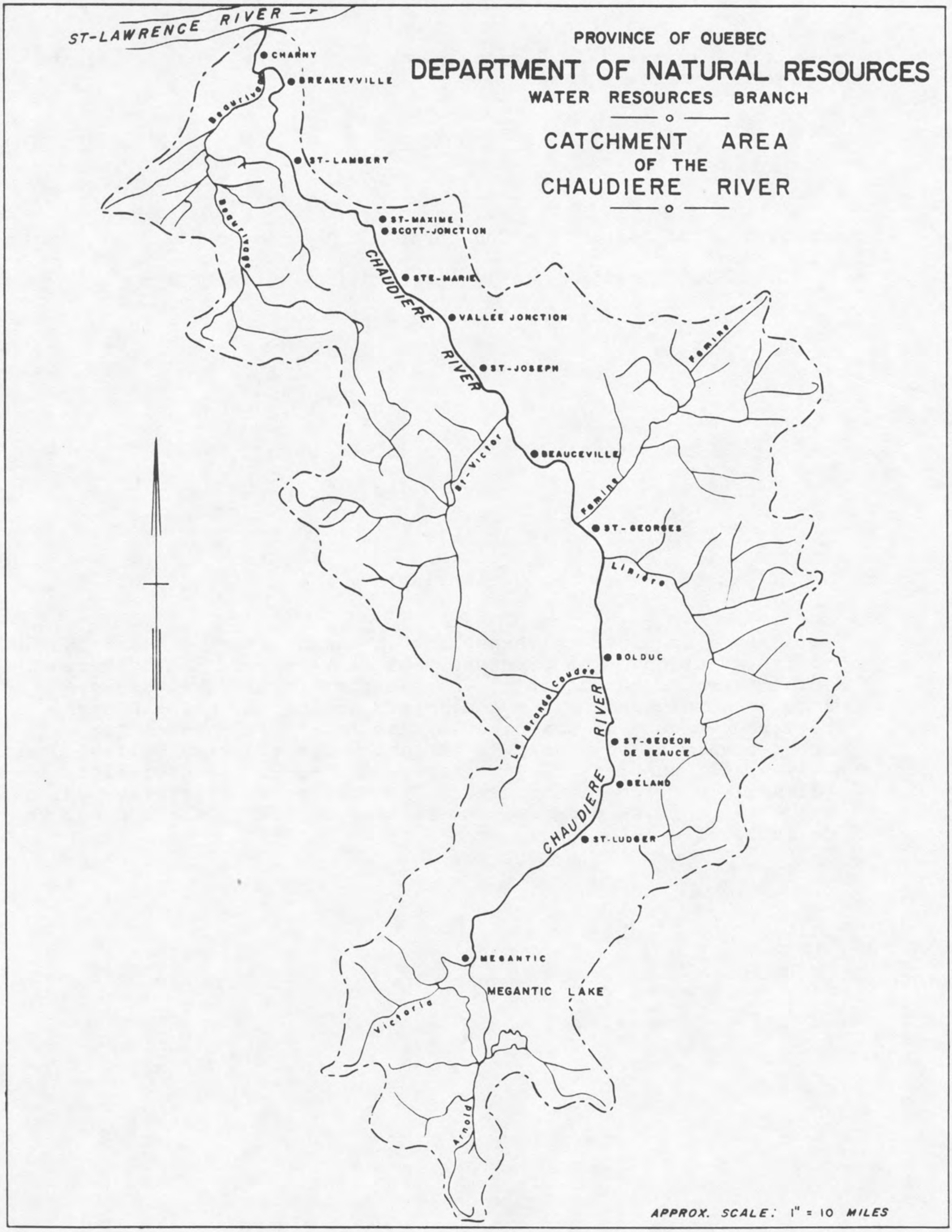
PROVINCE OF QUEBEC
DEPARTMENT OF NATURAL RESOURCES
WATER RESOURCES BRANCH
CATCHMENT AREA
OF THE
CHAUDIERE RIVER
ST-LAWRENCE RIVER
CHARNY
BREAKEYVILLE
Beaurivage
ST-LAMBERT
ST-MAXIME
SCOTT-JONCTION
CHAUDIERE
STE-MARIE
VALLÉE JONCTION
RIVER
ST-JOSEPH
St-Victor
BEAUCEVILLE
Famine
ST-GEORGES
Linière
BOLDUC
La Grande Coudée
RIVER
ST-GÉDÉON
DE BEAUCE
BÉLAND
CHAUDIERE
ST-LUDGER
MEGANTIC
MEGANTIC LAKE
Victoria
Arnold
APPROX. SCALE: 1" = 10 MILES

PROJECTS TO ALLEVIATE ICE-JAMS ON THE CHAUDIERE RIVER IN QUEBEC

by

C.-E. Deslauriers[1]

Abstract

Technical literature related to ice break-ups and ice-jams is scarce and poorly indicative as to the engineering design of remedial works in affected rivers. One deficiency is a lack of differentiation between the factors involved in break-ups and those, more precisely known, concerning the formation of ice covers. Another difficulty is the required search for relations between the many hydrologic and hydraulic factors which together are the sources of ice-jams and floods. Systematic observations and studies of the ice regime of the typical river have led to a certain basic knowledge, outlined in the paper, in connection with a program of remedial works now in progress.

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1. Introduction

Break-up phenomena are hazardous and violent; that probably explains why physical laws and characteristics of same are amongst the least known of all ice phenomena in rivers. Engineering decisions in this field are thus difficult to reach with a certain degree of certainty and they were almost impossible bets few years ago.

For many of our rivers, the occurrence of winter brings to many individuals and municipalities a regular load of sad expectations because of the final or intermittent break-ups to come. Consequently, requests for actions have been for long annual or intermittent headaches for the concerned public services.

Elaboration of recommendations and projects to alleviate ice-jam damages soon brought forward the necessity of observations and studies to further our knowledge, and we thought that the logical thing to do was to concentrate on one river, as long as it could be typical enough to allow conclusions as general as possible.

The Chaudière River was somewhat forcibly chosen for basic studies of ice-jam problems and of remedial works; the frequency and the importance of damages to riparian lands and properties have been very regular incentives for our technical services. The fact that said river is currently exposed to a great variety of ice and flood problems was also an attractive motive. It was soon found out that such problems are, as it is generally the case, the consequences of a certain number of factors and circumstances whose conjunction is more or less a favorable or an unfavorable event. In spite of its limited importance and of its specific characteristics and difficulties, the Chaudière reveals itself as quite a good typical model for ice-jam studies and for remedial projects.

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[1] Engineer, Director of Hydraulic Services, Department of Natural Resources, Quebec, Que.

The factors mainly responsible for the pecularities of its regime can be grouped as follows:

1o - Natural hydraulic deficiencies, and above all a too long stretch (40 miles) of dead or low velocity waters.

2o - South-North bearing for both the river and its watershed, together with characterized climatic differences between upper and lower Chaudière.

3o - All day normal coincidence, between solar path and ground slopes.

4o - Relative bareness and steepness of the upper basin, whose outlet coincides with the point of abrupt break of slope in the thalweg.

5o - Heavy sedimentary discharges in the river and its tributaries, plus effects of encroachments from individuals and municipalities.

6o - Numerous natural and artificial singularities, particularly in the section of Dead waters.

7o - In the recent past, there were certain deformations of the hydraulic regime traceable to maintenance and operation of industrial dams.

The Chaudière River is naturally divided into four main sections (see annex 1):

Section 1 - Upper Chaudière - - - Lake Megantic to St. Georges

Section 2 - Middle Chaudière - - St. Georges to St. Joseph

Section 3 - Dead Waters - - - St. Joseph to Scott

Section 4 - Lower Chaudière - - - Scott to the mouth of the river.

The essential characteristics of these sections are summarized in the tables and sketches of annex 2.

The damages attributed to the river are to be distinguished between: (a) icy floods; (b) summer floods.

The areas mostly affected are all situated in sections 2 and 3, that is to say in the Middle Chaudière and in Dead Waters. The distribution of the damages between these two sections is as follows:

a) Icy floods affect regularly the areas of the Middle Chaudière: St. Georges, Notre-Dame-des-Pins, Beauceville and St. Joseph;

b) Summer floodings are customary over the low lands bordering the "Dead Waters": St. Joseph, Vallée-Jonction, Ste. Marie and Scott.

The damages caused by floods and thawing are unequally distributed among the years and we may generally consider that intervals of recurrence are, for each type of floodings, quite short (0.5 to 1 per year for ordinary damages, 3 to 5 years for somewhat catastrophic events).

2 - General considerations concerning break-ups

<u>Cover formation and break-up are distinct and poorly comparable processes</u>

It is rather remarkable that a certain similarity is usually granted to the two phenomena. As outlined by the following comparisons, they differ essentially both by the involved factors and by the dominating characteristics:

Item	Cover formation	Cover break-up
1) Determining factor	Temperature of water in the stream	Runoff awakening on the watershed
2) Primary phenomenon	Formation of crystal flakes in the prevailing flow	Formation of undercover uplifting forces by the increasing flow
3) Early development	Progressive agglomeration of crystal flakes in floes of regular forms and limited dimensions	Disengagement of the ice cover from the shore, appearance of cracks and of local submergences
4) Normal progress	Upstream	Downstream
5) General character	Gradual and easy	Abrupt, rapid and steeplechasing
6) Hydraulic transport	Ascending suspension for the crystal flakes and progressive accumulation of incoming floes at water surface	Outbreaks from floating ice fields, undercover runs by lone blocks, the whole in a series of jams and releases
7) Primary consequences	Increase of prevailing depth of flow in the newly covered sections	Decrease of prevailing depth of flow in the newly freed sections
8) Ultimate consequences on the discharge	None in general	Major or persistent jam storages followed by abrupt or lean releases
9) Menace to riparian lands and structures	Local inondations generally of limited extent and duration	Destructive icy floods and waves whose violence, extent and duration are almost unpredictable

<u>Pre-break-up destructions of the ice cover</u>

The break-up of rivers is ordinarily a springtime phenomenon and then, it may either be an early, a normal or a late occurrence. Governing factors are evidently a conjuncture of climatic progresses and of atmospheric variations.

The above distinction with reference to the time of occurrence leads to a more indicative classification: prematured, matured and over-matured break-ups. Thus, a better recognition is readily gained as to the prevailing destructions of the cover at break-up time and as to the exact causes of same.

For brevity's sake, let us make an over simplified picture of the governing influences and of the consequent effects during the pre-break-up period.

Item	Class of break-up		
	Prematured	Mature	Over-matured
State of destruction			
a) thickness reduction	none	negligeable	apparent
b) ice quality and strength	original	nearly original	greatly reduced
c) adherence to shore	firm	inconsistent	inexistent
d) cover continuity	total	fairly destructed	generally disappeared
Accumulated influences			
a) solar radiation surface	none	negligeable	apparent
b) underneath melt by flowing waters	none	generally negligeable	consequent
c) hydromechanical disengagements, cracks and submergences	none	fair	overcomed by thermal influences

It is certainly true that such a tabular form of presentation is lacking many serious considerations and incidences: major distinctions are thus neglected while specific conclusions are perhaps too firmly extended. But as it is, the picture may be considered as satisfactory as needed for the general purpose of this report.

The main points to note are that:

1o - winter break-ups are essentially prematured and, consequently represent major possibilities for difficulties and damages.

2o - springtime or over-matured break-ups are usually calm and of little consequences.

3o - all break-ups include two distinct phases: the pre-break-up and the break-up itself.

4o - for Chaudière River, as for any other similar stream, disappearance of ice is usually the result of an hydraulic transport rather than a melting process.

Process and mechanism of the break-up

Excepting contrary influences exercised by the latitude or by other causes, break-up progresses downward. This applies both to the main and its tributaries. Nevertheless, the liberation is not a successive process from source to mouth. It is more generally some type of simultaneous destructions at rapids and at points of major inflow. As a matter of fact, the break-ups of the tributaries are earlier than those on the main. Often, when the general liberating wave occurs on the main, large sections of it are encumbered by the ice debris from the tributaries or liberated by local early break-ups.

Types and characteristics of ice-jams

An ice-jam is an accumulation of ice debris. It is thus the antonym of break-up, and even the dictionary gives a reassuring picture of it "piling up of dangerous ice".

Ice-jam is certainly a piling up of ice, but its characteristics, effects and consequences vary; they are more or less predictable.

However, observations have made it clear that on the typical river, three important types of ice-jams are likely to occur:

a) the lock ice-jam;

b) the stranted ice-jam;

c) the exhausted flow ice-jam.

Anyone of these types constitute a stoppage, but the importance and the duration of same necessarily differ. It follows that identification of the type of ice-jam likely to occur at a specific spot can lead to certain objective conclusions with regard to probable duration, height of blockage and importance of resulting damages.

The characteristics of ice-jams depend on the degree of maturity of the break-up, on the hydraulic singularities of a channel spot and on the ice volume that can be packed there at a certain moment. Information acquired from local experience and derived from a thorough study of the channel are the instruments permitting a certain forecast as to the type of ice-jam likely to occur within a given section of the river.

Hydraulic elements of break-ups

A flood wave starts the whole break-up process. Ice debris accumulate at singularities and block the passage of water (fig. 3.1). According to its amplitude and speed, the flood produces various reactions: it either rolls up the ice cover (fig. 3.2) or pushes it downstream (fig. 3.3). Three points are to be remembered:

1o - Passage of a long period wave (fig. 3.5), of measurable volume and speed: it is the hydromechanic cause of the cover's liberation.

2o - Exhaustion of the wave or its gradual breaking, depending whether it has to develop much or little energy in breaking the cover: it is the measure of the degree of difficulty for break-ups.

3o - Lock action by which the flow reconstitutes its live force: it is the ice-jam.

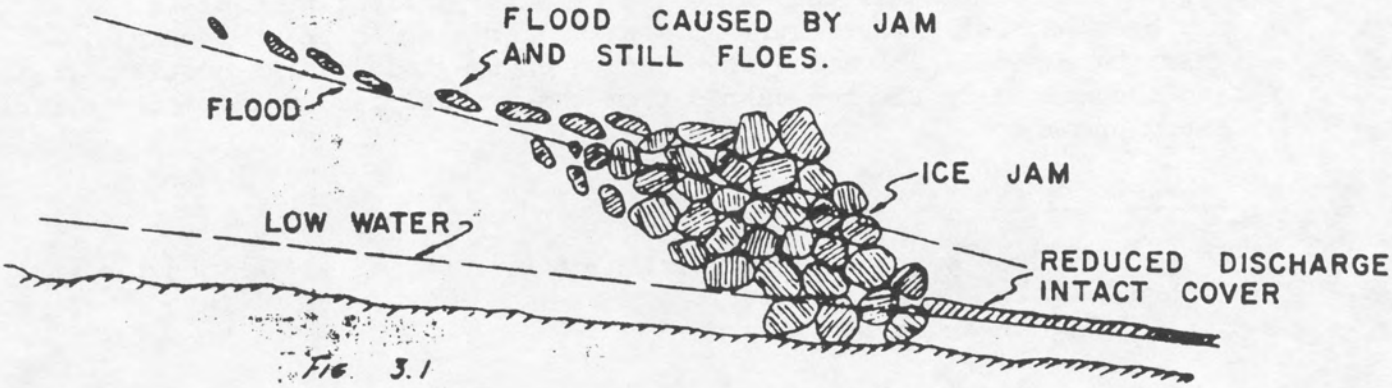


FIG. 3.1

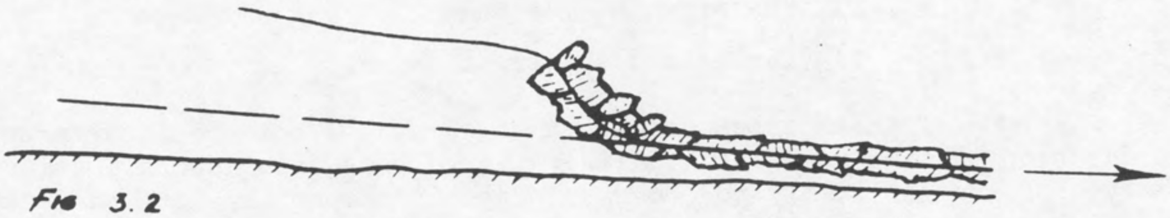


FIG 3.2

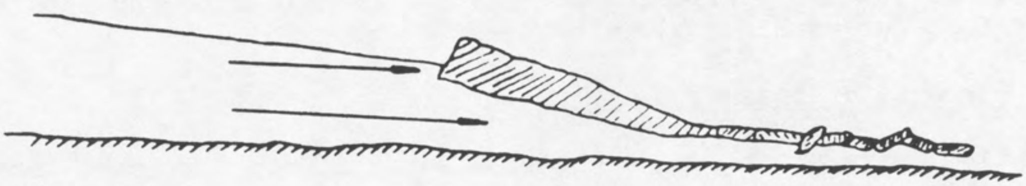
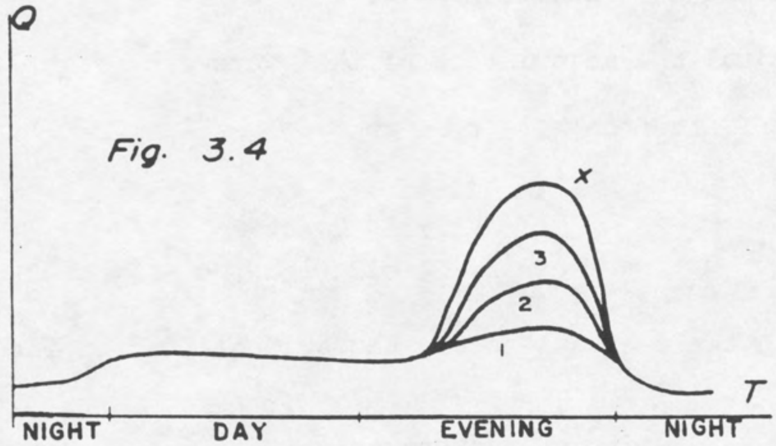
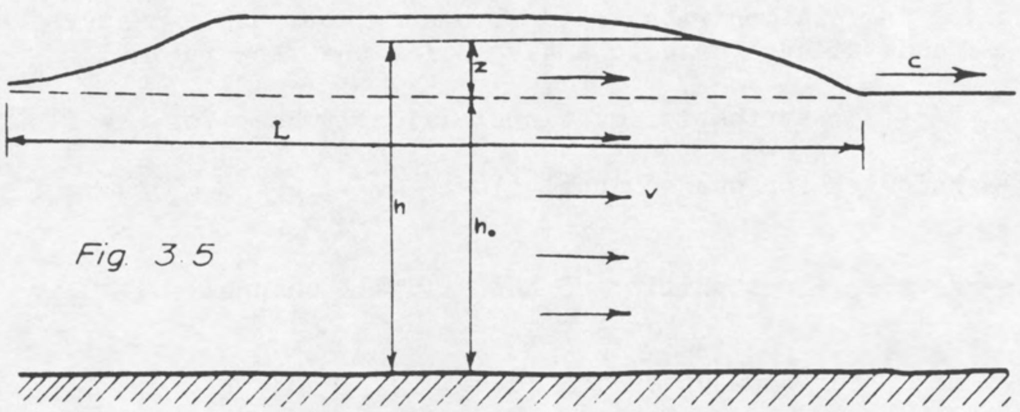


FIG. 3.3





TRANSLATION WAVE

Hydrodynamic elements

a) The daily flood-wave.

It happens late in the afternoon, lasts only a few hours (fig. 3.4) and the base of its hydrogram seems to keep relatively independent of the flood volume; consequently there is a gradual increase in steepness of the curve as springtime goes by and, soon, snow melt produces a destructive wave.

b) Liberating or transition wave.

The principal characteristics of that wave are (fig. 3.5):

Celerity of its front:	$c \quad gh_o$
Discharge:	$Q \quad zbc$
Volume:	$V \quad zbL \quad 2\ bct$
Energy:	$E \quad \frac{1}{2} Mc^2$

Symbols in these equations are those identified on figure 3.5 and the followings:

b	width of the channel
t	time
g	gravity force
M	mass

c) Hydraulic singularities of the channel.

The task is to find out which singularities provoke ice-jams. From observations and investigations, ordinary and exceptional jamming conditions at those singularities are to be scrutinized. They must also be mathematically studied in relation with a bed topometry thoroughly measured and under the light of a detailed hydraulic analysis for the flow regime.

The four synthetic equations basically used for the flow study are:

Chezy-Manning's, for open-channel flow: $Q_1 \quad \frac{1.49}{n} \quad b.h.^{5/3} \quad S^{1/2}$

DuBoys-Brown's, for stability of the alluvial channel: $Q_s \quad \frac{0.17}{d^{3/4}} \, w^2 \, bh^2 \, S^2$

Pavlovskii's, for flow under ice cover: $Q_g \quad 0.63 \, \frac{n}{n_1} \, Q1$

$$h \quad 1.32\left(\frac{n}{n_1}\right)^{3/5} - 1 \quad h$$

Schok...s, for surface encumbrance by ice blocks: bv constant

Q_1, open-channel discharge; Q_g, close channel discharge; Q_s, sedimentary load; n, roughness coefficient of the river bed; n_1, overall roughness of the ice covered channel; S, slope; γ, specific weight of water; d, sediment diameter; h, depth increment; percentage of surface encumbrance; v, surface velocity.

Chezy-Manning's formula, for open-channel flow, gives the relation between the various hydraulic characteristics of sections; at sections mostly affected by ice-jams, we can determine hydraulic influences upon the phenomena. DuBoys-Brown's formula, for alluvial channels, reveals the section stability and its relation with jamming conditions. Pavlovskii's equations are useful for analysing flow conditions during the winter, and the raising of the depth of flow caused by the ice cover. Schoklisch's equation is merely indicative of the surface's capacity for jamming. Those theoretical notions are used exclusively to realize remedial works by regularization of the bed. Other analyses, not mentioned here, cover the mechanism of break-up itself*.

The use of such relation is chiefly indicative: numerical values are not important by themselves, it is rather variations of the values with the channel's characteristics that count.

3 - Regularization of the ice regime of a river

Means to alleviate adverse effects of river freeze-ups and break-ups are to limited applications and efficiencies. Those more specifically related to break-ups can be distinguished as occasional preparatory works, urgency measures and permanent regularizations.

Occasional preparatory works

Advanced awakening or partial destruction of the ice cover at some bad spots in a water course is often an efficient preparation for a coming break-up. The main objective is either to reduce the rigidity of an ice slab, to break an ice pack or to create an open water channel. Breaking operations are achieved by the use of explosives (low speed types being more efficient) or by ice-breakers; melting operations by effects of thermo-chemical bombs, black dusts (captation of solar energy), melting salts, etc.

Urgency measures

They are often requested for the breakage of ice-jams already formed. The artificial destruction of a jam is ordinarily a difficult and hard operation, and usually a risky venture. Most of the time, the natural evolution and destruction of the ice blockage is completed even before the organization of an urgency measure has been completed. Whenever it can be undertaken with a certain degree of success and without risks of greater damages elsewhere below the affected spot, the urgency measure is to be considered as a venture for responsability and costly operations. However, in some peculiar spots and for certain types of jams, few successes are possible and some achievements may be sometimes economically realized.

Permanent regularization of break-ups

There are mainly four types of remedial works to alleviate riparian damages by break-ups:

1o - Canalization of the channel;

2o - Protection dikes;

3o - Flow regulation by reservoir;

4o - Artificial correction of ice regime.

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* Explanatory paragraph herein added in answer to questions received after conference presentation.

Whatever the possibilities and issues, repeated and systematic observations are to be extensively conducted first in order to find the exact cause of the trouble and of the involved singularities. Natural physical laws governing the river regime for each section in the vicinity of the sick spot are to be examined and respected.

Canalization, the most important type of remedial works, is also often useful to navigation, to timber floating, and to reduction of summer floods.

Protection dikes are partial solutions, since their construction at a sufficient height to eliminate dangers from the largest possible discharge is too costly. Nevertheless, they can be effective solutions. Anyway, the main factor regulating break-ups is not the importance of the discharge itself, but abruptness of the instantaneous rate of discharge variation with respect to time (Q/ t). Unfortunately, that ratio is seldom known.

It seems that wave routing and compensating basins installations could provide better results than flow regulation by large storage dams. The former can be more readily designed in relation with local singularities, while the operation of the latter can produce dangerous artificial effects.

4 - Outline of the Chaudière 5 Year-Plan

Basic principle

Above all, the Chaudière 5 year-plan to alleviate ice-jams is a systematic program of observations, studies and works to be achieved simultaneously. The basic proposals of the plan are (see annex 2):

1o - stabilize ice covers in section 1, in order to delay break-ups in same;

2o - accelerate ice liberation and improve ice transportation in section 3;

3o - regularize the ice regime (freeze-up and break-up) in section 2.

Essentially based upon data and indications gathered from ancient surveys, remote experiences and recent investigations, the proposed plan took into account some hopes derived from recent technological developments in connection with the formation of ice covers. The proposed plan was aware of the limitations imposed by Nature and considered low land zoning as a final outcome for various riparian plots or localities.

Main projects

They can be generally classified in two groups:

a) bed remedial works and shore protections;

b) ice detention and cover stabilization works.

Involvements

Geomorphology is often a major impediment to hydraulic remedial works. Those materially possible are limited by economy and legal aspects. Moreover,

CHAUDIERE RIVER - REMEDIAL WORKS - GENERAL PLAN
CHARACTERISTICS AND MAIN FACTORS

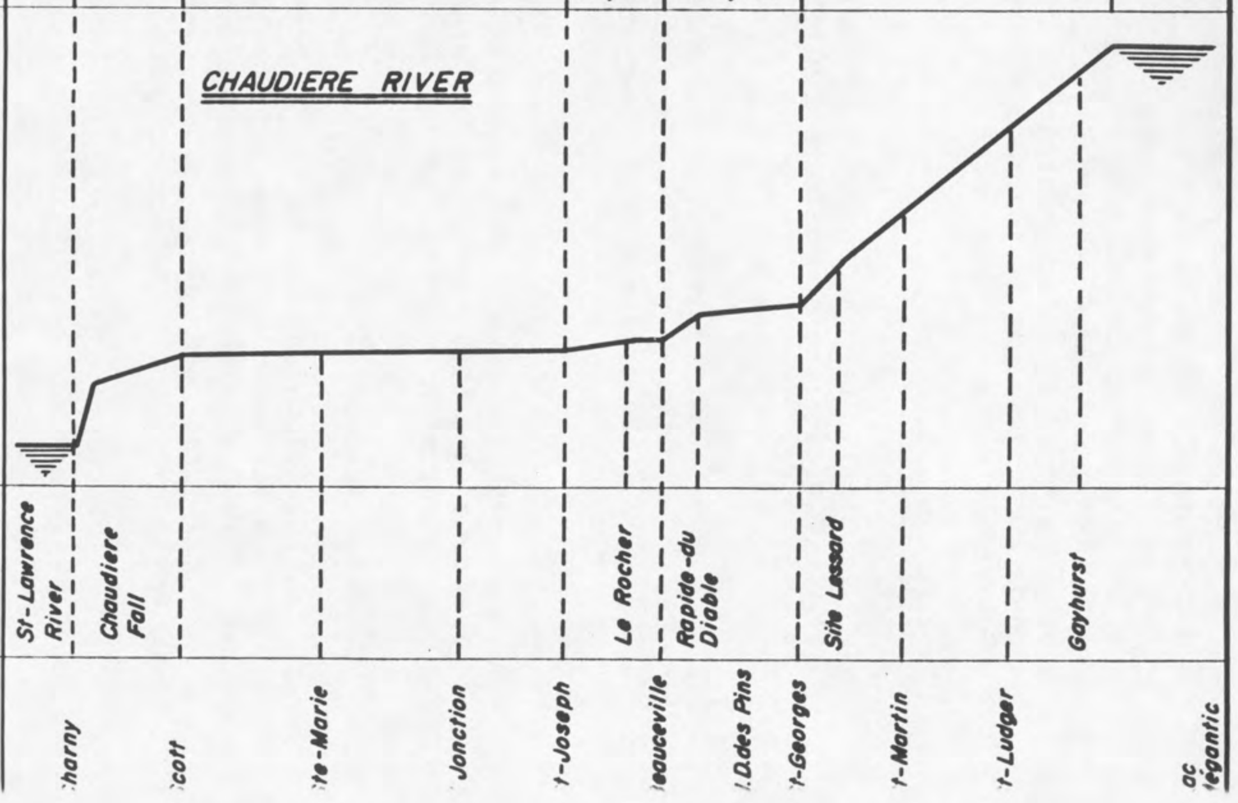
REACH Nº	4	3		2	1	
LENGTH IN MILES	24	27		13	66	
DIFFERENCE IN LEVEL (FEET)	278	20		81	711	
MEAN SLOPE (FEET PER MILE)	11.6	0.375	1.38	6.2	14.6	
HYDRAULIC REGIME	rapid	slow (dead waters)		transi-tory	supercritical	
MAIN TROUBLE	nil	Floods			nil	artificial regulari-sation
FREQUENCY AND MEAN VALUE OF DAMAGES	nil	1 in 10 years ($33,250.)	1 in 4 years $84,200	1 in 4 years $ 84,200	nil	

SCHEMATIC

LONGITUDINAL PROFILE

SINGULAR HYDRAULIC SPOTS

LOCALITY



distribution of required remedial investments between riparian localities does not ordinarily coincide with the distribution of damages between same; thence many political involvements have caused lasting impediments. Same were finally solved through municipal cooperation with the aid and assistance of the Provincial Government. As a matter of fact, the plan is a responsability of the Quebec Department of Natural Resources. It is realized for the municipalities with their nominal participation. The plan is also financially contributed by the Government of Canada under statutory provisions known as ARDA.

Estimated cost

Preliminary and overall estimates for the 5 year-plan amounted to $3,000,000. and the approximate distribution was as follows:

a)	preliminary surveys and investigations	$ 200,000.
b)	bed remedial works and shore protection	600,000.
c)	ice detention and cover stabilization works .	2,200,000.
		$3,000,000.

At this date, these estimates still hold while the progress of the plan indicates that the total cost might be somewhat lower and that the final distribution of costs might not be substantially modified.

Progress to date

Initiated by the end of 1961 after some preliminary steps (photogrammetry, break-up supervisions and investigations) the 5 year-plan effectively begins in September 1962 (systematic studies and observations). The first remedial works (bed regularization) were undertaken in 1963. Since, the developments were kept in accordance with the proposed time schedule and budget.

In terms of realizations, it is worth while to mention:

a) ground and aerial campaign for the observation of freeze-ups and break-ups from mouth to source and vice versa;

b) extensive bed topometry and ice cover soundings particularly in sections 2 and 3;

c) continuous annual construction works as to bed regularization and shore protection;

d) construction of one experimental station, being an ice detention boom located at a permanent site;

e) calculation and field control of backwater curves in sections 2 and 3 (approximately 50 miles);

f) hydraulic reconnaissances and geological explorations for determination of sites, types and characteristics of ice detention works;

g) theoretical research, laboratory experiments and field controls.

The valuable contribution of Dr. Bernard Michel, professor of hydraulics at the Department of Civil Engineering, Laval University, must be mentioned here. His theoretical researches and laboratory experiments were essential in bringing forth methods of treatment for aspects of break-up phenomena.