THE COORDINATING COMMITTEE ON GREAT LAKES
BASIC HYDRAULIC AND HYDROLOGIC DATA

RIVER FLOWS SUBCOMMITTEE

DISCHARGE MEASUREMENT PROCEDURES ON THE GREAT LAKES CONNECTING CHANNELS AND THE INTERNATIONAL SECTION OF THE ST. LAWRENCE RIVER

October 1991

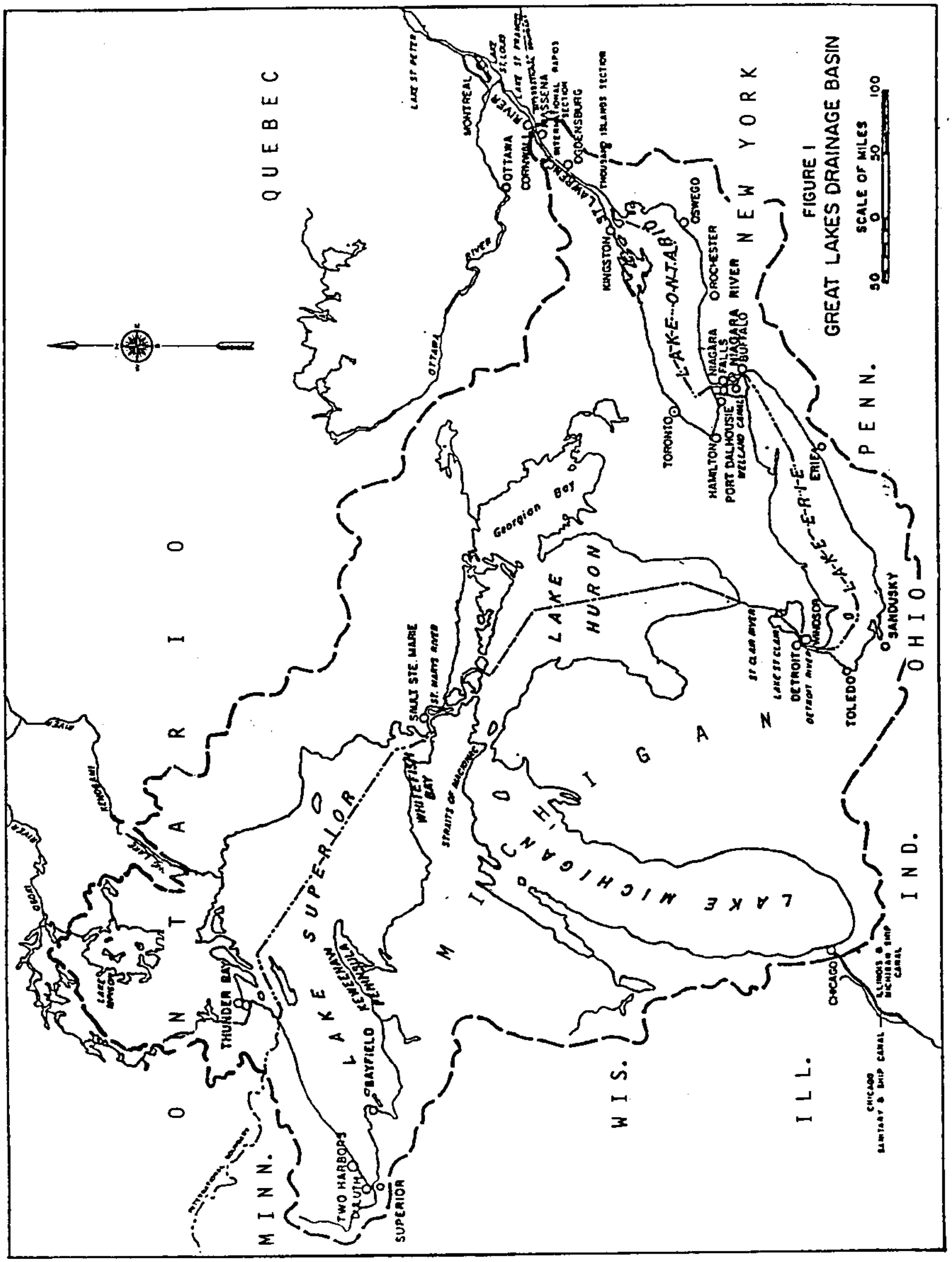

FIGURE I
GREAT LAKES DRAINAGE BASIN

SUMMARY

This report describes procedures and equipment used to date in discharge measurements on the Great Lakes connecting channels and the international section of the St. Lawrence River by the U.S. Army Corps of Engineers, Detroit District, and the Water Survey of Canada and their predecessors. As in previous Committee reports, a brief history of the Committee and a statement of its constitution and mandate are included. The report makes no conclusions or recommendations.

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1. INTRODUCTION

1.1 Requirement for Internationally Coordinated Data

The Great Lakes - St. Lawrence River drainage system extends westerly from the Gulf of St. Lawrence in the Atlantic Ocean a distance of some 3200 kilometres (2000 miles) to the headwaters of Lake Superior tributary streams in northern Minnesota and western Ontario. Eight states in the United States and two provinces in Canada border on the system, which drains an area of approximately 923000 square kilometres or 356000 square miles at its mouth near Sept-Iles, Quebec. The international section of this great system, including the Great Lakes basin (Figure 1), drains an area of approximately 775000 square kilometres or 300000 square miles measured at the foot of the international reach of the St. Lawrence River below Cornwall, Ontario. Coordinated hydraulic and hydrologic data are required for efficient management by the two countries of the boundary waters of this vast resource.

1.2 Establishment of International Study

Until 1953 most of the data were collected and compiled independently by various agencies in the two countries, with little coordination. This led to the development and use of several different reference planes for elevations and water levels, and other inconsistencies in the data which seriously encumbered their use in international water-related studies.

Attention was drawn to this situation in 1952 with the occurrence of extremely high water levels in the Great Lakes and imminent power and navigation development on the St. Lawrence River. Recognizing the urgent need for coordinated basic data, the responsible federal agencies in both countries (the U.S. Army Corps of Engineers in the United States and the Departments of Transport, Mines and Technical Surveys, and Resources and Development in Canada) opened discussions early in 1953 for the purpose of establishing a basis for the production and acceptance of identical data by both countries. These discussions culminated in a meeting of representatives of the agencies in Ottawa on May 7, 1953.

At that meeting, the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data was formed. Its purpose was to study the problem and establish a protocol. The Committee was made advisory to the agencies of both countries responsible for collecting and compiling Great Lakes hydraulic and hydrologic data.

The Committee was originally constituted as follows:

Canada	United States
T.M. Patterson, Chairman Water Resources Branch Dept. of Resources and Development	G.A. Hathaway, Chairman Corps of Engineers Department of the Army
D.M. Ripley, Member Special Projects Branch Department of Transport	W.T. Laidly, Member Corps of Engineers Department of the Army

Original constitution of the Committee (continued):

Canada

J.E.R. Ross, Secretary
Geodetic Survey of Canada
Department of Mines and
Technical Surveys

United States

E.W. Nelson, Secretary
Corps of Engineers
Department of the Army

The present (1989) membership of the Committee is as follows:

Canada

J.R. Robinson, Chairman
Environment Canada
Inland Waters Directorate
Ontario Region

G.M. Yeaton, Member
Dept. of Fisheries and Oceans
Ocean and Aquatic Sciences Branch
Ottawa

P.P. Yee, Secretary
Environment Canada
Inland Waters Directorate
Ontario Region

United States

D.J. Leonard, Chairman
Department of the Army
NCD Division
Corps of Engineers

P.C. Morris, Member
Department of Commerce
National Oceanographic and
Atmospheric Administration

R.E. Wilshaw, Secretary
Department of the Army
Detroit District
Corps of Engineers

C.M. Cross, A.T. Prince, J.B. Bryce, R.H. Clark, J.F. Forrester, C.G. Cline, D.F. Witherspoon, C.A. Gale, M.H. Quast, H.B. Rosenburg, R.H. Smith, F.I. Morton, and E.T. Wagner have also served as Canadian members of the Committee; and L.D. Kirshner, F.A. Blust, H.F. Lawhead, F.F. Snyder, C.I. Thurlow, B.G. DeCooke, and H.G. Dewey have served as United States members.

Four working groups, named the River Flow Subcommittee, the Vertical Control Subcommittee, the Lake Levels Subcommittee, and the Physical Data Subcommittee were formed to assist the Coordinating Committee in its work. This number was reduced to three in September 1969 when the Vertical Control and Lake Levels Subcommittees were merged to become the Vertical Control - Water Levels Subcommittee. The subcommittees were directed to conduct the required studies through collaboration of the appropriate agencies in the two countries and report back to the Committee.

This report was written and compiled under the direction of the River Flow Subcommittee, whose membership in 1983, the year of authorization of the report, was:

Canada

J.R. Robinson
Environment Canada
Inland Waters Directorate
Ontario Region
Cornwall

United States

R.E. Wilshaw
Department of the Army
Detroit District
Corps of Engineers

1983 membership of the River Flow Subcommittee (continued):

Canada	United States
M.H. Quast Environment Canada Inland Waters Directorate Ontario Region	F.H. Quinn Department of Commerce National Oceanographic and Atmospheric Administration Great Lakes Environmental Research Laboratory

Present (1989) membership of the subcommittee is as follows:

Canada	United States
L.J. Kamp Environment Canada Inland Waters Directorate Ontario Region	R.E. Wilshaw Department of the Army Detroit District Corps of Engineers
S. Dumont Environment Canada Inland Waters Directorate Ontario Region	F.H. Quinn Department of Commerce National Oceanographic and Atmospheric Administration Great Lakes Environmental Research Laboratory

Former members of the subcommittee include B.G. DeCooke, P. Tomandl, F.W. Townsend, I.M. Korkigian, and P.L. Cox, all of the Department of the Army, Detroit District, Corps of Engineers, from the United States; and C.G. Cline, J.B. Bryce, B.E. Russell, E.A. MacDonald, and E.T. Wagner of Environment Canada, Water Resources Branch, Ontario Region, from Canada.

1.3 Authority, Purpose, and Scope

An important part of the data collection program in the Great Lakes system is the measurement of discharge in the connecting channels - the St. Marys, St. Clair, Detroit, and Niagara Rivers and their diversions, and the upper or international reach of the St. Lawrence River. The lower St. Lawrence River is outside the scope of the Committee and this report.

The first recorded discharge measurements on the connecting channels were taken on the St. Clair River in 1867 by the U.S. Lake Survey. Since that time thousands of measurements have been taken in these channels for various purposes by public and private organizations in both countries. However only those measurements taken by federal agencies in the exercise of their mandates to advance the public interest fall within the scope of this report. Thus some important classes of discharge measurements, notably measurements by the Gibson method for verifying the performance ratings of hydraulic turbines in power plants located on the St. Marys, Niagara, and St. Lawrence Rivers and the Welland and Erie Canals are not included. These measurements, or Gibson tests, are done by contractors for the plant owners and operators. However the procedures and results are subject to review and approval by the appropriate IJC (International Joint Commision) board.

The federal agencies presently responsible for discharge measurements on the connecting channels are the U.S. Army Corps of Engineers, Detroit District, as successor to the U.S. Lake Survey, and the Water Survey of Canada, Ontario Region. The measurements are fully documented in project reports on file in the agencies' offices in Detroit and Guelph, along with field notes and other records. The present report, which was authorized by the Committee on December 13, 1983, is based on these records, as is a related Committee report entitled "Discharge Measurements and Regimen Changes in the Great Lakes Connecting Channels and the St. Lawrence River" (Reference 1). The latter report provides job and site specific details of procedures and equipment, while the present report attempts to present an overview of these activities.

1.4 Acknowledgements

The Committee acknowledges with thanks the contributions of the following agencies in the preparation of this report:

- U.S. Department of the Army, Detroit District, Corps of Engineers, Detroit, Michigan.

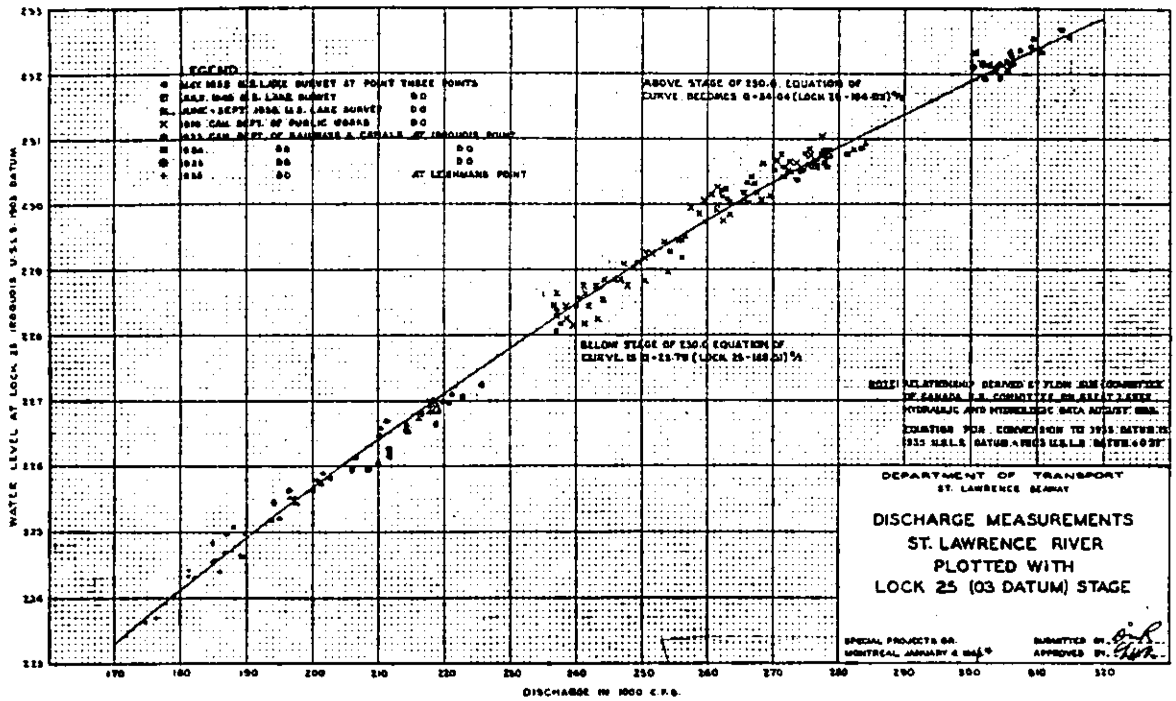
- U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan.

- Environment Canada, Inland Waters Directorate, Ontario Region:
  - Water Resources Branch, Guelph, Ontario;
  - Water Planning and Management Branch, Burlington, Ontario, and Cornwall, Ontario;

2. DISCHARGE MEASUREMENTS - GENERAL

2.1 Purpose

The main purpose of discharge measurements on the connecting channels is collection of flow data for the development of ratings for water level gauges and hydraulic structures or for verification of existing ratings. Figures 2 and 3 are examples of gauge and hydraulic structure ratings. Data may also be collected for a number of other applications, including input to numerical and hydraulic models, calibration of accoustic flow-meters and point velocity meters, and river regime and flow distribution studies. Numerical models developed by the Great Lakes Environmental Research Laboratory (GLERL) for prediction of water levels and flows are described in References 3 and 46. Several other numerical models are also in use for predicting lake levels and flows in the connecting channels, and hydraulic models of the Niagara and St. Lawrence rivers have been built by the Corps of Engineers at its facility in Vicksburg, Miss., and by Ontario Hydro in Toronto.



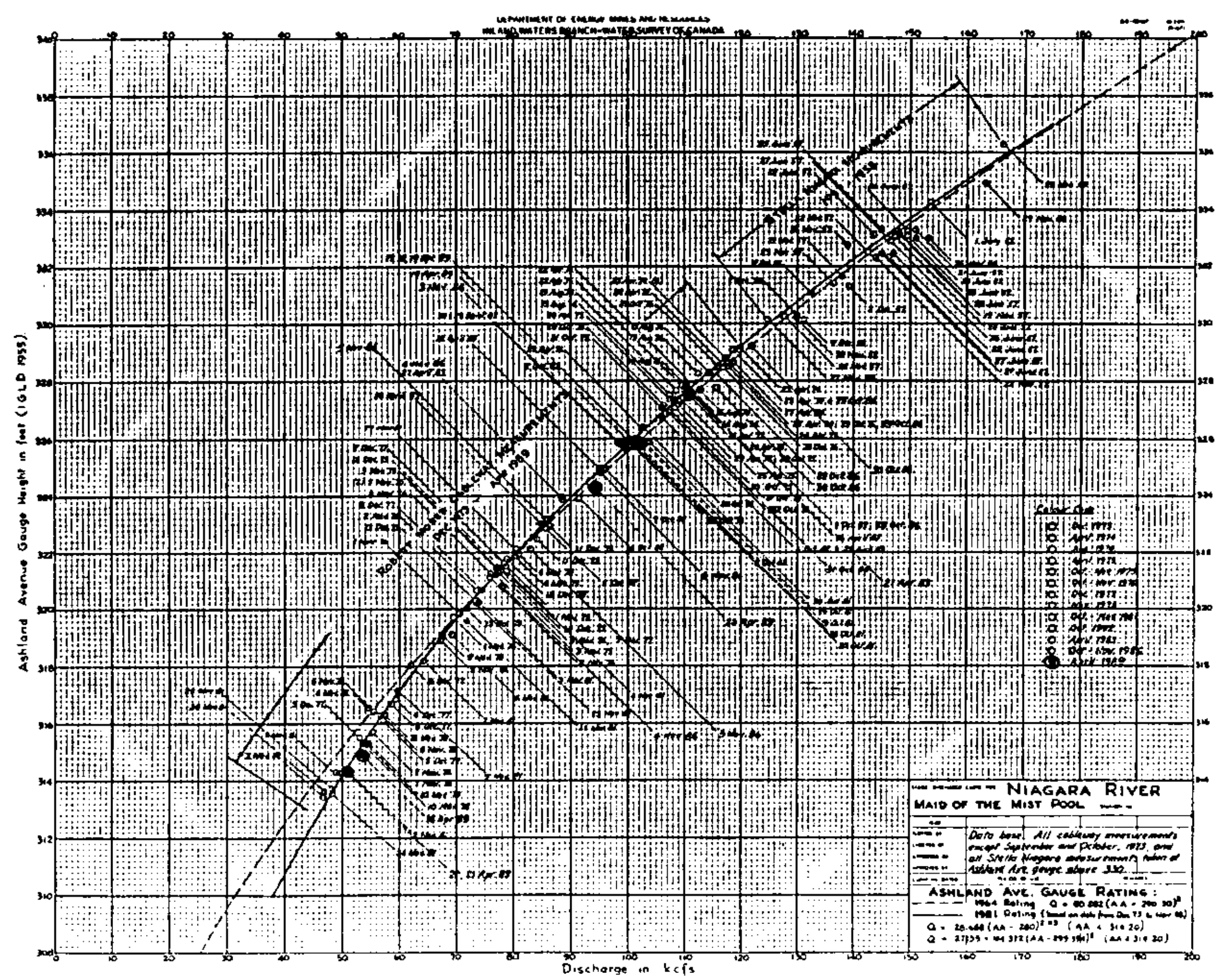
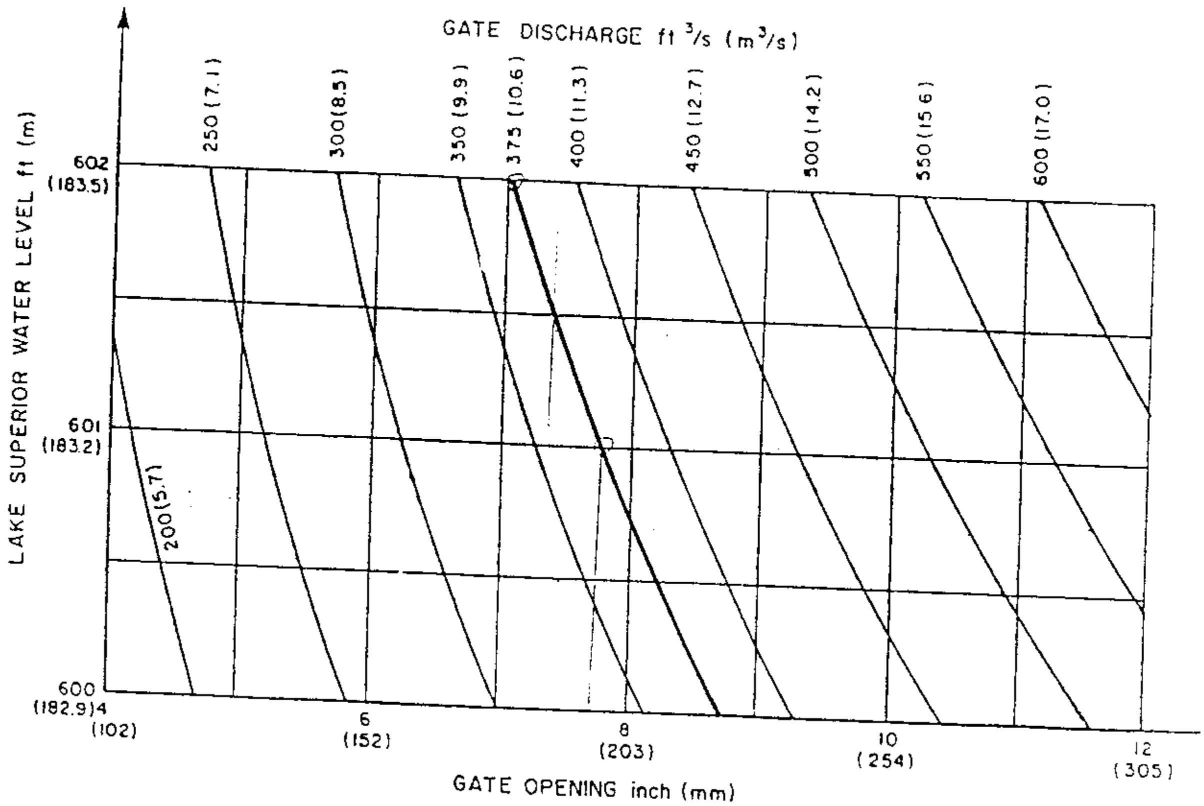


Figure 2

Examples of Gauge Ratings



THEORETICAL DISCHARGE - GATE 1 - COMPENSATING WORKS ACRES

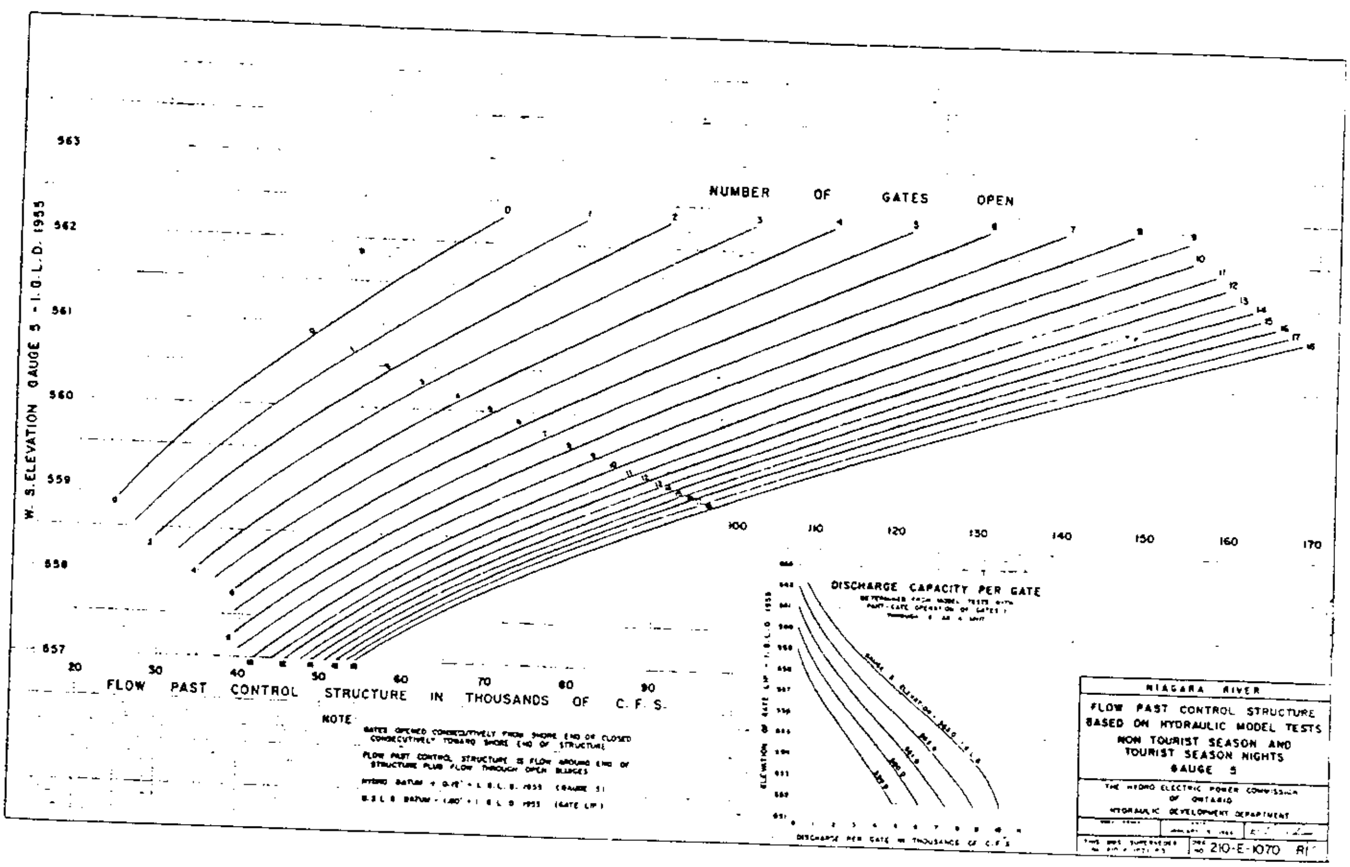


Figure 3
Example of Hydraulic Structure Ratings

Discharge data are used operationally in navigation, power production, and lake regulation; for water apportionment and monitoring compliance with agreements and treaties, and in a wide variety of studies. Daily discharge data for the St. Marys, Niagara, and St. Lawrence Rivers are published annually by Environment Canada Water Resources Branch in Surface Water Data series publications, and monthly lake outflows are published periodically by the Committee.

2.2 Methods

The discharge of a stream is usually defined as the volume of water in cubic metres or cubic feet flowing past a particular point on the stream in unit time, usually one second. Since no method is presently available for measuring the relatively large discharges of the connecting channels directly, a discharge measurement as presently practiced is a computation of discharge from measurements of related flow variables. These variables are current velocity and cross-sectional area in the velocity-area method and foreign substance concentration in the dilution method. A third method called the volumetric method can sometimes be used in special conditions.

Discharge measurements can be further classified according to the manner in which they are taken as discrete or continuous. The most common type of discrete discharge measurement on the connecting channels is the velocity-area measurement. This type of measurement is assumed throughout this report unless specified otherwise. Only in some isolated cases where conditions are such that a satisfactory measurement cannot be obtained by the velocity-area method have the other methods mentioned above been used.

The use of accoustic flowmeters for continuous measurement of discharge is also slowly gaining acceptance despite some practical difficulties in installation and the effect of sediment and debris on the readings. Trial installations on the upper Niagara River were tested unsuccessfully in 1973 and again in 1987. The results are reported in References 31 and 47. Later generation accoustic flowmeters are presently being tested on the Erie and Welland Canals but performance evaluations are not yet available.

The three methods of discrete discharge measurements mentioned above are briefly described in the following paragraphs.

Velocity-Area Method

As mentioned previously, the velocity-area method is the usual method of discharge measurement on the connecting channels and therefore the main subject of this report. The method is based on the relationship $Q = vA$, or discharge is the product of corresponding values of mean velocity and cross-sectional area. As usually applied, the method involves subdivision of the section into an appropriate number of segments, called panels, as illustrated in Figure 4. The panel areas are the products of the measured panel widths and mean depths, and the panel mean velocities are computed from measured velocities at a number of selected points in the panel. The usual procedure in measurements on the connecting channels was to measure velocities at each tenth of the depth in the central vertical of each

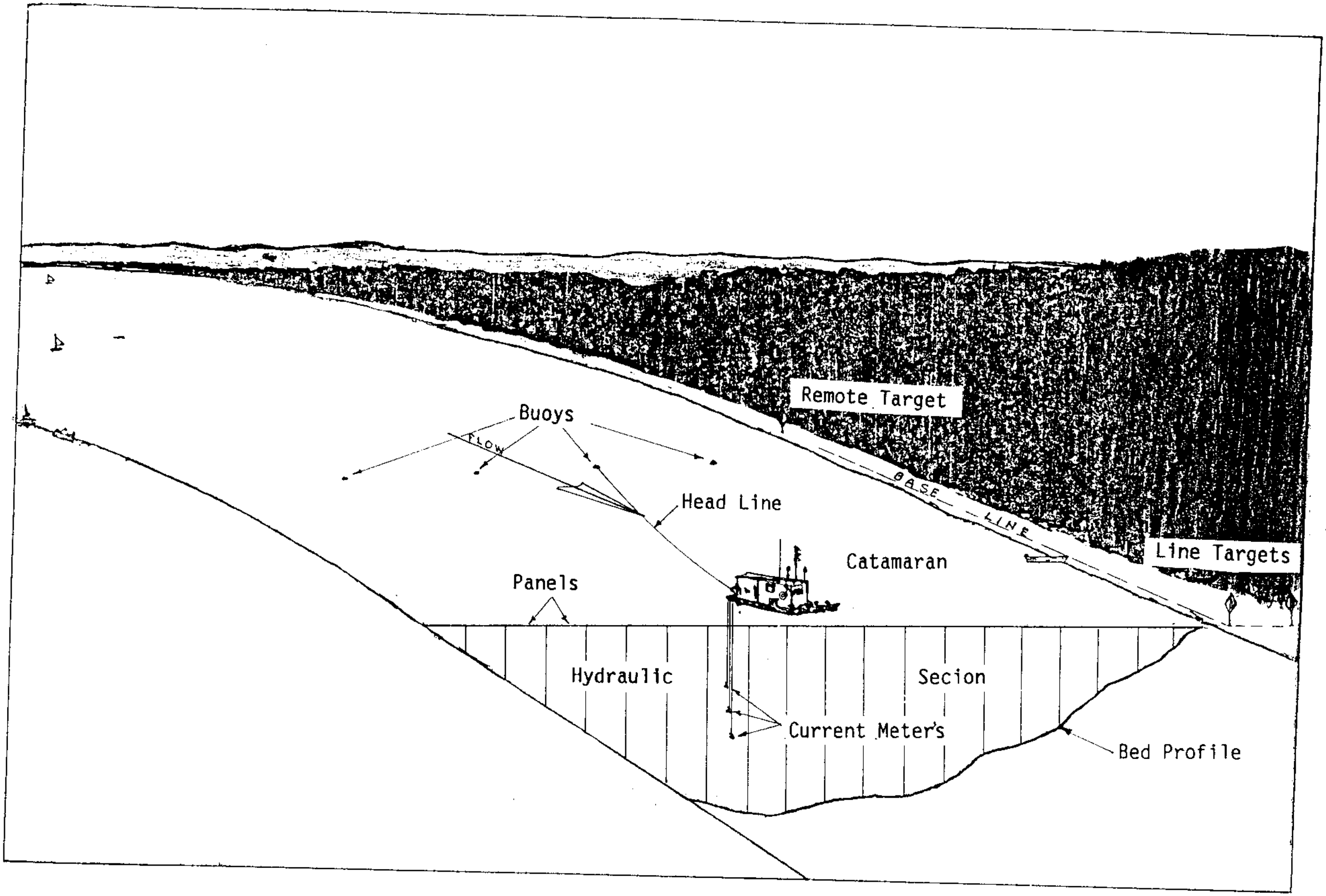


Figure 4
Diagram Depicting Conventional Discharge Measurement

panel, using current meters. Panel discharges were then computed as the products of the mean velocities and panel areas, and the total discharge at the section was the sum of the panel discharges. The section was usually divided into ten to twenty-five panels, depending on a number of factors which may include the width of the channel and the configuration of the cross-section, the velocity and flow distribution, the allowable time for the measurement, and the accuracy sought.

Besides current meters, floats and chemical tracers can also be used to measure the velocity component in velocity-area discharge measurements, but there are few such measurements on record in the connecting channels. Floats were used in the first recorded discharge measurements on the St. Clair River in 1867, and fluorometric dyes in measurements on the Chematogan Channel of the St. Clair River in 1968 (Reference 33). But the main use of floats and dye tracers on the connecting channels has been in flow distribution and direction surveys and time of travel studies. An example of a time of travel study using a fluorometric dye tracer was on the Niagara River in 1973. The dye was injected into the river from the Whirlpool Rapids bridge at the outlet of the Maid of the Mist Pool and traced by fluorometer at the Robert Moses Cableway Section, about three miles downstream. The time of travel was required to establish the lag between the Ashland Avenue Gauge and the Cableway to correlate stage and discharge data for verification of the gauge rating.

Two types of velocity-area measurement are presently being practised on the connecting channels: conventional measurements in which the boat is held stationary while velocity is measured at selected points in selected verticals across the section, and moving-boat measurements, in which the velocities are measured at selected points at a fixed depth while the boat is crossing the section. Conventional measurements are so called because this mode of measurement dates back to the start of the program on the connecting channels and accounts for the majority of the measurements. The moving-boat technique was developed by the U.S. Geological Survey in the 1950s and introduced into the connecting channels by the Michigan District of that agency and the Hydrometric Methods Section of the Water Survey of Canada in the 1960s. The technique has since gained general acceptance, and its use is increasing due to speed of measurement and reduced labour and equipment requirements in comparison to conventional measurements.

Another type of velocity measurement system, presently more suited to continuous than discrete measurement, is the previously mentioned accoustic velocity meter. This was developed in the 1950s in the United States and Europe, and is based on the principal that an accoustic signal travelling in a moving medium travels faster with the current than against it by an amount proportional to the current speed. In application, two transducers are mounted on opposite banks of the channel facing each other obliquely, one upstream of the other a minimum distance of about one third of the width of the channel, so that the line joining them, the accoustic path, is oblique to the current by an angle of at least 30 degrees. An electric impulse is transmitted by wire to both transducers, causing them to ring simultaneously and send high frequency accoustic signals through the water along the accoustic path to the other transducer. As each transducer receives the signal from the other it sends an impulse back to the control unit, the impulse from the downstream transducer arriving a moment ahead of the impulse from the upstream transducer. The difference in arrival times is the difference in travel times of the downstream and upstream signals, assuming instantaneous electrical transmission, and thus is a measure of the current speed. The number of readings per second, the method of storage, frequency of update, and other operational details vary with individual units and installations. The reader is again referred to References 31 and 47 for details of the two Niagara River installations. Besides those mentioned previously, the only other accoustic flowmeter in place in the Great Lakes system is on the Chicago Sanitary and Ship Canal and is used to measure the Lake Michigan diversion to the Illinois River at Chicago.

Dilution Method

The dilution method measures the discharge of a stream by comparison to a known discharge - the injection rate of a foreign substance, usually a fluorometric dye solution. The solution is introduced into the stream at the head of a turbulent reach or rapids to effect as complete mixing as possible. The comparison is achieved by measuring the concentration of the dye with a fluorometer set up at the foot of the rapids or other suitable downstream location. Figure 5 is a photograph of a strip chart analog recorder set up on the bank of the Niagara River at the American Falls Channel in 1971. It is connected to the fluorometer to record the measured dye concentrations.

There are two variations of the method - the constant rate injection method and the sudden or slug injection method (Figure 6). Procedures are described in detail in Reference 19, pages 213 to 259, References 14 and 15, and in other papers. The method is ideal at sites unsuitable for velocity-area measurements due to excessive turbulance. Such sites on the connecting channels include the rapids section on the St. Marys River at Sault Ste. Marie, and the Whirlpool Rapids and American Falls Channel sections on the Niagara River. Although pollution from the measurements is reported to be negligible if conducted properly, future development and use of the method on the connecting channels is unlikely due to concerns about pollution.

Volumetric Method

The volumetric method can be used in controlled conditions to measure the discharge entering or leaving a chamber of known size, e.g. a lock, by timing the rate of change of water level in the chamber. The method can be applied to the measurement of valve discharges and gate leakages in locks where a suitable measuring section for velocity-area measurements is not available. In applying the method, water levels in, above, and below the lock are measured at appropriate intervals, typically one minute, while the lock is filling or emptying. Water levels in the lock should be measured simultaneously at several locations to obtain an average. The required discharge can then be computed from the rate of change of water level in the lock and the head on the valves or gates. The only known application of this method to date was in measurements of gate leakages of the Canadian lock on the St.Marys River at Sault Ste. Marie in 1983.

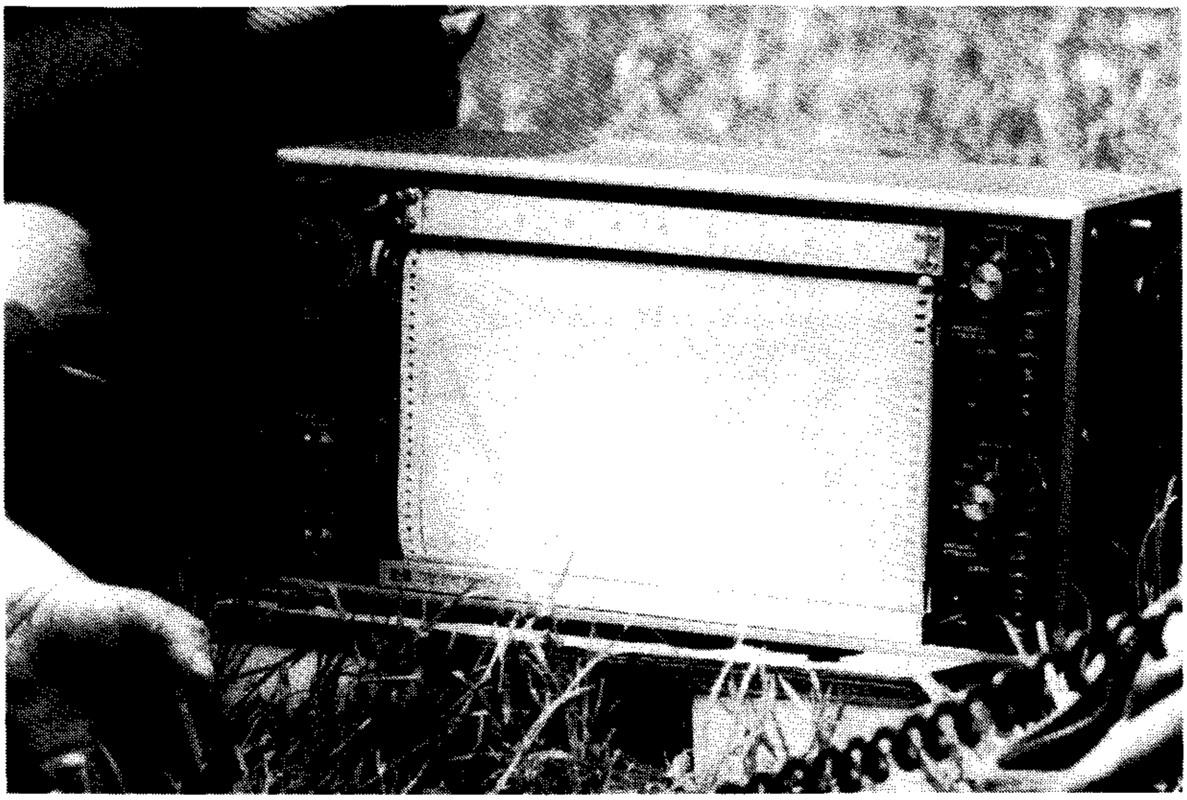


Figure 5
Fluorometer Recorder

Figure 6
Dilution Method - Slug Injection of Dye

2.3 Standards

The first international cooperative discharge measurement program of record on the connecting channels was on the St. Lawrence River at Point Three Points section in 1953. Participants were the U.S. Lake Survey and the Water Resources Branch of the Department of Northern Affairs and National Resources, Canada (Reference 37). The program was part of the St. Lawrence Seaway and Power Project, and incidentally coincided with the formation of the Coordinating Committee in that year. Until then, U.S. and Canadian agencies had operated independently, with occasional exchange of observers, and each had developed its own general procedures and standards.

In the United States, long standing U.S. Lake Survey standards for discharge measurements, developed for purpose of collecting and compiling discharge data, governed most discharge measurements by the U.S. agencies until 1970. In that year the Lake Survey, a district of the U.S. Army Corps of Engineers, was disbanded and its personnel and responsibilities divided between the Detroit District of the Corps of Engineers and the National Oceanographic and Atmospheric Administration (NOAA), Department of Commerce. The Detroit District assumed the discharge measurement role along with the regulation and water level forecasting functions. NOAA took over water level gauges, hydrographic services, and research functions through its Great Lakes Environmental Research Laboratory (GLERL).

The U.S. Lake Survey standards were developed and established through scientific investigation and flow measurements conducted since the early 1860's. As noted previously, the earliest measurements used floats to measure the direction and speed of surface currents. As equipment and techniques improved, standard procedures were developed to ensure improved accuracy and uniformity in discharge measurements. In general the Lake Survey procedures involved measurement of current speed at three points in each of ten to seventeen verticals in a section, after completion of preliminary section calibration surveys to develop standard soundings and coefficients for vertical and transverse distribution of velocity and direction of flow. A measurement program or sequence usually comprised from fifteen to thirty such measurements.

Prior to 1952, Canadian involvement in flow measurements in the Great Lakes and St. Lawrence River had been concentrated on the St. Lawrence River below the international boundary, where extensive programs had been in progress since the early 1920's. Measurement programs by Canadian federal agencies on the connecting channels to that time had been limited to occasional series of measurements on the Niagara and St. Lawrence Rivers and the Canadian Power Canal on the St.Marys River at Sault Ste. Marie. The procedures and standards developed in the measurements on the lower St. Lawrence River, which were similar to those developed by the U.S. Lake Survey, became the basis for later Canadian measurements on the upper St. Lawrence River at Point Three Points and Weaver Point in 1952 to 1954. With these exceptions, Canadian practice was to measure velocity in a minimum of twenty verticals in a section but only at two points (.2 and .8 of the depth) in each vertical. Vertical and transverse velocity coefficients were usually assumed to be one. This is the same standard developed and currently used by the U.S. Geological Survey and the Water Survey of Canada in their general stream gauging operations.

The present set of standards of the Corps of Engineers and the Water Survey of Canada for first order discharge measurements on the connecting channels was introduced in 1972 by the St. Lawrence Committee on River Gauging in connection with rating verification measurements of the Robert Moses - Robert H. Saunders hydro-electric plants on the St. Lawrence River at Cornwall, Ontario (Reference 41). These standards specify a minimum of twenty panels in the section with not more than ten percent of the total area or discharge in any one panel. Application of this specification results in varying panel widths across the section, except in unusually uniform sections. This is considered acceptable so long as no panel width exceeds twelve to fifteen percent of the total width, to ensure adequate sampling of low contributing parts of the section, such as wide shallow shelves off the banks. The mean velocity in a panel is determined by the velocity distribution method from a velocity-depth profile defined by at least six points, and usually nine, in each vertical.

The St. Lawrence Committee's standards described above were accepted by the International Niagara Working Committee in 1973 for Niagara River measurements, which that year included measurements at the newly erected Robert Moses Cableway and at the International Railway Bridge section on the upper river. Measurement programs usually consisted of ten to twenty measurements, depending on the range of flows to be measured and numerous other factors discussed later.

The accuracy of measurements conducted in accordance with the above standards can be expected to average about five percent, expressed as a standard error, according to the method of error analysis by Carter and Anderson (References 28 & 30). This analysis assumes average hydraulic conditions at the measuring section and steady flow. The dominant factor in the analysis is the number of panels in the section, with relatively little weight attached to the number of point velocity measurements used to determine the mean velocity in a vertical. Therefore it may give a somewhat unfavourable comparison of the relative accuracy of measurements on the connecting channels compared with measurements in general stream gauging operations, where velocities are usually measured at only one or two points in the verticals. The only section on the connecting channels where velocities are measured at only one or two points in each vertical is the American Falls bridge section on the Niagara River, where shallow depths prevent measuring at the usual nine points. An increased number of panels are used in measurements at this section to help compensate for the reduced sampling in the verticals.

In measurements with lower accuracy requirements, such as some flow distribution measurements or measurements of discharges affected by ice or other variable backwater conditions, the standards were downgraded to save time and resources. Usually this was accomplished by reducing the number of panels, sometimes to as few as five, but usually not less than eight, or by resorting to moving-boat measurements.

The use of moving-boat measurements, especially by Water Survey of Canada, has increased in recent years. The performance standards of the U.S. Geological Survey and the Water Survey of Canada have applied to these measurements, pending development of standards specific to the connecting channels. These standards relate to the number of measuring points in a section, the maximum departure from the section line during traverses, the determination of coefficients, and other factors.

While the foregoing largely tacit standards have enabled the federal agencies responsible for the measurement of discharge on the connecting channels to discharge their responsibilities in a reasonably uniform and mutually satisfactory manner, the need for formal standards or guidelines has been evident for some time. The development of such standards would appear to fall within the purview of the Committee.

3. SITE SELECTION

3.1 Existing Sites

Sites for discharge measurements for any particular purpose on the connecting channels are severely restricted by the complexity of many of the channels, their relatively short lengths, and extensive development for navigation and hydro-electric power production. As a result most of the best measurement sites were identified and established early in the program by the U.S. Lake Survey and remain in place to the present time. These original sites, which are shown in Figures 7 to 10, include:

- Brush Point, Bridge, Sprys Dock, Brewery, and Gates Sections on the upper St. Marys River, and West and Middle Neebish Sections on the lower St. Marys River.

- Drydock, St. Clair, Roberts Landing, and Bay Point Sections on the St. Clair River.

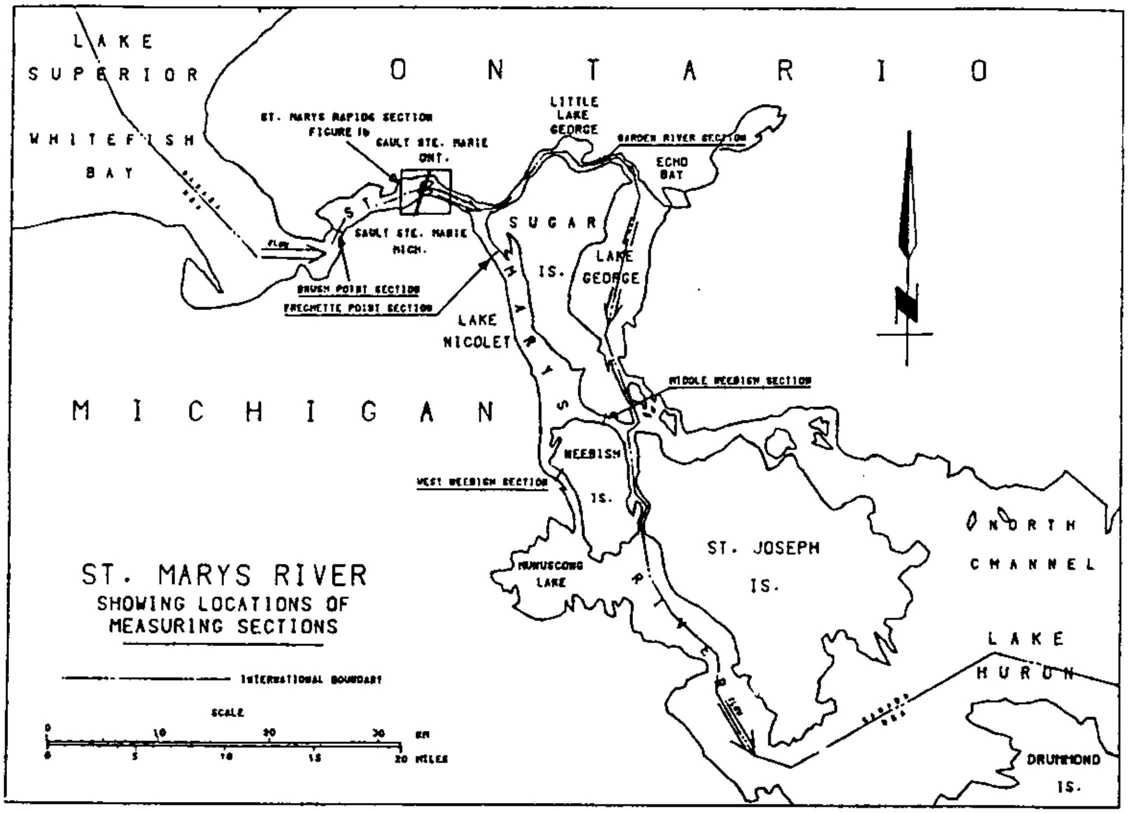
- Fort Wayne Section on the Detroit River;

- International Railway Bridge, Black Rock, and Austin Street Sections on the upper Niagara River.

The original sites for measurements to calibrate and verify the gauge ratings for Lake Ontario outflows were the Point Three Points, Iroquois Point, Leishman Point, Weaver Point,and Massena Point Hydraulic Sections on the St. Lawrence River. All of these sections, except Massena Point which was reoccupied as recently as 1972 for verification measurements of the Moses-Saunders power plant ratings, were inundated by the Seaway and power development in 1958. A new site for Lake Ontario outflow measurements was established above Iroquois Dam in 1972 as part of a water balance study of Lake Ontario for the International Field Year for the Great Lakes (IFYGL).

Other recently established sites include the following:

- Upper Gate Section on the St. Marys River, established in 1975 for measurement of the combined discharge of the Lake Superior Compensating Works and the U.S. Power Canal. Unsatisfactory for fewer than eight open gates. Replaced in 1989 by Lower Rapids Section, which was found satisfactory for up to eight open gates in the Compensating Works.



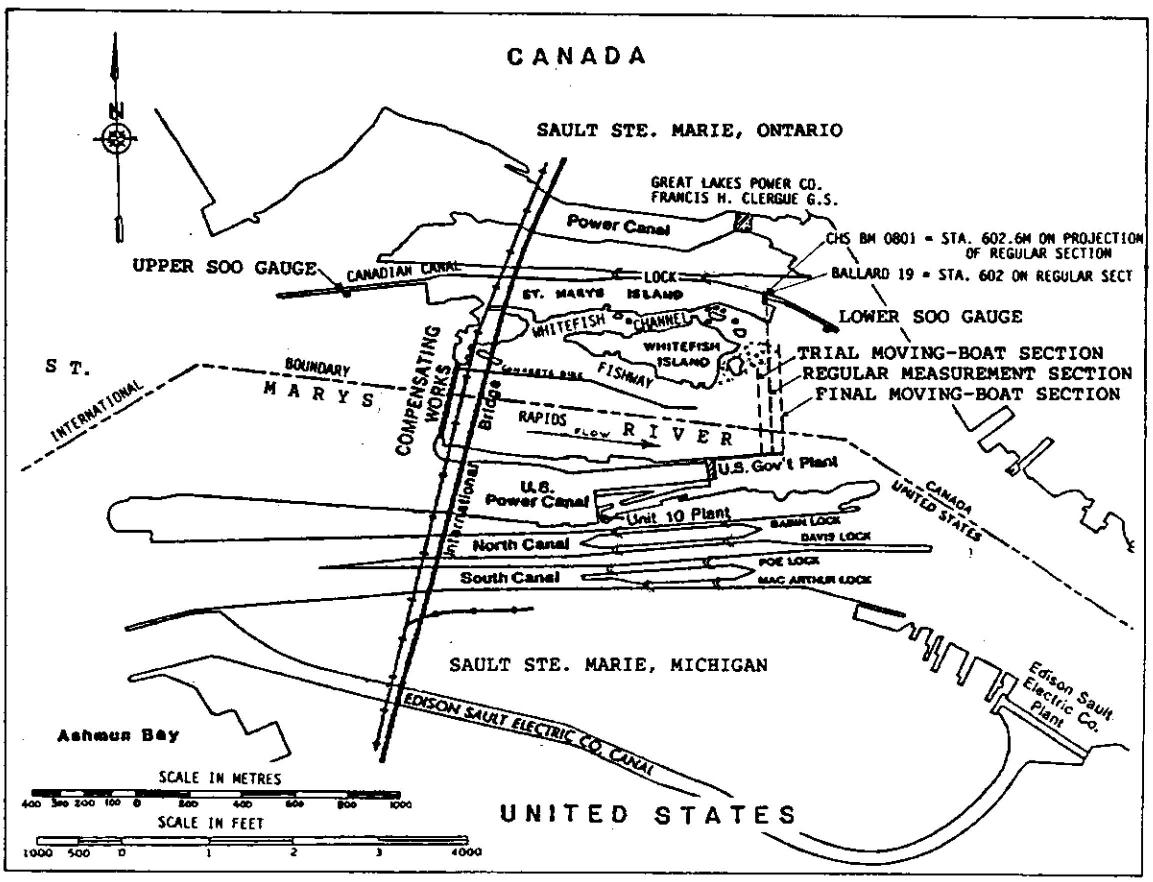


Figure 7
St. Marys River - Hydraulic Sections

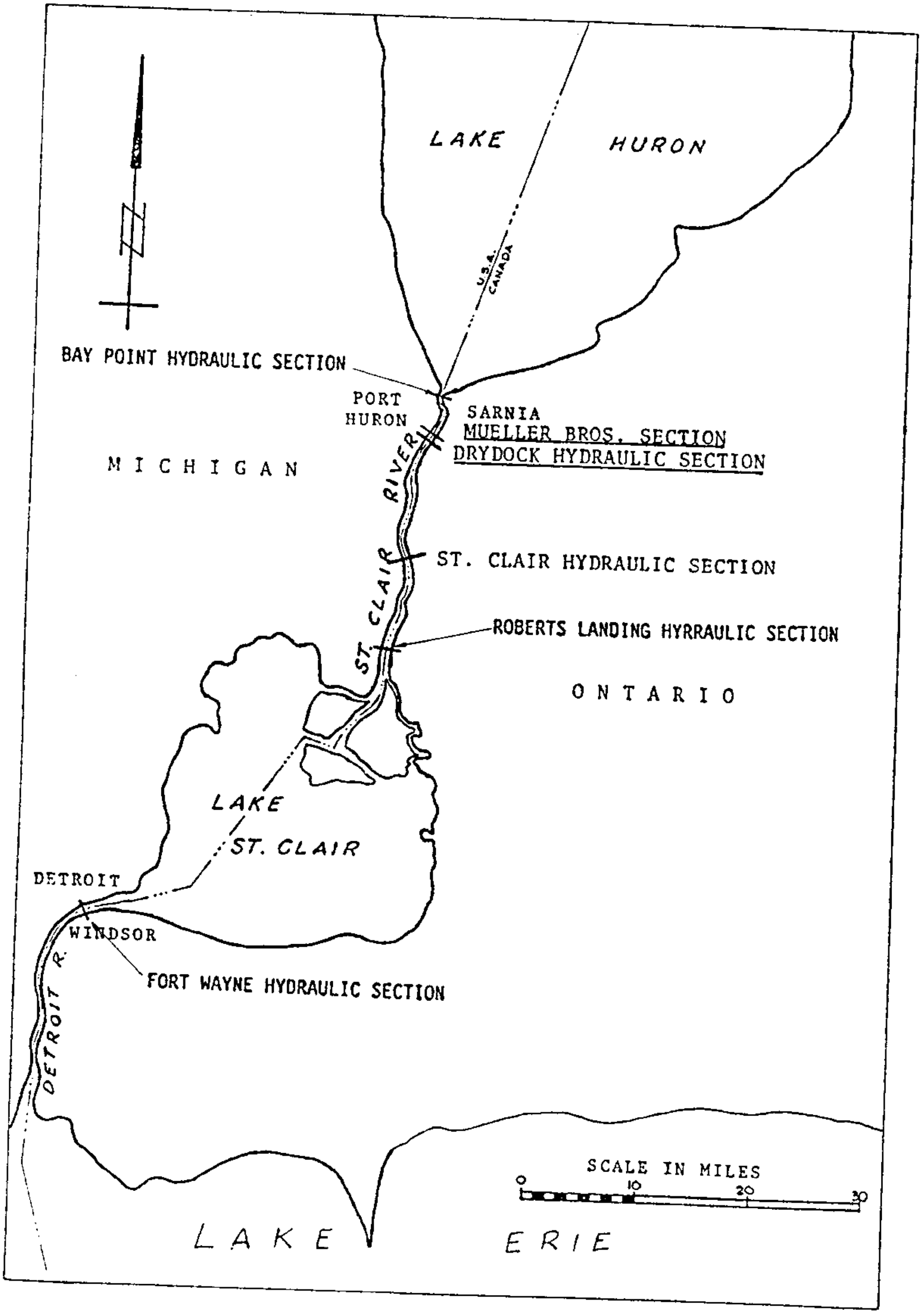


Figure 8

St. Clair and Detroit Rivers - Hydraulic Sections

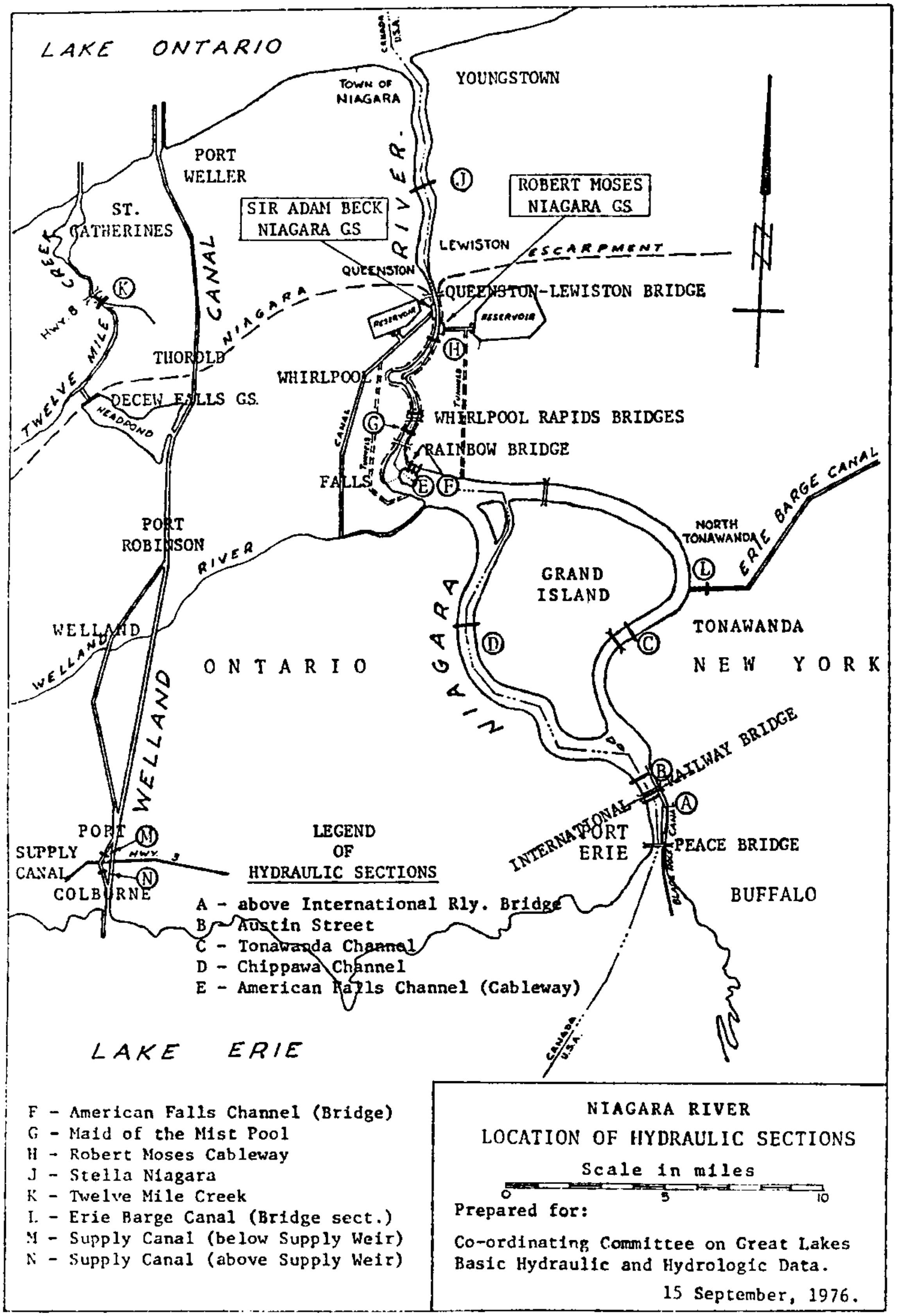


Figure 9

Niagara River - Hydraulic Sections

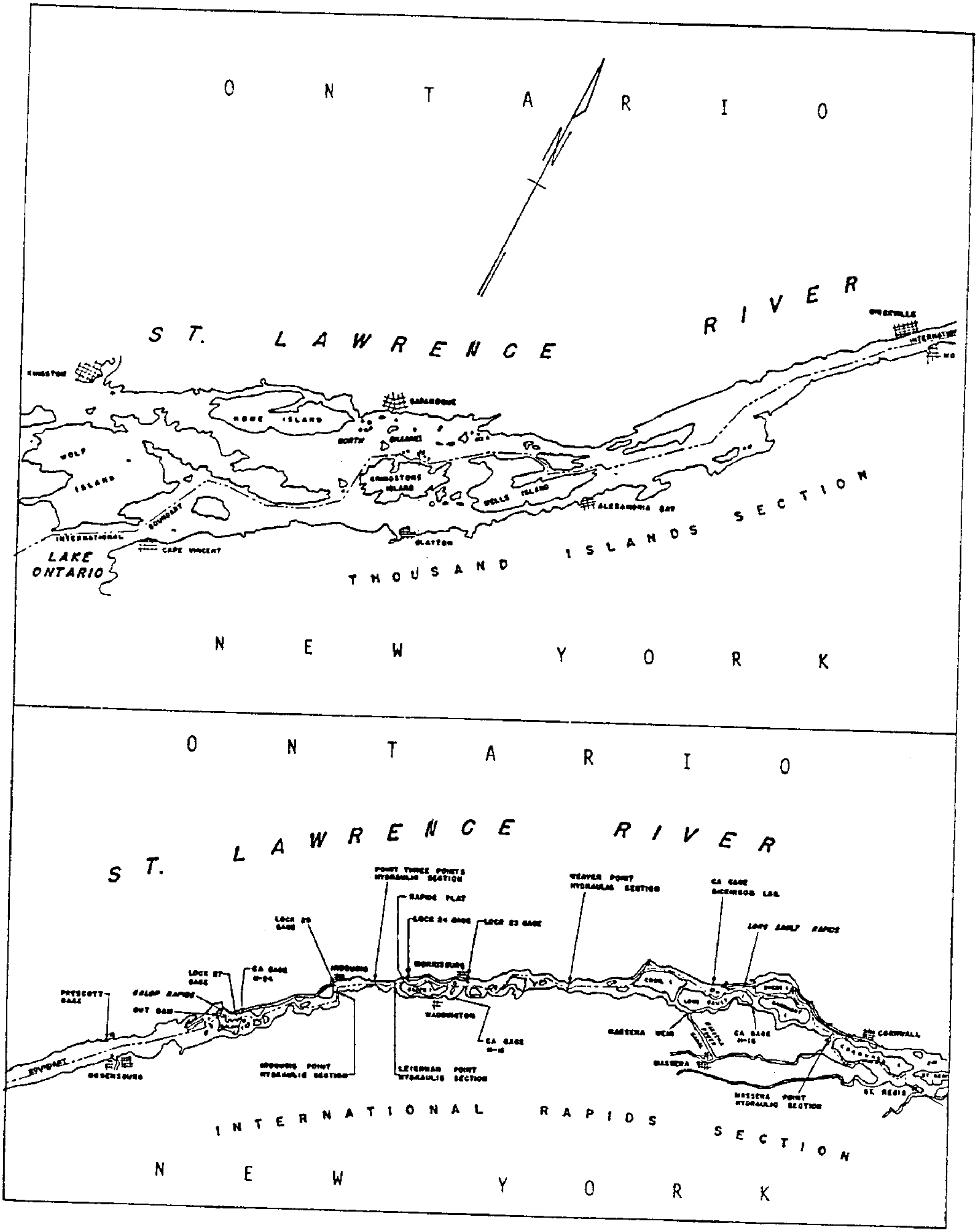


Figure 10
St. Lawrence River - Hydraulic Sections

- Frechette Point and Garden River sections on the lower St. Marys River, established in 1965 for measurements of total flow in the river and flow distribution around Sugar Island.

- St.Joseph Channel Section, also on the lower St.Marys River, established 1969 for measurement of flow in St.Joseph Channel.

- Chippewa (Bayers Creek) and Tonawanda Sections on the upper Niagara River, established in 1967 for the measurement of flow distribution around Grand Island.

- American Falls Section on the American Falls Channel of the upper Niagara River, established in 1971 for the measurement of discharge over the American Falls and calibration of the new American Falls gauge rating.

- Stella Niagara Section on the lower Niagara River, established in 1957 for the measurement of total Niagara River flow.

- Robert Moses Cableway section, also on the lower Niagara River, established in 1971 for the measurement of Maid of the Mist Pool outflows for verification of the Ashland Avenue gauge rating.

3.2 Criteria

The criteria and procedures used in the selection of the above sites are fully documented in the respective project reports and in Reference 1. Only some of the more generally applicable and perhaps obvious criteria and selection procedures are summarized in the following paragraphs.

In general the site selection process began with the acquisition and study of all available maps, hydrographic charts, aerial photographs, and notes and records from any previous surveys in the area. From these sources one or more possible sites were usually identified for further investigation in the field. Sometimes a field reconnaissance by boat or aircraft was also conducted to identify alternative sites. Each site was then evaluated in terms of suitability for the purposes of the proposed measurements, its channel and hydraulic characteristics, and operational considerations before a final selection was made.

The preferred site was usually located as close as possible to the lake outlet, gauge, or hydraulic structure under investigation in order to minimize uncertaintities due to time lags, intervening storage, local inflows, or other complicating factors. Desirable channel properties included linearity for at least 200 metres above and 100 metres below the measuring section, parallel banks, and regular cross-sectional profiles with depths in the 5 to 20 metre range. Preferred hydraulic properties included steady and uniform or gradually varied flow with current speeds between 1 and 3 metres per second.

Operational considerations take into account safety and accessibility; suitability of the site to available equipment and proposed measurement procedures, particularly with respect to anchoring, placement of buoys, and establishment of vertical and horizontal control; and compatibility with other users of the channel, including navigation, pleasure boating, fishing, and water skiing.

3.3 Reach Investigation

After a site had been selected and ground control network established the task of selecting and laying out the measuring section began. This usually involved cross-sectioning the reach under investigation at suitable intervals, typically 30metres or 100 feet, with echo soundings. Five to ten sections were usually sounded, depending on the length and regularity of the reach.

The usual procedure in these surveys was to lay out and measure a base line along one of the banks, parallel to the channel, and mark off the sections to be sounded with range poles or other suitable markers set at right angles to the base line. The sounding craft then traversed the channel along the range lines, its position on the line determined by on board sextant or electronic distance meter, or shore operated theodolite. An event line with appropriate notation was marked on the sounder chart at each positional sighting or reading of the distance meter to define the horizontal scale of the chart, which depended on both the chart speed and the boat speed. Usually ten to twenty position determinations were made across a section. Before or after each crossing, the sounder chart was annotated with the river name, section identification, date, time and water level, and any other pertinent information.

In recent technology the distance meter is interfaced with the sounder and event lines automatically marked on the chart at preselected intervals. An even more advanced computerized system developed by the Ottawa based Hydrometric Methods Section of the Water Survey of Canada prints out the depths and distances and the other documentation mentioned above, and produces a fully annotated plot of the cross section automatically on demand at the completion of each traverse.

The sounding boat was usually outfitted in a manner similar to the boats used for moving-boat discharge measurements described in Section 6. The transducer was either rod mounted over the side of the boat, or laid on the bottom of the boat and immersed in water. A bar check was first performed to verify the calibration of the sounder. This involved lowering an iron or aluminum bar below the transducer by means of graduated lines. The bar was usually a 5 or 6 centimetre (2 or 3 inch) angle section about 3 metres or 10 feet long. As it was lowered successively to selected depths below the water surface, the chart readings were compared with the measured depths and the sounder adjusted if necessary.

After completion of the survey the chart was removed from the sounder and inspected. Documentation was checked for accuracy and completeness and any additions or corrections made. Bed topography was then plotted and the best cross-section identified for the measuring section. The next step was usually a direction of flow survey as described in the next section, to determine the optimum bearing or alignment of the measuring section.

3.4 Direction of Flow Surveys

Direction of flow surveys consisted of tracking the paths of floats or drogues over the length of the reach of interest in several lines across the channel. The floats or drogues most frequently used in these surveys were double floats or velocity rods similar to those shown in Figure 11. The floats were selected or adjusted to travel at speeds representive of the mean current speed in the vertical planes of their paths. This was done in the case of double floats by adjusting the length of the line joining the surface and subsurface floats so that the latter travelled at a depth of about two thirds of the average depth along the path that the float was expected to follow. When velocity rods were used, they were made as long as possible without risk of touching bottom. This was done by the use of multi-section or telescopic rods, or two or more fixed rods of different lengths.

The path of the float as it drifted with the current was tracked by at least two, and preferably three theodolites or transits stationed at strategic points on the banks. The use of a third instrument not only increased confidence in the accuracy of the sightings, but also provided insurance against lost points if one of the instruments missed a sighting. Theodolite stations were located to provide optimum angles of intersection (25 to 155 degrees) of the lines of sight of the instruments at the float. When only two transits were used, they were often stationed at the ends of the base line, although the ideal deployment was to locate one instrument to sight along the path of the float and the other to intersect the path in the angle range quoted above. Sightings were taken at equal intervals, usually one minute, and were usually coordinated by the party chief from the boat being used to drop and pick up the floats. Hand signals, and more recently, radios, were used to communicate between boat and shore. Most surveys comprised ten to twenty-five lines of five to ten sightings each, the number and spacing of the lines depending on the flow variation across the section and other factors such as available time and resources.

Before automated plotting became common in the early or mid 1970's, direction of flow surveys were usually plotted at the site, either in a hotel room or office trailer parked at the site. This had the advantage of expediting the job and identifying any errors or omissions while they could be easily corrected. Today however, the usual practice is to return the data to the office for computer processing and plotting. Figures 12 and 13 are examples of manual and automated flowline plots.

Besides above purpose, direction of flow surveys were also performed in connection with flow distribution studies for navigational purposes, particularly in multichannel reaches of the connecting channels. The most recent such surveys were conducted by the Corps of Engineers in 1986 and 1987 on a number of channels in the St.Lawrence River between Ogdensburg, New York, and the approaches to the Wiley-Dondero Canal near Massena, N.Y. for the St Lawrence Seaway Development Corp. These surveys differed from the usual site investigation surveys in the lengths of the lines, which were usually much longer - up to sixty sightings per line.

While it may not have much connection with discharge measurements, it might be noted here that direction of flow surveys can also be conducted by aerial photography. Examples on the connecting channels include aerial drogue surveys of surface velocities over the entire lengths of the Detroit and St. Clair Rivers in 1974 and 1983 by the Corps of Engineers. The flowlines are plotted on large scale maps of the rivers in the reports

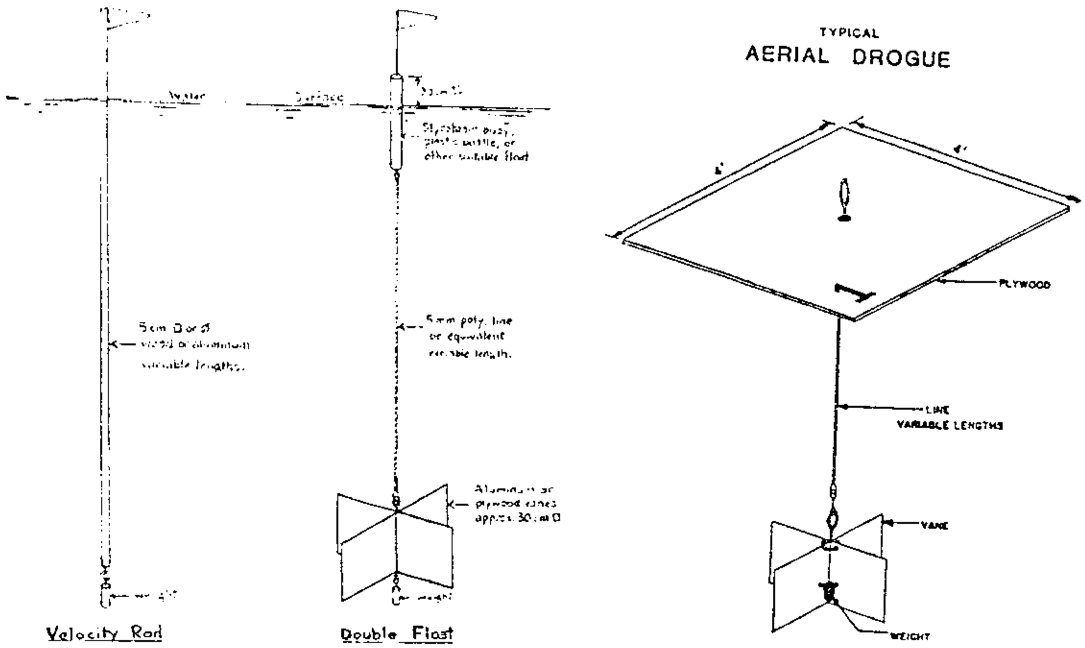


Figure 11
3 Types of Drogues

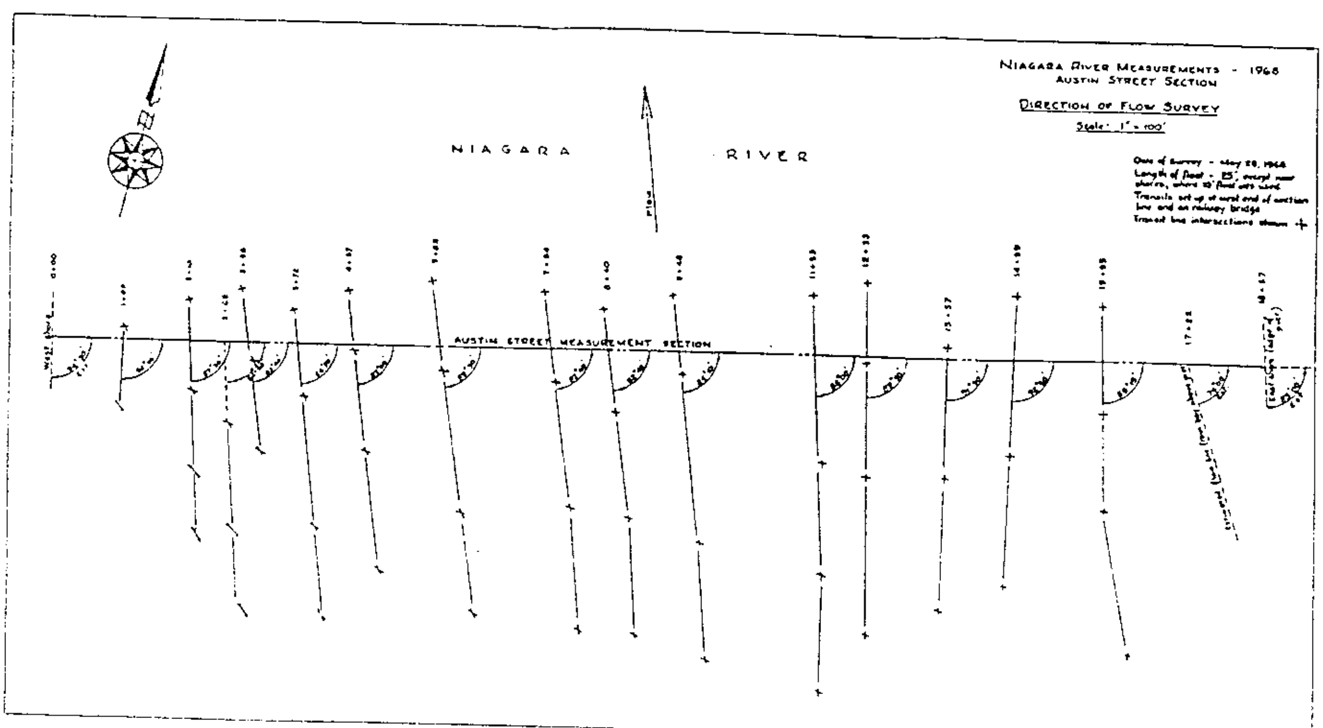
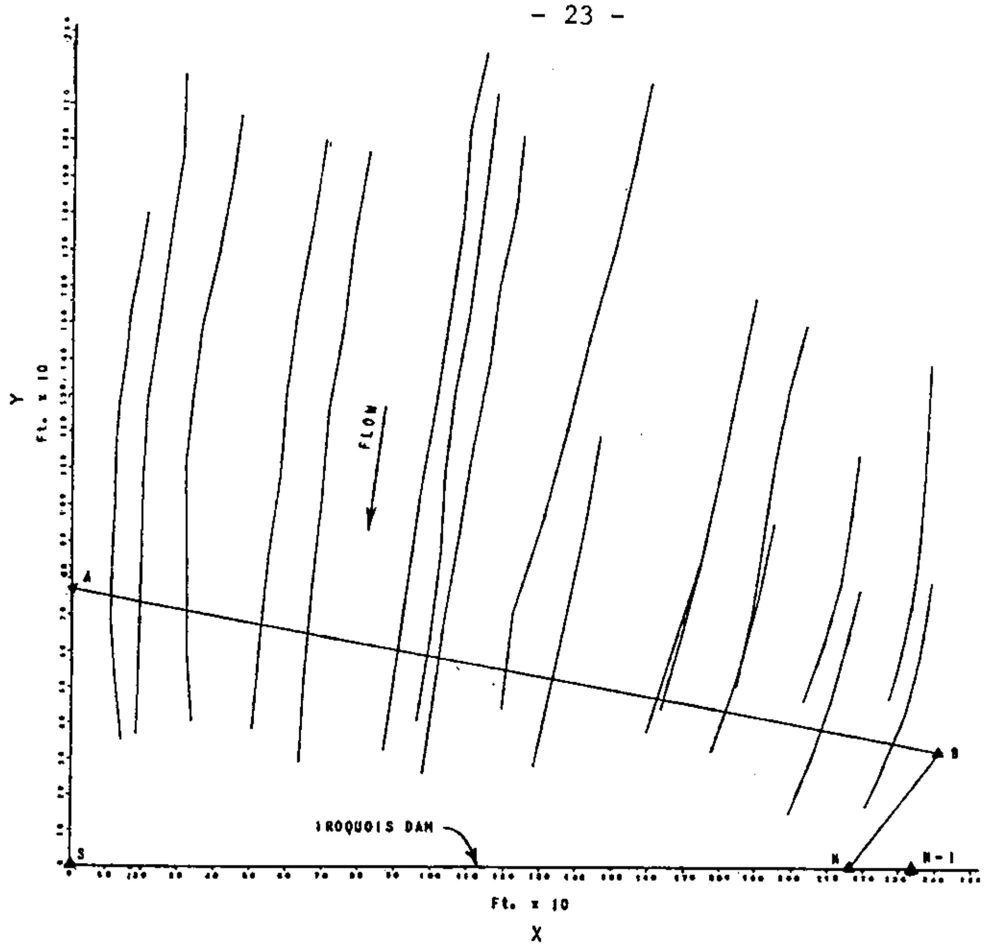


Figure 12
Manual Flowline Plot



ST. LAWRENCE RIVER DROGUE
IROQUOIS DAM SECT. 28 JUN 72

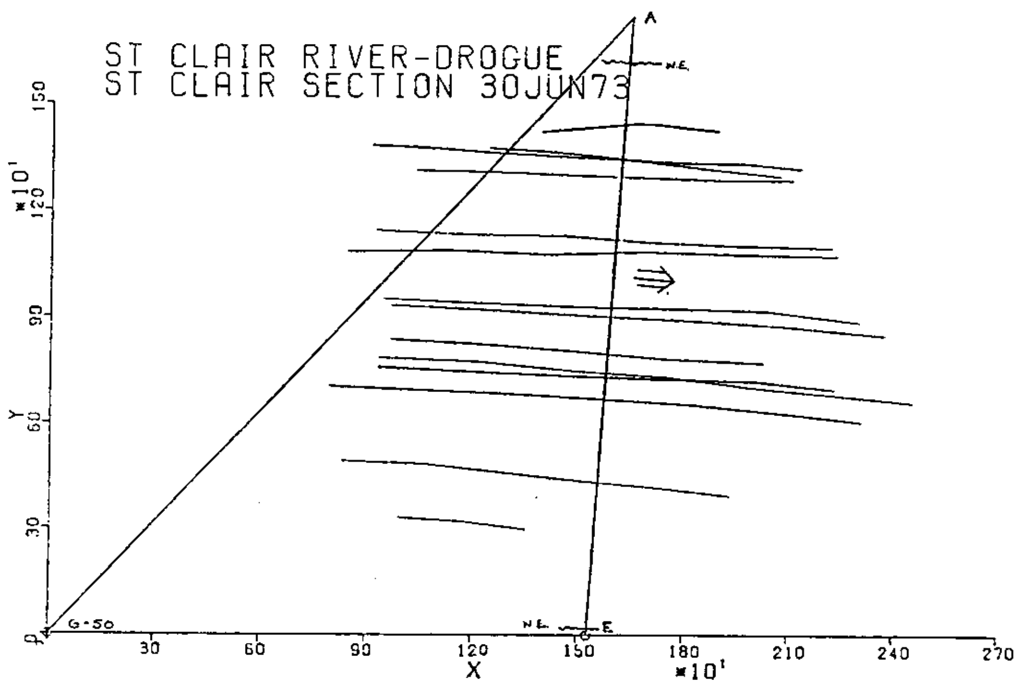


Figure 13
Automated Flowline Plots

(References 44 and 45), which also include descriptions of flow conditions in the rivers and the methods and equipment used in the surveys.

4. CONTROL SURVEYS

This section describes the procedures which were used to establish vertical and horizontal control points at new sites and recover and verify previously established control points at reoccupied sites.

4.1 Vertical Control

Vertical control points include bench marks, reference points, and water level gauges for measuring and referencing elevations and water levels to a standard datum. Since January 1, 1960, International Great Lakes Datum 1955 (IGLD 1955), which was developed by the Committee, has been the standard datum on the Great Lakes - St. Lawrence River system. Prior to that date, U.S. Lake Survey Datum 1903 and 1935 were standard, with one or two sites on Geodetic Survey of Canada (GSC) datum. Georgian Bay Ship Canal Datum and Public Works Canada Datum were two other early Canadian datums used locally.

Vertical control for hydraulic sections established before 1950 by the U.S. Lake Survey was established by second order differential levelling, the same order in effect today. This order of levelling is characterized by a maximum allowable error of closure of 8mm multiplied by the square root of the length of the run in kilometres (.035 foot x the square root of the length of the run in miles), and can be achieved with standard surveying instruments. Elevations using this method were transferred to the sites from U.S. Lake Survey water level gages. These gages provided a primary reference network for water levels throughout the Great Lakes and the connecting channels.

The earliest levels network or gauge network was established using water levels based on mean tide at New York. The network was derived from lines of precise levels run from tide water at New York to Lake Ontario and between Lakes Ontario and Erie, Erie and Huron, and Huron and Superior. Transfer of levels was accomplished on the lakes by comparison of gauge readings over periods of a month or more, assuming that the average surface of each lake was level. It was found that elevations could be transferred long distances by water level transfer with much greater accuracy than could be achieved by instrumental levels on land. The first accurate determination of the elevations of the Great Lakes was made in 1885. A second determination was made from 1898 to 1901 using improved instruments.

In 1903 the U.S. Coast and Geodetic Survey made an adjustment without the use of the orthometric correction based on level lines and tide gage records in the United States east of the Mississippi. This adjustment was available at a number of places on the Great Lakes and provided the basis for U.S. Lake Survey 1903 Datum. This datum was extended to all major harbours around the lakes, along the connecting channels, and down the St. Lawrence River to Cornwall, Ontario, by the U.S. Lake Survey and the Canadian Hydrographic Service through water level transfers and instrumental levelling, the Canadian Hydrographic Service making use of instrumental differences supplied by the Geodetic Survey of Canada.

About 1920, water level gauges on the same lake which originally had been set to the same elevation began to show disagreement. Investigations which were undertaken indicated that there was movement of the earth's crust, which changed the relative elevations at gauge points. By 1935 the discrepancies among gauges became of sufficient magnitude to affect the established planes. The U.S. Lake Survey at that time readjusted all gauges to one master gauge on each lake. This adjustment required the establishment of bench marks in every improved harbour that are referenced to the elevation of the master gauge on the lake on which the harbour is situate. This datum was called U.S. Lake Survey 1935 Datum, and was used for vertical control until December 31, 1959. On January 1, 1960 it was replaced by International Great Lakes Datum 1955, which is referenced to mean sea level at Point au Pere, Quebec. This datum is now being updated to 1985 by the Coordinating Committee.

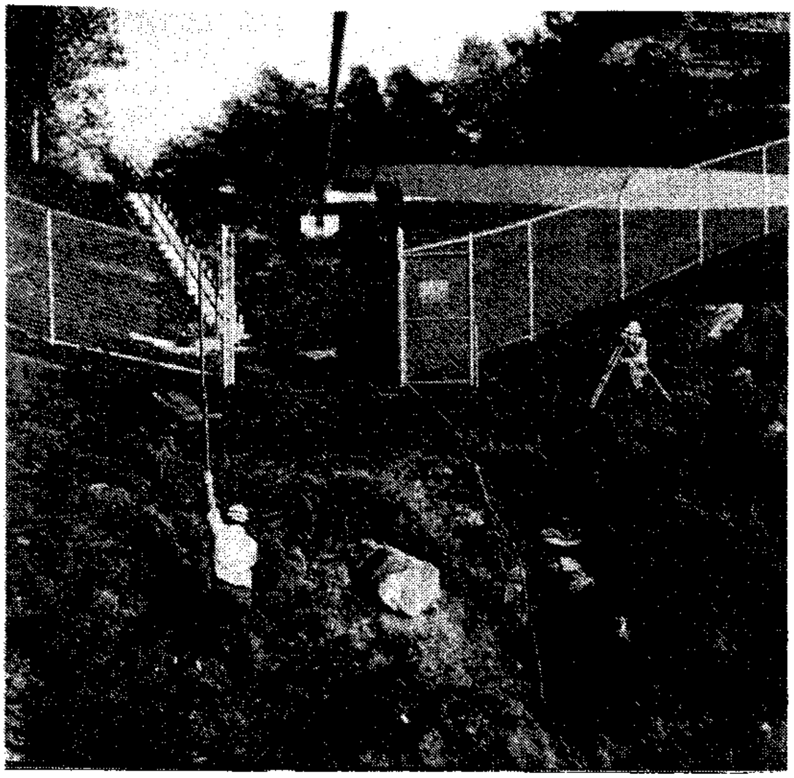
Since the establishment of IGLD 1955, all elevations for new hydraulic measurement sites were transferred to the site from the nearest U.S. Lake Survey or Geodetic Survey of Canada (GSC) primary bench mark by second order differential levelling. Figure 14 shows such levelling in progress at Robert Moses Cableway in 1981. Secondary bench marks were established at all measurement sites. Appendix A is an example of typical bench mark documentation from the report of the 1957-58 Stella Niagara measurements.

After establishing bench marks and secondary reference points at the site, a gauge for measuring the waterlevel at the section was set up and tied into the vertical control network, unless a permanent gauge was in close enough proximity to the section to serve as section gauge. Some examples of permanent section gauges include the American Falls Channel gauge, the Drydock gauge on the St. Clair River, the Upper Soo gauge on the upper St. Marys River at Sault Ste. Marie, Ontario, and until the opening of the Seaway in 1957, the Lock 25 gauge on the St. Lawrence River at Iroquois, Ontario.

A float actuated analog or digital recorder mounted in a wooden well (Figure 15) with a staff or electric tape gauge for reference and back-up was a commonly used section gauge installation. A type of digital recorder frequently used by the U.S. Lake Survey was the Fisher-Porter Punchtape Datalogger. Another widely used instrument was the Leupold and Stevens Type A analog or strip chart recorder.

Besides their use as reference or backup gauges, staff or board gauges were sometimes used as primary section gauges at sites where flows and water levels were expected to remain relatively steady for the duration of a measurement, and a gauge reader was available. An example was at the Robert Moses Cableway on the Niagara River where the gauge was read by a standby member of the metering party. A reading was taken at each panel during a measurement and transmitted by radio to the notekeeper in the cable car who recorded the reading on the measurement notes. The gauge (Figure 16) was checked by levels at the start and end of each series of measurements, after which it was dismantled and stored at the site. The wire-weight gauge shown in Figure 17 is another type of manual gauge.

Pressure actuated gauges such as the Ottboro and Bristol diaphragm types were sometimes used at sections where construction of a well was



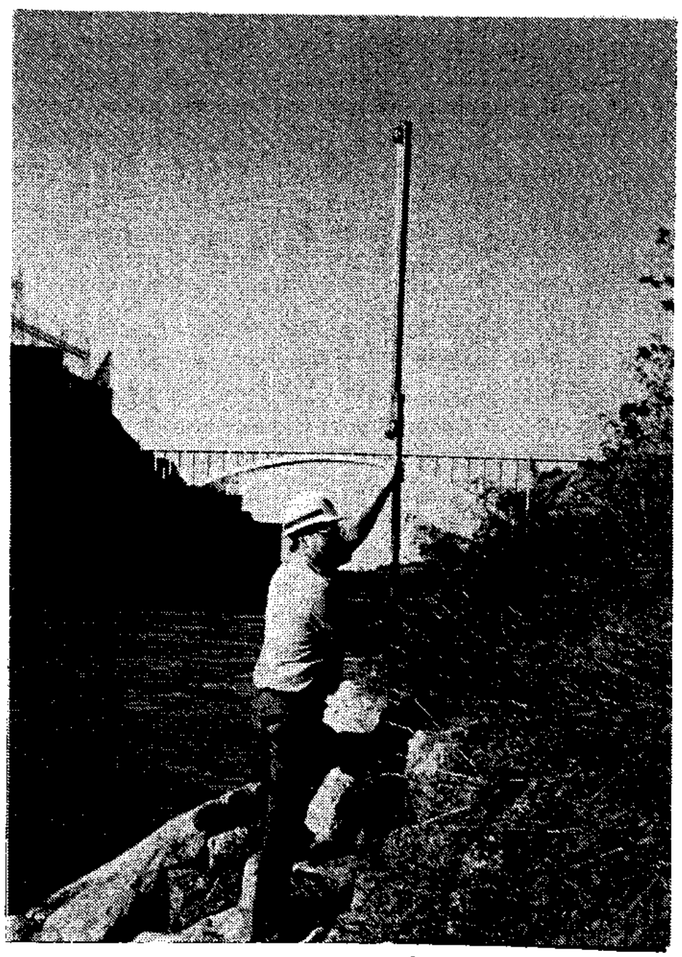
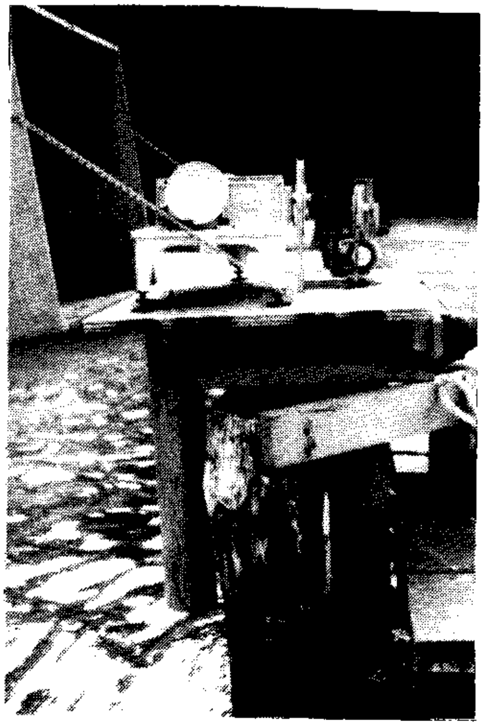
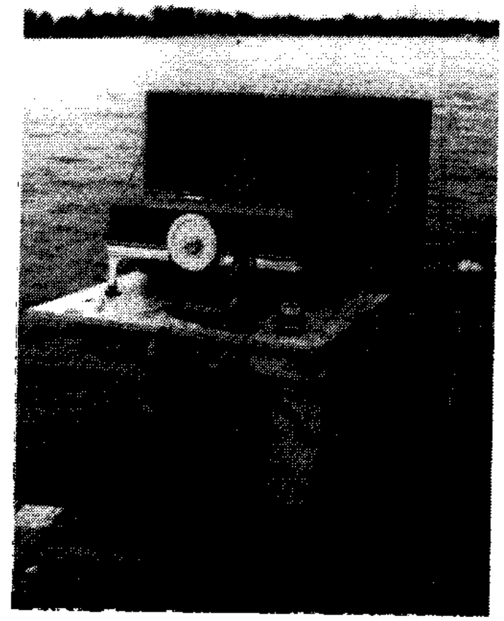


Figure 14
Second order levelling at Robert Moses Cableway
October 1981

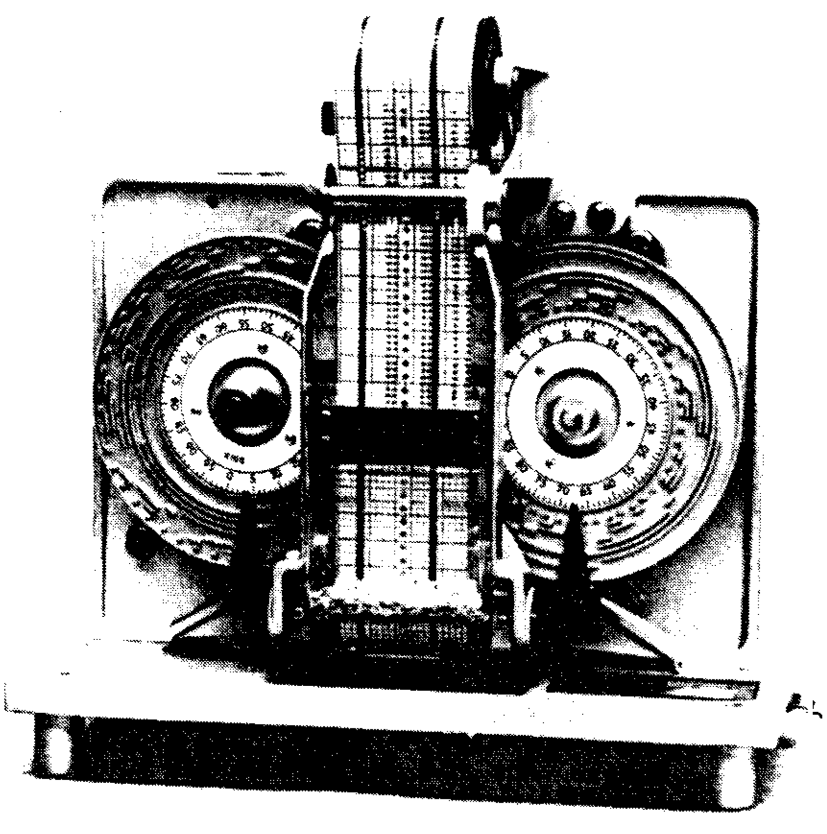


End View



Front View

Stevens A-71 Analog Recorder in Wooden Well



Fisher-Porter Punch Tape Datalogger

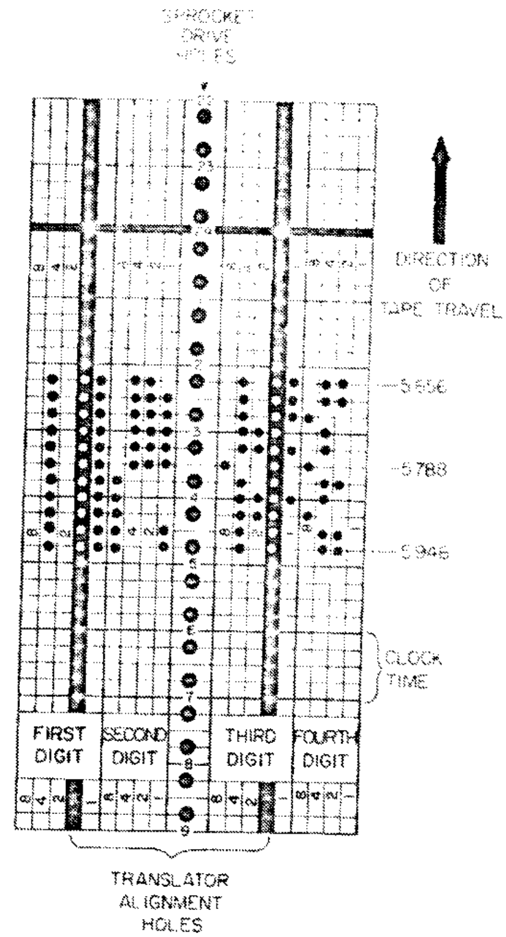


Figure 15
Examples of Digital and Analog Recorders

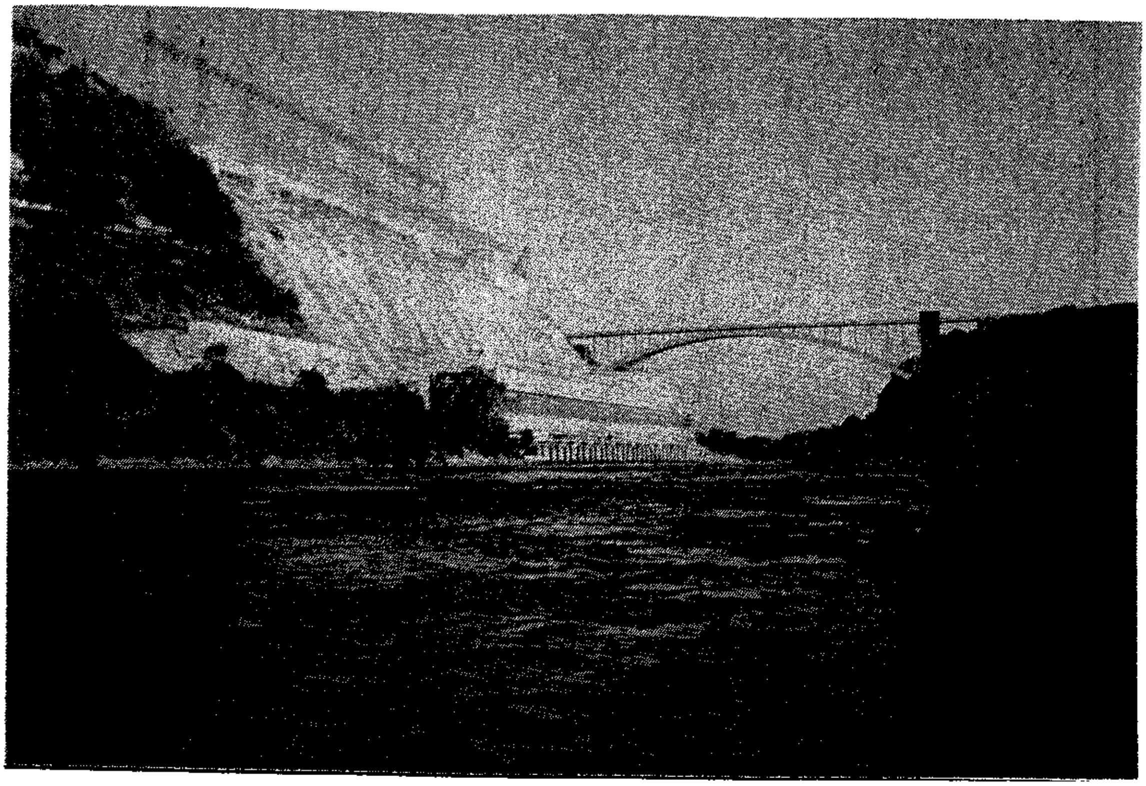


Figure 16
Staff Gauge - Niagara River at Robert Moses Cableway - 1981

Figure 17
Wire-Weight Gauge
Niagara River at Maid of the Mist Dock - 1981

not practical. An example was the Austin Street section on the Niagara River in 1968.

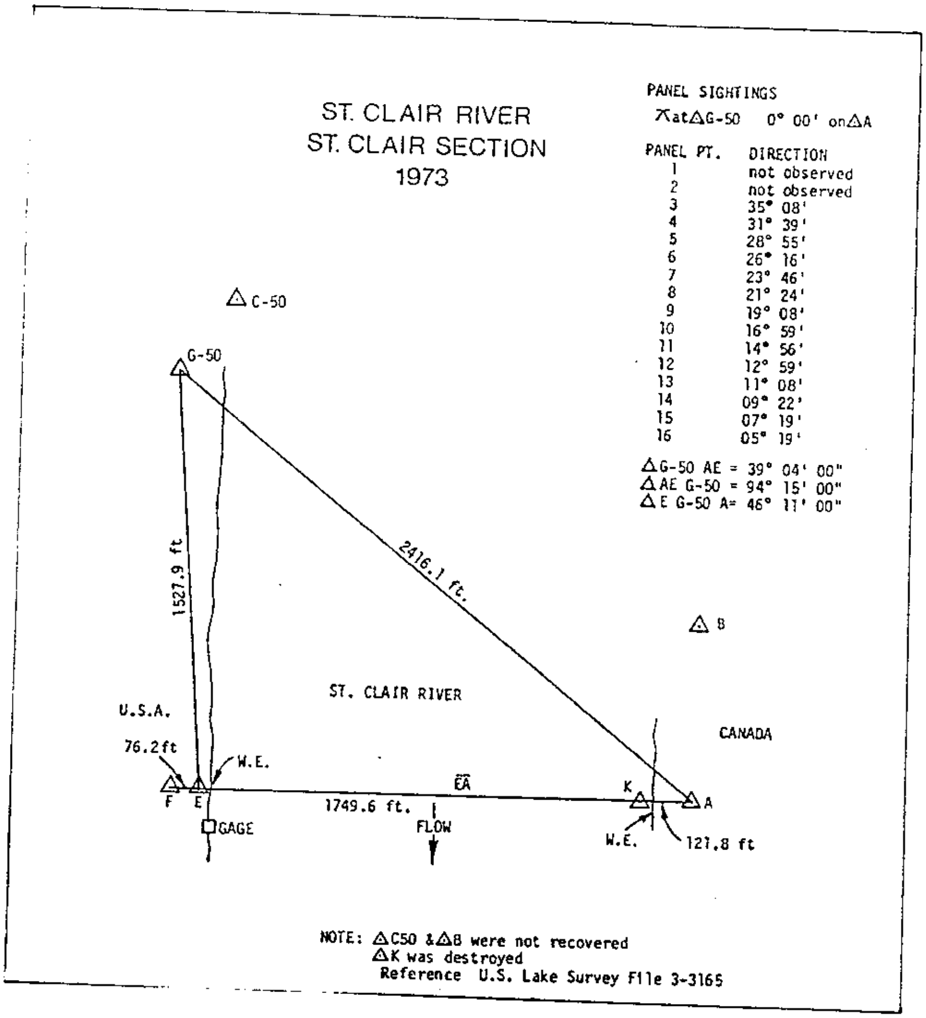
Another type of pressure actuated gauge installed at two locations on the connecting channels is the nitrogen bubbler gauge. This type of gauge measures the height of the water column above an orifice mounted at a known elevation below the lowest expected water level by maintaining a flow of nitrogen through a tube leading from the sensing device to the orifice. The sensor in one of the installations - on the Niagara River at the Fort Erie Customs Dock from 1969 to 1975 - was a balance beam type known as an 'Exactel'. The other - on the St. Marys River at the Garden River section from 1974 to date - is a mercury manometer. Both sensors actuate analog recorders through servo mechanisms.

4.2 Horizontal Control

Horizontal control is the term applied to the system set up to define the horizontal position of all points occupied during the measurements and preliminary surveys. It usually consisted of one or more base lines and a network of control points on the banks. The control points were usually monumented and referenced to facilitate future recovery. Until the early 1970s, triangulation was the ccustomary method of horizontal control for boat measurements on the main channels. On narrower channels, including diversions, tag lines were generally used, and at bridge and cableway sections the measuring points were marked on the railing or cable and referenced to control points at either or both ends of the section.

In the mid 1970s triangulation methods were replaced by electronic distance meters for positioning measuring craft during measurements, but the former control points were usually maintained as backup in case of malfunction of the distance meter. Typical triangulation networks are shown in Figure 18 and Appendix B is an example of the documentation of horizontal control points from the 1960 Massena Point measurements. The networks were laid out by conventional survey methods. All angles were read by transit or theodolite and the errors of closure distributed among the angles according to accepted geodetic practice, and base lines were generally measured with steel tapes and the measured distances corrected for slope and temperature where applicable.

After completion of the preliminary surveys described in the previous section and the selection and establishment of a measuring section, the section was monumented and tied into the triangulation network. Distances ances between reference points and the channel width were then computed, and targets or range poles were set up to mark the section; one marker being placed near the waters edge and the other as far back as possible to maximize sensitivity. At sites where channel widths exceeded five or six hundred metres (1600 to 2000 feet), section line markers were often set up on both banks. When a sextant was to be used to position the survey boat or catamaran at the measuring points on the section, a marker was also placed at the opposite end of the base line. Where the boat was to be positioned by means of a separate range line for each panel (sometimes called the pivot method) the network of range markers could not be set up until after the locations of the measuring points on the section had been determined by the further preliminary surveys described in the next section.



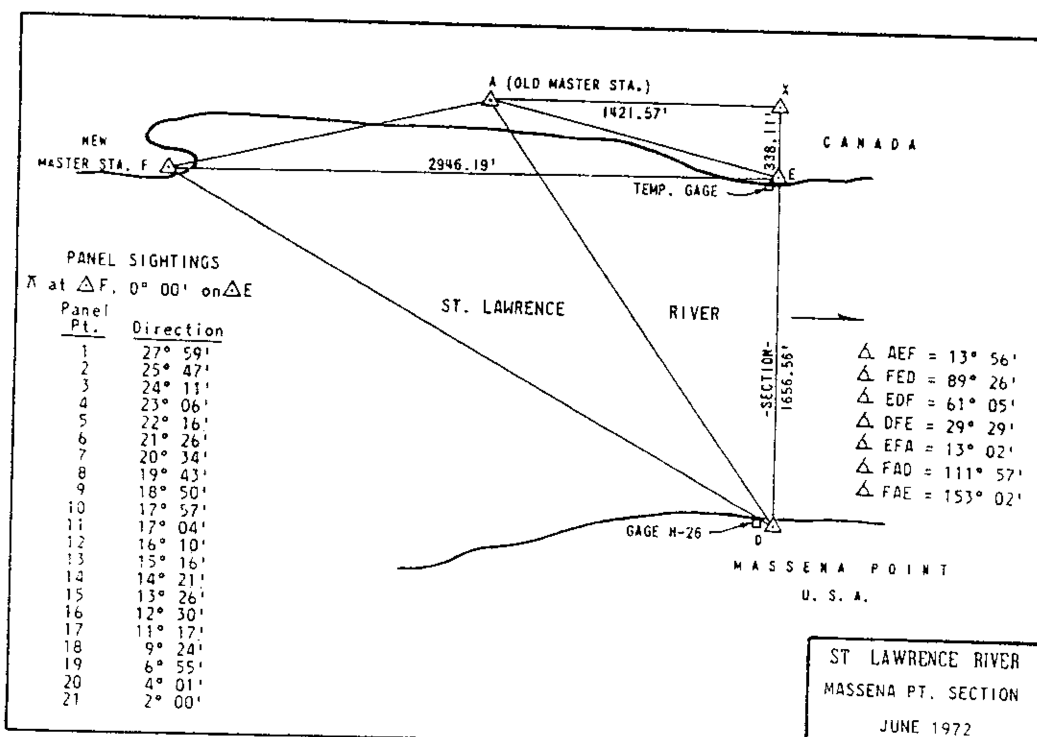


Figure 18
Examples of Horizontal Control Networks

5. CONVENTIONAL MEASUREMENTS

5.1 Section Preparation and Calibration

Section calibration was the term applied by the U.S. Lake Survey to the development of standard soundings and the evaluation of coefficients at a new measuring section prior to the start of the discharge measurements. These soundings and coefficients were then considered section parameters or constants for the duration of the current series of measurements, and subject to verification, for future series of measurements at the section. This procedure was designed to improve the efficiency, consistency, and accuracy of the measurements.

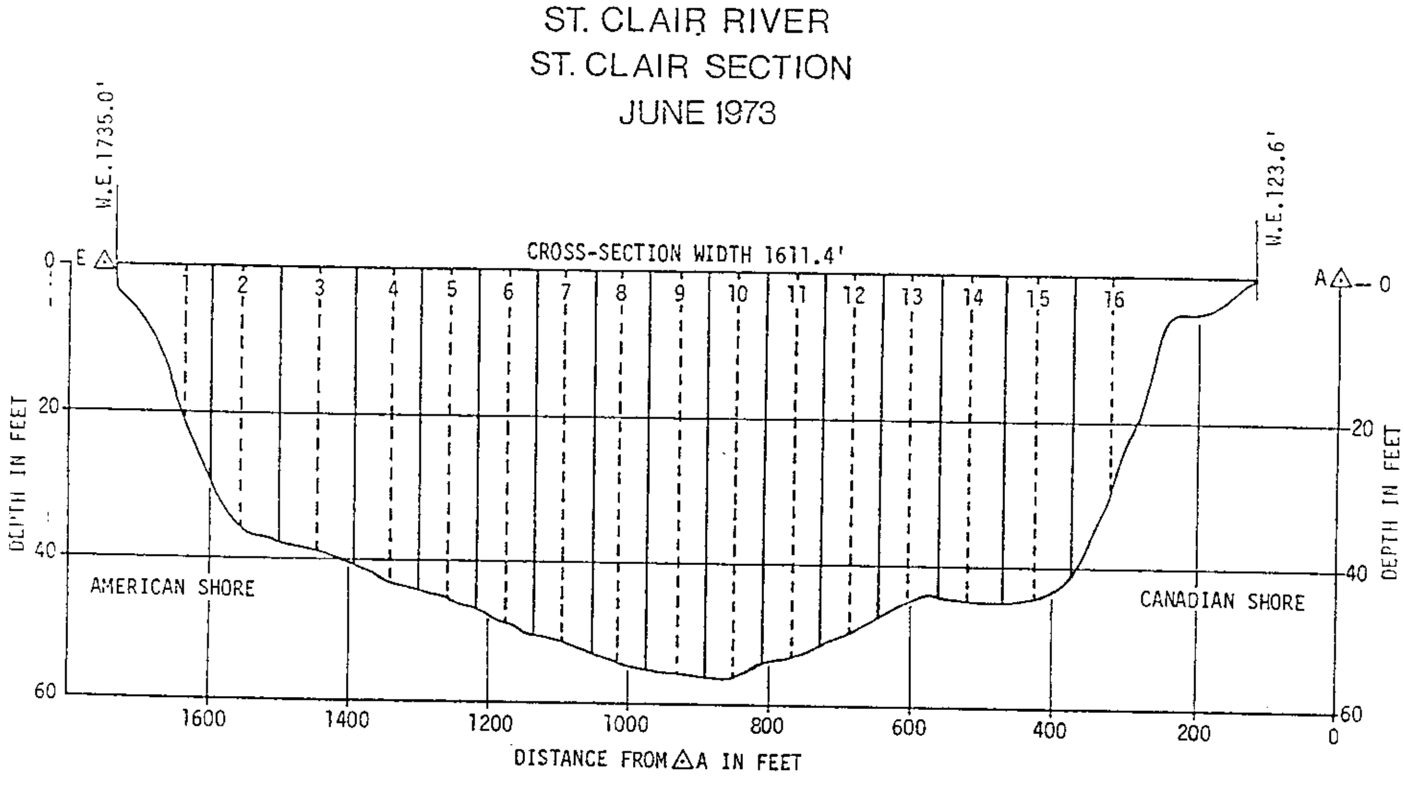
The coefficients usually standardized were those for direction of flow and vertical and transverse velocity. One set of coefficients applied to each panel. The standard soundings were usually converted to panel areas referred to a selected water level at the section gauge, or to mean bed elevations for each panel. The procedures used in the development or verification of the standard soundings and coefficients are described in the following paragraphs.

(1) Standard Soundings

After establishment of control points and installation of a section gauge, accurate definition of the bed profile of the measuring section by sounding was usually the next step in discharge measurement programs. Before echo sounders came into general use in the mid 1950s, lead line soundings were the usual method of sounding. Depths were usually sounded at intervals of 3 to 6 metres (10 to 20 feet, depending on the width of the section) along the section using the standard Columbus style lead sounding weights described later. The weights used ranged in size from 45 to 135 kilograms (100 to 300 pounds) depending on the current speed and depth. Sounding line deflection angles were measured by means of a protractor mounted on the winch boom, and line angle corrections (Tables 5 to 8, Reference 19) were applied where applicable. Transverse bed profiles at several typical measuring sections on the connecting channels are shown in Figure 19.

Echo sounders are now the standard sounding instrument, although lead lines are still used for verification and determination of current meter settings. The procedures for sounding the measuring section were the same as described in Section 3.3, except that the section was usually traversed at least twice, and often three or four times, depending on the roughness of the bed, to achieve the required accuracy.

The water level at the section gauge was usually read at the beginning and completion of each traverse of the section and entered on the notes or charts. Figure 20 shows a picture of a portable echo sounder of the type usually used for soundings in connection with discharge measurements on the connecting channels, and a piece of annotated chart. On completion of the soundings, a reference water level was selected and all soundings were adjusted to this water level and then plotted. Sometimes they were converted to elevations before plotting and in either case a standard bed profile was then drawn through the plotted points. The channel bed was



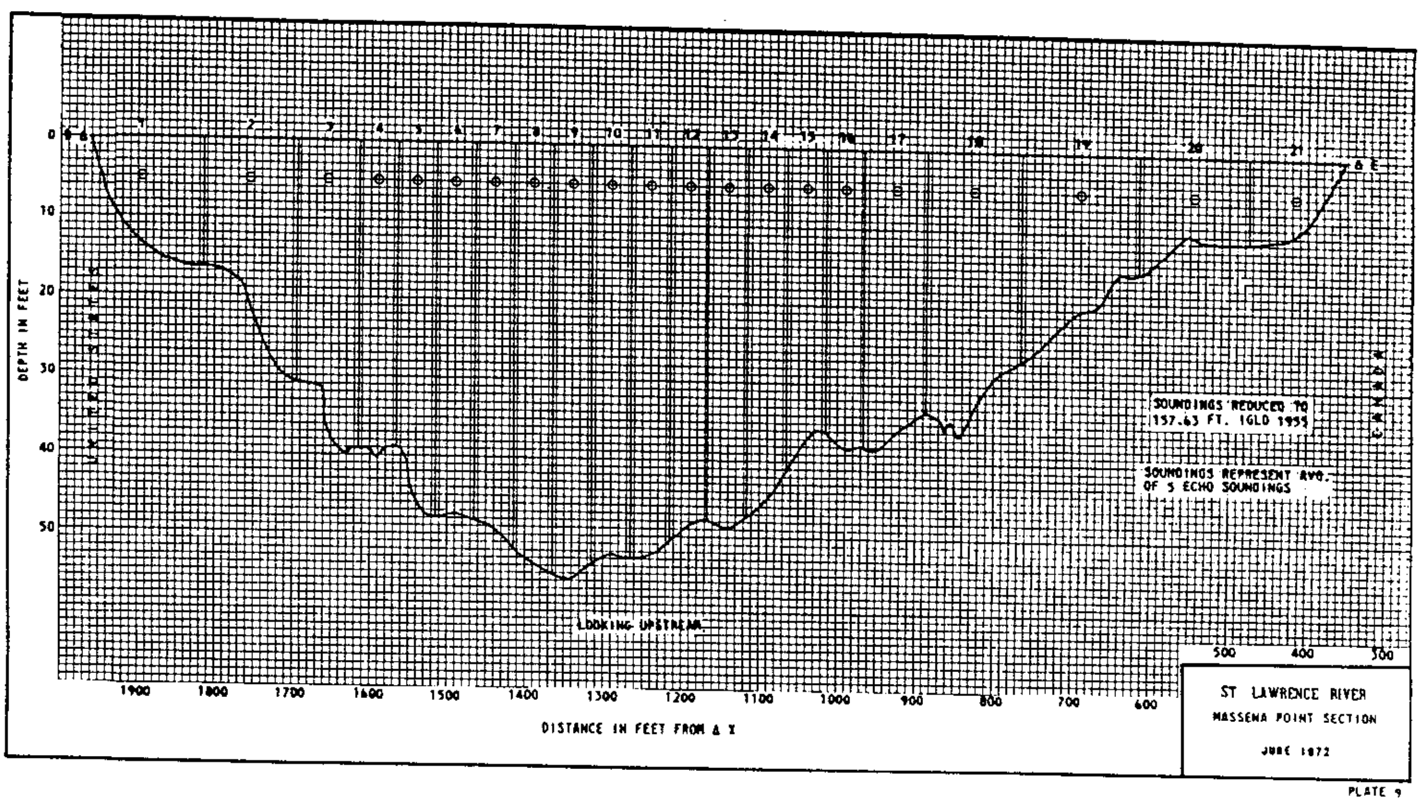


Figure 19
Typical Measuring Sections

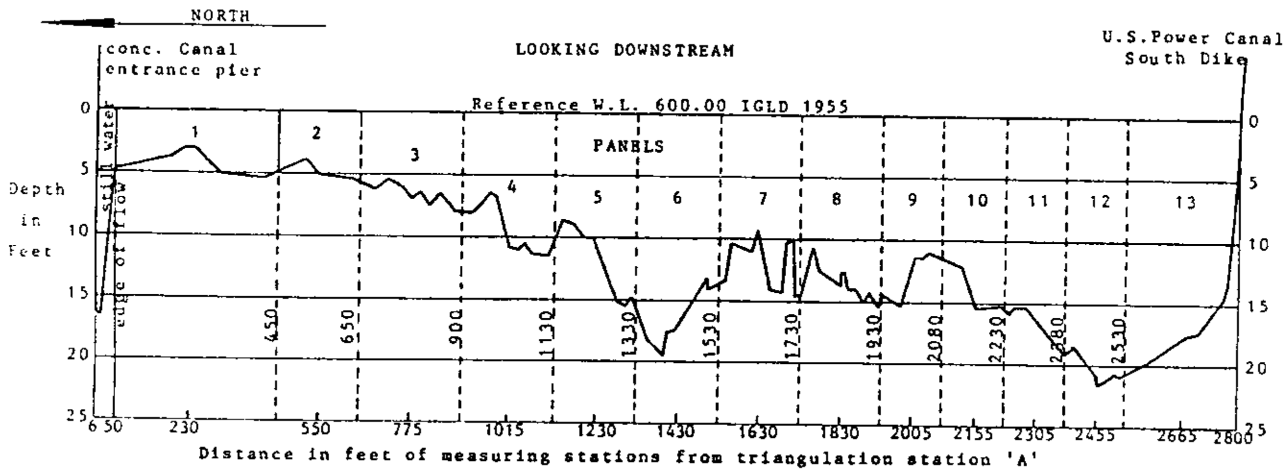
ST. MARYS RIVER AT SAULT STE. MARIE

UPPER GATE SECTION (1969 SECTION)

SCALE IN FEET

HORIZ. 0 300 600 900 1200

VERT. 0 10 20 30 40



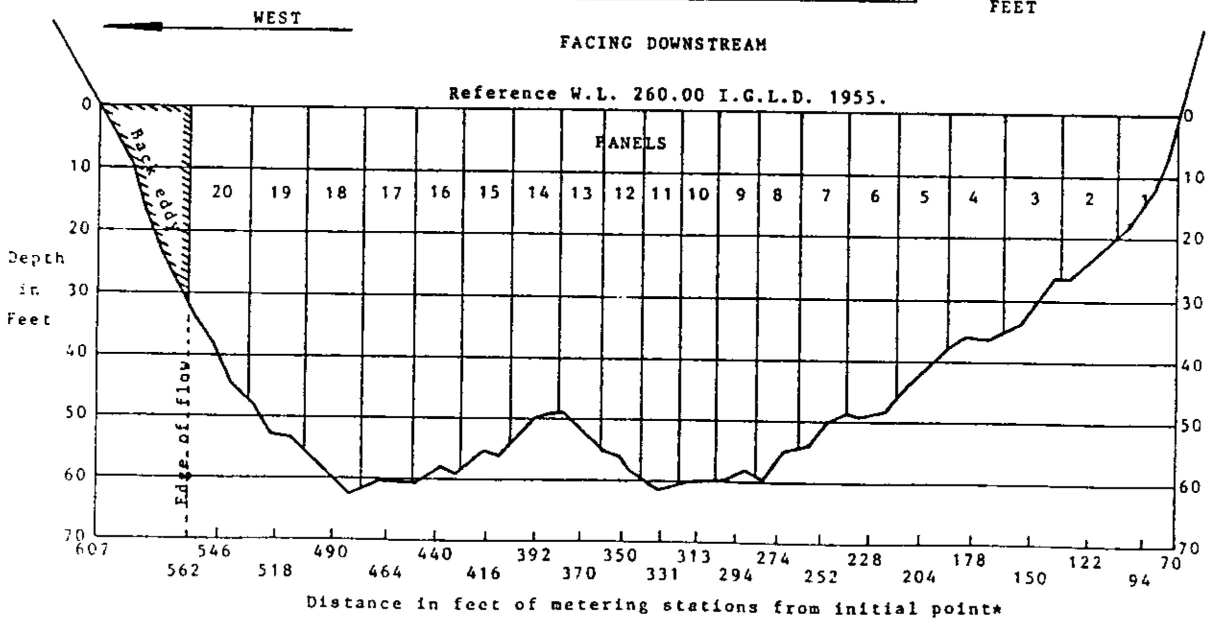
Date of original plot 26 June, 1969.
Section sounded 5 June, 1969, with
100# Columbus sounding weight. 217
depths taken.

Reproduced for Co-ordinating Committee
on Great Lakes Basic Hydraulic and
Hydrologic Data,
31 August, 1976.

NIAGARA RIVER AT ROBERT MOSES CABLEWAY
MAID OF THE MIST POOL OUTFLOW

HORIZ. 0 60 120 180 240 SCALE

VERT. 0 20 40 60 80 IN FEET



Section sounded by echo sounder 5 Oct., 1973.
* Initial point is west face of saddle base on cable anchor on U.S. side.

Original plot dated 22 Oct., 1973.
Reproduced for Co-ordinating Committee on Great Lakes Basic Hydraulic & Hydrologic Data, 24 August, 1976.

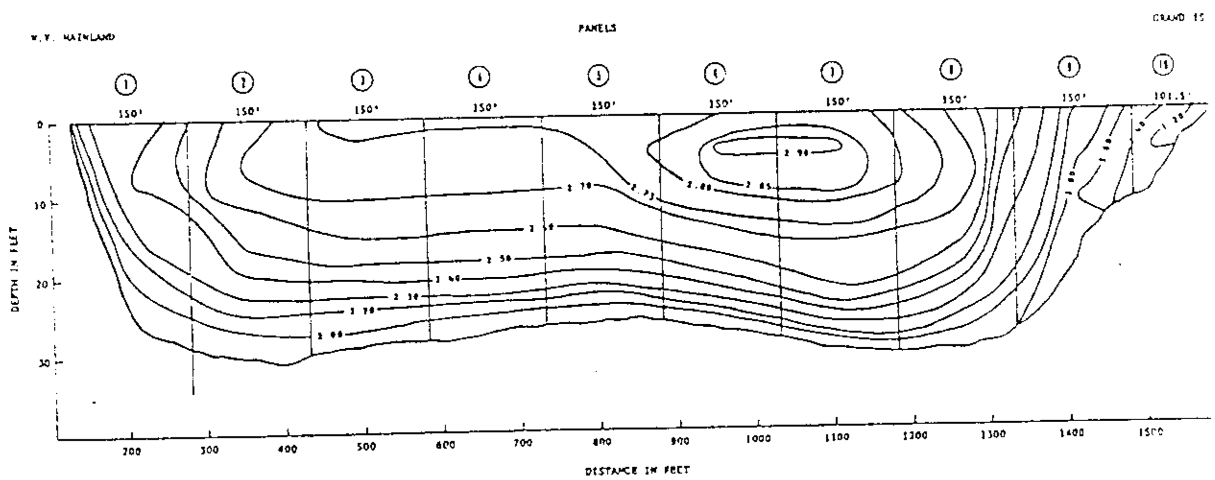
Fig. 19 (Cont'd.) - Typical Measuring Sections

HYDRAULIC STUDY OF THE UPPER NIAGARA RIVER
TONAWANDA HYDRAULIC SECTION
FALL 1967 DISCHARGE MEASUREMENTS
VELOCITY CONTOURS (FPS)

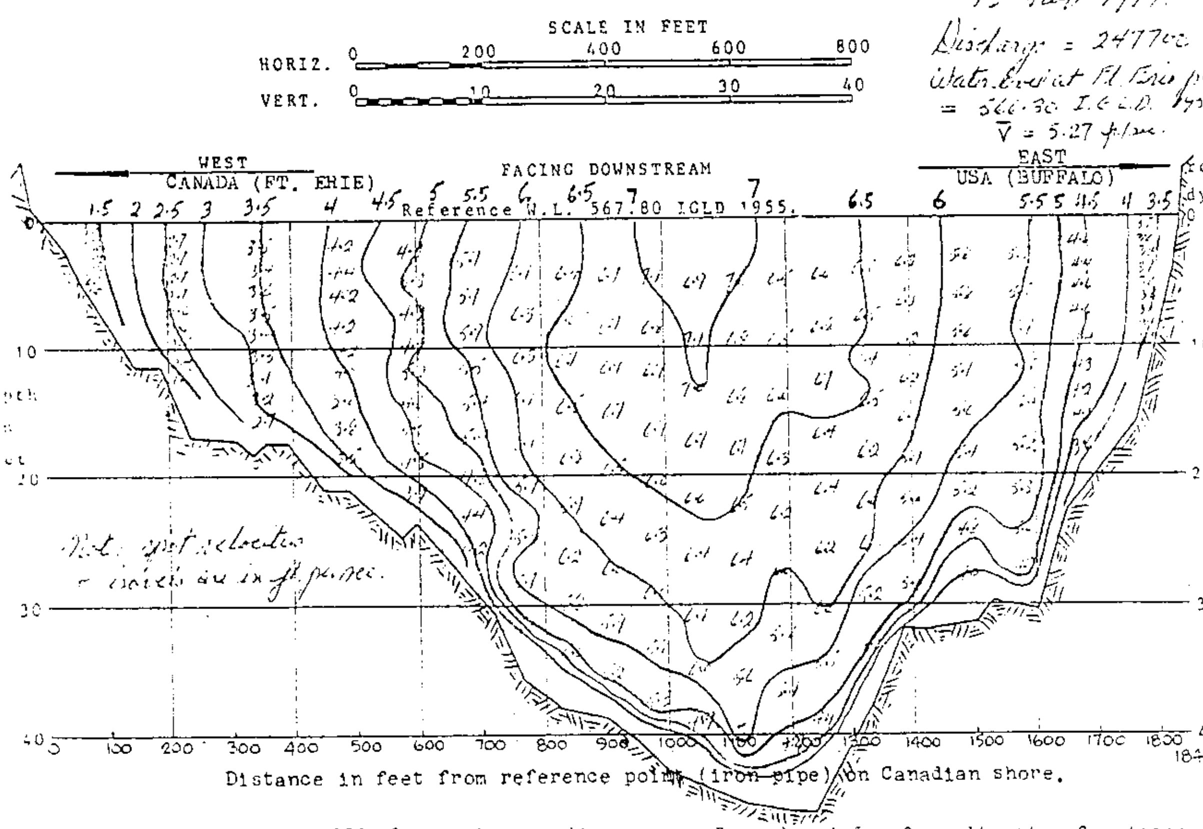
FIGURE 2

CROSS SECTION

Plotted from lead line soundings taken 1 Sep 1967
Adjusted to IGLD (1955) 563.77 feet



NIAGARA RIVER ABOVE INTERNATIONAL RAILWAY BRIDGE

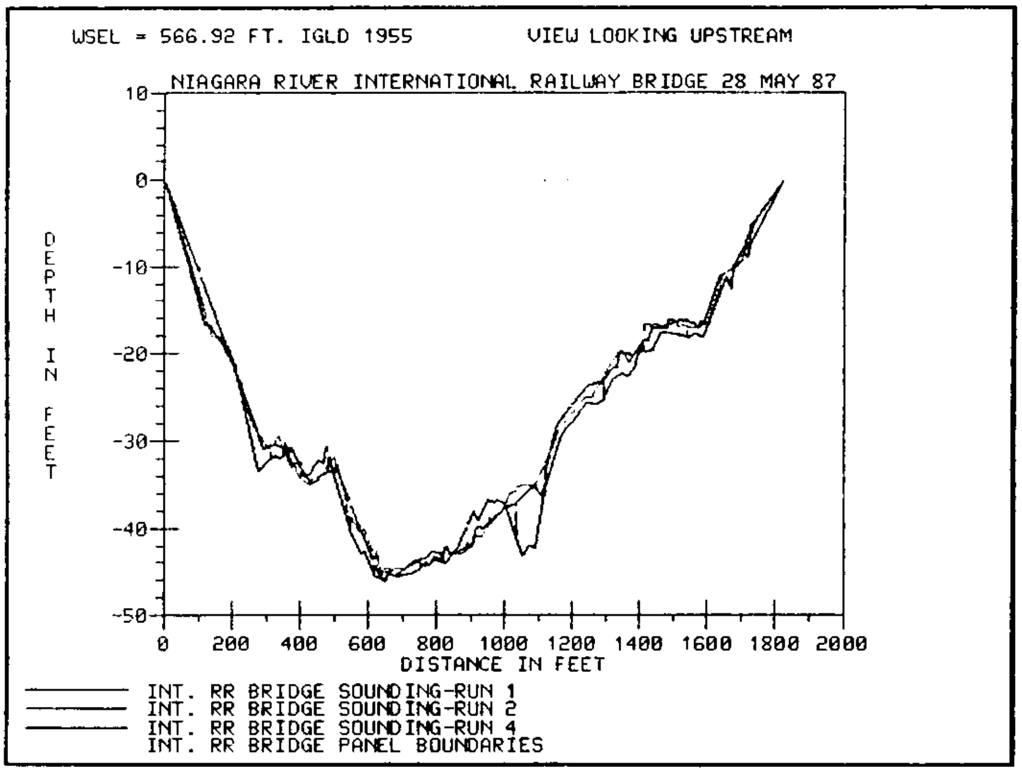


Distance in feet from reference point (iron pipe) on Canadian shore.

Original plot 10 May, 1973, from echo soundings taken 13 April, 1973, average of 5 runs.

Reproduced for Co-ordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 25 August, 1976.

Fig. 19 (Cont'd.) - Typical Measuring Sections



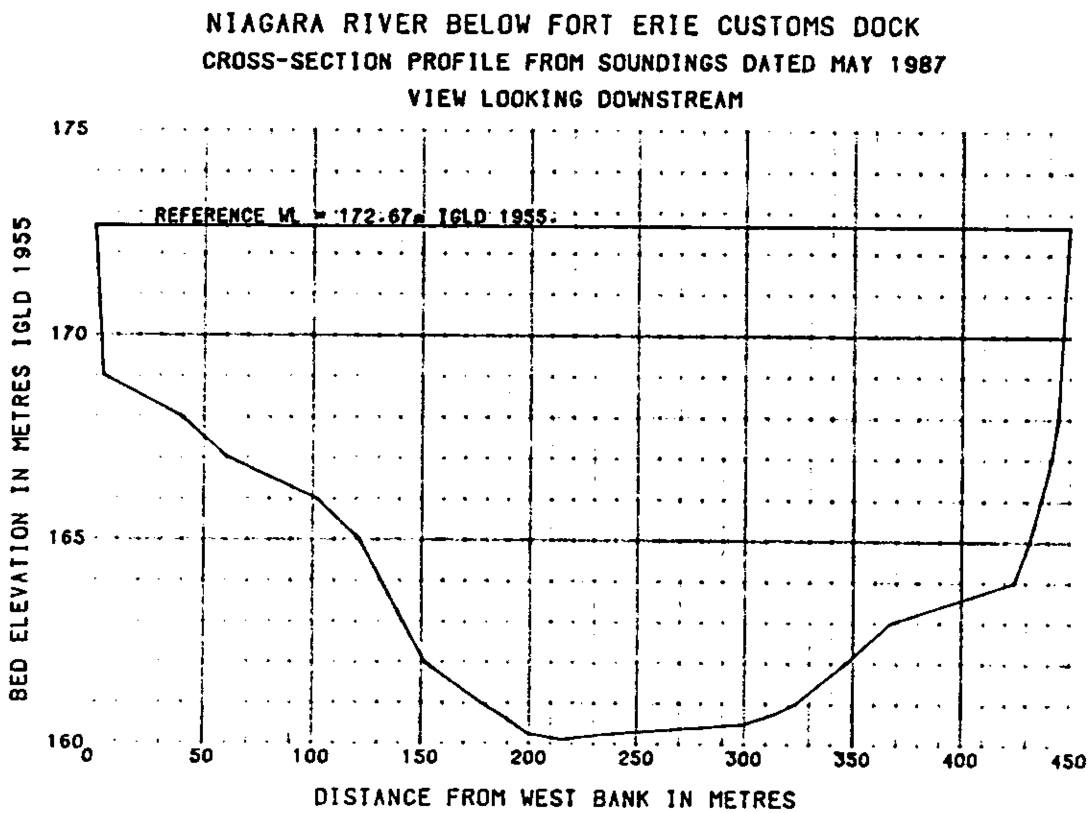
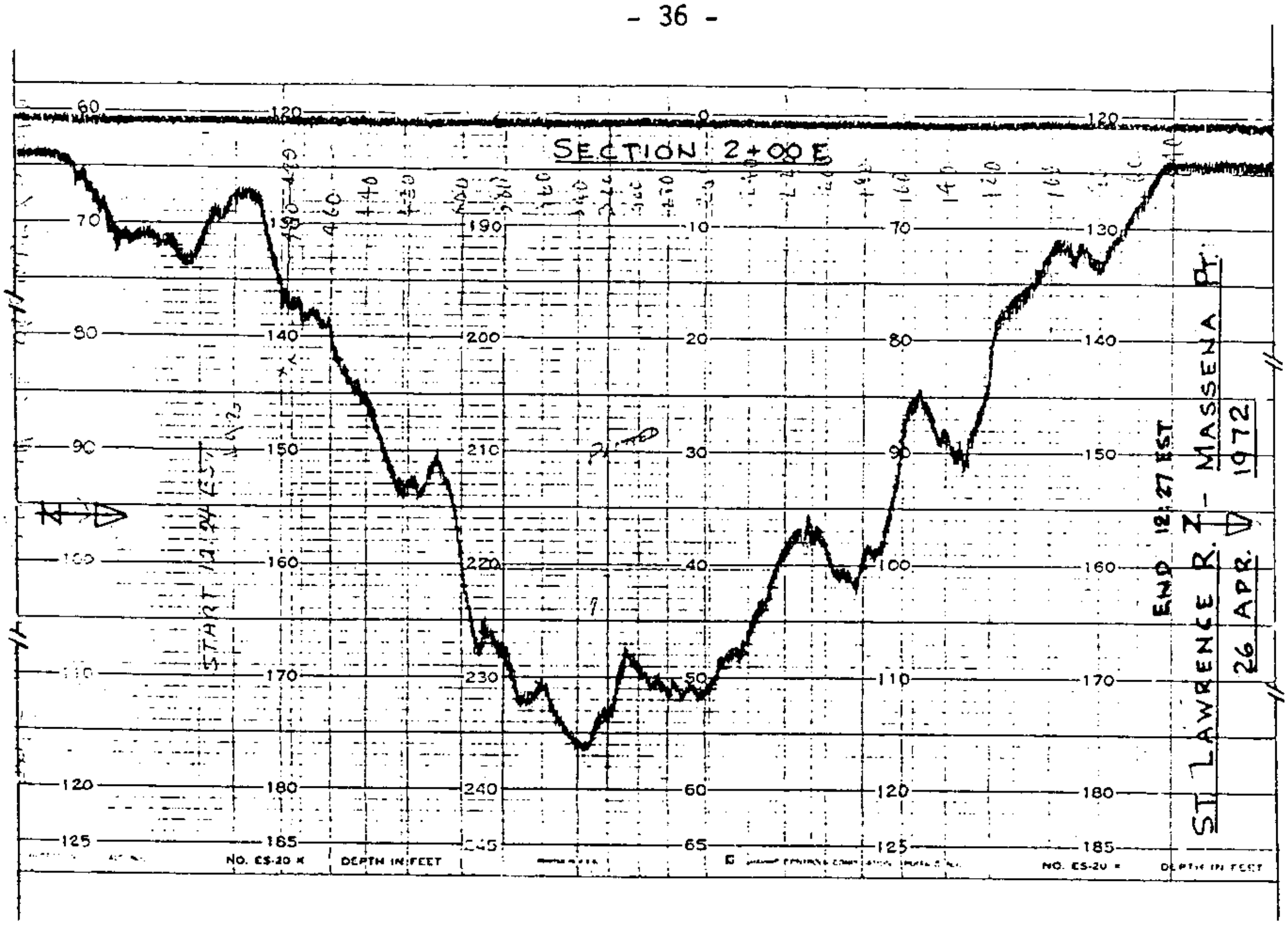
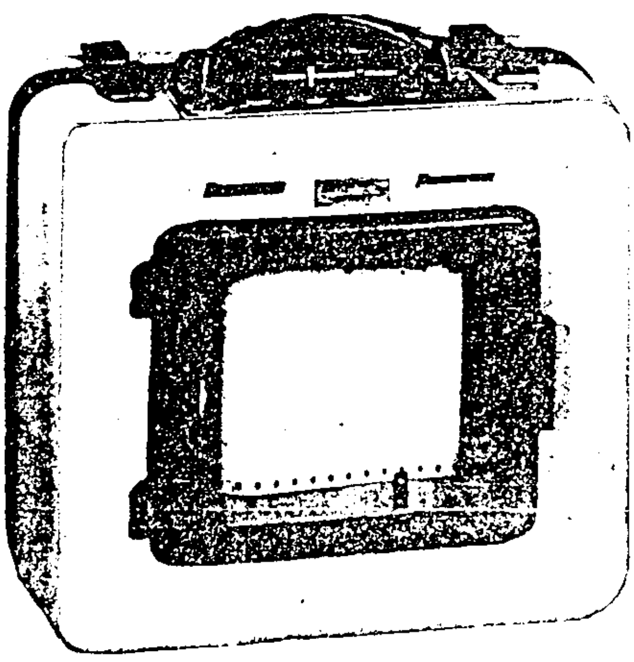


Figure 19 (Cont'd.)
Typical Measuring Sections



Sample Echo Sounder Chart - St. Lawrence River at Massena Pt.
26 April 1972



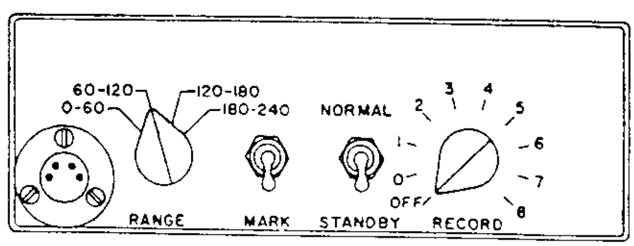


Figure 20
Echo Sounder, Control Panel, and Chart
(Courtesy of U.S. Geological Survey)

assumed to remain stable for the time of the current set of measurements and all cross-sectional areas used in the discharge computations were based on the standard profile. Current meter settings for selected water levels were occasionally computed from the standard soundings, but more often from lead line soundings taken at the time of the measurements.

The next step in the calibration of a new measuring section was the selection of the measuring verticals and the determination of the panel boundaries. Panel selection was designed to optimize velocity sampling in the section and satisfy requirements relating to the maximum allowable percentage of the total flow in any panel. To accomplish this, a plot of the distribution of flow across the section, sometimes called a transverse discharge profile or unit discharge curve was required. The distribution of mean vertical velocity across the section as defined by a transverse velocity profile, and the transverse bed profile were needed to construct the discharge curve. These distributions are described in the following paragraphs.

(2) Transverse Velocity Curve

The transverse velocity curve or profile shows the distribution of mean vertical velocities across the section. The velocity data were sometimes obtained from the direction of flow survey, but usually from preliminary current meter measurements at selected verticals across the section. The mean vertical velocities were computed from these measurements and plotted, and a smooth curve drawn through the plotted points. Sometimes standard transverse velocity coefficients for use in the discharge measurements were computed from this curve, but usually the coefficients were based on data collected in the individual discharge measurements. The coefficient is the ratio of the mean velocity in the panel obtained from the curve, to the mean velocity in the central vertical. Figure 21 shows an example of a transverse velocity curve.

(3) Transverse Discharge Profile

The transverse discharge curve or profile mentioned previously was then drawn through the series of plotted points representing the products of corresponding values of depths and mean vertical velocities across the section. Depths were taken from the standard bed profile and velocities from the transverse velocity curve. The number of points used to define the curve depended on the uniformity of the bed profile and the velocity distribution, and thus on the flow distribution. The area under the curve, which represented the total discharge, was divided by a process of trial and error into the required number of panels in such a way that discharge in any one panel did not exceed the allowable percentage of the total, usually ten percent in recent years.

After a satisfactory panel distribution was achieved, the boundaries were read from the graph and the measuring verticals were located at the midpoints of the panels. This procedure is a variation of the standard mid-section method of distributing panels, as described in References 10, 19, and 21. A typical transverse discharge curve is shown in Figure 22.

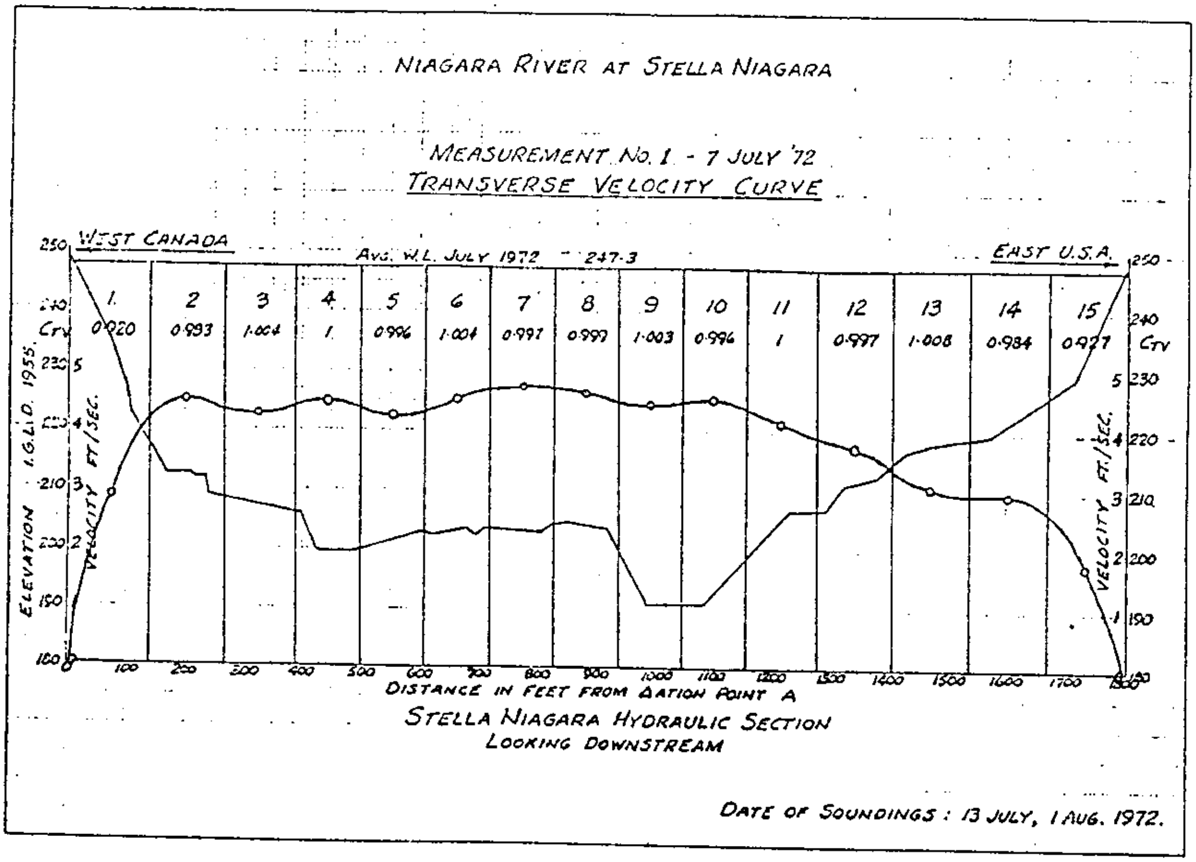


Figure 21
Transverse Velocity Curve

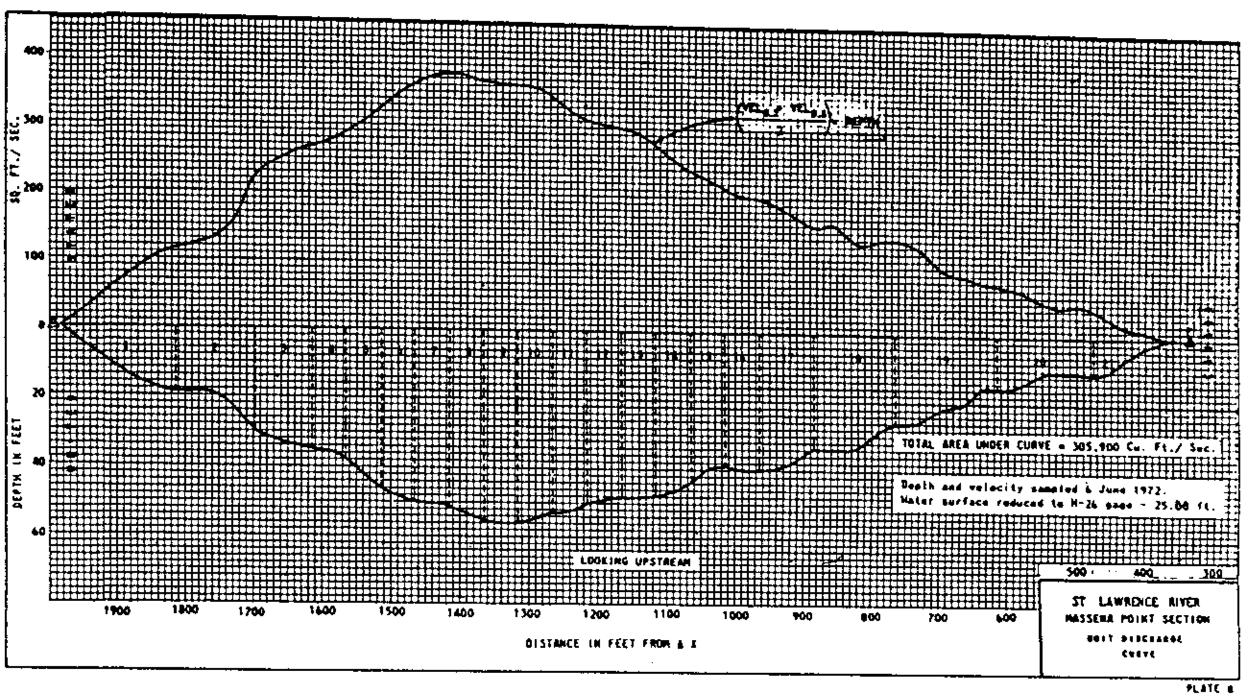


Figure 22
Transverse Discharge Curve

(4) Vertical Velocity Curves

Preliminary velocity-depth studies for determination of coefficients for distribution of velocities in the vertical direction were conducted as a part of most discharge measurement programs until about 1967. The graph of the velocity-depth profile was called a vertical velocity curve, with depth as ordinate and velocity as abscissa. The depth scale was usually expressed as a ratio of the total depth, from zero at the surface to one at the bottom. A smooth curve was visually fitted to the plotted data points representing the point velocity measurements, usually one at each tenth of the depth. The mean velocity in the vertical was computed by digitizing the curve, usually at twenty points, or measuring the area between it and the depth axis with a planimeter. Coefficients relating point velocities at selected depths to the mean velocity in the vertical were then computed for each measuring vertical and subsequently used in the discharge computations.

A typical procedure for collection of data in velocity-depth studies was the simultaneous suspension of three Price or Haskell current meters abreast. The central meter was set at a constant position in the vertical (usually .4 of the depth), while the two outside meters were lowered and raised over the total depth in opposite directions. A two minute current speed reading was taken at each tenth of the depth as follows:

Observation	left meter	centre meter	right meter
1	.1 depth	.4 depth	.9 depth
2	.2 "	"	.8 "
3	.3 "	"	.7 "
4	.4 "	"	.6 "
5	.5 "	"	.5 "
6	.6 "	"	.4 "
7	.7 "	"	.3 "
8	.8 "	"	.2 "
9	.9 "	"	.1 "

The centre meter, whose function was to register variations in current speed with time, was called the index meter. The variations registered by this meter were considered to apply throughout the vertical, and the velocities recorded at the other points were adjusted proportionally to simulate simultaneous observations at all points. The choice of .4 depth as an index setting was based on U.S. Lake Survey studies which showed that velocities at this depth displayed the most consistent relationship to the mean velocity in the vertical. The procedure is illustrated in the following excerpt from the report of discharge measurements on the Niagara River at the Stella Niagara section in 1957 and 1958, under the heading "Vertical Distribution of Velocity" on page 8.

"Observations were made to determine the vertical distribution of velocity at the measuring station in each of the ten panels of the section. Three meters were used simultaneously during these observations. Initially, the centre meter was placed at four-tenths depth, the left meter was placed at one-tenth depth,and the right meter was placed at nine-tenths depth."

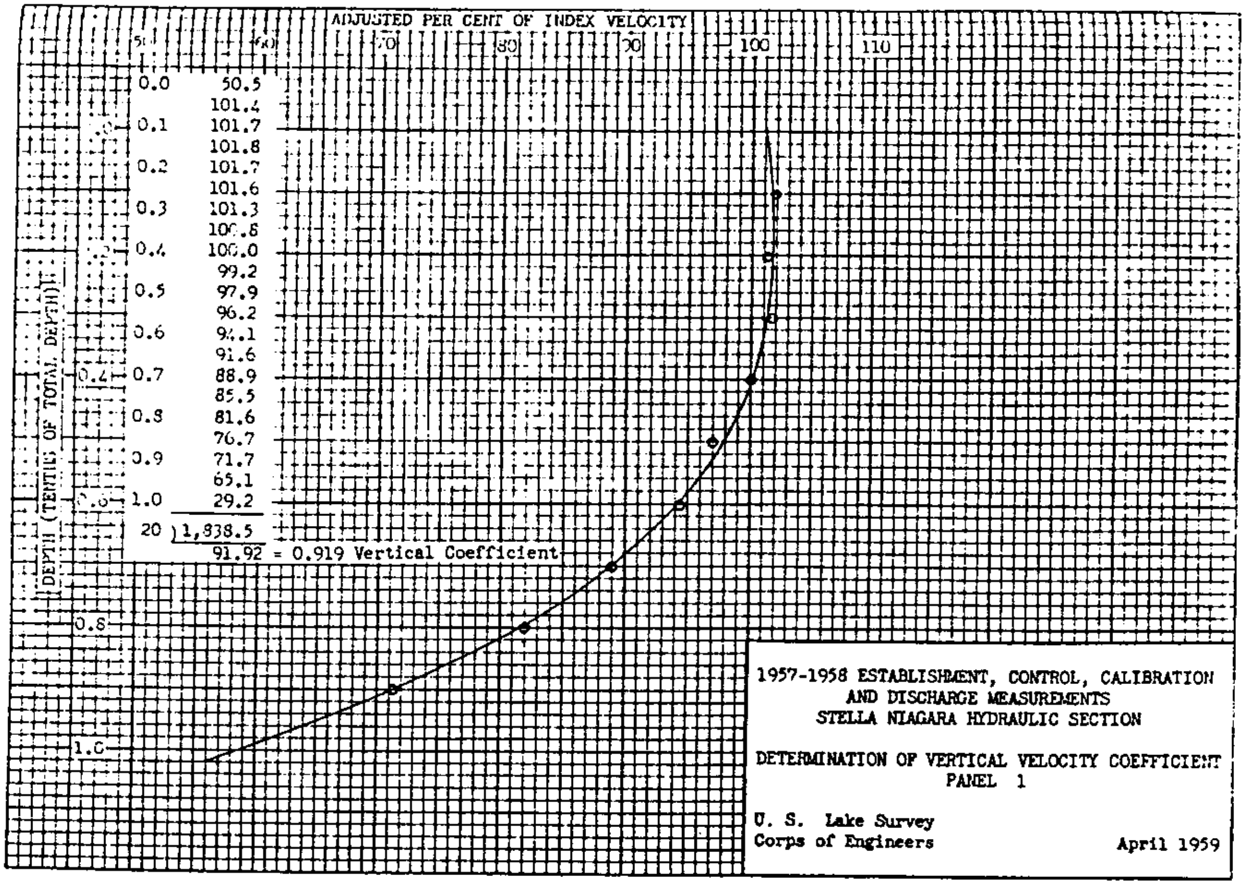
"After two, two-minute observations, the left meter was lowered to two-tenths depth, the centre meter remained at four-tenths depth, and the right meter was raised to eight-tenths depth. This procedure of changing progressively the depth settings of the left and right meters was followed until the right meter was at one-tenth depth and the left meter was at nine-tenths depth. Six determinations of the vertical distribution of velocity using the foregoing procedure was made for each panel. This work was accomplished in connection with the initial discharge measurements. It was not repeated subsequently because it was considered that the data obtained had adequately established the vertical distribution of velocity.

The velocity data obtained to determine vertical coefficients are shown in Tables 4 through 13. In these tables, the velocity observations from both left and right meters at each tenth depth are tabulated in a single column. The mean of the values listed in the column is compared to the mean of the corresponding column of observations of the centre meter at four-tenths depth. The percentage comparison between the mean of the observations made with the left and right meters at four-tenths depth and the corresponding centre meter observations was adjusted to 100% and the other percentages were adjusted proportionately. The adjusted percentages were plotted against depth, and the vertical coefficients were obtained as a function of the area between curve and depth axis. The determination of the vertical velocity coefficients are shown on Plates 5 through 14. The vertical coefficient applied to the velocity observed at the four tenths depth during discharge measurements converts the observed velocity to the mean velocity in the vertical plane through the measuring point of the panel." Vertical velocity curves and coefficient computations for five of the ten panels are shown in Figure 23.

While procedures similar to those described above were used in most pre 1967 measurement programs to define velocity-depth profiles and develop coefficients, an exception was the program on the St. Lawrence River at Massena Point in 1960. In this program velocities were measured at nine points (.1 to .9 depth) in each vertical in all twenty measurements. All the data were used in the development of coefficients which were then used used in the discharge computations to compute mean vertical velocities from the means of the nine point measurements.

The use of vertical velocity coefficients was discontinued in 1967 with the introduction of automated computations developed by the U.S. Lake Survey. Since then the velocity distribution method, in which the mean vertical velocity is computed from a theoretical distribution fitted to the observed data for each measurement, has been employed. The computer program developed by the Lake Survey, known as Program 4316, is described in Section 5.5.

The last item in section calibration was determination of the panel direction of flow coefficients. In most sections, vertically averaged coefficients were considered adequate. These coefficients, which are the sines of the angles of the flow line intersections at panel mid-points, were generally obtained by interpolation from the plot of the direction of flow survey. Occasionally, a transverse direction of flow diagram like the one shown in Figure 24 was prepared and the panel coefficients were read from the diagram.



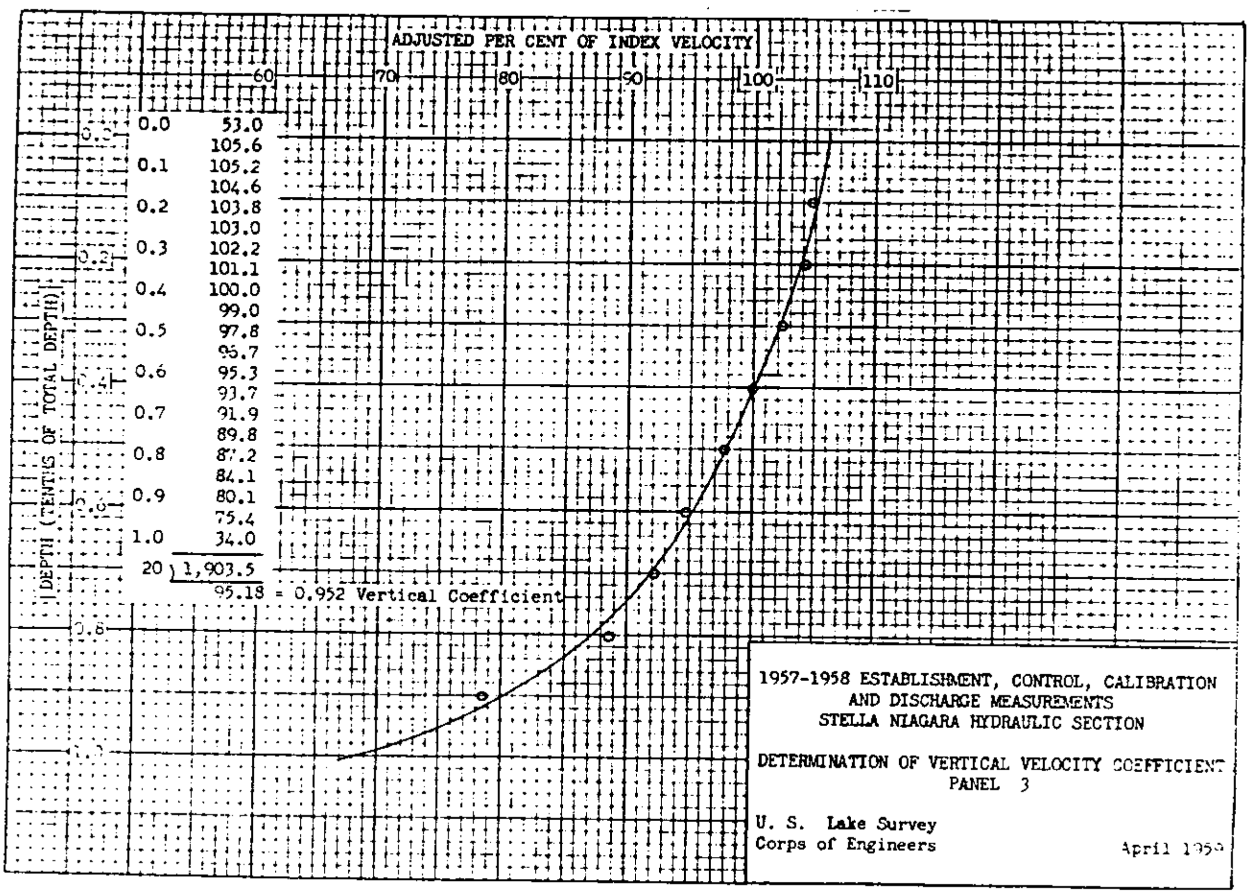
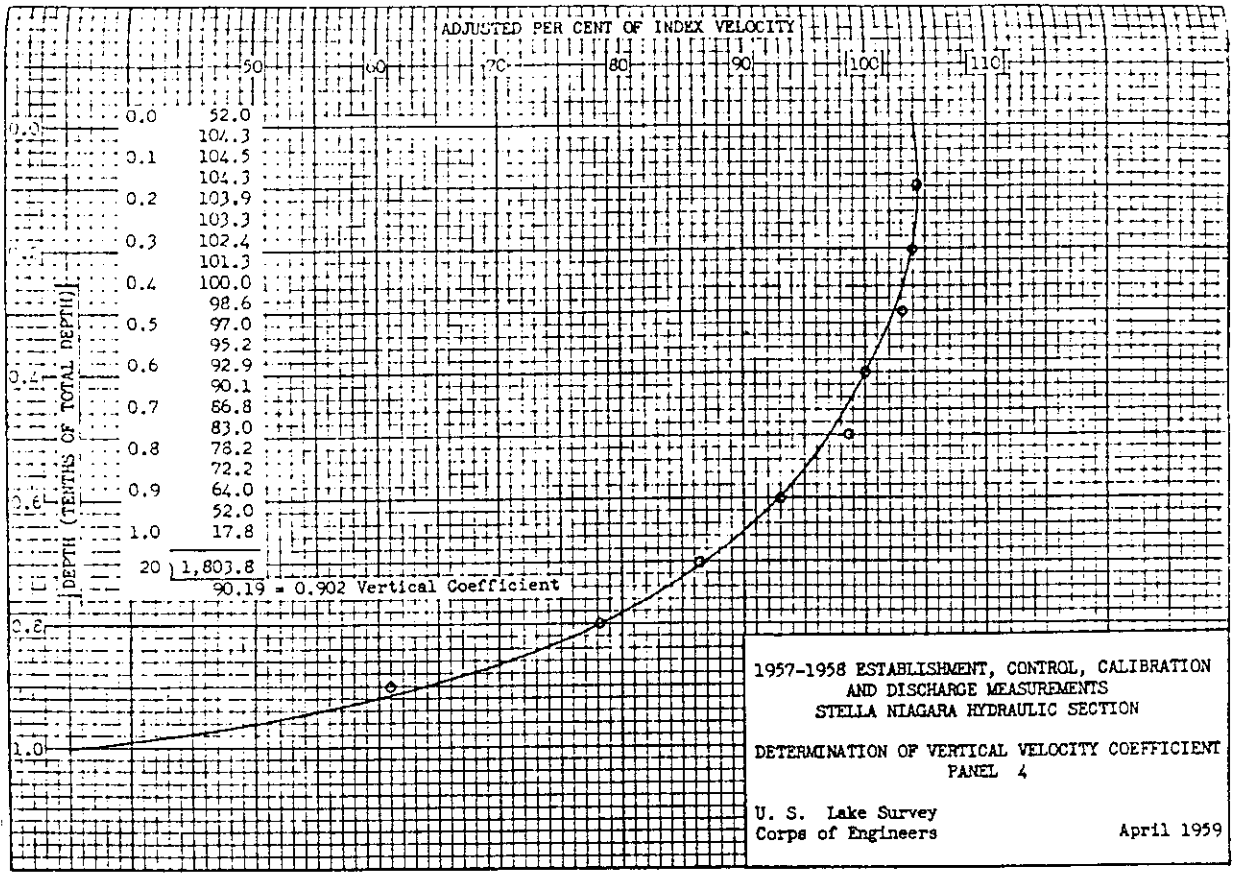


Figure 23
Vertical Velocity Curves



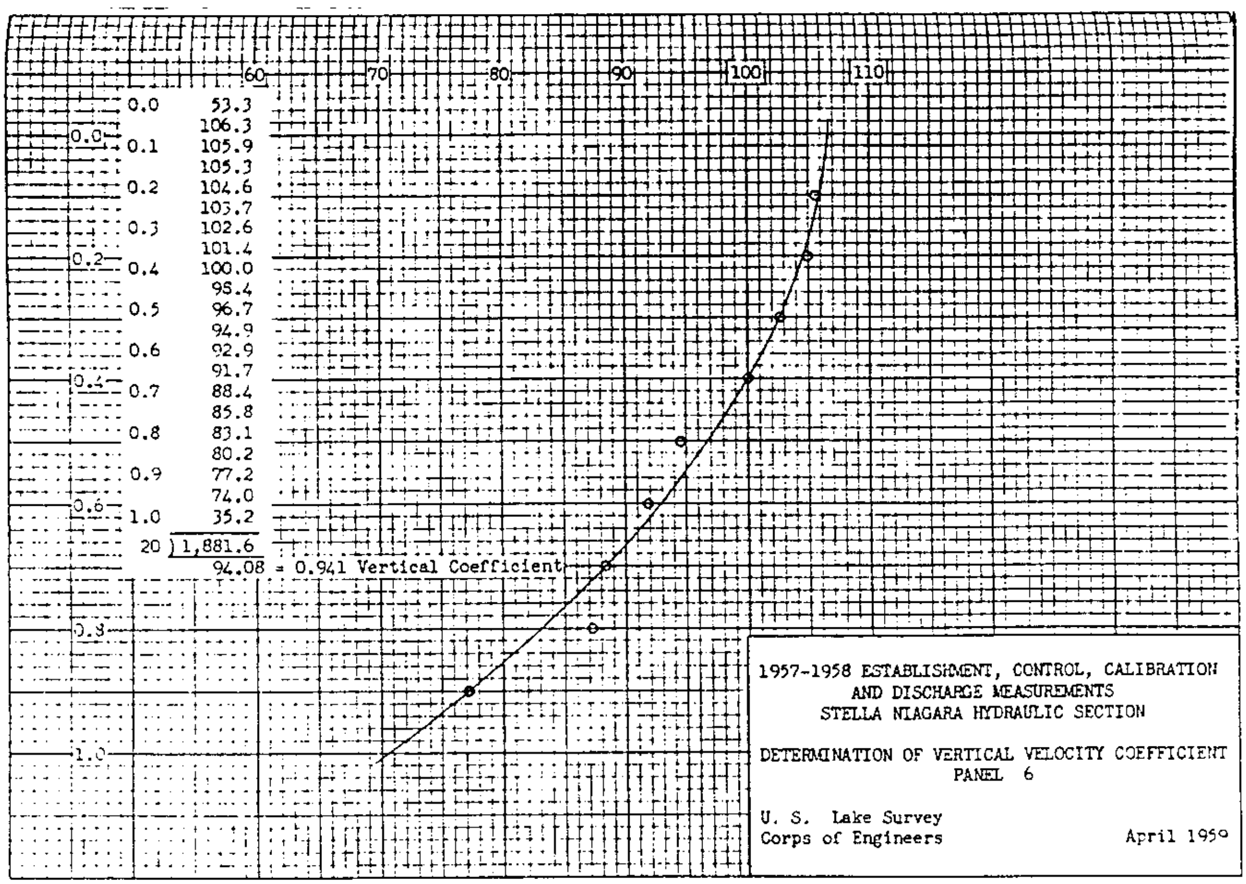


Figure 23 (Cont'd.)
Vertical Velocity Curves

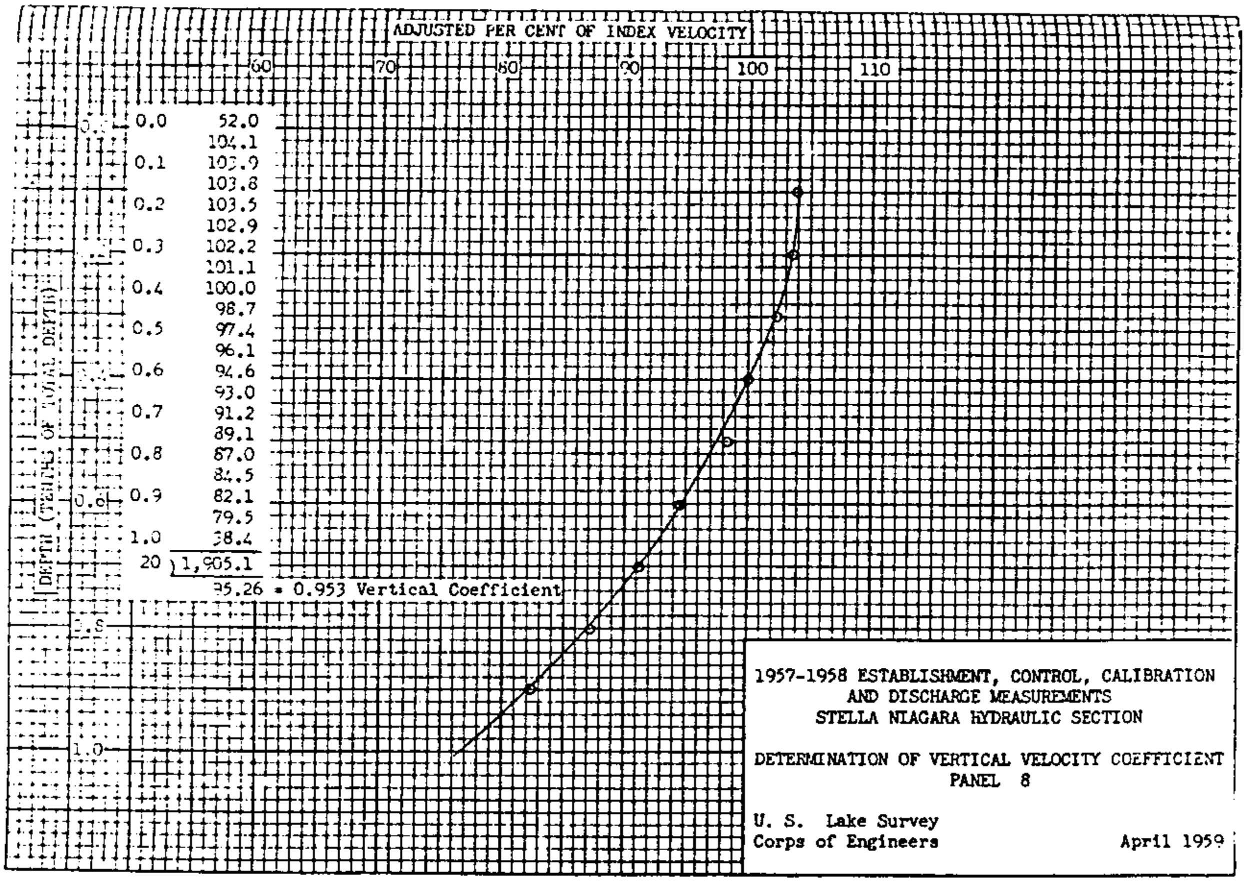
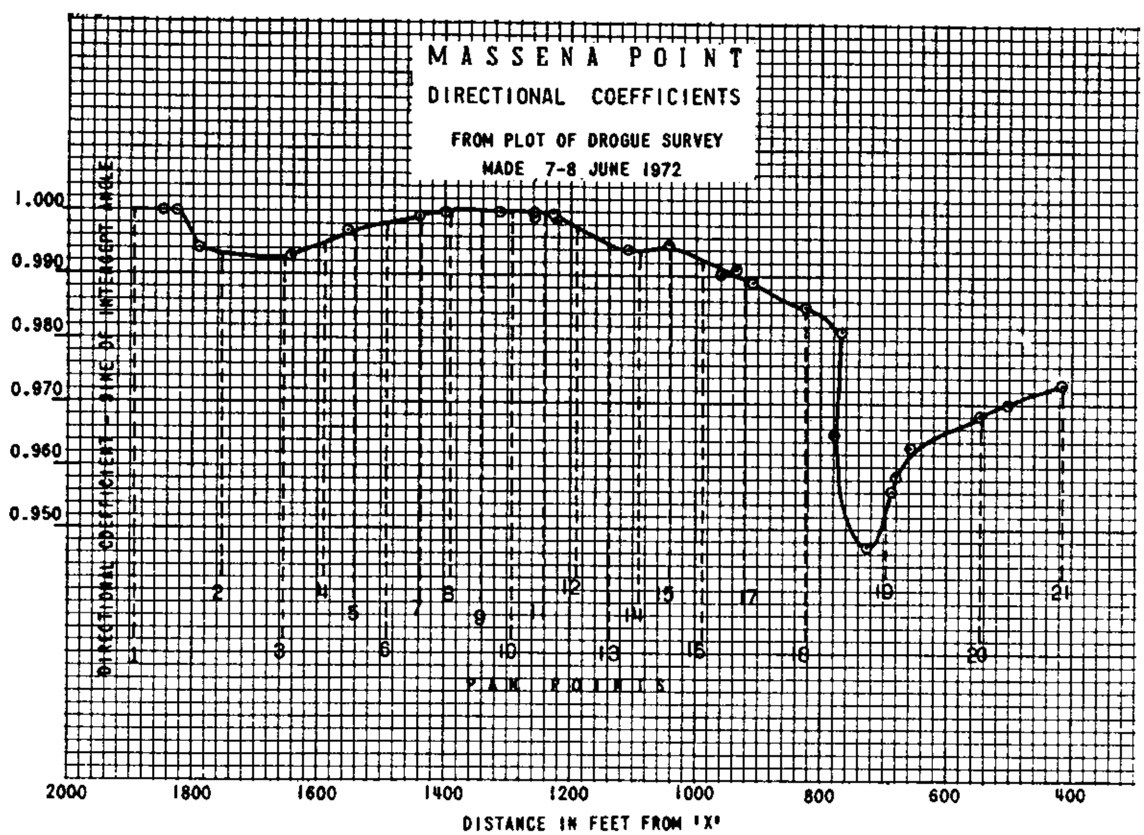


Figure 23 (Cont'd.) - Vertical Velocity Curves



PAN	DIR. COEFF.
1	1.000
2	0.993
3	0.992
4	0.995
5	0.997
6	0.998
7	0.999
8	1.000
9	1.000
10	1.000
11	1.000
12	0.997
13	0.995
14	0.994
15	0.994
16	0.992
17	0.989
18	0.985
19	0.954
20	0.968
21	0.973

Figure 24 - Transverse Directional Curve

PLATE 7

At very deep or turbulent sections, such as the old Point Three Points section on the St.Lawrence River or the Maid of the Mist Pool and Stella Niagara sections on the Niagara River, special studies to define current velocity (speed and direction) depth profiles at the measuring verticals were considered necessary. These studies were conducted using special direction of flow meters with built in direction sensors. Since these meters were expensive, fragile, and large and cumbersome compared to regular meters, their use was limited to these special studies.

The following makes of direction of flow meters were used at various times in the past, but only the Marsh-McBurney is still in regular use today on the connecting channels.

Direction of Flow Meters

		Components of velocity measured			
Figure	Brand name	magnitude	sensor	direction	sensor
-	Ott Arkansas	yes	propellor	yes	compass
-	VADA*	"	"	"	"
-	Savonius	"	"	"	"
25	Marsh-McBurney	"	electromagnetic coil	"	"
25	NRC**	no	-	"	gyroscope

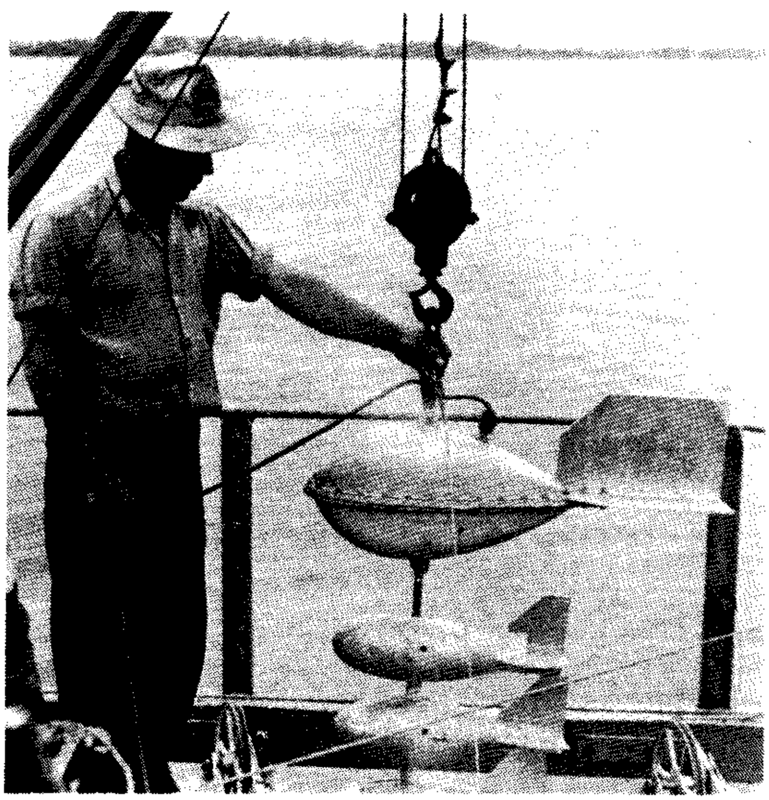
* Velocity Azimuth Depth Assembly
** National Research Council, Canada.

The magnetic bearings displayed by the four compass fitted meters were converted to current directions relative to the line of the section by subtracting the bearing of the section line, as determined by aligning the meter along the section with the meter out of the water at the start of the measurements. The directional coefficients, as mentioned before, were the sines of the angles of flow.

In most velocity-depth studies, observations were taken at each tenth of the depth and as close as practical to the water surface and the bed, usually one foot (.3 metre) from each. Even tenths were used to simplify manual calculation of depth settings, but with the present availability of computers or programable calculators, uniform distribution of observations in the intervening depth between the surface and bed readings probably would be preferable.

Depending on the variations of the velocities in the verticals and other considerations, the coefficients were either applied to the point velocities individually before computation of the mean vertical velocity, or a mean coefficient was computed for the vertical and applied to the uncorrected average velocity in the vertical. On many earlier jobs, the three coefficients - vertical and transverse velocity and direction of flow - were multiplied together and used as combined panel coefficients.

Marsh-McBurney Electromagnetic Velocity Meter



NRC Gyroscope DF Meter
St. Lawrence River at Weaver Point - 1954

Figure 25 - Direction of Flow Meters

(5) Measuring Platforms

Although the catamaran was the measuring platform usually associated with discharge measurements on the connecting channels, other types of boats, and bridges, cableways, and ice cover, were also used for taking measurements. The various platforms from which measurements were taken, and the procedures and equipment associated with each, are described in the following subsections.

5.2 Ice Measurements

The St. Marys and St. Lawrence Rivers are the only connecting channels on which discharge measurements have been taken from a complete ice cover by the subject agencies. However, measurements under ice floe conditions have occasionally been taken on the Niagara and St. Lawrence Rivers. The St. Lawrence River measurements were taken in the winters of 1953/54 and 1954/55. These measurements were taken from a catamaran with two support vessels, for the purpose of checking the performance of the current gauge ratings under ice conditions. The catamaran was fitted with retractible ice guards to protect the meter lines from ice floes, but apart from this equipment modification and the use of steam from one of the support vessels to de-ice the catamaran when necessary, procedures were much the same as in open water measurements.

Another series of measurements under ice conditions were taken on channels around Ogden Island in the St. Lawrence River in the winter of 1980 in support of ice condition surveys undertaken by Clarkson College of Technology for the St. Lawrence Seaway Development Corporation. The purpose of the measurements was to study the effect of accumulations of frazil ice on current velocity and flow distribution patterns. However, the measurement program was limited to three measurements in each channel due to constraints imposed by time and regulation considerations.

The St. Marys River ice measurements were taken at the Garden River and Frechette Sections on the north and west channels around Sugar Island during the winters of 1972, 1973, and 1776 in support of winter navigation studies. The purpose of the measurements was to measure the effect of ice cover on current velocity and flow distribution.

The hydraulic sections used for these under ice measurements were divided into six panels ranging in width from 30 to 90 metres (100 to 300 feet). The number and arrangement of the panels was based on knowledge of the area and prevailing winter conditions which could exist at the time of the measurements. Each section was established prior to the program, and cross-sectional profiles under open water conditions were also obtained.

The procedures were similar to those used in open water measurements, with the exception that ice thickness and the effective area of flow in the section was determined prior to measuring. The effective area of flow across the section was determined by lowering a meter through a hole in the ice sheet until a current was first detected. A sounding was then taken from that elevation. Under a smooth ice cover this was located just below the under side of the ice. Under broken ice it varied up to three feet below the ice surface, depending on the amount of ice layering and roughness.

A specially designed ice sled (Figure 26) was used to transport and support the metering equipment, which included a Price meter, a winch and batteries, and a counter to record the revolutions of the current meter. The meter was connected to a 50 pound (23 kilogram) weight and lowered through 2 foot by 3 foot holes (.6 by .9 metre) cut in the ice at each panel metering station. Panel points were established by measuring the respective distances from a control point on the bank and marked by placing wooden stakes in the ice. The current speed was measured for two minutes at each tenth of the effective depth from .1 to .9. A water level reading was taken at each panel during the period of measurement from permanent water level gauges located near the section. The sections were lead line sounded in 1969 and the soundings were spot checked for this series of measurements. A comparison of the soundings checked closely in all cases.

During the measurement, meter revolutions for the two minute periods were recorded on data forms together with the section gage reading, the meter identification, the time and date, and other pertinent data. The data were then placed in a computer file for processing by the discharge measurement program 4316 developed by the U.S. Lake Survey.

5.3 Bridge Measurements

Due to navigational clearance requirements of 36 metres (120 feet), the fixed bridges over the shipping lanes of the connecting channels are too high above the water to serve as satisfactory measuring platforms for discharge measurements. For this reason, most bridge measurements have been confined to the non-navigable channels in the system. Nevertheless, measurements have been taken by the U.S. Lake Survey from the Bluewater Bridge over the St. Clair River at Port Huron - Point Edward in 1962, and velocity measurements from the Peace Bridge over the upper Niagara River at Buffalo/Fort Erie in 1973.

From 1898 to 1929 a great many discharge measurements on the Niagara River were taken from the International Railway Bridge at Buffalo/Fort Erie by agencies of both countries. This bridge has a swing span for the passage of shipping, but it has not been opened for many years since most ships use the Black Rock Canal, which bypasses this section of the river. The bridge consists of eight overhead steel truss spans on masonry piers. Documentation of the procedures used by the U.S. Lake Survey in their measurements from this bridge can be obtained from the project reports or from Reference 1. One hundred and twenty-one measurements were taken from the bridge by the Canadian agency Dominion Water Power and Reclamation Service between 1921 and 1925. Although documentation is missing, it is likely that the accepted Canadian practice of measuring velocities at .2 and .8 of the depth in 20 to 25 verticals was used in these measurements. Since it would have been necessary to raise the meter at every measuring point to move the meter line around the truss members, a power winch was probably used.

Discharge measurements were also taken by the U.S. Lake Survey from the International Bridge over the rapids section of the St. Marys River at Sault Ste. Marie in 1899, 1902 and 1909.

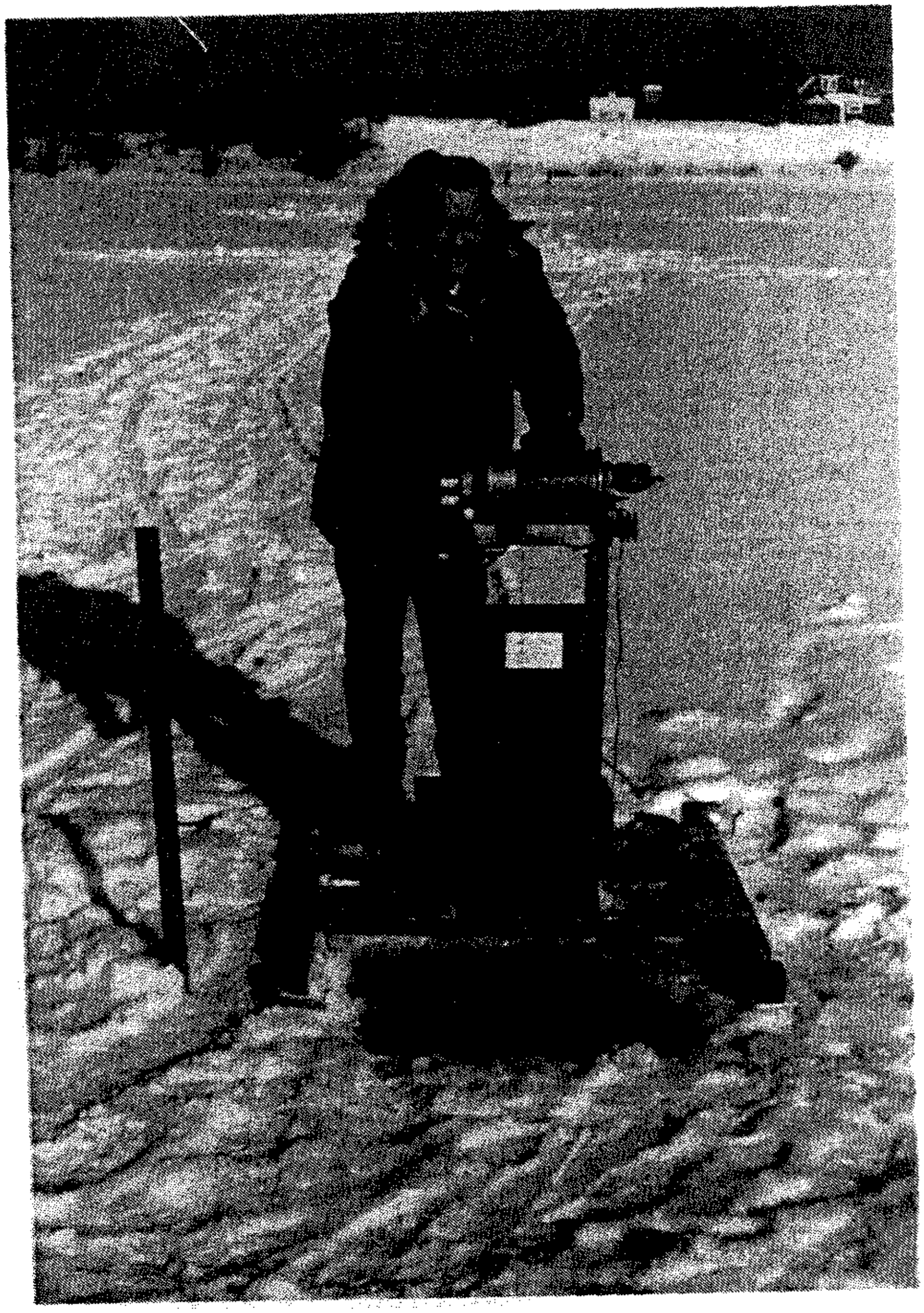


Figure 26
Ice Sled - St. Marys River - 1974

The only other bridges used for measurements in the mainstreams of the subject channels were the American Falls bridges over the American Falls channel of the Niagara River (Figure 27). These bridges are located in the rapids section of the channel about 500 metres above the American Falls and are separated by a small island called Green Island. The measuring sections are located on the downstream side of the north or American Falls bridge and the upstream side of the south or Bridal Veil bridge. The sections were established and calibrated in 1971 and measurements were conducted in 1971, 1977, 1978, and 1984. Due to unfavourable hydraulic conditions at these sections, including an extremely rough bed, shallow depths, high velocities and extreme turbulance, it was necessary to modify some of the usual procedures to facilitate the measurements and achieve acceptable accuracy. These modifictions included increasing the number of panels to fifty-five, while measuring velocities at only one or two points in each vertical due to insufficient depth to measure at the usual nine points. Four meters were deployed simultaneously from special bridge cranes mounted on carts. Each crane was manned by two people. The bed profile was lead-line sounded in advance and standard cross-sections were developed. An innovation was the placement of a wire line across the section about 1 metre above the water surface, and supported against the upstream edges of the piers as shown in lower left photo of Figure 27. In other spans, ropes were passed under the span from the upstream side of the bridge and attached to the meter-weight assemblies to stabilize them in position on the section line.

Several diversions were measured at bridge sections, including:

- the Edison Sault power canal at the Fort Street bridge in Sault Ste. Marie, Michigan (Figure 28);

- the Abitibi Paper Company groundwood mill tailrace at the Canadian Lock access bridge in Sault Ste. Marie, Ontario. A cableway located a few metres above the bridge was also used for these measurements. The Abitibi groundwood mill was torn down in 1982 during the construction of the new Francis H. Clergue Generating Station for the Great Lakes Power Company;

- the Erie Canal at a bridge in North Tonawanda, also shown in Figure 28;

- the Decew Falls G.S. tailrace (Twelve Mile Creek) at the old Highway 8 bridge in St. Catharines, Ontario.

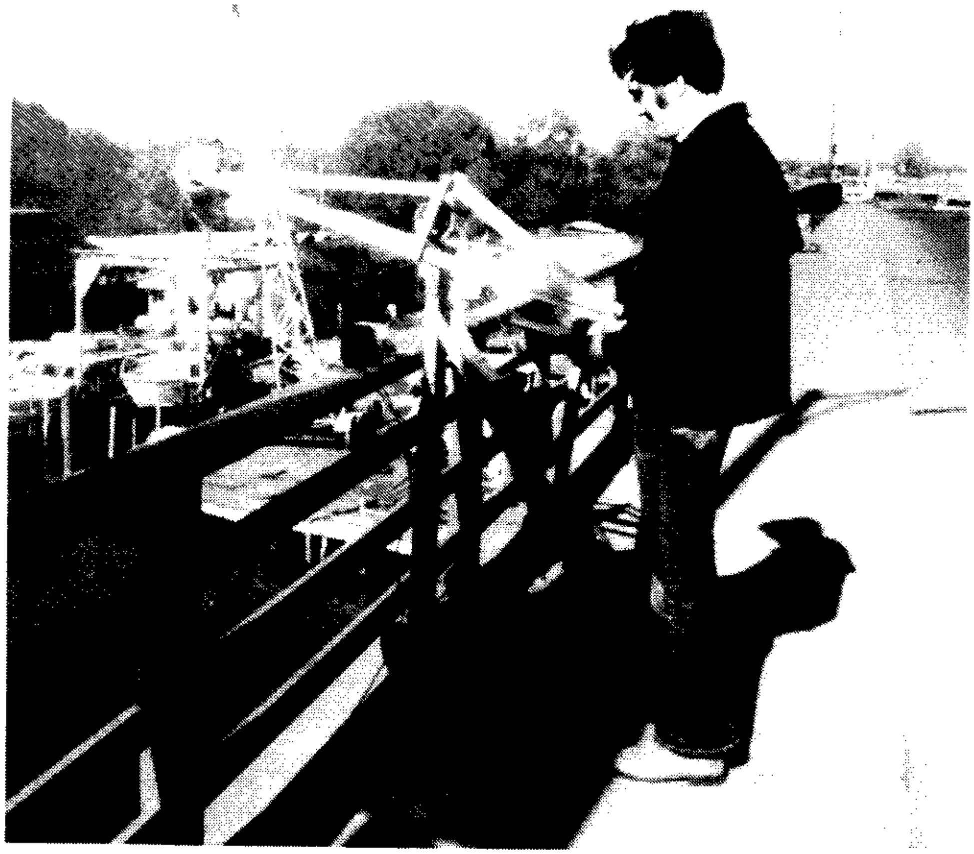
Since discharge measurements from bridges are an important part of the stream gauging operations of both the U.S. Geological Survey and the Water Survey of Canada, equipment available and procedures presently practiced are described in their respective hydrometric field manuals (References 19 and 21). Earlier equipment and procedures used by the U.S. Geological Survey are described in Reference 18. Since the equipment and procedures used in bridge measurements on the subject channels were essentially the same except in a few special cases, the reader desiring more information is referred to the above sources.

1973

Nov. 1984

Nov. 1984

Figure 27
American Falls Channel Bridge Measurements



Erie Canal at North Tonawanda - 1974

Edison Soo Power Canal at Fort St. Bridge - 1975

Figure 28 - Bridge Measurements on Diversions

5.4 Cableway Measurements

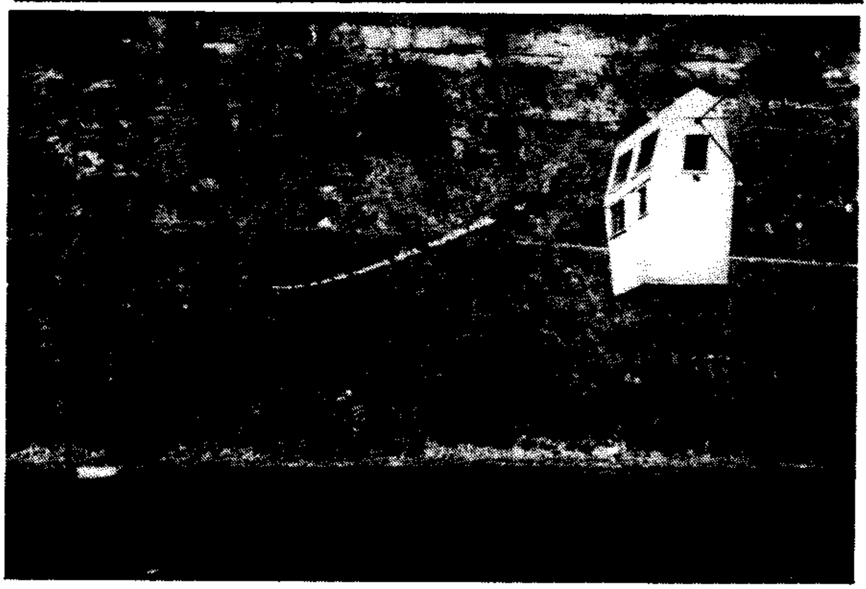
The only permanent cableway for taking discharge measurements on the connecting channels is the Robert Moses Cableway (Figure 29) which spans the lower Niagara River about 100 metres (330 feet) upstream from the tailrace of the New York State Power Authority's Robert Moses Generating Station. However, records show that at least two temporary cableways were used at various times in the past for discharge measurements by the subject agencies, and indicate that several others were used by power companies and the seaway authorities for discharge measurements in diversions for operational purposes.

The Robert Moses Cableway was built in 1973 and is still in service. The fully enclosed cablecar has a welded steel frame, aluminum panels, and plexiglass windows. It accommodates two persons comfortably in all but the most severe weather conditions. The car is driven by a 1/3 HP 36 volt DC moter coupled to the drive sheave by twin V belts and supplied by three on-board car batteries. It is outfitted for suspension of a single meter through one end of the car. The meter can be lowered and raised manually or by motor.

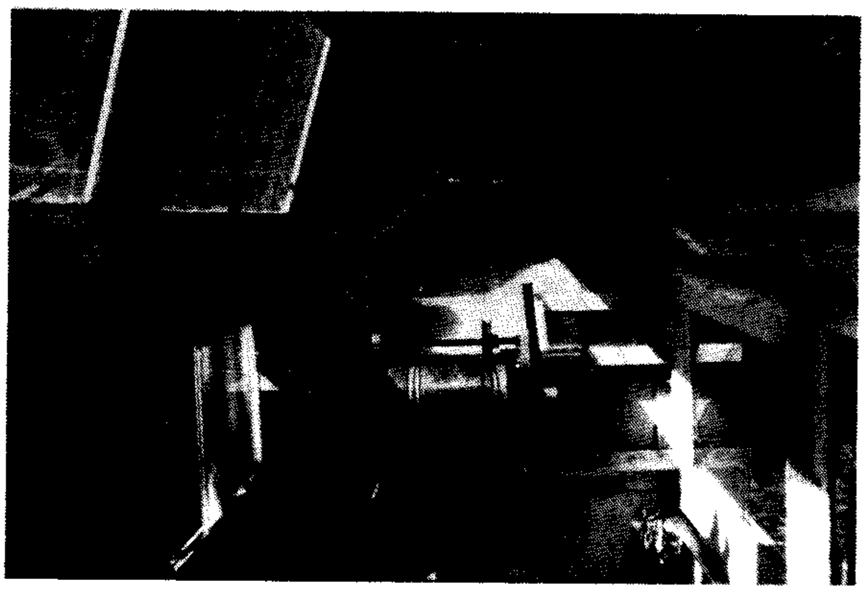
The cable is 25mm (1 in.) diameter galvanized bridge strand anchored at each end by reinforced concrete gravity anchors set deep in the banks. Turnbuckles are fitted at each end for sag adjustment. The design and construction of the cableway was a joint project of the U.S. Army Corps of Engineers, Buffalo District, and the Water Survey of Canada, Ontario Region, with valuable assistance by Ontario Hydro and the New York State Power Authority. The cableway is maintained by the power companies and accessed through the grounds of the Robert Moses Generating Station, where it is stored in a fenced enclosure.

The two temporary cableways mentioned above were light duty continuous cable types for carrying meters only, not personnel. The cable was set up at the start of, and dismantled and removed at the completion of each series of measurements. This type of cableway was last used in the 1960's on the Abitibi groundwood mill tailrace at Sault Ste. Marie, Ontario, and on the American Falls Channel. The cableway section on the American Falls channel was located about 100 metres above the present section and above the rapids section of the channel. The measurements were taken there to establish and verify the stage-discharge relationship (rating) of the old American Falls Channel gauge, which was relocated upstream in 1976. The measurements for rating the new gauge were taken from the bridge downstream as previously mentioned.

At these cableways the meter was suspended from a travelling frame and controlled by cables from the banks. The cables were suitablly marked to position the meter at the measuring points. The meter was then lowered to the water surface and the depth counter set to zero. A sounding was then taken and the meter was raised to the desired depth setting based on the sounded depth. The meter revolutions were transmitted by electrical impulses to an electromagnetic counter on the bank by a conductor in the core of the meter suspension cable. A sounding was usually taken at each measuring vertical to set the meter at the desired position for velocity measurements, but standard soundings were usually used in the discharge computations.



General Views



Interior of cablecar

Figure 29 - Robert Moses Cableway

5.5 Boat Measurements

(1) Catamarans

Until the early 1970's catamarans (Figures 30 to 40) were the type of boat used in most main channel discharge measurements on the connecting channels. Developed over the years specifically for this type of service, they featured low initial cost and overhead, high stability, shallow draft, low current resistance, and maximum usable deck area in close proximity to the water surface. The latter feature made them particularly suitable for the suspension of current meters over the forward deck between the pontoons. Their main disadvantages were low mobility and transportability due to their size and weight and low top speed of only 3 to 5 knots.

The typical river survey catamarans of the period measured about ten metres or 33 feet in length with a beam of six to eight metres (twenty to twenty-five feet) and weighed from six to fifteen tons fully outfitted. Basically mobile floating docks, they consisted of a wooden or steel deck on twin steel pontoons with rudders mounted at the ends of the pontoons and a small cabin at the stern. Most later models were self propelled and powered by twin outboard motors ranging in size from 25 to 60 HP. The earlier models had to be towed. Most carried three anchor winches and three or four meter cranes. The main anchor winch and the meter cranes were usually mounted along the front edge of the deck, and one side anchor winch was located on each side of the deck about two metres or six feet astern of the forward winch. The procedures for anchoring and positioning the catamarans are described in a later paragraph.

Other types of boats were also used in the early surveys. One type of motor launch employed by the Canadian Department of Transport on the St. Lawrence River between 1915 and 1920 is described in one of the reports as "a double ended or whale boat model of the well known "Hand V-bottom" type, beam 8 1/2 feet, length 35 feet overall, and 2 1/2 feet draft, powered with a 4-cycle motor." The report continues with the following description of how the boat was anchored and held in position. "The boat is held in position by a bow anchor of 100 pounds and a stern anchor of 80 pounds. The bow anchor is first placed some distance above the line, then the engine reversed and the boat run a little below the line when the stern anchor is let go. These anchors are attached to 5/16 inch flexible steel cables which are controlled from winches on the bow and on the stern. By means of these winches the anchor cables may be hauled taut and the boat held very steady."

Wooden pointers, whalers, skiffs, and canoes were used as utility and support craft in these earlier measurements. Present day support craft are usually small aluminum or fiberglass boats, or inflatable rubber dinghies powered by 10 to 25 HP outboard motors. Figures 30 to 33 are photographs of Canadian catamarans and support craft on the St. Lawrence River at Point Three Points and Weaver Point engaged in winter discharge measurements in 1953 to 1955.

The third Canadian catamaran (Figure 34) was built in Guelph, Ontario in 1967 by Alloy Welding Limited of Guelph for the Inland Waters Branch. It was launched in the Niagara River in May of that year (Figure 35) and

Figure 30
First Canadian Catamaran
St. Lawrence River at Point Three Points
December 1953

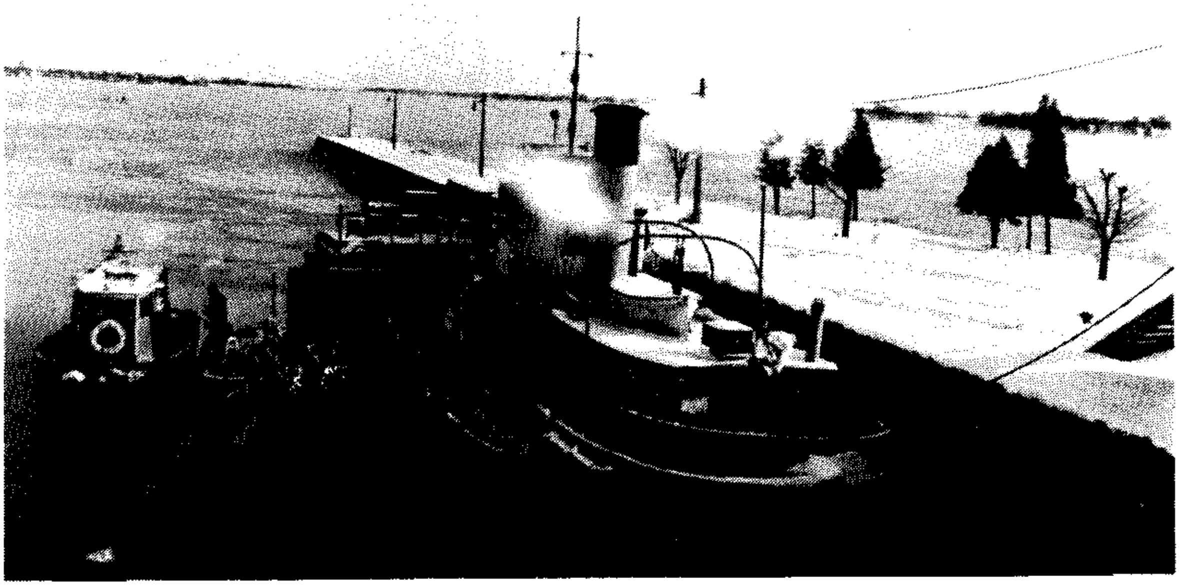
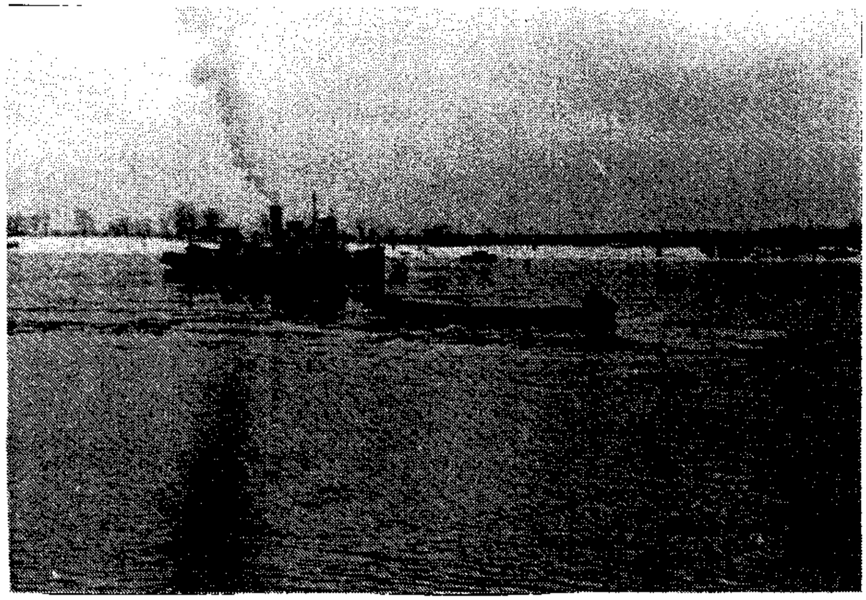


Figure 31
Canadian and U.S. Lake Survey Catamarans and Support Craft
docked at Lock 25, Iroquois, Ontario
December 1953

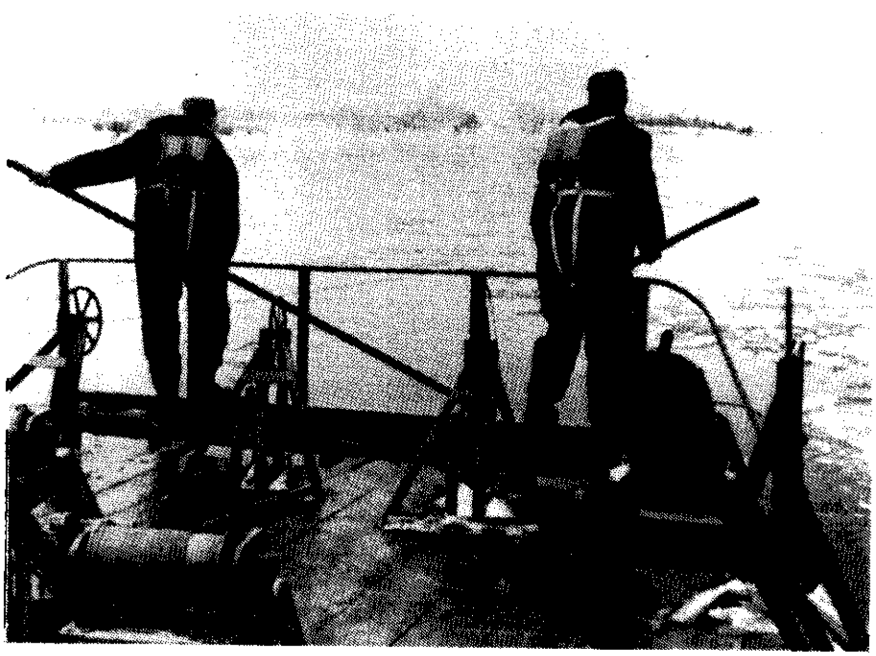


Support craft at winter buoys about 300m (1000 ft.) above section. D.O.T. tug "W.A. Bowden" tied to 1st buoy. Work boat "Ledo" tied to 3rd buoy. Pointer service in foreground.

Work boat "Ledo" tied to winter buoy. Catamaran on section line in background.

Figure 32
Support Craft - St. Lawrence R. at Weaver Point - Feb. 1955

Catamaran at metering section showing retractible ice guards in lowered position.



Front deck of catamaran

Figure 33
Second Canadian Catamaran
St. Lawrence R. at Weaver Point - Winter 1954/55

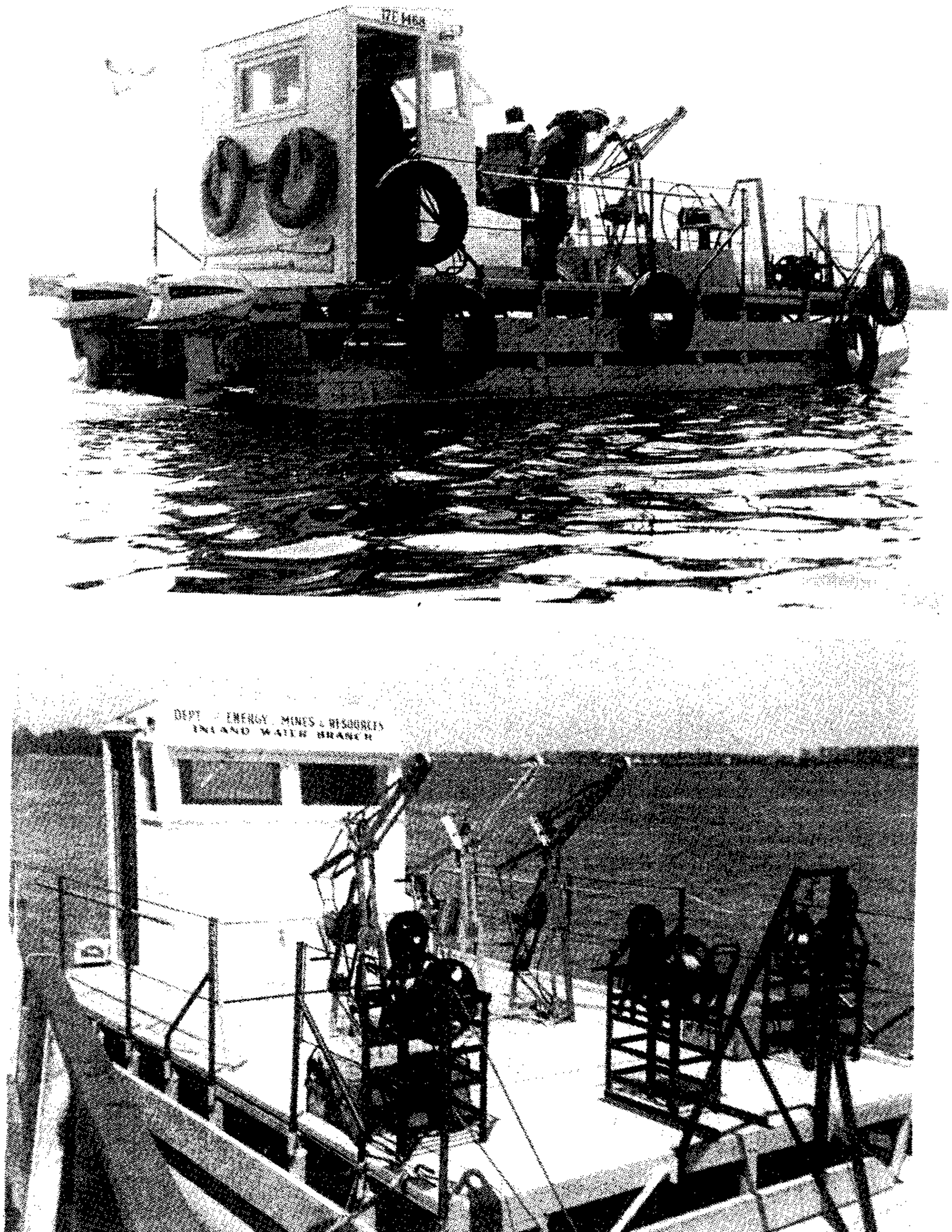
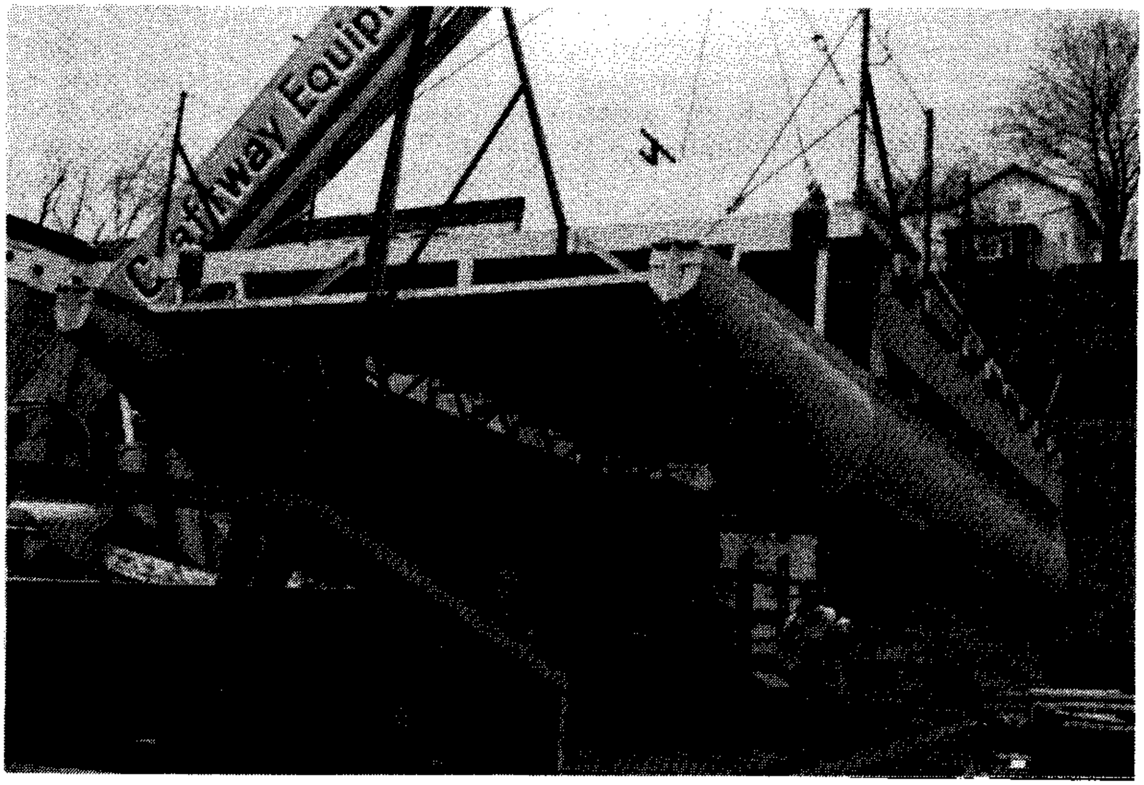


Figure 34
3rd Canadian Catamaran - Niagara River 1967



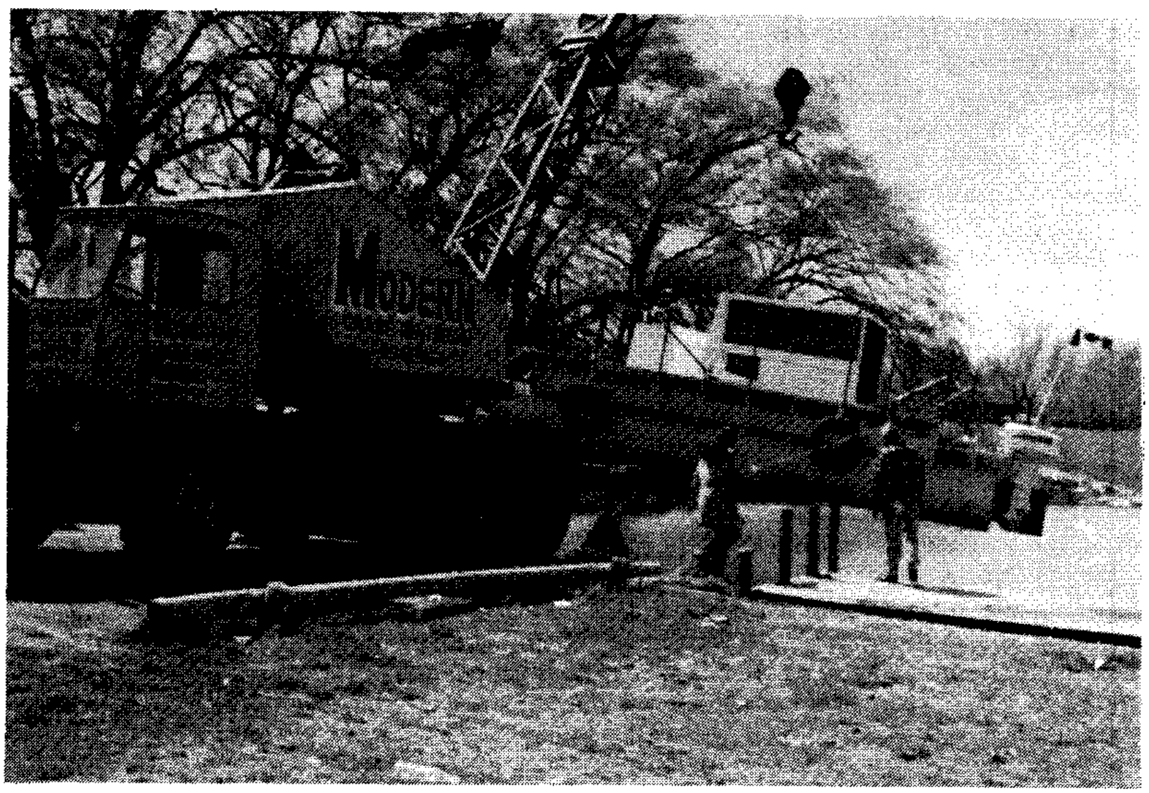


Figure 35
Launching 3rd Canadian Catamaran
Niagara River 1967

remained in service on the connecting channels until 1971, when it was reassigned to the National Water Research Institute and converted into a diving support vessel. It was powered by twin 33HP outboard motors and had a top speed of about 6 knots. A feature of its construction was light gauge sheet metal pontoons filled with styrofoam, which prevented water from entering the pontoon in case of puncture.

A more modern design of catamaran, which might also be classified as a motor launch, was designed and built on the Canadian west coast for hydrometric and sediment surveys on the Fraser and Mackenzie Rivers and introduced in the connecting channels in 1970 by Water Survey of Canada. Called the Wasuca III and shown in Figure 36, it was used for discharge measurements on the connecting channels from 1970 to 1975, when it was taken out of service due to lack of work and returned to the west coast. Of moulded fiberglass construction, it measured about ten metres (33 feet) in length with a beam of about five metres (16 ft). It was powered by twin stern drive 85 horsepower engines, and had a top speed of about 20 knots. The catamaran was equipped with a battery powered headwinch, but no side winches. Three meters were suspended from a custom built rack and lowered into the water through a hatch in the forward deck. The fourth meter was suspended from a crane at the stern.

Catamarans Nos. 3 and 4, shown in Figures 37 to 39, were the flagships of the U.S. Lake Survey fleet from the late 1940's to about 1975. Pictures of earlier catamarans are not available. Catamaran No. 5, shown in Figure 40 in the Maid of the Mist Pool on the Niagara River with support craft, was specially built for trailer transportation on the road down the side of the Niagara gorge to the Maid of the Mist dock, where it was launched in July 1967. It was used at the Maid of the Mist Pool section in a series of simultaneous measurements there and at the Stella Niagara Section in the lower Niagara River. The purpose of the measurements was to verify the Ashland Avenue gauge rating for Maid of the Mist Pool outflow for Niagara Falls flows of 50000 and 100000 cubic feet per second (1415 and 2830 cubic metres per second).

(2) Motor Launches

Because of their greater versatility and mobility, motor launches have now replaced catamarans as measuring craft on the connecting channels. One of the latest and most up to date is the 35 foot (11 metre) 'Korkigian' (Figure 41), named for Ira M. Korkigian, a former Committee member and head of the River Flows Section, Detroit District, Corps of Engineers. Of welded aluminum alloy construction with a 12 foot (4 metre) beam and 3 foot (1 metre) draft, and powered by twin inboard 350 HP engines, the Korkigian was designed by the Detroit District specifically for hydraulic measurements on the Great Lakes and connecting channels.

Launched in 1980, the Korkigian is outfitted with four boom and winch assemblies mounted on the forward deck (Figure 42), and carries a digital datalogger system (Figure 43) for recording current meter responses and echo soundings. This system provides for the recording of data on magnetic tape in a format for direct transfer to a computer for processing. The system was designed for data compatibility with Program 4316 as described in Section 5.5.

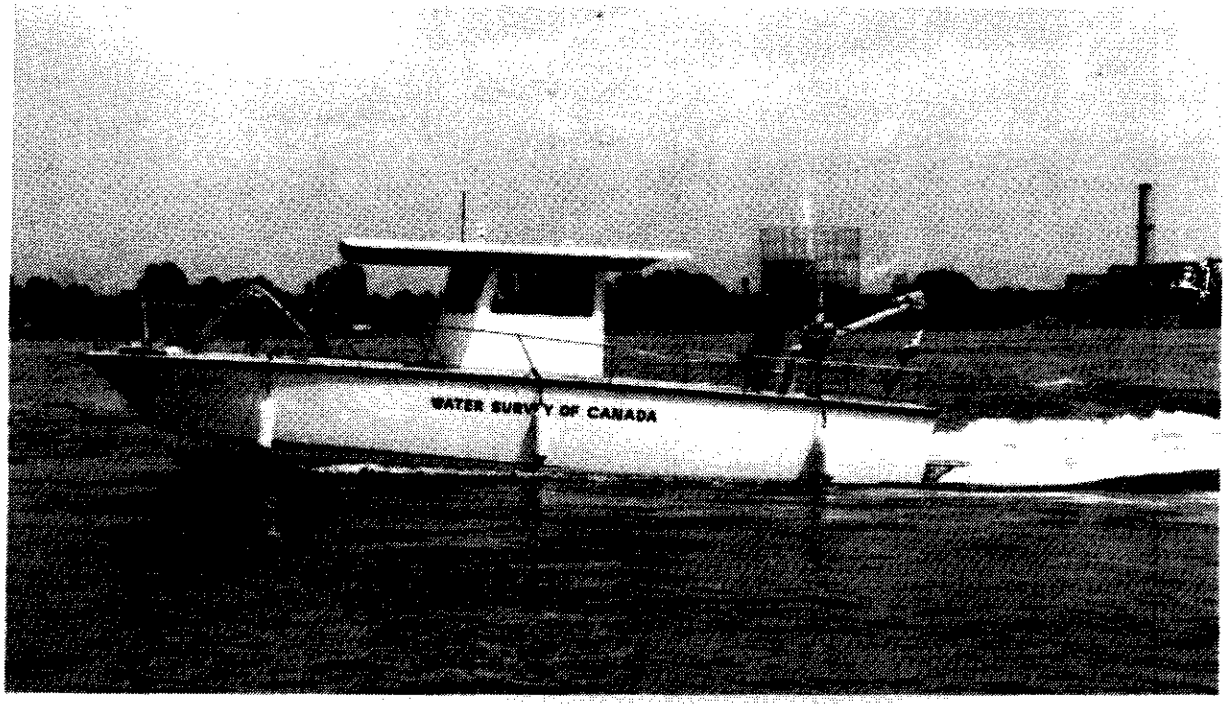


Figure 36a
ML Wasuca III - Niagara River 1972

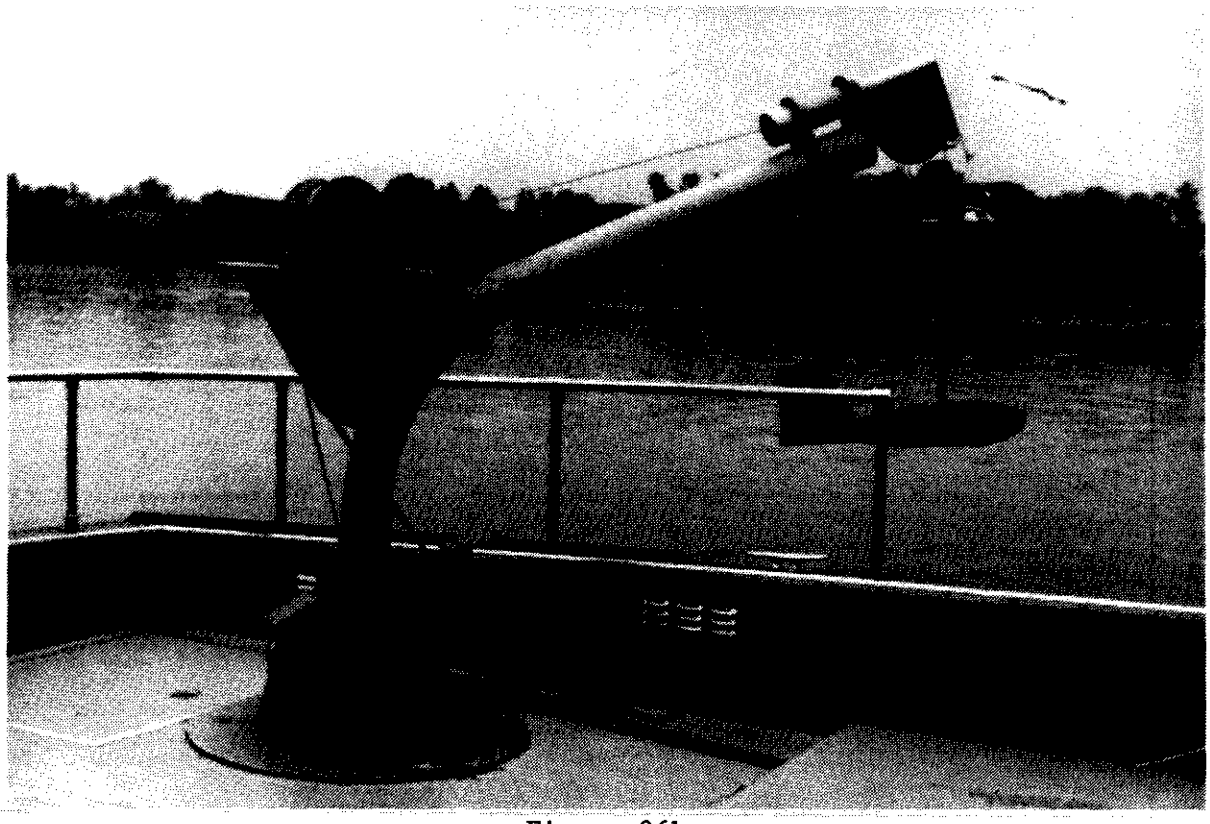


Figure 36b
Stern Meter Suspension Assembly - Wasuca III

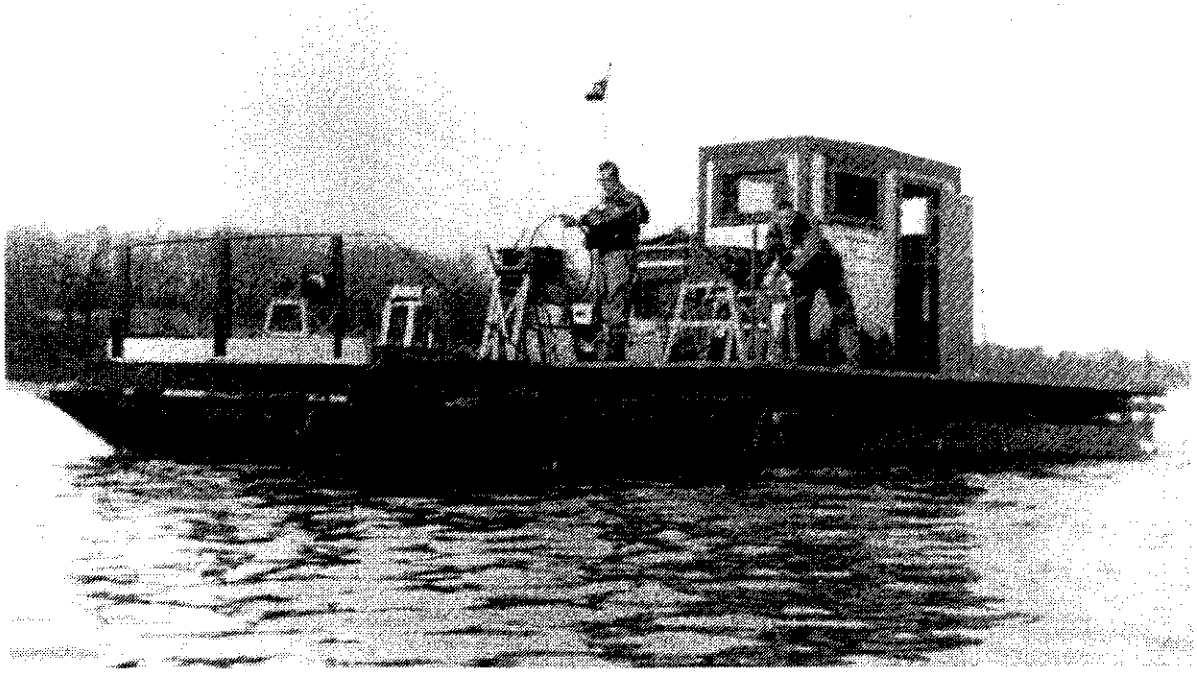


Figure 37 - U.S. Lake Survey Catamaran No. 3

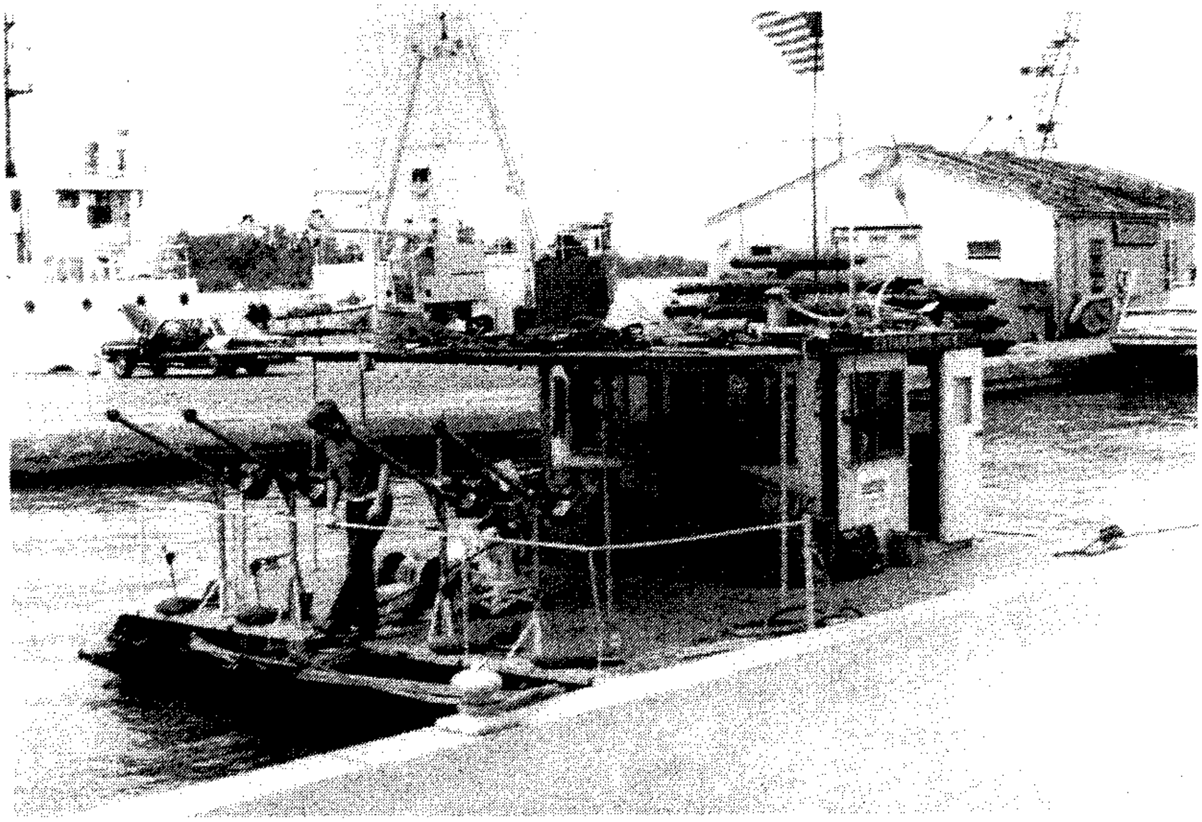


Figure 38 - U.S. Lake Survey Catamaran No. 4

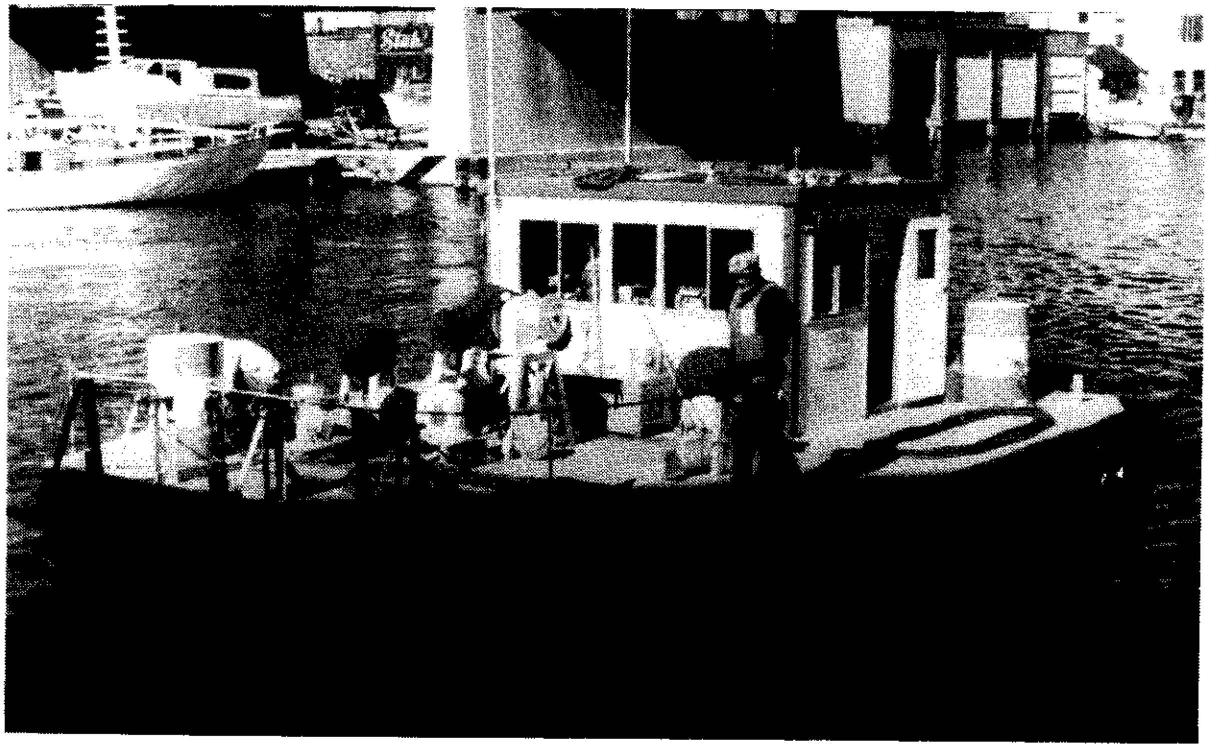


Figure 39 - U.S. Lake Survey Catamaran No. 4

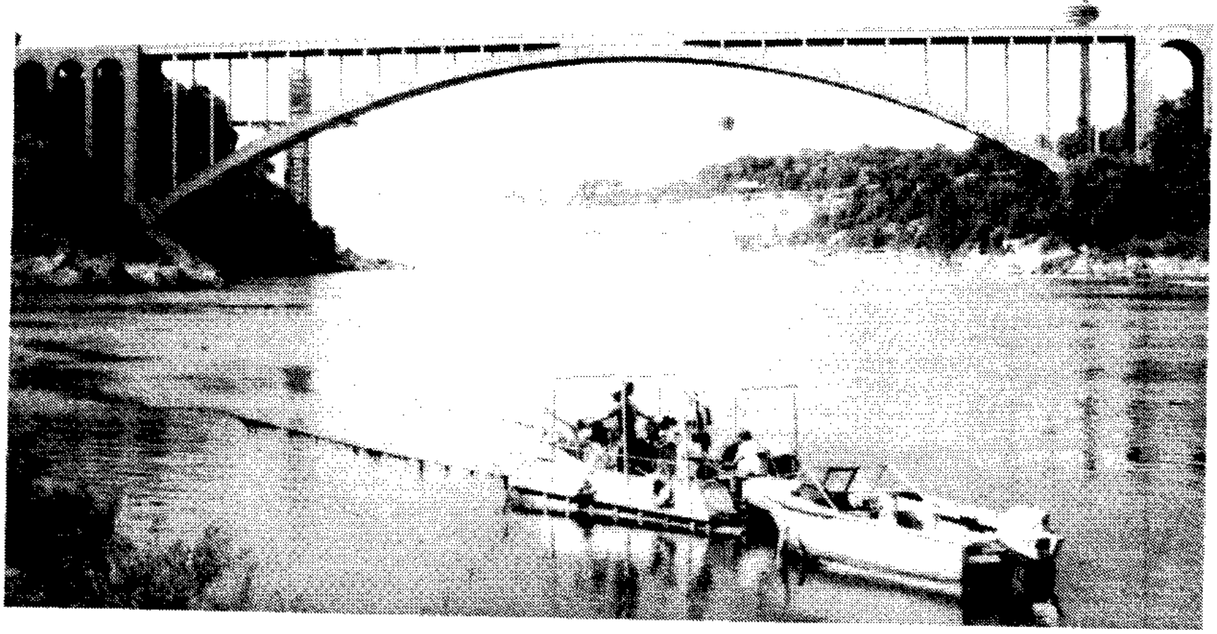


Figure 40 - U.S. Lake Survey Catamaran No. 5 with support launch
Niagara River - Maid of the Mist Pool - July 1967
(Rainbow Bridge in background)

Figure 41 - SL Korkigian on Detroit River
at Fort Wayne Hydraulic Section - Sept. 1976

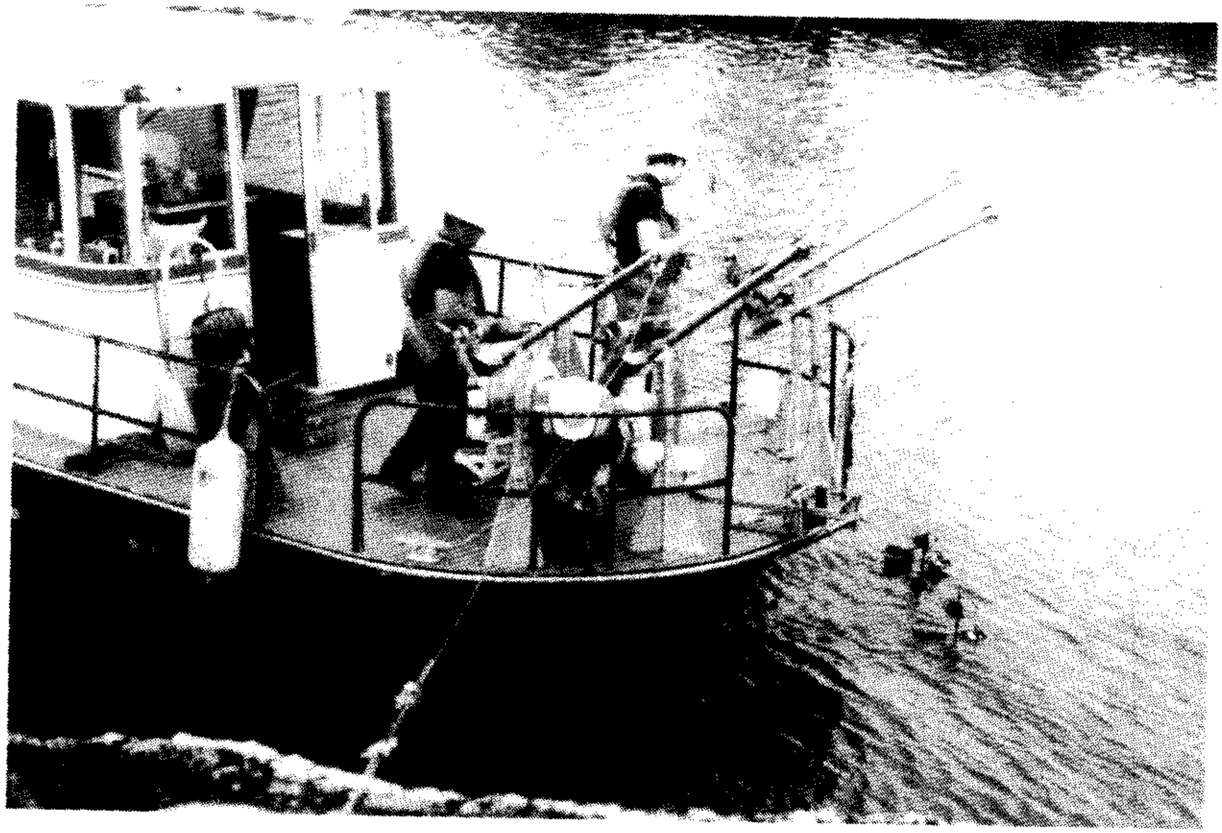


Figure 42
Meters suspended from forward deck of Korkigian

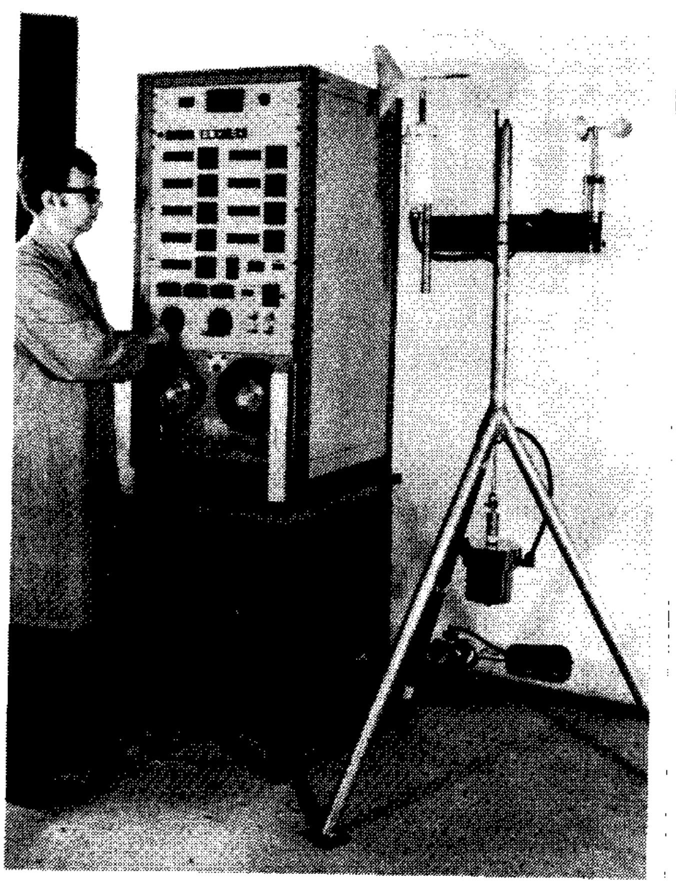


Figure 43
Digital Datalogger
aboard
SL Korkigian

Besides the Korkigian, the Detroit District also owns and operates two 6.5 metre (21 foot) motor launches for general duty, including discharge measurements, on the connecting channels. These exceptionally stable, cathedral hull, plate aluminum alloy launches have a beam of about 2.5 metres (8 feet) and a draft of about .4 metre (1.5 feet) fully loaded. They are powered by twin 85 HP outboard motors and are capable of speeds up to 25 knots, making them very versatile compared to most survey craft. Each has a heavy duty tandem wheel trailer for transport to work sites and storage when not in the water. The trailers can be towed by van or 3/4 ton pickup truck and the boats can be launched at most ramps.

Figure 44 shows Survey Launch No. 3 engaged in discharge measurements on the Chicago Canal at Lockport, Ill. Like the Korkigian, these launches are also outfitted with four removable boom and winch assemblies and the necessary wiring to operate four current meters simultaneously. As seen in Figures 44 and 45, two meters are suspended over each side of the boat from the rear deck. The launches are fitted with canvas convertible tops for the helm area, and can be converted to cabin launches with fiberglas or polycarbonate caps available as accesories.

The Hydrometric Methods Section of the Water Survey of Canada owns three jet propelled motor launches which can be available for discharge measurements on the connecting channels if required. One of these boats, the 12 metre (40 foot) "Aquagauger" is specially designed and outfitted for moving-boat measurements in tidal rivers, and is presently being used mostly in the lower St. Lawrence River, but would be ideal for measurements on the connecting channels as well. The other two are 7.5 metre (25 foot) aluminum shallow draft river boats powered by 450 HP inboard engines. One is outfitted with the latest sophisticated instrumentation for sediment and hydrographic surveys, and was used on the upper Niagara River at Fort Erie in September 1988 for site investigation surveys in connection with the installation of the Stork-Servex accoustic flowmeter at the Fort Erie Customs dock. The other is used mostly for moving-boat measurements, including many on the connecting channels, but is readily adaptable for conventional measurements, if required.

The Canada Centre for Inland Waters in Burlington, Ontario, which owns and operates a large fleet of vessels for water quality sampling and research in the Great Lakes and connecting channels, can also provide on a loan basis motor launches and operators for discharge measurements, and has done so on several occasions in the past.

(3) Anchoring

On projects of more than about ten measurements, the usual procedure in the past was to anchor a number of buoys above the section to support the catamaran during measurements. These buoys, which often were standard 200 litre (45 gallon) barrels, were placed along a line about 150 to 300 metres (500 to 1000 feet) above the measuring section in sufficient number to enable the catamaran to occupy all the measuring points on the section. Three to six buoys were usually required. If possible, the buoys were anchored by the metering party, using 30 to 45 kilogram (66 to 100 pound) hook anchors. The buoys were usually attached to the anchors by about

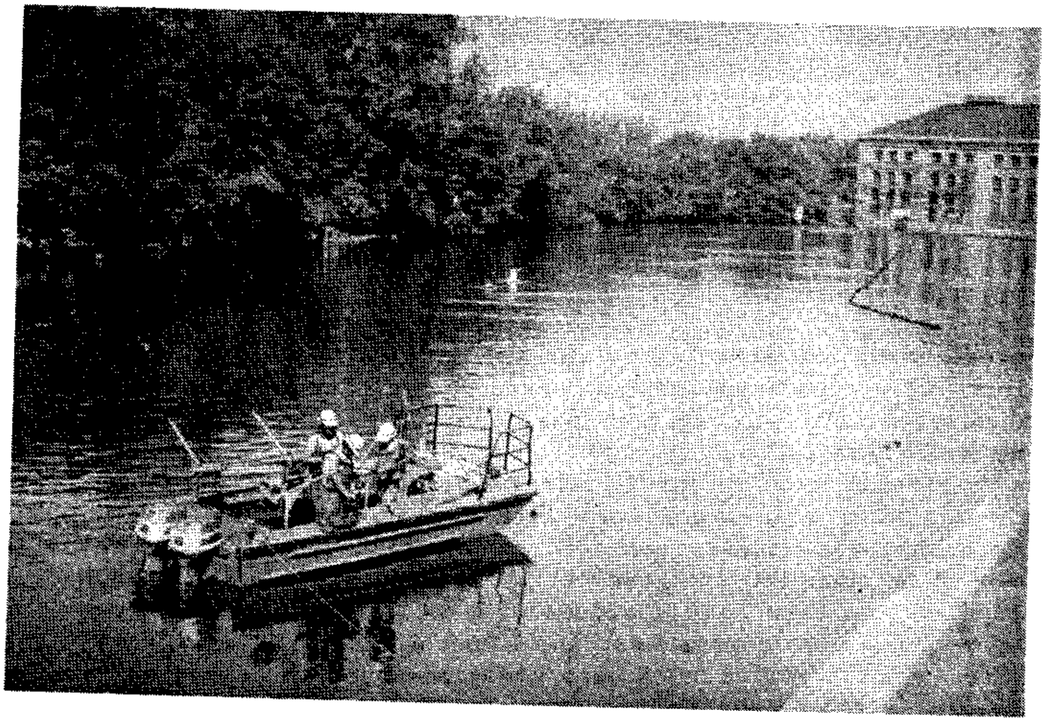


Figure 44
SURVEY LAUNCH #3 ENGAGED IN CURRENT METERING
AT LOCKPORT POWERHOUSE TAILRACE SECTION
(NOTE: STEEL CABLE, STERN LINE, SAVONIUS IN-SITU
METERING SECTION AND LOCKPORT POWERHOUSE)
Chicago Ship and Sanitary Canal - August 1979

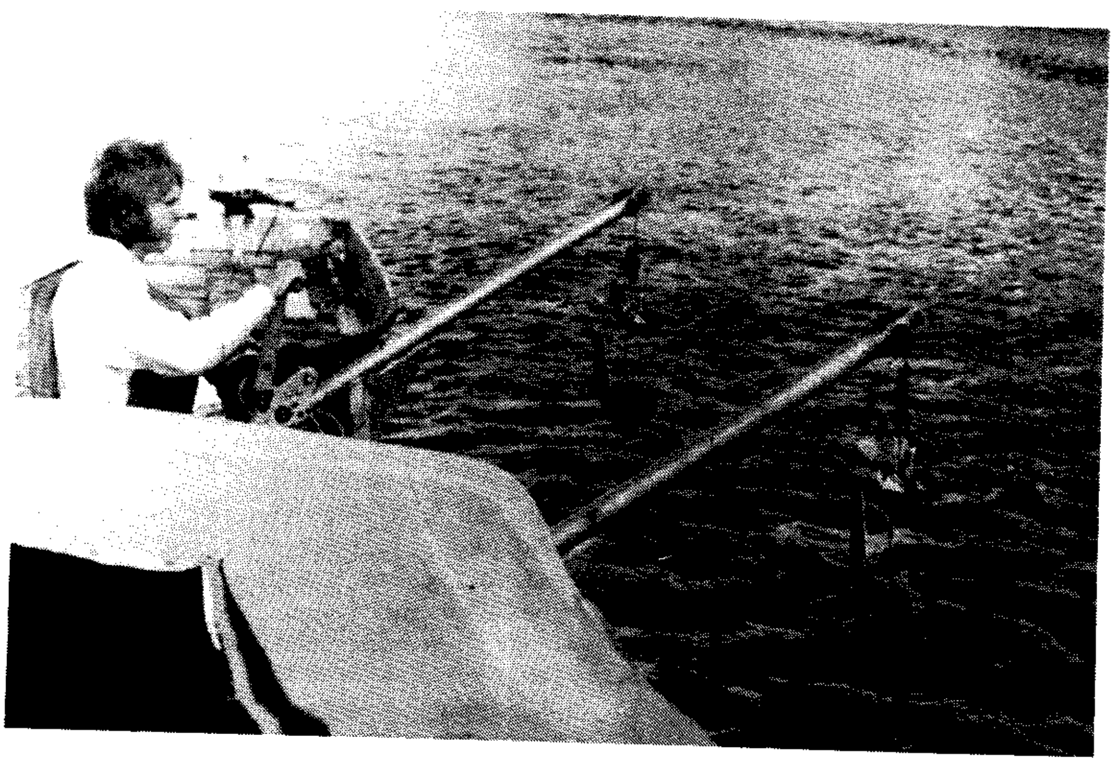


Figure 45
Meters suspended over port side of Survey Launch No. 3

100 metre (300 feet) of 8 millimetre (5/16 inch) steel chain or wire rope. If it was found that this type of anchor would not hold, the assistance of a U.S. Coast Guard or Canadian Department of Transport buoy tender was sought. They usually obliged by providing concrete gravity anchors, and on some occasions, as on the St. Lawrence River in 1953 (Figures 46 and 47), also supplied illuminated navigation buoys instead of the usual barrels. Lamps were attached to the buoys at all locations where there was navigation. Battery operated flashing barricade lanterns were often used for this purpose. On several jobs, notices to mariners advising of the buoys and the lines attached to them were issued in accordance with maritime regulations.

The catamaran was attached to the appropriate buoy by an 8 millimetre (5/16 inch) wire rope headline and backed down to the section where it was then manouvered into the required position. Floats were attached to the headline as it was let out to mark it for traffic and to prevent it from sinking to the bottom. Four to six panels were usually occupied from each tie-up. The catamarans were also fitted with side line winches. One side anchor was usually deployed to one side or other of the series of panels to be occupied from the current tie-up and the line drawn taut. The catamaran was then held stationary by pulling against the two lines with the rudders. At panels near the banks a side line was usually tied to a shore anchor. Sea anchors were sometimes used to help stabilize the catamaran in difficult conditions, such as a combination of a stiff tail breeze and a weak current. The use of bow thrusters or rudders has been suggested as an aid in stabilizing boats or catamarans while measuring, but has not yet been tried on the connecting channels.

For fewer than ten measurements buoys were not usually used. Instead the catamaran was attached directly to the anchor, which was usually a 20 or 25 kg anchor of the Danforth or Northill type. The anchor was dropped a distance upstream equal to about twenty times the depth, to a maximum of about 200 metres or 600 feet. Four to six panels were usually occupied from each anchorage. In other respects, procedures were much the same as described in the preceding paragraphs.

Since setting anchors is laborious and time consuming, side anchors have seldom been used in recent years, thus placing added reliance on the skill of the boat operator to maintain position with engines and rudders, or accept a lower standard of accuracy. With reduced availability of time and labour, it is expected that anchoring and setting of buoys will be eliminated in future measurements and reliance placed solely on operator skill assisted by automated positioning systems. This has started to take place in 1987 and later measurements on the Niagara and St. Marys Rivers. The results of these measurements are presently under review.

Conventional measurements without anchoring have now been successfully conducted for several years by the Water Survey of Canada on large rivers in western Canada, and the results are reported to compare favourably with moving-boat measurements. Although in these measurements, as in regular conventional measurements using anchors, it is mandatory to maintain the boat as stationary as possible while metering, this applies particularly to lateral motion along the section line, which always increases meter readings. Meter motion in the direction of the current, i.e. drift, can

Figure 46
Mooring Buoys - St. Lawrence R. at Point 3 Points
January 1954

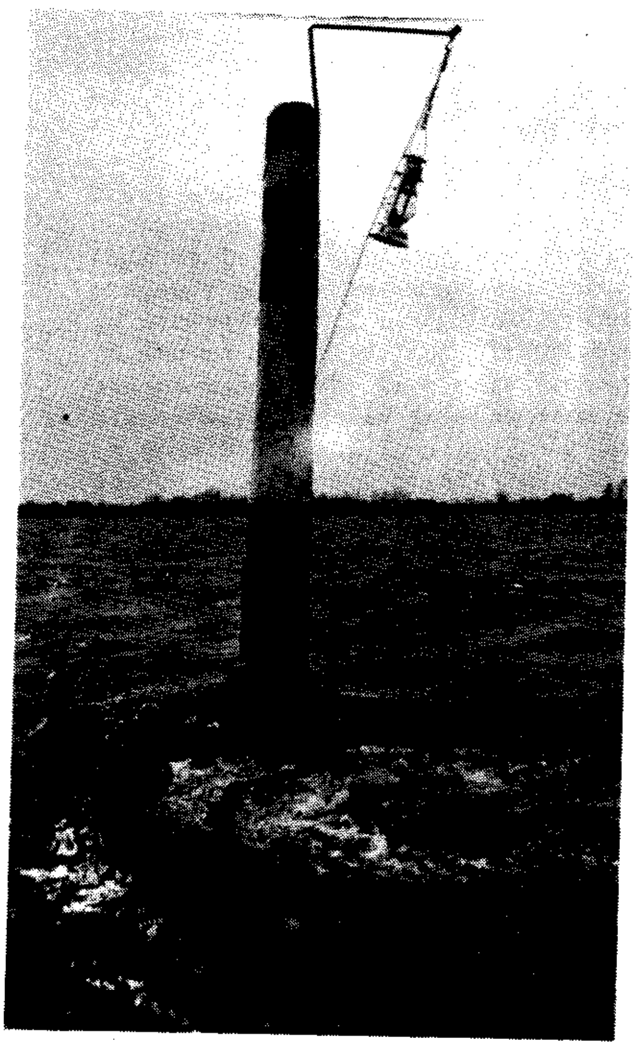


Figure 47
Spar Mooring Buoy
St. Lawrence R. at Pt. 3 Points
January 1954

be either positive or negative, and theoretically should compensate if the meter is on the section line at the beginning and end of the timing period. To achieve this would require a change from fixed to variable meter timing periods.

A study of the effect of drift on velocity measurement was conducted by the International Organization for Standardization (ISO) and reported in Paper 748-1973, Annex D (Reference 10). Because the study is considered relevant to present and future measurements on the connecting channels, Annex D is appended hereto as Appendix C.

(4) Positioning of Boats at Measuring Points

Where conditions, i.e. width, current speed, and boat traffic, permit, a graduated wire cable commonly called a tag line stretched across the channel is the simplest and most satisfactory way to position a boat for discharge measurements. But the use of tag lines is possible on only a few diversions on the connecting channels, such as power canals. On the mainstreams, range lines and instrumentation must be used to position the boat or catamaran at the required locations.

Range lines set up on the banks as previously described were usually used to position boats on the section line. Once on line, the boat was positioned at the required distance along the line by electronic distance meters (EDMs) since the early 1970s; before then by trigonometric methods using either a sextant or a theodolite to measure the angles, or by means of individual panel range lines (the pivot method). These methods are described briefly in the following paragraphs.

(1) Electronic distance meters - these instruments, which use radio or infra-red transmissions to measure distances between master and remote units, became economically available in the early 1970s, and since then have been used almost exclusively for positioning boats at the required locations on the measuring section. The primary unit is usually set up in the boat and the secondary or remote unit at a control point on one of the banks. The distance between the two instruments is then continuously displayed on either or both units. The most popular makes of electronic distance meters used to date on the connecting channels include MicroFix, Tellurometer (shown in Figure 48), Hewlett-Packard, Motorola, Del Norte, and Wild-Leitz.

(2) Sextant or theodolite (transit) - these instruments were used to read the predetermined angles for positioning the boat at the required location on the section line, assuming the boat to be on the line. Since the length of the base line and the angle between it and the section line were known from previous measurement, measurement of a second angle in the triangle formed by the base line and the boat permitted solution of the triangle and hence the distance of the boat from the control point. The length of the base line was made at least one third the length of the section line to ensure a minimum sextant or theodolite angle of twenty degrees at the far end panel.

A sextant, usually operated by the boat operator, was used to measure the angle at the boat subtended by the base line. Since its use did not

Figure 48
Electronic distance meter - 1973

require an extra man, as in the case of a theodolite, it was the preferred instrument for this purpose. The first diagram in Figure 49 is a sketch of a typical layout for positioning a boat using a sextant or theodolite. The accuracy of a sextant in this application is discussed in Reference 34.

A theodolite was used to position the boat by turning off the angle at the remote end of the base line or other strategic point in the control network. Commumication between the instrumentman (or cut-off man) and the boat was effected by hand signals or radio.

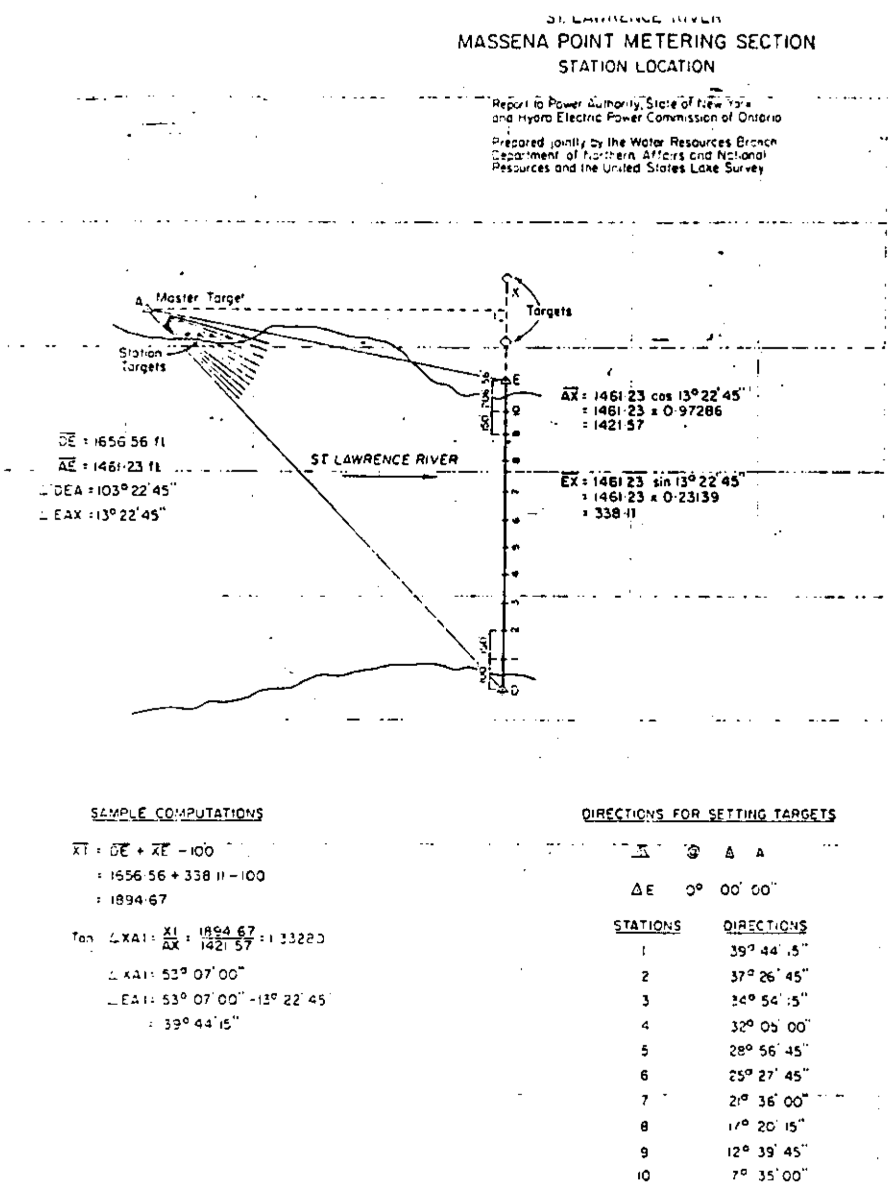
At some sites, after the required position was initially determined by sextant or theodolite, it could be referenced to the alignment of vertical objects in the vicinity such as poles, trees, towers, building features, etc. against distant objects or irregularities in the sky line. Sketches or photographs showing these panel reference objects were sometimes used.

(3) Individual panel range lines or the pivot system - this system required more preliminary preparation than other systems, but once in place afforded the best control (prior to EDMs) and therefore was the most widely used method of positioning a boat during discharge measurements. A range line was set up for each panel, and the boat operator positioned the boat at the intersection of the appropriate range line and the section line. Two examples of layouts are shown in Figure 49. Details of the layout at each site depended on bank and other local conditions, but most layouts comprised a row of panel markers near the bank, more or less parallel to it, and a common (or master) target in the background. At the International Railway Bridge section on the upper Niagara River at Fort Erie/Buffalo, the smoke stack of the Buffalo incinerator was used as the rear section line marker, and corresponding upstream and downstream bridge truss members were used for panel range lines as shown in Figure 49.

(4) Tag lines - usually made of 4 to 6 millimetre (1/8 to 1/4 inch) diameter galvanized or stainless steel strand, tag lines were used on some of the narrower channels where there was no navigation or boating. These sections included the Niagara River at the cableway section before construction of the cableway, the Great Lakes and U.S. power canals at Sault Ste. Marie, the Erie Canal at Lockport, New York, the Chicago Ship and Sanitary Canal at Lockport, Illinois, and the Welland supply canal at Port Colborne, Ontario. Figure 50 shows measurements in progress at two of these sites.

5.6 Wading Measurements

The only wadeable channel in the subject waterways is the Fisheries Remedial Channel on the north side of the St. Marys River rapids section at Sault Ste. Marie. This channel was separated from the main channel by a concrete dike built in 1984 and the flow is regulated by Gate 1 of the Lake Superior Compensating Works. Two wading measurements were taken in this channel at a section just below the international highway bridge in October 1987, to check the Gate 1 rating developed by Acres Consultants. The measurements involved stringing a tag line across the channel, which has a width of about 45 metres (150 feet) and a maximum depth of about 1.1 metre (3.6 feet) at this section, and measuring depths and velocities



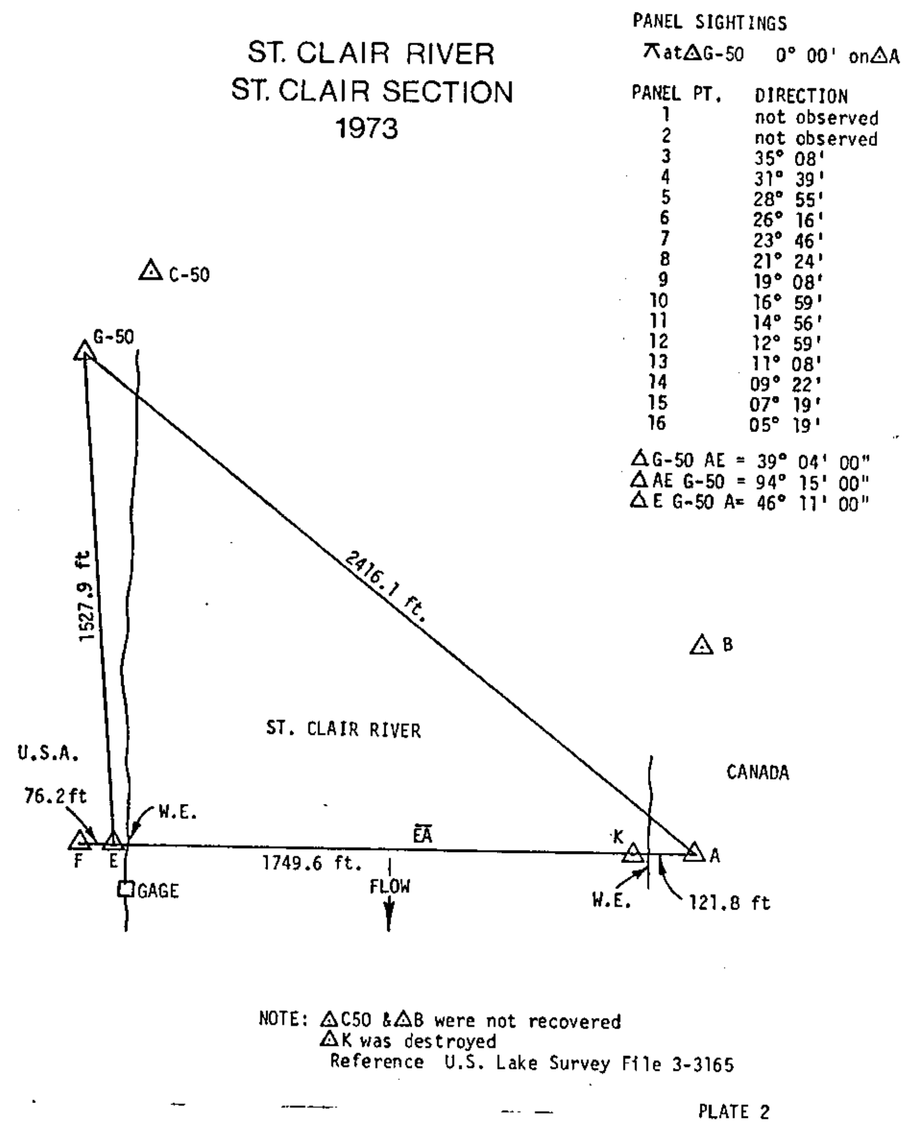
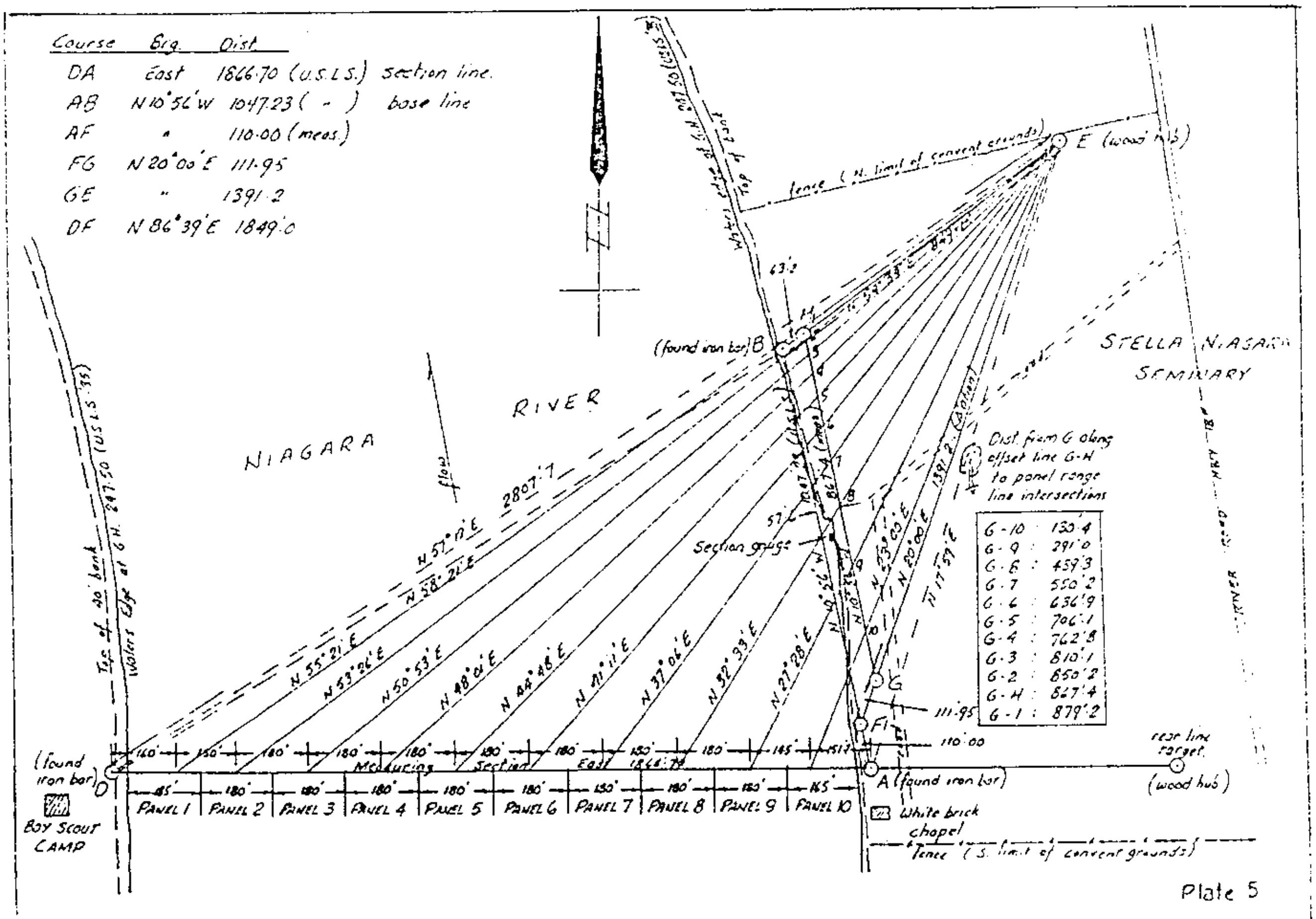


Figure 49 - Horizontal Control Layouts



Pivot Control Network
Stella Niagara Section - 1967

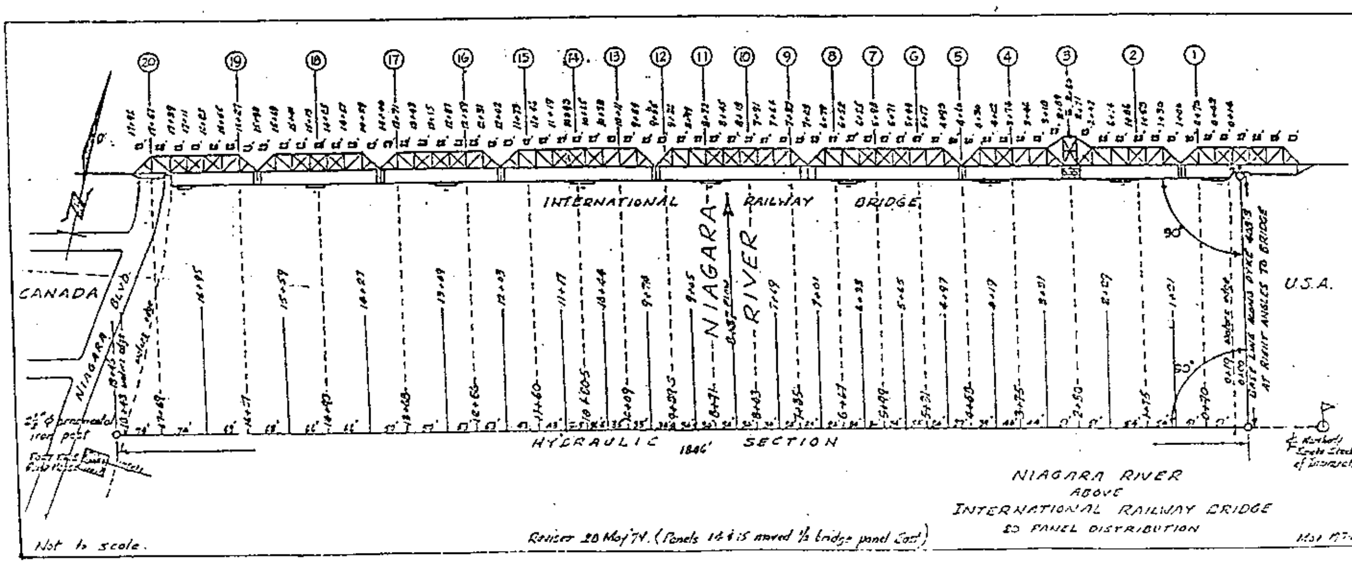
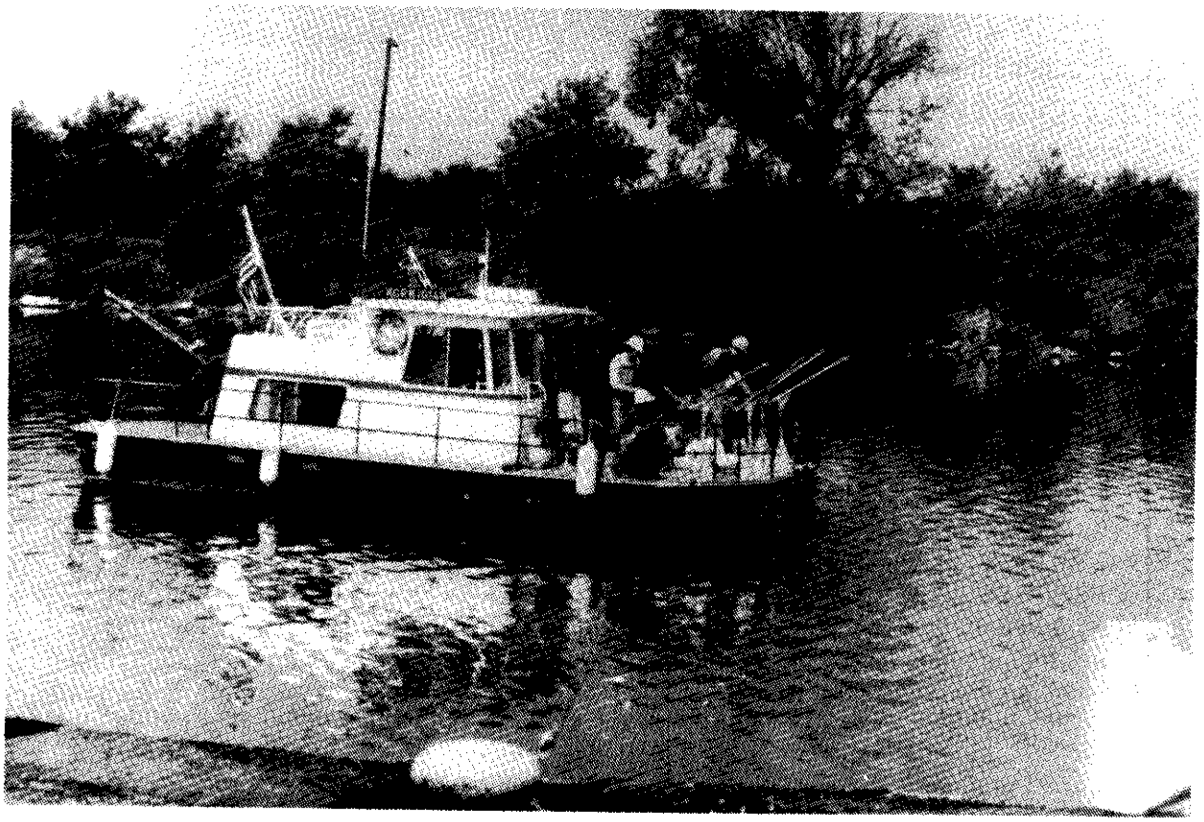
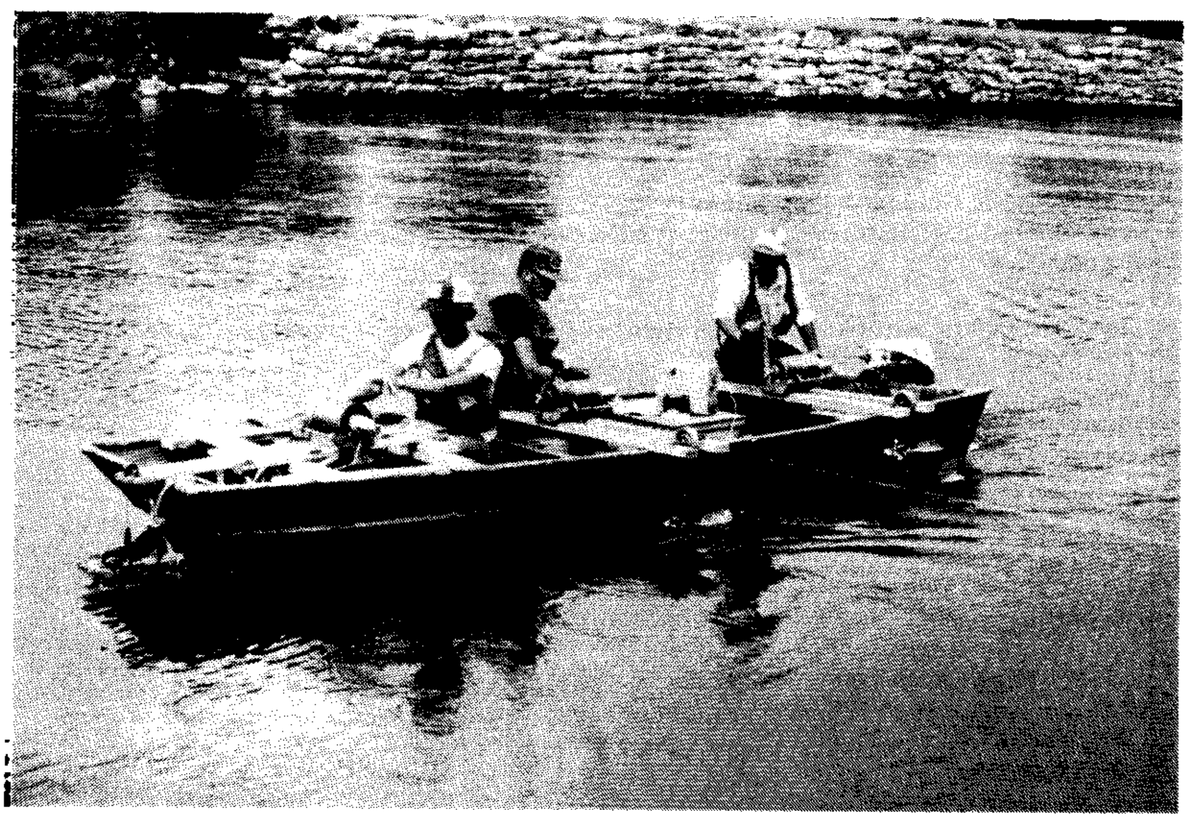


Figure 49 (Cont'd.)
Horizontal Control Networks



SL Korkigian at the Lockport Upper Pool Section
August 1979



Photograph of Discharge Measurements at the Welland Canal taken on 9 August 1984.

Figure 50
Boat Measurements using taglines

ENCLOSURE 2

at twenty evenly spaced points across the section. The current meter was mounted on a standard Water Survey of Canada wading rod and velocity readings were taken at .2 and .8 of the depth at verticals more than .6 metre deep, and at .6 of the depth at verticals less than .6 metre deep. The average of the .2 and .8 depth measurements, and the .6 measurement were assumed to be the mean velocity in the vertical. Measured discharges were about 15.5 m3/s (550 cfs).

5.7 Measurement of Velocity

(1) Current Meters

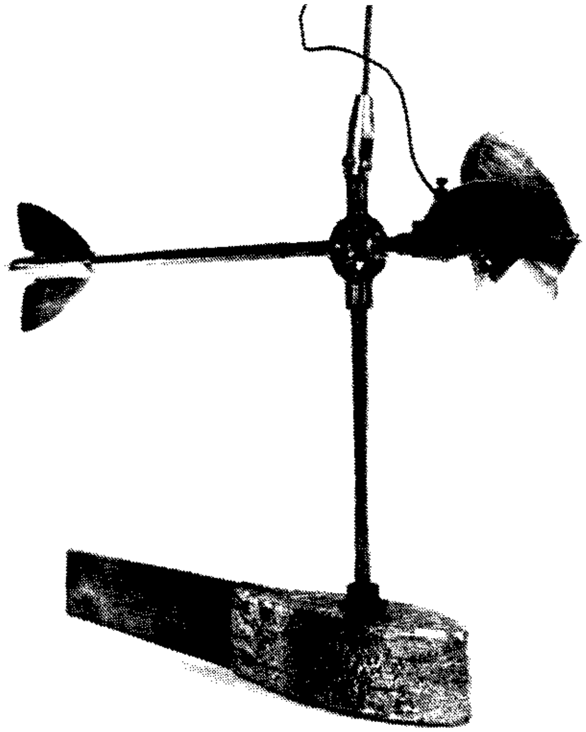
The first current meters used by the U.S. Lake Survey on the connecting channels were mechanical meters with both cup and propeller type rotors. They operated on the principle that their rotor speed is proportional to current speed, as do present day meters; see meter ratings, Section 5.7(2). The cup meter, or Henry meter, was developed by D.F. Henry in 1867, and was found to be superior to the propeller meters because of less friction and a more stable rating. Henry meters were used in measurements on the Niagara and St. Clair Rivers in 1868 and 1869. The Haskell meter, shown in Figure 51, was developed by E.E. Haskell in 1893 for the U.S. Lake Survey and was first used by that agency in 1895 on the St. Marys River. It was also used by Public Works Canada in measurements on the St.Lawrence River from 1915 to 1920. The meter was supplied with interchangeable propellors of different blade pitches for optimum performance in a wide range of current speeds. It was the standard meter of the U.S. Lake Survey from 1895 to 1954, when it was replaced by the Price meter.

The Price cup-type current meter, also shown in Figure 51 with a 100 lb (45 kg) Columbus stabilizing weight, was first used on the connecting channels in 1909 on the St. Clair River. It was developed in 1882 by W.G. Price, and was a redesign of the Ellis meter developed in 1870 by T.G. Ellis. The meter was used by the U.S.Lake Survey, the U.S.Geological Survey, and Water Survey of Canada periodically from 1909 until 1953, when it became the standard meter for discharge measurements on the connecting channels.

The decision to replace the Haskell meter with the Price meter was the result of comparisons of their performances in a joint U.S. Lake Survey and Water Survey of Canada measurement program on the St. Lawrence River at Point Three Points section in June and July 1953 (see Reference 36). The relevant section (VII-c-1) of the report reads as follows:

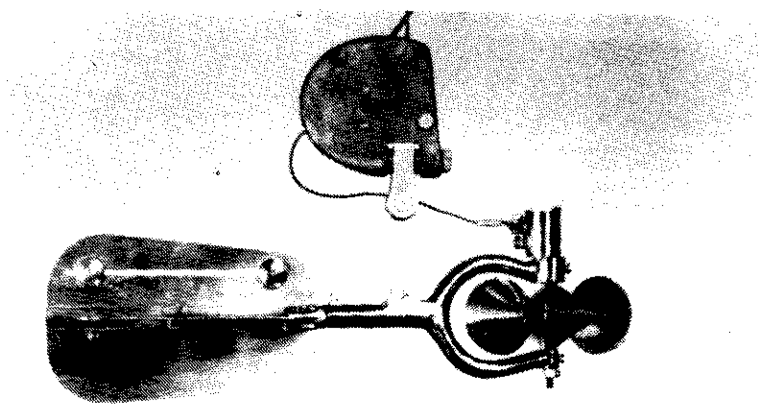
"(1) Comparison of Haskell and Price Meters: 26 concurrent measurements (listed in Table 2) were made using Haskell and Price meters. In 18 cases the Haskell meters and in 8 instances the Price meters registered higher velocities.

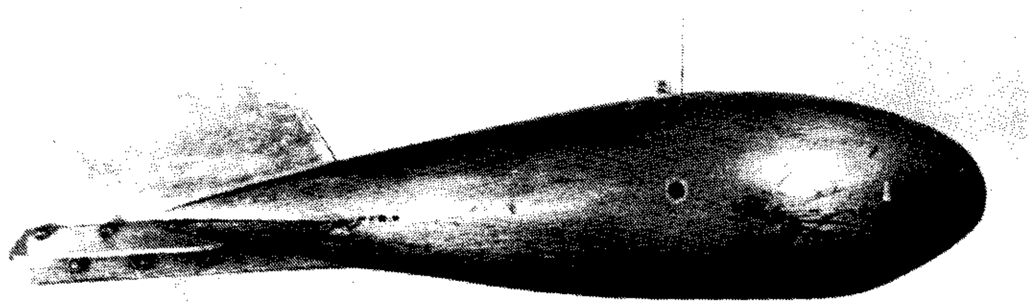
Discharges computed from Haskell readings averaged 1.3 percent higher than those computed from Price meterings. The greatest variation of any Haskell metering from its concurrent Price metering was about six percent. When Haskell meters were operated concurrently, readings from individual meters showed a greater variation than when Price meters were operated concurrently.



Haskell Current Meter
with old style weight

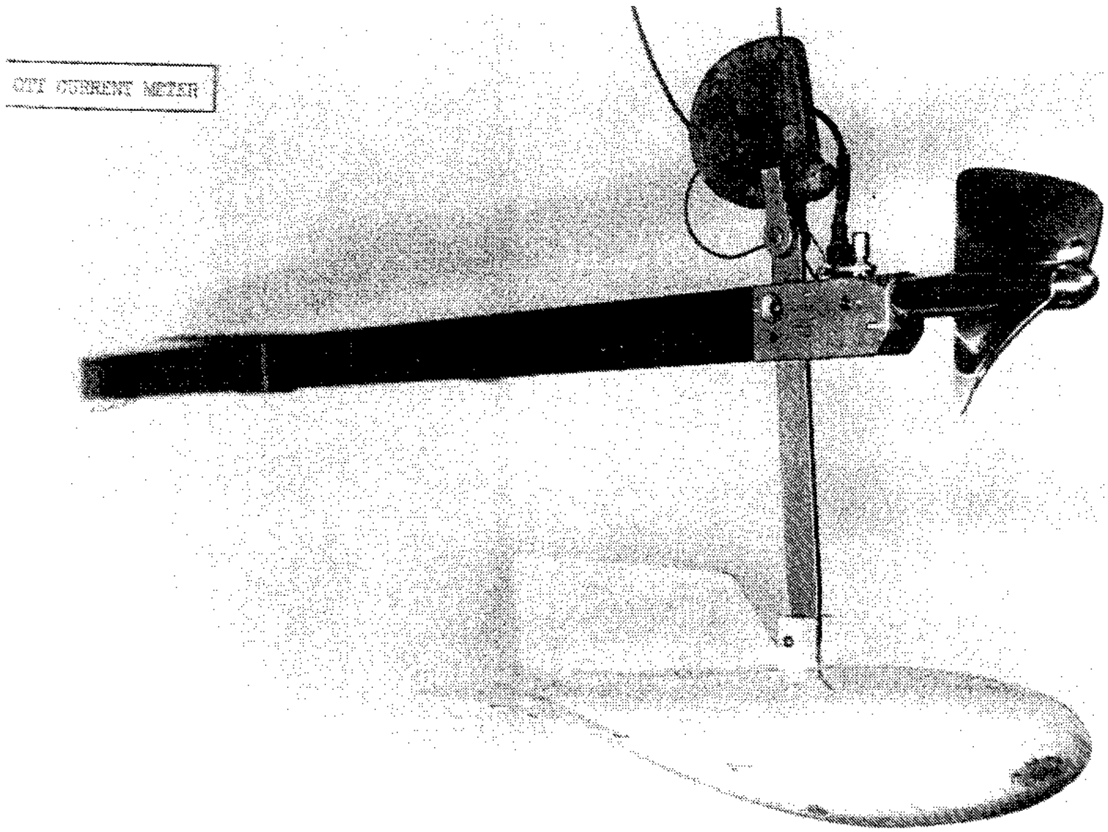
PRICE CURRENT METER



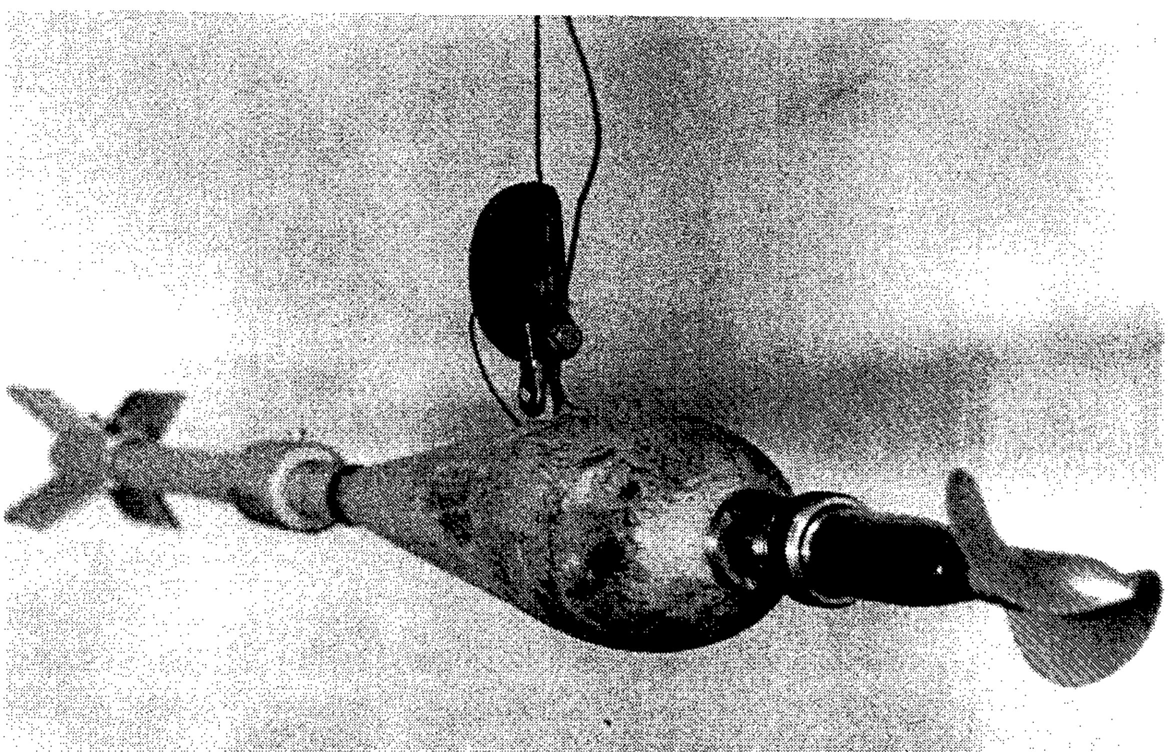


Price 622AA Current Meter with 45kg (100 lb) Columbus Weight

Figure 51 - Current Meters



Ott current meter with 40kg (88 lb) Special weight



Nehyrpic Meter with integrated weight

Figure 51 (Contd.) - Current Meters

It should be pointed out that, when considering the difference in the two makes of meters, the Price meters were rated by the Calgary rating station and the Haskell meters by the metering station at Ann Arbor, Mich. If further comparison of these meters is required, ratings should be made at the same station under identical conditions."

Over the next several years the U.S. Lake Survey acquired a number of new meters, including the German made Ott and the French made Nehyrpic meters, also shown in Figure 51. Both these meters are of the propeller type, widely used in Europe at the time. The meters were tested at the Stella Niagara section on the lower Niagara River in 1957 and 1958 (see Reference 29). The tests indicated the performance of the meters to be comparable to the Price meter under normal conditions, and superior under conditions of heavy loadings of moss or grass, where the Price meter is vulnerable to fouling due to grass winding around its exposed vertical shaft. Hence the Price meter was adopted as the standard meter for conventional measurements in normal conditions, and the Ott meter was relegated to standby service in special conditions, such as on the Niagara River at the Robert Moses cableway in August 1974, when heavy loadings of moss were experienced. However, the Ott meter has been adopted as the standard meter for moving-boat measurements because it is less affected by oblique currents.

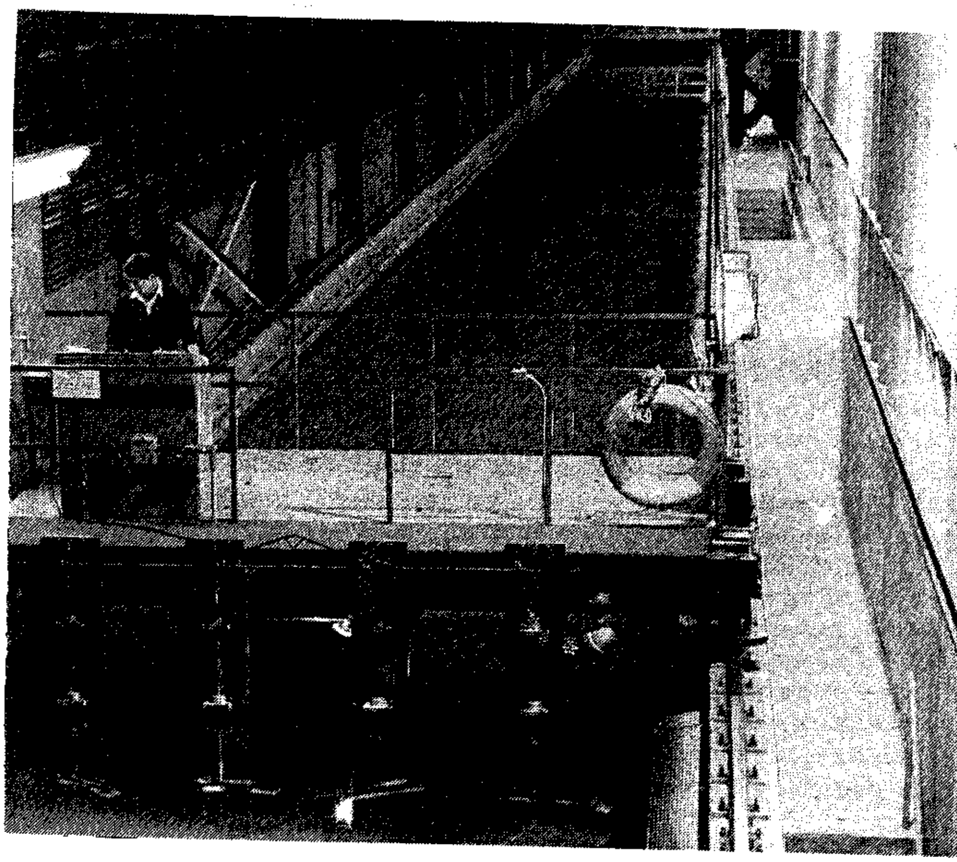
Other makes of meters tested in earlier measurements were the Hoff and Gettner meters, both with propellor rotors. Reports on their performance are available in U.S. Lake Survey files. The only recorded use of another early meter, the large Price meter (Pattern 600), was on the St. Lawrence River at Weaver Point, where it was used in 13 measurements in the summer of 1954, and in 17 measurements in the winter of 1955. The job reports state that it did not retain its rating as well as the small Price meters (Patterns 622 and 623), and its use was discontinued.

(2) Current Meter ratings

Meters were rated before and after each measurement program at meter rating stations similar to the one shown in Figure 52, reproduced from Reference 35. The U.S. Lake survey and the Detroit District, Corps of Engineers utilized a rating station at the University of Michigan in Ann Arbor, Michigan, and the Water Survey of Canada operated one at Calgary, Alberta, until 1969. Since then, Water Survey of Canada meters have been rated by the National Calibration Service of the National Water Research Institute (NWRI), a branch of Environment Canada, at the Canada Centre for Inland Waters in Burlington, Ontario. The towing tank and carriage at this facility are described in Figure 52.

The following description of the theory, equipment, and procedures for rating meters is excerpted from Reference 32. The meter was rated in combination with the same stabilizing weight and hangar bar used in discharge measurements.

"The rating of the meter is accomplished by propelling it over a measured course through still water in a rating flume. The flume at the Bureau of Standards is 400 feet long, 6 feet wide, and 6 feet deep, and the meter is moved through it at various uniform speeds ranging from the



1.3 Towing Tank and Carriage

The towing tank and carriage are used by the National Calibration Service to calibrate all types of current meters for government departments, educational institutes and the private sector. The facility is also used for various other hydrodynamic tests on models, prototypes and instruments.

The carriage can be operated on board or from a control room. Operation from the control room, in addition to the manual mode, provides an auto-sequence mode and a preselect mode. The auto-sequence mode allows the operator to program the carriage to execute six successive speeds in any one of the three speed ranges during any one run. The preselect mode allows the operator to preset up to six speeds. In this case, however, the system does not execute the sequence automatically but rather successive velocities are engaged at the discretion of the operator.

Tow Tank

The tank, constructed of reinforced concrete, founded on piles, is 122 metres long and 5 metres wide. The full depth of the tank is 3 metres, of which 1.5 metres is below ground level. Normally the water depth is maintained at 2.7 metres. Concrete was chosen for its stability, vibration reduction and to reduce possible convection currents.

At one end of the tank is an overflow weir. Waves arising from towed current meters and their suspensions are washed over the crest, reducing wave reflections. Parallel to the sides of the tank, perforated beaches serve to dampen lateral surface wave disturbances. The large cross section of the tank also inhibits the generation of waves by the towed object.

At the head and half way along the tank a set of three observation windows, let into one of the side walls below ground level, permits subsurface observations.

Towing Carriage

The carriage is 3 metres long, 5 metres wide, weighs 6 tonnes and travels on four precision machined steel wheels. An opening of 1.7 metres by 1.4 metres in the floor symmetric about the geometric centre of the carriage permits suspension of large current meters as well as other test bodies.

The carriage is operated in three overlapping speed ranges: 0.5 cm/sec-6.0 cm/sec; 5.0 cm/sec-60 cm/sec; 50 cm/sec-600 cm/sec. In all speed ranges the constant speed is well within a tolerance of ±1% of the mean. The maximum speed of 600 cm/sec can be maintained for 12 seconds within the specified tolerance.

The carriage velocity data are obtained with an electronic counter which measures the average period of the pulses emitted from the measuring wheel within a fixed measurement time of 0.2 seconds.

The carriage position along the tank is obtained by accumulating the pulses from the measuring wheel in an electronic events counter. Although distance is not a direct parameter required for calibration with this system, it is important for many other tests.

Figure 52
Meter Rating Facility
Courtesy Environment Canada - National Water Research Institute

lowest speed that will cause the meter wheel to revolve to the highest speed that it is anticipated may be needed in the use of the particular meter being rated. The results of the various runs of the meter are plotted, with speed of travel on one axis and revolutions of the meter wheel on the other: a curve is adjusted to the points thus obtained and the curve is converted to tabular form for convenience in use."

"This method of rating assumes that the same rate of rotation of the meter wheel will occur when the meter is propelled through still water at a certain speed as when the meter is held at a fixed point in water flowing past it at that speed. It has not been, and perhaps cannot be, proved that this assumption is strictly correct. However, comparisons of current meter measurements of discharge with measurements of the same water by weirs, calibrated tanks, and weighing tanks have demonstrated that there can be no appreciable error in the meter ratings thus made in still water"

Meter ratings are usually one or more straight lines relating speed of the medium (current speed) to rotor speed over a specified range of current speeds, as follows:

$$v = An + B \qquad (v1 < v < v2)$$

where: v = current speed in m/s or ft/s, and v1 and v2 are the limits of the rating;
n = rotor speed in revolutions/sec

and A and B are regression coefficients. Generic coefficients for the Price 622AA meter are .670 and .006 for metric units and 2.20 and .020 for English units. Individual ratings seldom depart by more than one or two percent from these values.

(3) Meter Suspension and Recording Systems

The most frequently used meter-weight combination on the connecting channels was a Price 622 meter mounted on a steel bar above a 45 kg (100 pound) Columbus style lead stabilizing weight, as shown in Figure 51. The hangar bar was drilled so that the distance from the axis of the meter to the bottom of the weight was usually an even 1 foot (30.5 cm) and the depth counter on the sounding reel was usually set to zero with the meter at the water surface. Thus meter setting depths were read directly, but a one foot correction had to be added to soundings. Two-foot hangar bars were used on occasion in earlier measurements to reduce the effect of the weight on meter response, but were awkward to handle and susceptible to damage, and so are now seldom used. They are considered unnecessary since the influence of the weight on the meter is accounted for in the rating.

The meter weight combination was suspended by special Ellsworth reverse lay galvanized steel cable, 2.5 mm (0.1 inch) diameter, with an insulated conducter in the core for transmitting electrical impulses from the meter to the counter. The cable was wound on a sounding reel, with the conductor at the dead end of the cable connected to a brass pickup disk. Electrical impulses were transmitted from this disk via a carbon brush to the counter circuit. The free end of the cable, after passing through a series of sheaves, was attached by a special connector to the top of the hanger bar supporting the meter weight assembly. U.S. Geological Survey type "B" sounding reels were generally used for sounding and meter suspension. These aluminum reels have drums of 145 mm (5.75 inches) diameter and are fitted with a depth counter and a brush and pickup disk to complete the electrical circuit from the meter to the counters. They are also equipped with a clutch to permit weights to be lowered by gravity, and some with a pulley and gear train for power operation.

The systems of cranes and sheaves used to suspend the meters over the front or sides of the boat were customized to the individual boat. On the older catamarans, the meters were suspended three or four abreast over the bow as seen in Figures 33 and 38, and spaced 1 to 1.5 m (3 to 5 ft) apart. On launches, two cranes were usually mounted on each side, one about 1.2 m (4 feet) ahead of the other as in Figures 44 and 45. The third Canadian catamaran and the Wasuca III had hatches in their forward decks through which three meters were suspended abreast.

At bridge sections the cranes were mounted on dollies or carts as in Figures 27 and 28. A folding bridge crane specially designed by the U.S Geological Survey for bridge measurements, called an "A" crane, is shown in Figure 28 being used in a bridge measurement on the Erie Canal at North Tonawanda, N.Y. in 1973. At the Robert Moses Cableway on the lower Niagara River a single B reel is mounted on a bracket in the cable car (Figure 29).

Recording Systems

Meter revolutions were transmitted as electrical impulses produced by closing a low voltage electrical circuit by a wire contact or magnetic reed switch in the meter head, to electromagnetic counters through a system of cables and relays. The revolutions were usually counted for time periods ranging from one to five minutes, with two minutes the most common. The earlier counters were permanently installed on the control panels in the cabins of the catamarans, but later models were mounted in banks of 3 or 4 in compact portable cases with the necessary controls for use in most types and conditions of measurements.

(4) Metering Procedures

The mean velocity in a vertical can be measured directly by a technique called depth integration, or estimated from point velocity measurements at a number of selected points in the vertical. The latter procedure was generally used in the subject measurements, but since there may have been occasions on which the first procedure was used, it is briefly described in the next paragraph.

Depth-Integrated Velocity Measurement

The depth integration method involves slowly lowering the meter from the water surface to the bed and then raising it back up again at a uniform speed in a continuous operation. A coefficient of .94 to .98 was usually applied to the measured mean velocity to correct for the vertical motion of the meter and non measurement of the relatively low velocity in the bottom 30 cm (1 foot) of the depth. When successfully applied, the method has attractive features, including savings in time and equipment and easy computation of discharge at the site.

Another recently developed instrument which shows great promise for future measurements is the accoustic Doppler current profiler for direct measurement of mean vertical velocities. A version of this type of meter, Model 1200 RDDR, manufactured by RD Instruments of Akron, Ohio, was tested on the St. Clair River in November 1984 by the Great Lakes Environmental Research Laboratory. The meter measures averaged vertical velocities for approximately 1 metre (3.3 feet) consecutive depth segments throughout the water column above the meter.

Point Velocity Measurements

Before adoption in 1967 of the velocity distribution method (Reference 10) for estimating the mean velocity in a vertical, point velocities were usually measured at one to four selected depths in each vertical. The average of the readings was multiplied by a previously determined vertical velocity coefficient to derive the mean velocity in the vertical. In these measurements, three meters were usually suspended simultaneously at either the same or different depths. The U.S. Lake Survey measured at .2, .4, and .8 of the depth, while the Water Survey of Canada measured at .2, .6, and .8 of the depth. Meter revolutions were usually counted for periods of from two to five minutes. A fourth meter was often set at .4 depth by the U.S. Lake Survey as an index meter. The time required for a discharge measurement was usually between 3 1/2 and 6 hours, depending largely on the time required for anchoring and positioning the launch or catamaran.

The velocity distribution method as presently applied in the subject measurements involves the simultaneous suspension of four meters, except at bridge and cableway sections. One meter serves as an index meter to measure variations of current speed with time while the other three meters are measuring current speeds at different selected depths in the vertical. The index meter is set at .4 depth, while the other three meters are set to measure current speeds at even decimals of the depth from .1 to .9, usually in the sequence .3,.6,.9; .2,.5,.8; and .1,.4,.7 of total depth. Either the settings were computed in advance for a range of water levels and tabulated for use in the measurements, or the depth was sounded at each panel and the meter settings computed on the spot from the sounded depth.

Meter revolutions were usually counted for two minutes per setting and recorded on standard forms along with the time and any other relevant data available, such as the water level. Wind speed and direction, and air and water temperatures were also sometimes recorded, and in a few cases velocity-depth profiles were plotted as the data were recorded, to identify suspicious readings and repeat if necessary. Barring problems, the average time required for a measurement was usually about four hours.

The usual procedure at bridges and cableways was to measure velocities in each vertical or measuring station from bottom to top, using only one meter, after first sounding the depth and determining the required meter positions. On bridges, the distances of the measuring stations from one end of the bridge were usually measured by steel tape and marks made on the railing at the stations, or a tag line stretched across the bridge and the locations of the measuring stations determined from the marks on the line. Generally from one to four two-person measuring crews worked simultaneously. As in boat measurements, meter revolutions were usually counted for two minutes.

At the Robert Moses Cableway, tables of meter settings for a range of maximum meter line deflection angles from 10 to 35 degrees and a 10 foot range of water levels were prepared in advance from previous measurements and used in subsequent measurements. The deflection angles corresponded to flows ranging from 50000 to 120000 cfs. The tables were computed from the following empirical equation:

$$MS = D \left[\frac{d}{1-d(1-\cos A)} \right]$$

where: MS = meter setting for the decimal depth d;
D = total depth;
d = decimal depth with values of .1 to .9;
A = measured line angle in degrees with meter near bottom.

A discharge measurement at the Cableway usually took between 3 1/2 and four hours.

5.8 Computation of Discharge

As previously mentioned, the discharge at a section is the sum of the panel discharges, each of which is the product of the mean velocity and area of the panel. Prior to introduction of automated computations in 1967 by the U.S. Lake Survey, computations were done manually and procedures varied somewhat from job to job, particularly with respect to development and application of vertical and transverse velocity coefficients. The procedures described in the following paragraphs are believed typical.

(1) Manual Computations

(i) Computation of Area

Panel areas were computed from standard reference areas or from mean bed elevations, these parameters having been previously scaled from the cross-sectional profile, as described in a previous section. The reference water level was usually the water level at the time of the soundings. If standard areas were used, the panel area for the measurement was the standard panel area adjusted for the difference in water level at the time of the measurement. If mean bed elevations were used, the panel area for the measurement was the height of the water level at at the time of the measurement above the mean bed elevation, multiplied by the panel width.

(ii) Computation of Mean Panel Velocity

The first step in the computation of the mean panel velocities is the computation of the mean velocities in the measuring verticals from the measured point velocities as previously computed from the meter data using the appropriate meter ratings. Meters were usually rated before and after each job, and the average of the two ratings used. Where an index meter was used, the velocities were adjusted proportionally to the variations registered by the index meter.

The mean vertical velocity was then computed either by multiplying the average of the point velocities by the vertical coefficient developed in the calibration process, or by plotting the point velocities and fitting a vertical velocity curve, from which the mean velocity was determined by one of the procedures previously described.

Mean panel velocity is the area under the transverse velocity curve between the panel boundaries, divided by the panel width. Sometimes the transverse velocity curves were drawn for each measurement by fitting a smooth curve through the plotted points representing the mean vertical velocities at the panel mid-points as computed above. Areas under the curve between panel boundaries were then determined arithmetically or by planimeter, and the mean panel velocity obtained by dividing the areas by the panel widths. Alternatively, transverse velocity coefficients for for each panel were computed from one or more previously defined standard ard transverse velocity curves, as described in Section 5.1. This method assumed that no significant variation in flow distribution across the section occurred during the time of the measurements. The mean panel velocities were then obtained by multiplying the previously computed mean vertical velocities by the appropriate panel transverse velocity and directional coefficients.

In measurements using at least twenty panels with end panels measured at the mid-points, it was found that the transverse velocity coefficients did not significantly affect the computed discharge, i.e. they tended to average out across the section.

(iii) Computation of Discharge

The mean panel velocities were then multiplied by the corresponding panel areas to obtain the panel discharges, which were then summed across the section to obtain the measured discharge. Examples of typical manual discharge computations from the 1957-58 Stella Niagara measurements and the 1960 Massena Point measurements are given in Appendix D.

(2) Automated Discharge Computations

Computer Program 4316 for automated discharge computations, developed and implemented in 1967 by the U.S. Lake Survey, was immediately accepted by the other agencies engaged in the subject measurements. The program has been used, with minor variations to suit local conditions, to compute all discharge measurements since.

Program 4316 is a comprehensive and versatile data reduction program which accepts as input, point meter revolution data, meter rating data, directional coefients, panel configuration, and stage height data. The program then performs all calculations required for the determination of panel areas, mean vertical velocities (References 19 and 20), mean panel velocities, panel discharges, and total discharge at the section.

The velocity-depth algorithm used in the program to compute the mean vertical velocities was developed by F.H. Quinn (Reference 25), based on

Prandtl and von Karmann boundary layer theory. A logarithmic distribution is fitted to the point velocity data by the method of least squares. The depth function is:

$$f(d) = 1 - d^{1/2} - \ln(1 - d^{1/2})$$

where d is the ratio of the depth of the velocity observation measured from the surface to the total depth. Thus the adjusted or fitted velocity at any depth d is:

$$v = A\, f(d) + B$$

where v is the fitted velocity at depth d, and A and B are regression coefficients.

It was found that the residuals were minimized by breaking the curve at .3 depth from the surface and performing separate regressions on each segment. The mean velocity is then equal to the sum of the areas under the two curves determined by integration, i.e.

$$\bar{v} = 1/3\ Au + 3/2\ Al + .3\ Bu + .7\ Bl$$

where $\bar{v}$ is the mean vertical velocity and Au and Bu, and Al and Bl are regression coefficients for the upper and lower segments, respectively.

The transverse velocity routine in Program 4316 fits a parabolic curve through the mean velocity in each measuring vertical across the section, taking the points three at a time and assuming zero velocity at the banks. The area under the curve in each panel, computed by integrating between panel boundaries, divided by the panel width is the mean panel velocity. Transverse coefficients are computed and printed on the output listings for measurement analysis, but do not enter into the computations.

Appendix E is an example of a typical output listing from Program 4316, in this case for the June 1987 discharge measurements on the Niagara River above the International Railway Bridge.

5.9 Error Analysis

Neither the Detroit District nor the Water Survey of Canada has as yet developed standard methods or uncertainty functions for the analysis of errors and the determination of the accuracy of discharge measurements on the connecting channels. Agencies active in this line of research include the U.S. Geological Survey and the International Organization for Standardization. Published papers on the subject include References 10, 11, 12, 13, 26, 28, 30, 36, 47, and 49.

Reference 26 is an application of two of the available error analysis models to a pair of typical discharge measurement series on the connecting channels. The paper, by Frank H. Quinn, entitled "Relative Accuracy of Connecting Channel Discharge Data with Application to Great Lakes Studies" was published in the 1979 journal of the International Association for Great Lakes Research and is appended hereto as Appendix F. The standard error of typical discharge measurements was found to be in the order of three to five percent, depending on the number of panels. Measurement series were found to have a practical limit of about 25 measurements, and a standard error of about one percent for this number of measurements. Further study and development in this area by the Detroit District and the Water Survey of Canada is recommended.

The following figures relating accuracy, expressed as uncertainty in percent at the 95 percent confidence level, to measurement variables, are reproduced from Reference 49. Figure 53 - current meter rating accuracy versus current speed; Figure 54 - measurement accuracy versus number of points in the vertical; Figure 55 - measurement accuracy versus time of exposure; and Figure 56 - measurement accuracy versus number of verticals.

Particular attention might be drawn to Figure 54, which suggests that little increase in accuracy is gained by more than four or five points in the vertical, although the number of data points on the graph is minimal. This suspicion is supported by ISO research reported in Technical Report 7178 "Liquid flow measurements in open channels - Velocity-area methods - Investigation of total error" (Reference 12), Table 1.

6. MOVING-BOAT MEASUREMENTS

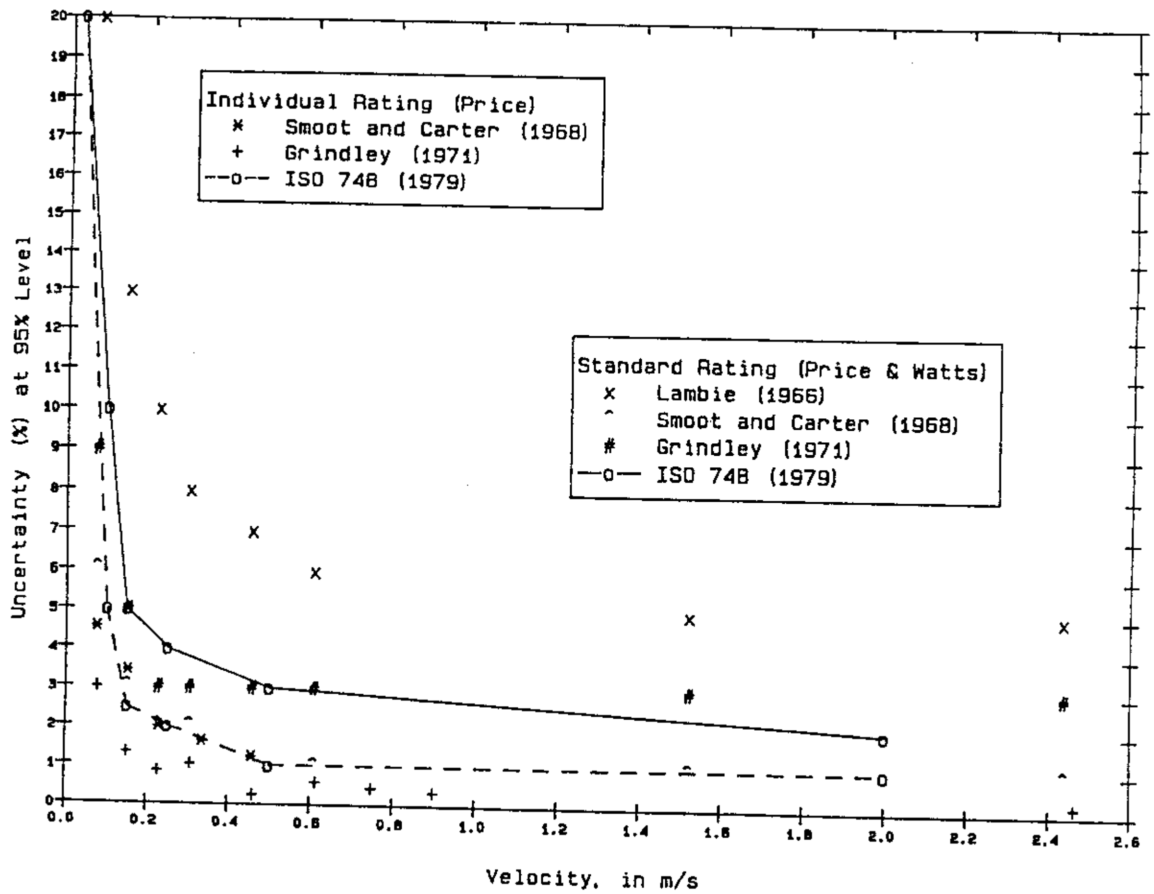
6.1 General Description

In moving-boat measurements the current meter is moved across the section by boat at a fixed depth in a continuous motion from a starting buoy on one side of the channel to a finish buoy on the other side. The buoys are placed about 10m from each waters edge, depth permitting, and about 5m above or below the section. Their purpose is to demarcate the space available for the boat to manoeuvre into position at the start and end of each run. The distances from the buoys to the reference points on the banks are measured by tape or electronically.

The meter is usually mounted on a swivel rod over the bow or side of the boat as shown in Figure 57 at a depth of 1 metre (3.3 feet) or less at shallow sections. A pointer or compass is attached to the top of the rod to show the direction of the meter with respect to the section line, and an echo sounder is used to measure depths.

The preferred meter for moving-boat measurements is the Ott propeller type. This meter generates 24 electrical impulses per revolution, which are transmitted by cable to an on-board pulse rate recorder and processor where they are converted to a pulse rate and displayed. The control unit also counts and displays the impulses from the meter. When the count reaches a preset number or a multiple thereof, the processor actuates an event marker on the echo sounder and emits an audible signal or beep. This tells the crew that a sampling point has been reached, whereupon the operator reads and records the pulse rate meter and the angle reader reads and calls out the pointer direction.

The preset number of counts is selected from a range of five provided by the control unit. The range selection, which depends on boat speed,


Individual Rating (Price)
* Smoot and Carter (1968)
+ Grindley (1971)
--o-- ISO 748 (1979)
Standard Rating (Price & Watts)
x Lambie (1966)
^ Smoot and Carter (1968)
# Grindley (1971)
—o— ISO 748 (1979)
Uncertainty (%) at 95% Level
Velocity, in m/s

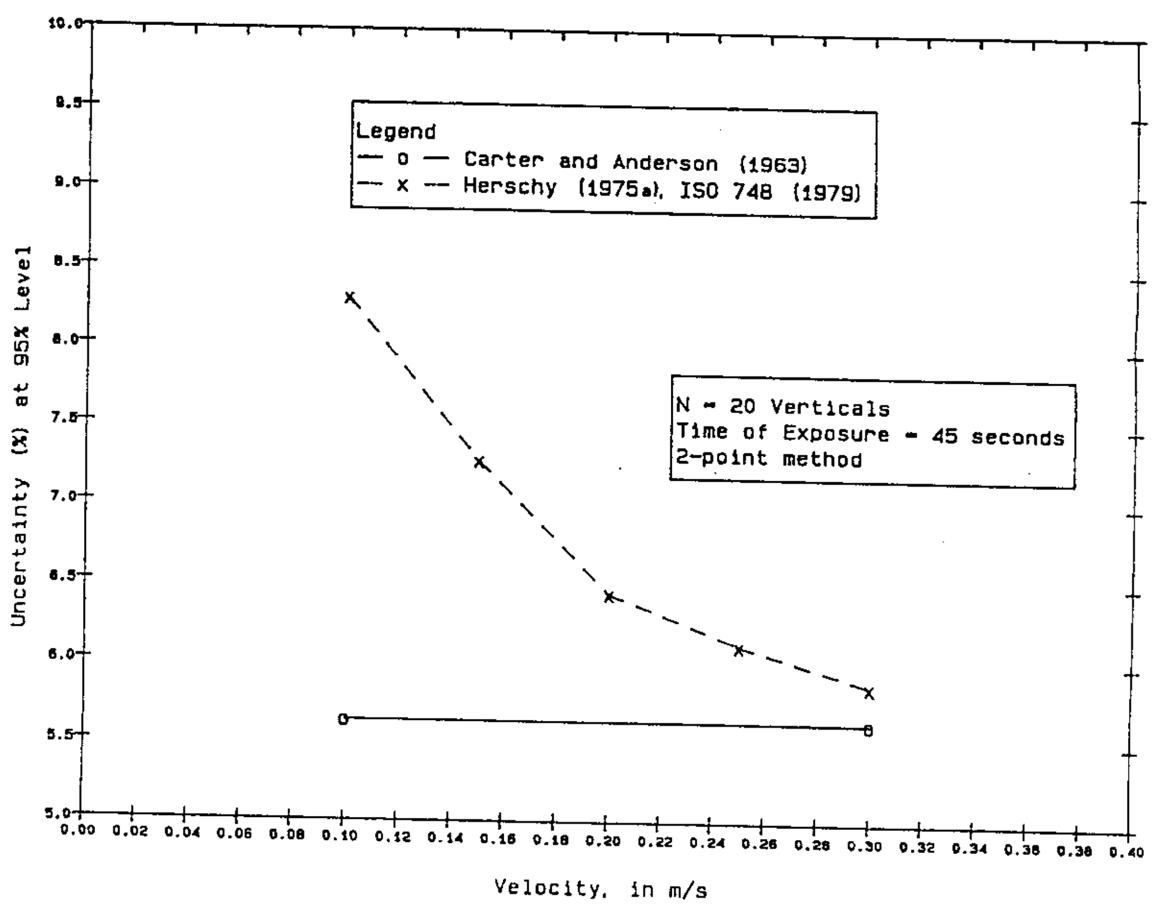
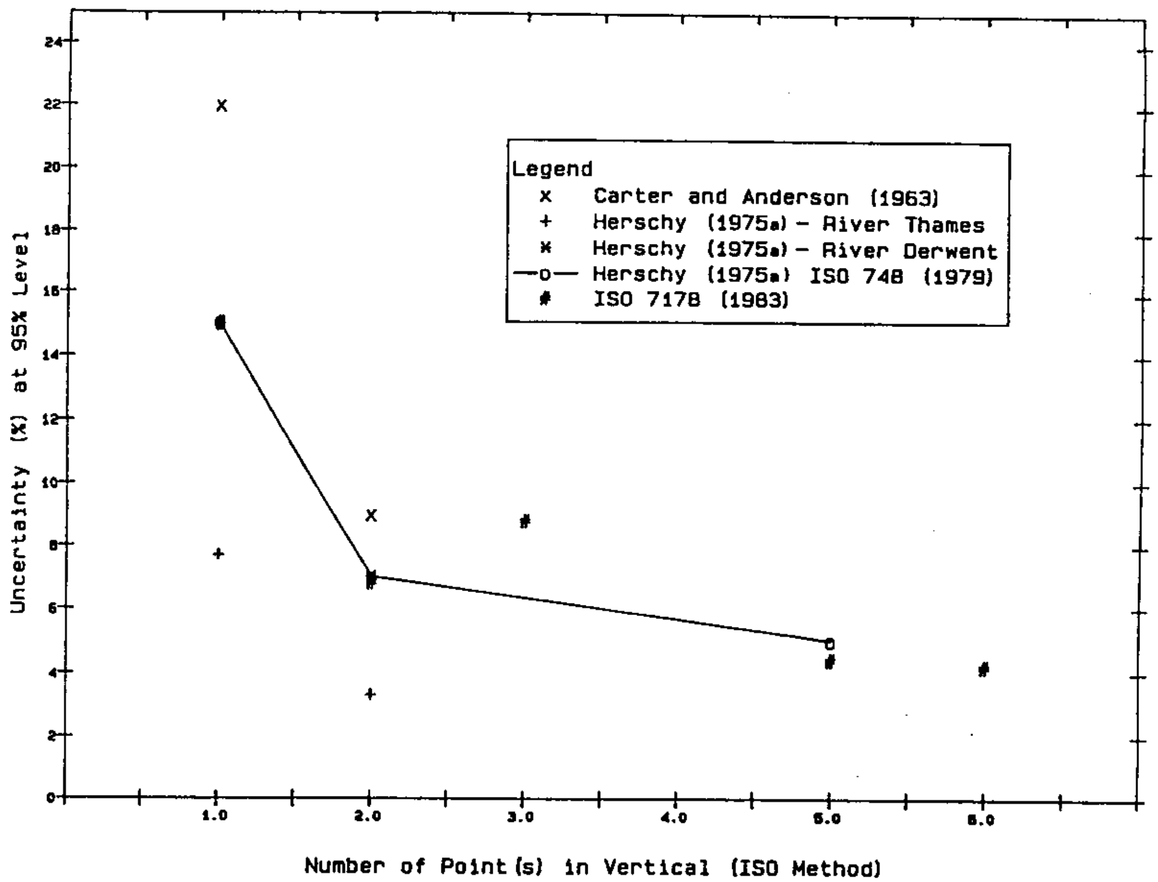
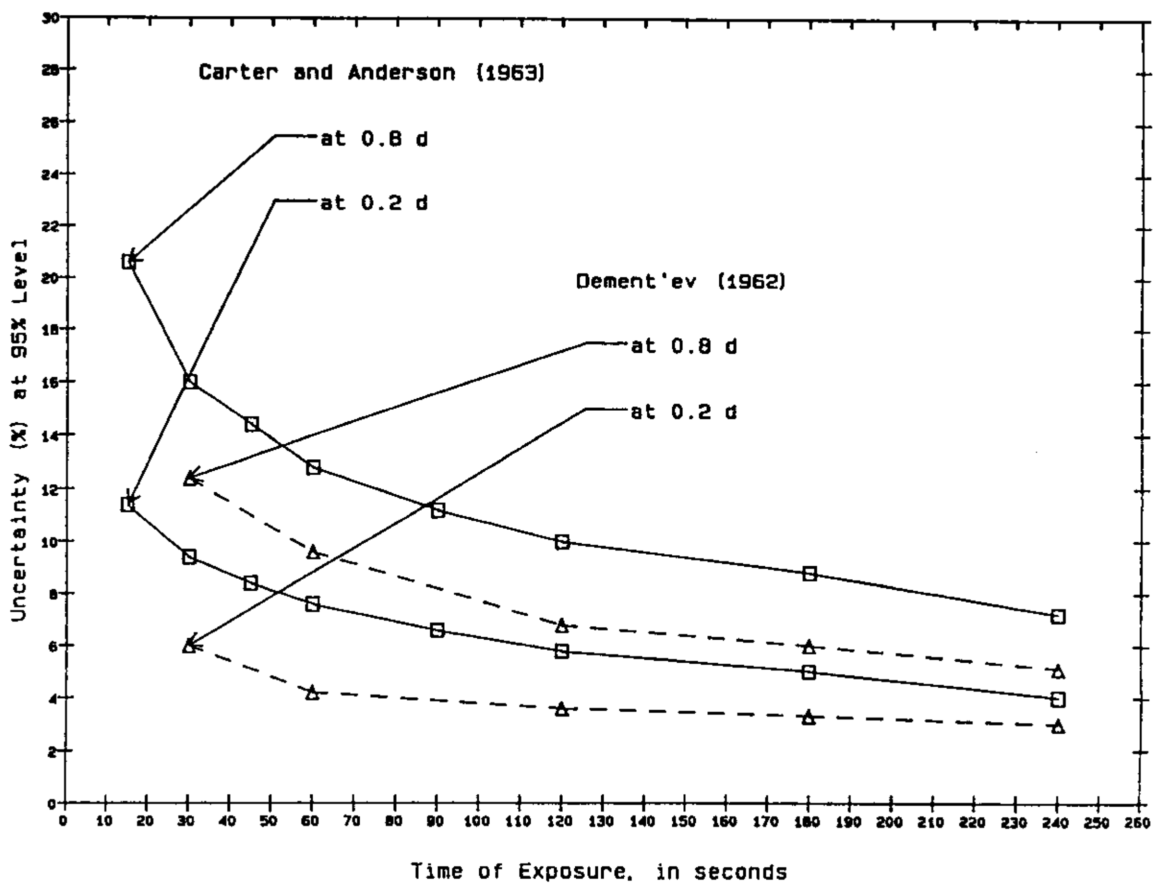

Legend
— o — Carter and Anderson (1963)
— x — Herschy (1975a), ISO 748 (1979)
N = 20 Verticals
Time of Exposure = 45 seconds
2-point method
Uncertainty (%) at 95% Level
Velocity, in m/s

Figure 53



Legend
x Carter and Anderson (1963)
+ Herschy (1975a) - River Thames
* Herschy (1975a) - River Derwent
—o— Herschy (1975a) ISO 748 (1979)
ISO 7178 (1983)
Uncertainty (%) at 95% Level
Number of Point(s) in Vertical (ISO Method)



Carter and Anderson (1963)
at 0.8 d
at 0.2 d
Dement'ev (1962)
at 0.8 d
at 0.2 d
Uncertainty (%) at 95% Level
Time of Exposure, in seconds

Figure 55

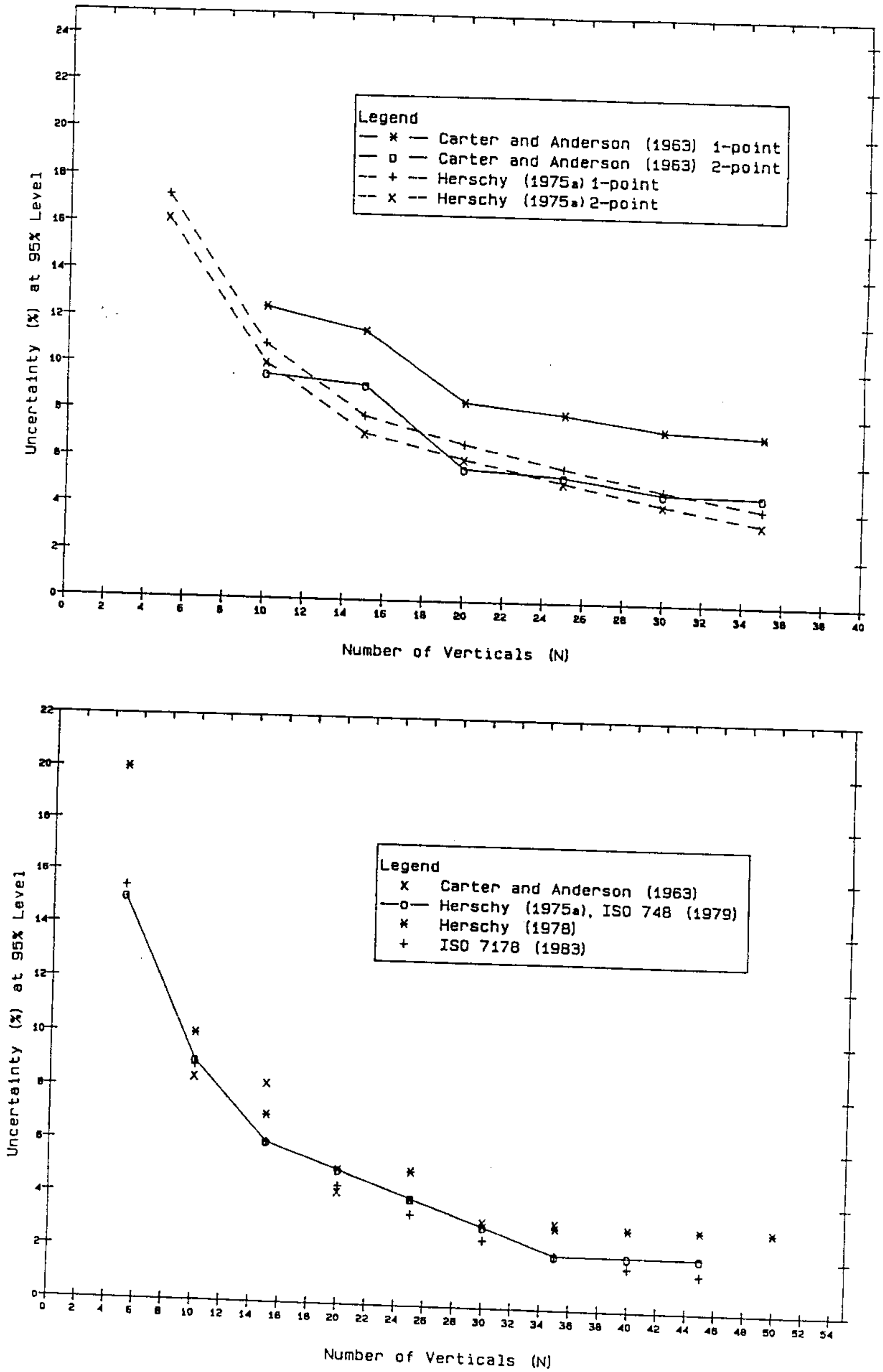
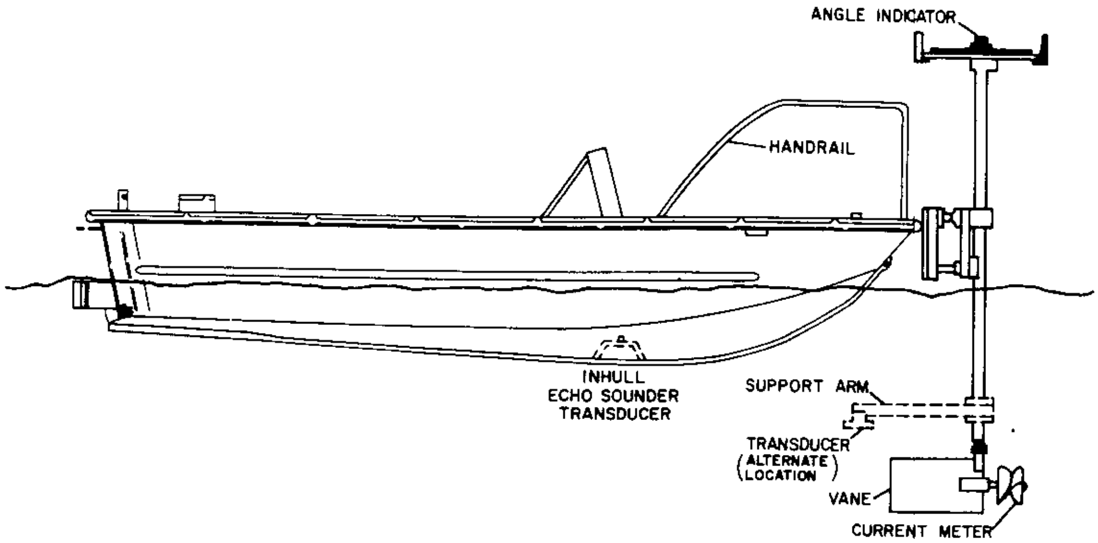
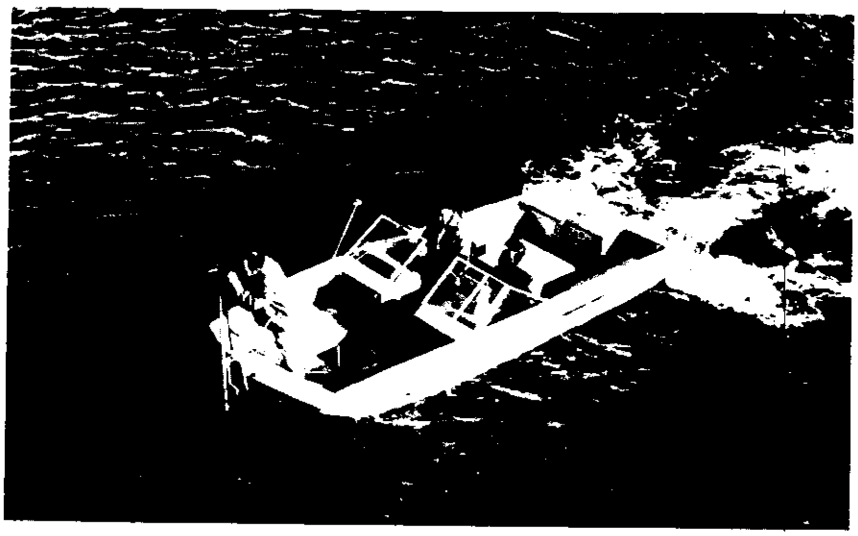

Legend
Carter and Anderson (1963) 1-point
Carter and Anderson (1963) 2-point
Herschy (1975a) 1-point
Herschy (1975a) 2-point
Uncertainty (%) at 95% Level
Number of Verticals (N)
Legend
Carter and Anderson (1963)
Herschy (1975a), ISO 748 (1979)
Herschy (1978)
ISO 7178 (1983)
Uncertainty (%) at 95% Level
Number of Verticals (N)

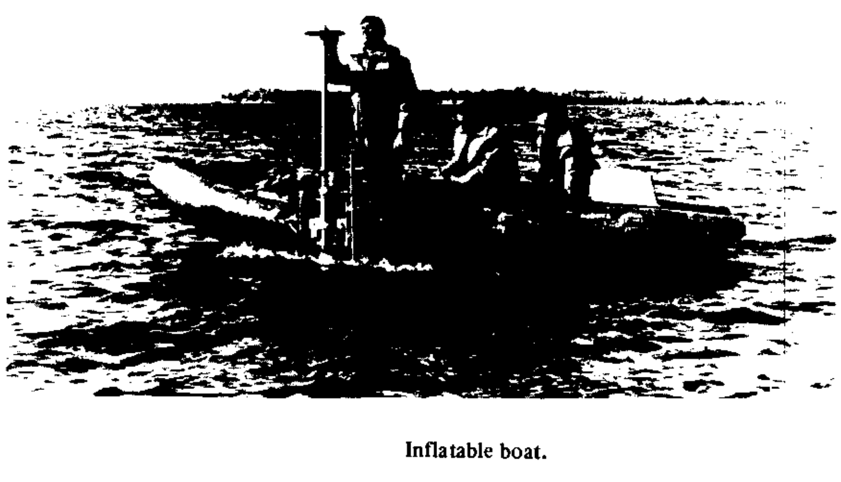
Figure 56



Typical boat with angle-indicating assembly.



Fibreglass boat.



Inflatable boat.

Figure 57 Boats for Moving-Boat Measurements current velocity, and section width, determines the number of sampling points or panels in the section. Between 25 and 40 are recommended. The meter pulse rate, which is the resultant of current and boat velocities, is related to distance travelled in accordance with the meter rating. The ranges available are as follows:

Range	Pulse Counts	Distance (m)
1	1024	5.6
2	2048	11.2
3	4096	22.4
4	8192	44.8
5	16384	89.6

Since the computations are based on the assumption that the section is normal to the direction of flow, a discharge measurement is considered to consist of two traverses of the section in opposite directions. This compensates for any non-normality of the section line, or variations in the direction of flow across the section. The average of the discharges computed from each traverse, corrected for distance and velocity-depth distribution, is considered the measured discharge. The velocity-depth coefficient is usually defined by 10 or 11 point velocity measurements in three or four verticals across the section, usually at the third or quarter points. The velocity data are usually plotted at the site and a curve fitted visually, from which the mean velocity in the vertical and the velocity at the meter depth are determined. The required coefficient is then the ratio of the mean velocity to the fitted velocity at the meter depth. If no profiles are taken, the coefficient is usually assigned a value of .9, an average value based on previous experience.

The discharge between the marker buoys and the waters edges is either measured by conventional measurement or estimated and added to the measured discharge from the moving-boat computations. The distance between buoys as determined from the meter impulse counts is adjusted to correspond to the actual distance as measured electronically.

References 19, 20, and 23 are manuals on moving-boat measurements by the U.S. Geological Survey and the Water Survey of Canada. Figure 57 is a reproduction from Reference 19 showing a typical boat set up for manual moving-boat measurements, and photographs of measurements in progress.

Reference 24 is a manual by the Water Survey of Canada describing an automated moving-boat discharge measurement system developed in 1982 by the Hydrometric Methods Section in Ottawa and called the 'Datem' system. This system features an on-board computer programmed to perform all the required functions in a measurement except driving the boat. The computer is interfaced with the meter, echo sounder, and a compass which replaces the pointer used in the manual system for determination of boat direction. After accepting initial values and section and measurement parameters, including name, width, left and right waters edges, transducer draft, meter draft, pulse rate range, speed of sound, velocity coefficient, time and date, and number and direction of the traverse, the computer continuously receives, processes, stores, and displays the data being collected. On completion of the measurement it prints out a summary of relevant data on paper tape, including start and finish time, elapsed time, measured width and discharge, width adjustment factor, width adjusted area and discharge, and depth adjusted discharge.

Figure 58 includes a diagram taken from Reference 24 of a typical boat outfitted for automated moving-boat measurements, and a copy of a notice from a trade journal describing the 'Datem' moving-boat package. Figure 59 is a simulation of a tape from the 1986 measurements on the St. Marys River at the Frechette Point hydraulic section, and Appendix H contains summaries of velocity-depth profile data and moving-boat measurement data from 1989 measurements on the St. Marys River at the recently established rapids section at Sault Ste. Marie.

6.2 Applications on Connecting Channels

Besides the St. Marys River, the automated moving-boat system has also been successfully applied on the St. Clair, Niagara, and St. Lawrence Rivers in recent years by the Hydrometric Methods Section of the Water Survey of Canada, and the Detroit District is presently in the process of developing equipment and expertise in the technique. In addition, manual moving-boat measurements have been taken by the Michigan District of the U.S. Geological Survey on the St. Clair and Detroit Rivers, and by the Water Survey of Canada on the Niagara and St. Lawrence Rivers. The use of the method is expected to increase in the future with further development and refinement of equipment and techniques.

6.3 Error Analysis

Procedures for the analysis of errors and determination of accuracy of moving-boat measurements on the connecting channels have not yet been developed, but action in this area is expected in the near future as use of the method becomes more prevalent. Most attempts to date to evaluate the accuracy of moving-boat measurements on the connecting channels have consisted of comparisons with simultaneous conventional measurements. The following table is such a comparison, taken from a report of measurements on the upper Niagara River at the International Railway bridge in 1987. The velocity-depth coefficient used in the moving-boat measurements was 0.89, derived from data collected in the conventional measurements, at a section about 100 metres below the moving-boat section.

COMPARISON OF CONVENTIONAL & MOVING-BOAT MEASUREMENTS

Measurement No.			E.S.T.		Water level at Section (feet)	Measured Discharge (cfs)		Difference Conventional minus Moving-boat	
Conv.	Moving boat	Date	start	fin.	IGLD 1955	Conv.	Moving boat	cfs	%
8	1- 8	2 June 1987	1245	1407	566.60	240900	249700	8800	3.7
12	9-13	3 June 1987	0901	1017	566.87	245700	242500	-3200	-1.3
13	13-16	3 June 1987	1024	1129	567.05	261400	251800	-9600	-3.7
14	17-21	3 June 1987	1301	1447	567.31	267300	261600	-5700	-2.1

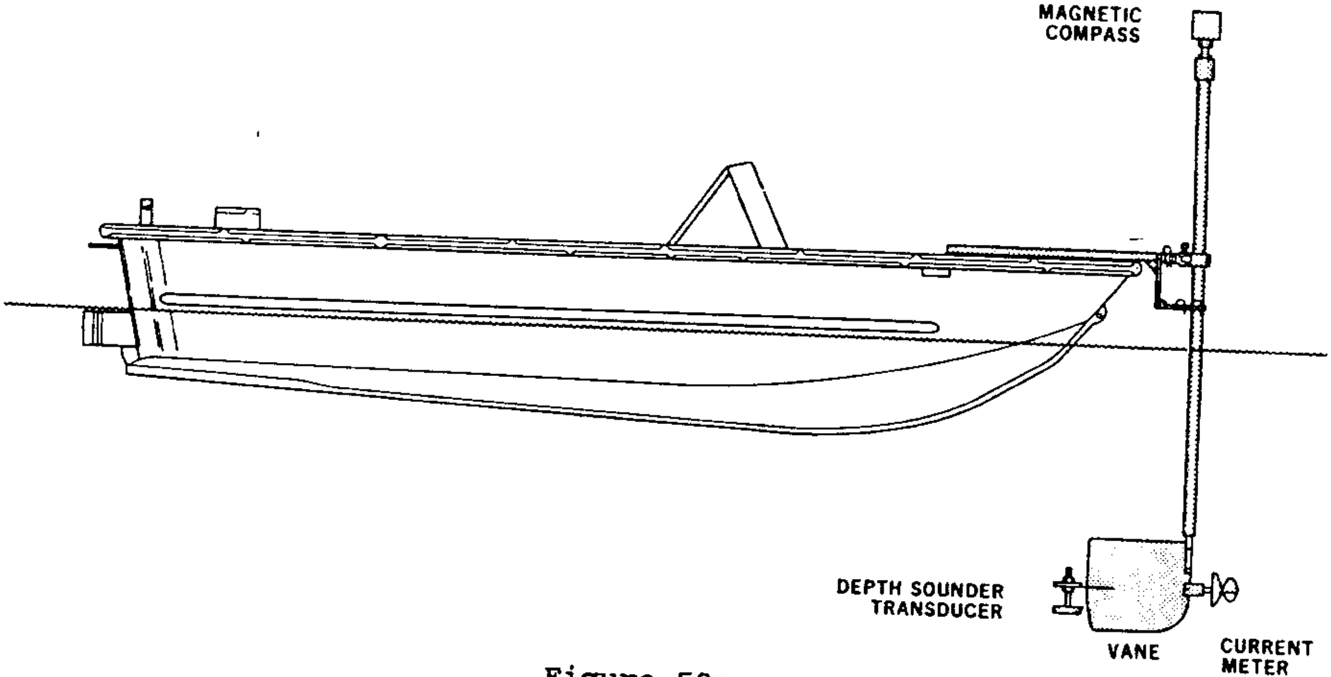
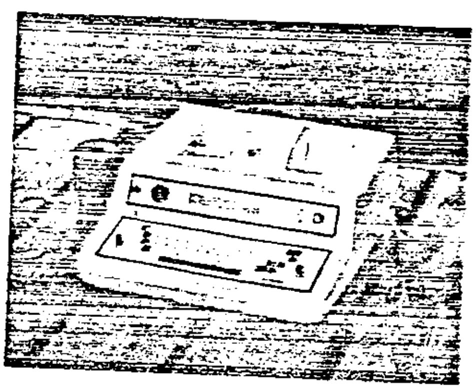


Figure 58a
Typical Boat with Magnetic Compass



Computerized water resource management

The Moving Boat System used in the measurement of discharge of larger waterways provides a "user-friendly" completely automated system based on the I.S.O. Moving Boat Method. Baseline data is provided by an electronic compass, with integral digital depth sounder providing depth information and a standard Ottmeter used for velocity data. The system displays, stores, processes and prints in a workable format, all data in realtime; operational modes allow complete edit, replay and copy capabilities. A Hydrographic Data Collection package is also available which provides collection of position, time and depth data into its non-volatile bubble memory. The system includes a single board computer with on-board PROMS, interface for the current meter, compass and RS232 line printer, a 12-volt power supply, Datem bubble memory mass storage system using iSBX 251 bubble memory board containing 128 Kbytes of non-volatile storage, Datem Integral Data Terminal with independent 8031 processor, full ASCII keyboard, 80-character 2-line Liquid Crystal Display and 40-character per line dot matrix printer, electronic compass with mount, 20-foot cable with connector and an external depth input connector. The Canadian price of this system is $25,000 with the Hydrographic Data Collection Package available at an additional $4,000.
Datem Ltd.

Figure 58b
Automated Moving-Boat Package

TYPICAL AUTOMATED MOVING-BOAT MEASUREMENT COMPUTER TAPE

```
DATEM MOVING-BOAT DISCH'GE ANALYSIS,VI
ENTER TITLE: ST MARYS R.  FRECHETTE PT
ENTER DATE (00/00/00): 86/09/10
ENTER TIME (00:01:39): 11:27:00

DIOS VERSION 1.0
>P
ENTER DATE (86/09/10):
ENTER TIME (11:27:16):
DISPLAY IN METRES(DEFAULT)/FEET(F):
ENTER LEW(00.0): 99
ENTER REW (00.0) 30
ENTER ACTUAL WIDTH (0000.0): 456
VELOCITY ADJUST FACTOR (1.0000): 92
ENTER SPEED OF SOUND (1500):
ENTER TRANSDUCER DRAFT (0.00): 1.0
SET BASELINE; HIT "RETURN" WHEN READY:
OTTMETER CONSTANTS FILENAME: PAUL 10
FILE NOT FOUND; USE ASSUMED CONSTANTS

ENTER RECORD FILENAME: PAUL 10
ENTER SELECTED RUN NUMBER (01):
REVERSE TRAVEL DIRECTION (Y OR N)? N
ENTER SELECTED RANGE (01): 5

RUN 01    86/09/10     11:36:21
ST MARYS R  FRECHETTE PT
0.00541 0.02203  (DEFAULT VALUES)
LEW 99.0 REW 30.0 W 0456.0 V 0.9200
ENTER PRINT SUPPRESSION  (0 - 10):

SMP CA DA   ETIME VX   WIDTH    Q
-01 59 02.8 000.0 0.58 099.0 0080.5
-02 54 03.1 007.8 0.58 003.3 0005.9
-03 46 03.5 013.3 0.61 007.8 0016.5
-04 44 03.9 011.9 0.65 008.1 0020.5
-05 45 03.7 011.1 0.71 007.9 0020.9
-06 46 04.1 010.7 0.75 007.8 0024.0
-07 47 05.1 010.5 0.78 007.6 0030.4
-08 47 05.3 012.2 0.67 007.6 0027.1
-09 48 05.6 011.0 0.76 007.5 0031.7
-10 52 08.2 010.1 0.87 006.9 0049.3

-11 53 10.8 009.4 0.95 006.7 0069.2
-12 53 10.9 008.8 1.02 006.7 0074.6
-13 52 11.1 008.9 0.99 006.9 0075.8
-14 53 11.1 008.7 1.03 006.7 0076.9
-15 53 11.0 008.6 1.04 006.7 0077.1
-16 52 11.2 007.2 1.23 006.9 0094.5
-17 52 11.5 007.1 1.24 006.9 0098.4
-18 52 11.4 006.8 1.30 006.9 0101.9
-19 52 11.0 006.9 1.28 006.9 0096.9
-20 49 11.1 007.5 1.13 007.3 0091.9
-21 49 11.5 007.2 1.17 007.3 0099.1
-22 51 11.6 006.8 1.28 007.0 0104.5
-23 51 11.4 007.1 1.23 007.0 0098.3
-24 52 11.2 007.3 1.21 006.9 0093.2
-25 54 11.0 007.4 1.22 006.6 0088.6
-26 53 11.1 007.4 1.21 006.7 0090.4
-27 51 11.3 006.9 1.26 007.0 0100.3
-28 50 11.5 007.4 1.16 007.2 0095.8
-29 48 11.9 008.8 1.04 007.5 0092.7
-30 50 11.9 008.7 0.99 007.2 0084.7
-31 54 11.3 008.9 1.02 006.6 0075.7
-32 55 10.7 009.6 0.96 006.4 0065.6
-33 52 10.5 010.6 0.83 006.9 0060.2
-34 48 10.5 010.2 0.82 007.5 0064.1
-35 46 07.7 010.6 0.76 007.8 0045.5
-36 45 04.2 011.7 0.68 007.9 0022.5
-37 46 03.3 013.1 0.61 007.8 0015.8
-38 44 03.2 002.6 0.48 001.3 0002.0
- END SEGMENT                   0023.1

            *** SUMMARY ***
MEASURED DISCHARGE                02486
MEASURED AREA                     02483
MEASURED WIDTH                   0385.0
WIDTH ADJUSTMENT FACTOR          1.1841
WIDTH ADJUSTED DISCHARGE          02943
WIDTH ADJUSTED AREA               02940
DEPTH ADJUSTED DISCHARGE          02708

ELAPSED TIME 00:05:30 (0330.0 SECS)
** START 11:36:48  STOP 11:45:29 **
>R
```

Figure 59

Computer tape from Automated Moving-boat Measurement

COMPARISON OF CONVENTIONAL & MOVING-BOAT MEASUREMENTS (Cont'd.)

Measurement No. Conv.	Measurement No. Moving boat	Date	E.S.T. start	E.S.T. fin.	Water level at Section (feet) IGLD 1955	Measured Discharge (cfs) Conv.	Measured Discharge (cfs) Moving boat	Difference Conventional minus Moving-boat cfs	Difference Conventional minus Moving-boat %
17	22-26	4 June 1987	0847	1147	566.68	230200	226000	-4200	-1.8
18	26-27	4 June 1987	1050	1218	566.65	237800	230400	-7400	-3.1
19	26-32	4 June 1987	1201	1405	566.79	238600	242500	3900	1.6
Mean % difference									-1.0
Standard deviation of % differences									2.7

7. CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations are not included in the terms of reference of this report. Therefore none are made.

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APPENDIX A

TYPICAL DOCUMENTATION - VERTICAL CONTROL

U. S. LAKE SURVEY
CORPS OF ENGINEERS

1957-1958 ESTABLISHMENT, CONTROL, CALIBRATION
AND DISCHARGE MEASUREMENTS
STELLA NIAGARA HYDRAULIC SECTION

Table 2 - Benchmark Elevations and Descriptions

B.M. STATUE, (1957), is in Niagara County, New York, approximately 2.0 miles downriver from the intersection of Center and Fourth Streets in Lewiston, on the river side of River Road (Highway 18F), on property of the Stella Niagara Seminary, just west of a winged angel statue which is northwest of the Seminary building, 132.9 feet northwest of a 30-inch diameter oak, 80.5 feet southwest of a 30-inch diameter oak, 29.7 feet west of northwest corner of the statue, 0.9-foot southeast of a water faucet, flush with the ground surface, being highest point on top of a one-inch diameter steel rod, 6-1/2 feet long.

Elevation 320.247 feet

B.M. WILLOW, (1957), is in Niagara County, New York, approximately 2.0 miles downriver from the intersection of Center and Fourth Streets in Lewiston, on property of the Stella Niagara Seminary, on river side of River Road (Highway 18F), on north side of a winding cinder and dirt road which is opposite the end of Pletcher Road, 84.4 feet southeast of southwest corner of the shrine, 42.0 feet from centerline of the cinder and dirt road, 0.7-foot south of a 24-inch willow, flush with the ground surface, being highest point on top of a one-inch diameter steel rod, 6-1/2 feet long.

Elevation 275.348 feet

B.M. N 36, (1937), is in Niagara County, New York, approximately 2.0 miles downriver from the intersection of Center and Fourth Streets in Lewiston, on the east side of River Road (Highway 18F), on the road face of Stella Niagara Seminary, 54.5 feet downriver from southwest corner of the chapel, 4 feet above the ground, being horizontal line of cross in bronze disc set into the limestone wall.

Elevation 326.895 feet

B.M. INTAKE, (1957), is in Niagara County, New York, approximately 2.0 miles downriver from the intersection of Center and Fourth Streets in Lewiston, on property of the Stella Niagara Seminary, on river side of River Road (Highway 18F), at the foot of a winding cinder and dirt road which is opposite the end of Pletcher Road, about 655 feet north of the north face of a small brick chapel, near top of bank of the Niagara River, on river side wingwall of steps leading down into an abandoned concrete intake pumphouse, 4.7 feet above top step of the stairs, 0.1-foot north of outer angle in wingwall, being highest point in a one-inch diameter knob cut in top of the concrete wingwall.

Elevation 263.495 feet

APPENDIX B

TYPICAL DOCUMENTATION - HORIZONTAL CONTROL

TABLE 1*

STATION DESCRIPTION

FOR

HORIZONTAL CONTROL

A (1954), is in Stormont County, Ontario, about two miles upstream from Cornwall, about 700 feet downstream from the lower gate of Cornwall Canal Lock 19, at the top of the stone embankment between the water's edge and the road parallel to and south of the Canal, 95 feet northerly of the water's edge, 69.4 feet upstream from a triangular blaze in a power line pole, 54.0 feet south of the center line of the road, 41.3 feet downstream from the most westerly fence post of the east-west fence line, flush with the ground surface, being the center of a standard Corps of Engineers bronze disc set into the top of a 6 inch diameter concrete post 3 feet long.

Pointings at A (1954)

B Distance 1428.23 feet	264°	28'	00"
C	293	34	30
D	324	31	30
E	283	23	00
Lightning rod on apex of silo, American shore	3	39	00
Apex of power line tower, northernmost tower of northerly pair	73	57	30

B (1954), is in Stormont County, Ontario, approximately two miles upstream from Cornwall between the water's edge and the road south of and parallel to the Cornwall Canal, 104 feet northeasterly of the center of a 1 x 1 foot boulder flush with the ground surface, 92.2 feet easterly of the center of a 3 foot triangular boulder lying about 14 feet south of the center line of the road, 53.8 feet south-westerly of the last niggerhead east of Lock 19, 28.2 feet southerly from the center line of the road, 4.0 feet south of the east-west fence line, flush with the ground surface, being a standard Corps of Engineers bronze disc set into the top of a 6 inch diameter concrete post 3 feet long.

Pointings at B (1954)

D	0°	00'	00"
E Distance 475.66 feet	00	00	00
A Distance 1428.23 feet	84	28	00
C	307	54	30
Lightning rod apex of silo, American shore	22	50	30
Apex power line tower, northernmost tower of northerly pair	74	49	30
Southerly lightning rod on tallest chimney	262	34	00

*Table 1 from "First Interim Report on Calibration of South Barnhart Island Channel Gages for Determination of Lake Ontario Outflows During Construction of the Power and Seaway Project", prepared by the U. S. Lake Survey, Corps of Engineers, dated April 1956.

TABLE 1 (Cont'd)

STATION DESCRIPTIONS

FOR

HORIZONTAL CONTROL

C, (1953), is in Stormont County, Ontario, on the north-western edge of Cornwall Island, about 300 feet downstream of Pollys Gut near top of bank, 60 feet upstream of north-south fence line, 45 feet from water's edge, 15.0 feet southerly of center of a 4 x 4 foot granite boulder, 2.0 feet north of old east-west fence line, extending 1 foot above ground surface, being the center of a 1 inch square iron bar set in a concrete truncated pyramid having the upper face 4 inches square.

Pointings at C (1953)

A	113°	34'	30"
B	127	54	30
D	79	34	30
E	119	25	00
Easterly lightning rod on stack on Canadian shore	177	05	30
Southerly lightning rod on paper mill stack	229	49	00
Apex of northernmost power line tower of north pair	110	31	00

D, (1953), is in St. Lawrence County, New York, approximately 500 feet upstream from the north-eastern tip of Massena Point, downstream of the Price cottage on the slope to the water's edge, 78 feet upstream of a 2 x 3 foot boulder approximately 18 feet from the water's edge, 51 feet northerly of out-door fire place, 34.0 feet downstream of the center of a 2 x 3 foot boulder near water's edge, about 13 feet southerly of water's edge, extending about 1 foot above the ground surface, being the center of a 1 inch square iron bar set in a concrete truncated pyramid having the upper face 4 x 4 inches square.

Pointings at D (1953)

B	180°	00'	00"
E	180	00	00
A	144	31	00
C	259	34	30
Easterly lightning rod on red brick stack	199	57	00
Southerly edge of south eastern steel upright, Roosevelt Bridge	248	11	00
Center line of Power Line Tower	103	30	00

TABLE 1 (Cont'd)

STATION DESCRIPTIONS

FOR

HORIZONTAL CONTROL

E, (1953), is in Stormont,County, Ontario, approximately two miles upstream from Cornwall, about one-quarter of a mile downstream from Lock 19, 162 feet downstream of the center of a 4 x 3 foot granite boulder on the slope to the water's edge, 34 feet northerly of water's edge, 9.3 feet upstream of a 1/2 inch drill hole in a 1-1/2 x 2 foot granite boulder, extending 6 inches above ground surface, being the center of a 1 inch square iron bar set in a concrete truncated pyramid with upper face 4 inches square.

Pointings at E (1953)

D	0°	00'	00"
B Distance 475.66 feet	180	00	00
A	103	22	30
C	299	25	00
Southerly edge (at tip)of south upright, Roosevelt Bridge	267	27	30
Southerly lightning rod on south chimney	256	29	00
Lightning rod on apex silo, American shore	25	35	00

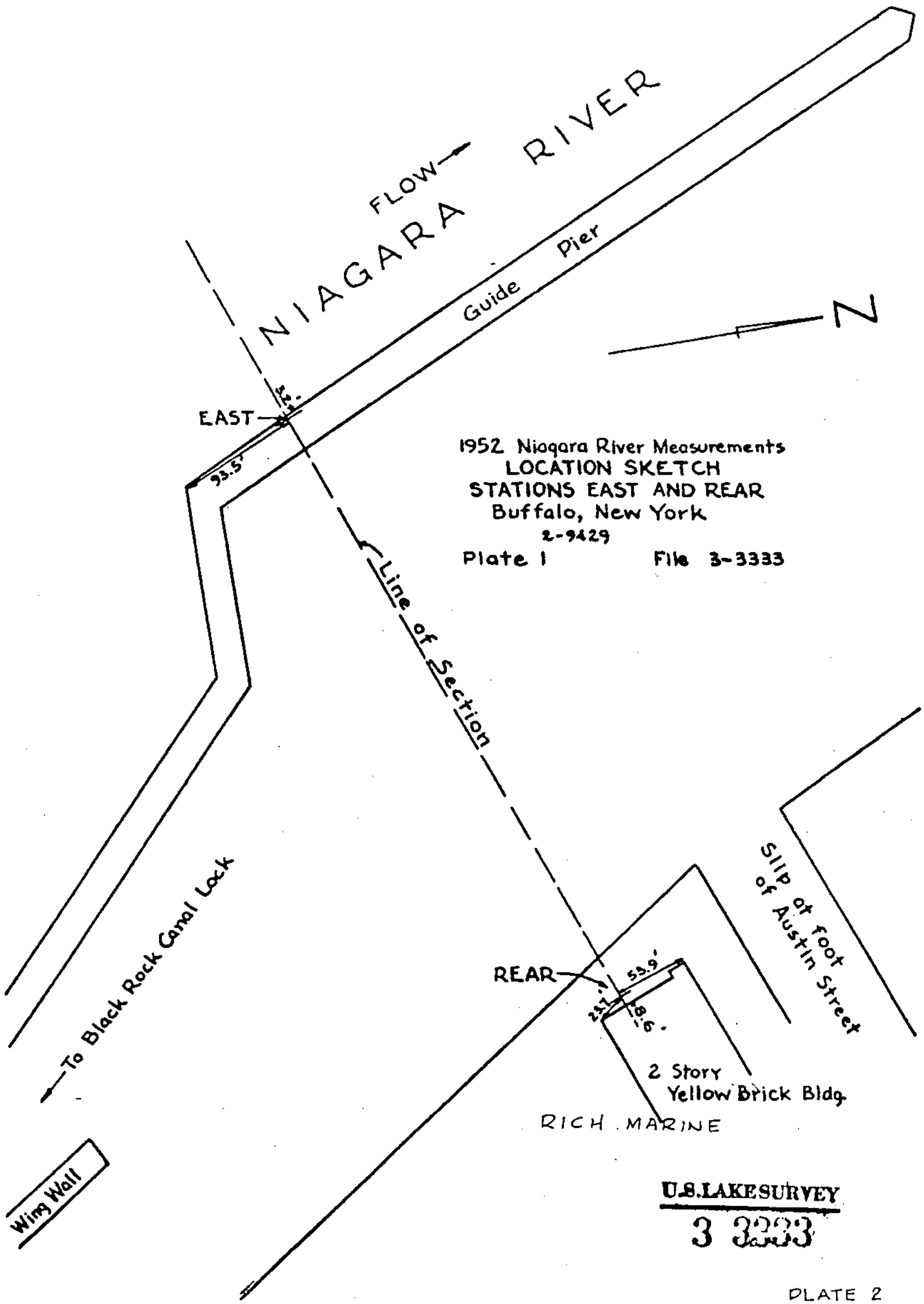
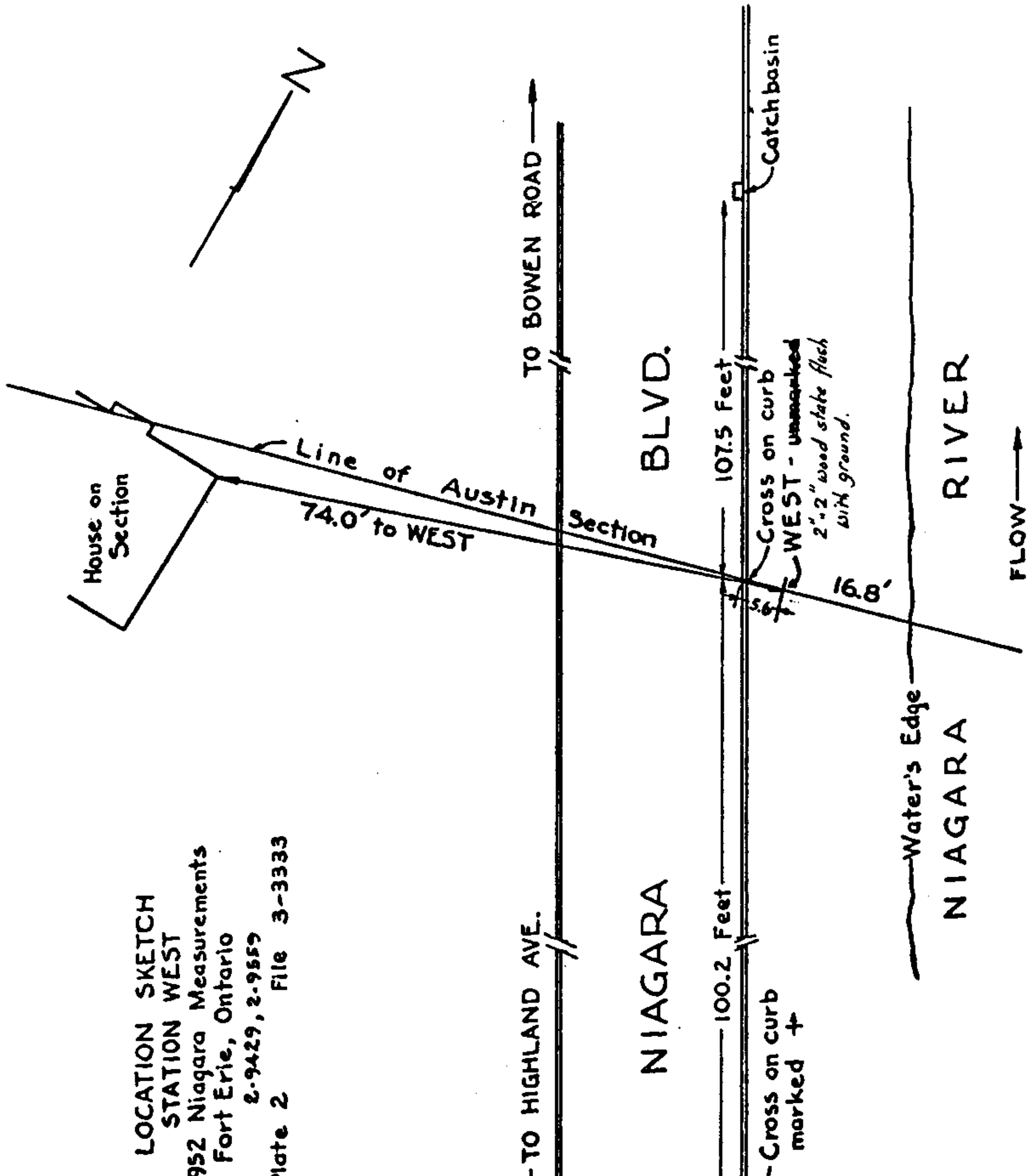

NIAGARA RIVER
FLOW
Guide Pier
N
EAST
93.5'
1952 Niagara River Measurements
LOCATION SKETCH
STATIONS EAST AND REAR
Buffalo, New York
2-9429
Plate I
File 3-3333
Line of Section
Slip at foot of Austin Street
REAR
53.9'
8.6'
2 Story
Yellow Brick Bldg.
RICH MARINE
To Black Rock Canal Lock
Wing Wall
U.S. LAKE SURVEY
3 3333

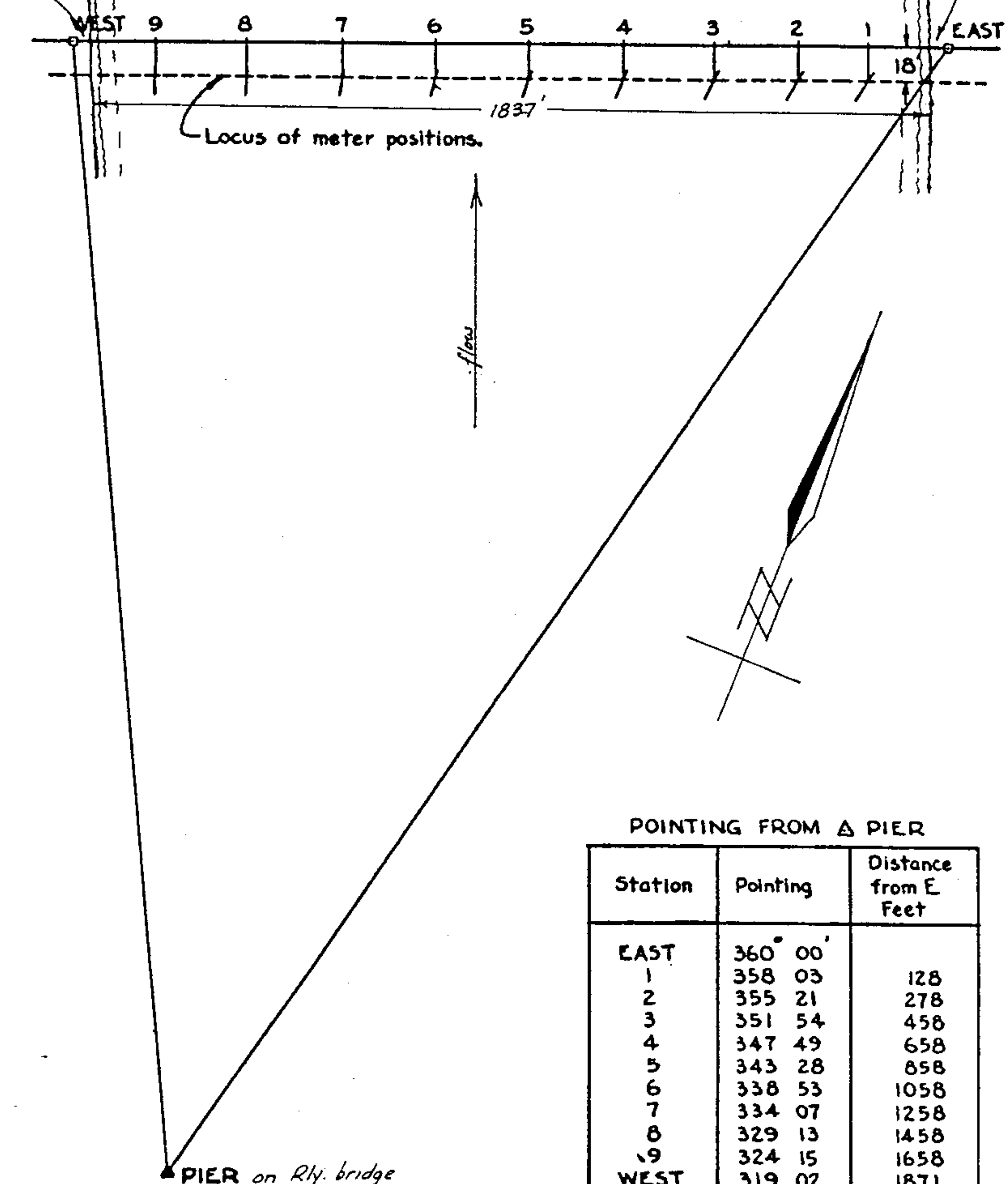
PLATE 2



U.S.LAKESURVEY
3 3333

PLATE 3

1952 Niagara River Discharge Measurements
LOCATION OF METERING STATIONS
AUSTIN SECTION, BUFFALO, N.Y.
U.S. Lake Survey
April 1953
Plate 6 File 3-3333



POINTING FROM Δ PIER

Station	Pointing	Distance from E Feet
EAST	360° 00'	
1	358 03	128
2	355 21	278
3	351 54	458
4	347 49	658
5	343 28	858
6	338 53	1058
7	334 07	1258
8	329 13	1458
9	324 15	1658
WEST	319 02	1871

U. S. Lake Survey
July 1953
3-3333

1952 Niagara River Measurements

AUSTIN SECTION HORIZONTAL CONTROL

Plate 5

Station EAST. Located on the guide pier at Black Rock Canal locks in Buffalo, New York, about 600 feet from the end of the guide pier, 93.5 feet from outer angle of pier, 87.4 feet northwesterly from light pole at outer angle, 26.8 feet westerly from first spud from the outer angle, 3.2 feet from westerly edge of guide pier, being a standard bronze C of E disc stamped EAST, 1952.

Pointings from Station EAST

Pointing	Object
0° 00' 00"	Station WEST
180 00 00	Station REAR
58 06 00	Clock tower near Fort Erie Tank
346 45 00	Tank in Fort Erie
256 52 30	New stock on Squaw Island
90 01 00	Becco tank

U.S.LAKE SURVEY
3 3333

U. S. Lake Survey
July 1953
3-3333

1952 Niagara River Measurements

AUSTIN SECTION HORIZONTAL CONTROL

Plate 4

Station REAR. Located in Buffalo, New York, about 100 feet southerly from slip at foot of Austin Street, 53.9 feet southerly from northwest corner and 23.7 feet from southwest corner of two story yellow brick building of the Gravel Products Corporation, 8.6 feet out from west face of building, being a 1 inch drill hole 0.2 feet from edge of curb.

Pointings from Station REAR

Pointing	Object
0° 00 '00"	Station EAST
308 22 30	Water tank in Canada
69 24 00	Easterly radio tower of two
82 57 00	Becco tank

U.S.LAKE SURVEY
3 3333

U. S. Lake Survey
July 1953
3-3333

1952 Niagara River Measurements

AUSTIN SECTION HORIZONTAL CONTROL

Plate 3

Station WEST. Unmarked station in Fort Erie, Ontario about 2400 feet along Niagara Blvd. downstream from the International Railroad Bridge between Highland Avenue and Bowen Road. Station is between Niagara Blvd. and the river, 5.6 feet from inner edge of curb, about 17 feet from the water's edge and 74.0 feet from the northeast corner of a house on the line of section. The line of AUSTIN SECTION is marked by a cross cut in the center of the easterly curb along Niagara Blvd. 107.5 feet southeasterly from iron catchbasin near Bowen Road and 100.2 feet northwesterly from a reference cross cut in the curb towards Highland Avenue from the section.

Pointings from Station WEST

Pointing	Object
0° 00'00"	Station EAST
180 00 00	Centerline of brick chimney on house on section
13 43 30	Centerline of clock tower
15 16 15	Centerline at top of squat tank
51 02 00	Centerline steeple canopy
288 08 30	Flagpole at Chevrolet Plant
312 30	R. R. C. G.

U.S.LAKE SURVEY
3 3333

APPENDIX C

ISO STANDARD 748 (1973) - ANNEX D

ANNEX D[1)]

CORRECTION FOR DRIFT

Where motor launches are used they shall be of sufficient power to avoid drift under normal conditions. In great depths and high velocities, it is sometimes impossible to keep the measuring launch exactly at the desired point. The upstream or downstream and lateral movements of the launch during velocity observation shall be measured by appropriate surveying techniques or electronic distance-measuring equipment, and a vector analysis made to determine the true velocity corrected for movement of the measuring-launch.

For downstream drift in high velocities, the drift can be measured and due allowance made in the velocity measurement. For example, based on 388 observations carried out on the river Indus at Kotri (range of velocities between 1,146 and 2,911 m/s (3.76 to 9.55 ft/s)), the correction for drift was obtained statistically with the following formula :

$$\bar{v}_p = 0{,}064 + 0{,}98\,\bar{v}_b + 0{,}98\,\bar{v}_d$$

where $\simeq \bar{V}_b + \bar{V}_d$

$\bar{v}_p$ is the true velocity, in metres per second;

$\bar{v}_b$ is the velocity, in metres per second, observed at the point with the boat drifting;

$\bar{v}_d$ is the drift velocity, in metres per second;

$$\bar{v}_d = \frac{\text{drift in metres}}{\text{120 s (period of observation)}}$$

In the above set of observations, the velocity without drift was observed by means of a sufficiently powered motor launch, while that with drift was observed by means of a flat-bottomed boat. A two-pronged anchor weighing 28,123 kg (62 lb) was used for partially anchoring the boat, the length of the rope paid out generally varying between 20 and 25 m. After the boat was towed sufficiently upstream, the anchor was dropped, and the velocity was measured while the boat drifted.

The drift velocity was measured from drift flags fixed at known distances apart on both the banks.

APPENDIX D

TYPICAL MANUAL DISCHARGE COMPUTATIONS

U. S. Lake Survey | Corps of Engineers

1957-1958 ESTABLISHMENT, CONTROL, CALIBRATION AND DISCHARGE MEASUREMENTS STELLA NIAGARA HYDRAULIC SECTION

Table 19 - Typical Discharge Computation

Measurement No. 8

Date: 26 June 1957

Panel No.	E.S.T. Start	E.S.T. End	Section Gage	Panel Area	Meters: Observed 0.4 Depth Velocity Left	Center	Right	Mean	Combined Coefficient	Mean Panel Velocity	Panel Discharge
1	0847	0855	246.72	3,338	3.30	3.28	3.28	3.29	0.768	2.527	8,435
2	0910	0917	246.66	6,696	3.73	3.70	3.69	3.71	0.942	3.495	23,403
3	0929	0933	246.70	8,044	3.76	3.75	3.68	3.73	0.943	3.517	28,291
4	0811	0830	246.66	7,792	3.65	3.69	3.75	3.70	0.901	3.334	25,979
5	1002	1010	246.70	7,568	3.96	3.97	3.98	3.97	0.922	3.660	27,699
6	1022	1027	246.64	9,242	3.65	3.68	3.68	3.67	0.936	3.435	31,746
7	1039	1043	246.72	8,389	3.40	3.44	3.40	3.41	0.952	3.246	27,231
8	1135	1144	246.64	6,297	2.94	2.97	2.97	2.96	0.965	2.856	17,984
9	1118	1125	246.76	4,877	2.57	2.63	2.63	2.61	0.942	2.459	11,993
10	1103	1108	246.89	2,488	2.20	2.26	2.63	2.36	0.731	1.725	4,292
		Mean Gage	246.71							Total Discharge	207,053

TABLE NO. 24

COMPUTATION FOR DISCHARGE MEASUREMENT NO. 1

Date of Measurement 10 October 1960.

STA.	TIME EDST		WATER LEVEL H-26 CA	PANEL AREA	RUN # 1 AT 0.1, 0.4, 0.7 DEPTHS			RUN # 2 AT 0.2, 0.6, 0.8 DEPTHS			RUN # 3 AT 0.3, 0.5, 0.9 DEPTHS			MEAN ADJ. VEL	TRANS. X DIR COEFF.	PANEL VEL.	PANEL DISCHARGE
	START	END			MEAN VEL.	VERT. COEFF.	ADJ. VEL.	MEAN VEL	VERT. COEFF.	ADJ. VEL.	MEAN VEL.	VERT COEFF.	ADJ. VEL.				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	10:48	11:06	156.25	1364	4.09	0.913	3.73	3.64	0.972	3.54	4.24	0.962[a]	3.65	3.64	0.936	3.41	4651
2	11:15	11:35	.27	3368	5.79	0.935	5.41	5.24	1.002	5.25	5.03	1.029	5.18	5.28	0.992	5.24	17643
3	11:55	12:24	.20	5942	5.75	0.938[b]	4.32	5.33	0.986	5.26	5.12	1.026	5.25	5.11	1.007	5.15	30601
4	12:33	12:45	.20	7111	6.04	0.947	5.72	5.84	0.978	5.71	5.56	1.017	5.65	5.69	0.984	5.60	39822
5	13:03	13:15	.19	7730	5.33	0.940	5.01	5.07	0.975	4.94	4.87	1.019	4.96	4.97	1.011	5.02	38805
6	13:27	13:42	.17	6860	5.19	0.929	4.82	4.91	0.990	4.86	4.74	1.024	4.85	4.84	0.980	4.74	32516
7	13:48	14:01	.16	5665	4.54	0.916	4.16	4.26	0.997	4.25	3.98	1.023	4.07	4.16	1.002	4.17	23623
8	14:17	14:30	.16	4381	4.07	0.909	3.70	3.80	0.992	3.77	3.81	1.025	3.91	3.79	0.980	3.71	16254
9	14:44	14:56	.16	2789	3.96	0.902	3.57	3.52	0.997	3.51	3.40	1.046	3.56	3.55	0.946	3.36	9371
10	15:10	15:25	.14	1904	3.23	0.913	2.95	3.15	0.997	3.14	3.42	0.993[a]	3.05	3.05	0.567	1.73	3294

a. Vert. Coeff. at 0.3 and 0.5 Depths only

b. Vert. Coeff. at 0.1 and 0.4 Depths only

MEAN WATER LEVEL 156.19

TOTAL DISCHARGE 216,600

CURRENT METER RATING

FOR

GURLEY-PRICE METER No. 1-53

Revolutions in 3 minutes	Velocity in ft. per sec. 3 Sept. 1960 "As Repaired"	Velocity in ft. per sec. 3 Nov. 1960 "As Received"	Mean Velocity Col. $\frac{2+3}{2}$
1	2	3	4
120	1.54	1.53	1.535
150	1.92	1.90	1.910
180	2.30	2.27	2.285
240	3.05	3.00	3.025
300	3.82	3.76	3.790
450	5.71	5.60	5.655
600	7.59	7.44	7.515

CURRENT METER RATING TABLE
FOR GURLEY-PRICE METER NO. 1-53

(Mean of "As Repaired" - "As Received" from Table 2)

Revolutions in 3 minutes	Velocity F.P.S.*	Revolutions	Velocity F.P.S.*	Revolutions	Velocity F.P.S.*
120	1.54	250	3.15	380	4.78
130	1.66	260	3.28	390	4.91
140	1.78	270	3.41	400	5.03
150	1.91	280	3.53	410	5.16
160	2.04	290	3.66	420	5.28
170	2.16	300	3.79	430	5.41
180	2.28	310	3.91	440	5.53
190	2.41	320	4.04	450	5.66
200	2.53	330	4.16	460	5.77
210	2.65	340	4.29	470	5.90
220	2.78	350	4.41	480	6.03
230	2.90	360	4.54	490	6.16
240	3.02	370	4.66	500	6.28

* Feet per second.

TABLE 16

DIRECTION OF FLOW COEFFICIENTS

Panel	Direction of Flow	Coefficient (Sine of angle in Col. 2)
1	2	3
1	89° 00'	1.000
2	88° 30'	1.000
3	85° 30'	0.997
4	88° 00'	0.999
5	85° 00'	0.996
6	85° 45'	0.997
7	84° 00'	0.994
8	79° 30'	0.983
9	72° 10'	0.952
10	71° 40'	0.949

VERTICAL VELOCITY COEFFICIENTS

Measuring Station	Concurrent Velocities at Depths of Observation									
	0.1,0.4	0.1,0.7	0.4,0.7	0.1,0.4,0.7	0.2,0.6	0.2,0.8	0.2,0.6,0.8	0.3,0.5	0.3,0.9	0.3,0.5,0.9
1				0.913			0.972	0.862		
2				0.935			1.002			1.029
3	0.838	0.938		0.905			0.986			1.026
4				0.947			0.978			1.017
5	0.919			0.940		0.990	0.975		1.072	1.019
6	0.879		0.963	0.929	0.917		0.990		1.085	1.024
7				0.916			0.997			1.023
8				0.909			0.992			1.025
9				0.902			0.997			1.046
10	0.847			0.913			0.997	0.893		

TRANSVERSE VELOCITY COEFFICIENTS

Item	Panel Number									
	1	2	3	4	5	6	7	8	9	10
Mean Velocity Under Transverse Velocity Curve	3.63	4.87	5.08	5.30	4.81	4.65	3.98	3.67	3.38	1.75
Mean Observed Velocity at Measuring Stations	3.88	4.91	5.03	5.38	4.74	4.73	3.95	3.68	3.40	2.93
Coefficient	0.936	0.992	1.010	0.985	1.015	0.983	1.008	0.997	0.994	0.597

COMBINED TRANSVERSE AND DIRECTIONAL COEFFICIENT

Panel	Coefficient		
	Transverse	Directional	Combined
1	0.936	1.000	0.936
2	0.992	1.000	0.992
3	1.010	0.997	1.007
4	0.985	0.999	0.984
5	1.015	0.996	1.011
6	0.983	0.997	0.980
7	1.008	0.994	1.002
8	0.997	0.983	0.980
9	0.994	0.952	0.946
10	0.597	0.949	0.567

CROSS SECTION AREA TO ELEVATION 158.00 FEET, 1935 DATUM,
FROM MANUAL SOUNDINGS IN OCTOBER 1960

Item	Panel Number										Total
	1	2	3	4	5	6	7	8	9	10	
Mean Depth (Feet)	9.806	24.693	41.467	49.533	53.760	47.707	40.240	30.760	20.507	9.502	
Width (Feet)	160.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	245.0	1605.0
Area (Sq. Feet)	1569	3704	6220	7430	8064	7156	6036	4614	3076	2328	50,197

CROSS SECTION AREA TO ELEVATION 158.00 FEET, 1935 DATUM,
FROM MANUAL SOUNDINGS 1 NOVEMBER 1960

Item	Panel Number										Total
	1	2	3	4	5	6	7	8	9	10	
Mean Depth (Feet)	10.587	24.593	41.533	49.633	53.733	48.000	40.387	30.460	20.147	9.661	
Width (Feet)	160.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	245.0	1605.0
Area (Sq. Feet)	1694	3689	6230	7445	8060	7200	6058	4569	3022	2367	50,334

TABLE 22

COMPARISON OF AREAS DETERMINED

BY MANUAL SOUNDINGS IN 1954, 1955, 1956 and 1960

(Area to Elevation 158.00 feet, 1935 Datum)

Year	Panel Number										Total
	1	2	3	4	5	6	7	8	9	10	
1954	1686	3728	6285	7361	7867	7014	5803	4649	3020	2314	49,727
1955	1711	3593	6232	7329	8032	7191	5922	4747	3142	2433	50,332
Spring 1956	1533	3515	6174	7358	7980	7100	5884	4658	3060	2338	49,600
Autumn 1956	1668	3539	6132	7362	8007	7140	5945	4706	3068	2382	49,949
Autumn 1960	1569	3704	6220	7430	8064	7156	6036	4614	3076	2328	50,197
Autumn 1960	1694	3689	6230	7445	8060	7200	6058	4569	3022	2367	50,334
Mean	1644	3628	6212	7381	8002	7134	5941	4657	3065	2360	50,024

TABLE 23

PANEL AREA TABLE

(Computed using mean areas in Table 22)

Water Surface Elevation (1935 Datum) Feet	Panel Number									
	1	2	3	4	5	6	7	8	9	10
155.60	1260	3268	5852	7021	7642	6774	5581	4297	2705	1772
155.70	1276	3283	5867	7036	7657	6789	5896	4312	2720	1796
155.80	1292	3298	5882	7051	7672	6804	5611	4327	2735	1821
155.90	1308	3313	5897	7066	7687	6819	5626	4342	2750	1846
156.00	1324	3328	5912	7081	7702	6834	5641	4357	2765	1870
156.10	1340	3343	5927	7096	7717	6849	5656	4372	2780	1894
156.20	1356	3358	5942	7111	7732	6864	5671	4387	2795	1919
156.30	1372	3373	5957	7126	7747	6879	5686	4402	2810	1944
156.40	1388	3388	5972	7141	7762	6894	5701	4417	2825	1968
156.50	1404	3403	5987	7156	7777	6909	5716	4432	2840	1992
156.60	1420	3418	6002	7171	7792	6924	5731	4447	2855	2017
158.00	1644	3628	6212	7381	8002	7134	5941	4657	3065	2360

APPENDIX E

TYPICAL AUTOMATED DISCHARGE COMPUTATIONS

PROGRAM 4316 OUTPUT

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

NIAGARA RIVER

INTERNATIONAL RAILWAY BRIDGE

6 JUL 1987 1551
INPUT PARAMETERS

I

						NIAGARA RIVER								RIVER	1
20						INTERNATIONAL RAILWAY BRIDGE								SECTION	2
														DESCRIPT	3
1 0100000000000000000000000C0000000000														SWITCH	4
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	DIR COEF	5
1000	1000	1000	1000	1000	1000	0	0	0	0	0				DIR COEF	6
651	1959	2882	2780	2633	2368	2756	3062	3037	2966	2898	2724	2958	2836	AREA	7
2463	2419	2428	2221	1975	718	0	0	0	0	056692				AREA	8
102	108	102	88	78	63	68	68	68	68	68	68	78	30	WIDTH	9
82	96	118	132	136	147	0	0	0	0	0				WIDTH	10
0	0													PAN PT	11

0.	51.	156.	261.	356.	439.	512.		
580.	648.	716.	784.	852.	920.	993.	X	12
1072.	1153.	1242.	1349.	1474.	1608.	1720.		
1823.	0.	0.	0.	0.	0.		X	13
0.	102.	210.	312.	400.	478.	546.		
614.	682.	750.	818.	886.	954.	1032.	Z	14
1112.	1194.	1290.	1408.	1540.	1676.	1823.		
0.	0.	0.	0.	0.	0.		Z	15

0	0	0	0										ELEV	16
0	0	0	0	0	0	0	0	0	0	0	0	0	OMEA	17
0	0	0	0	0	0	0	0	C	0	0	0	0	OMEA	18
0	0	0	0	0	0	0	0	0	0	0	0	1	MEA	19

SW 1 ON
SW 3 ON

WARNING METER CODE K
INTERSEPT ZERO 0

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

NIAGARA RIVER

INTERNATIONAL RAILWAY BRIDGE

6 JUL 1987 1551

TABLE 1 - CURRENT METER RATING EQUATIONS

CODE	NUMBER	EQUATION
G	20	VELOCITY = 2.127 REV. + 0.06
A	17	VELOCITY = 2.175 REV. + 0.01
X	12	VELOCITY = 2.218 REV. + -0.02
L	23	VELOCITY = 2.199 REV. + -0.01
C	18	VELOCITY = 2.148 REV. + 0.01
N	25	VELOCITY = 2.122 REV. + 0.02
9	9	VELOCITY = 2.266 REV. + -0.03
S	28	VELOCITY = 2.152 REV. + 0.05
K	22	VELOCITY = 2.256 REV. + 0.00
8	8	VELOCITY = 2.195 REV. + 0.07

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

NIAGARA RIVER

INTERNATIONAL RAILWAY BRIDGE

6 JUL 1987 1551

TABLE 3

PANEL NUMBER	PANEL WIDTH FEET	PANEL AREA SQ FEET	DIRECTIONAL COEF
1	102	651	1.000
2	108	1959	1.000
3	102	2882	1.000
4	88	2780	1.000
5	78	2633	1.000
6	68	2368	1.000
7	68	2756	1.000
8	68	3062	1.000
9	68	3037	1.000
10	68	2966	1.000
11	68	2898	1.000
12	68	2724	1.000
13	78	2958	1.000
14	80	2836	1.000
15	82	2463	1.000
16	96	2419	1.000
17	118	2428	1.000
18	132	2221	1.000
19	136	1975	1.000
20	147	718	1.000

PANEL AREA REFERENCE ELEVATION 566.92

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

NIAGARA RIVER

INTERNATIONAL RAILWAY BRIDGE

6 JUL 1987 1551

TABLE 4

PANEL	X AND Z LOCATION	DISTANCE IN FEET FROM EDGE OF WATER TO PANEL POINT X	PANEL EDGE Z
	1	0.	0.
1	2	51.	102.
2	3	156.	210.
3	4	261.	312.
4	5	356.	400.
5	6	439.	478.
6	7	512.	546.
7	8	580.	614.
8	9	648.	682.
9	10	716.	750.
10	11	784.	818.
11	12	852.	886.
12	13	920.	954.
13	14	993.	1032.
14	15	1072.	1112.
15	16	1153.	1194.
16	17	1242.	1290.
17	18	1349.	1403.
18	19	1474.	1540.
19	20	1608.	1676.
20	21	1720.	1823.
	22	1823.	0.

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

NIAGARA RIVER

INTERNATIONAL RAILWAY BRIDGE

6 JUL 1987 1551

VERTICAL VELOCITY

I	1	1	6	1987	1	800	1	G	3.80	2	G	3.66	3	G	3.70
I	1	1	6	1987	1	800	4	A	3.83	5	A	3.30	6	A	4.03
I	1	1	6	1987	1	800	7	X	3.66	8	X	3.70	9	X	3.51
I	1	1	6	1987	2	814	1	G	4.49	2	G	4.64	3	G	4.43
I	1	1	6	1987	2	814	4	A	4.39	5	A	4.56	6	A	4.25
I	1	1	6	1987	2	814	7	X	4.38	8	X	4.10	9	X	4.02
I	1	1	6	1987	3	830	1	G	5.41	2	G	5.43	3	G	5.30
I	1	1	6	1987	3	830	4	A	5.41	5	A	5.58	6	A	5.05
I	1	1	6	1987	3	830	7	X	5.45	8	X	5.39	9	X	4.18
I	1	1	6	1987	4	849	1	G	5.10	2	G	5.60	3	G	5.43
I	1	1	6	1987	4	849	4	A	5.35	5	A	5.53	6	A	5.43
I	1	1	6	1987	4	849	7	X	4.83	8	X	4.53	9	X	4.25
I	1	1	6	1987	5	856	1	G	6.04	2	G	6.10	3	G	5.74
I	1	1	6	1987	5	856	4	A	5.87	5	A	5.92	6	A	5.43
I	1	1	6	1987	5	856	7	X	5.29	8	X	5.44	9	X	4.76
I	1	1	6	1987	6	907	1	G	6.64	2	G	6.11	3	G	5.96
I	1	1	6	1987	6	907	4	A	6.29	5	A	5.78	6	A	5.46
I	1	1	6	1987	6	907	7	X	5.41	8	X	5.40	9	X	4.39
I	1	1	6	1987	7	915	1	G	6.25	2	G	5.80	3	G	6.31
I	1	1	6	1987	7	915	4	A	6.01	5	A	5.67	6	A	5.93
I	1	1	6	1987	7	915	7	X	5.40	8	X	4.92	9	X	3.65
I	1	1	6	1987	8	925	1	G	6.45	2	G	6.05	3	G	6.04
I	1	1	6	1987	8	925	4	A	6.11	5	A	6.10	6	A	5.94
I	1	1	6	1987	8	925	7	X	5.87	8	X	5.58	9	X	5.98
I	1	1	6	1987	9	940	1	G	6.13	2	G	6.72	3	G	5.80
I	1	1	6	1987	9	940	4	A	5.49	5	A	6.20	6	A	5.65
I	1	1	6	1987	9	940	7	X	5.02	8	X	5.24	9	X	4.45
I	1	1	6	1987	10	946	1	G	6.51	2	G	6.26	3	G	6.43
I	1	1	6	1987	10	946	4	A	6.32	5	A	6.25	6	A	5.85
I	1	1	6	1987	10	946	7	X	5.20	8	X	6.09	9	X	4.84
I	1	1	6	1987	11	756	1	C	5.35	2	C	5.98	3	C	6.31
I	1	1	6	1987	11	756	4	N	6.75	5	N	6.54	6	N	6.28
I	1	1	6	1987	11	756	7	9	5.75	8	9	5.29	9	9	4.85
I	1	1	6	1987	12	813	1	C	6.25	2	C	6.00	3	C	5.81
I	1	1	6	1987	12	813	4	N	6.18	5	N	6.35	6	N	6.34
I	1	1	6	1987	12	813	7	9	5.61	8	9	5.31	9	9	4.99
I	1	1	6	1987	13	826	1	C	6.06	2	C	5.83	3	C	5.86
I	1	1	6	1987	13	826	4	N	6.39	5	N	6.33	6	N	6.13
I	1	1	6	1987	13	826	7	9	5.29	8	9	5.43	9	9	4.84
I	1	1	6	1987	14	836	1	C	5.29	2	C	5.34	3	C	5.14
I	1	1	6	1987	14	836	4	N	6.12	5	N	5.91	6	N	5.81
I	1	1	6	1987	14	836	7	9	5.25	8	9	5.25	9	9	4.46
I	1	1	6	1987	15	846	1	C	4.38	2	C	4.46	3	C	4.42
I	1	1	6	1987	15	846	4	N	5.26	5	N	4.96	6	N	4.81
I	1	1	6	1987	15	846	7	9	4.00	8	9	3.70	9	9	3.74
I	1	1	6	1987	16	901	1	C	4.35	2	C	3.93	3	C	3.97
I	1	1	6	1987	16	901	4	N	4.60	5	N	4.45	6	N	4.26
I	1	1	6	1987	16	901	7	9	3.84	8	9	3.74	9	9	3.18
I	1	1	6	1987	17	903	1	C	3.46	2	C	3.43	3	C	3.19
I	1	1	6	1987	17	903	4	N	3.54	5	N	3.67	6	N	3.38
I	1	1	6	1987	17	903	7	9	3.03	8	9	3.04	9	9	2.81
I	1	1	6	1987	18	918	1	C	3.84	2	C	2.49	3	C	2.53
I	1	1	6	1987	18	918	4	N	4.17	5	N	2.76	6	N	2.79
I	1	1	6	1987	18	918	7	9	3.46	8	9	2.18	9	9	2.08
I	1	1	6	1987	19	926	1	C	2.28	2	C	2.24	3	C	2.14
I	1	1	6	1987	19	926	4	N	2.54	5	N	2.46	6	N	2.43
I	1	1	6	1987	19	926	7	9	1.71	8	9	2.12	9	9	1.65
I	1	1	6	1987	20	937	1	C	1.32	2	C	1.32	3	C	1.39
I	1	1	6	1987	20	937	4	N	1.28	5	N	1.49	6	N	1.53
I	1	1	6	1987	20	937	7	9	1.14	8	9	1.12	9	9	1.24

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

NIAGARA RIVER

INTERNATIONAL RAILWAY BRIDGE

6 JUL 1987 1551

MEASUREMENT NUMBER 1
1 JUN 1987

PANEL NO	SECTION GAGE	PANEL AREA	MEAN VERT VEL 9 DEPTHS	TRANSVERSE CURVE PANEL AREA	TRANSVERSE CURVE MEAN PANEL VELOCITY	TRAN COEF	DIR COEF	MEAN PANEL VEL	PANEL DISCHARGE
1	566.91	650	3.72	341	3.35	0.900	1.000	3.35	2177
2	566.88	1955	4.33	469	4.34	1.002	1.000	4.34	8485
3	566.84	2374	5.16	523	5.13	0.994	1.000	5.13	14744
4	566.80	2769	5.21	460	5.22	1.002	1.000	5.22	14454
5	566.79	2623	5.55	432	5.54	0.998	1.000	5.54	14531
6	566.77	2358	5.62	381	5.61	0.998	1.000	5.61	13228
7	566.76	2745	5.37	368	5.41	1.007	1.000	5.41	14850
8	566.75	3050	6.02	406	5.97	0.992	1.000	5.97	18208
9	566.73	3024	5.54	379	5.58	1.007	1.000	5.58	16874
10	566.72	2952	5.95	403	5.92	0.995	1.000	5.92	17476
11	566.91	2397	5.68	387	5.69	1.003	1.000	5.69	16484
12	566.88	2721	5.77	392	5.76	0.999	1.000	5.76	15673
13	566.85	2953	5.68	442	5.67	0.998	1.000	5.67	16744
14	566.83	2829	5.26	419	5.24	0.996	1.000	5.24	14824
15	566.81	2454	4.27	352	4.30	1.006	1.000	4.30	10552
16	566.78	2406	3.93	376	3.92	0.997	1.000	3.92	9432
17	566.77	2410	3.22	332	3.24	1.006	1.000	3.24	7808
18	566.76	2200	2.85	374	2.84	0.995	1.000	2.84	6248
19	566.74	1951	2.11	235	2.10	0.995	1.000	2.10	4097
20	566.73	690	1.29	137	0.93	0.720	1.000	0.93	642
								TOTAL	237531

DISCHARGE MEASUREMENT REDUCTION - 4316 - 722F3026

NIAGARA RIVER

INTERNATIONAL RAILWAY BRIDGE

6 JUL 1987 1551

SUMMARY OF MEASURED DISCHARGE

MEASUREMENT NUMBER	DATE	DISCHARGE IN CFS
1	1 JUN 1987	237500
2	1 JUN 1987	243900
3	1 JUN 1987	247000
4	1 JUN 1987	244100
5	2 JUN 1987	266400
6	2 JUN 1987	236600
7	2 JUN 1987	249500
8	2 JUN 1987	240900
9	2 JUN 1987	243700
10	2 JUN 1987	237500
11	3 JUN 1987	257600
12	3 JUN 1987	245700
13	3 JUN 1987	261400
14	3 JUN 1987	267300
15	3 JUN 1987	251700
16	4 JUN 1987	236500
17	4 JUN 1987	230200
18	4 JUN 1987	237800
19	4 JUN 1987	238600
	MEAN	245994

APPENDIX F

DISCHARGE MEASUREMENT ERROR ANALYSIS

J. Great Lakes Res., 1979
Internat. Assoc. Great Lakes Res. 5(1) 73-77.

RELATIVE ACCURACY OF CONNECTING CHANNEL DISCHARGE DATA WITH APPLICATION TO GREAT LAKES STUDIES[1]

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ABSTRACT. The flows in the Great Lakes connecting channels are a major component in the water balance of the Great Lakes Basin. The increased emphasis on Great Lakes water quality and quantity requires an assessment of the accuracy of both measured and computed connecting channel discharge data. In this study, the standard error of typical discharge measurements was found to be approximately 3 to 5 percent, depending upon the number of panels used in the cross section. Mesurement sets were found to have a practical limit of about 25 measurements. The standard error of a set of measurements was found to be on the order of 1 percent. The procedure used to compute the published flows of the Niagara River was found to have an apparent bias of about 2 percent on the high side. It is recommended that the published Niagara River flows be adjusted prior to use in detailed water balance studies.

INTRODUCTION

The flows in the Great Lakes connecting channels are a major component of the water balance of the Great Lakes Basin. Two of the channels, the Detroit and St. Clair Rivers, are not continually measured. Their discharges are computed by stage-fall-discharge equations (Quinn 1978) or by mathematical transient models (Quinn and Wylie 1972). On the other hand, the flows in the Niagara, St. Lawrence, and St. Marys Rivers are continually monitored by power plant ratings, compensating gate ratings, and in the case of the Niagara River, the Maid-of-the-Mist pool rating equation.

With the increased emphasis on the water quality and quantity of the Great Lakes, it is necessary to evaluate the relative accuracy of the various discharge calculations for use in Great Lakes studies. This paper addresses two important aspects of Great Lakes discharges. The first is the accuracy of the discharge measurements used to calibrate equations and models and to compute water quality loadings. The second is a comparison of the power plant ratings for the Niagara and St. Lawrence Rivers with discharge measurements taken during the International Field Year for the Great Lakes (IFYGL).

[1]GLERL Contribution No. 143.

DISCHARGE MEASUREMENT PROCEDURE

Typical connecting channel discharge measurement procedures as applied to the Niagara and St. Lawrence Rivers are given by the Water Survey of Canada (1972) and Cox (1974). The Niagara River was measured at the Stella Niagara section located 2 miles below Queenston, Ontario. The measuring section, 550 m wide, was divided into 12 panels. The interior panels consisted of eight 43 m-wide panels and two 49 m-wide panels. The two end panels were 52 m wide and 50 m wide. Four Price current meters were used to measure the velocity at 0.1 depth increments in each panel. This required three different meter settings of 2 minutes each. Three current meters were adjusted to new depths after each setting in each panel, while the fourth meter was held constant at the 0.4 depth to correct for flow fluctuations. The current meters were individually rated and a separate rating curve developed for each meter.

Similar procedures were applied to the St. Lawrence River with the measuring section located at Iroquois Dam. The St. Lawrence section consisted of 15 panels rather than the 12 used on the Niagara.

DISCHARGE MEASUREMENT ANALYSIS

The error analysis of the discharge measurements used the procedures recommended by Carter (1970) and Herschy (1970). Each of these procedures computes the standard error of a discharge measurement based upon the technique involved. Carter (1970) computes the overall standard error of a discharge measurement, XQ, from

$$XQ^2 = S_{R_i}^2 + S_{R_t}^2 + S_{R_s}^2 + S_{R_N}^2 \qquad (1)$$

where S_{R_i} is the standard error due to instrument error, 1.0 percent

S_{R_t} is the standard error due to velocity pulsation

S_{R_s} is the standard error due to vertical velocity curve errors

S_{R_N} is the standard error due to the number of measuring stations in the cross section.

The velocity pulsation error is given by

$$S_{R_t} = \frac{S_{r_t}}{\sqrt{N_p}} \qquad (2)$$

where S_{r_t} is the standard error due to velocity fluctuations at a point

N_p is the number of observation points

The standard error due to the point sampling of velocity in the vertical is given by

$$S_{R_s} = \frac{S_{r_s}\,[1 + (N\text{-}1)\,\rho]^{1/2}}{\sqrt{N}} \qquad (3)$$

where S_{r_s} is the standard error due to the shape of the vertical velocity curve at a station

N is the number of panels in a cross section

ρ is the average correlation coefficient, 0.04, between the ratios of the average 0.3 and 0.8 depth velocities and the mean in the vertical for a given section.

Carter (1970) provides a table of values for S_{r_t}, S_{r_s}, and S_{R_N}. Applying Carter's (1970) procedure to Niagara River, we obtain

$$XQ^2 = 1.0^2 + \left(\frac{2.9}{\sqrt{12}}\right)^2 + \left(\frac{4.3[1 + (12\text{-}1)0.004]^{1/2}}{\sqrt{12}}\right)^2 + 4.1^2$$

$$XQ = 4.6 \text{ percent}$$

The 95 percent confidence level (2XQ) is then 9.2 percent. For the Niagara River, Carter's (1970) tables indicate

S_{r_t} is 2.9 for 2 minute measurements

S_{r_s} is $\leq$ 4.3 for vertical measurements at each 0.1 depth

S_{R_n} is 4.1 for 12 panels.

The 95 percent confidence level for the set of Niagara River discharge measurements, 24 in total, is given by

$$2\,\overline{XQ} = \frac{2\,XQ}{\sqrt{N_m}} = \frac{9.2}{\sqrt{24}} = 1.9 \text{ percent} \qquad (4)$$

where N_m is the number of measurements.

Herschy (1970) computes the overall standard error, XQ, of a discharge measurement by

$$XQ = \pm\sqrt{(X_q')^2 + (X_q'')^2} \qquad (5)$$

where X_q' is the overall random error in discharge

X_q'' is the overall systematic error in discharge.

The overall random error in discharge is given by

$$X_q' = \sqrt{X_m'^2 + \frac{1}{m}(X_b'^2 + X_d'^2 + X_v'^2)} \qquad (6)$$

where X_m' is the error due to the choice of the number of verticals

X_b' is the error in measuring width

X_d' is the error in measuring depth

X_v' is the error in measuring velocity

m is the number of panels.

The error in measuring velocity is given by

$$X_v' = \pm\sqrt{\frac{X_f^2}{P} + X_o^2} \qquad (7)$$

where X_f is the error due to the choice of duration of exposure of current meter

X_o is the error due to the choice of the number of points in a vertical

P is the number of measuring points in the vertical.

The overall systematic error in discharge is

$$X_q = \pm\sqrt{X_b''^2 + X_d''^2 + X_v''^2} \qquad (8)$$

where X_b'' is the systematic error in measuring width

X_d'' is the systematic error in measuring depth

X_v'' is the systematic error of the current meter.

Herschy (1970) also provides tables to aid in evaluating the above errors. By applying Herschy's procedure to the Niagara measurements, the following values are obtained from his tables

$X_m' = 3.6$ percent for 12 panels

$X_f' = 6$ percent

$X_o' = 0.5$ percent for using the 9 point velocity distribution

X_b' is recommended as 0.5

$X_d' = 1.5$ percent

Thus

$$X_v' = \sqrt{\left(\frac{6^2}{9} + 0.5^2\right)} = 2.06$$

$$X_q' = \left(3.8^2 + \frac{1}{12}(0.5^2 + 1.5^2 + 2.06^2)\right)^{1/2} = 3.87.$$

The systematic error is computed as follows:

$X_b'' = 0.5$ percent

$X_d'' = 0.5$ percent

$X_v'' = 0.5$ percent for velocity greater than 0.3 m/sec

$$X_q'' = \sqrt{(0.5^2 + 0.5^2 + 0.5^2)} = 0.87.$$

The overall standard error then becomes

$$XQ = \left(3.87^2 + 0.87^2\right)^{1/2} = 3.97 \text{ percent.}$$

The 95 percent confidence level 2XQ then becomes 7.9 percent. This is approximately 1.3 percent less at the 95 percent confidence level than computed by Carter's procedure. The difference in the results is largely due to the differing percentages ascribed to the error induced by the number of panels in the cross section. This is the largest contributor to error in both procedures. In actuality, the overall error is probably somewhat less than indicated in both procedures because transverse coefficients are determined from the measured transverse velocity curve and applied to each of the panels in the discharge measurement computations. The flow variation between the mesurements was relatively small with the coefficient of variation being approximately 7 percent. A correlation analysis between the percent error and the flow rate indicated very little correlation with the coefficient of determination being approximately 12 percent.

For the St. Lawrence River measurements the basic procedure given above for the Niagara River was followed except that 15 rather than 12 panels were used in the cross section. This results in standard errors, XQ, of 4.5 and 3.2 percent by Carter's and Herschy's procedures, respectively. The difference is due to Carter's step function for SR_N. Because the step function changes rapidly between the 15th and 16th panels, there is a reduction of 1.7 percent in the standard error. Thus, Herschy's value of 3.2 percent is the more probable value. The standard error of the mean set of 19 measurements then becomes

$$XQ = \frac{XQ}{\sqrt{N_m}} = \frac{3.2}{\sqrt{19}} = 0.7 \text{ percent.}$$

The preceding analysis can also serve as a guide to achieve desired accuracy in an individual or a set of discharge measurements. Using standard connecting channel flow measuring procedure, accuracy can be improved by increasing the number of panels in the case of an individual discharge measurement and also by increasing the number of measurements in the case of a group of measurements. Figure 1 shows the variation in the standard error of a single discharge measurement with the number of panels in the cross section. The impact of Carter's step function for SR_N, as mentioned earlier, is readily apparent. It is also noted that a reduced rate of improvement results from using over 25 panels. Figure 2 shows the standard error of a set of measurements versus the number of measurements for the situation where the error of a single discharge measurement is 9.2 percent at the 95 percent confidence level. It is seen that the optimum number of measurements in a set would approach 25. Above 25 measurements the incremental increase in accuracy for additional measurements is substantially reduced.

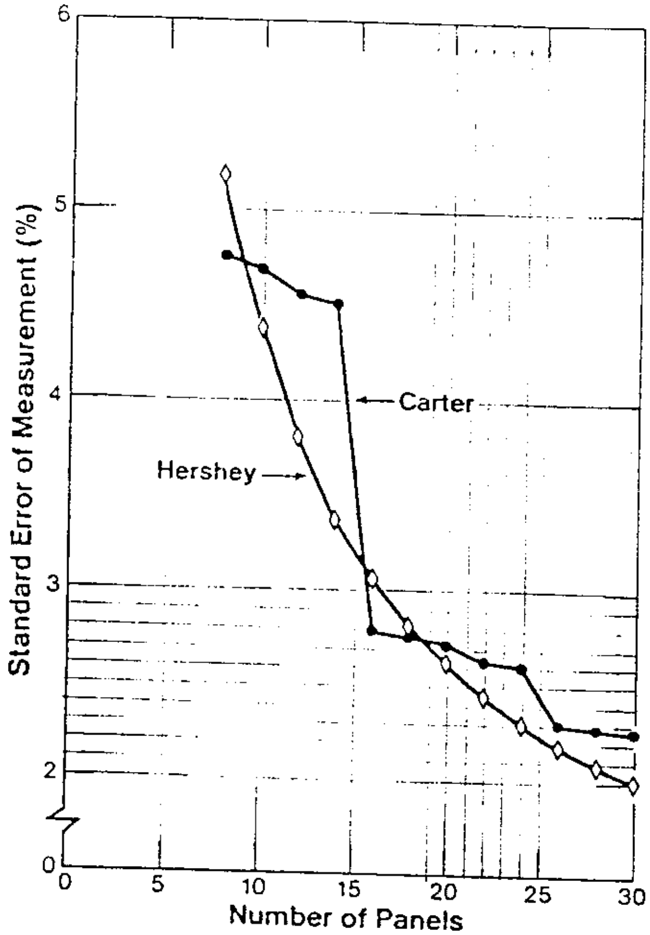

FIG. 1. Standard error of measurement vs. number of panels in the cross-section.

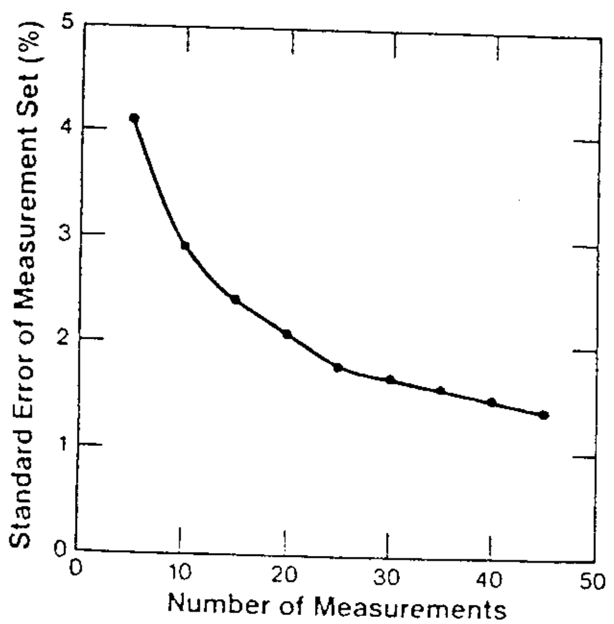

FIG. 2. Standard error of measurement set vs. number of measurements for XQ = 9.2% at the 95% confidence limit.

COMPARISON OF DISCHARGE MEASUREMENTS AND POWER PLANT RATINGS

The aforementioned discharge measurements were taken during IFYGL to verify the power plant ragings used to compute the Niagara and St. Lawrence River flows on an operational basis. If either of the ratings were biased, corrections should be applied prior to use in Lake Ontario water balance studies. The plant ratings and measured discharges were compared using the paired Student's t test. Table 1 gives the differences between the plant ratings and the measured Niagara River discharges, expressed as a percentage of the measured flow (Water Survey of Canada 1972).

The Student's t is given by

$$t = \frac{\mu_p}{S_p} N_m^{1/2}$$

where μ_p is the mean percentage difference between the paired measured and rating flows

S_p is the standard deviation of the percent differences

N_m is the number of measurements.

The Student's t for the 24 Niagara River measurements is given by

$$t = \frac{1.9\,(24)^{1/2}}{1.05} = 8.86$$

At the 1 percent significance level, 0.5 percent in each tail, the critical value of t for 23 degrees freedom is 2.81. Since this is less than the t value of 8.86, the power rating appears to be biased. Thus, the recorded Niagara River discharges should be corrected by 1.9 percent prior to use in sensitive Lake Ontario water balance studies. Also, additional measurements should probably be taken to verify the above conclusion.

The impact of a 1.9 percent change in Niagara River inflow on water balance studies is that it reduces computed water balance evaporation by approximately 200 mm/year or about 30 percent.

The differences between the power plant rating and measured St. Lawrence River discharges for the 19 measurements are given in Table 2. The Student's t for the St. Lawerence River is

$$t = \frac{0.49\,(19)^{1/2}}{1.08} = 1.98$$

As the computed value of 1.98 is less than the

TABLE 1. Comparison of measured and power plant ratings of Niagara River flows at Stella at the Niagara Section, 1972.

Measurement Number	Percent Difference	Measurement Number	Percent Difference
1	0.7	22	2.0
3	1.6	23	3.2
4	1.0	24	2.7
5	1.1	25	1.3
7	0.8	26	0.9
9	2.3	27	2.8
10	0.5	28	1.9
12	1.8	29	1.0
14	2.5	30	3.3
15	2.0	31	3.4
16	0.2		
17	3.5	Mean μ_p	1.9
18	3.5	Std. Dev. S_p	1.05
19	0.9		

TABLE 2. Comparison of measured and power plant ratings of St. Lawrence River flows at Iroquois Dam, July 1972.

Measurement Date	Percent Difference	Measurement Date	Percent Difference
6	2.9	20	-0.8
7	0.3	21	-0.1
8	1.1	22	1.0
11	0.6	24	0.1
12	1.2	25	-0.8
13	0.4	26	1.6
14	0.2	27	-0.9
15	1.6	28	-0.1
17	0.1		
18	2.1	Mean μ_p	0.5
19	-1.1	Std. Dev. S_p	1.08

critical value of 2.88 for 18 degrees of freedom at the 1 percent significance level, the St. Lawrence power ratings appear unbiased and recorded values can be used without correction in the Lake Ontario studies.

CONCLUSIONS

The standard error of individual connecting channel discharge measurements is found to be on the order of 3 to 5 percent, depending upon both the procedure used and the number of panels in the cross section. The optimal number of panels from an error standpoint appears to be approximately 25. Figure 1 can be used to assess the errors involved when practical considerations limit the number of panels.

Measurement sets used in the calibration of discharge equations or models should comprise approximately 25 measurements. Above this number a relatively small incremental gain in accuracy is obtained for an increased number of measurements. Figures 1 and 2 can be used to design a set of measurements to meet varying objectives.

Of particular importance to Lake Ontario water balance studies is the apparent bias in the procedure used to determine the Niagara River flows for publication. The published flows appear to be biased on the high side by approximately 2 percent. Pending additional measurements, it is recommended that the published Niagara River discharges for 1972 and 1973 be reduced by 1.9 percent for IFYGL water balance studies.

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APPENDIX G

TYPICAL MANUAL MOVING-BOAT DISCHARGE COMPUTATIONS

HYDROMETRIC SURVEY NOTES
MOVING BOAT METHOD

Run No. 2
Direction L - R

Station St. Lawrence River at LaSalle ..... Sta. No. 02OA016

Date June 2, 1976 ..... Party Tremblay, Jones, Kowalski

Temp. A 22 °C W 10 °C Width 905 ..... Area 5800

Mean vel. 2.00 Corr. M.G.H. 19.603 ..... Discharge 11600

Width/area adjustment coeff. 0.94 ..... Velocity adjustment coeff. 0.92

Measurement began at 13:30 ..... ended at 13:45

Levels obtained NO

Gauge Readings				
Time	Remarks	Pen	Inside	Outside
13:30		19.602		
13:45		19:604		
Weighted M.G.R.		19.603		
Correction		0		
Correct M.G.H.		19.603		

Meter number A-21204

Date calibrated 1975-12-11

Current meter one m below surface

Depth sounder trans. adj. —— m

Range 4 ..... Distance 44.8 m

I.P. to left edge water 80 m

Left edge water to float 46 m

Float to right edge water 61 m

Right edge water to E.P. 75 m

Number of sections 30

Measured width 905 ..... Computed width 967.9

Mean velocity in vertical/velocity at meter 1. 0.94 2. 0.90 3. 0.92

Weather conditions clear and mild ..... Wind NW 10-15

Measurement: one m (km) above (below) gauge

Remarks: Include condition of station equipment

control clear of debris

Computed by T. Jones ..... Checked by P. Kowalski

067-2150E (03/78) R-22-A(M)

Station St. Lawrence River at La Salle

Angle α	D	Dist. from initial point	Width	Depth	Pulses per second	V_v	Sin α	V_v sin α	Area	Discharge
IP		0								
LEW		80	23.0							
70	46.0	126.0	28.6	5.7	450	2.46	.940	2.31	163.0	376.5
(½) 60	11.2	137.2	19.4	5.8	470	2.57	.866	2.23	112.5	250.9
52	27.6	164.8	28.5	5.4	470	2.57	.788	2.03	153.9	312.4
49	29.4	194.2	30.6	5.6	470	2.57	.755	1.94	171.4	332.5
45	31.7	225.9	28.7	5.8	520	2.84	.707	2.01	166.5	334.7
55	25.7	251.6	26.4	6.2	550	3.00	.819	2.46	163.7	402.7
53	27.0	278.6	25.7	7.3	520	2.84	.799	2.27	187.6	425.9
57	24.4	303.0	27.2	7.5	510	2.78	.839	2.33	204.0	475.3
48	30.0	333.0	32.2	7.6	500	2.73	.743	2.03	244.7	496.7
40	34.3	367.3	31.9	8.5	570	3.11	.643	2.00	271.2	542.4
49	29.4	396.7	29.7	8.1	530	2.89	.755	2.18	240.6	524.5
48	30.0	426.7	30.3	8.4	550	3.00	.743	2.23	254.5	567.5
47	30.6	457.3	30.3	8.4	590	3.22	.731	2.35	254.5	598.1
48	30.0	487.3	30.6	7.6	550	3.00	.743	2.23	232.6	518.7
46	31.1	518.4	29.7	8.3	590	3.22	.719	2.32	246.5	571.9
51	28.2	546.6	28.5	8.2	620	3.38	.777	2.63	233.7	614.6
50	28.8	575.4	29.4	9.0	600	3.27	.766	2.50	264.6	661.5
48	30.0	605.4	30.3	8.7	640	3.49	.743	2.59	263.6	682.7
47	30.6	636.0	30.9	8.7	610	3.32	.731	2.43	268.8	653.2
46	31.1	667.1	30.9	7.9	640	3.49	.719	2.51	244.1	612.7
47	30.6	697.7	29.1	7.6	560	3.05	.731	2.23	221.2	493.3
52	27.6	725.3	32.4	7.0	590	3.22	.788	2.54	226.8	576.1
34	37.1	762.4	35.7	6.4	620	3.38	.559	1.89	228.5	431.9
40	34.3	796.7	33.6	7.9	580	3.16	.643	2.03	265.4	538.8
43	32.8	829.5	34.5	7.8	570	3.11	.682	2.12	269.1	570.5
36	36.2	865.7	35.3	6.0	480	2.62	.588	1.54	211.8	326.2
40	34.3	900.0	33.8	4.6	370	2.02	.643	1.80	155.5	202.2
42	33.3	933.3	32.8	3.0	270	1.48	.669	0.99	98.4	97.4
44	32.2	965.5	26.8	2.2	300	1.65	.695	1.15	59.0	67.9
(0.70) 47	21.4	986.9	41.2	2.1	320	1.75	.731	1.28	86.5	110.7
REW	61.0	1047.9	30.5							
EP		1122.9								
	967.9		968.5						6164.2	13370.4

WIDTH/AREA ADJUSTMENT COEFF. = 905 / 967.9 = 0.94

ADJUSTED AREA = 6164.2 (0.94) = 5800

ADJUSTED DISCHARGE = 13370.4 (0.94) = 12568.2

VELOCITY ADJUSTMENT COEFF. = 0.92

ADJUSTED DISCHARGE = 12568.2 (0.92) = 11600

Figure 10. Sample moving boat measurement.

Station St. Lawrence River at La Salle

ANGLE α	[illegible]	DIST FROM INITIAL POINT	WIDTH	DEPTH	PULSES PER SECOND	V_v	SIN α	$\frac{V_v}{\text{SIN } \alpha}$	AREA	DISCHARGE
IP		0								
LEW		80	23.0							
70	46.0	126.0	28.6	5.7	450	2.46	.940	2.31	163.0	376.5
(½) 60	11.2	137.2	19.4	5.8	470	2.57	.866	2.23	112.5	250.9
52	27.6	164.8	30.5	5.4	470	2.57	.788	2.03	164.7	334.3
42	33.3	198.1	32.8	3.0	270	1.48	.669	0.99	98.4	97.4
44	32.2	230.3	26.8	2.2	300	1.65	.695	1.15	59.0	67.9
(0.70) 47	21.4	251.7	41.2	2.1	320	1.75	.731	1.28	86.5	110.7
REW	61.0	312.7	30.5							
EP		387.7								
	232.7		232.8						684.1	1237.7

Figure A-1. A short form discharge measurement.

APPENDIX H

TYPICAL AUTOMATED MOVING-BOAT DISCHARGE COMPUTATIONS

ST. MARYS RIVER BELOW RAPIDS AT SAULT STE. MARIE

JULY/AUGUST 1989 MOVING-BOAT DISCHARGE MEASUREMENTS

SUMMARY OF VELOCITY-DEPTH PROFILE DATA

Date	E.S.T	W.L. (1)	Distance from South Bank m	Depth m	(2) Mean Vel. m/s	(3) Meter Depth m	(4) Velocity at Meter Depth m/s	(5) Coef.	Average Coef. for Section
25 JULY 89	15 40a	176.72	40a	2.00	0.86	0.4	1.01	0.846	0.828
	16 10a		114	2.90	0.57	0.4	0.70	0.813	
	16 40a		182	2.32	0.30	0.4	0.36	0.826	
26 JULY 89	10 30	176.69	40	2.40	0.52	0.4	0.63	0.819	0.828
	11 00		116a	2.70	0.37	0.4	0.46	0.815	
	11 30		175a	2.25	0.19	0.4	0.22	0.849	
27 JULY 89	08 08	176.67	30a	2.25	0.38	0.4	0.46	0.820	0.830
	08 20		116a	2.60	0.33	0.4	0.39	0.851	
	08 40		175a	2.65	0.17	0.4	0.21	0.818	
29 JULY 89	15 00a	176.66	35a	2.20	1.60	0.4	1.97	0.811	0.826
	15 20a		116a	2.62	1.16	0.4	1.39	0.832	
	15 45a		175a	2.43	0.65	0.4	0.78	0.834	
1 AUG 89	16 30	176.80	50a	2.63	1.99	0.6	2.35	0.848	0.848
	16 45		116a	2.80	1.81	0.6	2.11	0.859	
	17 02		175a	2.77	1.03	0.6	1.23	0.838	
2 AUG 89	15 45a	176.85	40a	2.60	2.23	0.6	2.59	0.861	0.849
	16 10a		116a	3.22	1.68	0.6	2.00	0.839	
	16 30a		175a	3.00	1.18	0.6	1.39	0.847	
3 AUG 89	13 10	177.01	50	2.80	2.26	0.6	2.64	0.857	0.851
	13 35		110	3.30	1.85	0.6	2.20	0.840	
	14 00		180	2.90	1.35	0.6	1.58	0.855	

Notes: a = approximate
- (1) Average water level in metres IGLD 1955 at Lower Soo gage for the time of the three profiles.
- (2) Mean velocity by Quinn-von Karmann numerical procedure as used in Program 4316 of Detroit District, U.S. Army Corps of Engineers for reduction of velocity data in discharge measurements in the Great Lakes connecting channels.
- (3) Depth of current meter below water surface in moving-boat measurements for the day.
- (4) Fitted velocity at meter depth by above (2) procedure.
- (5) Column (2) divided by Column (4).

TYPICAL AUTOMATED MOVING-BOAT MEASUREMENT COMPUTER TAPE

```
DATEM MOVING-BOAT DISCH'GE ANALYSIS,VI
ENTER TITLE: ST MARYS R.  FRECHETTE PT
ENTER DATE (00/00/00): 86/09/10
ENTER TIME (00:01:39): 11:27:00

DIOS VERSION 1.0
>P
ENTER DATE (86/09/10):
ENTER TIME (11:27:16):
DISPLAY IN METRES(DEFAULT)/FEET(F):
ENTER LEW(00.0): 99
ENTER REW (00.0) 30
ENTER ACTUAL WIDTH (0000.0): 456
VELOCITY ADJUST FACTOR (1.0000): 92
ENTER SPEED OF SOUND (1500):
ENTER TRANSDUCER DRAFT (0.00): 1.0
SET BASELINE; HIT "RETURN" WHEN READY:
OTTMETER CONSTANTS FILENAME: PAUL 10
FILE NOT FOUND; USE ASSUMED CONSTANTS

ENTER RECORD FILENAME: PAUL 10
ENTER SELECTED RUN NUMBER (01):
REVERSE TRAVEL DIRECTION (Y OR N)? N
ENTER SELECTED RANGE (01): 5

RUN 01     86/09/10      11:36:21
ST MARYS R  FRECHETTE PT
0.00541 0.02203  (DEFAULT VALUES)
LEW 99.0 REW 30.0 W 0456.0 V 0.9200
ENTER PRINT SUPPRESSION  (0 - 10):

SMP CA DA   ETIME VX   WIDTH    Q
-01 59 02.8 000.0 0.58 099.0 0080.5
-02 54 03.1 007.8 0.58 003.3 0005.9
-03 46 03.5 013.3 0.61 007.8 0016.5
-04 44 03.9 011.9 0.65 008.1 0020.5
-05 45 03.7 011.1 0.71 007.9 0020.9
-06 46 04.1 010.7 0.75 007.8 0024.0
-07 47 05.1 010.5 0.78 007.6 0030.4
-08 47 05.3 012.2 0.67 007.6 0027.1
-09 48 05.6 011.0 0.76 007.5 0031.7
-10 52 08.2 010.1 0.87 006.9 0049.3
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-11 53 10.8 009.4 0.95 006.7 0069.2
-12 53 10.9 008.8 1.02 006.7 0074.6
-13 52 11.1 008.9 0.99 006.9 0075.8
-14 53 11.1 008.7 1.03 006.7 0076.9
-15 53 11.0 008.6 1.04 006.7 0077.1
-16 52 11.2 007.2 1.23 006.9 0094.5
-17 52 11.5 007.1 1.24 006.9 0098.4
-18 52 11.4 006.8 1.30 006.9 0101.9
-19 52 11.0 006.9 1.28 006.9 0096.9
-20 49 11.1 007.5 1.13 007.3 0091.9
-21 49 11.5 007.2 1.17 007.3 0099.1
-22 51 11.6 006.8 1.28 007.0 0104.5
-23 51 11.4 007.1 1.23 007.0 0098.3
-24 52 11.2 007.3 1.21 006.9 0093.2
-25 54 11.0 007.4 1.22 006.6 0088.6
-26 53 11.1 007.4 1.21 006.7 0090.4
-27 51 11.3 006.9 1.26 007.0 0100.3
-28 50 11.5 007.4 1.16 007.2 0095.8
-29 48 11.9 008.8 1.04 007.5 0092.7
-30 50 11.9 008.7 0.99 007.2 0084.7
-31 54 11.3 008.9 1.02 006.6 0075.7
-32 55 10.7 009.6 0.96 006.4 0065.6
-33 52 10.5 010.6 0.83 006.9 0060.2
-34 48 10.5 010.2 0.82 007.5 0064.1
-35 46 07.7 010.6 0.76 007.8 0045.5
-36 45 04.2 011.7 0.68 007.9 0022.5
-37 46 03.3 013.1 0.61 007.8 0015.8
-38 44 03.2 002.6 0.48 001.3 0002.0
- END SEGMENT                    0023.1

              *** SUMMARY ***
MEASURED DISCHARGE                02486
MEASURED AREA                     02483
MEASURED WIDTH                   0385.0
WIDTH ADJUSTMENT FACTOR          1.1841
WIDTH ADJUSTED DISCHARGE          02943
WIDTH ADJUSTED AREA               02940
DEPTH ADJUSTED DISCHARGE          02708

ELAPSED TIME 00:05:30 (0330.0 SECS)
** START 11:36:48  STOP 11:45:29 **
>R
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Table 3

St. Marys River below Rapids at Sault Ste. Marie

Summary of July/August 1989 Moving-Boat Discharge Measurements

Date	Run No.	Dir.	Start E.S.T. h	Start E.S.T. m	Run Time m	Run Time s	Avg. Depth m	Meter Draft m	Coef.	True Width m	Meas. Width m	Meas. Disch. cms	Meas. Area m2	Adj. Area m2	Mean Vel. m/s	Adj. Disch. cms	Average Discharge cms	Average Discharge cfs	
25 July 89	1	N	13	3	2	17	3.39	0.4	0.83	208.	142.1	701.	482.	706.	1.21	852.	713.	25194.	X
25 July 89	2	S	13	6	1	58	3.07	0.4	0.83	208.	187.0	623.	574.	638.	0.90	575.			
25 July 89	3	N	13	11	3	38	1.93	0.4	0.83	208.	138.3	344.	267.	402.	1.07	429.	381.	13455.	X
25 July 89	4	S	13	32	2	14	1.96	0.4	0.83	208.	168.7	325.	330.	407.	0.82	333.			
25 July 89	5	N	13	36	2	51	2.04	0.4	0.83	208.	113.8	296.	232.	424.	1.06	449.	474.	16724.	X
25 July 89	6	S	13	45	1	14	2.11	0.4	0.83	208.	153.2	442.	323.	439.	1.14	498.			
25 July 89	7	N	13	52	2	56	1.82	0.4	0.83	208.	115.9	339.	211.	379.	1.33	505.	485.	17125.	X
25 July 89	8	S	14	8	2	12	2.70	0.4	0.83	208.	129.6	349.	350.	562.	0.83	465.			
25 July 89	9	N	16	51	4	57	2.84	0.4	0.83	232.	214.2	467.	609.	660.	0.64	420.	352.	12440.	
25 July 89	10	S	17	0	3	57	2.85	0.4	0.83	232.	194.8	288.	555.	661.	0.43	285.			
25 July 89	11	N	17	6	5	11	2.89	0.4	0.83	232.	216.0	490.	625.	671.	0.65	437.	350.	12375.	
25 July 89	12	S	17	13	3	26	2.85	0.4	0.83	232.	199.1	273.	567.	661.	0.40	264.			
25 July 89	13	N	17	19	4	4	2.93	0.4	0.83	232.	225.2	498.	659.	679.	0.63	426.	367.	12947.	
25 July 89	14	S	17	25	4	12	2.93	0.4	0.83	232.	187.3	299.	548.	679.	0.45	307.			
26 July 89	1	N	9	0	5	5	2.71	0.4	0.83	243.	194.0	271.	525.	658.	0.43	282.	214.	7541.	
26 July 89	2	S	9	7	5	35	2.70	0.4	0.83	243.	254.0	183.	687.	657.	0.22	145.			
26 July 89	3	N	9	16	7	38	2.61	0.4	0.83	243.	167.9	217.	438.	634.	0.41	261.	224.	7916.	
26 July 89	4	S	9	27	9	40	2.75	0.4	0.83	243.	275.2	256.	757.	668.	0.28	188.			
26 July 89	5	N	9	43	5	55	2.62	0.4	0.83	243.	176.6	228.	463.	637.	0.41	260.	208.	7352.	
26 July 89	6	S	9	50	6	54	2.69	0.4	0.83	243.	247.0	191.	665.	654.	0.24	156.			
26 July 89	7	N	9	59	4	49	2.59	0.4	0.83	243.	189.3	272.	491.	630.	0.46	290.	212.	7470.	
26 July 89	8	S	10	6	4	25	2.69	0.4	0.83	243.	252.8	167.	679.	653.	0.20	133.			
26 July 89	9	N	10	19	4	56	2.63	0.4	0.83	243.	192.4	250.	506.	639.	0.41	262.	210.	7423.	
26 July 89	10	S	10	26	4	51	2.69	0.4	0.83	243.	249.7	196.	671.	653.	0.24	158.			
26 July 89	11	N	10	33	5	7	2.62	0.4	0.83	243.	182.3	246.	477.	636.	0.43	272.	209.	7389.	
26 July 89	12	S	10	40	4	20	2.73	0.4	0.83	243.	245.4	178.	671.	664.	0.22	146.			
26 July 89	13	N	13	3	4	1	2.75	0.4	0.83	243.	206.9	270.	569.	668.	0.39	263.	232.	8198.	
26 July 89	14	S	13	10	4	23	2.71	0.4	0.83	243.	235.7	235.	638.	658.	0.31	201.			
26 July 89	15	N	13	17	4	15	2.75	0.4	0.83	243.	212.4	214.	584.	668.	0.30	203.	214.	7549.	
26 July 89	16	S	13	22	4	9	2.70	0.4	0.83	243.	227.5	253.	615.	657.	0.34	224.			
26 July 89	17	S	13	42	11	6	2.71	0.4	0.83	243.	271.6	243.	735.	658.	0.27	180.	198.	7009.	
26 July 89	18	N	13	55	8	4	2.75	0.4	0.83	243.	197.5	212.	544.	669.	0.32	216.			
26 July 89	19	N	14	12	7	48	2.75	0.4	0.83	243.	190.2	221.	524.	669.	0.35	234.	207.	7303.	
26 July 89	20	S	14	23	11	41	2.75	0.4	0.83	243.	277.9	247.	765.	669.	0.27	179.			
26 July 89	21	N	14	43	8	11	2.74	0.4	0.83	243.	200.8	233.	551.	667.	0.35	234.	207.	7322.	
26 July 89	22	S	14	56	10	1	2.80	0.4	0.83	243.	262.4	235.	734.	680.	0.27	181.			
26 July 89	23	N	15	7	10	53	2.77	0.4	0.83	243.	201.3	227.	558.	674.	0.34	227.	218.	7701.	
26 July 89	24	S	15	20	9	50	2.75	0.4	0.83	243.	248.4	257.	682.	667.	0.31	209.			
26 July 89	25	N	15	32	9	30	2.80	0.4	0.83	243.	193.8	213.	543.	681.	0.33	222.	201.	7098.	
26 July 89	26	S	15	44	10	18	2.79	0.4	0.83	243.	265.1	237.	739.	677.	0.27	180.			

X = measurement rejected acc. excessive turbulance at this section. New section established commencing with Run 9.

........(Cont'd.)