64

Direc

INLAND WATERS ~~BRANCH~~

DEPARTMENT OF THE ENVIRONMENT

Jet Boat - Tellurometer Technique for Measuring Streamflow in Large Rivers

E.J. FAST

TECHNICAL BULLETIN NO. 64

CANADA

TECHNICAL BULLETIN NO. 64

Jet Boat - Tellurometer Technique for Measuring Streamflow in Large Rivers

E.J. FAST

INLAND WATERS BRANCH
DEPARTMENT OF THE ENVIRONMENT
OTTAWA, CANADA, 1972

Contents

Illustrations

Tables

Jet Boat - Tellurometer Technique for Measuring Streamflow in Large Rivers

E.J. FAST

INTRODUCTION

Over the years since June 1894 when the first recorded stream measurement in Canada was made, the hydrometric survey has expanded throughout Canada to provide the water resources manager with the data necessary to plan and operate his projects. The intensity of the hydrometric program has varied from river basin to river basin. Such factors as the remoteness of a river, its relative importance and the total funds available to carry out hydrometric work have all greatly influenced the collection of data or lack of same. Large rivers have posed a special problem in that the wide, swift-flowing expanses of water have constituted technical difficulties which only recently have been largely overcome through technological advancement.

The demand for more streamflow data, has established the need to maintain the hydrometric surveys through all seasons. This in turn presents certain difficulties. Backwater conditions during winter and high flows during spring require more intense and elaborate metering programs. Flowing ice in winter and floating debris in spring make conventional metering methods both hazardous and time consuming. These difficulties become especially troublesome on rivers whose widths prohibit the use of conventional equipment and whose high velocities often make accurate anchoring of a boat in a cross-section extremely hazardous and difficult; positioning a boat using a sextant or shore-based transit and holding position in midstream with anchors is the method which has been used most often to date. Considerable manpower is required and communication problems often exist.

The Mackenzie, St. Lawrence and the lower reaches of the Fraser River are unquestionably in the "large river" classification. The following describes a new method of measuring large rivers which was successfully carried out on the St. Lawrence River during 1971. While it deals specifically with the St. Lawrence River and difficulties encountered on that river, the method can, with modification, be related to any other river with similar characteristics.

The metering section chosen was on the St. Lawrence River at Ville La Salle, Quebec, on the southern shore of Montreal Island and approximately one-half mile above the Lachine Rapids. The discharge measurements are referred to the gauge commonly called Old Aqueduct Gauge, Number 020A016.

The physical features of this section made standard metering procedures unworkable. The extremely high velocities (up to 10 feet per second) in a relatively shallow channel made anchoring a craft undesirable.

The 2,500-foot channel width made stringing a conventional tagline impractical whereas construction of a cableway was not economically feasible. Measurements from Mercier Bridge two miles upstream were complicated and time consuming due to the numerous piers and subsequent angular flows. Throughout the winter, ice conditions in this stretch of the St. Lawrence River vary from day to day and from morning to afternoon. Figure 6 on the centrefold shows ice conditions during January 1971. Ice can form overnight at the edge of the ice pack on upstream Lake St. Louis. If winds and temperatures rise throughout the morning, this overnight ice may break free and float through the section in varying sizes up to twenty feet square and two inches thick. Occasionally, pieces up to twelve inches thick break off the ice pack. A constant vigil must be kept because these floes can prove to be extremely dangerous to light craft on the river. When temperatures are below 20°F., the channel is often covered with floating frazil ice which can clog metering gear. This ice disappears on most days when temperatures rise in the afternoons. When temperatures drop to 10°F., or lower, a thick fog often forms over the open water and makes hydrometric activity impossible. After heavy snowfalls, municipal river snow dumps are very active and large frozen snow lumps often break off the shore and float through the section. The overcoming of these winter obstacles was of prime importance in the development of a new technique.

The time element was also considered to be of prime importance. The ever changing flow patterns across the channel caused by channel configuration and upstream regulation made it desirable that the measurement be carried out in as short a time as possible. The danger to men and equipment would also be reduced if less time were spent on the water.

It was decided that the method should employ a boat having sufficient power and manoeuverability to enable it to operate free of any type of anchorage. The time of measurement should be limited to a maximum of two hours. Suitable equipment should be obtained to instantaneously monitor the position of the boat in relation to the shore and to the metering cross-section. All equipment should be of suitable design and quality to withstand the varying environmental conditions. A general description of the equipment used and the techniques employed is as follows:

EQUIPMENT AND TECHNIQUE

The boat, chosen for all season operation, had a steel displacement hull and was propelled by a water pressure jet. A boat with this type of propulsion is commonly called a "Jet Boat". It was chosen for its stability in strong currents and for its lack of subsurface moving parts or projections which could be damaged by ice.

The boat is controlled by varying the intensity and direction of the water thrust created by the pump. When operating, water is sucked in through a steel grate in the hull approximately three feet ahead of the transom, forced through an axial impeller pump and expelled under pressure through the transom. The engine speed is regulated by a foot throttle which in turn regulates the pump pressure. The boat is manoeuvered by a steering wheel connected by a cable to a pair of baffle plates set vertically at each side of the pump outlet. Turning the steering wheel moves the plates sideways into the water stream and deflects the thrust sideways (Fig. 1). An additional cupped baffle plate, located above the exhaust port, is used to deflect the jet stream downward, thus reducing the effective force propelling the boat; deflecting the jet downward also adds stability to the boat (Fig. 2). A shift rod, controlling the movement of the cupped baffle plate,

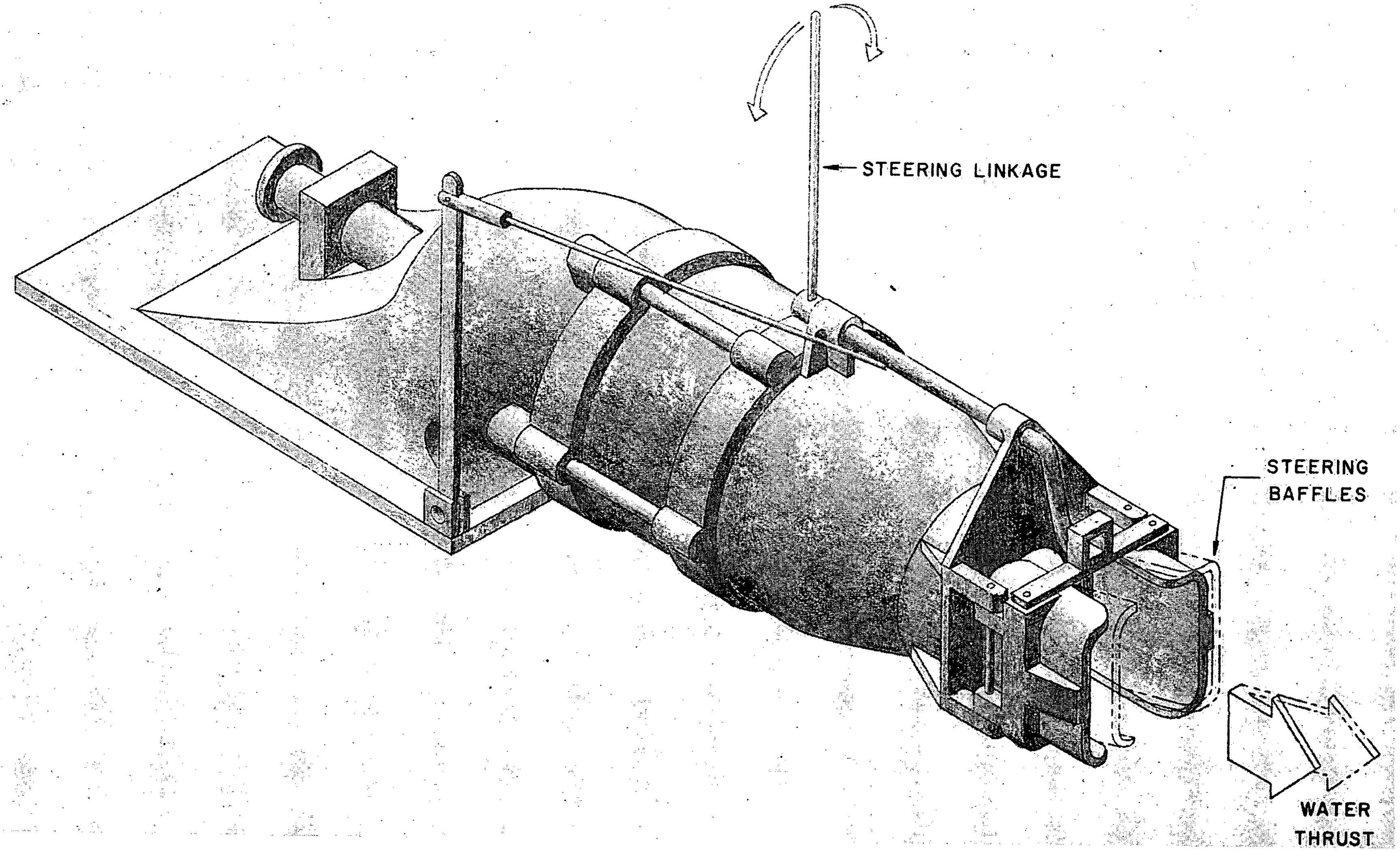


Figure 1. Hamilton jet pump showing steering baffles.

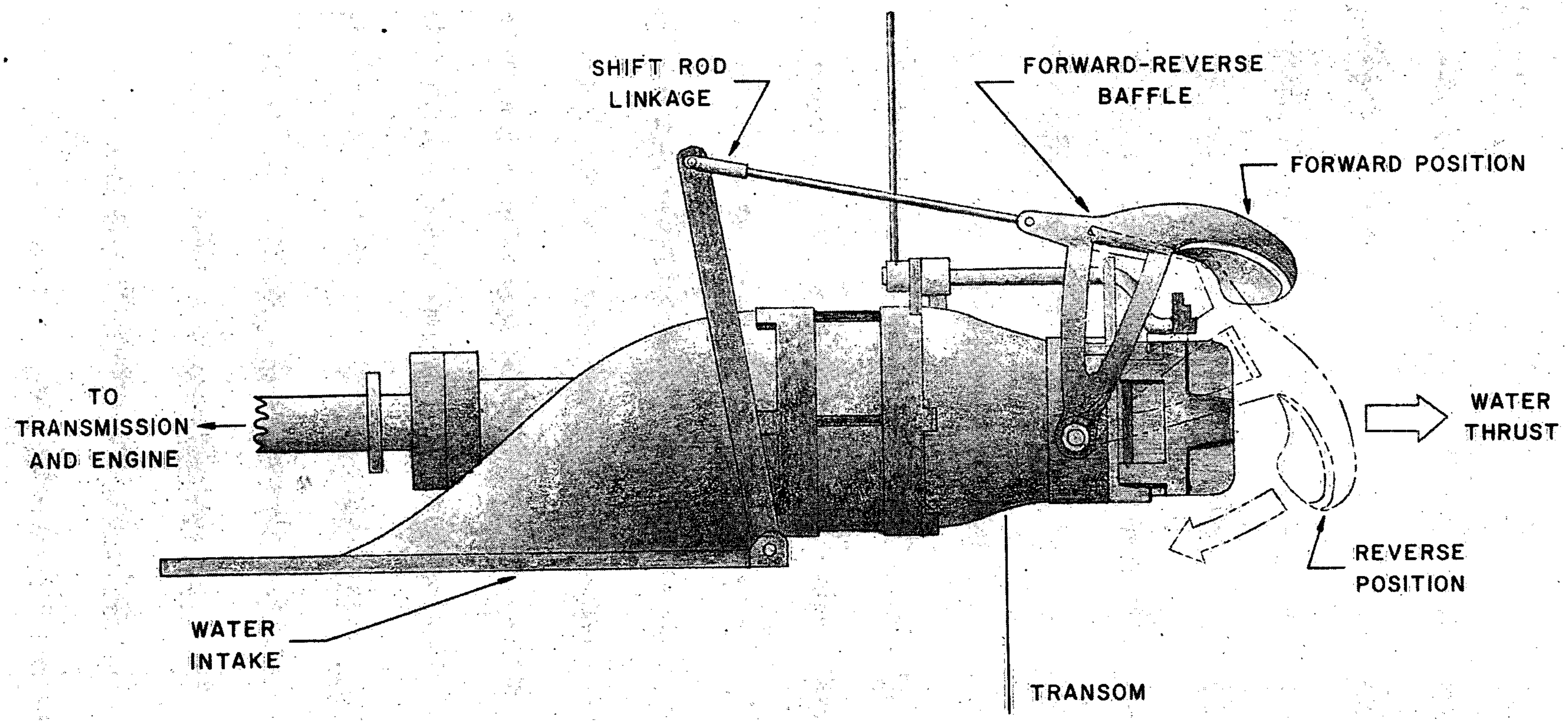


Figure 2. Hamilton jet pump showing cupped baffle plate.

is located beside the pilot's seat. For forward movement the shift rod is in a forward position and the baffle is clear of the water thrust. In neutral the shift rod is in a vertical position and the baffle plate directs the water thrust directly downward into the water. In reverse the shift rod is pulled back of neutral causing the baffle plate to direct the water thrust back under the hull. Aside from being the reversal mechanism when extended to the full down position, it can be set manually in any position between forward and reverse and serve as a "fine tuning device" when positioning the boat in surging water. The throttle is set to maintain slight headway over the current and by manipulating the shift rod the slightest amount, the boat can be held stationary in the current.

The boat used for this program was rented from a marine firm in Montreal. The boat, some 17 feet long with an 80 inch beam, was manufactured from 1/8-inch welded steel plate and had a total weight of 4,000 lbs. The craft was propelled by a two-stage marine jet driven through a reversible hydraulic transmission by a 297 cubic inch V-8 marine engine. The transmission offered the advantage of flushing weeds or ice pans from the intake grate by reversing the pump impeller. Removal of debris must be done manually with non-reversible jet units.

Subsequent to the 1971 spring measurement program, The Water Survey of Canada purchased a jet boat which incorporated the basic features of the steel boat. This boat shown in Figures 3 and 4 has a fiberglass hull to reduce its weight and increase its portability. Trials indicate that this boat performs as well as if not better than the steel boat but may be subject to greater damage by ice.

A B-56 reel was mounted on a steel boat frame across the gunwales near the stern of the boat. The Price-type meter with a 100-pound Columbus weight was used for all measurements.

A pair of 4' x 4' plywood markers, each divided into two equal triangles painted in contrasting colours, were placed on each shore on the cross-section line. These markers provided the boat pilot with a visual check of his position upstream or downstream of the cross-section line. The marker pairs were positioned to be coincident when the boat was on the section line.

In total, eleven discharge measurements designated 71-1, 71-2, 71-3...., 71-11, were carried out using the new equipment. For measurements 71-1 to 71-3, the boat was positioned along the section line using the targets and predetermined angles from a theodolite positioned on a base line on the north shore. When the boat was bisected by the vertical crosshair of the theodolite, the pilot was informed by two-way radio that he was in position for that station. The pilot received continuous information as to his movement left or right and used the on-shore targets to correct for movement upstream or downstream of the cross-section during the period of measurement at each station. This system proved unsatisfactory as the time lag of information from shore to boat delayed position corrections by the pilot. This system also could not indicate accurately how far, in feet, the boat was actually moving off position.

For measurements 71-4 through 71-11, the MRB-201 Tellurometer, an electronic distance-measuring system specifically designed to measure distances from fixed points to moving vessels, was incorporated in the system. This instrument depicted in Figures 6 and 7, operates on the standard Tellurometer principle. A carrier is transmitted in the S-Band,

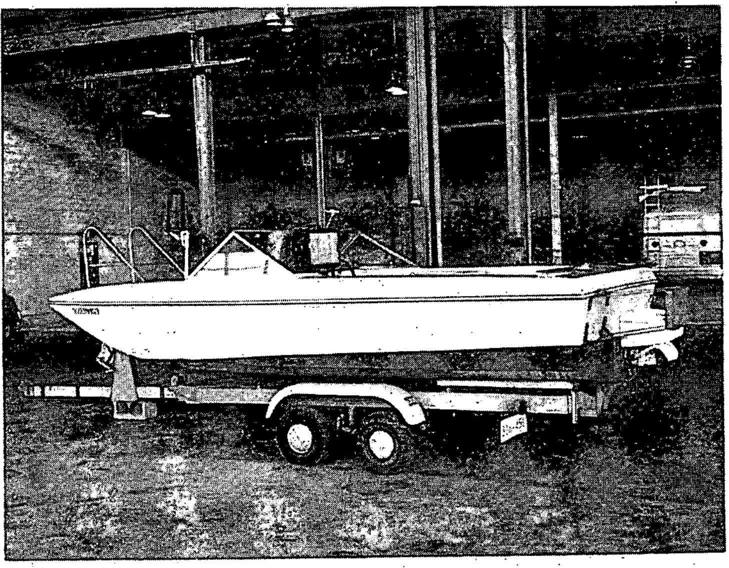


Figure 3. The Water Survey of Canada's fibreglass jet boat.

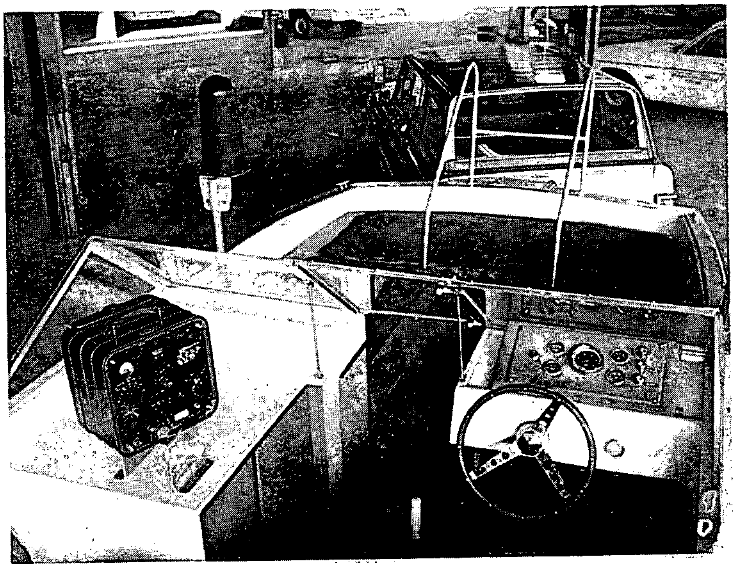


Figure 4. A view of the jet boat showing boat controls, tellurometer and omni-directional antenna.

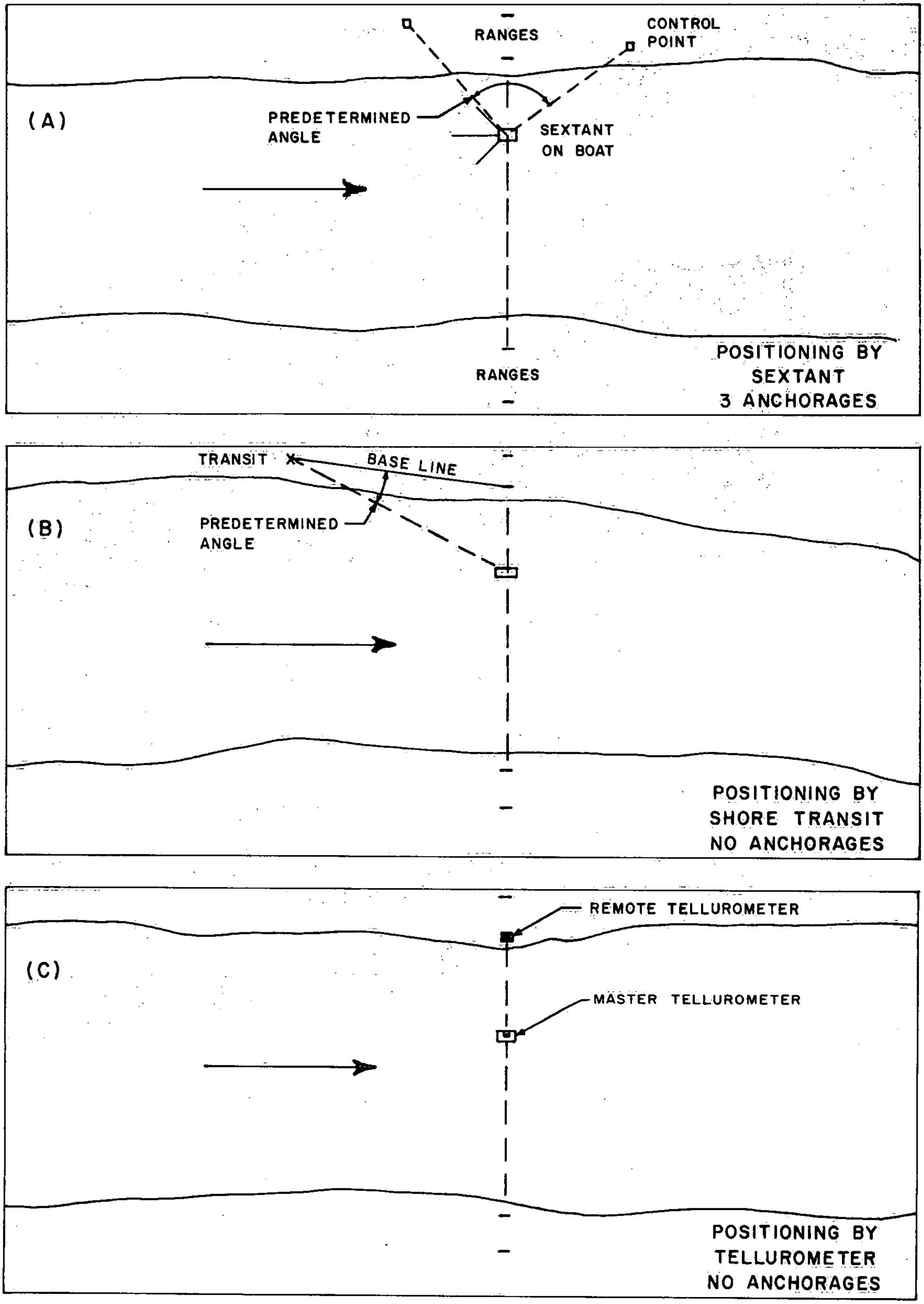


Figure 5. Different methods of positioning boat on range during a discharge measurement.

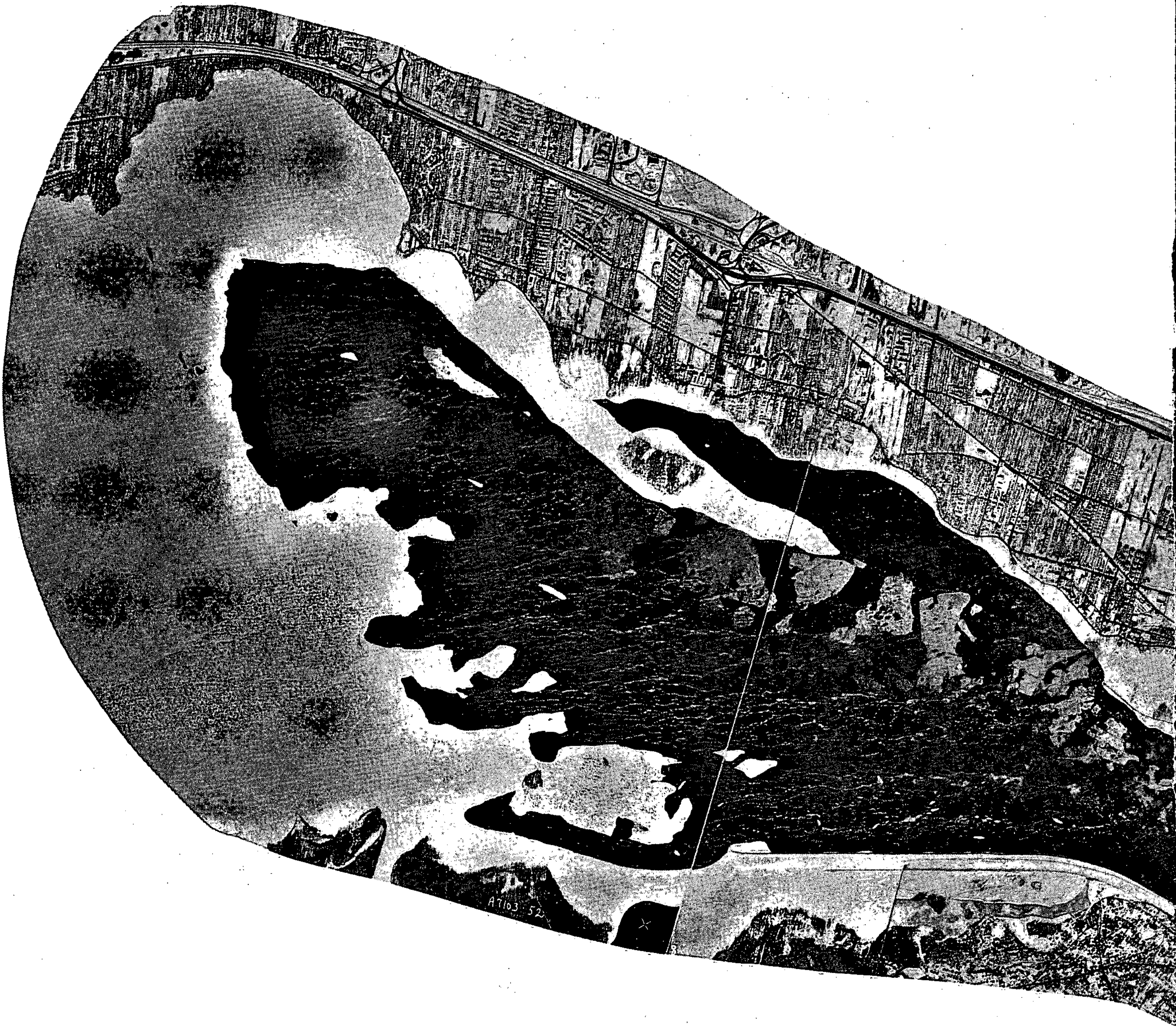
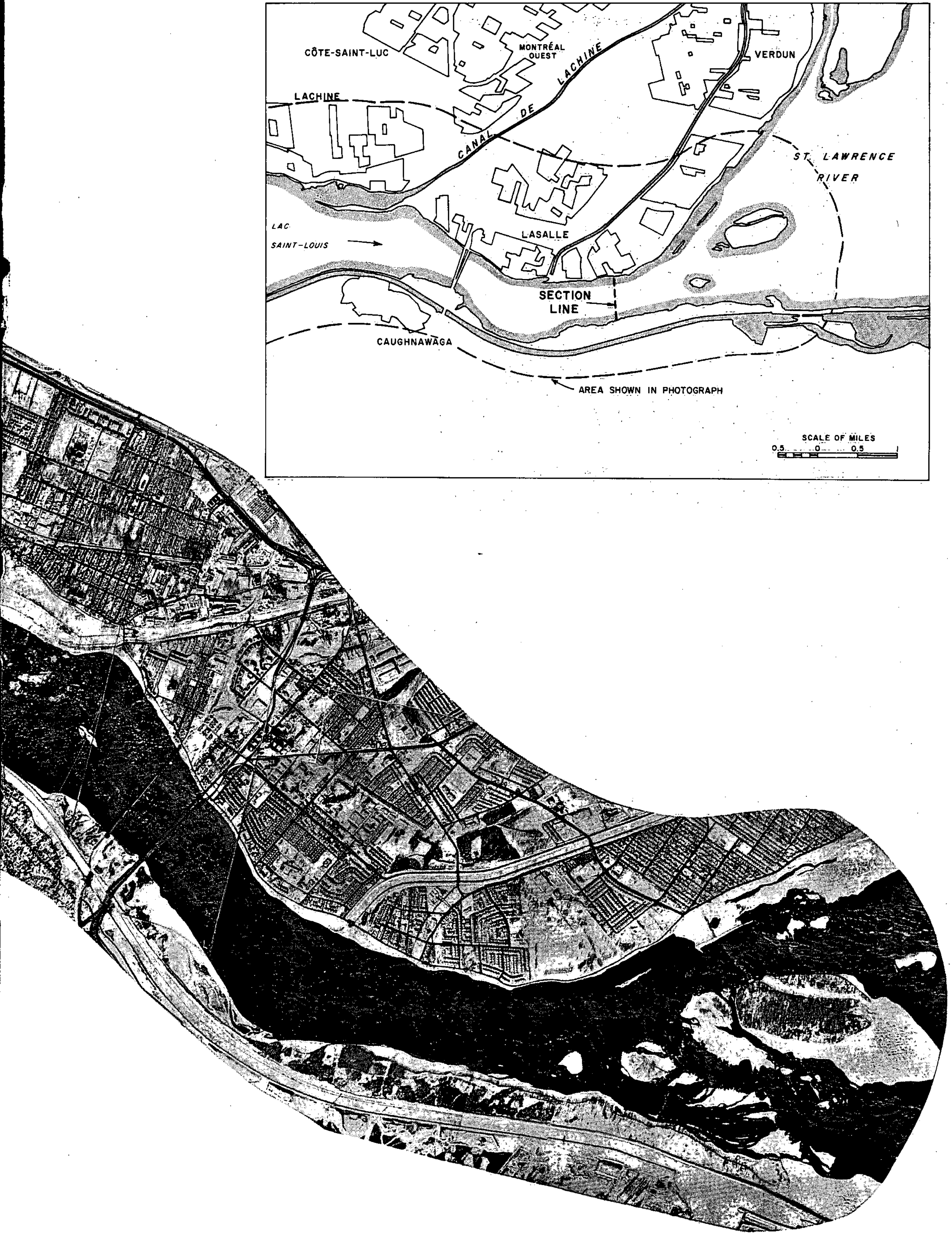


Figure 6. Ice conditions at the Ville La Salle metering site in January 1971.


CÔTE-SAINT-LUC
MONTRÉAL OUEST
VERDUN
LACHINE
CANAL DE LACHINE
ST. LAWRENCE RIVER
LAC SAINT-LOUIS
LASALLE
SECTION LINE
CAUGHNAWAGA
AREA SHOWN IN PHOTOGRAPH
SCALE OF MILES
0.5
0
0.5
1

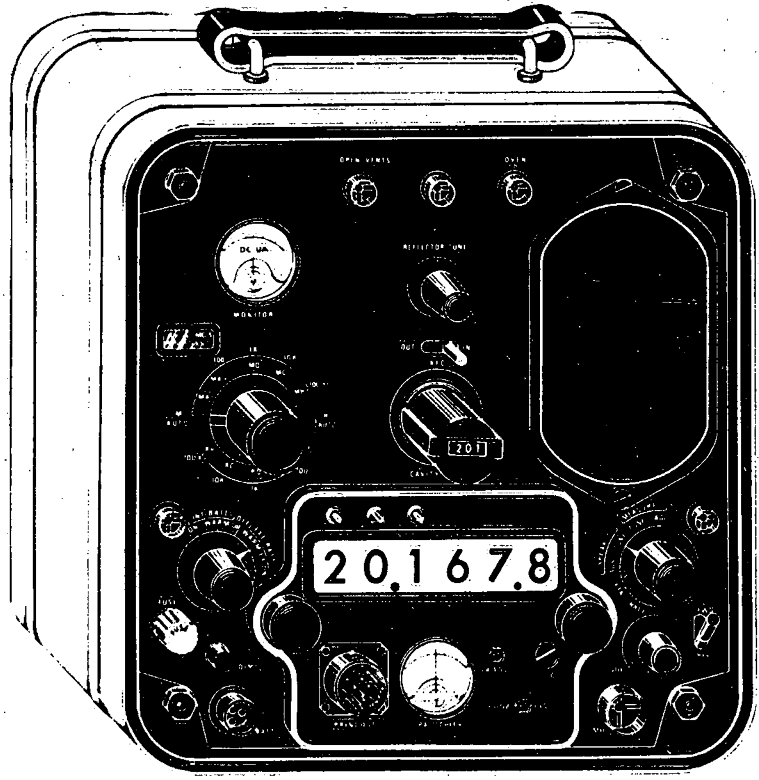


Figure 7. Tellurometer MRB 201 master unit with digital display.

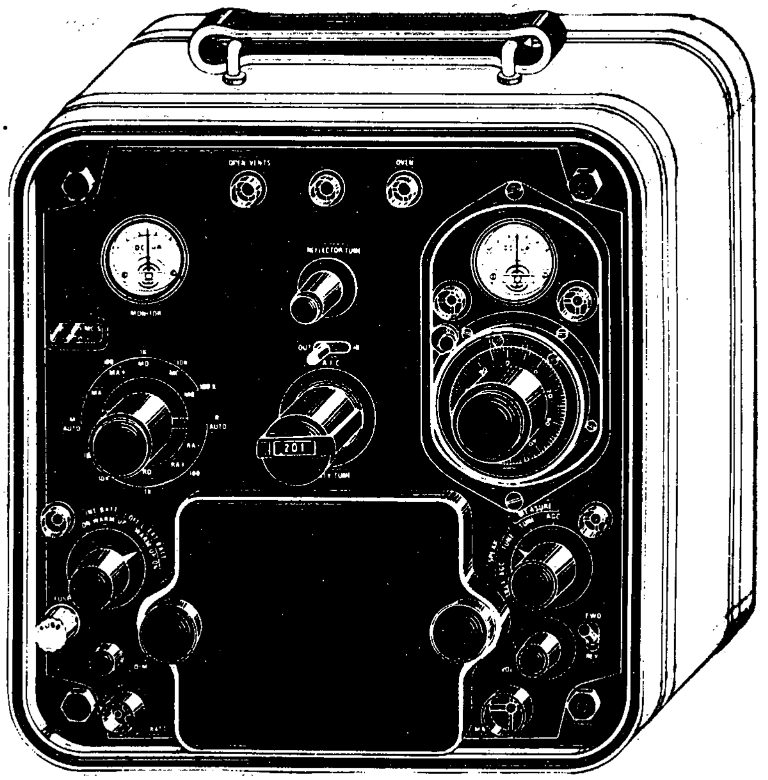
a microwave carrier frequency. This is processed to carry phase information from master to remote unit. The remote unit automatically receives and retransmits this phase information, also on an S-Band carrier. The master unit receives this information and compares it with the originally transmitted phase information. This comparison is processed to come up with a measure of the distance between the two units. The two independent electronic units were located as follows: the remote (slave) unit, positioned on the north shore at a fixed point and aimed along the section line and; the master unit mounted on the boat and, when properly tuned to the remote unit on shore, gave an instantaneous distance readout in meters on a six-digit, nixie-tube display. This readout varied instantly with an increase or decrease in distance from the slave unit. The accuracy of the unit under dynamic conditions is 1.5 metres with a 0.1 metre resolution. A two-channel digital printer was interfaced with the master unit to record the boat's movement during each velocity observation.

Very high velocities were encountered throughout the measuring section and, in order to obtain accurate soundings, a Bludworth marine model ES 130SS echo sounder was used to determine the bottom profile. The sounder produced a chart trace with a resolution of 0.1 foot. Accurate soundings using a 100-pound Columbus weight would have been extremely difficult to obtain. The echo sounder, in conjunction with the tellurometric system, was used to develop an accurate bottom profile of the cross-section.

A detailed summary of field procedures for measurements 71-4 to 71-11 is outlined in the following paragraphs.

The boat was outfitted for a discharge measurement as follows: boat frame, B reel, meter and sounding weight were assembled and fastened

Figure 8. Tellurometer MRB 201 remote unit.



across the gunwale near the stern of the boat. The echo sounder was positioned near the metering gear enabling the instrument man to visually determine his station depth from the chart trace if necessary. The transducer was attached to the transom of the boat allowing for quick removal. The tellurometer's master unit was mounted to a solid stand beside the boat pilot. Prior to these operations the tellurometer's slave unit had been positioned over a brass plug on the section line and placed in operation. When all of the equipment had been assembled, tested and calibrated, the boat proceeded to the section line. The pilot took up a position near the section line and the tellurometer master was tuned to the shore unit. The boat then proceeded to Station One which was at a predetermined distance from the slave tellurometer on the shore. The pilot positioned the boat at Station One using the permanently positioned shore ranges as a line of sight indication of his position upstream or downstream of the section line. Distances were constantly called out to the pilot indicating his position in meters along the section line. He had a list of the station distances which he could check at a glance. The pilot had control of the intensity and direction of the water thrust from the jet pump through a foot throttle, hand lever, and his steering. Using these controls he manoeuvered the boat into position at Station One. When he felt the boat was stationary against the current at Station One, he indicated to the instrument man that he was in position and had control of the boat. The instrument man, who had a list of standard soundings for stations one to twenty and had calculated his 0.2 and 0.8 meter settings corrected to the gauge reading prior to the measurement, lowered the meter to the first position and took a velocity observation at 0.8 depth and then at the 0.2 depth. To decrease errors caused by boat movement, the velocity observation was limited to between forty and sixty seconds. While the velocity observations were taken, a constant stream of metric numbers were called out to the pilot by the third man on the boat. The pilot corrected his positon when necessary, using the verbal information and the shore ranges. These corrections are made gradually since quick movement by the boat could affect the velocity observation. If the boat moved suddenly due to a strong surge or if it drifted excessively off position, the observation at that station was repeated. It was found from the digital printer that the average deviation from initial position was within a radius of 8 feet. When the velocity observation at Station One was completed, the boat was moved to Station Two. This procedure was repeated at each station until all 20 predetermined stations were completed.

The cost of equipment (1971 prices) required for this operation was as follows:

Model MRB201 Tellurometer consisting of 1 remote unit, complete, 1 master unit, complete, 1 omni-directional antenna, 1 standard B.C.D. printer with A.C. to D.C. converter	$25,000
1 17-foot fiberglass boat with two-stage Hamilton jet, hydraulic transmission, and V-6 155 H.P. marine engine	6,000
Miscellaneous (shore ranges, batteries, etc.)	500
Metering equipment; electric B-56 reel, meter crane, and related equipment	2,000
TOTAL	$33,500

The Tellurometer has other applications which will justify the expenditure. It is also very useful for establishing horizontal control on reservoir surveys and other baseline surveys.

The cost of the boat is quite flexible as the choice of a boat must suit each individual need. Portability is important as it greatly increases the utilization of this equipment.

COMPUTATIONS

a. Standard areas - an accurate bottom profile of the cross-section was derived combining the digital output from the tellurometer and chart trace of the echo sounder. The chart trace was marked at 10-metre intervals to co-ordinate the soundings with a horizontal distance along the section line. Four independent sounding runs were made along the section line. The soundings were reduced using the section line gauge elevation and plotted. Manual soundings using a 100-pound Columbus weight, less meter, were made at stations 1 to 20 and were also plotted on the profile. The profile was divided horizontally into 20 panel areas 144 feet wide which corresponded to metering stations 1 to 20. Standard soundings for water surface elevation 60.00 feet were derived for each station. The 20 areas were planimetered to elevation 60.00 feet. Standard area tables were prepared to cover the full range of stage.

b. Velocity computations - velocity measurements were taken at 0.2 and 0.8 depths for all 11 measurements. For measurements 71-1 to 71-3 the 0.2 and 0.8 depths were obtained using both the echo sounder and a 100-pound weight. For measurements 71-4 to 71-11 the meter positions were determined from standard echo soundings corrected to the gauge reading prior to the measurement. Standard calculations were employed to determine the mean velocity for each panel area.

c. Stage data - a manual staff gauge was installed near the north shore of the section line. Standard soundings for measurements 71-4 to 71-11 were adjusted to this gauge. The stage component for the stage-discharge relation was obtained from the automatic recording gauge at station 02OA016 (Old Aqueduct Gauge). The gauge has an A-35 Stevens float-type water level recorder interfaced to a telemark; stages are telemetered by a Stevens remote impulse recorder which produces a chart record in the Montreal Area office. The gauge was located on the north shore, approximately 1/4 mile above the metering section. Stage data were obtained from the corrected chart trace for each measurement.

d. Data corrections - a-direction-of-flow survey was carried out in June 1970 employing the droque-transit method in which the path of a partially submerged float is observed. It was decided from the results of this survey that angular flow was negligible for the range of stage encountered. Measurements 71-1 to 71-3 were corrected to the standard areas obtained from the bottom profile. No corrections were made for vertical or transverse velocity because it was not possible to determine coefficients using the data available. This should not imply that corrections should not be considered but, as our prime criteria in this program was to carry out the measurement quickly and with acceptable accuracy, the extra time consuming data collection was eliminated.

Corrections for mean vertical and transversed velocity were applied to measurements taken between 1960 and 1962 from an anchored catamaran on the St. Lawrence River at Lachine, a section four miles upstream from the present measuring site. The total discharge varies by about 2% if these velocity coefficients are applied. It should be noted, however, that the Lachine section was considerably wider (4200 ft.) and was subject to more variable flow patterns than the present section.

e. Discharge data - a breakdown of the results obtained from measurement 71-1 to 71-11 is shown in Tables 1 and 2. Panel velocities and discharges are tabulated for each measurement. Per cent deviation from the stage-discharge curve is listed for each measurement. The panel discharges indicate that some of the individual panels accounted for almost 10 per cent of the total flow. The panel widths were chosen for a previous measurement program by the Catamaran - sextant system during June 1970. The panel widths should have been adjusted but were not because the results from the jet boat-tellurometer system were to be compared to those of the previous program.

TABLE 1

PANEL DISCHARGES - ST. LAWRENCE RIVER OLD AQUEDUCT

	Measurement No.										
	71-1	71-2	71-3	71-4	71-5	71-6	71-7	71-8	71-9	71-10	71-11
DATE	Mar 12	Mar 12	Mar 19	Apr 25	Apr 25	May 1	May 6	May 19	May 26	June 17	June 23
PANEL NO.											
1	5,280	4,770	4,860	9,780	9,660	8,620	7,140	7,460	5,930	3,010	3,160
2	7,080	6,970	5,750	13,000	12,700	11,600	13,000	8,740	10,000	8,170	6,500
3	17,600	17,700	13,900	23,400	23,200	23,800	25,100	20,800	20,900	18,200	17,000
4	12,300	13,700	12,400	18,700	18,500	16,800	18,100	16,300	15,000	14,600	12,700
5	15,300	15,600	14,700	23,700	22,500	23,700	23,700	21,100	19,600	18,200	19,500
6	21,400	21,100	19,700	27,000	27,400	26,700	27,900	24,900	24,000	21,700	19,400
7	17,600	17,700	16,800	24,400	25,300	24,900	28,100	21,900	20,500	19,000	17,400
8	22,800	23,700	21,200	28,200	32,400	32,200	32,100	26,600	26,800	24,400	22,800
9	25,300	25,300	23,800	31,500	35,100	31,200	33,100	28,700	27,100	25,900	23,500
10	20,100	21,000	21,800	28,300	26,400	28,900	27,500	23,600	24,100	20,000	19,000
11	22,300	21,600	21,200	29,400	31,300	27,700	32,400	26,400	24,700	23,700	20,600
12	23,400	22,400	21,500	33,000	26,800	31,100	30,400	27,100	26,800	23,800	21,000
13	19,000	19,800	18,700	29,400	26,200	26,900	29,900	24,700	23,200	20,500	19,200
14	16,600	16,900	17,300	22,400	22,900	23,500	24,100	21,300	18,700	17,000	14,500
15	15,300	15,100	13,800	21,400	22,000	20,100	24,000	17,100	16,700	16,300	15,000
16	14,300	15,400	12,700	22,000	23,000	19,800	21,500	17,000	16,000	16,200	12,300
17	10,400	11,200	8,380	15,200	14,800	15,000	16,900	13,300	12,800	12,200	10,300
18	7,000	8,040	6,930	10,700	11,200	11,500	11,300	9,580	10,000	8,110	7,360
19	1,930	1,930	3,070	5,050	4,990	4,460	5,690	3,630	3,220	2,870	2,040
20	-	-	-	3,180	3,200	2,880	4,010	1,870	1,300	852	399
MEAN G.H.	61.95	61.96	61.94	64.73	64.69	64.52	64.93	63.21	62.91	62.25	61.63
A (000's)	53.8	53.9	54.3	61.9	63.8	60.8	62.4	57.9	56.9	55.4	53.8
Q (000's)	295	300	278	420	419	411	436	362	348	315	286
Deviation from curve 71-3	- 1.0%	- 0.5%	- 6.6%	- 0.5%	- 0.3%	- 0.2%	+ 0.5%	+ 3.1%	+ 3.0%	+ 1.6%	0.0%
MEAN V	5.48	5.56	5.13	6.80	6.58	6.77	6.99	6.25	6.11	5.67	5.31

A - Total section area - ft.
Q - Total discharge - c.f.s.
V - Mean velocity - f.s.

TABLE 2

PANEL VELOCITIES - ST. LAWRENCE RIVER AT OLD AQUEDUCT
(MEAN OF 0.2 AND 0.8)

	Measurement No.										
PANEL NO.	71-1	71-2	71-3	71-4	71-5	71-6	71-7	71-8	71-9	71-10	71-11
1	3.46	3.12	3.14	5.07	5.02	4.60	3.65	4.32	3.54	1.88	2.07
2	4.42	4.34	3.54	6.52	6.36	5.38	6.44	4.85	5.73	4.86	4.06
3	6.74	6.80	5.30	7.80	7.73	8.09	8.31	7.42	7.60	6.78	7.31
4	6.19	6.86	6.16	7.84	7.77	7.24	7.52	7.46	7.01	7.07	6.41
5	5.31	5.42	5.06	7.26	6.90	7.36	7.19	6.86	6.49	6.15	6.77
6	6.78	6.66	6.18	7.76	7.72	7.62	7.78	7.42	7.26	6.70	6.12
7	5.06	5.08	4.79	6.29	6.54	6.52	7.20	5.96	5.64	5.33	4.99
8	6.18	6.42	5.72	6.93	7.96	8.00	7.82	6.84	7.00	6.48	6.19
9	7.00	7.01	6.56	7.87	8.77	7.90	8.21	7.54	7.22	6.48	6.19
10	6.49	6.78	7.01	8.12	7.58	8.40	7.82	7.16	7.42	6.29	6.13
11	6.32	6.12	5.97	7.52	8.01	7.18	8.21	7.09	6.74	6.57	5.86
12	6.00	5.74	5.48	7.68	6.26	7.33	7.04	6.62	6.63	5.98	5.40
13	5.56	5.78	5.42	7.71	6.86	7.14	7.78	6.82	6.49	5.85	5.62
14	5.41	5.50	5.59	6.48	6.62	6.91	6.92	6.53	5.83	5.42	4.72
15	5.34	5.26	4.78	6.58	6.78	6.28	7.38	5.57	5.55	5.55	5.26
16	4.30	4.60	3.78	5.90	6.18	5.38	5.73	4.82	4.59	4.75	3.70
17	4.16	4.50	3.33	5.26	5.12	5.30	5.80	4.94	4.84	4.75	4.14
18	3.33	3.82	3.26	4.27	4.48	4.70	4.50	4.16	4.46	3.72	3.50
19	1.80	1.80	2.81	3.45	3.42	3.16	3.82	2.86	2.84	2.50	1.91
20	-	-	-	3.26	3.30	3.20	3.97	2.61	2.00	1.55	2.25

f. Stage-Discharge Curve - a best fit curve designated 71-3 based on measurements 71-1 to 71-11 and corresponding Old Aqueduct stage data is shown in Figure 9. A ± 3% deviation band was drawn on curve 71-3 to indicate the proximity of measurements 71-1 to 71-11 to the mean curve. Figure 10 portrays curve 71-3 in comparison with curves 1955-1 and 1956-2, based on over one hundred Mercier Bridge measurements.

OBSERVATIONS

A series of 11 discharge measurements was obtained between March 12 and June 23, 1971 employing the jet boat-tellurometer technique. The measurements were taken under varying weather conditions and through a 3.30-foot range of stage corresponding to a change in flow of 158,000 cfs. The following observations were made on the performance of the equipment and the technique in general.

The steel-hulled jet boat performed satisfactorily through all measurements. Ice did not damage the hull, nor clog the pump impeller. Some problems were encountered with pan ice being pressed against the intake and creating a power loss. This was overcome by reversing the pump impeller and clearing the intake. The boat was operated in temperatures as low as + 10°F. with no mechanical problems. The boat, which held its position against the current with only momentary drifting caused by sudden surges, was never operated at greater than one-half throttle, even against currents of up to 10 feet per second. The extent of the boat's movement depended primarily upon the skill of the pilot manipulating the controls and anticipating sudden changes in river velocity.

The fiberglass jet boat was not used for the winter (ice) period. Extremely cold temperatures cause fiberglass to become brittle and severe hull damage could result if heavy ice were encountered. Measurements in future will be taken with this boat under moderate flowing ice conditions to determine the durability of the fiberglass hull.

The tellurometer functioned adequately throughout the program. The features of quick assembly and tuning as well as providing instantaneous distance readings on the boat were prime factors in reducing the time of measurement. Problems were encountered with signals reflected from nearby electric transmission towers and buildings as well as the water surface. These secondary signals caused the display readout to flutter at distances over 1,000 feet from the slave unit. This problem has not been solved, but can be largely overcome by proper positioning of the slave unit and tuning both units to the most acceptable frequency.

The velocity observations were consistent through the 40 to 60 second observations. Fluctuating meter counts were not noticeable as might have been anticipated if the boat was moving suddenly against or with the current.

The shore targets were of great assistance in upstream - downstream alignment of the boat. During the first two measurements, this movement was monitored using a theodolite positioned on the north shore marker plug of the section line. The motion of the boat above or below the section line was relayed to the pilot by radio from shore. This procedure was eliminated after the second measurement because the amount of movement proved to be insignificant. Strobe-type lights mounted on the shore targets would prove valuable under conditions of poor visibility.

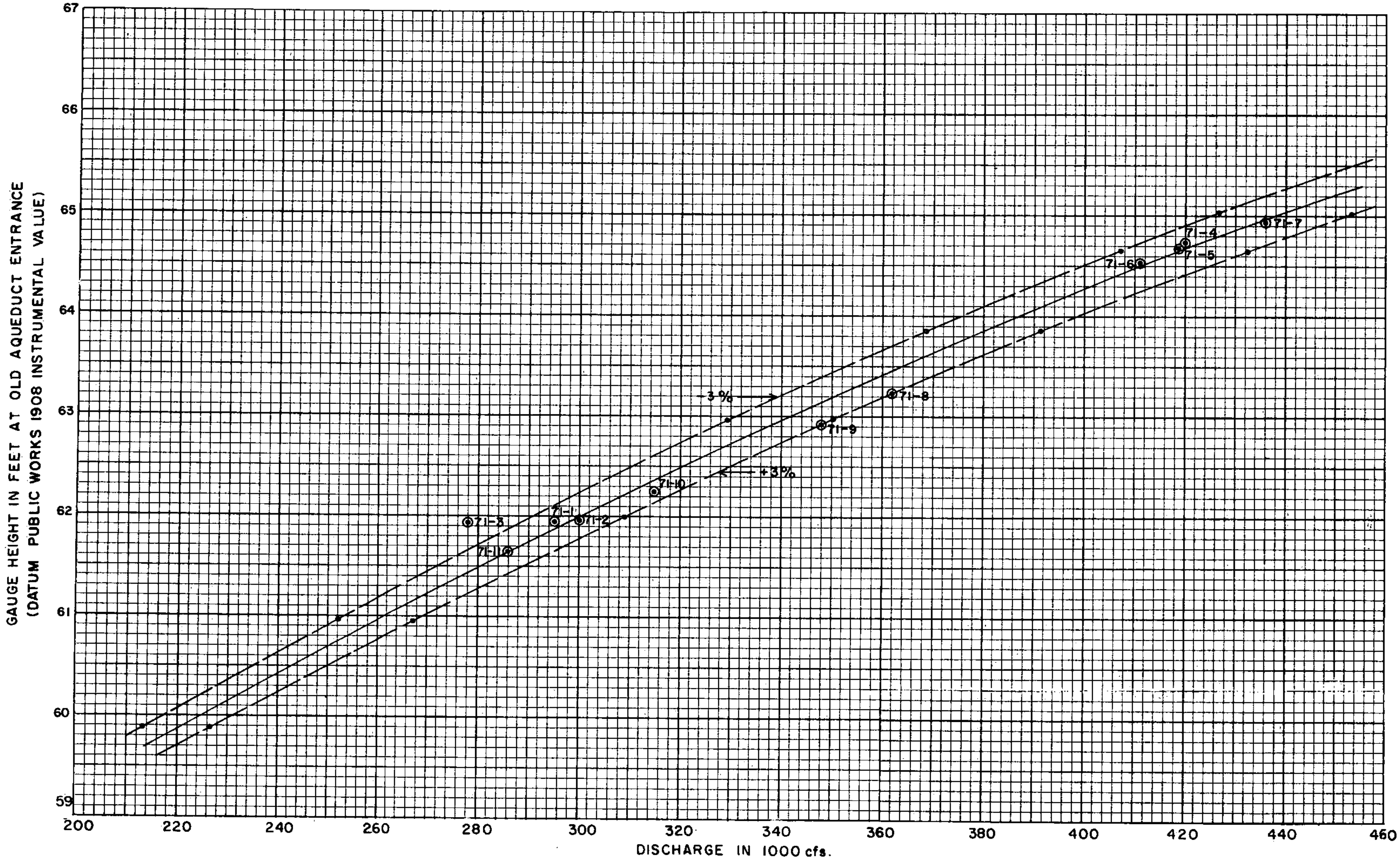


Figure 9. The 1971 stage-discharge (provisional) for Old Aqueduct Gauge showing 3% deviation bands.

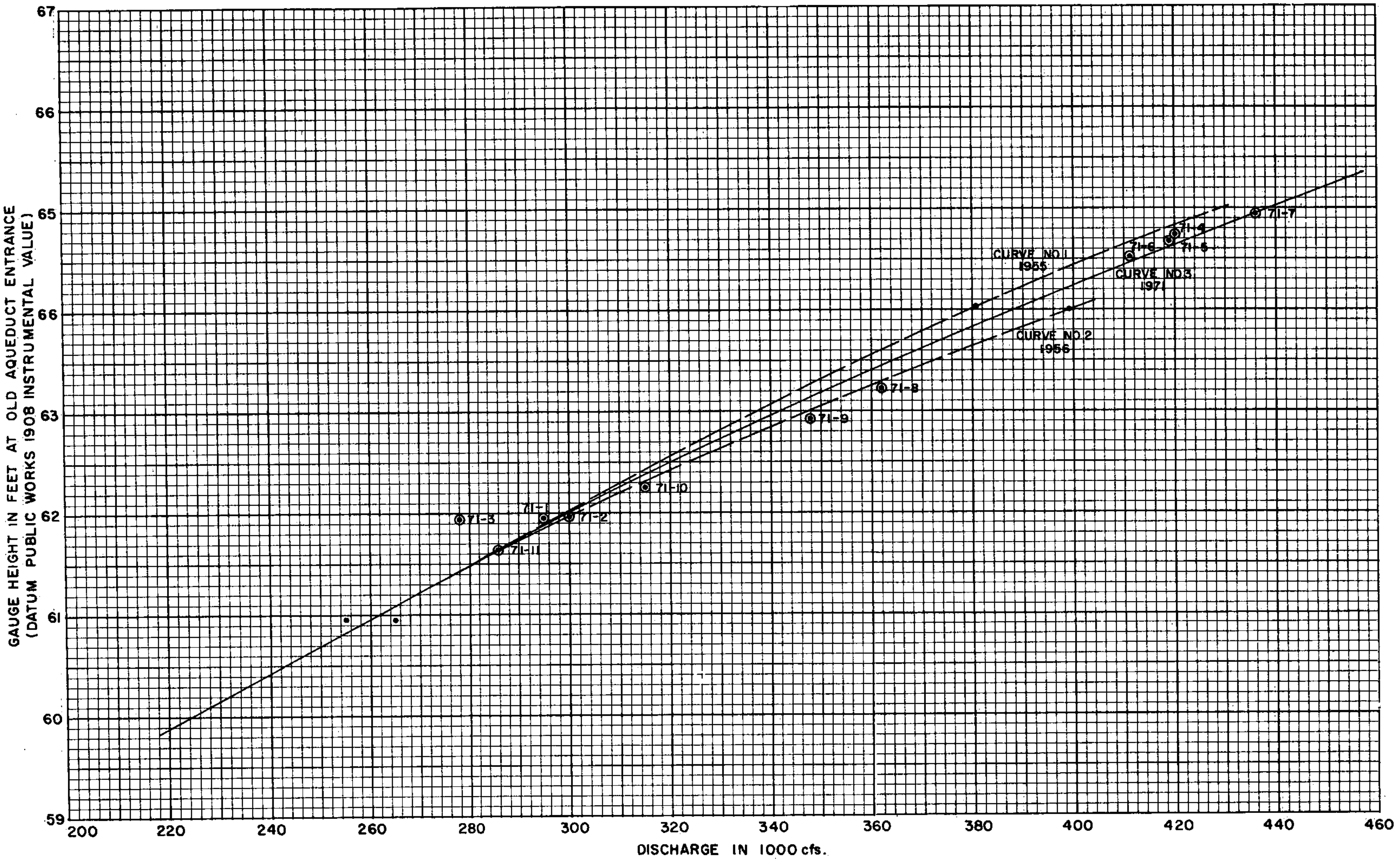


Figure 10. A comparison of the 1971 stage-discharge curve (provisional) for Old Aqueduct Gauge and 1955 and 1956 curves obtained from Mercier Bridge measurements.

It was found that a crew of three men was needed to carry out a measurement - the boat pilot, the instrument man, and a helper. The pilot operated the boat and kept it in position. The instrument man operated the metering gear, tabulated the meter notes, and ensured that the tellurometer was operating properly. The helper relayed the metric digits from the tellurometer to the pilot and kept watch for floating ice and debris. The pilot presently is unable to simultaneously monitor the tellurometer and the shore range targets, and manoeuver the boat. Instrumentation is in the planning stages to allow the pilot to monitor his upstream - downstream position from an indicator in the boat. This could reduce to two the crew required.

There are limitations to the use of a jet boat which discourage its use under certain conditions. It is limited to velocities above 2.5 feet per second. Trials were made on the Ottawa River at velocities below 2.0 feet per second with poor results. The jet boat is difficult to control at low speeds and tends to wander excessively.

Narrow channel widths may also limit the use of this method because, with much narrower channels, the error introduced as the boat moves off the point and nearer to an adjacent point may become more significant. Boat movement will, of course, vary from river to river.

CONCLUSIONS

The method, as outlined, has met the basic criteria of speed with acceptable accuracy. Each measurement was of a duration of between 1 1/2 and 2 hours. Ten of the eleven measurements used to draw discharge curve 71-3 fell within a ±3% band. This is a good indication of the accuracy which can be obtained using this method because the measurements were taken independently of each other under varying conditions, and consistent errors should therefore not be prevalent. Future measurements under open water conditions should fall within this ±3% band if strict measurement procedures are adhered to. The accuracy attained by this method is heavily dependent upon the expertise of the field party. Skills achieved by practice in the operation of all the equipment will determine the accuracy of the results obtained.

It is recommended that further testing be done to determine comparative accuracy of this method with conventional measurements. Simultaneous measurements using the anchoring - sextant method and the jet boat - tellurometer method should provide this information. Further study should also be done on relating varying boat movement to velocity errors. This could possibly be accomplished by interfacing the tellurometer printout with a chart trace of velocity variations. It is also recommended that all equipment employed in the new method be built into a compact instrument package to prevent damage and increase portability. The instrument package can then be adapted to other types of craft, increasing the scope of this procedure.