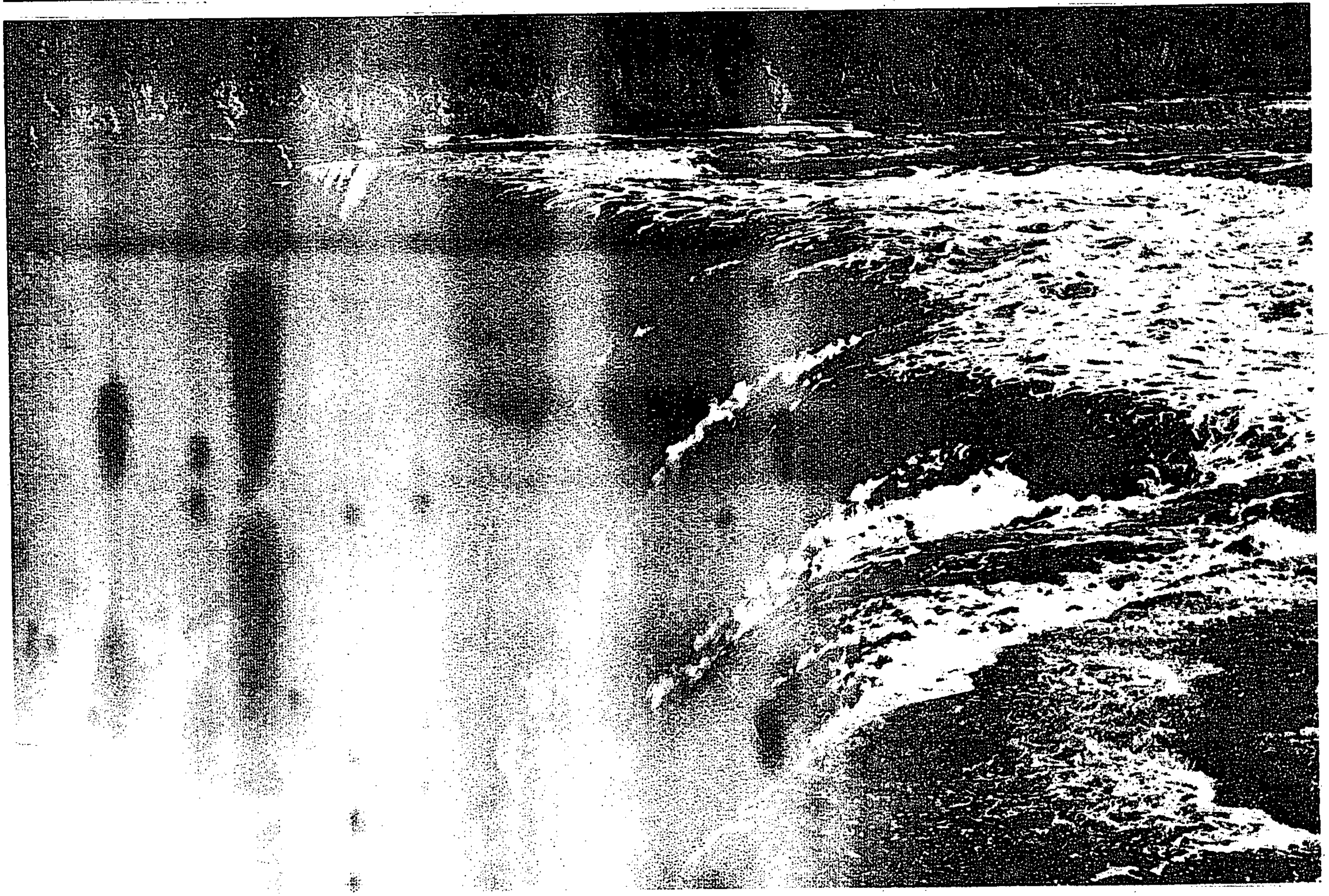
The Niagara River Acoustic Streamflow Measurement System

R. A. Halliday, W. M. Archer and P. [illegible] Campbell



TECHNICAL BULLETIN NO. 86
(Résumé en français)

INLAND WATERS DIRECTORATE
WATER RESOURCES BRANCH
OTTAWA, CANADA, 1975

Environment Canada

Environnement Canada

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Preface

The contents of this paper are essentially the same as those of a paper with the same title that was presented at the International Water Resources Association's Seminar on "Instruments and Systems for Measuring and Monitoring Water Quality and Quantity" in Chicago in June 1974. A few editorial changes have been made to the text and the Figures.

Abstract

Work conducted in other countries in the 1960's demonstrated the feasibility of using acoustic velocity measurement devices for determining flow in open channels. Accordingly, a decision was made to install one such instrument, the Westinghouse Leading Edge (LE) Flowmeter, on a large Canadian river where there was a demand for "real time" streamflow data and where the stage-discharge relationship was affected by backwater. Results obtained would be used to determine the feasibility of operating an acoustic streamflow measurement system under Canadian conditions. A flow meter having a 1700-foot (530-metre) long acoustic path was installed in 1971 and, despite some installation and operational problems, is providing accurate streamflow data. The plans for the future include telemetry of the data to users and further calibration of the instrument.

Résumé

Les travaux exécutés dans les autres pays au cours des années 60 ont montré la faisabilité d'employer des dispositifs de mesurage acoustique de la vitesse pour déterminer l'écoulement dans les canaux ouverts. Par conséquent, on a décidé d'installer un de ces instruments, le débitmètre *Westinghouse Leading Edge,* sur une grande rivière canadienne pour laquelle on avait demandé des données d'écoulement «en temps réel» et où le rapport niveau-débit était modifié par des remous. Les résultats obtenus serviront à déterminer la faisabilité d'employer un dispositif de mesurage acoustique de l'écoulement dans les conditions canadiennes. En 1971, on a installé un débitmètre dont le champ acoustique est de 1,700 pieds (530 mètres) et qui, malgré certains problèmes d'installation et de fonctionnement, fournit des données précises sur l'écoulement. Pour l'avenir, les plans consistent à faire la télémesure des données pour les usagers et à calibrer de nouveau l'instrument.

The Niagara River Acoustic Streamflow Measurement System

R. A. Halliday, W. M. Archer and P. I. Campbell

INTRODUCTION

The concept of measuring fluid velocity by acoustic techniques is not new, but only from the 1960's have commercial devices suitable for measuring water flow in open channels become available. One such system, the Westinghouse Leading Edge (LE) Flowmeter, was investigated for use on the Niagara River at the outlet of Lake Erie.

The Niagara River, which forms part of the boundary between Canada and the United States, flows over Niagara Falls approximately 15 mi (24 km) downstream from the Lake Erie outlet. The 1950 International Niagara Treaty establishes the minimum quantity of water that must pass over the Falls, the excess being diverted for power generation. The diversions are controlled by the international control structure located 1 mi (1.6 km) upstream from the Falls.

To experiment with the use of acoustic flow meters under Canadian conditions and to provide an accurate measurement of flow out of Lake Erie to ensure optimum use of the water for power generation, an LE Flowmeter was installed in 1971.

One of the main reasons for considering the use of the acoustic flow meter on Canadian rivers is the effect of ice, weed growth, operation of hydraulic structures, etc., on the stage-discharge relationship of many streams. Data from a velocity measuring device would enable a more accurate interpretation of discharge versus stage interactions. Other assets of an acoustic system are freedom from fouling of components in the river and the capability of telemetering data to users.

It was felt that the potential impact of acoustic flow measurement systems on conventional streamflow data gathering techniques was sufficient to warrant an experimental installation in Canada. Consideration was given to a site on the St. Lawrence River near Montreal and to a site on the Niagara River at the outlet of Lake Erie. Eventually, the Niagara River site was chosen.

This paper discusses the principle of operation of acoustic velocity measuring devices, the history of their use for water flow measurement work, the Niagara River site and the installation of the LE Flowmeter on the river. The installation and operational problems, accuracy achieved and future plans for the system are also discussed.

OPERATING PRINCIPLES

Acoustic velocity meters use the basic principle that the time required for a sound pulse to travel through a fluid medium is less in the direction of fluid movement than against it. This principle can be applied to the measurement of water velocity as shown in the following discussion.

With reference to Figure 1, if two acoustic transducers are placed in a river at an angle, θ, to the current and a known distance, L, apart, the downstream transit time will be given by:

$$T_{AB} = \frac{L}{c+V\cos\theta} \qquad (1)$$

where c is the speed of sound in water and V is the mean water velocity along the path between the transducers.

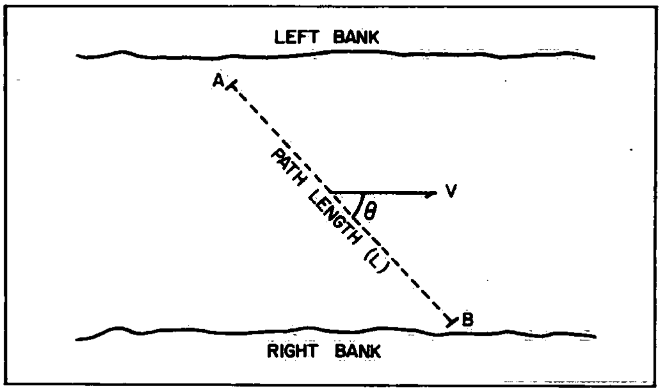

Figure 1. Transducer arrangement.

Similarly, the upstream transit time will be given by:

$$T_{BA} = \frac{L}{c-V\cos\theta} \qquad (2)$$

These two basic equations can be manipulated in various ways to provide easily measured quantities for a water velocity computation. There are two basic types of acoustic velocity meters now in use for measurement of water flow in open channels. Some manufacturers use the "sing-around" method and others use the "differential-time" method. Complete derivations of operative equations appear in McShane (1971).

The "Sing-Around" Method

In this method the reception of an acoustic pulse at one receiving transducer triggers another pulse from the transmitting transducer. This process continues to repeat until a predetermined number of pulses or lengths of time have elapsed. The direction of the sing-around circuit is then reversed and the procedure repeated. The equation governing the river velocity computation can be derived from the reciprocals of equations (1) and (2), that is:

$$V = \frac{L}{\cos\theta} \left(f_{BA} - f_{AB}\right) \tag{3}$$

where f_{BA} and f_{AB} are sing-around frequencies.

Several systems using the sing-around techniques have been developed. Two of these systems used for open channel measurements are described by Lowell (1971) and Genthe and Yamamoto (1971).

The "Differential-Time" Method

In this case, the difference in arrival times of two sonic pulses, triggered simultaneously from each transducer, is measured. Several discrete measurements of time difference are made, a velocity computed for each value, and the results processed to compute a mean velocity for a certain time period. The equation used in the velocity computation can be derived by rewriting equations (1) and (2) as follows:

$$c + V\cos\theta = \frac{L}{T_{AB}} \tag{4}$$

and
$$c - V\cos = \frac{L}{T_{BA}} \tag{5}$$

Subtracting (5) from (4) and solving for V yields:

$$V = \frac{L}{2\cos\theta}\left(\frac{1}{T_{AB}} - \frac{1}{T_{BA}}\right) \tag{6}$$

or
$$V = \frac{L\Delta T}{2T_{AB}\,T_{BA}\cos\theta} \tag{7}$$

It should be noted that both L, the path length, and θ, the angle of the acoustic path to the flow direction, appear in equations (3) and (7), but that c, the speed of sound in water, is eliminated from the velocity computation. The path length, L, can be measured directly or computed using conventional surveying techniques.

Measurement of θ cannot be determined exactly, since this would require measurement of θ at several points along the acoustic path and weighting the results with respect to velocity. In most cases the value of θ would change as the river discharge changes. This problem is overcome by using an approximate value of θ and compensating for this fact during the flow calculation.

The Niagara LE Flowmeter

The LE Flowmeter is an acoustic velocity measurement system manufactured by the Westinghouse Electric Corporation. This is the device used on the Niagara River and the one whose performance is discussed in this paper.

The LE Flowmeter operates on the differential time basis. The name "Leading Edge" is derived from the method used by the Westinghouse instrument to detect the incoming signal from a transducer. A typical receive signal is shown in Figure 2; the vertical scale is one volt per division and the horizontal scale is 50 microseconds per division.

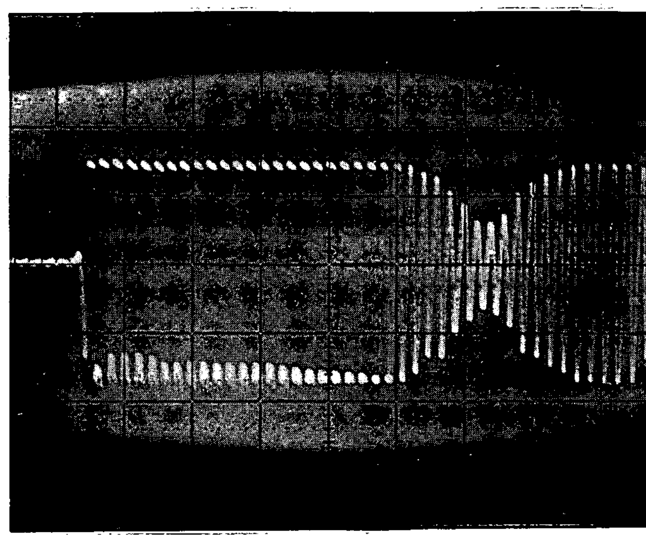

Figure 2. LE Flowmeter receive signal.

The flow meter detects the change in voltage caused by the incoming downstream pulse and starts a clock when the voltage reaches a set level. The upstream pulse is similarly detected and the clock is stopped, providing a measure of ΔT. The value of T_{AB} is measured by another clock. Therefore, the mean velocity along the acoustic path can be computed from equation (7). Sixty-four independent and equally spaced measurements of T_{AB} and ΔT are made during 99 percent of the update interval (15 min or 1 min). These data are screened to ensure that they are valid and as many as 36 measurements can be rejected without degrading accuracy.

At the end of each update interval, the system performs an internal check on its performance, the velocity value is displayed and a light is illuminated to indicate whether fewer than 28 valid samples were used to compute the velocity value.

The velocity reading in feet per second, the update interval and the diagnostics are punched on paper tape in eight-level American Standard Code for Information Exchange (ASCII) code as shown in Figure 3.

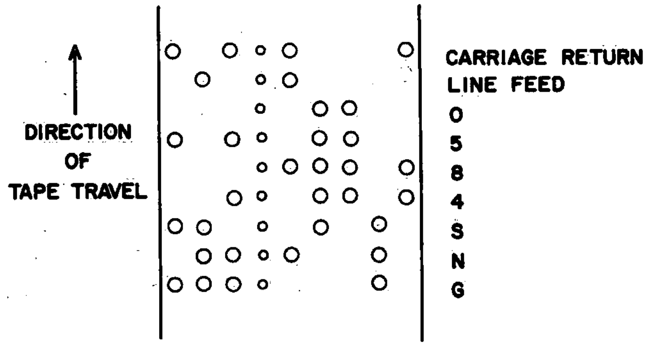

Figure 3. Tape format.

The "carriage return" and "line feed" enable data to be processed by standard computer facilities or to be transmitted over Teletype lines. The letter *S* is punched if the instrument is in the 15-minute update mode; the letter *F* is punched in the 1-minute mode. The letter *N* shows that the velocity computation is based on more than 28 values; a *P* shows that the computation used less than 28 values. The *G* indicates that the internal check was good; a *B* indicates that the internal check was not satisfactory.

A photograph of the electronics console is shown in Figure 4.

River Discharge Computation

It should be noted that all acoustic velocity measuring devices measure the mean velocity on a path between a pair of transducers and that this value is not necessarily the mean velocity in the channel. If a measure of mean river velocity is required, it would be possible to obtain good values using four acoustic paths and reducing the data using Gaussian quadrature integration (Hastings, 1969) to compute a mean velocity. Mean velocities to five percent accuracy are possible if water level fluctuations are ten percent or less of the total river depth. The manufacturer states that the error in line velocity measurement by the LE Flowmeter is within 0.5 percent. The velocities computed by the Niagara flow meter are called velocity indexes to show that they should not be considered as mean river velocities.

For single path systems such as that on the Niagara River, it is necessary to calibrate the system after installation to compute discharge from the relationship:

$$Q = KV_iA \qquad (8)$$

where Q is the discharge in cfs, V_i is the recorded velocity index in ft/sec, A is the area in sq ft from a stage-area table and K is a value that may be related to stage. The value K also compensates for inaccuracies in measurement of L and θ used in equation (3) and (7). Values of L and θ are entered in the flow-meter program by means of Plug-in Programmers (PIPs) that fit into standard integrated circuit sockets in the data processing unit of the instrument.

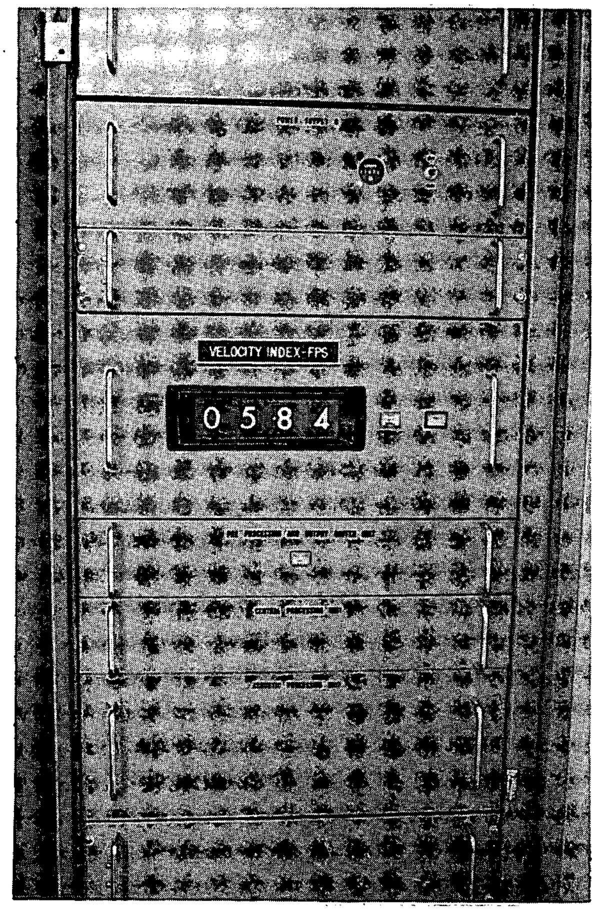

Figure 4. Electronics console.

HISTORY

McShane (1971) traces the early history of acoustic velocity measurement from the first recorded instance in 1919 to developments in the 1960's. Although the early experiments verified the validity of the concept, it was necessary to wait until improvements were made in transducer and electronic technology before workable systems could be put into service. Work in the 1950's and 1960's produced many practicable systems for measurement of liquid flow, although most applications involved flow in closed conduits rather than open channels.

The development of acoustic velocity meters for measurement of open channel flow seems to have achieved

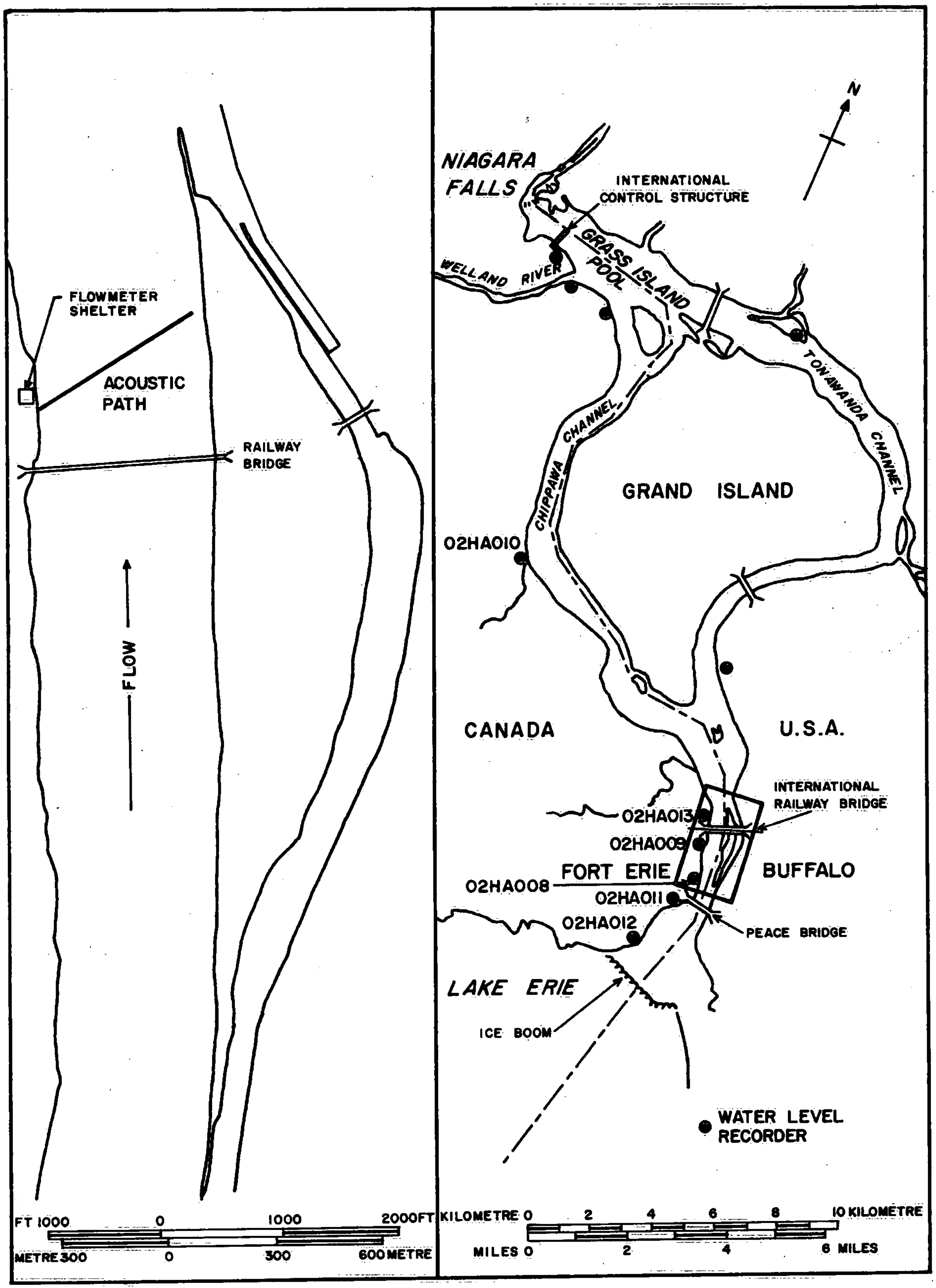

Figure 5. Location of acoustic flow meter.

results in the mid-1960's in Japan (Suzuki *et al*, 1970) and in the United States (Smith, Hubbard and Laenen, 1971), and in the 1970's in the United Kingdom (Loosemore, 1973). In 1967, one of the authors of this paper (Campbell) investigated the feasibility of installing a commercially available acoustic flow measurement system on a large Canadian river. A large river could be considered as having a width, surface velocity and depth that make stringing a tagline for conventional boat and tagline discharge measurements difficult. Usually a river with widths of 1200 to 1600 ft (365 to 500 m) or greater would be in this category.

THE NIAGARA RIVER

Flows in the Niagara River trend northeastward from Lake Erie to Lake Ontario, from where they are conveyed to the Atlantic Ocean by the St. Lawrence River. The Niagara's course between the two lakes is 33 m (53 km) in length; the mighty Niagara Falls is located approximately 15 mi (24 km) downstream from Lake Erie.

Flow out of Lake Erie into the Niagara River is controlled in the main by a natural weir in the form of a series of limestone ledges located about a mile (1.6 km) upstream from the Peace Bridge. The Peace Bridge is located near the head of the river, and the International Railway Bridge crossing is 2 mi (3.2 km) farther downstream as shown in Figure 5.

Over the long term, the natural flow is dependent upon inflow from the upper lakes. Owing to the enormous amounts of natural storage upstream, the river produces a comparatively steady flow. The long-term mean flow is approximately 202,000 cfs (5720 cu m/sec). It is, however, affected by short-term influences and seasonal effects, such as weed growth, anchor ice, and the daily and hourly effects of local changes in the level of Lake Erie. In 1972 and 1973, record high precipitation occurred in the Great Lakes basin, which has resulted in flows averaging 240,000 to 270,000 cfs (6800 to 7650 cu m/sec).

Lake Erie, being a long, shallow lake, is subject to violent wave action caused by winds parallel to the long axis of the lake and by local differences in barometric pressure. Wind set-up of as much as 9 ft (2.7 m) has been recorded at Buffalo. The flow of the river, dependent upon the level of Lake Erie at Fort Erie, is subject to large changes over short periods of time resulting from wave action. Maximum instantaneous flows in excess of 350,000 cfs (9910 cu m/sec) and minimum instantaneous flows below 90,000 cfs (2550 cu m/sec) have been recorded.

The Niagara River has long been a major source for hydroelectricity, with power production beginning in the late 1880's. At present, there are five hydro-generating stations that divert water from the Niagara River above Niagara Falls. The combined diversion capacity out of the Niagara River is approximately 175,000 cfs (5000 cu m /sec). About 85 percent of the water diverted for power production is diverted from the Chippawa-Grass Island Pool, a large placid pool 1 mi (1.6 km) upstream from the Falls. This water is diverted to the Sir Adam Beck and Robert Moses Plants located 6 mi (9.7 km) downstream from the Falls, using a head of over 300 ft (90 m) on the turbines including a 170-foot (50-metre) drop over the Falls.

Owing to the ever-increasing diversion of water from the Niagara River above the Falls and the concern for maintenance of their beauty, the Niagara Treaty of 1950 between the governments of Canada and the United States was signed. This Treaty requires a minimum flow over the Falls of 100,000 cfs (2830 cu m/sec) between the hours of 08:00 a.m. EST and 10:00 p.m. EST from April 1 to September 15, and between the hours of 08:00 a.m. and 08:00 p.m. from September 16 to October 31. A minimum flow of 50,000 cfs (1420 cu m/sec) is required at all other times.

A 2200-foot (670-metre) long control dam was constructed upstream from the Falls to maintain natural levels in the upper river under the heavy demands imposed by the diversions to the power plants and to provide proper flows over the Falls as required by the 1950 Treaty, while at the same time providing control for power diversions. The operation of the control structure is regulated by the International Niagara Board of Control. It has been determined that the control structure creates backwater upstream to the outlet of Lake Erie.

To adhere to the 1950 Treaty and to maximize power generation, there was a need for an accurate forecast of flow out of Lake Erie on a near "real time" basis. The computation of flow in the upper Niagara River, however, proved difficult because of backwater from the control structure, ice effect in the winter, aquatic growth in the summer, and wedge storage during periods of seiche effect.

The Water Survey of Canada decided to install a Westinghouse LE Flowmeter at the outlet of Lake Erie to provide an accurate measurement of river discharge to the control structure. Figure 5 shows the location of the flow-meter site below the International Railway Bridge and Figure 6 shows an ice run on the river. Lake Erie is at the top of the photograph and the flow-meter site is at the bottom of the photograph.

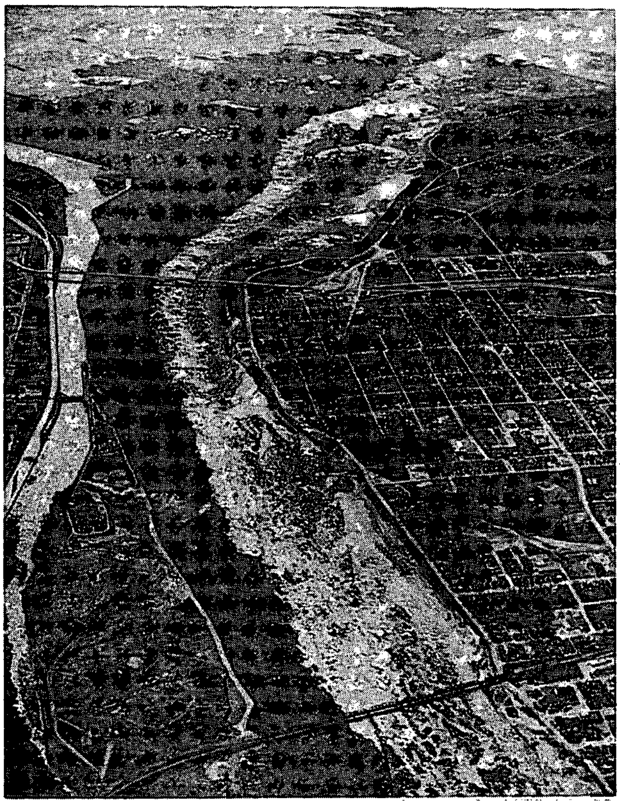

Figure 6. Ice run on the Niagara River.

SELECTION OF SITE AND INSTALLATION OF FLOW METER

Several possible sites were investigated in the Fort Erie reach at the outlet of Lake Erie. Criteria that were considered essential for the site are

a) property available for a shelter to house a water level recorder and the flow-meter console,
b) availability of an overhead structure to carry a line between transducers on the Canadian and U.S. sides of the river. An underwater cable was considered impractical because the river bed is relatively smooth and velocities are high, thus requiring substantial anchorage which would be very costly. Also, the cable would be subjected to damage from heavy runs or ice out of Lake Erie and weed drag in the summer months,
c) suitable sites for installation of transducers on the Canadian and U.S. sides of the river, and
d) selection of reach of river where there was no aeration or significant temperature gradient to deflect acoustic signals between the transducers.

The maximum sediment concentration was also a consideration, since high concentrations of suspended solids could cause attenuation of the acoustic signals. No problems of this nature were expected to take place on the Niagara River, however, as sediment concentration is much less than 100 mg/l.

A suitable site was chosen approximately 1200 ft (366 m) downstream from the International Railway Bridge (Fig. 5). An 8 ft by 10 ft (2.4 m by 3.0 m) metal shelter was erected on the Canadian Fort Erie Customs Dock property in early 1971. A pressure-actuated water level recorder and the Westinghouse LE Flowmeter console were then installed. The shelter can be seen in Figure 7.

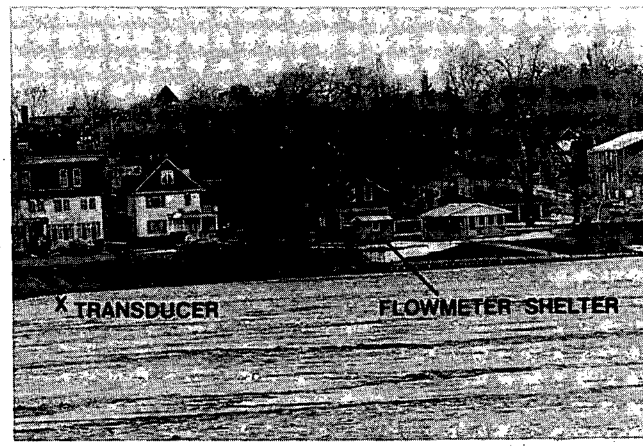

Figure 7. LE Flowmeter site – Canadian shore.

A hollow piling, 1 ft (0.30 m) in diameter, was driven into the river bed approximately 2100 ft (640 m) downstream from the International Railway Bridge, 85 ft (26 m) from the U.S. shore. The U.S. transducer was fastened to this piling 4 ft (1.22 m) above the river bottom at elevation 545 ft (166 m) International Great Lakes Datum (IGLD), 1955, by means of U bolts. Several breakdowns have been experienced in the underwater cable to the U.S. shore. The line was severed once, probably by a deadhead, and the underwater connection to the transducer shorted several times. The location of the U.S. transducer is indicated in Figure 8.

The initial line along the U.S. shoreline to the U.S. end of the International Railway Bridge was encased in a flexible conduit and buried. Unfortunately, this line ran through the Squaw Island sanitary fill site and was eventually torn up by bulldozers. It was then replaced by a cable encased in a flexible plastic pipe, 1 in. (25 mm) in diameter, along the top of the rock dyke which separates the sanitary fill site from the Niagara River. This line is subject to vandalism and has been cut several times. The entire line from the U.S. transducer to the bridge will be replaced by a transducer cable having a breaking strength of 20,000 lb (89,000 N).

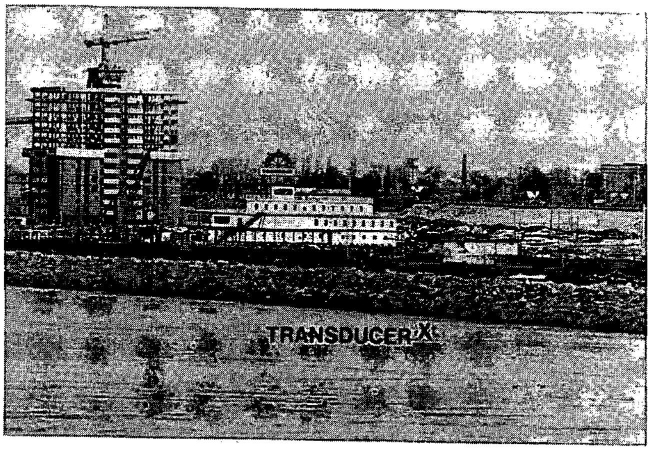

Figure 8. LE Flowmeter site – U.S. shore.

From the U.S. end of the Railway Bridge, the transducer cable was clamped to the underside of the bridge inside a split plastic conduit. As the International Railway Bridge has a swing span to permit movement of large boats, it was necessary to provide couplings at each end of the span so that the bridge could be opened. Fortunately no boat traffic that would warrant operating the swing span has approached the bridge since installation of the flow meter. The line from the Canadian end of the bridge to the flow-meter shelter was encased in flexible conduit and buried.

Initially, the Canadian transducer was attached to the face of the Customs Dock and connected to the flow meter. During the first summer of operation, however, it was discovered that a significant temperature gradient existed in this area because of a back eddy. This resulted in the acoustic signal being intermittently deflected, thus causing loss of data. After a trial at a temporary location upstream, the Canadian transducer was attached to the face of a

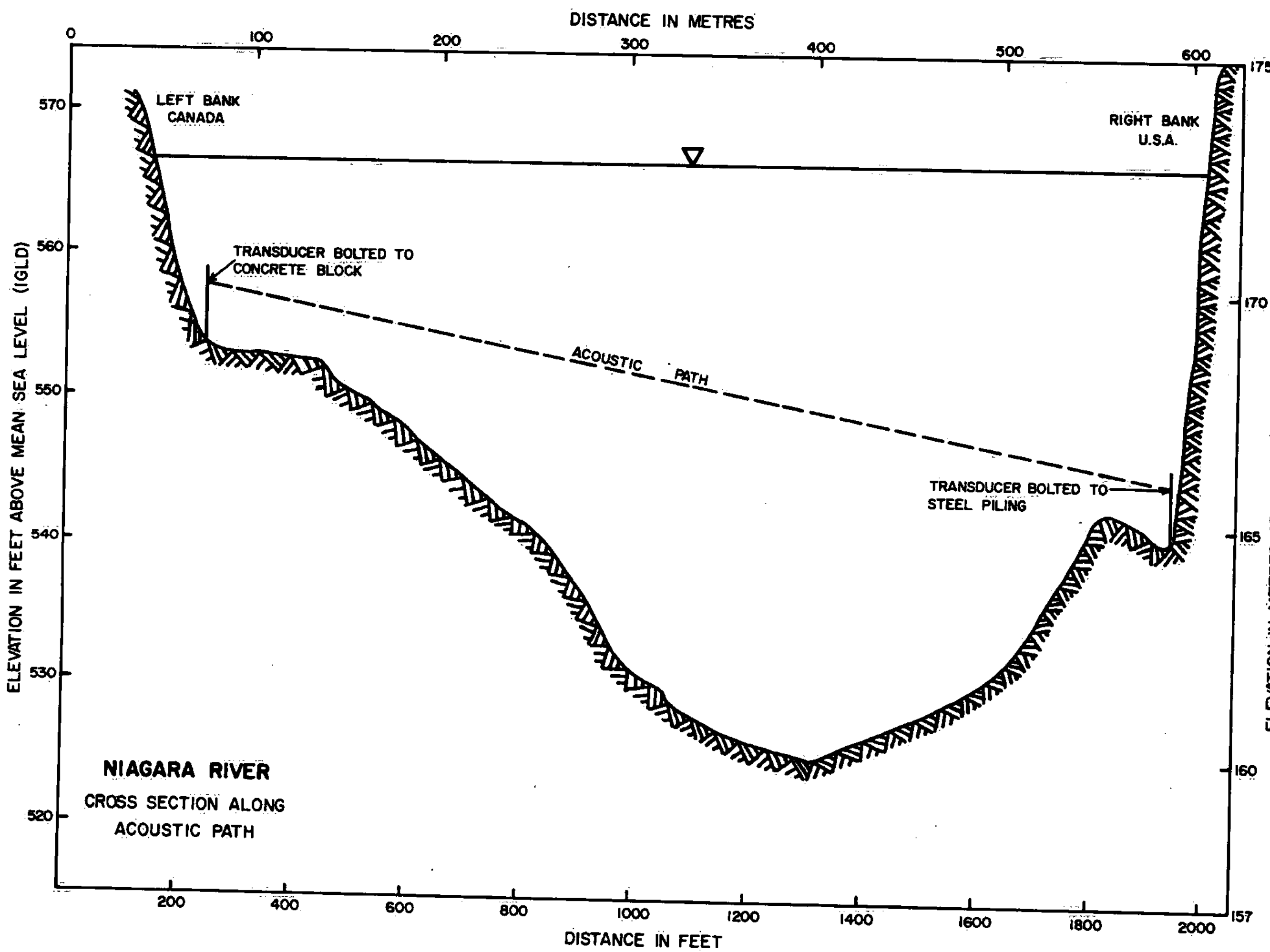

Figure 9. Niagara River – cross section along acoustic path.

4-foot (1.22-metre) cubical concrete block placed upstream from the Customs Dock. The elevation of the Canadian transducer is 559 ft (170 m), IGLD, 1955. Figure 9 depicts the channel cross section along the acoustic path.

Each transducer was attached to its mounting by four studs with compression springs which allowed the alignment of the transducers. The alignment was made by divers adjusting the position of the transducers, while a Westinghouse engineer observed the strength of the signal with an oscilloscope. The alignment was considered good when a strong signal was received. The position of the front face of each transducer was adjusted until vertical, since the difference in elevation (½° of arc) between the two transducers is not significant for alignment purposes. Figure 10 shows the Canadian transducer assembly prior to installation. The diameter of the 100 kHz transducer face is 8 in. (0.20 m).

INITIAL FLOW-METER SET-UP

To set up the flow meter, a number of field surveys were carried out. First, the distance between the transducers (acoustic path length) was measured by triangulation and was found to be 1697.5 ft (517.4 m) in length. Also, a drogue survey was made to determine the angle between the acoustic path and the river current. The angle was calculated to be 58.6° at the time of the survey. This information was then entered in the flow-meter program by PIPs, and thus the velocity index calculated by the instrument was adjusted for path length and angle.

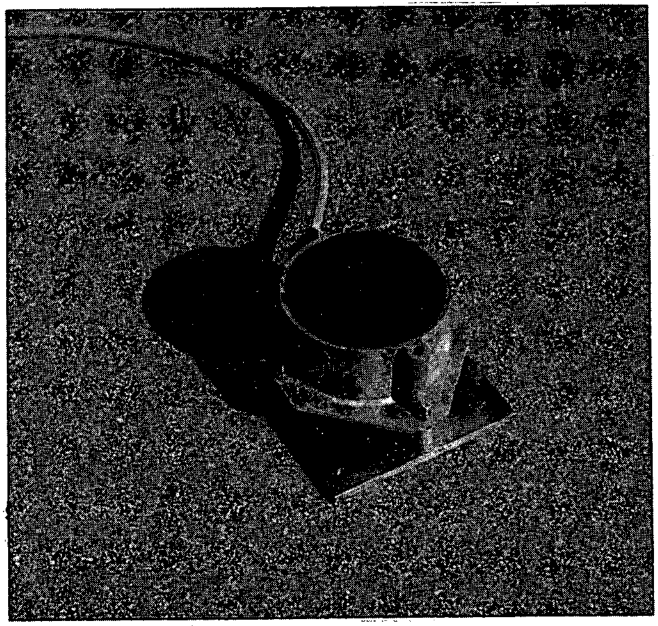

Figure 10. Transducer assembly.

The cross-sectional area along the acoustic path was surveyed by sonic sounder and sounding weight, then adjusted to values perpendicular to the flow. A stage-area

Table 1. Discharge Measurements from Catamarans

Measurement number	Date (1973)	Gauge height (ft) (IGLD, 1955)	V_i	AV_i (cfs)	Q measured (cfs)
1	April 17	566.90	5.97	266,000	261,000
2	April 17	566.90	5.97	266,000	260,000
5	April 18	566.88	5.99	267,000	264,000
6	April 18	566.88	5.99	267,000	264,000
7	April 19	566.76	5.82	258,000	257,000
8	April 19	566.75	5.83	258,000	256,000
9	April 19	566.72	5.93	263,000	259,000
10	April 20	566.76	5.84	259,000	254,000
11	April 24	566.98	5.91	264,000	265,000
12	April 24	567.02	5.97	267,000	270,000
13	April 24	567.02	6.00	269,000	268,000
14	April 25	566.68	5.86	259,000	250,000
15	April 25	566.66	5.83	258,000	249,000
16	April 25	566.64	5.74	254,000	254,000
17	April 25	566.64	5.75	254,000	252,000
18	April 26	566.72	5.93	263,000	258,000
19	April 26	566.78	5.94	264,000	257,000
20	April 26	566.77	5.93	263,000	254,000
21	April 26	566.72	5.86	260,000	257,000
22	April 27	566.49	5.77	253,000	243,000
23	April 27	566.49	5.77	253,000	244,000

1 m = 3.2808 ft
1 cu m/sec = 35.315 cfs

table was prepared covering the entire range of stage that would be likely to occur. At elevation 560.00 ft (170.68 m), IGLD, 1955, the area is 40,000 sq ft (3720 sq m) and at 570.00 ft (173.74 m), the area is 49,500 sq ft (4600 sq m). The table is virtually linear.

NIAGARA FLOW-METER CALIBRATION

As discussed earlier, the LE Flowmeter measures the mean velocity along a fixed path between a pair of transducers and this value is not necessarily the mean velocity in the channel. The error in the velocity computed by the LE Flowmeter is less than 0.5 percent; this value, however, is not indicative of the accuracy of the discharge computation.

A single path instrument must be calibrated in place by determining the value of K in the equation $Q = KV_iA$. This K factor could be constant or curvilinear with respect to stage or velocity.

To calculate K, a series of 23 discharge measurements were obtained at the metering section 408 ft (124 m) above the International Railway Bridge in April 1973. These measurements were taken from anchored catamarans by determining the velocity distribution in the vertical as a best fit to the Prandtl-von Karman distribution. The time taken for a discharge measurement was about 3 to 4 hours. The results of the measurements are shown in Table 1.

In addition, 36 measurements were obtained at the same section in June 1973 using the moving-boat method (Smoot and Novak, 1969). Use of this technique enabled a discharge measurement to be completed during the 15-minute update interval of the flow meter; thus one discharge measurement could be compared directly to one flow computation from the instrument. The results of the measurements are shown in Table 2.

Table 2. Discharge Measurements Using Moving-Boat Method

Measurement number	Date (1973)	Gauge height (ft) (IGLD, 1955)	V_i	AV_i (cfs)	Q measured (cfs)
1	June 26	567.11	5.86	263,000	262,000
2	June 26	567.12	5.84	262,000	268,000
3	June 26	567.11	5.84	262,000	252,000
4	June 26	567.12	5.87	264,000	275,000
5	June 26	567.12	5.89	264,000	270,000
6	June 26	567.13	5.91	265,000	266,000
7	June 26	567.13	5.89	264,000	268,000
8	June 26	567.02	5.81	260,000	262,000
9	June 26	566.98	5.76	257,000	272,000
10	June 26	566.96	5.72	256,000	266,000
11	June 26	566.93	5.71	255,000	262,000
12	June 26	566.87	5.70	254,000	271,000
13	June 26	566.87	5.70	254,000	276,000
14	June 26	566.90	5.80	259,000	276,000
15	June 27	567.34	5.79	262,000	285,000
16	June 27	567.38	5.84	265,000	294,000
17	June 27	567.45	6.00	273,000	292,000
18	June 27	567.41	6.13	278,000	298,000
19	June 27	567.42	6.19	281,000	290,000
20	June 27	567.35	6.10	276,000	283,000
21	June 27	567.23	6.01	271,000	272,000
22	June 27	567.18	5.88	265,000	268,000
23	June 27	567.13	5.78	260,000	276,000
24	June 27	567.08	5.80	260,000	268,000
25	June 27	567.04	5.74	257,000	254,000
26	June 27	567.03	5.69	255,000	256,000
27	June 27	567.04	5.70	255,000	262,000
28	June 28	567.15	5.89	265,000	262,000
29	June 28	567.14	5.86	264,000	264,000
30	June 28	567.17	5.84	263,000	261,000
31	June 28	567.16	5.87	264,000	264,000
32	June 28	567.17	5.92	266,000	272,000
33	June 28	567.19	5.92	266,000	272,000
34	June 28	567.13	5.84	262,000	265,000
35	June 28	567.13	5.84	262,000	264,000
36	June 28	567.15	5.86	264,000	269,000

1 m = 3.2808 ft
1 cu m/sec = 35.315 cfs

The discharge measurements cover a small range in discharge from 220,000 cfs (6230 cu m/sec) to 280,000 cfs (7930 cu m/sec), since none were obtained when river flow was influenced by wave action on Lake Erie. On the basis of these results, K seems to be a constant having a value of 1.00 ± 0.02.

Additional discharge measurements at other flows will be needed to verify these results. Comparisons have been made between flow-meter data obtained in the winters of 1972-73 and 1973-74 and hydro plant discharge records during ice conditions. It appears that the reduction in cross-sectional area caused by anchor ice is compensated by a slight increase in the velocity index; thus there is no loss in accuracy. This effect could be attributed to an adjustment of the vertical velocity distribution caused by decreased roughness of the stream bed even during periods when the discharge is affected by backwater because of ice effects.

This constant K is not too surprising, since the acoustic path is higher than the 0.6 depth (measured from the water surface) for its entire length with the exception of about 200 ft (61 m) near the Canadian transducer and 100 ft (30.5 m) near the U.S. transducer. The path thus falls on the nearly vertical portion of the vertical velocity curve, and therefore the ratio of the velocity index to the mean velocity in the vertical remains nearly constant with perhaps a slight increase with increase in stage. K being near unity is the result of accurate measurement of the path length and use of a good approximation of the mean angle of the path to the current.

FUTURE PLANS

Calibration

Discharge measurements have been made over a relatively small portion of the total possible range in discharge. Although these measurements have indicated that the velocity index recorded by the flow meter is very close to the mean velocity in the cross section, this relationship should be checked at other discharges and at times when weed growth or anchor ice effects are significant. Some work has been done by Wigle (1970), on the study of anchor ice phenomena in the vicinity of the flow-meter site, but additional data are required to ensure that the growth of anchor ice does not affect the stage-area relationship or the velocity index in such a way that accuracy is reduced.

Data Telemetry

At the present time, velocity data are recorded on site and are not available to users on demand. Since these data are recorded in ASCII format, it would be relatively easy to use a conventional Teletype system to transmit the data to a user. Also, the LE Flowmeter has the capability of accepting stage data and thus carrying out a flow computation. This wiring change could be made or, alternatively, the stage data could be transmitted by Teletype and the discharge computation made in a central data processing facility. This procedure would enable trouble shooting procedures to be carried out more easily, since both stage and velocity records would be available for examination.

As Teletype systems become more sophisticated, for example, when data must be provided to more than one user, the operating costs increase significantly. One possible means of overcoming this problem is to use satellite retransmission via ERTS, GOES or similar systems (Halliday, Reid and Chapman, 1973). These systems eliminate the need for any rental equipment and are sufficiently flexible that supply of data to more than one user does not increase operating costs. It has been estimated that the cost of converting the LE Flowmeter so that data can be presented in parallel digital format for retransmission would be about $10,000.

POTENTIAL FOR WIDESPREAD USE IN CANADA

Given that the Niagara acoustic streamflow measurement system continues to operate successfully, there are some factors that would tend to prohibit widespread use of these instruments in Canada.

One factor is that most Canadian rivers form a permanent ice cover in the winter. Ice thickness in excess of 10 ft (3 m) and slush ice depths of 30 ft (9 m) have been observed at some gauging stations. A problem would arise in determining the correct cross-sectional area to which the velocity data, produced by an acoustic velocity meter, must be applied. Pressure-actuated water stage sensors can be modified without difficulty to measure net ice thickness at a point; the authors, however, are not aware of any easy means of determining the ice thickness along an acoustic path automatically. This factor would restrict installations to those sites that remain free of ice cover or to those where accurate winter records are not required. Some river channels in the far North remain free of ice throughout the winter (Strilaeff and Wedel, 1970), but this situation can vary from year to year.

Many Canadian gauging stations are in isolated locations far from conventional sources of electrical power and are subject to temperatures lower than -40°C. Site access may be by fixed-winged or rotary-winged aircraft. Operating an acoustic velocity meter under these conditions would necessitate the use of heating systems to maintain the electronic unit above the freezing point and operation of a substantial power supply. The system components would have to be small enough for aircraft transport. Therefore, existing commercially available acoustic velocity meters would be difficult to operate in isolated regions of Canada.

The relatively high cost of purchasing and installing an acoustic velocity measuring device tends to restrict its use to those sites where accurate flow data are valuable for water supply or other purposes. The requirement for calibration of the system in place may be an obstacle, but techniques now available permit accurate discharge measurements to be made on any large river. If the channel cross section is not stable, the results from an acoustic flow meter will tend to be inaccurate between calibration checks.

If the cross-sectional area of a channel could be defined accurately and automatically, it seems that all other problems could be solved by the electronic technology now available.

CONCLUSIONS

The LE Flowmeter is a modern manifestation of a principle that has been known for many years. The instrument provides an accurate measurement of water velocity along a path between two transducers. This value can be related to the discharge of a river.

An experimental installation of a LE Flowmeter on the Niagara River has provided accurate values of river discharges under various flow conditions. The main problem since installation has been to maintain the integrity of the line to the U.S. transducer.

The plans for the future include further calibration checks on the instrument and telemetry of data to the users. Other possible sites for acoustic velocity meter installations are under consideration.

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The photograph in Figure 6 was provided by the Power Authority of the State of New York.

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