RECORD ST. CLAIR RIVER ICE JAM OF 1984

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ABSTRACT: The record St. Clair River ice jam of April 1984 produced major impacts on the levels and flows of the Great Lakes, and on navigation throughout the system. Following the onset of the jam, Lake St. Clair water levels dropped about 0.6 m as the inflow was decreased by the jam. At the peak of the jam the flows were reduced by approximately 65%. The jam had a duration of 24 days. Following the jam breaking on April 29, 1984, the waters of Lake St. Clair rose rapidly, recovering approximately 75% of the drop in levels in four days. Computer simulations indicate that it will take about a year for most and at least 3 years for all the excess water stored in Lakes Michigan and Huron during the jam to be dissipated and for levels in those lakes (and Lakes St. Clair and Erie, downstream) to return to prejam conditions.

INTRODUCTION

The Great Lakes system, shown in Fig. 1, consists of the five Great Lakes (Superior, Michigan, Huron, Erie, and Ontario) and Lake St. Clair, linked by the connecting channels, the St. Marys, St. Clair, Detroit, and Niagara Rivers. The system is naturally regulated due to the large surface areas of the lakes and the constricted outlets of the connecting channels. This natural regulation is accentuated by ice retardation in the connecting channels during the winter and early spring. Ice flowing down and accumulating in the connecting channels increases flow resistance and may substantially jam the channels, further decreasing their discharge capacity. This results in decreased water supplies to the downstream lakes and storage of water on the upper lakes during the winter and spring; this accentuates the seasonal cycle. This is particularly important on the St. Clair River, the outlet from Lake Huron with large supplies of ice flows, and with an extensive river delta that retards the passage of these ice flows. While ice retardation in the connecting channels has been decreasing due to dredging and other factors, its continuing importance in the hydrology of the basin was illustrated by the record ice jam of April 1984. This jam had a major impact on levels and flows, as well as on navigation throughout the system. This study addresses the causes and hydrologic impacts of the jam.

The ice jams complicate normal flow processes in the connecting channels, and for accurate flow determination velocity measurements are needed. However, normal river measurements are impractical or impossible during severe ice conditions. Fortunately, during the April 1984 ice jam, continuous velocity measurements were available from an ex-

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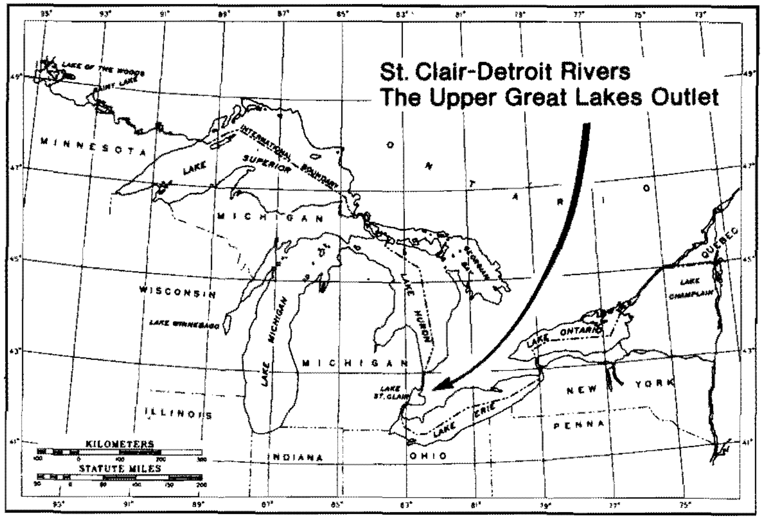

FIG. 1.—Great Lakes Basin

perimental winter flow project, which had been conducted on the St. Clair River for the last few years by the Great Lakes Environmental Research Laboratory (GLERL).

Description of St. Clair-Detroit River Outflow System

The St. Clair River, along with Lake St. Clair and the Detroit River, forms the natural outlet from the upper Great Lakes, comprised of Lakes Superior, Michigan, and Huron (Fig. 1). The combined water surface area of these lakes covers 200,000 km^2. The immediate upstream lakes, Michigan and Huron, have a combined surface area of 117,400 km^2. Because of the broad and deep connection through the Straits of Mackinac, these two lakes are hydraulically considered to be a single lake and are frequently referred to as Lake Michigan-Huron.

The St. Clair River carries the upper Great Lakes' water southward, connecting Lake Huron to Lake St. Clair, which empties through the Detroit River into Lake Erie (Fig. 2). Levels and flows in the St. Clair-Detroit River system are important because of the system's role in the hydrologic mass balance, navigation, sediment and ice transport, and the movement of pollutants. The St. Clair River proper is approximately 63 km long, with a total fall of about 1.5 m. Flow in the river produces an average discharge of 5,100 m^3/s, which varies seasonally from a winter low of 4,200 m^3/s to a summer high of 5,500 m^3/s per month, with somewhat larger extremes for shorter periods. The single-stem St. Clair River channel above the river delta is about 45 km long and contains nearly all of the river's slope with a fall of about 1.4 m. An extensive delta region, known as the St. Clair Flats, forms the lower river reach, which extends downstream for the remaining 18 km to Lake St. Clair. In

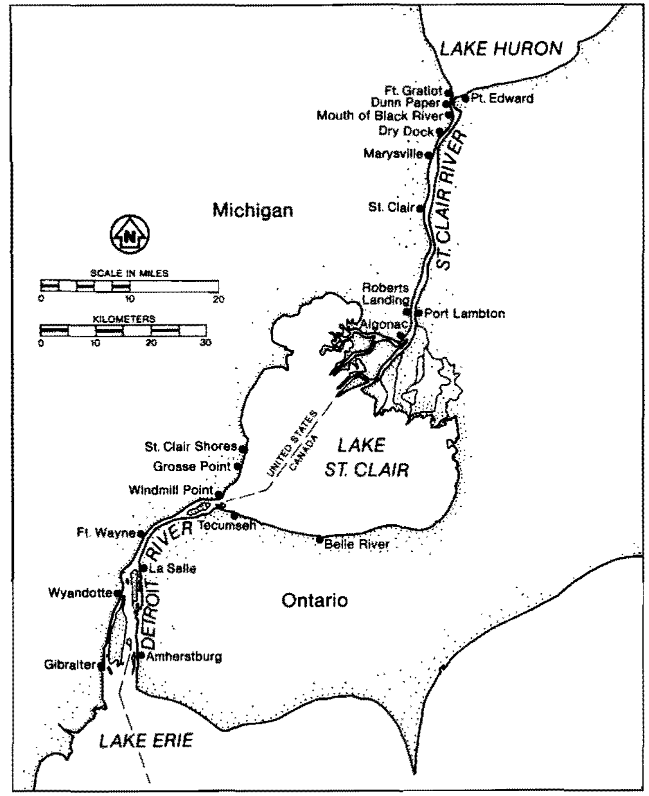

FIG. 2.—St. Clair-Detroit River System with Location of Water Level Gages

this reach the river falls less than 0.2 m and is characterized by extensive marshy flats with poorly defined and complicated flow patterns in multiple channels. The river width in the upper river and the main delta channels generally varies from about 300 to 900 m with the midchannel depths between 8 and 15 m and the deepest waters at the head of the river about 21 m. Highest river velocities also occur at the river's head, with maximum surface currents under the Blue Water Bridge exceeding 2 m/s. The average velocities in the river vary between 0.6 and 1.8 m/s but generally approach 1 m/s. Because of high currents, the upper St. Clair River does not freeze over and generally remains free of ice above the delta. However, under favorable weather conditions, Lake Huron may provide a practically unlimited supply of ice flows, which can produce heavy ice concentrations and severe ice jams in the lower river.

Lake St. Clair is a shallow basin that serves as a connecting water body between the St. Clair and Detroit Rivers. The lake is about 42 km long and 39 km wide, with a surface area of 1,110 km^2. The average depth of the lake is about 3.4 m with a maximum natural depth of 6.4 m. A dredged 8.2-m navigation channel bisects the lake, running in a northeast-southwest direction between the St. Clair cutoff channel in the St. Clair River delta and the head of the Detroit River. The lake drains about 12,400 km^2 of land area but the local inflow from this drainage area is relatively insignificant, and the St. Clair River provides by far most of the water supplied to the lake. The average difference between the flows in the St. Clair and Detroit Rivers is only 3%. The lake has an average water level elevation of about 174.7 m, which varies seasonally from winter low to summer high between about 174.5 and 174.9 m, respectively. Because the lake is relatively small and shallow it responds quickly to wind and temperature changes. Wind forces, along with the flow through pattern from the St. Clair River, determine the lake's circulation pattern. Because of its limited heat storage capacity, ice cover on the lake forms and melts quickly during winter. The lake is usually ice-covered by the end of January and free of ice in March. During the period of greatest ice cover, the ice is usually fast and thick in the bays and protected areas, with heavy consolidated ice flows of brash and cake ice in the middle of the lake.

The Detroit River connects Lake St. Clair with Lake Erie, running initially in the southwesterly direction and changing midway to the southern direction. The total length of the river is approximately 51 km and its total fall about 0.9 m. Flow in the river produces an average discharge of 5,200 m^3/s and varies seasonally from a winter low of 4,400 m^3/s to a summer high of 5,700 m^3/s per month. Ice conditions in the Detroit River are considerably different from those in the St. Clair River because of the differences in the respective upstream lakes, which are the primary ice supply sources for both rivers. Ice cover on Lake St. Clair forms and deteriorates sooner, and the supply of ice flows is much smaller than on Lake Huron, consequently, ice problems on the Detroit River are usually much less severe and large ice jams are rare. However, during storm surges on Lake Erie short-period water level and flow reversals may occur, especially in the lower river.

Brief Description of GLERL Field Experiment

St. Clair River flows are normally determined by mathematical unsteady flow models, which are calibrated from periodic discharge measurements taken over the years during the open-water season (Derecki and Kelley 1981). Consequently, the calculated flows normally exhibit good accuracy during ice-free periods but may contain large errors during winter months with extensive ice cover. The winter flow discrepencies are produced by heavy ice accumulation and/or ice jams, which normally originate in the lower river reaches.

A St. Clair River winter flow experiment was undertaken to improve methods for determining winter flow in the St. Clair River and to produce more accurate estimates of winter flows. The objectives of the experiment were initiated to accurately determine flow retardation in the river due to ice jams; to test accuracy of water balance transfers between the St. Clair and Detroit Rivers, when one of the rivers is ice free; to assess errors in current procedures for computing winter flows; to provide better winter flows; and finally to determine the feasibility of using in situ current meters to monitor the St. Clair winter flows. Accurate

flow determination during periods of heavy ice concentration and/or ice jams can only be accomplished by a time series of in situ winter current meter measurements. Practical requirements for these measurements dictated the use of current meters without moving parts (to avoid clogging), which are capable of prolonged operation (six months) at frequent sampling rates. After examination of the types of meters available, an electromagnetic current meter was selected (Marsh McBirney, Model 585) and modified to include an externally located recording system, which provides unlimited continuous operational capacity and access capability via the telephone-recorder to both the meter and a cable-connected recording system located on the shore.

After extensive field testing and problem analysis, including several meter modifications, a data-collection program was started in September 1981, with deployment of two electromagnetic meters in the upper St. Clair River, near the river's head at Port Huron, Michigan (Fig. 3). The meters were installed on the United States side of the river, outside the navigation channel, about 50 and 70 m from shore, in 13 to 15 m of water, with sensors positioned 2 m above the bottom. All deployments

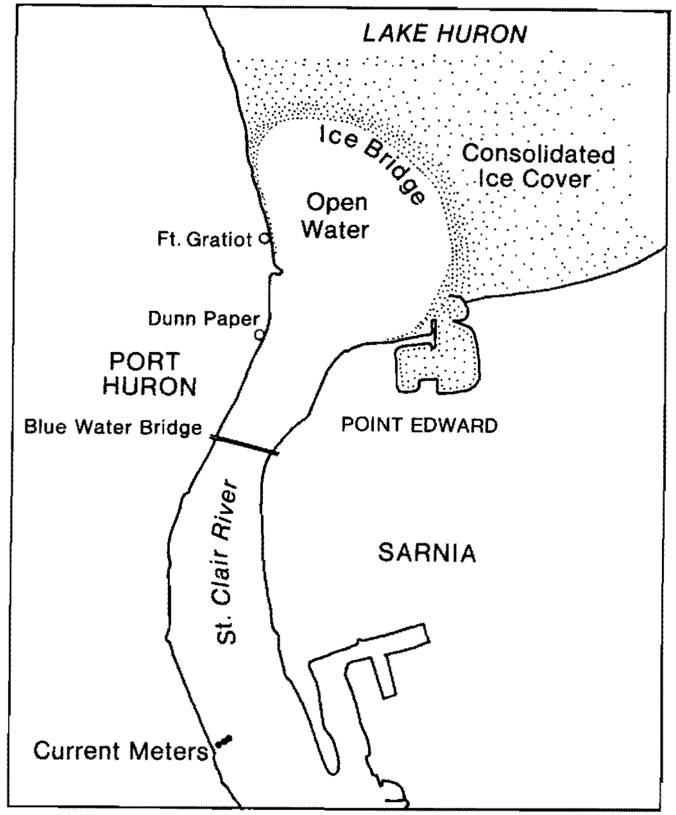

FIG. 3.—Location of St. Clair River Current Meters and Ice Bridge

and subsequent removals of meters took place with the assistance of the U.S. Coast Guard Cutter *Bramble* and a commercial diver, who guided the underwater operation. Additional participation in this study was provided by the U.S. Army Corps of Engineers, Detroit District, by making discharge measurements during open water conditions to enable calibration of velocities measured by the meters to the mean river flow. The current meter field seasons normally cover late fall, winter, and spring months (November–June). The meters were redeployed for the 1982–83, 1983–84, and 1984–85 winter seasons. The 1983–84 field program measurements provided the high quality river velocity data during the record ice jam of April 1984.

General Meteorological Conditions Leading to the Jam

Following freezeup, ice accumulates in southern Lake Huron leading to the development of an ice bridge across the head of the St. Clair River (shown in Fig. 3), which generally keeps the river free of ice. The ice bridge is broken up during spring breakup and periodically during the winter by storms (with strong southerly winds), producing drifting ice flows at the river entrance. Under certain weather conditions (northerly winds), many of these flows are transported rapidly to the lower river, where they tend to jam. The ice jams normally form just above the delta and proceed progressively upstream during severe jams.

The 1983–84 winter season was characterized by severe cold spells during the end of December and the first half of January, producing a lot of ice on Lake Huron. This was followed by a very warm February and cold March, producing some ice thawing and refreezing, respectively. April temperatures were normal with a large volume of ice remaining in southern Lake Huron. The ice-cover conditions in southern Lake Huron prior to the ice jam and after its development are shown in Fig. 4. The navigation season on the Great Lakes officially opened on March 26, 1984, and continuous attempts by the shipping industry to use the waterway contributed to the ice jam problems on the St. Clair River. The ships kept breaking up the accumulated ice flows at the head of the river, preventing establishment of an ice bridge, which would have kept additional ice flows from entering the river. The large amounts of accumulated lake ice were being forced downstream through the St. Clair River by predominantly northerly winds (Fig. 5), producing a record ice jam which lasted 24 days (April 5–29, 1984). Throughout the ice jam period, the Detroit River and Lake St. Clair were free of ice, serving as holding areas for many ships awaiting passage through the St. Clair River. The transit of ships through the river was very slow, with several stranded vessels, despite continuous assistance from all available ice breakers. The Lake Carriers' Association in Cleveland, Ohio (Waymire 1984), reported estimated losses of $1,700,000 a day due to shipping delays during the ice jam, which established a record for both the magnitude and lateness of occurrence.

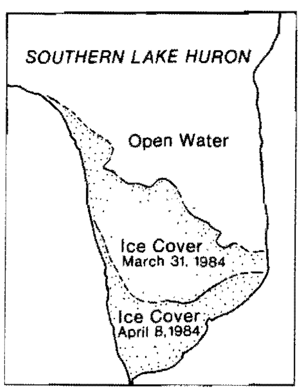

FIG. 4.—Southern Lake Huron Ice Cover, March 31–April 8, 1984

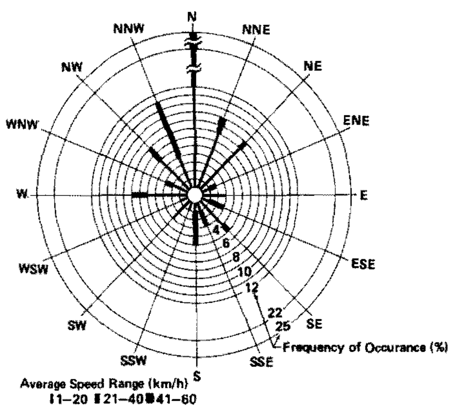

FIG. 5.—Wind Rose for Port Huron, Michigan, March 26–April 30, 1984

Impact on Levels and Flows

Measured Impact.—In conjunction with the current meter measurement program, ice conditions in the river are monitored and checked as needed by periodic surveys. The ice-monitoring program involves the analysis of the river profile for the development of abnormal river stages and falls associated with the ice jams. The water level conditions on the St. Clair River before, during, and after the record 1984 ice jam (March–May) are indicated in Fig. 6, which shows the river stages and the changes in the normal river profile associated with this huge ice jam. The water level at the river head (Fort Gratiot) is affected only slightly because Lake Michigan-Huron is large enough to absorb even drastic changes in the St. Clair River flows. Stages in midriver (St. Clair) increased sharply due to partial blockage and reduction of the river flow by the ice jam. Stages in the lower river (Algonac) dropped sharply due to the ice jam above

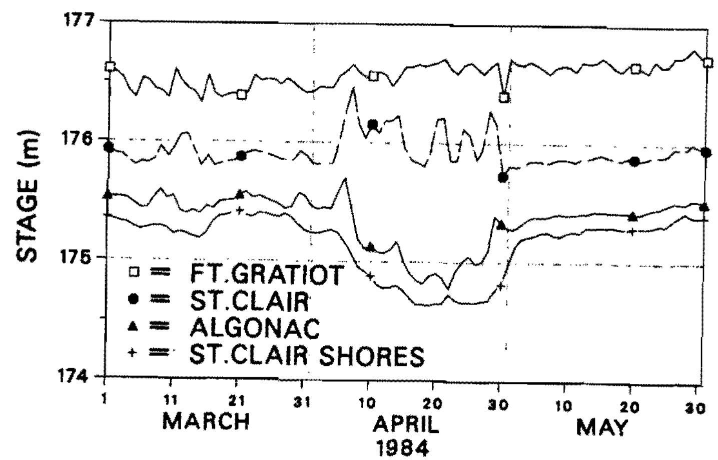

FIG. 6.—St. Clair River Stages, March–May, 1984

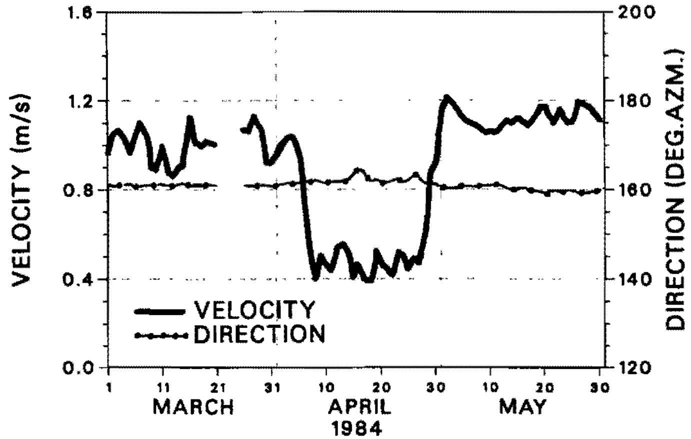

FIG. 7.—St. Clair River Current Meter Velocity and Direction, March–May, 1984

this location. Similar conditions are shown for Lake St. Clair, which dropped about 0.6 m. Fig. 6 also shows the storage of water on Lake Michigan-Huron indicated by higher April and May stages at Fort Gratiot, while the St. Clair stages for March and May 1984 remained about the same.

The collection of high quality current meter data during the record ice jam represents a major accomplishment and invaluable information on the St. Clair River winter flow regime. Results of the current meter program (velocity and direction) are indicated in Fig. 7, which shows the effect of the ice jam on the upper river flows. The velocity during most of April was reduced by about 50%, changing near the bottom at the meter location from about 1.0 to 0.5 m/s. Higher velocities at the beginning of May, following the ice jam breakup, were produced by the increase in stage differences in the upper river (Fort Gratiot and St. Clair).

Modeled Impact.—The intermediate-to-long-term impacts of the jam on the water levels and flows of the system cannot be determined directly by measurements, but must be analyzed with the use of hydrologic routing models. In this study the Great Lakes hydrologic response model (Quinn 1978) was used to determine levels and flows impacts. The only directly measured effect on lake levels that can be attributed to the ice jam is the rapid drop of 0.6 m in the level of Lake St. Clair. It is impossible to determine from the water level measurements the impacts on the levels of Lakes Michigan-Huron and Erie. These lakes are much larger and their response to changes in the St. Clair River flows (lake outflow and essentially inflow, respectively) is measured in years, as opposed to days for Lake St. Clair. The current meter data provided St. Clair River flows, which can be used in conjunction with the flows recorded prior to the jam to estimate the volume of additional water stored in Lake Michigan-Huron. These flow data consist of model-simulated flows prior to the jam and flows derived from the current meter velocity measurements during the jam, when, because of large ice concentrations, the model results are completely inadequate. The change in water level on Lake Michigan-Huron attributable to the jam is computed by

$$dL = \frac{Q_s - Q_m)t}{A} \quad (1)$$

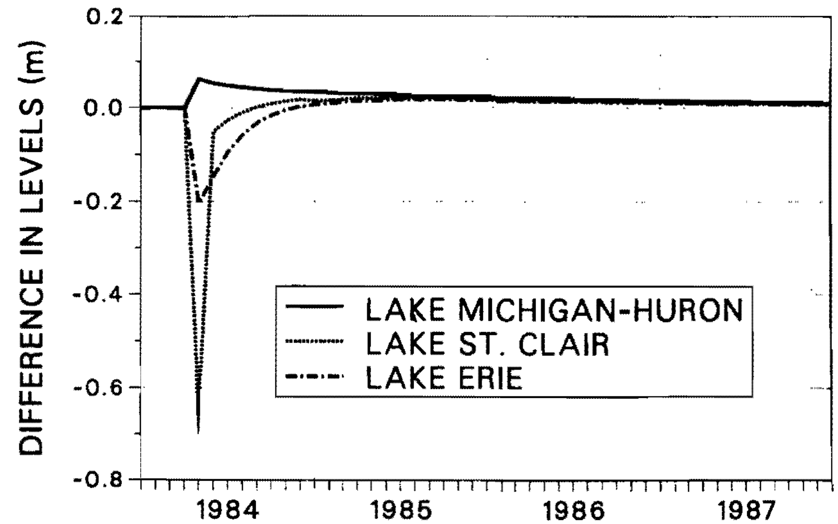

FIG. 8.—Effect of Ice Jam on B-O-M Levels, 1984–87

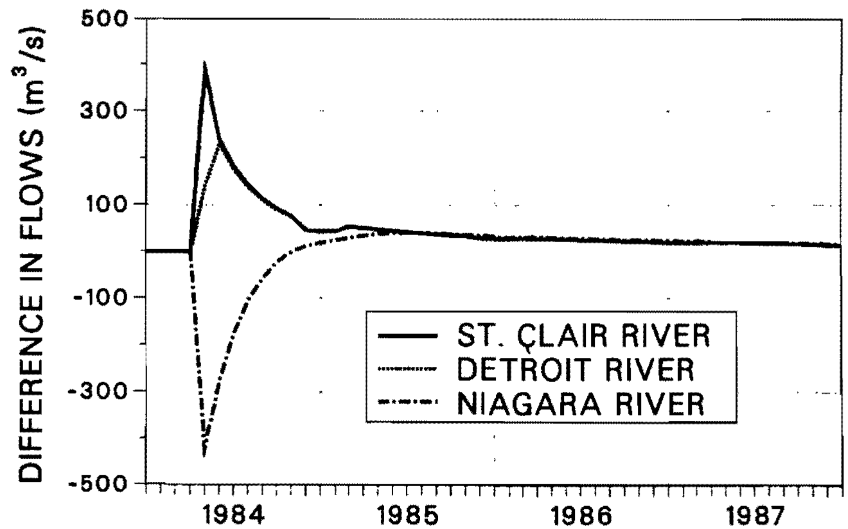

FIG. 9.—Effect of Ice Jam on Flows, 1984–87

where dL = the increase in lake level on Lake Michigan-Huron, in m; Q_s = the estimated St. Clair River flow, in m^3/s, prior to the jam; Q_m = the St. Clair River flow, in m^3/s, obtained from the current meters; t = the duration of time the jam lasted, in sec (24 days); and A = the surface area of Lake Michigan-Huron in m^2 (117,400 km^2).

Based upon the jam lasting 24 days, Eq. 1 results in a computed increase of 0.06 m on the lake, which is equivalent to a reduction of lake outflow by 3,400 m^3/s for the 24-day period. If the whole month (30 days) is considered, the outflow reduction represents about 2,700 m^3/s, which agrees with monthly outflow (about 5,500 m^3/s) and flow reduction by the ice jam of about 50% (Fig. 7). The required hydrologic response model inputs, in addition to the starting lake levels, are monthly values for runoff, precipitation, lake evaporation, and diversions. As these data were not yet available for 1984, the conditions for 1973 through 1979 were used as surrogate variables. The model runs were made assuming Lake Superior outflow conditions were similar to 1973, a year of similarly high water levels. The reported results could vary slightly due to minor changes in the regulation of Lake Superior resulting from the ice jam.

Two model runs were made, a base condition assuming the ice jam did not take place, and a second run starting with the condition due to the jam. The impact of the jam on levels and flows in the system was determined by subtracting the run with the jam from the base run. The results for the effects of the ice jam on the beginning of the month levels and flows are given in Figs. 8 and 9, respectively. The rapid recovery of Lake St. Clair due to its small surface area is readily apparent (Fig. 8), and is the rapid increase in Detroit and St. Clair River flows (Fig. 9). The Niagara River flow lags due to the fact that it is a function of the elevation of Lake Erie only. Both Lakes St. Clair and Erie rise above the levels that would have occurred without the jam due to the increased flows in the St. Clair and Detroit Rivers. Thus, the ice jam contributed to the record-high lake levels that occurred during the spring of 1985. It is apparent from these figures that most of the ice jam effects (above about 0.02 m) will be recovered in about a year, but measurable effects (about 0.01 m) of the jam will remain through 1987. The maximum effects are +0.06, −0.65, and −0.20 m on Lakes Michigan-Huron, St. Clair, and Erie, respectively.

Comparison with Historic Conditions.—The ice jam of April 1984 was the largest ice jam in the historical record. Ice jams in the connecting channels are usually categorized by the amount of flow retardation resulting from the jam. By this criteria the jam was the largest in the historical records going back to 1900. A comparison with recent data from the 1937-to-1984 period is shown in Fig. 10. Two observations are pertinent. The first is that April ice jams of any magnitude are relatively rare events. The second is that comparisons with recorded ice jams from 1937 to date indicate that this jam, with an average monthly retardation of about 2,700 m^3/s, is the largest jam regardless of date, being approximately 42% larger than the second-largest jam, which occurred during February 1942 (1,900 m^3/s). Additional analysis conducted by the U.S. Army Corps of Engineers (1984), indicates that the jam was larger than any during the period from 1900 to 1936 also.

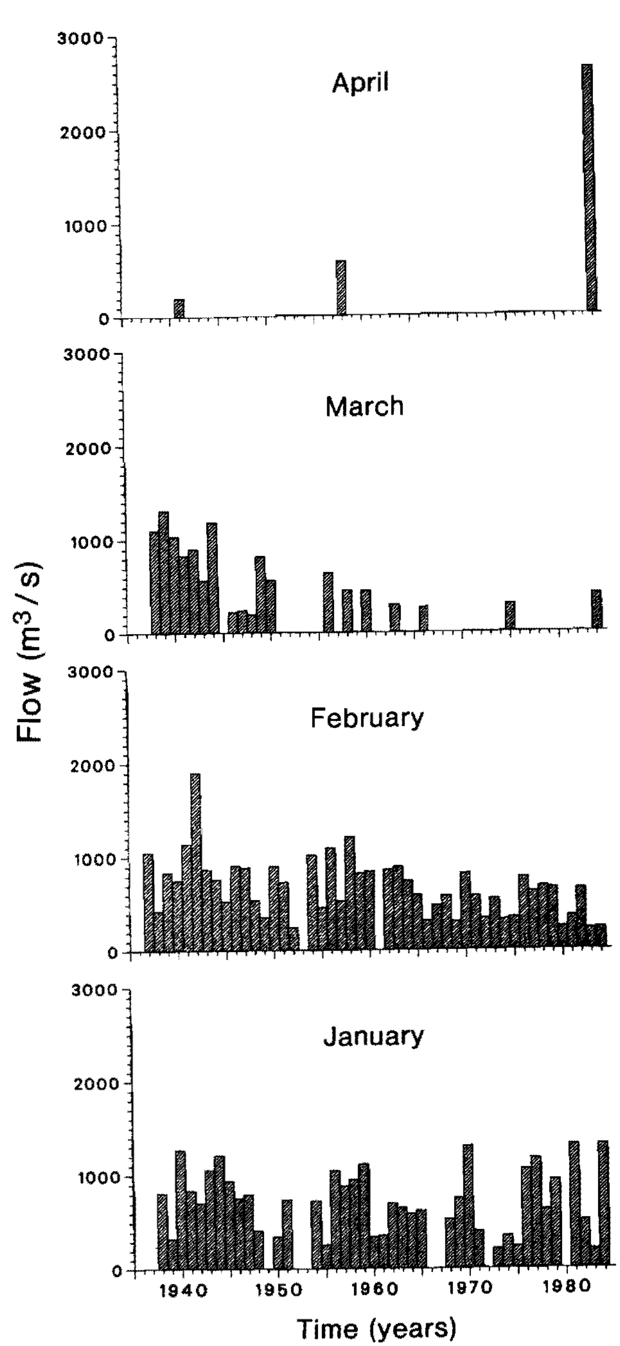

FIG. 10.—Ice Retardation in St. Clair River Flows, January–April (1937–84)

Summary and Conclusions

The record St. Clair River ice jam of April 1984 resulted in major impacts on the levels and flows of the Great Lakes and on navigation throughout the Great Lakes. The impact on water levels was measured at a number of sites located along Lake St. Clair and the St. Clair River. Flows in the St. Clair River were monitored by continuously recording electromagnetic current meters at a special flow-measuring station located in the upper river, near its head. The ice jam lasted 24 days, with major jamming starting on April 5 and the jam breaking on April 29. The jam established a new St. Clair River record for both its magnitude and the lateness of occurrence. Following the onset of the jam, Lake St. Clair water levels dropped about 0.6 m due to a decrease of lake inflow by the jam. At the peak of the jam, the St. Clair River flows were reduced by approximately 65%. After the breaking of the jam, the river flows and the waters of Lake St. Clair rose rapidly, and the lake recovered approximately 75% of the drop in levels in 4 days. The ice jam's impact on navigation was dramatically documented in the regional newspapers, which reported shipping losses of $1,700,000 per day. This record ice jam vividly demonstrated the feasibility of using in situ current meters to monitor the Great Lakes connecting channels winter flows. Measured velocities during the jam represent unique data for the study of the St. Clair River winter flow regimes.

Verification of the St. Clair River flow monitoring and extrapolation of measured velocities to the entire river cross section is provided by flow transfer from the Detroit River, which was free of ice during the St. Clair River ice jam period. Conversely, good agreement in derived flows by two completely independent methods demonstrates that the St. Clair-Detroit River flow-transfer method is a very useful technique, provided one of the rivers is free of ice problems. Computer simulations indicate that it will take about a year for most (substantially all) and at least three years for all the excess water stored in Lake Michigan-Huron during the jam to be dissipated and for levels in those lakes to return to prejam conditions. Furthermore, after initial rebound, both Lakes St. Clair and Erie will have higher water levels during that period (through 1987) as the stored water drains through them. This record ice jam also illustrates the process of natural regulation of the Great Lakes system on the seasonal cycle of levels and flows.

Appendix I.—References

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Appendix II.—Notation

The following symbols are used in this paper:

A = surface area of Lake Michigan-Huron;
dL = increase in lake level on Lake Michigan-Huron;
Q_m = St. Clair River flow obtained from current meter measurements;
Q_s = estimated St. Clair River flow prior to jam; and
t = duration of time jam lasted.