SECTION 6

HYDRAULIC DISCHARGE MEASUREMENTS ON THE NIAGARA RIVER

6.1 Near Black Rock Harbor, 1841.

In the summer of 1841, Z. Allen and E.R. Blackwell (Siliman's Journal #46, First Series, p.67) made a few observations of the current in the Niagara River at the Black Rock Harbor, above Niagara Falls. Three section lines were established, one-eighth of a mile apart, and sounded. Measurements were made using surface floats. The velocities of the floats were observed as the floats passed between the first and second, second and third and first and third section lines. Discharge was computed by means of Eytelwein's Formula and found to be 374,000 cubic feet per second (cfs). As reported in 1868, D. Farrand Henry of the U.S. Lake Survey District, Corps of Engineers, recomputed the discharge using Allen's and Blackwell's notes and more recent soundings (depths were smaller than used by Allen and Blackwell). Henry obtained a flow of 244,797 cfs. He then corrected this value for the difference in levels between 1841 and 1867 and obtained a flow of 245,797 cfs. The only evidence of Henry's computations was a brief description in the Report of the Chief of Engineers, 1868, page 962.

6.2 Lower Niagara River, 1867-1868.

6.2.1 Purpose.

Except for information cited in Subsection 6.1, the first measurements of flow in the Niagara River were made by D. Farrand Henry of the U.S. Lake Survey District, Corps of Engineers, in 1867. After revising his method of measuring discharge, in 1868 Henry again measured the flow. Both sets of measurements were later to be recomputed by the U.S. Lake Survey District, in 1946-47. These series of measurements were part of a larger project conducted by D. Farrand Henry to measure the flow in the Great Lakes connecting channels. Measurements were also made in the St. Marys River (1867), the St. Clair River (1867 and 1868) and the St. Lawrence River (1867 and 1868).

6.2.2 Description of Section.

In 1867, discharge measurements were made in the lower Niagara River near Youngstown, New York. Two section lines were established, approximately 700 feet apart, about three miles above the mouth of the river. The section lines were divided into ten divisions or panels, about 200 feet apart. Discharge measurements using floats were made from August 20 through September 25, 1867.

In 1868, measurements were again made at this location. This time, however, only one section line was used and it was divided into eleven panels. A series of 65 discharge measurements were made between June 12 and September 17, 1868.

The approximate location of this discharge measurement section is shown on Figure 6-1.

6.2.3 Measurement Techniques.

In 1867, under the direction of D. Farrand Henry, determination of the discharge in the Niagara River was made by means of double floats. Subsection 3.1.3 (St. Marys River, 1867) details the method used to make these measurements. In summary, two section lines were established and sounded, and the movements of floats past these sections were observed. The floats were set in the river with the lower part at various depths. The point where each float crossed the upper and lower sections, together with the time required for passage, were recorded. Velocities were observed at each five feet of depth.

Henry believed that the floats indicated velocities as much as ten percent too large. During the summer of 1868, Henry made discharge observations using electrical recording current meters that he devised from old anemometers. A description of these meters can be found in the Report of the Chief of Engineers, 1869, page 565.

A meter would be lowered into the water and a set of cups, attached to an axis, would spin as the water passed. An electric device would record the number of revolutions of the cups, as they completed an electric circuit on each full revolution. The meters were rated often (before, during and after the measurement series) to determine a conversion from revolutions per unit of time to feet per second.

Velocity measurements, for the purpose of determining discharge through the section, were made across the section, at points 200 feet apart. To determine the vertical distribution of the velocity, measurements were made at each five feet of depth. Only a few positions were occupied a day. Several attempts were made to measure the entire section in one day. This was done by only measuring two of three depths at each station. No record of water surface elevations was kept, except those at the section.

6.2.4 Discharge Computation.

1867 Reduction of 1867 Measurements. The soundings of the two cross-sections were averaged to obtain a mean cross-section. This mean cross-section was divided into 11 divisions or panels and an area was computed for each.

The actual distance each float traveled in passing between two section lines, as determined from the angles from the base line recorded by the observers, divided by the time required for passage gave the velocity of the river at that depth and place on the mean

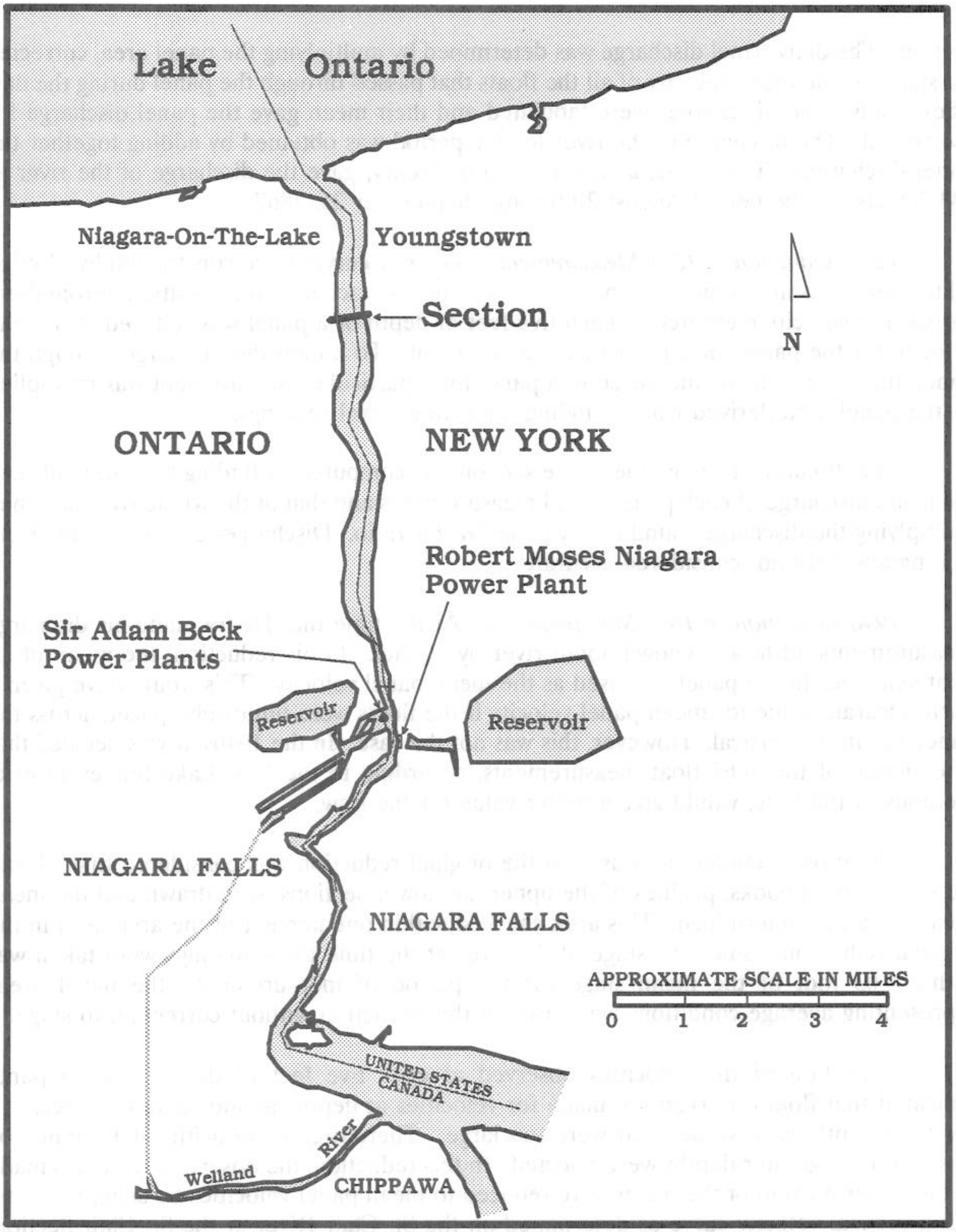

Figure 6-1

Lower Niagara River, 1867-1868 Section Location

section. The daily panel discharge was determined by multiplying the panel area, corrected for stage, by the mean velocity of all the floats that passed through the panel during the day. These daily panel discharges were tabulated and their mean gave the panel discharge for the period. The discharge of the river for the period was obtained by adding together the panel discharges. This value, as determined by Henry, gave the discharge of the river as 243,706 cfs for the period August 20 through September 25, 1867.

1868 Reduction of 1868 Measurements. Velocity curves were constructed by plotting all the velocities measured at each five feet of depth, at each measuring station. From these curves, the velocity measured at each five feet of depth of a panel was reduced to a mean velocity for the panel for a particular measurement. To obtain the discharge through the panel, the mean velocity measured in a panel for a particular measurement was multiplied by the panel area derived from soundings and water level readings, .

The discharge through the entire section was computed by finding the ratio between the mean discharge of each panel for all measurements and that of the whole river and then multiplying the discharge found in any panel by this ratio. Discharges computed only from side panels were not considered accurate.

1946 Reduction of 1867 Measurements. At the time that Henry made his discharge measurements, little was known about river hydraulics. In his reduction, the mean of all float velocities in the panel was used as the mean panel velocity. This would have given a fairly accurate value for mean panel velocity if the floats were uniformly spaced across the panel and in the vertical. However, this was not the case. In the 1940s, it was decided that a reduction of the 1867 float measurements, according to the U.S. Lake Survey District methods of the time, would give a better value for the flow.

The cross sectional area used in the original reduction was considered first. From data in the field books, profiles of the upper and lower sections were drawn and the mean area of the two determined. This area checked within one percent of the area used in the original reduction. Since the stage of the river at the time the soundings were taken was within 0.03 foot of the mean stage for the period of measurements, the panel areas representing average conditions were used in this reduction without correction to stage.

Inspection of the velocities observed at each five feet of depth in each panel indicated that float observations, made for velocities at depths greater than 60 percent of the total depth, gave values that were too large. Therefore, all velocities determined by floats at these greater depths were rejected. In this reduction, the observed velocities made in the upper portion of the panel were reduced to mean panel velocities by using the same mean vertical velocity curve as determined on the St. Clair River at the St. Clair Section. The St. Clair section has a mean depth that is comparable with the lower Niagara River section. A transverse curve drawn through the mean panel velocities indicated that the transverse coefficient needs to be applied only to the end panels.

The mean discharge of each panel for the period of measurements was the product of the originally determined panel area and the reduced mean panel velocity. This gave a total average Niagara River discharge of 223,700 cfs for the period during which the observations were made. Henry's original reduction gave the river flow as 243,706 cfs. The stage at Buffalo, New York, during the observations, reduced to the 1935 Datum, was 573.09 feet.

1947 Reduction of 1868 Measurements. Using the observed velocities at five-foot depths and soundings from the 1868 measurements, a profile of each river section was drawn and divided into panels. Panel areas were determined; these areas represented the average condition during the period of observations. Velocities observed in each panel were tabulated. Means of each five-foot depth were taken and reduced to 0.4 depth velocities, according to the vertical velocity curve as previously determined on the St. Clair River in 1944. The 0.4 depth velocities were plotted and a transverse velocity curve was drawn. From this curve, velocities for mid-panel at the 0.4 depth were determined. These mid-panel 0.4 depth velocities were reduced to mean panel velocities, using coefficients derived from the vertical and transverse velocity curves. The product of the mean panel velocity and panel area gave the average panel discharge during the period of observations. The sum of the panel discharges gave a total Niagara River average discharge of 308,400 cfs for the period of observations, as compared to an average of 273,329 cfs computed by Henry.

Henry's report on the measurements made in 1867 is given in the Report of the Chief of Engineers, 1868, page 949. The report on the 1868 measurements is in the Report of the Chief of Engineer of 1869, page 563. The 1946 reduction of the 1867 measurements is documented in the U.S. Lake Survey Archives, file 3-3094, (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland). The 1947 reduction of the 1868 measurements is documented in file 3-3100 of the same archives. Tables 6.1 and 6.2 (see Appendix C) summarize the 1867 and 1868 measurements, respectively, as reduced in those years.

6.3 Bridge Section, 1897-1899 and Open Section, 1899-1900.

6.3.1 Purpose.

In 1897, the Board of Engineers on Deep Waterways began measurements of the flow of the Niagara River from the International Railroad Bridge. In 1898, this work was taken over by the U.S. Lake Survey District, Corps of Engineers. In 1899-1900, measurements were made at a hydraulic section established about 1,800 feet below the bridge, as a check upon the work done at the bridge.

6.3.2 Description of Sections.

The **Bridge Section** was established along the downstream edge of the International Railroad Bridge, which spans the Niagara River from Buffalo, New York, to Fort Erie, Ontario. Discharge measurements were made directly from the bridge and each span constituted from 2 to 3 panels of the section. There were a total of 21 panels. A series of 34 measurements were made by the Board of Engineers on Deep Waterways, from October 5 to November 1, 1897 and 27 measurements were made between July 16 and August 17, 1898. At this point, the U.S. Lake Survey District took over the project. Between September 10, 1898 and December 10, 1899, 86 additional discharge measurements were made at this section.

The **Open Section** was established about 1,800 feet downstream of the International Railroad Bridge, just below Squaw Island. The section was divided into 17 panels. A total of 88 discharge measurements were made between October 4, 1899 and July 24, 1900. Measurements (33) were also made between August 30 and September 23, 1899; the number of panels not known.

The approximate locations of these discharge measurement sections are shown on Figure 6-2.

6.3.3 Measurement Techniques.

The U.S. Lake Survey District inherited this project and the equipment used from the Board of Engineers on Deep Waterways, in the late summer of 1898. The U.S. Lake Survey District continued the work at the Bridge Section in a manner similar to that used by the Board. The discharge measurements at the Bridge Section were made using a moveable cart, which held a reel and pulley setup used to lower current meters to the required depths. This cart was moved along the bridge from station to station. For the discharge measurements, velocity was measured at the center of the panel at the 0.3 depth.

The Bridge Section was resounded every ten feet, and extensive vertical velocity measurements were made by the U.S. Lake Survey District, during the period February through July 1900. Complete vertical measurements, consisting of observations at one foot from the bottom, one foot from the surface and at nine equidistant points in between, were made every 20 feet across the section. Two meters were used simultaneously for making the vertical velocity measurements. One meter was held steady at the 0.3 depth, while the other meter was raised or lowered through the various depths measured. The direction of flow past the section was observed to be nearly perpendicular to the line of the section.

Measurements at the Open Section were made from a catamaran. The section was lead-line sounded. Discharge measurements were made by observing the velocity at the 0.4 depth at the panel midpoints. Vertical velocity measurements were made at the panel midpoints at one foot from the bottom and at each tenth depth. The direction of flow past the section was measured.

The section gauge for the Bridge Section was located on the U.S. side of the river, just below the center line of the bridge. The gauge recording levels at the Open Section was

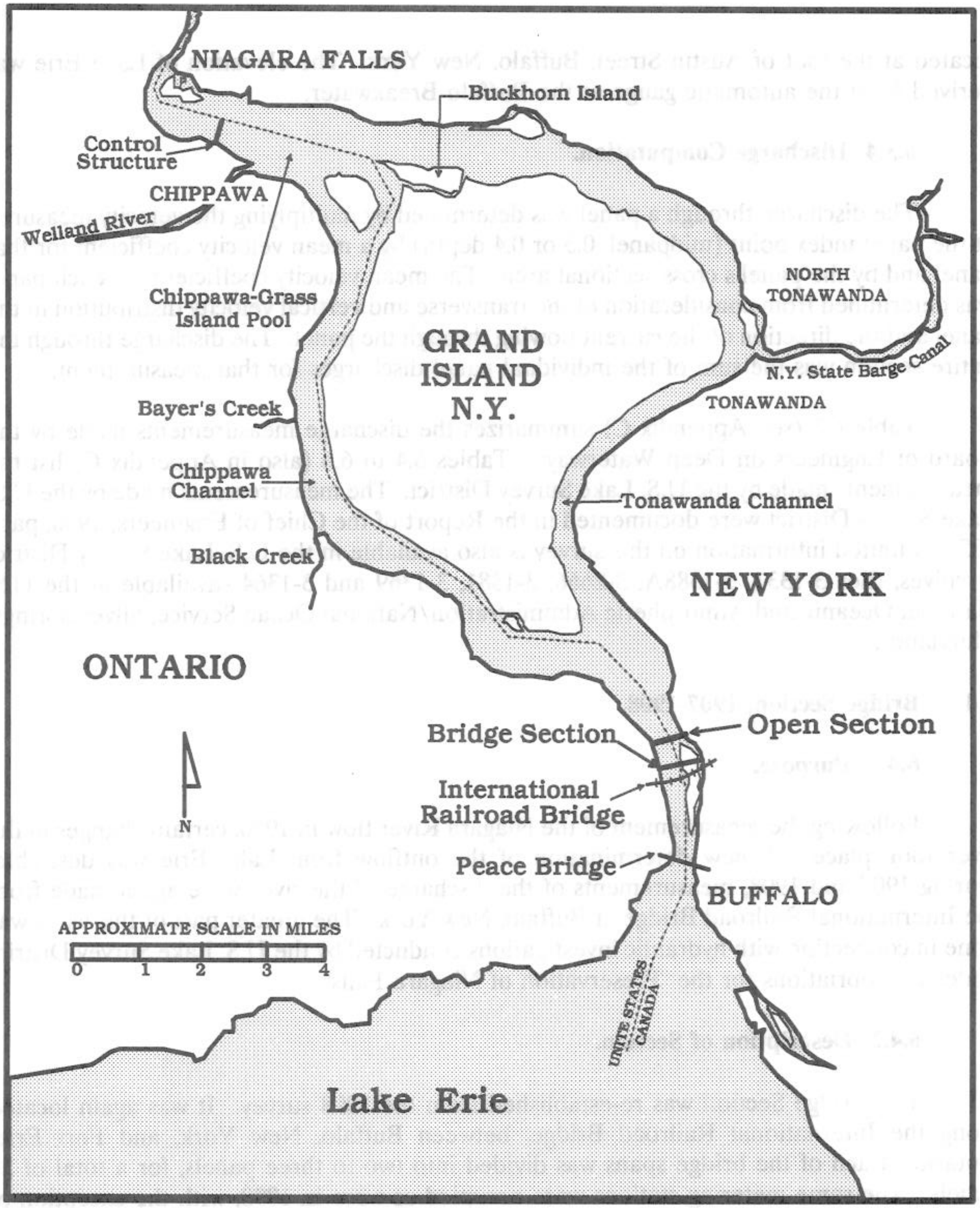

Figure 6-2

Niagara River, 1897-1900 Bridge and Open Section Locations

located at the foot of Austin Street, Buffalo, New York. The elevation of Lake Erie was derived from the automatic gauge at the Buffalo Breakwater.

6.3.4 Discharge Computation.

The discharge through a panel was determined by multiplying the velocity measured at the panel index point (midpanel, 0.3 or 0.4 depth) by a mean velocity coefficient for that panel and by the panel's cross sectional area. The mean velocity coefficient for each panel was determined from consideration of the transverse and vertical velocity distribution in the panel and the direction of the current flowing through the panel. The discharge through the entire section was the sum of the individual panel discharges for that measurement.

Table 6.3 (see Appendix C) summarizes the discharge measurements made by the Board of Engineers on Deep Waterways. Tables 6.4 to 6.6 (also in Appendix C) list the measurements made by the U.S. Lake Survey District. The measurements made by the U.S. Lake Survey District were documented in the Report of the Chief of Engineers, 1900, page 5352. Limited information on this survey is also available in the U.S. Lake Survey District Archives, files 3-1331, 3-1388A, 3-2666, 3-1381, 3-1369 and 3-1364 (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland).

6.4 Bridge Section, 1907-1908.

6.4.1 Purpose.

Following the measurement of the Niagara River flow in 1900, certain changes in the river took place. A new determination of the outflow from Lake Erie was desirable. During 1907 and 1908, measurements of the discharge of the river were again made from the International Railroad Bridge at Buffalo, New York. The greater part of this work was done in connection with hydraulic investigations conducted by the U.S. Lake Survey District under appropriations for the "Preservation of Niagara Falls".

6.4.2 Description of Section.

The Bridge Section was re-established from the 1898 survey. It was again located along the International Railroad Bridge, between Buffalo, New York, and Fort Erie, Ontario. Each of the bridge spans was divided into two to three panels, for a total of 21 panels. The same metering stations were occupied as were in 1898, with the exception of two in spans 8 and 9. These two points were changed by about 4 feet, because of the interference of the structural members of new bridge trusses.

Forty discharge measurements were made between October 21 and November 4, 1907. From June 26 to August 6, 1908, 78 measurements were made. An additional eight discharge measurements were made in October 1908. Figure 6-2 shows the approximate location of this section.

6.4.3 Measurement Techniques.

The methods employed in the earlier discharge measurements at this section were followed as closely as possible. The same meter stations were occupied with the exception of the two in spans 8 and 9. These two points were changed by about 4 feet, because of interference from newly placed bridge trusses.

No coefficient work was done in 1907 or 1908. It was assumed that the velocity coefficients, which were determined in the earlier work, had not changed. In measuring a discharge, an 120-second duration observation was made at the 0.3 depth at each index point. In 1907, observations in spans 1 and 9 were frequently omitted. The flow through these spans was small and the discharge was interpolated from the gauge heights.

For the purpose of determining any changes which may have occurred in the cross section since 1898, spans 1, 2, 3 and 4 were re-sounded in August 1908. No change in depth was apparent in spans 1, 3 and 4; however, the mean depth of span 2 had increased by about 2 feet. This was probably the result of dredging, which had been done a short distance above the bridge, close to Squaw Island.

The section gauge was located, as nearly as possible, at the position of the one used in the earlier work. It was situated on the U.S. side of the river, just below the center line of the bridge. The gauge was referenced to the P.B.M. International Bridge No. 2, which is no longer in existence. The elevation of Lake Erie was derived from the automatic gauge at the Buffalo Breakwater, which was referenced to P.B.M. Buffalo Lighthouse (590.101 feet above the mean tide at New York, adjusted to 1903 levels; 588.375 IGLD 1955).

6.4.4 Discharge Computation.

The transverse curve of velocities had changed somewhat. The flow through the spans near the United States shore was slightly greater than it was in 1898, while those near the Canadian side showed a corresponding decrease. This indicated a slight shifting of the direction of the current and was probably due to the increased depth in span 2.

Using the observed velocity and gauge heights at the section for the time of the measurement, the discharge for each station was taken directly from curves prepared in 1898, using velocity coefficients and panel areas determined from that earlier survey. The increased area in span 2 prevented the use of these curves for the stations in this span. The discharge through span 2, as well as through spans 1 and 9, was computed directly from the areas and velocity coefficients determined in 1898. The discharge through span 2 was then increased by 19.2 percent, corresponding to the increase in the cross sectional area as determined by the soundings of 1908.

Tables 6.7 and 6.8 (see Appendix C) summarize the discharge measurements made in 1907 and 1908 at the Bridge Section. A report documenting this survey can be found in file 3-1903 of the U.S. Lake Survey District Archives (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland).

6.5 Split Section, 1913.

In 1913, a series of discharge measurements were made to measure the separation of flow around Grand Island. At the time it was established, it was known as the Split Section. Very little information was recovered on this earlier series of measurements.

6.6 Bridge and Bridgeburg Sections, 1921-1929.

6.6.1 Purpose.

Between 1921 and 1929, several series of discharge measurements were made from the International Railroad Bridge over the Niagara River. These measurements were made to determine the effect of changes taking place in the river upon the relationship of discharge and stage.

Dominion Water Power and Hydrometric Bureau of Canada made measurements at a section called Bridgeburg, which was defined by the upstream edge of the International Railroad Bridge. These measurements were made between June 14, 1921 and September 28, 1929.

Between August 4 and 28, 1925, discharge measurements were made at the Bridge Section, located along the downstream edge of the railroad bridge. These measurements were carried out by the U.S. Lake Survey District, Corps of Engineers, for the Buffalo District, Corps of Engineers, and the Niagara Falls Power Company.

6.6.2 Description of Sections.

Both the **Bridge** and **Bridgeburg Sections** were located adjacent to the International Railroad Bridge, which spans the Niagara River between Buffalo, New York, and Fort Erie (Bridgeburg), Ontario. The Bridgeburg Section ran along the upstream edge of the bridge and the Bridge Section (previously surveyed) was located along the downstream edge. Both sections were divided into 20 panels. The water level gauge used to record levels at these sections was located on the downstream end of the pier, between spans 2 and 3. The location of the International Railroad Bridge is shown on Figure 6-2.

6.6.3 Measurement Techniques.

Because of their proximity to each other, the Bridge and Bridgeburg Sections were basically considered to be one and the same. All coefficient work, soundings and area determinations made at the Bridge Section were felt to be applicable to the Bridgeburg Section. Prior to the series of measurements made in 1925, the velocity coefficients and panel areas determined at the Bridge Section in 1898 were used. All discharge measurements were made at the panel metering points, using one current meter lowered to the 0.4 depth (index point).

In 1925, the Bridge Section was re-sounded and new panel areas determined. Also in 1925, the vertical velocities were re-measured. Vertical velocity curves were measured at several points within a panel by measuring the velocity at each tenth depth and at the top and bottom of the panel. At the same time, a meter simultaneously measured the velocity at the 0.4 depth of the panel's metering point (index point). Vertical velocity coefficients were determined as a ratio of the vertical velocity curves to the velocity at the index point.

The revised coefficient work and the discharge measurements made at the Bridge Section by the U.S. Lake Survey District were done using Haskell current meters. The Canadian discharge measurements at the Bridgeburg Section were made using Price meters. All meters were rated before and/or after each series of discharge measurements.

6.6.4 Discharge Computation.

As mentioned previously, prior to the measurements made in 1925, discharge measurement data were reduced using the velocity coefficients and panel areas determined at the Bridge Section in 1898. From the vertical velocity work done in 1925, new velocity coefficients were determined for panels 1 to 9. The 1898 velocity coefficients were still used to reduce discharges at the remaining panels. The 1925-1929 discharge measurements also made use of the new panel areas determined in 1925.

As in the past, the section discharge for a particular measurement was taken as the sum of the panel discharges (20 in this case) for that measurement. A panel discharge was the product of the velocity measured at the index point of the panel, the panel's area and the panel's velocity coefficient.

Tables 6.9 to 6.13 (see Appendix C) summarize the discharge measurements made at the Bridge and Bridgeburg Sections between 1921 and 1929. What information was available on these surveys was found in the U.S. Lake Survey District Archive files 3-2666, 3-3722 and 3-4225 (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland).

6.7 Split, Black Rock, Wickwire and Oakfield Sections, 1931.

6.7.1 Purpose.

In 1913, a series of discharge measurements were made to measure the separation of flow around Grand Island. At the time it was established, it was known as the Split

Section. Very little information was recovered on this earlier series of measurements.

In 1931, the U.S. Lake Survey District attempted to re-establish the position of the Split Section, to again measure the distribution of flow around Grand Island. This time it was considered to be two separate hydraulic sections - Wickwire and Oakfield. The total flow was measured upstream of Grand Island at the Black Rock Section.

6.7.2 Description of Sections.

The **Black Rock Section** was nearly identical to the earlier Open Section, surveyed in 1900. It was located about 1,800 feet north of the International Railroad Bridge and just below Squaw Island. The section extended across the river from Buffalo, New York, to Fort Erie, Ontario. The section was divided into 18 panels. Between June 12 and November 12, 1931, 141 discharge measurements were made at this section.

The **Wickwire Section** (previously the Split Section) was located about 2 3/4 miles north of Buffalo, New York, and spanned the river between the United States mainland and Grand Island. Because of weed growth and dead water along the shore, only 1,700 feet of the 2,130-foot water expanse was considered. This length was divided into 10 panels. Fourteen discharge measurements were made during the period September 22 to October 1, 1931.

The **Oakfield Section** (previously the Split Section) traversed the river from Grand Island west to the Canadian mainland. The 2,670-foot wide section was divided into 11 panels. Between September 21 and 29, 1931, 14 discharge measurements were made.

The approximate locations of these discharge measurement sections are shown on Figure 6-3.

6.7.3 Measurement Techniques.

Both the Wickwire and Oakfield Sections were sounded prior to the making of discharge measurements. Vertical velocity measurements were made at the Wickwire Section from October 2 to October 6, 1931, after the discharge measurements were made. These vertical velocity measurements were made at each tenth depth for eight metering stations (6+100, 7, 7+100, 8, 8+100, 9, 9+80, 10), using two Haskell velocity meters suspended simultaneously at the panel index point (0.4 depth).

No information was recovered on how measurements were made at the Black Rock Section.

6.7.4 Discharge Computation.

Transverse coefficients were determined for each section. All of the index point

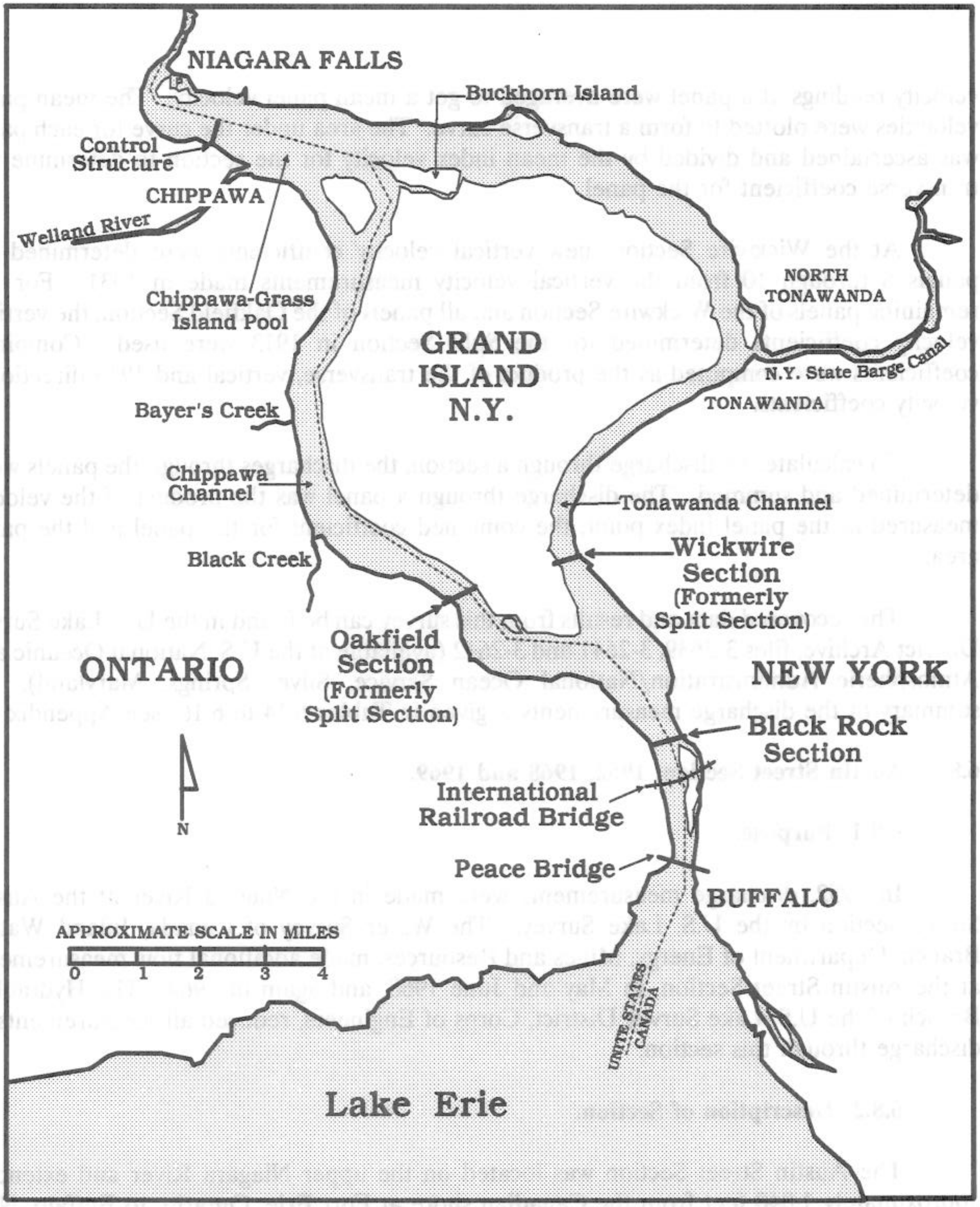

Figure 6-3

Niagara River, 1931 Section Locations

velocity readings at a panel were averaged to get a mean panel velocity. The mean panel velocities were plotted to form a transverse curve. The area under the curve for each panel was ascertained and divided by the mean index velocity for the section to determine the transverse coefficient for the panel.

At the Wickwire Section, new vertical velocity coefficients were determined for panels 6 through 10 from the vertical velocity measurements made in 1931. For the remaining panels of the Wickwire Section and all panels of the Oakfield Section, the vertical velocity coefficients determined for the Split Section in 1913 were used. Combined coefficients were computed as the product of the transverse, vertical and 1913 directional velocity coefficients.

To calculate the discharge through a section, the discharges through the panels were determined and summed. The discharge through a panel was the product of the velocity measured at the panel index point, the combined coefficient for the panel and the panel area.

The recovered data and results from this survey can be found in the U.S. Lake Survey District Archive, files 3-2639, 3-2641 and 3-2642 (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland). A summary of the discharge measurements is given in Tables 6.14 to 6.16 (see Appendix C).

6.8 Austin Street Section, 1952, 1968 and 1969.

6.8.1 Purpose.

In 1952, discharge measurements were made in the Niagara River at the Austin Street Section by the U.S. Lake Survey. The Water Survey of Canada, Inland Waters Branch, Department of Energy, Mines and Resources, made additional flow measurements at the Austin Street Section, in May and June 1968, and again in 1969. The Hydraulics Branch of the U.S. Lake Survey District, Corps of Engineers, reduced all measurements of discharge through this section.

6.8.2 Description of Section.

The Austin Street Section was located on the upper Niagara River and extended approximately 1,840 feet from the Canadian shore at Fort Erie, Ontario, to Buffalo, New York, on the U.S. mainland. For the 1968 project, the section was divided into 12 panels. A series of 31 discharge measurements were made between May 10 and June 14, 1968.

The approximate location of this discharge measurement section is shown on Figure 6-4.

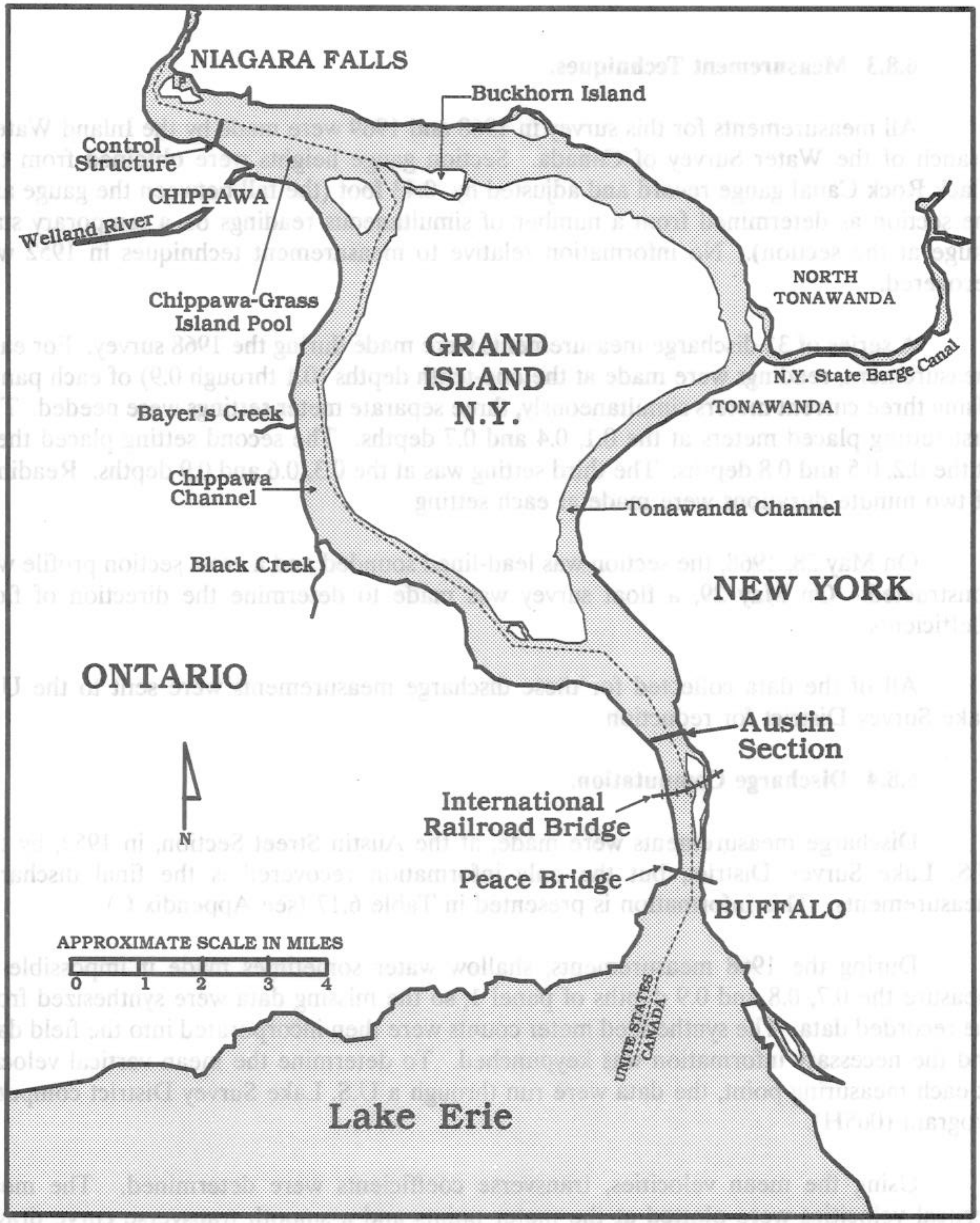

Figure 6-4

Niagara River, 1952-1969 Austin Street Section Location

6.8.3 Measurement Techniques.

All measurements for this survey in 1968 and 1969 were made by the Inland Waters Branch of the Water Survey of Canada. Section gauge heights were obtained from the Black Rock Canal gauge record and adjusted by -0.43 foot (the fall between the gauge and the section as determined from a number of simultaneous readings on a temporary staff gauge at the section). No information relative to measurement techniques in 1952 was recovered.

A series of 31 discharge measurements were made during the 1968 survey. For each measurement, readings were made at the one-tenth depths (0.1 through 0.9) of each panel. Using three current meters simultaneously, three separate meter settings were needed. The first setting placed meters at the 0.1, 0.4 and 0.7 depths. The second setting placed them at the 0.2, 0.5 and 0.8 depths. The third setting was at the 0.3, 0.6 and 0.9 depths. Readings of two minute durations were made at each setting.

On May 28, 1968, the section was lead-lined sounded and a cross section profile was constructed. On May 29, a float survey was made to determine the direction of flow coefficients.

All of the data collected for these discharge measurements were sent to the U.S. Lake Survey District for reduction.

6.8.4 Discharge Computation.

Discharge measurements were made, at the Austin Street Section, in 1952, by the U.S. Lake Survey District, but the only information recovered is the final discharge measurements. This information is presented in Table 6.17 (see Appendix C).

During the 1968 measurements, shallow water sometimes made it impossible to measure the 0.7, 0.8 and 0.9 depths of panel 1, so the missing data were synthesized from the recorded data. The synthesized meter counts were then incorporated into the field data and the necessary information was keypunched. To determine the mean vertical velocity at each measuring point, the data were run through a U.S. Lake Survey District computer program (065H).

Using the mean velocities, transverse coefficients were determined. The mean vertical velocities were plotted at the meter points and a smooth transverse curve drawn through them. The panels were drawn and the panel areas under the curve were determined by planimeter. The panel area was divided by the panel width and the result was divided by the average velocity at the metering point to give the transverse coefficient for the panel.

The basic data, along with the vertical, transverse and directional coefficients, were run through another U.S. Lake Survey District program (068H), to determine the discharge through the panels. The individual panel discharges were added to get the discharge through the section for each measurement.

The water level gauge used to record levels at the Austin Street Section was the Black Rock Canal gauge. It is a permanent recording gauge located above the section at the foot of Bridge Street, Buffalo, New York, on the west wall of the Black Rock Canal lock.

A summary of the results of this survey can be found in Table 6.18(see Appendix C). The data and results can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, file number 3-4349, of the Detroit District, Corps of Engineers, Detroit, Michigan.

Additional discharge measurements were made in 1969, by Canada, and are summarized in Table 6.19 (also in Appendix C). No other information was readily recoverable for this series of measurements.

6.9 Stella Niagara Section, 1957-1962.

6.9.1 Purpose.

Article IV of the Niagara River Water Diversion Treaty of 1950, between the United States and Canada, provides for "sufficient amounts of water in the Niagara River for scenic purposes". The amount of water diverted from the river above the Falls is to be regulated, in order to maintain the minimum flow over the Falls as specified in the Treaty. The International Niagara Board of Control, which was created by the International Joint Commission in 1953, recognized the need for a water level gauge (with a rating for flow) in the Maid-of-the-Mist Pool (below the Falls), to determine adherence to the provisions of Article IV of the Treaty. For this purpose, in 1957, the Ashland Avenue gauge was installed at the foot of Ashland Avenue, Niagara Falls, New York.

The U.S. Lake Survey District, Corps of Engineers, in cooperation with the Water Resources Branch, Department of Northern Affairs and National Resources, Canada, studied proposed locations for a hydraulic section where discharge measurements could be taken to provide basic data for the development of an Ashland Avenue gauge rating for the Maid-of-the-Mist Pool outflow. A hydraulic section was established in the lower Niagara River below Lewiston, New York -- the Stella Niagara Section. At this location, it is necessary to subtract the discharge of the Sir Adam Beck Niagara Generating Stations and the Robert Moses Niagara Power Plant from the measured flow to obtain the discharge past the Ashland Avenue gauge.

Between 1957 and 1962, five series of discharge measurements were made at the Stella Niagara Section by the U.S. Lake Survey District. The purpose was to obtain flow data for the range of stages experienced in the Maid-of-the-Mist Pool when the flow over the Falls is reduced, as allowed by the 1950 Treaty.

6.9.2 Description of Section.

The Stella Niagara Section was established in the lower Niagara River, one and one half miles below Lewiston, New York, and extended from the Canadian to the U.S. mainland. The section was divided into ten panels. In five series of discharge measurements made between June 1957 and November 1962, a total of 116 discharge measurements were made at this section.

The approximate location of this discharge measurement section is shown on Figure 6-5.

6.9.3 Measurement Techniques.

The hydraulic section was thoroughly sounded in June 1957, at the time of the initial series of discharge measurements. Soundings were spaced along the hydraulic section at intervals of less than five feet. These were reduced to a base stage of 244.71 feet (IGLD, 1955) as recorded at the section gauge and a profile of the hydraulic section was drawn. The section was sounded during each of the series of discharge measurements. The subsequent soundings indicated no change in the profile of the hydraulic section as determined from the June 1957 soundings.

The section gauge for the Stella Niagara Section was located a short distance downstream from the United States side of the section and was referenced to bench marks N-36, STATUE and WILLOW. Water levels were recorded continuously by a recording gauge, during each series of discharge measurements. At the Ashland Avenue gauge, located in the Maid-of-the-Mist Pool, water levels were recorded continuously after the gauge was placed in operation on June 17, 1957. This gauge was referenced to bench marks N-32A, SILL and CURB. The elevation of these bench marks are as follows:

Bench Mark	Bench Mark Elevations (feet) IGLD 1955
N-36	325.612
WILLOW	274.060
STATUE	318.960
N-32A	369.474
SILL	371.608
CURB	370.487

The direction of flow past the section was ascertained by placing rod floats in the river above the section and tracing them by transit intersection as they drifted with the

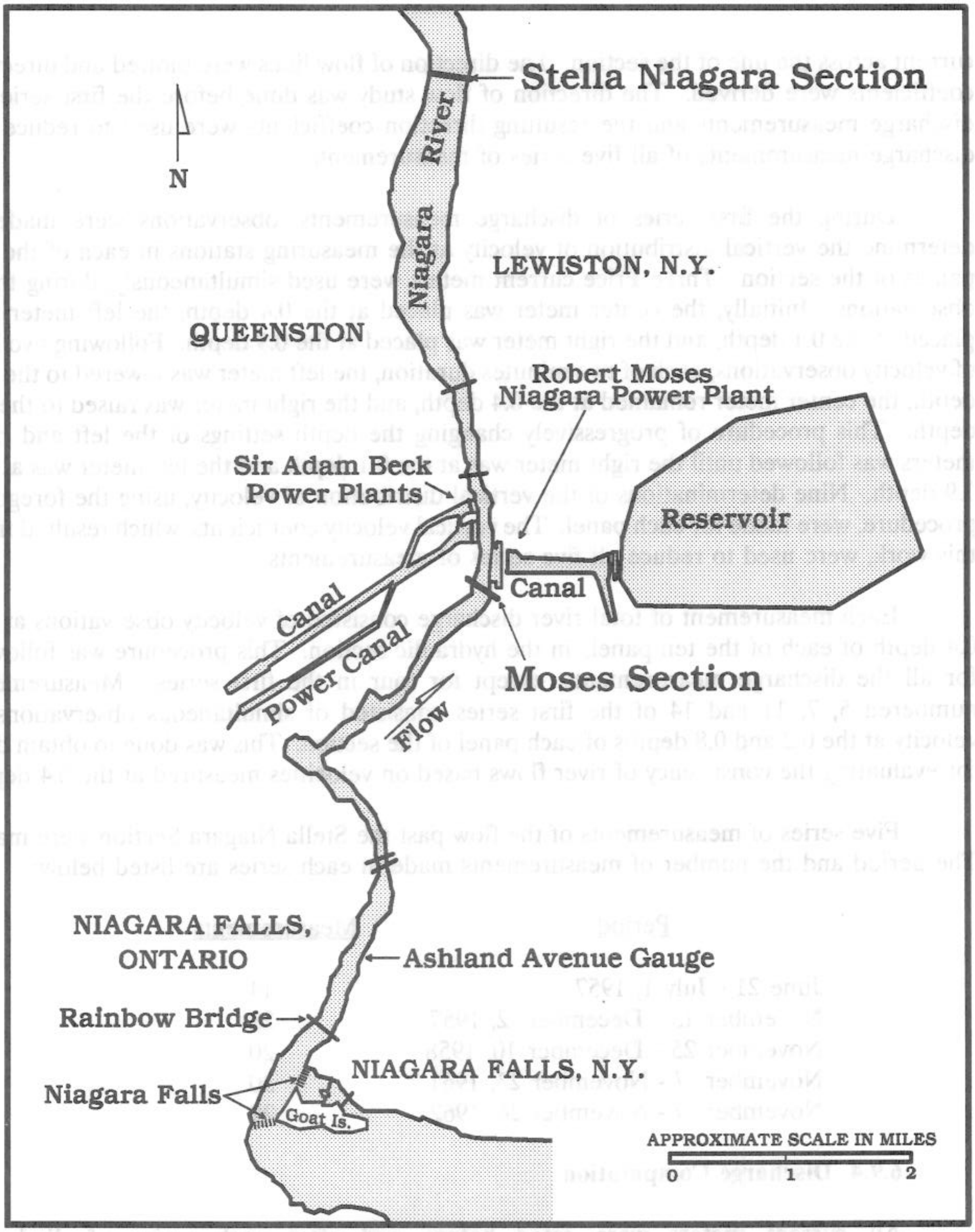

Figure 6-5

Niagara River, Stella Niagara and Moses Section Locations

current across the line of the section. The direction of flow lines were plotted and direction coefficients were derived. The direction of flow study was done before the first series of discharge measurements and the resulting direction coefficients were used to reduce the discharge measurements of all five series of measurements.

During the first series of discharge measurements, observations were made to determine the vertical distribution of velocity at the measuring stations in each of the ten panels of the section. Three Price current meters were used simultaneously, during these observations. Initially, the center meter was placed at the 0.4 depth, the left meter was placed at the 0.1 depth, and the right meter was placed at the 0.9 depth. Following two sets of velocity observations, each of two minutes duration, the left meter was lowered to the 0.2 depth, the center meter remained at the 0.4 depth, and the right meter was raised to the 0.8 depth. This procedure of progressively changing the depth settings of the left and right meters was followed until the right meter was at the 0.1 depth and the left meter was at the 0.9 depth. Nine determinations of the vertical distribution of velocity, using the foregoing procedure, were made for each panel. The vertical velocity coefficients, which resulted from this work, were used to reduce all five series of measurements.

Each measurement of total river discharge consisted of velocity observations at the 0.4 depth of each of the ten panels in the hydraulic section. This procedure was followed for all the discharge measurements, except for four in the first series. Measurements numbered 5, 7, 11 and 14 of the first series consisted of simultaneous observations of velocity at the 0.2 and 0.8 depths of each panel of the section. This was done to obtain data for evaluating the consistency of river flows based on velocities measured at the 0.4 depth.

Five series of measurements of the flow past the Stella Niagara Section were made. The period and the number of measurements made in each series are listed below:

Period	Measurements
June 21 - July 1, 1957	14
November 13 - December 2, 1957	23
November 25 - December 10, 1958	20
November 7 - November 23, 1961	30
November 9 - November 26, 1962	29

6.9.4 Discharge Computation.

All current meters were rated before and after each series of discharge measurements. Ratings were compared with previous ratings, and appropriate current meter equations, based on least square solutions, were adopted to reduce the recorded current meter revolutions per second to velocity in feet per second.

Vertical velocity measurements made in 1957 were used to determine the vertical distribution of velocity for each panel. The mean velocities observed for each tenth depth were reduced to a percent of the mean velocity observed by the center meter, which was always at the 0.4 depth. The observations made at the 0.4 depth with the left and right meters were adjusted to 100% of the corresponding center meter observations. The other percentages were adjusted proportionately. The adjusted percentages were plotted against depth and a smooth curve was drawn through the points. Vertical velocity coefficients were obtained from the ratio of the mean percentage in the vertical to the percentage at the 0.4 depth. The vertical velocity coefficient, applied to the velocity observed at the 0.4 depth, converts the observed velocity to a mean velocity in the vertical plane through the measuring point of the panel.

Transverse velocity coefficients were determined for each series of measurements. First, a transverse velocity curve was developed based on the mean of all the observed velocities recorded at the 0.4 depth of each measuring station during that series of measurements. From this curve, the mean horizontal velocity in each panel was determined. The transverse velocity coefficient is the ratio of the mean horizontal velocity in the panel to the mean velocity recorded at the measuring station. The transverse velocity coefficient is applied to the observed velocity to obtain a mean horizontal velocity across the panel at the 0.4 depth.

The directional, vertical velocity and transverse velocity coefficients were multiplied together to produce a single coefficient for converting the velocity observed at the measuring station at the 0.4 depth to a mean velocity throughout the entire panel. During the summer of 1957, discharge measurements (four measurements) were made by metering simultaneously at the 0.2 and 0.8 depths. The mean of the 0.2 and 0.8 depth velocities, in these cases, was assumed to be the mean velocity in the vertical; therefore, only the directional and transverse coefficients were combined to produce a single coefficient for converting these observations to the mean velocity through the panel.

Panel areas were determined for the time of each measurement, using the section profile and levels recorded at the section gauge during the measurement. The mean velocity in the panel multiplied by the panel area gives the panel discharge. The sum of the discharges in the ten panels is the discharge through the hydraulic section. Tables 6.20 through 6.24 (see Appendix C) summarize the results of the discharge measurements made in 1957, 1958, 1961 and 1962. Reports resulting from these surveys can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, files numbered 3-3822 and 3-4011 of the Detroit District, Corps of Engineers, Detroit, Michigan.

6.10 Maid-of-the-Mist Section, 1967.

6.10.1 Purpose.

This series of measurements were obtained, at the request of the International Niagara Board of Control, to determine the day and night flows over Niagara Falls and to analyze the Ashland Avenue gauge stage-discharge relationship of the Maid-of-the-Mist Pool. This project was carried out by the U.S. Lake Survey District, Corps of Engineers.

6.10.2 Description of Section.

The Maid-of-the-Mist Section was located in the Maid-of-the-Mist Pool, approximately 1,500 feet downstream of the Rainbow Bridge. The section was divided into ten panels, extending from the U.S. shore to the Canadian shore. The eight interior panels were each 70 feet in width. The width of the two end panels varied with the flow over the falls.

Between June 29 and July 22, 1967, twenty discharge measurements were made to measure the daytime flow over the Falls, which by agreement should be no less than 100,000 cfs. Ten discharge measurements were made at night, between July 8 and 21, 1967, when the flow was approximately 50,000 cfs.

The approximate location of this discharge measurement section is shown on Figure 6-6.

6.10.3 Measurement Techniques.

Prior to establishing a hydraulic section, the Maid-of-the-Mist Pool was echo sounded from the Rainbow Bridge to the Ashland Avenue Sewage Treatment Plant to determine a suitable section site. The selected site was chosen, because it had a minimum of turbulence and a uniform bottom profile. Upstream of the section, extreme depth and turbulence were the prohibitive factors. Downstream there were numerous back eddies in the flow pattern and a rougher, less uniform bottom profile.

After the section was established, a drogue study was made to determine the direction of flow across the section. A weighted float was tracked as it drifted past the section line at many points along the section. The tracks of the drogues were plotted and a flow pattern was determined.

The section was lead-line sounded with a 100 pound weight at five to ten foot intervals, before and after the series of measurements at the 100,000 cfs flow and once during the series at the 50,000 cfs flow. All soundings were reduced to a common water level elevation and two profiles were plotted, one for use with the velocity measurements

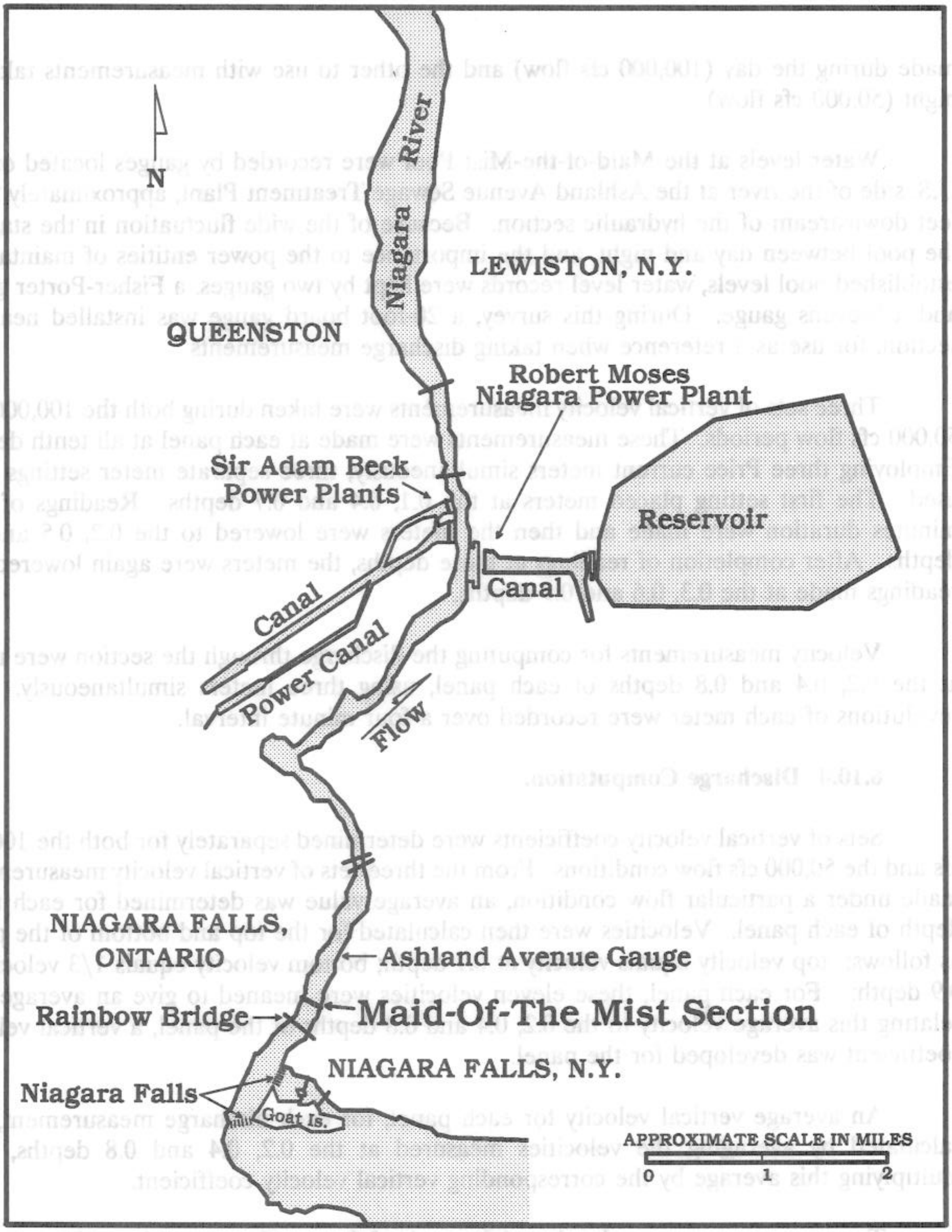

Figure 6-6

Niagara River, 1967 Maid-Of-The Mist Section Location

made during the day (100,000 cfs flow) and the other to use with measurements taken at night (50,000 cfs flow).

Water levels at the Maid-of-the-Mist Pool were recorded by gauges located on the U.S. side of the river at the Ashland Avenue Sewage Treatment Plant, approximately 2,600 feet downstream of the hydraulic section. Because of the wide fluctuation in the stage of the pool between day and night, and the importance to the power entities of maintaining established pool levels, water level records were kept by two gauges, a Fisher-Porter gauge and a Stevens gauge. During this survey, a 20-foot board gauge was installed near the section, for use as a reference when taking discharge measurements.

Three sets of vertical velocity measurements were taken during both the 100,000 and 50,000 cfs flow periods. These measurements were made at each panel at all tenth depths. Employing three Price current meters simultaneously, three separate meter settings were used. The first setting placed meters at the 0.1, 0.4 and 0.7 depths. Readings of four minutes duration were made and then the meters were lowered to the 0.2, 0.5 and 0.8 depths. After completion of readings at these depths, the meters were again lowered and readings made at the 0.3, 0.6 and 0.9 depths.

Velocity measurements for computing the discharge through the section were made at the 0.2, 0.4 and 0.8 depths of each panel, using three meters simultaneously. The revolutions of each meter were recorded over a four minute interval.

6.10.4 Discharge Computation.

Sets of vertical velocity coefficients were determined separately for both the 100,000 cfs and the 50,000 cfs flow conditions. From the three sets of vertical velocity measurements made under a particular flow condition, an average value was determined for each tenth depth of each panel. Velocities were then calculated for the top and bottom of the panel as follows: top velocity equals velocity at 0.1 depth; bottom velocity equals 1/3 velocity at 0.9 depth. For each panel, these eleven velocities were meaned to give an average. By relating this average velocity to the 0.2, 0.4 and 0.8 depths of the panel, a vertical velocity coefficient was developed for the panel.

An average vertical velocity for each panel, for each discharge measurement, was calculated by averaging the velocities measured at the 0.2, 0.4 and 0.8 depths, then multiplying this average by the corresponding vertical velocity coefficient.

Transverse curves were developed for each of the two flow conditions. The average vertical velocities, for the appropriate flow conditions, were averaged for each panel. These values were plotted at the metering points of the panels and a curve was drawn from shore to shore through all the plotted points. The panel widths were drawn in and the panel areas under the curve were determined by planimeter. These areas, when divided by the panel widths, produced the average transverse velocity of the panel. The average transverse velocity divided by the average vertical velocity at the metering point gave the transverse coefficient for the panel. The transverse coefficient was multiplied by the directional coefficient to form the combined coefficient for the panel. Directional coefficients, as determined from the drogue study, were taken as the sine of the average angle that the flow in the panel made to the section line.

The discharge through a panel during a measurement was calculated as the product of the average vertical velocity, the combined coefficient and the panel area. The panel was taken from the section profile for the appropriate flow condition and adjusted for the water levels recorded at the time of the measurement. The total discharge through the section was the sum of the individual panel discharges.

The data and the report resulting from this survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, file number 3-4367, of the Detroit District, Corps of Engineers, Detroit, Michigan. The results of the discharge measurements are summarized in Tables 6.25 and 6.26 (see Appendix C).

6.11 Chippawa Channel and Tonawanda Channel Sections, 1967.

6.11.1 Purpose.

A cooperative discharge measurement program on the upper Niagara River was authorized by the International Niagara Board of Control, in a resolution dated February 2,1967. Simultaneous measurements were made around Grand Island, in the Chippawa and Tonawanda Channels, with the following objectives:

a. To check the Fort Erie-Buffalo and Buffalo-Black Rock stage-discharge equations.

b. To check the weed effect correction tables.

c. To check the flow distribution around Grand Island.

d. To try to define the upstream limit of backwater resulting from the Control Structure operations.

e. To provide basic data, discharges and water levels, for the development of a mathematical model of the upper Niagara River.

Three sets of measurements were proposed. The first, to commence as soon as possible after ice had left the river, to take advantage of high spring flows and weed free conditions; the second, during the summer, to attempt to define the extent of weed effect; and the third, late in the fall, under weed free conditions and low flows, to extend the range of coverage.

Discharge measurements in the Chippawa Channel were made by the Department of Energy, Mines and Resources, Inland Waters Branch, Water Survey of Canada, Ontario District. In the Tonawanda Channel, measurements were made by the U.S. Lake Survey District, Corps of Engineers.

6.11.2 Description of Sections.

The **Chippawa Channel Section** was located in the Chippawa Channel of the Niagara River about half a mile below Bayers Creek. The section was divided into 23 panels starting from the Canadian shore and extending across to Grand Island. Thirty discharge measurements were made during each of the three series of measurements. They were taken between May 17 and June 6; August 14 and August 31; and November 15 and December 5, 1967.

The **Tonawanda Channel Section** was located in the Tonawanda Channel of the Niagara River, about 1/3 mile northeast of Two Mile Creek at Tonawanda, New York. It extended from the U.S. mainland, across the channel to Grand Island. For this survey, the section was divided into ten panels. Three series of 30 measurements each were made at this section: from May 17 to June 6; August 14 to August 31; and November 15 to December 5, 1967.

The approximate locations of these discharge measurement sections are shown on Figure 6-7.

6.11.3 Measurement Techniques.

Chippawa Channel Section. As previously mentioned, the survey work and the discharge measurements in this section were accomplished by the Water Survey of Canada. The section's location was selected following examination of all available hydrographic survey data for the channel. A direction of flow survey was performed to establish a bearing for the section line normal to the general direction of flow in the channel. A recording gauge, operating in a stilling well, was installed at the section to provide water level data.

Using an echo sounder, six runs were made across the section on May 26, 1967, and another six runs on June 12, 1967. Accurate vertical and horizontal control was difficult to establish and the desired accuracy was not attained. For this reason, detailed lead-line soundings, at 10 to 15 foot intervals across the section, were made on September 1 and again on December 5. These lead-line soundings, along with panel index point soundings, were used to produce the final cross section of the section.

To make the velocity measurements, Gurley Price, pattern 622, current meters were used. Four sets of vertical velocity measurements were made, during the spring series of measurements, to establish the vertical and transverse velocity curves. For these measurements, readings were made at each tenth depth of each of the 23 panels.

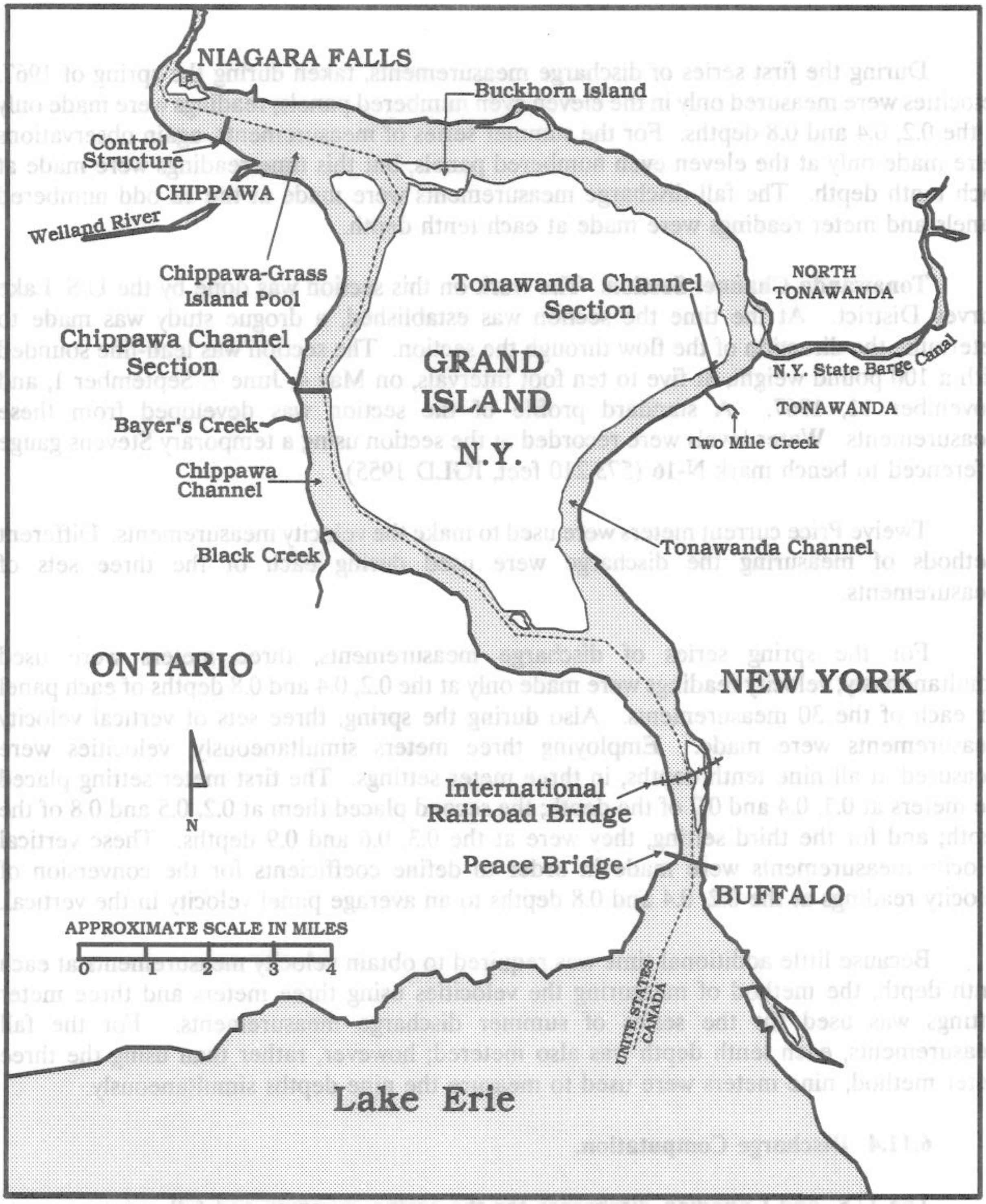

Figure 6-7

Niagara River, 1967 Section Locations

During the first series of discharge measurements, taken during the spring of 1967, velocities were measured only in the eleven even numbered panels; readings were made only at the 0.2, 0.4 and 0.8 depths. For the summer series of measurements, again observations were made only at the eleven even numbered panels, but this time readings were made at each tenth depth. The fall discharge measurements were made at the 12 odd numbered panels and meter readings were made at each tenth depth.

Tonawanda Channel Section. The work on this section was done by the U.S. Lake Survey District. At the time the section was established, a drogue study was made to determine the direction of the flow through the section. The section was lead-line sounded with a 100 pound weight, at five to ten foot intervals, on May 4, June 7, September 1, and November 11, 1967. A standard profile of the section was developed from these measurements. Water levels were recorded at the section using a temporary Stevens gauge referenced to bench mark N-16 (573.210 feet, IGLD 1955).

Twelve Price current meters were used to make the velocity measurements. Different methods of measuring the discharge were used during each of the three sets of measurements.

For the spring series of discharge measurements, three meters were used simultaneously; velocity readings were made only at the 0.2, 0.4 and 0.8 depths of each panel for each of the 30 measurements. Also during the spring, three sets of vertical velocity measurements were made. Employing three meters simultaneously, velocities were measured at all nine tenth depths, in three meter settings. The first meter setting placed the meters at 0.1, 0.4 and 0.7 of the depth; the second placed them at 0.2, 0.5 and 0.8 of the depth; and for the third setting, they were at the 0.3, 0.6 and 0.9 depths. These vertical velocity measurements were made in order to define coefficients for the conversion of velocity readings at the 0.2, 0.4 and 0.8 depths to an average panel velocity in the vertical.

Because little additional time was required to obtain velocity measurements at each tenth depth, the method of measuring the velocities using three meters and three meter settings was used for the series of summer discharge measurements. For the fall measurements, each tenth depth was also metered; however, rather than using the three meter method, nine meters were used to measure the nine depths simultaneously.

6.11.4 Discharge Computation.

The U.S. and Canadian discharges for the spring, summer and fall measurements were computed by similar methods. The discharge at a section was the sum of the discharges through all the panels. The discharge through a panel for a particular measurement was the product of the panel's cross sectional area and the mean panel velocity at the time of the measurement.

Standard cross sections were determined from the soundings and adjusted to common water surface elevations. Panel areas were determined by planimeter. These areas varied with the stage and had to be adjusted using levels recorded during the measurement to give the area of the panel at the time of the measurement.

The mean panel velocity was determined as the average vertical velocity at the measuring point multiplied by the directional and transverse velocity coefficients.

Prior to making the spring discharge measurements, vertical velocity measurements were made at both sections. From these measurements a vertical velocity curve was developed for each panel of the section. Coefficients were determined from these curves for use in converting the spring velocities measured at the 0.2, 0.4 and 0.8 depths to an average velocity in the vertical. For the summer and fall measurements no coefficients were needed, since measurements were made at all tenth depths. To obtain the average vertical velocity necessary to calculate discharges, the velocities at each tenth depth of a panel during a measurement were averaged.

Directional coefficients were determined from the drogue studies made at the time the section lines were established. The directional coefficient for each panel was the sine of the average angle of flow in relation to the section line.

The transverse velocity coefficient adjusts the measured velocity to an average across the panel. The average vertical velocity at each metering point was plotted and a smooth transverse velocity curve was drawn through them from shore to shore. The panel widths were drawn in and the panel areas under the curve were determined by planimeter. This area was divided by the panel width and the result was divided by the average velocity at the metering point to give the transverse coefficient for the panel.

A summary of the results of this survey can be found in Tables 6.27 through 6.32 (see Appendix C). The data and reports resulting from the survey can be found in the Great Lakes Hydraulic and Hydrology Branch Archives of the Detroit District, Corps of Engineers, Detroit, Michigan. The material on the Tonawanda Section is in file number GLHH 71-3. The final report on the Chippawa Channel Section is in file number 3-4370.

6.12 Stella Niagara Section, 1967.

6.12.1 Purpose.

The Water Survey of Canada, Inland Waters Branch, made this series of discharge measurements, on the Niagara River below Niagara Falls, to measure both day and night flow conditions.

6.12.2 Description of Section.

The Stella Niagara Section was originally established in 1957 and recovered for this survey. The section was located in the lower Niagara River, 1-1/2 miles below Lewiston, New York. Extending from the Canadian to the U.S. mainland, the section was divided into ten panels for metering purposes. Forty discharge measurements were made between June 26 and July 27, 1967.

The approximate location of this discharge measurement section is shown on Figure 6-5.

6.12.3 Measurement Techniques.

The section was sounded to redetermine the section profile, and a direction of flow survey was performed.

Discharge measurements were made during both day and night flow conditions. For measurements 1, 2, 3, 13, 14 (day flows) and 27, 31, 33, 35, 37 (night flows), velocity measurements were made at each tenth depth. These were used to determine vertical velocity coefficients to be used with the remaining discharge measurements; where velocities where observed at only the 0.2, 0.6 and 0.8 depths.

6.12.4 Discharge Computation.

A vertical velocity curve was constructed for each panel for both day and night flow conditions. From these curves, vertical velocity coefficients were determined for converting velocities measured at the 0.2, 0.6 and 0.8 depths to an average velocity in the vertical. For the ten measurements where velocities were measured at each tenth depth (used to determine the vertical velocity coefficients), the average velocity in the vertical was the average of the nine measured velocities.

Transverse velocity coefficients were determined for both day and night flow conditions. These coefficients were derived from transverse curves constructed from the average velocities in the vertical of each panel.

To determine the discharge through a panel during a measurement, the panel area was multiplied by the average velocity in the vertical and by the appropriate transverse and directional coefficients. The discharge through the section was the sum of the panel discharges.

The U.S. Lake Survey District of the Corps of Engineers also determined discharges from the basic data provided to them by the Water Survey of Canada. The U.S. Lake Survey District used a computer program similar to that documented in Appendix A to reduce the data. The differences obtained between the Canadian and U.S. discharges where felt to be due largely to the different assumptions made about the shape of the vertical velocity curve below the 0.9 depth. Table 6.33 (see Appendix C) summarizes the results of this survey. File 3-4362 of the Great Lakes Hydraulics and Hydrology Branch Archives, Detroit District, Corps of Engineers, Detroit, Michigan, contains some of the data, on which these results were based.

6.13 International Railroad Bridge Section, 1970 - 1992.

6.13.1 Purpose.

The 1970 discharge measurements were made to study the effect on Lake Erie of altering the water level in the Chippawa-Grass Island Pool. A drawdown test was made by Ontario Hydro, during the period November 13-16, 1970, by order of the International Niagara Board of Control. The U.S. Lake Survey District and the Water Survey of Canada were instructed to take discharge measurements at a suitable Niagara River section, while the Chippawa-Grass Island Pool was being held steady at a drawdown level on November 14, 15 and 16. Measurements were again made at this section, in June 1971, for similar reasons.

The November 1971 series of measurements were made to provide data for the calibration of the Leading Edge Flowmeter, located downstream of the International Railroad Bridge at Buffalo, New York. When the flowmeter was originally installed, technical difficulties within the meter prevented the scheduled calibration. Personnel of the Great Lakes Hydraulics and Hydrology Branch, Detroit District, Corps of Engineers, were in the area conducting hydraulic measurements at the Niagara Powerhouse; it was decided that the crew should also take a series of measurements at the International Railroad Bridge Section, to provide the data needed for the calibration.

Measurements were also taken at the International Railroad Bridge Section in December 1972 and again in April 1973. During both periods, the Detroit District, Corps of Engineers, and the Water Survey of Canada simultaneously made discharge measurements at the section. The two crews started at different panels and independently completed full sets of measurements.

Under the auspices of the International Niagara Board of Control, a drawdown test was made by Ontario Hydro, during the period November 12 to 14, 1974. To gather preliminary data, a series of discharge measurements were made at the International Railroad Bridge Section, in May 1974.

In 1987, a series of discharge measurements were taken jointly by the Corps of Engineers and the Water Survey of Canada in the upper Niagara River above the International Railroad Bridge at Buffalo, New York/Fort Erie Ontario. The series included conventional and moving-boat measurements. The conventional measurements were taken for the International Niagara Working Committee by the Corps of Engineers, Detroit

District, with manpower assistance from the Buffalo District and the Water Resources and Water Planning and Management Branches of the Inland Waters and Lands Directorate, Ontario Region, Environment Canada. The purpose of these measurements was to verify the Buffalo, New York, and Fort Erie, Ontario, gauge ratings, to define the velocity-depth coefficient for the moving-boat measurements, and to provide a basis for comparison and evaluation of results. The moving-boat measurements were taken by the Water Survey of Canada's Hydrometric Methods Section, Ottawa, with manpower assistance from the above mentioned agencies. The purpose of these measurements was to measure the effect of water levels in the Chippawa-Grass Island Pool on Lake Erie outflows.

In 1988, a series of conventional and moving-boat discharge measurements were made jointly by the Corps of Engineers and the Water Survey of Canada, on the upper Niagara River above and below the International Railroad Bridge between Buffalo, New, York and Fort Erie, Ontario. The purpose of these measurements was to further verify the stage-discharge relationship for the Fort Erie and Buffalo Harbor gauges, and provide an additional data base for the International Joint Commission Reference study on the Great Lakes water levels. The moving-boat measurements were taken by the Water Survey of Canada's Hydrometric Methods Section, Ottawa.

In 1989, a series of conventional discharge measurements were taken jointly by the Corps of Engineers and the Water Survey of Canada, on the upper Niagara River above the International Railroad Bridge between Buffalo, New York, and Fort Erie, Ontario. The purpose of these measurements was the same as in 1988. It was determined by the Niagara Board of Control that discharge measurements should be scheduled for every three years, until such time that sufficient data are available to determine an acceptable Lake Erie outflow relationship.

In 1992, a series of conventional and moving-boat discharge measurements were taken jointly by the Corps of Engineers and the Water Survey of Canada on the upper Niagara River above the International Railroad Bridge between Buffalo, New York and Fort Erie, Ontario. The purpose of these measurements was the same as those in 1988 and 1989. The moving-boat measurements were taken by the Water Survey of Canada's Hydrometric Methods Section, Ottawa. Currently, three equations were available to calculate the Lake Erie discharge through the Niagara River. Two relationships, the 1953 Equation and the Reference Equation, were a function of the levels measured at Buffalo Harbor, New York. The Reference Equation was developed in 1988 for use in the IJC Levels Reference Study; the 1953 Equation has been the relationship used by the Niagara Board of Control. The third relationship, the Fort Erie Equation, is a function of the levels measured at Fort Erie, Ontario. In 1992, these equations were converted to IGLD 1985 and metric units. The next series of flow measurements is tentatively scheduled for 1995.

6.13.2 Description of Section.

The International Railroad Bridge Section was originally established in 1970 by the U.S. Lake Survey District, Corps of Engineers, and the Water Survey of Canada. The section was located about 408 feet above the International Railroad Bridge on the upper Niagara River.

For the 1970 and June 1971 survey, the section was divided into 13 panels, extending approximately 1,810 feet from Buffalo, New York, to Fort Erie, Ontario. Five discharge measurements were made at the section between November 14 and November 16, 1970, and eleven between June 8 and June 11, 1971. For the November 1971 survey, the section was divided into 14 panels; a total of 15 discharge measurements were taken between November 1 and November 17, 1971. For the 1972-1973 survey, the section was divided into 14 panels. Between December 7 and December 15, 1972, 19 discharge measurements were made by both the U.S. and Canadian field crews. During the period April 17 to April 27, 1973, the Water Survey of Canada took 10 measurements and the Detroit District took 13 measurements.

Starting in 1974, the International Railroad Bridge Section was divided into 20 panels. Between May 7 and May 16, 1974, 26 discharge measurements were gathered and between November 12 and November 14, 1974, 8 more were taken.

In 1987, both conventional and moving-boat measurements were made. The conventional measurements were taken at a section 408 feet above the International Railroad Bridge. A total of 19 conventional discharge measurements were taken: 13 with the Chippawa-Grass Island Pool at 560 feet and 6 with the Pool at 559 feet. The moving-boat discharge measurements were taken at a section about 300 feet above the conventional measurement section. A total of 35 moving-boat measurements were taken: 8 on June 2, when the Chippawa-Grass Island Pool was at elevation 559 feet, and 27 on June 3 and June 4, when the Pool was at 560 feet. Between May 24 and May 27, 1988, a total of 11 conventional measurements were taken: 2 with the Chippawa-Grass Island Pool at 561.20, 3 at 561.19, 4 at 561.15 and 2 at 561.00 feet. Between May 24 and May 26, 1988, a total of 65 moving-boat discharge measurements were taken. A total of 18 discharge measurements were taken between May 15 and May 18, 1989. Between May 11 and May 15, 1992, a total of 16 conventional measurements were taken at the usual hydraulic section; that is, 408 feet above the International Railway Bridge. Moving-boat measurements (36) were taken, between May 13 and May 15, 1993, at a section 790 feet below the International Railway Bridge.

The approximate location of this discharge measurement section is shown on Figure 6-8.

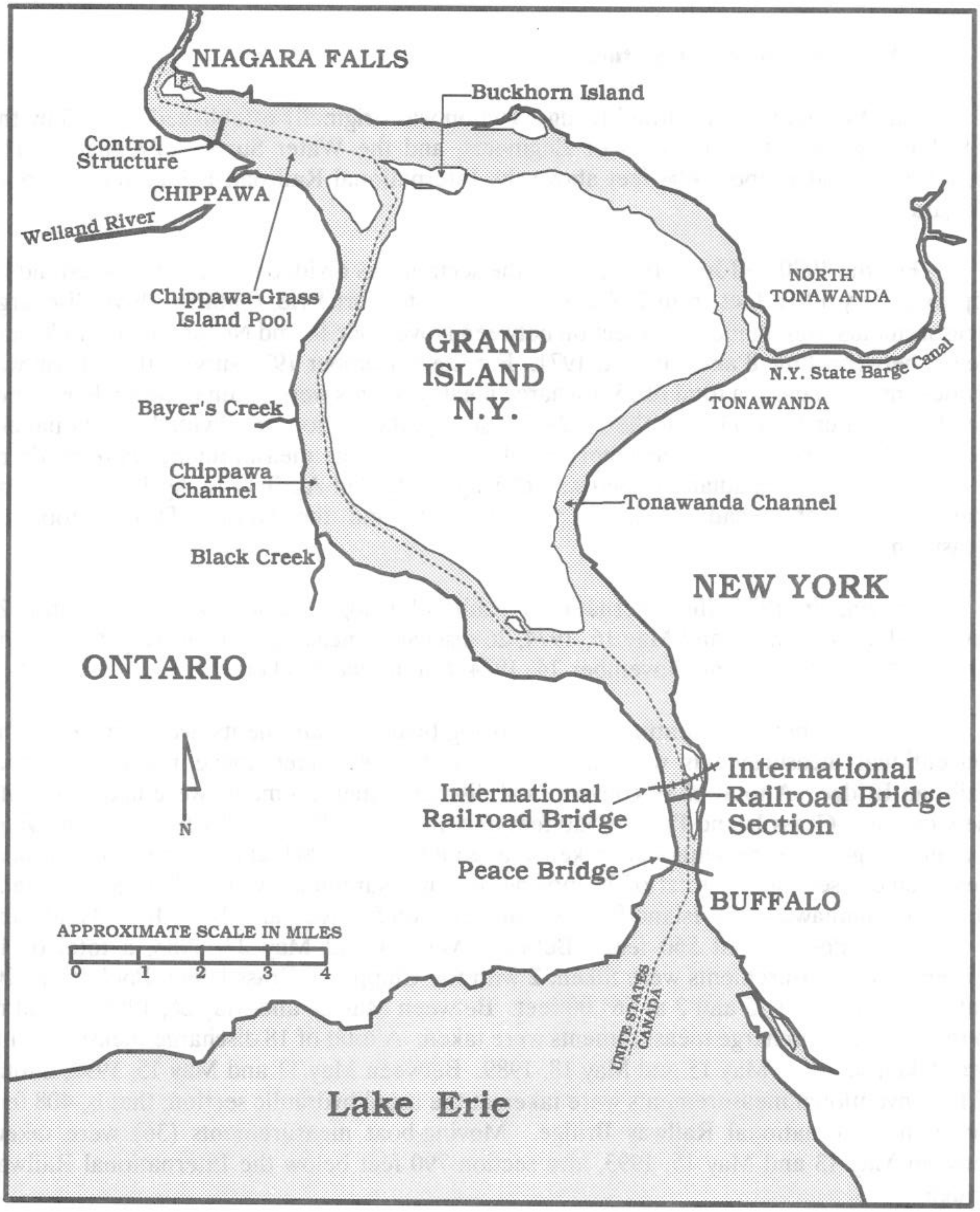

Figure 6-8

Niagara River, 1970-1989 International Bridge Section Location

6.13.3 Measurement Techniques.

The cross section profile was determined from the results of four echo sounding runs made on November 13, 1970, adjusted to a common water level elevation. Water levels were recorded at the section gauge, located at the Fort Erie pumphouse.

The U.S. Lake Survey District measured velocities in panels 1 to 6, while the Water Survey of Canada measured panels 7 to 13. Each survey crew employed four Price pattern 622 current meters to make the measurements at each panel. One meter was kept at the 0.4 depth, as an index meter, while the remaining three meters were used to make point velocity measurements in the vertical. Nine velocities were observed in the vertical, at depths of approximately each 0.1 of the total depth, starting at 0.05 of the total depth from the surface.

Direction of flow coefficients were determined from a drogue survey made on November 16, 1970. These coefficients were used for the 1971 series of measurements, as no significant change in the flow pattern was anticipated. Two sounding runs, using echo sounding equipment, were made on November 18, 1971, to check and update the earlier soundings.

Seven gauge locations were used, during the measuring period, to relate the measured discharge to the water level of the river. These were LaSalle Yacht Club, Peace Bridge, Huntley, Tonawanda, Niagara Intake, Ontario Street and Buffalo gauges. A temporary Fischer Porter digital gauge, installed at the U.S. Transducer site on the Squaw Island Dike about 1,400 feet downstream of the International Railroad Bridge, provided the stage relationships used in computing the discharge measurements.

During the period November 1 through November 17, 1971, a total of 15 discharge measurements were taken at the International Railroad Bridge Section. Each measurement consisted of nine meter settings at each of the 14 panels. Four Price current meters were used to meter each panel. Three meters were used to take two-minute readings at each of the nine tenth depths and the fourth was an index meter set at a constant 0.4 depth. A water level reading was taken from the section gauge at the start of each panel measurement.

In 1972-1974 the same basic method was used to meter the section as was used on previous surveys. Four Price current meters were suspended from the survey vessel. One meter was kept at the 0.4 depth as an index meter. The remaining three meters made readings at each of the nine tenth depths.

The Detroit District made five echo soundings of the section, on April 13, 1973. During the discharge measurements and sounding runs, the water level at the section was being recorded at the permanent Fort Erie pumphouse gauge. No drogue study was made to determine current direction. The values determined in the 1970 drogue study were used for the 1972-1974 measurements.

The 1987 moving-boat measurements were taken at a section about 300 feet above the conventional measurement section, while the 1988 and 1992 moving-boat measurements were taken at a section approximately 790 feet below the International Railroad Bridge, both taken from a 26-foot aluminum jet propelled boat. An Ott propeller-type current meter, mounted on a swivel rod, was used on these measurements. The meter was set at a depth of 3.28 feet below the water surface and moved across the section as uniformly as possible. The direction of the meter, relative to the section line, was measured by a compass attached to the top end of the rod, and the depth was sounded continuously by echo sounder. In the automated system used in these measurements (see "Discharge Measurement Procedures on the Great Lakes Connecting Channels and the International Section of the St. Lawrence River", by the Coordinating Committee on Great Lakes Basic Hydraulics and Hydrologic Data, dated October 1991), meter speed and direction, and sounded depth are continuously input to an on-board computer, which instantly computes and displays panel discharges as the measurement progresses, and prints out a total discharge and measurement summary at the completion of each traverse of the section. Two consecutive traverses of the section, in opposite directions, constitute a measurement; the time required for a measurement averaged approximately 15 minutes.

During the 1987, 1988, 1989 and 1992 survey, a series of conventional discharge measurements were taken jointly by the Corps of Engineers and the Water Survey of Canada. The conventional discharge measurements were taken at a section 408 feet above the International Railroad Bridge. All measurements were by the velocity-area method, using Price current meters to measure current speeds, and sounding lines weighted by 100 lb. lead Columbus sounding weights, to both measure depths and keep the meter assembly stationary while submerged. The meters were suspended off of two 22-foot outboard motor powered launches, outfitted with 4 meter suspension reels and manned by crews of up to four men. One boat would meter panels 1 to 10, while the other launch would meter panels 11 through 20. Two minute measurements were made at each point in the vertical; a complete measurement would take approximately two hours. The data were reduced by the Detroit District, using the standard discharge reduction program.

6.13.4 Discharge Computation.

The mean velocity in the vertical, at each measuring point, was determined, as described in Appendix A, from nine point observations, either as directly measured, or as calculated from the index meter reading. Both methods were used and gave similar results.

The mean velocity in the vertical, at a measuring point, was converted to a mean panel velocity using the appropriate equation for the panel. These equations were derived from the transverse velocity curve and assumed a straight line velocity distribution between measuring points. The mean panel velocity was then corrected for direction of flow and multiplied by the panel cross-sectional area to give the panel discharge. The sum of the panel discharges for a measurement becomes the measured section discharge.

The data collected by the U.S. were processed on a digital computer, using the Detroit District's discharge measurement program (see Appendix A). The Water Survey of Canada reduced their data using a similar discharge reduction program.

A copy of the field report of the 1970 survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, file GLHH 72-18, of the Detroit District, Corps of Engineers, Detroit, Michigan. Information on the June 1971 survey can be obtained from Environment Canada, Water Survey of Canada, Water Resources Branch, Guelph, Ontario. The data and results of the November 1971 survey can be obtained from the Great Lakes Hydraulics and Hydrology Branch Archives, file GLHH 72-15. The 1972-73 data can be found in file number GLHH 73-19, and data collected during the 1974 survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, files numbered GLHH 75-5 (May) and GLHH 74-7 (November). The 1987-92 data can be found in the Great Lakes Hydraulics and Hydrology Branch. Tables 6.34 to 6.46 (see Appendix C) list the results of these surveys.

6.14 American Falls Section, 1971.

6.14.1 Purpose.

Measurements were made, at this section, in order to verify the stage-discharge relationship for the American Falls gauge. Flows were varied for each measurement by previous arrangement with officials at the Grass Island Pool control structure and the power companies. The measurements were made by personnel from the Department of the Environment, Water Survey of Canada and the Corps of Engineers, Buffalo and Detroit Districts.

6.14.2 Description of Section.

The American Falls Section, as established for this survey, consisted of two segments, the Bridal Veil Channel segment, between Goat Island and Green Island, and the American Falls Channel segment, between Green Island and the U.S. mainland. The Bridal Veil Channel segment contributes about 10% of the total flow. The Bridal Veil Channel segment was metered from the upstream side of the Bridal Veil portion of the Goat Island Bridge, a view-mobile/pedestrian bridge. The American Falls Channel segment was metered from the downstream side of the American Falls portion of the Bridge. Both segments were divided into three panels for metering purposes. Between June 2 and 5, 1971, 12 sets of discharge measurements were made.

The approximate location of this discharge measurement section, in two segments, is shown on Figure 6-9.

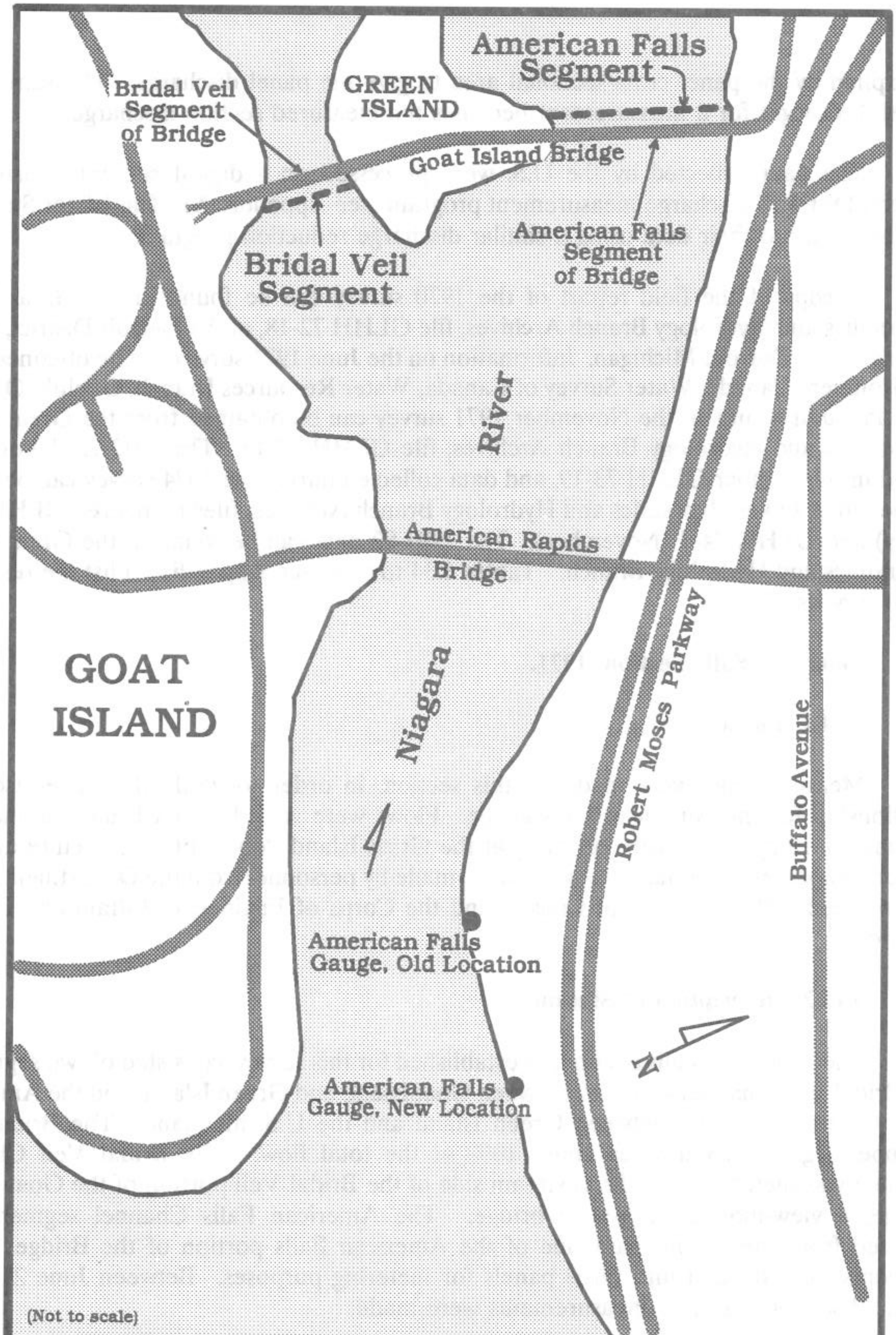

Figure 6-9

Niagara River, American Falls Section Location (Two Segments)

6.14.3 Measurement Techniques.

Velocities were measured at fifty-five points along the section (two segments), not more than ten feet apart. Velocities were obtained at the 0.6 depth in the Bridal Veil Channel segment and at the 0.2 and 0.8 depth in the American Falls Channel segment. Angles of flow were measured and recorded and coefficients applied. A considerable portion of the water in some panels could have been flowing in other than a horizontal (normal) direction, due to extreme turbulence. Four crews made measurements at the section simultaneously. They could complete a measurement in less than one hour.

Seven water level gauges were operated in the area at the time, but the primary one was the American Falls gauge. This gauge was located on the U.S. mainland, opposite the head of Goat Island, at Niagara Falls, New York. The IGLD (1955) elevation at the American Falls gauge site was established by precise levels from Buffalo, New York, and depended on the elevation of B.M. "BUFFALO L.H." as being 588.375 feet (IGLD 1955).

6.14.4 Discharge Computation.

A standard cross-sectional area times velocity relationship was used to obtain panel discharges, which were totaled to give the section discharge.

These measurements are summarized in Table 6.47 (see Appendix C). Documentation of this survey can be obtained from Environment Canada, Water Survey of Canada, Water Resources Branch, Guelph, Ontario.

6.15 Moses Section, 1971, and Stella Niagara Section, 1971 and 1972.

6.15.1 Purpose.

The 1971 measurements were made to check the discharge ratings of both the Robert Moses Niagara and Sir Adam Beck Powerhouses. Measurements were made during weekends, when it was possible for the power entities to hold the plant flows steady. In November 1971, simultaneous measurements were made, by personnel from the Water Survey of Canada and the Detroit District, Corps of Engineers, at sections established upstream and downstream of the powerhouses.

In 1972, a series of discharge measurements was taken at the Stella Niagara Section, by the Water Survey of Canada, to measure the Niagara River contribution to Lake Ontario inflow. This was part of a terrestrial water balance project in connection with the International Field Year for the Great Lakes (IFYGL).

6.15.2 Description of Sections.

Moses Section. A short stretch of river just upstream of the Robert Moses tailrace was first investigated in 1970, to determine the feasibility of establishing a hydraulic section in this reach of the lower Niagara River. At that time, from soundings and velocity measurements, it was concluded that such a section was feasible. The Moses Section was established, in November 1971. The section was located about 500 feet upstream of the Robert Moses Powerhouse tailrace. Extending from the U.S. to the Canadian shore, the section was divided into nine panels. Between the end of the ninth panel and the Canadian shore, there was a 58-foot wide area of dead water. Between November 13 and November 21, 1971, 11 discharge measurements were made at this section.

Stella Niagara Section. This section, established in 1957 (see Subsection 6.9), was located 1-1/2 miles below Lewiston, New York, on the lower Niagara River. For the 1971 survey, the section was divided into 13 panels. A series of 13 discharge measurements were made between November 13 and 21, 1971. The section was again recovered for a 1972 series of discharge measurements. The 1972 survey was comprised of 31 discharge measurements made between July 7 and August 2.

The location of both the Stella Niagara and the Moses discharge measurement sections are shown on Figure 6-5.

6.15.3 Measurement Techniques.

A drogue study was made at the Moses Section, on November 4, 1971, and at the Stella Niagara Section, on November 16. On December 23, 1971, another drogue study was made at the Stella Niagara Section, because the November values differed radically from those of previous surveys. The Moses Section was sounded, on November 12, and the Stella Niagara Section, on November 21, 1971, in order to prepare section profiles and determine panel areas. A temporary recording gauge was installed near each section, for use as section gauges during the taking of discharge measurements.

To make the 1971 discharge measurements, four Price current meters were used simultaneously, to meter each panel. One meter was kept at the 0.4 depth, as an index meter, and the remaining three meters took readings at each of the tenth depths of the panel. Each reading was of two minutes duration.

For the 1972 Stella Niagara measurements, the monumentation for the original 1957 section was recovered. The section was realigned by 1.75 degrees to make it normal to the main current direction, as defined by the December 1971 direction of flow survey, and new monumentation was installed.

A new triangulation network was also established, for the 1972 survey, with a base line along the Canadian shore and the section width recomputed. The original cut-off station, on a dock, on the U.S. shore, 1,873.8 feet south of the section line was recovered and used for positioning the catamaran during the measurements.

For the 1972 survey, previously established vertical control points were recovered and a section gauge comprised of a Stevens A-35 analog recorder and a back-up staff gauge, set to IGLD 1955, were installed in the Stella Niagara boat slip located about 300 feet below the section line.

The 1972 Stella Niagara Section was echo-sounded on July 13 and August 1, and a profile was plotted; standard areas for use in the computation of discharge were also developed. Lead-lined soundings were taken at each panel point to determine meter settings. A 15 panel distribution was used for the first 2 measurements, but was subsequently reduced to 12 to allow completion of measurements in a regular work day.

The Water Survey of Canada's catamaran, "Wasuca III", with a crew of three, was used for the 1972 series of Stella Niagara measurements. A fourth crew member was stationed ashore, at the cut-off station, signalling panel positions to the catamaran, which was held in position on section by a 5/16 inch wire rope anchor line attached to an 80 pound Danforth anchor dropped about 600 feet above the section. The line of the section was defined by a range line set up on the U.S. shore. Four panels could usually be occupied from each anchorage.

In the 1972 Stella Niagara measurements, four Price meters with 100 pound Columbus stabilizing weights were deployed simultaneously, to measure velocities at nine points in each vertical, while an index meter monitored variations in flow. A two minute timing period was used in the velocity measurements.

6.15.4 Discharge Computation.

The data collected at both sections was processed by the Detroit District, Corps of Engineers, using its discharge measurements reduction program. Appendix A contains a description of this program. The data and results of the 1971 survey may be found in the Great Lakes Hydraulics and Hydrology Branch Archives, file number GLHH 75-4, of the Detroit District, Corps of Engineers, Detroit, Michigan. A detailed report of the 1972 survey is on file in the Guelph, Ontario, office of the Water Survey of Canada. A summary of the discharge measurements can be found in Tables 6.48 to 6.50 (see Appendix C).

6.16 Cableway and Stella Niagara Sections, Fall 1973.

6.16.1 Purpose.

As a result of a study conducted in 1970, to determine the feasibility of a hydraulic section in the reach of the Niagara River just upstream of the Robert Moses Powerhouse tailrace, the Moses Section was established and discharge measurements were successfully made in November 1971. To improve the measurement technique at a section judged to be the most important on the Niagara River, a cableway spanning the Niagara Gorge was installed in 1973, approximately at the location of the Moses Section. The Robert Moses Cableway was built jointly by the Water Survey of Canada and the Power Authority of the State of New York, and became operational in September of 1973. During September and October 1973, the Detroit District, Corps of Engineers, under the auspices of the Niagara Working Committee of the International Niagara Board of Control, made discharge measurements from the cableway, in order to establish and calibrate the new Cableway Hydraulic Section, which is meant to provide data to verify the rating curve used to determine the discharge from the Maid-of-the-Mist Pool (Ashland Avenue gauge rating curve).

In support of the measurements made at the Cableway Section, the Water Survey of Canada conducted measurements at the Stella Niagara Section, during the same period.

6.16.2 Description of Sections.

The **Cableway Section** was located about 500 feet upstream of the Robert Moses tailrace on the lower Niagara River, extending approximately 520 feet from the U.S. shore west to the Canadian shore. A cablecar was constructed to run along the cable, providing shelter for the survey crew. In this survey, 17 discharge measurements were made with a ten-panel configuration, and three measurements with the section divided into eleven panels. This was tried to check the adequacy of the panel distribution, but no discernible difference from the two configurations was noted. Between the end of the last panel of the section and the Canadian shore was a 40-foot wide area of dead water. An eddy, caused by a change in the channel direction upstream of the section, created this area of calm. A total of 20 measurements were made between September 20 and October 5, 1973.

The **Stella Niagara Section,** recovered from previous surveys, was about 1-1/2 miles below Lewiston, New York, on the lower Niagara River. Extending approximately 1,800 feet from the Canadian shore to the U.S. shore, the section was divided into 16 panels. A series of 20 discharge measurements were made between September 19 and October 5, 1973.

The approximate locations of these discharge measurement sections are shown on Figure 6-10.

6.16.3 Measurement Techniques.

Both sections were echo sounded, in early October 1973. At the Cableway Section, the transverse velocity across the river was sampled in order to define the transverse velocity distribution.

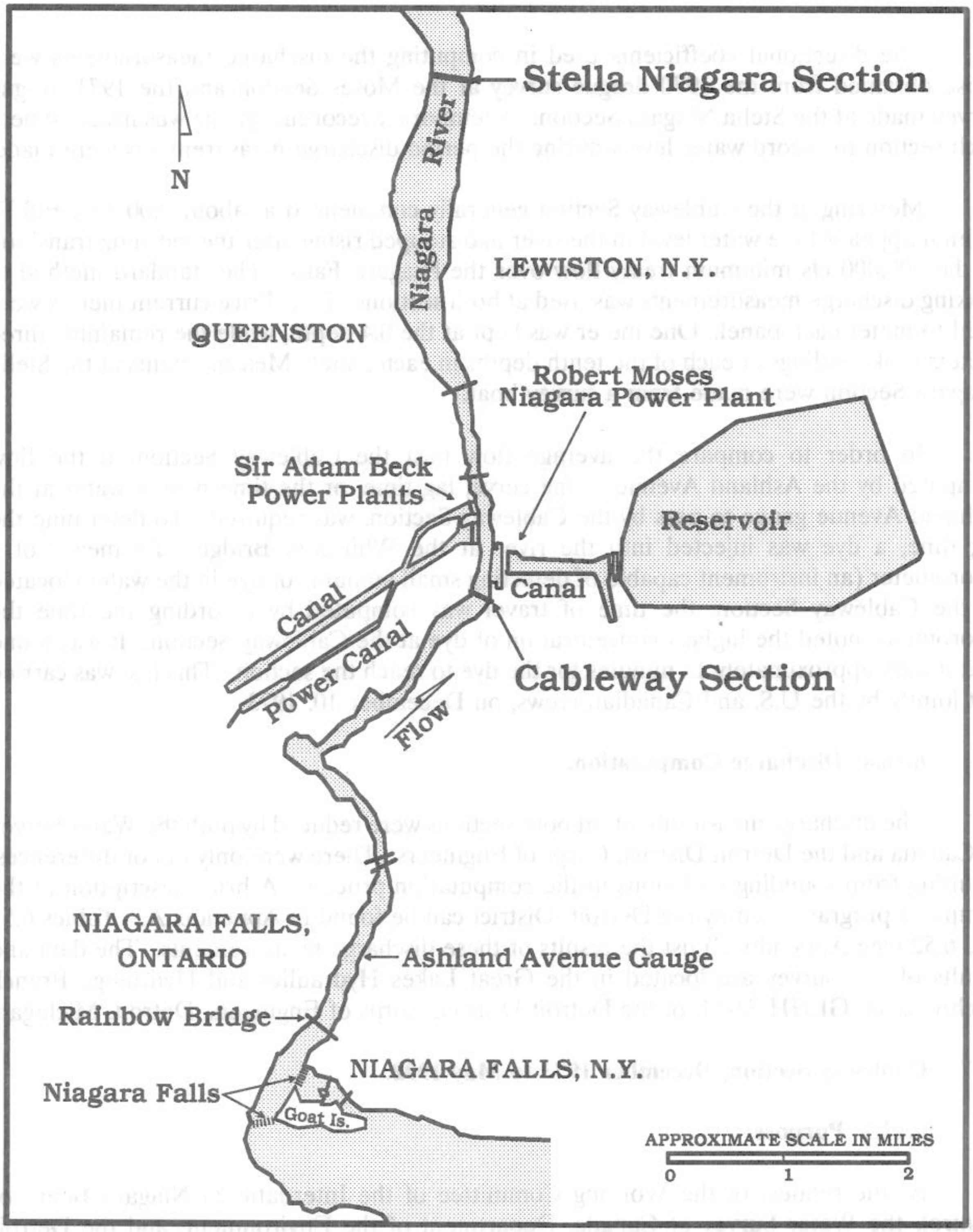

Figure 6-10

Niagara River, 1973 Cableway and Stella Niagara Section Locations

The directional coefficients used in computing the discharge measurements were those obtained from the 1970 drogue survey at the Moses Section and the 1971 drogue survey made at the Stella Niagara Section. A temporary recording gauge was installed near each section to record water levels during the period discharge measurements were made.

Metering at the Cableway Section generally commenced at about 9:00 a.m. E.S.T., when it appeared the water level in the river had stopped rising after the morning transition to the 100,000 cfs minimum treaty flow over the Niagara Falls. The standard method of making discharge measurements was used at both sections. Four Price current meters were used to meter each panel. One meter was kept at the 0.4 depth, while the remaining three meters took readings at each of the tenth depths in each panel. Measurements at the Stella Niagara Section were made from a survey boat.

In order to compare the average flow past the Cableway Section to the flow computed by the Ashland Avenue rating curve, lag time, or the time it took water at the Ashland Avenue gauge to pass by the Cableway Section, was required. To determine the lag time, a dye was injected into the river at the Whirlpool Bridge. By means of a fluorometer (an instrument capable of detecting small amounts of dye in the water) located at the Cableway Section, the time of travel was computed by recording the time the fluorometer noted the highest concentration of dye at the Cableway Section. It was found that it took approximately 15 minutes for the dye to reach the section. This test was carried out jointly by the U.S. and Canadian crews, on December 10, 1973.

6.16.4 Discharge Computation.

The discharge measurements at both sections were reduced by both the Water Survey of Canada and the Detroit District, Corps of Engineers. There were only minor differences, resulting from rounding variations in the computation process. A brief description of the computer program used by the Detroit District can be found in Appendix A. Tables 6.51 and 6.52 (see Appendix C) list the results of these discharge measurements. The data and results of this survey are located in the Great Lakes Hydraulics and Hydrology Branch Archives, file GLHH 74-11, of the Detroit District, Corps of Engineers, Detroit, Michigan.

6.17 Cableway Section, December 1973 to May 1992.

6.17.1 Purpose.

At the request of the Working Committee of the International Niagara Board of Control, the Water Survey of Canada, Department of the Environment, and the Detroit District, Corps of Engineers, have jointly conducted discharge measurement surveys at the Cableway Section, since 1973. The Niagara Board has prescribed that measurements at the Cableway Section be conducted no less than every three years. The purpose of these measurements is to verify the Ashland Avenue rating curve for the Maid-of-the-Mist Pool outflows.

6.17.2 Description of Section.

In 1970, a study was conducted to determine the feasibility of a hydraulic section upstream of the Robert Moses Powerhouse tailrace, on the lower Niagara River. In November 1971, a preliminary section was established (see Subsection 6.15, Moses Section) and discharge measurements were taken. A cableway spanning the river, upstream of the powerhouse tailrace, was installed by the Water Survey of Canada and the Power Authority of the State of New York, and became operational in September 1973. Discharge measurements and soundings for the calibration of the section were conducted during September and October 1973 (see Subsection 6.16).

The Cableway Section spans the lower Niagara River, about 500 feet upstream of the Robert Moses tailrace. The standard cross section for all flow measurements, subsequent to October 1973, consisted of 20 panels with standard panel widths and areas agreed upon by the Detroit District and the Water Survey of Canada. Forty feet of the Cableway Section was considered dead water, due to an eddy near the Canadian shore. In November 1978, the section was resounded and the panel widths were recomputed. At a new reference elevation, the area of dead water off the Canadian shore was determined to be 34 feet wide. New panel widths and areas were agreed upon. The coordinated soundings from the 1978 measurement series were retained for the 1981 studies.

The approximate location of the Cableway discharge measurement section is shown on Figure 6-10.

6.17.3 Measurement Techniques.

The discharge measurements and preliminary survey work, at this section, was carried out jointly by the Water Survey of Canada and the Detroit District, Corps of Engineers.

As noted above, soundings were made in September 1973. Since the river bottom in this area is composed of rocks large enough to resist shifting by the current, soundings were not conducted again until November 1978 and again in November 1986. On each occasion, echo soundings were made from both a boat and from the cablecar.

A series of drogue measurements were conducted during November 1971 (see Subsection 6.15.3). The directional coefficients derived from these measurements have become the standards for current directions at this section.

A board gauge, providing water surface elevations used for panel area calculations during the time of the discharge measurements, was installed prior to the start of each period of measurement. This gauge was referenced to bench mark GANTRY (299.458 feet, IGLD 1955). Positioning of the gauge took into consideration the anticipated changes in water stage, as well as visibility for the observers on shore. Levels were run prior to and after the measurement periods, to respectively establish and then check the gauge board reference elevation. In 1981, the section board gauge was moved approximately 40 feet downstream of the section line on the United States shore, with common levels being run from the primary bench mark, GANTRY, through B.M.'s RETAIN, STEP, GAGE and CABLE, to the top of the gauge. A reference elevation of 250.969 IGLD was derived from the initial level run; for purposes of these measurements, this figure was rounded to 251.00 feet IGLD through mutual agreement between the Water Survey of Canada and the Detroit District, Corps of Engineers.

Discharge measurements were made from a cable car, which was built to traverse the section. One Price current meter was used to meter a panel. This meter took readings of one-minute duration at intervals of each tenth of the sounded depth, from 0.1 to 0.9, inclusive. Due to the height of the cable car above the water and the high velocities encountered, the meter and weight assembly tended to be carried downstream from the section. Air and wet line corrections had to be applied to the original soundings to obtain the proper meter settings. A formula was developed by the Water Survey of Canada to calculate these corrections.

Metering time generally commenced around 9:00 a.m. E.S.T., when it appeared that the water level at the cableway had stabilized after the transition to the minimum treaty flows set for Niagara falls (100,000 cfs minimum daytime flows between April 1 and September 15, and 50,000 cfs minimum flow at all other times; see Subsection 6.10). The 9:00 a.m. E.S.T. starting time would also allow time for the high head hydropower plants to adjust for their morning loads.

Subsection 6.17.4 contains a summary of the dates when the above described measurements were taken and the number of measurements made during each survey.

6.17.4 Discharge Computation.

Data from these surveys were reduced by both the Water Survey of Canada and the Detroit District, Corps of Engineers. Both agencies used digital computer programs. A brief description of the computer program used by the Detroit District, Corps of Engineers, is given in Appendix A. All results were coordinated between the Water Survey of Canada and the Detroit District. The dates of the measurements, the number of measurements made during a particular survey, and the Detroit District's archive number for the file containing the data and/or results of the survey are listed below.

Date	Number of Measurements	Detroit District Archive File
Dec. 11-14, 1973	7	GLHH 74-11
Apr. 22-26, 1974	8	GLHH 74-6
Aug. 12-16, 1974	7	GLHH 74-6
Apr. 21-25, 1975	8	GLHH 76-9, 75-8

Continued from Previous Page

Oct. 29 - Nov. 5, 1975	13	GLHH 76-9
Oct. 28 - Nov. 3, 1976	11	GLHH 77-2
Dec. 5-9, 1977	9	GLHH 78-7
Nov. 6-10, 1978	10	GLHH 79-10
Oct. 28 - Nov. 27, 1981	19	GLHH 82-31
Oct. 5-8, 1982	7	GLHH 82-31
Apr. 26-29, 1983	7	GLHH 82-31
Oct. 28 - Nov. 5, 1986	13	GLHH 82-31
Apr. 17-Apr. 21, 1989	9	GLHH 91-33, 91-34
May 5-8, 1992	7	Not yet assigned

The above noted archive files can be obtained from the Great Lakes Hydraulics and Hydrology Branch of the Detroit District, Corps of Engineers, Detroit, Michigan. A summary of the discharge measurements can be found in Tables 6.53 to 6.59 (see Appendix C).

As prescribed by the Board, the 1981 Ashland Avenue rating equations were converted to IGLD 1985 and metric units. The converted equations were agreed upon by the Detroit District and Environment Canada and were subsequently approved by the International Niagara Committee. The updated Ashland Avenue equation is as follows:

$$Q = 10.000\,(AA - 85.504)^{2.113} \quad \text{for Q: 0 to 1416 m}^3\text{/s and}$$

$$Q = 768 + 31.81\,(AA - 91.415)^2 \quad \text{for Q: 1416 m}^3\text{/s and greater}$$

where: Q = the Niagara discharge in m^3/s and
AA = the water level (IGLD 1985) at Ashland Avenue, NY, in meters

6.18 American Falls Section, 1976 - 1990.

6.18.1 Purpose.

Due to a 1976 relocation of the American Falls water level gauge house, which was moved 400 feet upstream of its former location, discharge measurements were required in the American Falls Channel to re-establish the stage-discharge relationship for the flow over the American Falls.

The first series of measurements for this purpose were gathered in June and October 1976, followed by a further series of measurements in November and December 1977. Based upon these measurements, a new rating, called the 1978 rating, was developed for the American Falls gauge.

Between October 30 and November 2, 1984, a series of discharge measurements was taken to meet the Board's goal to assess flows over the American Falls approximately every five years. These measurements were the first taken at this site since the Board adopted the 1978 stage-discharge relationship (rating curve) for the American Falls gauge. Discharge measurements were taken, in 1989, for the same purpose. The results from that series, however, exceeded the acceptable error parameters for conventional discharge measurements. In 1990, discharge measurements were undertaken to confirm whether the 1989 measurements reflected an actual change in the hydraulic regimen of the American Falls Channel, or were the result of a faulty sounding profile. Results indicated that the latter was true, and the information gathered provided additional data for verification of the 1978 stage-discharge relationship.

6.18.2 Description of Section.

The American Falls Section was originally established by the Water Survey of Canada, in 1971. The section consisted of two segments (channels), the Bridal Veil Channel segment, between Goat Island and Green Island, and the American Falls Channel segment, between Green Island and the U.S. mainland. The Bridal Veil Channel segment contributes about 10% of the total flow. The Bridal Veil Channel segment was metered from the upstream side of the Bridal Veil portion of the Goat Island Bridge, a view-mobile/pedestrian bridge. The American Falls Channel segment was metered from the downstream side of the American Falls portion of the Bridge. For the 1976 measurements, the section (both segments) were re-established as close as possible to the 1971 gauge rating section. The American Falls Channel segment consisted of three spans and a total of 37 panels, while the Bridal Veil Channel segment consisted of three spans and a total of 18 panels. The section was again recovered for the 1977, 1984, 1989 and 1990 surveys. A total of 37 discharge measurements were made at this section, during the period June 21 to June 26 and October 21 to October 26, 1976. Twenty two discharge measurements were taken between November 28 and December 2, 1977, twenty two between October 30 and November 2, 1984, seventeen between May 9 and May 12, 1989 and twenty between May 15 and May 18, 1990. The next measurement sequence for the American Falls is scheduled for 1995.

The approximate location of this discharge measurement section, in two segments, is shown on Figure 6-9.

6.18.3 Measurement Techniques.

The two segments of this section were lead-line sounded at five-foot intervals and at any abrupt change in the river's hydrography, such as large rocks or boulders. From these soundings a uniform plot of the section (both segments) was drawn. Direction of flow was determined visually. Metering points and panels were created whenever feasible to match the section geometry developed by the Water Survey of Canada in 1971. In some instances it was not possible to do so, as the profile had changed slightly from 1971.

Velocities were measured at fifty-five points along the section. Due to the number of panels and the various depths encountered, the section was metered at the 0.2 and 0.8 depths, where possible, and at a depth of 0.6 in shallower areas. These measurements proved satisfactory and were consistent with the 1971 measurements. This procedure was applied, because of the shallow depth and the size and weight of the equipment used.

The equipment used for the metering operation consisted of movable carts with a boom and B reel. Price current meters were used; three on the American Falls Channel segment and one on the Bridal Veil Channel segment.

Water surface elevations used in the calculation of the discharges were obtained from the American Falls gauge elevation readings, transferred from bench marks set near the center of each span. This was done by measuring down from the bench marks to the water surface, using a weighted, graduated tape. The water level gauge used was the new American Falls gauge located approximately 400 feet upstream of the old American Falls gauge. Levels were run to re-establish the water surface elevation to IGLD 1955. The water level gauge was located in a concrete gauge house, owned and maintained by the National Oceanic and Atmospheric Administration. The gauge was a Fischer-Porter digital water level recorder, with a 15-minute sampling cycle.

6.18.4 Discharge Computation.

During measurement sequences, the meter revolutions for a one-minute period were recorded on data forms together with the section's gauge readings, meter identifications, time, date, etc. The data were keypunched and processed on a digital computer using the Detroit District, Corps of Engineers, discharge measurement program.

The average velocity in the vertical was computed using a modified von Karman equation to determine the configuration of the vertical velocity curve near the bottom. Once the average velocity in the vertical was computed for each panel, the area under the transverse curve for each panel was computed. The area under the transverse curve divided by the panel width was the average velocity for the panel; this value was multiplied by the panel area to compute the panel discharge.

The panel areas were adjusted for variations in stage. The adjusted panel area was multiplied by the average panel velocity and by the corresponding directional coefficient for the panel to determine the flow normal to the panel. Individual panel discharges were then summed to obtain the total section discharge.

The data and results of the 1976 and 1984 survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, file numbers GLHH 77-4 and GLHH 85-11, respectively, of the Detroit District, Corps of Engineers, Detroit, Michigan. The data and results of the 1977, 1989 and 1990 surveys can be found in Archive file numbers GLHH

91-40; GLHH 91-33, 34 and GLHH 91-36, 37, respectively. A summary of the discharge measurements is given in Tables 6.60 to 6.64 (see Appendix C).

6.19 Summary of Discharge Measurements.

For easy reference, a matrix of the identifiable historical Niagara River discharge measurements is provided in Table 6.1. The table contains only basic information in an abbreviated format; therefore, for more information on a particular series of measurements refer to the noted subsection in the table.

TABLE 6.1 Summary of Niagara River Discharge Measurements

NAME OF SECTION	PERIOD	PURPOSE	LOCATION	MEASUREMENT TECHNIQUES	DISCHARGE MEASUREMENTS*
Near Black Rock Harbor **(See Subsection 6.1)**	1841	To determine the flow of the Niagara River	Black Rock Harbor	Floats	See text, Subsection 6.1
Lower Niagara River **(See Subsection 6.2)**	Aug. 20 - Sep. 25, 1867 & June 12 - Sep. 17, 1868	To measure the flow of the Niagara River	In the lower Niagara River, near Youngstown, New York	Floats	Tables 6.1 & 6.2
Bridge & **(See Subsection 6.3)**	Oct. 5 - Nov. 1, 1897; July 16 - Aug. 17, 1898; & Sept. 10, 1898 - Dec. 10, 1899	To determine the flow of the Niagara River	Downstream edge of International Railroad Bridge	Bridge	Tables 6.3 & 6.4
Open	Aug. 30 - Sept. 23, 1899 & Oct. 4, 1899 - July 24, 1900		1800 ft. downstream of the International Railroad Bridge, just below Squaw Island	Conventional	Tables 6.5 & 6.6
Bridge **(See Subsection 6.4)**	Oct. 21 - Nov. 4, 1907 & June 26 - Oct. 22, 1908	To determine the outflow from Lake Erie	Downstream edge of International Railroad Bridge	Bridge	Tables 6.7 & 6.8
Split **(See Subsection 6.5)**	1913	To measure the distribution of flow around Grand Island	Not known	Not known	Not recovered
Bridge & **(See Subsection 6.6)**	Aug. 4 - 28, 1925	To determine the effect, upon the relationship of discharge and stage, of changes in the river	International Railroad Bridge, both downstream and upstream edge	Bridge	Tables 6.9 - 6.13
Bridgeburg	June 14, 1921 - Sept. 28, 1929				
Black Rock, **(See Subsection 6.7)**	June 12 - Nov. 12, 1931	To measure the distribution of flow around Grand Island	1800 ft. north of the International Railroad Bridge, just below Squaw Island	Conventional	Table 6.14
Wickwire &	Sept. 22 - Oct. 1, 1931		2-3/4 miles north of Buffalo, NY; from Grand Island east to U.S. mainland		Table 6.15
Oakfield	Sept. 21 - 29, 1931		From Grand Island west to the Canadian mainland		Table 6.16

TABLE 6.1 Summary of Niagara River Discharge Measurements (cont'd)

NAME OF SECTION	PERIOD	PURPOSE	LOCATION	MEASUREMENT TECHNIQUES	DISCHARGE MEASUREMENTS*
Austin Street **(See Subsection 6.8)**	June 19 - July 25, 1952, May 10 - June 14, 1968 & July 25 - Sept. 30, 1969	To determine Niagara River flow	On the upper Niagara River, extending from Canadian shore at Fort Erie, Ontario, to U.S. shore at Buffalo, NY	Conventional	Tables 6.17 - 6.19
Stella Niagara **(See Subsection 6.9)**	June 21, 1957 - Nov. 26, 1962	To obtain flow data for the range of stages experienced in the Maid-of-the-Mist Pool	1-1/2 miles below Lewiston, NY, from Canadian mainland to U.S. mainland	Conventional	Tables 6.20 - 6.24
Maid-of-the-Mist **(See Subsection 6.10)**	June 29 - July 22, 1967 & July 8 - 21, 1967	To determine the day and night flows over Niagara Falls and to analyze the Ashland Ave. gauge stage-discharge relationship	Approximately 1500 ft. downstream of the Rainbow Bridge	Conventional	Tables 6.25 & 6.26
Chippawa Channel & **(See Subsection 6.11)** Tonawanda Channel	May 17 - June 6, Aug. 14 - 31, & Nov, 15 - Dec. 5, 1967	To check: stage-discharge equations, weed effect correction tables, and flow distribution around Grand Island; to define upstream limits of backwater resulting from Control Structure operation; and to provide data for development of a math model	On the Chippawa Channel about 1/2 mile below Bayers Creek On the Tonawanda Channel, 1/3 mile Northeast of Two Mile Creek, NY	Conventional	Tables 6.27 - 6.32
Stella Niagara **(See Subsection 6.12)**	June 26 - July 27, 1967	To obtain day and night flow data	1-1/2 miles below Lewiston, NY, from Canadian mainland to the U.S. mainland	Conventional	Table 6.33
International Railroad Bridge **(See Subsection 6.13)**	Nov. 14, 1970 - May 15, 1992	To study the effect on Lake Erie of altering the Chippawa-Grass Island Pool water level; to calibrate a flowmeter; to verify gauge ratings; to define velocity-depth coefficient for moving-boat measurements	408 ft. & 708 ft. above the International Railroad Bridge on the upper Niagara River	Conventional & Moving-boat	Tables 6.34 - 6.46

TABLE 6.1 Summary of Niagara River Discharge Measurements (cont'd)

NAME OF SECTION	PERIOD	PURPOSE	LOCATION	MEASUREMENT TECHNIQUES	DISCHARGE MEASUREMENTS*
American Falls **(See Subsection 6.14)**	June 2 - 5, 1971	To verify the stage-discharge relationship for the American Falls gauge	Between Goat Island and Green Island (Bridal Veil segment) and between Green Island and U.S. mainland (American Falls segment)	Conventional	Table 6.47
Moses & **(See Subsection 6.15)**	Nov. 13 - 21, 1971	1971–To check the discharge ratings of the Robert Moses Niagara and Sir Adam Beck Powerhouses; 1972–To measure Niagara River contribution to Lake Ontario inflow	500 ft. upstream of the Robert Moses Powerhouse tailrace	Conventional	Table 6.48
Stella Niagara	Nov. 13 - 21, 1971 & July 7 -Aug. 2, 1972		1-1/2 miles below Lewiston, NY, from Canadian mainland to U.S. mainland		Tables 6.49 & 6.50
Cableway & **(See Subsection 6.16)**	Sept. 20 - Oct. 5, 1973	To calibrate new Cableway Section and to provide data to verify the Ashland Avenue gauge rating curve	500 ft. upstream of the Robert Moses tailrace	Conventional (Cablecar and survey boat)	Table 6.51
Stella Niagara	Sept. 19 - Oct. 5, 1973		1-1/2 miles below Lewiston, NY, from Canadian mainland to U.S. mainland		Table 6.52
Cableway **(See Subsection 6.17)**	Dec. 11, 1973 - May 8, 1992	To verify the Ashland Avenue rating curve for the Maid-of-the-Mist Pool outflows	500 ft. upstream of the Robert Moses tailrace	Cablecar	Tables 6.53 - 6.59
American Falls **(See Subsection 6.18)**	June 21 - Oct. 26, 1976, Nov. 28 - Dec. 2, 1977, Oct. 30 - Nov. 2, 1984, May 9 - 12, 1989 & May 15 -18, 1990	To re-establish the stage-discharge relationship for a relocated American Falls gauge, across from the head of Goat Island, Niagara Falls, NY	Between Goat Island and Green Island (Bridal Veil segment) and between Green Island and U.S. mainland (American Falls segment)	Conventional	Tables 6.60 - 6.64

*See Appendix C (under separate cover)