as follows:-

(a) EVAPORATION

The water content of the snow-cover, as measured at Oskelaneo River near the Gouin Dam, has averaged 7.31 inches during the last 24 years, while the average Winter snowfall (November through March) amounts to about 129 inches. Even if the generally accepted density factor of 10% is considerably in error, there still remains a substantial water equivalent which can be accounted for only by evaporation of the snow.

There is a wide-spread belief that evaporation does not take place from water in the solid form, but every housewife who hangs out washing to dry in freezing weather knows that this belief is erroneous. The extent of this type of evaporation is not easy to determine under field conditions, but doubtless is associated with snow surface structure, atmospheric temperature, wind travel and solar radiation.

The water content of the snow-cover, as measured prior to the beginning of the Spring flood, is the net initial water supply after evaporation has taken place, while the precipitation occurring during the Spring flood includes evaporation, interception and transpiration losses. Therefore, in combining these two quantities for purposes of forecasting, we are combining data which are different in quality.

(b) THE CONDITION OF THE GROUND

We know that an impervious surface or a wet surface will yield more run-off than will a porous or a dry surface.

Consequently, Spring run-off from ground which has been frozen and saturated in the previous Autumn will be greater than from ground which had a low water-table at the beginning of Winter and which was unfrozen when blanketed with the first snow.

(c) ATMOSPHERIC CONDITIONS

It is known that consistently high air temperatures during the melting period are conducive to the occurrence of a high yield and that temperatures which are above freezing during the day but below the freezing level at night make for a minimum of run-off, particularly if they are associated with high wind travel.

(d) RATE OF PRECIPITATION DURING THE MELTING PERIOD

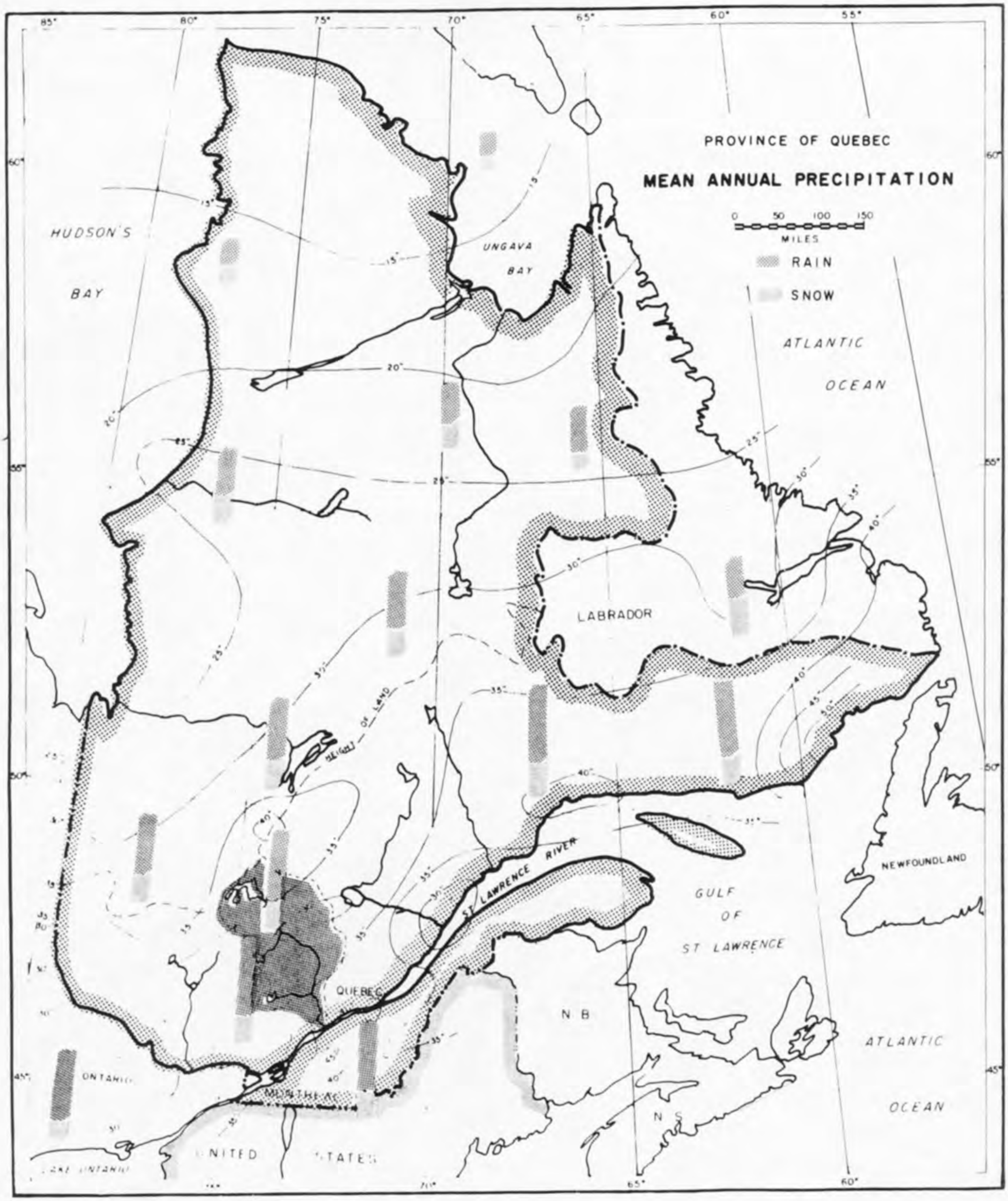
If a high rate of melting favours a high yield, this rate will be accelerated by the occurrence of rainfall, which contributes to the flood both through its direct value as free water and as an agency to supply the required latent heat of fusion to convert snow to water.

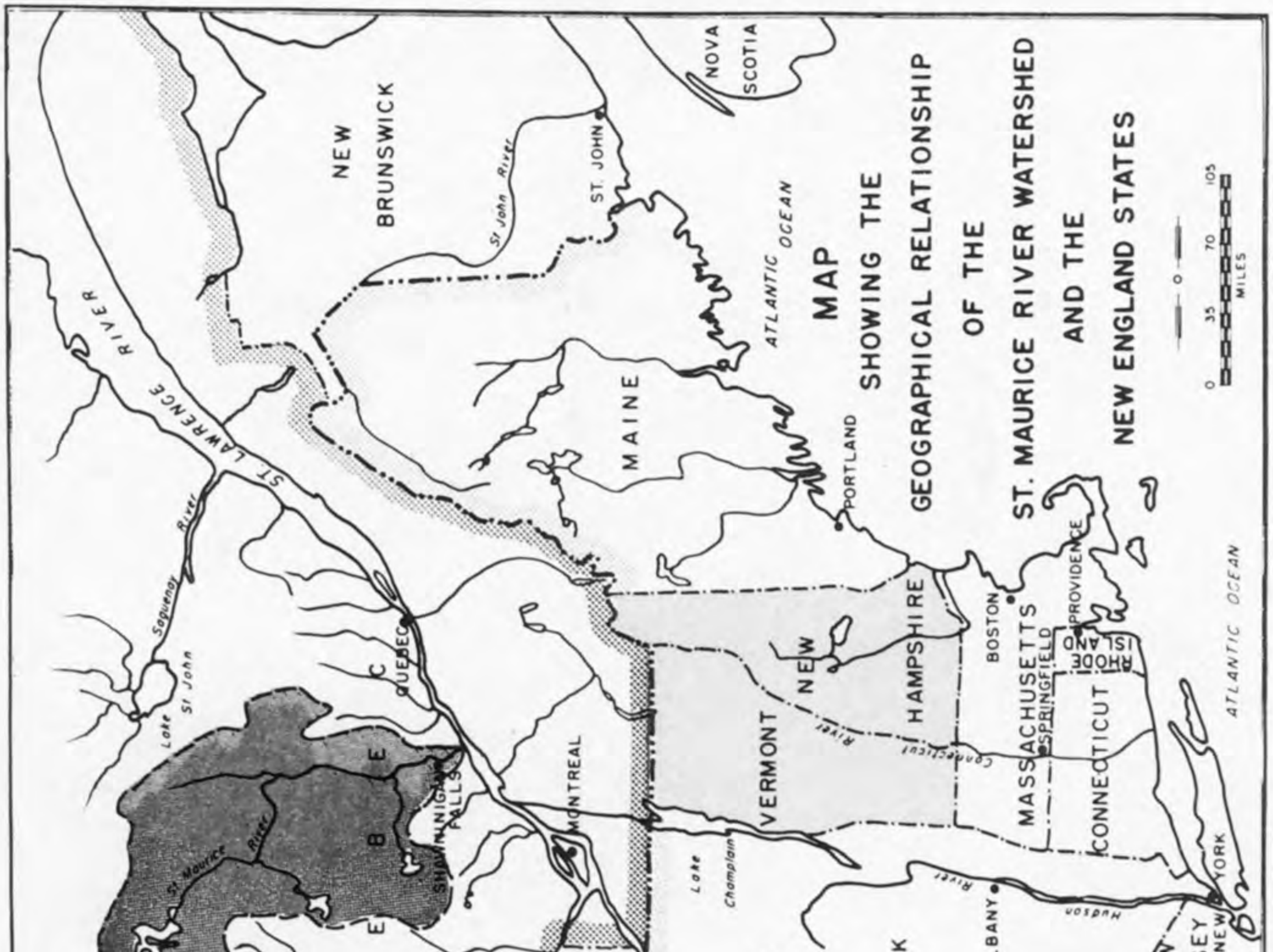
GENERAL OBSERVATION

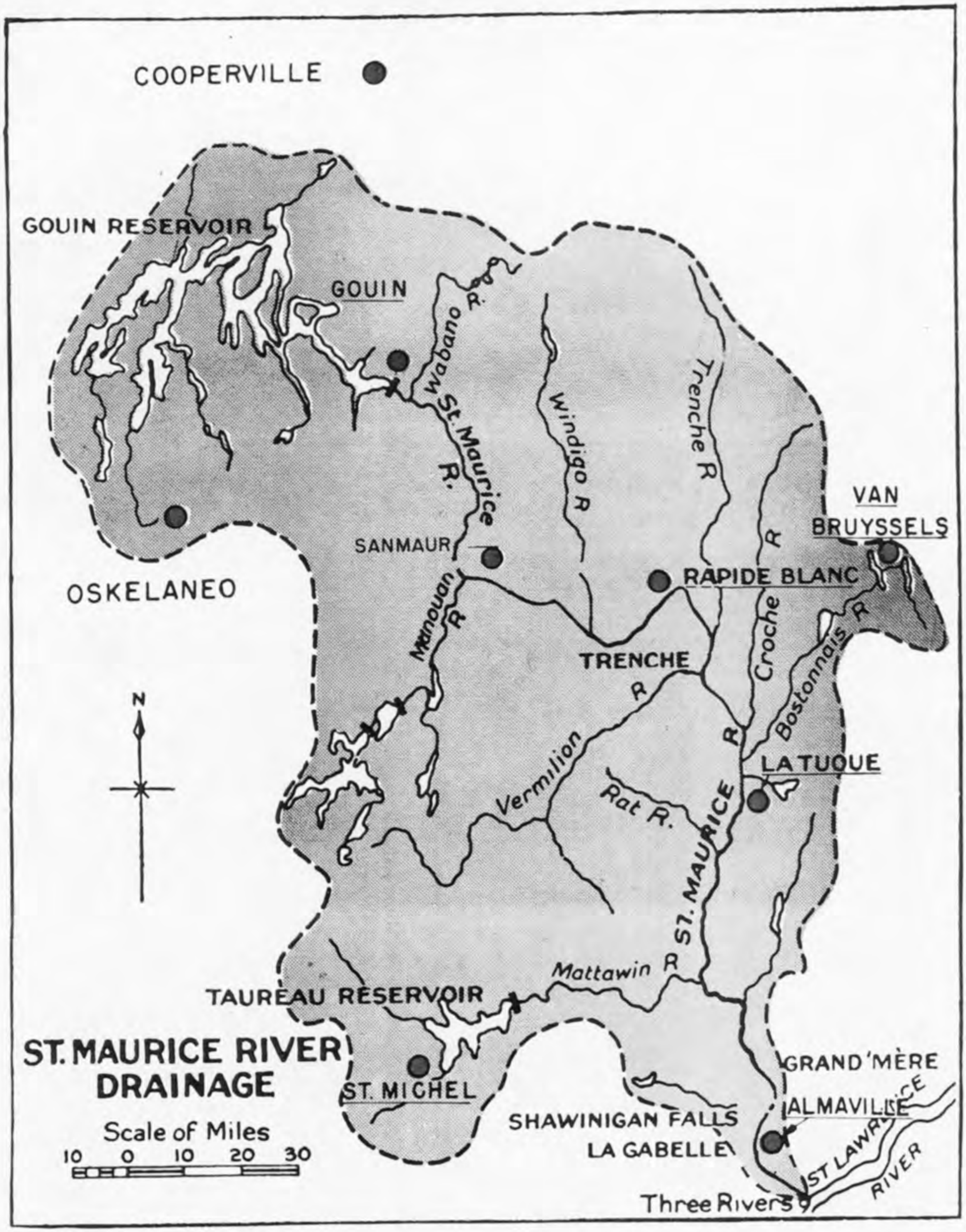
The ability to predict reservoir catchment would be of great economic advantage to any electrical utility, but especially so to one whose entire output is from hydraulic sources and whose operating and construction programs must be planned well in advance of their execution; but the prediction must be reliable if it is to have any value, for the demands of modern hydro-electric practice are severe and permit little margin for error. In considering the components of an operating program, probability of occurrence is a dangerous guide which is apt to be misleading. Uniformity of performance is to be preferred. For example, in appraising the impact of any one factor, it is much more important that its evaluation be consistently within definite limits for all of the time, rather than completely accurate for most of the time and grossly in error occasionally.

In so far as the major rivers of Quebec are concerned, the characteristics of the Spring freshet appear to be associated with many natural phenomena which prevail during the flood period itself. None of these can be predicted and each of them is subject to wide departures from the normal.

Since the one factor which can be determined accurately, namely, the water content of the snow-cover appears to have an influence that is far from being dominant, the prospect of making accurate forecasts of Spring freshet volume on the basis of snow-surveys does not appear to be encouraging.


PROVINCE OF QUEBEC
MEAN ANNUAL PRECIPITATION
0 50 100 150
MILES
RAIN
SNOW
HUDSON'S BAY
UNGAVA BAY
ATLANTIC OCEAN
LABRADOR
HEIGHT OF LAND
ST LAWRENCE RIVER
GULF OF ST LAWRENCE
NEWFOUNDLAND
QUEBEC
N B
N S
ONTARIO
MONTREAL
UNITED STATES
ATLANTIC OCEAN


MAP
SHOWING THE
GEOGRAPHICAL RELATIONSHIP
OF THE
ST. MAURICE RIVER WATERSHED
AND THE
NEW ENGLAND STATES
0 35 70 105
MILES
NEW BRUNSWICK
NOVA SCOTIA
ST. JOHN
St John River
ATLANTIC OCEAN
MAINE
PORTLAND
ST LAWRENCE RIVER
Saguenay River
Lake St John
QUEBEC
St Maurice River
SHAWINIGAN FALLS
MONTREAL
OTTAWA
Ottawa River
ONTARIO
VERMONT
NEW HAMPSHIRE
Connecticut River
MASSACHUSETTS
BOSTON
SPRINGFIELD
PROVIDENCE
RHODE ISLAND
CONNECTICUT
Lake Champlain
NEW YORK
ALBANY
Hudson River
NEW YORK
NEW JERSEY
PENNSYLVANIA
LAKE ONTARIO
TORONTO
LAKE ERIE



LOCATION OF SNOW COURSES

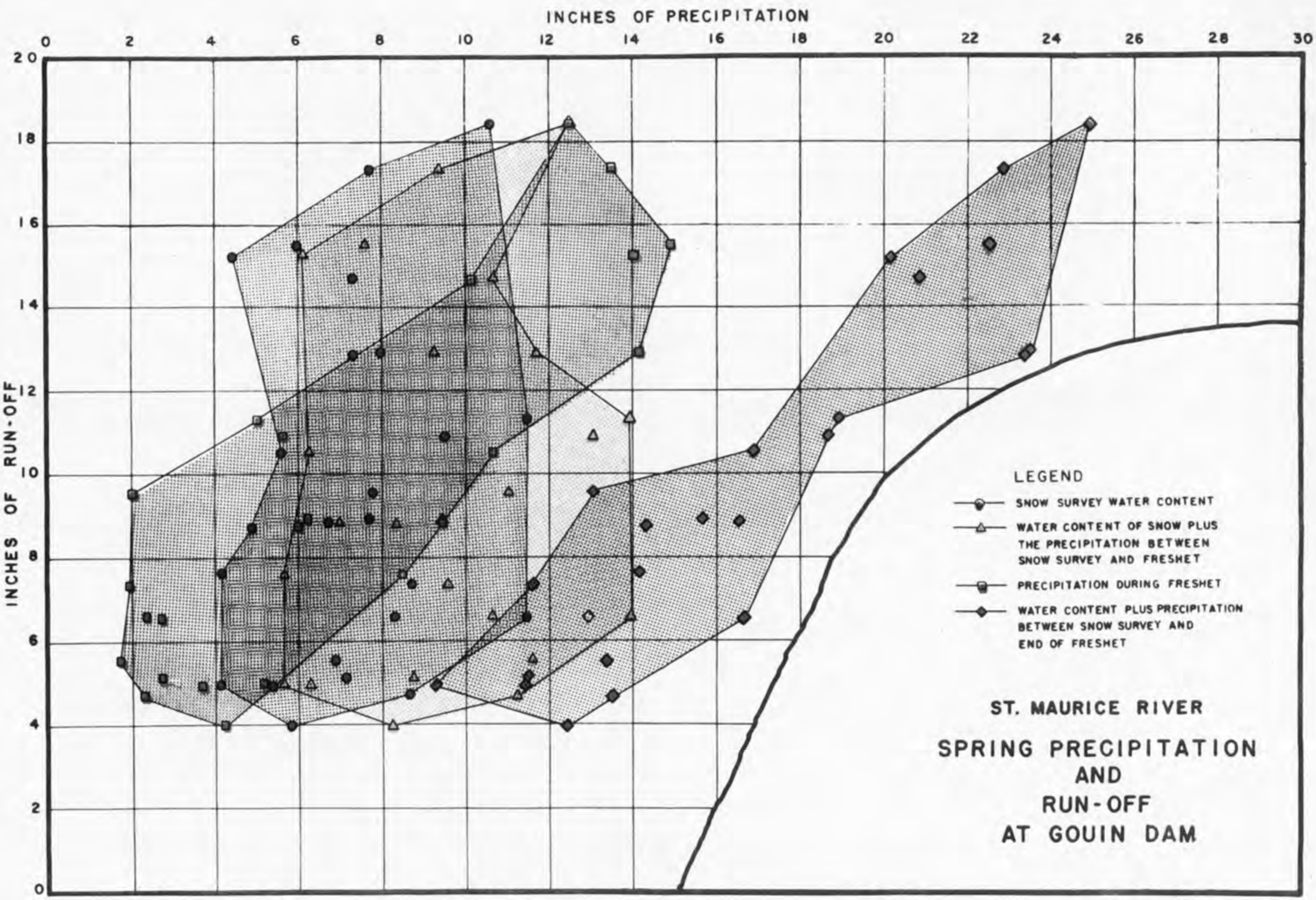
ST. MAURICE RIVER

GOUIN RESERVOIR

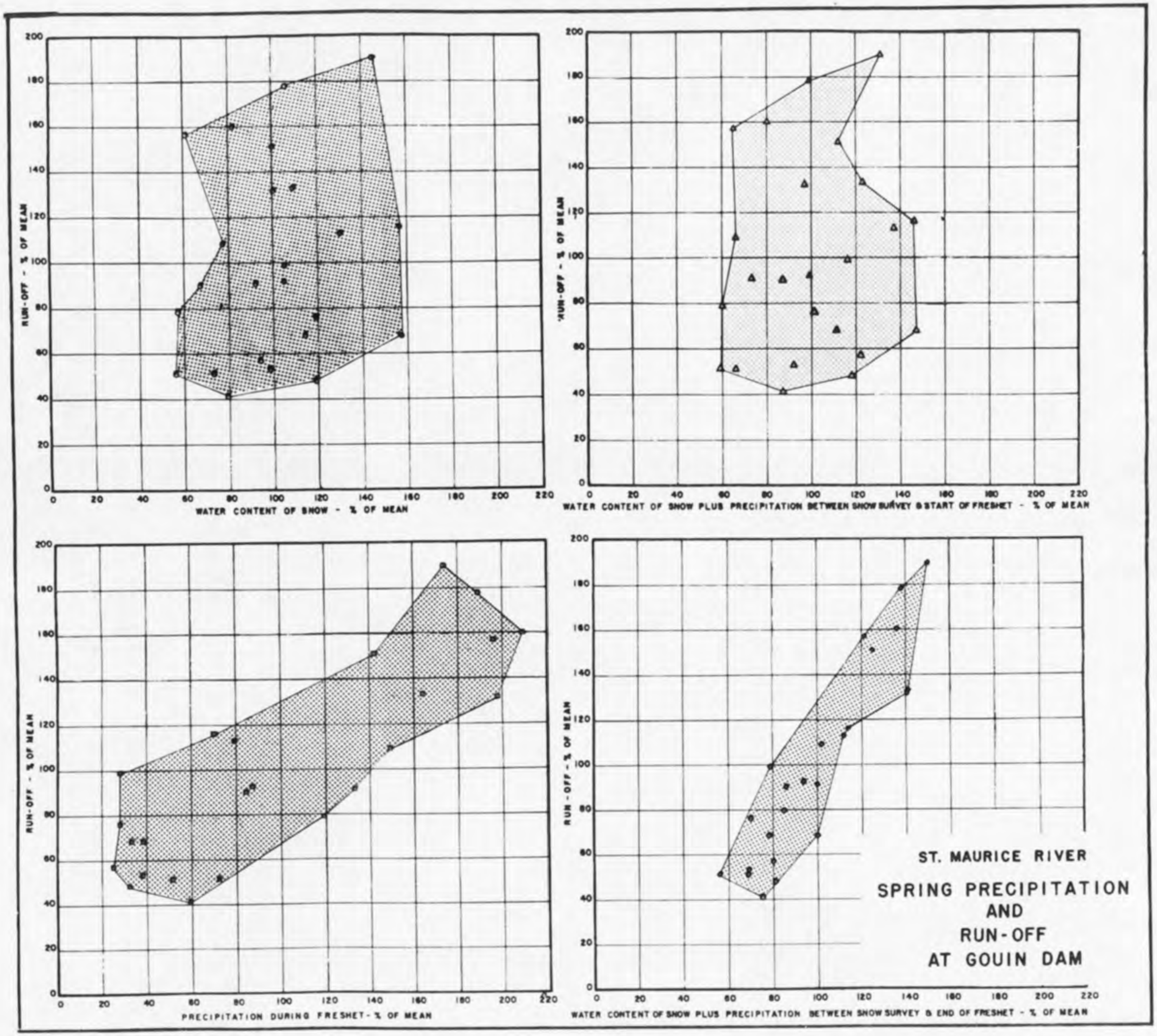
SNOW-MELT IN RELATION TO SPRING RUN-OFF

No.	Year of Occurrence	SPRING FRESHET PERIOD			INFLOW TO RESERVOIR				AVAILABLE WATER CONTENT											
									SNOW SURVEY										
		Started	Ended	Days of Duration	B.C.F.	000's Ac.Ft.	Inches Run-Off	% Mean	Date	Water Content	% Mean	Precip. Date of Survey to Start of Freshet	Ajd. Water Content (11+13)	% Mean	Precip. During Freshet Period	% Mean	Adj.Water Content +Precip. During Freshet Period (11+13+16)	% Mean	% Yield
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1947	Apr. 8	July 10	94	144.2	3,310	18.40	190	Mar. 13	10.64	145	1.86	12.50	131	12.47	174	24.97	150	74
2	1928	7	31	116	135.2	3,110	17.36	178	24	7.73	106	1.67	9.40	99	13.49	189	22.89	138	76
3	1930	11	24	105	121.4	2,790	15.50	160	18	5.99	82	1.62	7.61	80	14.93	209	22.54	136	69
4	1936	Mar. 18	June 30	105	119.1	2,740	15.21	157	11	4.44	61	1.73	6.17	65	14.01	196	20.18	121	76
5	1929	Apr. 20	July 22	94	115.0	2,640	14.68	151	9	7.32	100	3.36	10.68	112	10.16	142	20.84	125	70
6	1940	29	8	72	101.0	2,320	12.88	133	13	7.97	109	3.79	11.76	123	11.71	164	23.47	141	55
7	1949	12	15	95	100.8	2,310	12.83	132	16	7.30	100	1.95	9.25	97	14.17	198	23.42	141	55
8	1933	7	June 14	69	88.6	2,040	11.30	117	14	11.51	157	2.45	13.96	146	4.98	70	18.94	114	60
9	1943	24	24	62	85.8	1,970	10.93	113	15	9.53	130	3.54	13.07	137	5.62	79	18.69	112	59
10	1946	Mar. 26	17	84	82.7	1,900	10.56	109	13	5.60	77	0.66	6.26	66	10.65	149	16.91	102	62
11	1942	Apr. 21	May 31	41	75.0	1,720	9.55	99	14	7.69	105	3.38	11.07	116	2.00	28	13.07	79	73
12	1939	26	June 17	54	69.9	1,605	8.91	92	Apr. 7	7.70	105	1.73	9.43	99	6.22	87	15.65	94	57
13	1945	Mar. 29	24	88	69.2	1,590	8.82	91	Mar. 22	6.70	92	0.30	7.00	73	9.54	133	16.54	100	53
14	1938	Apr. 15	5	52	68.7	1,575	8.76	90	18	4.88	67	3.46	8.34	87	5.97	84	14.31	86	61
15	1950	21	July 3	74	59.7	1,370	7.62	79	14	4.18	57	1.52	5.70	60	8.48	119	14.18	85	54
16	1937	20	June 7	49	57.8	1,328	7.36	76	21	8.71	119	0.90	9.61	101	1.99	28	11.60	70	63
17	1951	8	May 30	53	51.7	1,189	6.59	68	19	8.30	114	2.31	10.61	111	2.35	33	12.96	78	51
18	1934	17	31	45	51.5	1,181	6.56	68	14	11.46	157	2.53	13.99	147	2.68	38	16.67	100	39
19	1948	21	27	37	43.7	1,002	5.57	57	15	6.90	94	4.69	11.59	122	1.76	25	13.35	80	42
20	1941	14	12	29	40.2	923	5.12	53	12	7.14	98	1.61	8.75	92	2.73	38	11.48	69	45
21	1931	11	June 6	57	39.0	895	4.97	51	13	5.35	73	0.95	6.30	66	5.14	72	11.44	69	43
22	1932	11	8	59	38.7	888	4.94	51	15	4.12	56	1.50	5.62	59	3.66	51	9.28	56	53
23	1935	17	May 21	35	36.6	840	4.66	48	12	8.68	119	2.55	11.23	118	2.27	32	13.50	81	35
24	1944	25	20	26	31.3	718	3.99	41	11	5.80	79	2.46	8.26	87	4.19	59	12.45	75	32
		Apr. 13	June 18	66	76.1	1,745	9.70	100		7.31	100	2.19	9.53	100	7.14	100	16.62	100	58

Montreal, P.Q.
January 28, 1952
HMF:DEL



INCHES OF PRECIPITATION
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
INCHES OF RUN-OFF
20
18
16
14
12
10
8
6
4
2
0
LEGEND
SNOW SURVEY WATER CONTENT
WATER CONTENT OF SNOW PLUS THE PRECIPITATION BETWEEN SNOW SURVEY AND FRESHET
PRECIPITATION DURING FRESHET
WATER CONTENT PLUS PRECIPITATION BETWEEN SNOW SURVEY AND END OF FRESHET
ST. MAURICE RIVER
SPRING PRECIPITATION
AND
RUN-OFF
AT GOUIN DAM


ST. MAURICE RIVER
SPRING PRECIPITATION
AND
RUN-OFF
AT GOUIN DAM
RUN-OFF - % OF MEAN
WATER CONTENT OF SNOW - % OF MEAN
WATER CONTENT OF SNOW PLUS PRECIPITATION BETWEEN SNOW SURVEY & START OF FRESHET - % OF MEAN
PRECIPITATION DURING FRESHET - % OF MEAN
WATER CONTENT OF SNOW PLUS PRECIPITATION BETWEEN SNOW SURVEY & END OF FRESHET - % OF MEAN