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Calibration of a 90° V-Notch Weir Using Parameters Other Than Upstream Head

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CALIBRATION OF A 90° V-NOTCH WEIR USING PARAMETERS OTHER THAN UPSTREAM HEAD

by

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FOREWORD

Environmental measurements are required to determine the quality of ambient waters and the character of waste effluents. The Environmental Monitoring and Support Laboratory-Cincinnati conducts research to:

° Develop and evaluate technique to measure the presence and concentration of physical, chemical, and radiological pollutants in water, wastewater, bottom sediments, and solid wastes.

° Investigate methods for the concentration, recovery, and identification of viruses, bacteria, and other microorganisms in water. Conduct studies to determine the responses of aquatic organisms to water quality.

° Conduct an Agency-wide quality assurance program to assure standardization and quality control of systems for monitoring water and wastewater.

This publication of the Environmental Monitoring and Support Laboratory, Cincinnati, entitled: Calibration of a 90° V-Notch Weir Using Parameters Other than Weir Head reports the results of a study for measuring the flow rate using two other parameters, i.e. depth and width of water at the weir notch. Field Sampling personnel should find that these methods permit easier measurement without sacrificing flow accuracy as compared to the often difficult head measurement upstream of the V-notch weir.

Dwight G. Ballinger
Director
Environmental Monitoring and
Support Laboratory

ABSTRACT

Traditional calibration of 90° V-notch weirs has involved the establishment of a head-discharge relationship where the head is measured well upstream of weir drawdown effects. This parameter is often difficult to measure in field weir installations for checking compliance to discharge regulations. Two other parameters are proposed for use as correlation parameters to weir discharge. These parameters are depth and width of flow at the weir notch. Techniques for measuring these parameters are proposed that result in less than 10% error in discharge at the 95% probability level in the laboratory environment.

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ACKNOWLEDGMENTS

The Department of Civil Engineering, West Virginia University, wishes to thank Mr. Edward Berg of the Environmental Monitoring and Support Laboratory, Cincinnati for his interest, advice and support in connection with this project. Appreciation is also extended to the Environmental Protection Agency for their monetary support of this important research.

A special thanks is due Mr. Gary Bryant of the Environmental Protection Agency, Wheeling, West Virginia, office for his help in organizing the subject research investigation and providing field data, information and equipment to assist the laboratory experiments.

SECTION 1

INTRODUCTION

In general, wastewater discharge is regulated by both state and federal organizations under criteria set forth by the Federal Water Pollution Control Act Amendment of 1972 (FWPCA). The purpose of the FWPCA is to "restore and maintain the chemical, physical, and biological integrity of the nation's waters". Towards this end, a permit system has been established to enforce specific effluent standards for municipal and industrial facilities. This system is the National Pollutant Discharge Elimination System (NPDES), so named because a goal of the FWPCA is the elimination of pollutant discharge into navigable waters by 1985.

Monitoring of wastewater quality and quantity is carried on by the NPDES permit holder and is checked by the regulatory agencies, primarily the EPA. Usually, wastewater characteristics are assessed at the end of the discharge pipe. In other words, parameters established in the NPDES permit are usually measured immediately prior to the waste stream discharge into the receiving body of water. Accurate determination of flow rate is required to compute the weight of specific pollutant discharged per unit time. Flow measurement devices include a broad range of classical open channel and pressure conduit devices as well as an indescribable array of individually designed devices and techniques. In open channel flow, weirs or flumes are often the most serviceable and economical measuring devices where sufficient fall exists in the channel and flow rates are within accurate weir measurement ranges. When weirs are properly installed and maintained, flow measurement can be made within ±3 to ±5%.

The scope of this research lies exclusively within the area of the testing of a 90° V-notch weir. The 90° V-notch is typically used to measure flows from 1 to 10 cubic feet per second (c.f.s.). It should be noted that the methods developed herein should be applicable to the whole family of V-notch weirs.

SECTION 2

CONCLUSIONS

The experimental effort involved the attempted calibration of two additional measurement parameters to that of head over a 90° V-notch weir. The calibration tests, including a statistical error experiment, were successful for the parameters; 1) depth of flow at the weir and 2) width of flow at the weir. Based on test statistics and experience with the measurement techniques, the depth of flow at the weir notch was the easiest to obtain with the least probability of significant error. However, both techniques resulted in errors in discharge of less than 10% with a probability of 95%. This level of accuracy is deemed sufficient to approve both techniques for field testing.

Calibration tables for the standard measurement of head over the weir plus depth and width of flow at the notch are included in the Appendix C. These both are for the precision machined brass weir and the field grade, straight cut weir, for units in feet and inches. The tabulated values in the calibration tables are based on the equations fitted to the experimental data. The equation giving the discharge as a function of the flow measurement parameter is of the following form:

$$Q= aH^{b}$$

The regression coefficients a and b are tabulated in the results.

The machined brass weir required two curve fits, one for flows less than 0.06 cfs and one for flows greater than 0.06 cfs. This was required since the weir nappe began to cling to the weir plate at 0.06 cfs. The overlap of these two fitted equations proved to be relatively continuous and presented no problems in compiling the calibration tables. The calibration tables are intended for use in the field where discharges are required as a function of the measurement parameters. In view of outstanding regression analysis curve fits, the fitted equations are sufficient for use with assurance of a high level of accuracy.

SECTION 3

RECOMMENDATIONS

In view of the high level of success achieved in the operation of the experimental apparatus and the calibration of new discharge measurement parameters, it is proposed that continuing efforts be made to adapt these new measurement techniques to other weir configurations and to field conditions. Field tests need to be carried out to determine if any unforeseen problems exist with application of the new techniques that were not uncovered in the laboratory. In addition, the 90^{o} V-notch weir and weir box system were constructed with great care and specifications not encountered in the field. Weir plates for example, are often straight cut from aluminum sheet without the knife edge and precision of machining exercised in construction of the laboratory apparatus (similar to the weir used herein), and installed rather haphazardly. Therefore, it is recommended that experiments proceed with the exsisting laboratory apparatus modified to reflect actual field conditions. This would include the straight cut weir already tested in conjunction with modifications in installation and stilling basin configuration. A detail statistical study can then be conducted to determine the expected field accuracy of actual weir installations, as opposed to carefully tabulated laboratory developed head-discharge relationships. This would involve the recalibration of each of the three measurement parameters investigated in this report. This additional laboratory work would also proceed with other weir configurations such as rectangular weirs.

SECTION 4

LITERATURE SEARCH

In general, a weir is a precisely designed obstruction or dam erected across an open channel for the purpose of defining an accurate stage-discharge relationship. It acts as a flow control and essentially defines flow characteristics at its point of installation. A logical extension of flow regulation by weirs is flow measurement by weirs. Furthermore, weirs of different configurations create different flow characteristics. It was discovered that certain shaped weirs were better suited to measure specific flow rates. The 90° V-notch is suitable for measuring lower flow rates, (0 to 5 cfs) while rectangular and Cipolletti weirs are more useful at higher flow rates (1,2).

Francis (3), in 1852, derived a general formula to describe flow over weirs. This formula was based upon experimental data, and related flow to the head of water upstream of the weir crest. Thompson (4) presented a formula for flow over a 90° V-notch weir in 1858.

<u>Thompson Formula</u> $$Q = 0.305\ H^{5/2} \tag{4.1}$$

where

Q = flow (c.f.s.)

H = upstream head (ft.)

Barr (4) refined this formula in 1907 in order to achieve greater accuracy of flow calculations at very low (less than 0.20 ft.) and very high heads (greater than 3 ft.).

<u>Barr Formula</u> $$Q = 2.48\ H^{2.48} \tag{4.2}$$

Other formulas include the following:

<u>University of Michigan Formula</u> $$Q = 2.52\ H^{2.47} \tag{4.3}$$

<u>Cone Formula</u> $$Q = 2.49\ H^{2.48} \tag{4.4}$$

These formulas were developed for standard 90° V-notch weirs and are based upon experimental data. The Cone formula is the most common relation used in practice and is regarded as more accurate than the others (2).

The use of V-notch weirs in flow measurement has been extensively explored. Interest was due to the simplicity of the weir, its ability to pass corrosive or high temperature liquids without damage, and its accuracy over a given range of flows of from .0 to approximately 5 c.f.s. (5). Measurement of the upstream head could be easily and accurately accomplished.

Standard operating criteria were established, primarily to ensure close agreement between actual flows and derived formulas. It was found that water had to have a smooth surface as it crossed the weir, and that the channel had to be of sufficient depth and width to avoid excessive approach velocities (3). Flows with heads of less than 0.20 feet tended to stick on the weir face, causing a deviation of actual flow from discharge formulas of up to 25% (6). Correction coefficients were established to compensate for conditions where the nappe did not spring free.

After the accuracy of V-notch weirs used as flow measurement devices operating under standard conditions was established, (±1-2%) (7), research began in the area of flow measurement of liquids other than water. Since the 90° V-notch was shown to be the most accurate triangular weir over a wide range of discharges (7), a large portion of this work utilized 90° V-notch weirs for low flow rates. Formulas were developed by Lenz (8) for liquids of varying viscosities. V-notch weirs were also calibrated for corrosive liquids (9), and high temperature liquids (5). As above, the general form of these equations is:

$$Q = aH^b$$

where

Q = flow

H = head upstream of the notch

a & b = coefficients characteristic of specific liquids tested

Techniques for precise weir measurements followed similar formats and utilized similar testing apparatus. The basic testing components consisted of a weir box or flume, weir plate, weighing tank and timing mechanism, and several methods of accurately determining the upstream head. The particular fluid tested was passed through the flume, across the weir, and then into the weighing mechanism or a diversion device. Measurements of weight per unit time were converted to standard flow units (c.f.s.) and compared to corresponding measurement of head. While velocity profiles were established for very high flow rates, the major parameter investigated was the upstream head. Correcting coefficients were established for variations in the weir plate such as roughness, angle of notch, sharpness of edge, and irregularities.

The purpose of this study centers on the exploration of weir calibration parameters other than the upstream head. Search of past work suggests that the sole means of V-notch weir calibration was the upstream head. Other work is not reported specifically because the other measurements more than doubled the error as compared to upstream head.

During the course of this investigation, several sources were used to develop the apparatus design and testing procedures. As an example, Schoder's paper (10) dealt with the testing of weirs ranging from 0.5 to 7.5 feet in height. Heads ranged from 0.012 to 2.75 feet, and channel widths ranged from 0.9 to 4.2 feet. The major thrust of this investigation was the derivation of a more universal weir discharge formula which would include corrections for the condition of the weir crest, channel characteristics, and differing methods of head measurement.

While the above work dealt largely with rectangular weirs, several features of the testing apparatus and procedure were applicable to this project. Water entered the weir box from a source of constant head, passed through a series of baffles, and into a weighing tank by way of the weir. A diversion device was incorporated to allow the weighing tank to empty between runs. Measurement of the head was done by hook or plumb-bob gauges mounted in the weir box or in a stilling well. A float gauge was often used to measure variations in stage, and was located in a stilling well. The basic measurement was weight per unit time. This measurement was derived from the manual operation of a stopwatch and the observation of a scale. Weir crests were brass or painted steel, with bevels ranging from 30° to 60°. Water temperature was recorded, along with general testing conditions. Zero head was established by a carefully repeated procedure. A hook gauge was read at the weir crest with the water exactly level with the crest or notch. Simultaneously, gauges in stilling wells were read. The procedure was repeated until consistent readings were obtained.

During a test run, the head was measured with the stilling well gauges. Water was allowed to flow across the weir and into the weighing tank until the tank was close to full. The flow was then diverted and the weight difference and time interval recorded. The data were analyzed to provide comparison with existing formulas, and to derive correction coefficients for discharge variation resulting from variables such as crest condition, channel width, etc.

The general apparatus and method of testing used in this study are very similar to those described in the literature above. This was done to duplicate previous data using similar methodology, and to derive new data using accepted methods of research.

Of further interest in the literature is a table in King's <u>Handbook</u> (1), pp. 50-51, which tabulates errors in weir discharge resulting from errors in the measurement of head. Discharges between 0.05 and 1.00 c.f.s. over a 90° standard V-notch weir would have the percent error shown in Table 1. This information is significant in that it indicates that field measurement procedures may produce significant errors in subsequent flow calculations.

TABLE 1. ERROR IN WEIR DISCHARGE AS A FUNCTION OF ERRORS IN THE MEASUREMENT OF HEAD (KING AND BRATER(1))

Discharge (c.f.s.)	Error in Head (ft)	Percent Error in Q
0.05	0.001	1.2
	0.005	6.1
	0.010	12.2
0.10	0.001	0.9
	0.005	4.6
	0.010	9.1
0.50	0.001	0.5
	0.005	2.4
	0.010	4.8
	0.050	23.8
1.00	0.001	0.4
	0.005	1.8
	0.010	3.6
	0.050	18.0

SECTION 5

CURRENT PRACTICE

Difficulties have arisen in securing accurate measurements of the head of water acting on the weir for the purpose of checking for proper installation and operation. Weirs may be located in inaccessible places or placed in the outfall of culverts or pipes. Standard practice requires the measurement of the upstream head at a distance of at least four times the upstream head from the weir face. This is to preclude faulty depth measurements which may result from drawdown and contraction of the water surface as the flow accelerates through the notch. The most convenient instantaneous technique, used by EPA to check discharge rates at the weir face (when hook or staff gages are not installed), is the use of a carpenter's square to measure head. The longer side of the square is inserted in the notch and projected into the flow. A single bubble hand held level is then used on the shorter side of the square to plumb it in the center of flow (see Figure 1). Depth of water is then read from the square in inches. This reading is converted to feet and the appropriate discharge computed from tables.

Several disadvantages seem to exist in using this system of measurement. Concurrently with leaning over the nappe of the weir, the individual doing the testing has to place the square in the notch, adjust the level bubble so that the square is plumb, and read the water depth as accurately as possible. Besides from being physically difficult to accomplish, the water depth may or may not be taken at the prescribed distance from the weir face, since the square may not extend past the drawdown area upstream of the weir plate. The lack of sensitivity of a single bubble level could further compound error. Thus the error inherent in the technique might exceed 1/8 inch, (0.010 feet). At higher flow rates, an error of 1/2 inch, (0.42 feet), would not be unreasonable. Errors of this nature would create an excess of 10% error in flow calculation. Since pollutant discharge is directly proportional to flow, a 10% error in flow would create a 10% error in discharge pollutant quantities. Therefore, another parameter of calibration for 90° V-notch weirs is desirable in order to attain a higher degree of accuracy in flow measurement, and to facilitate the actual measurement technique.

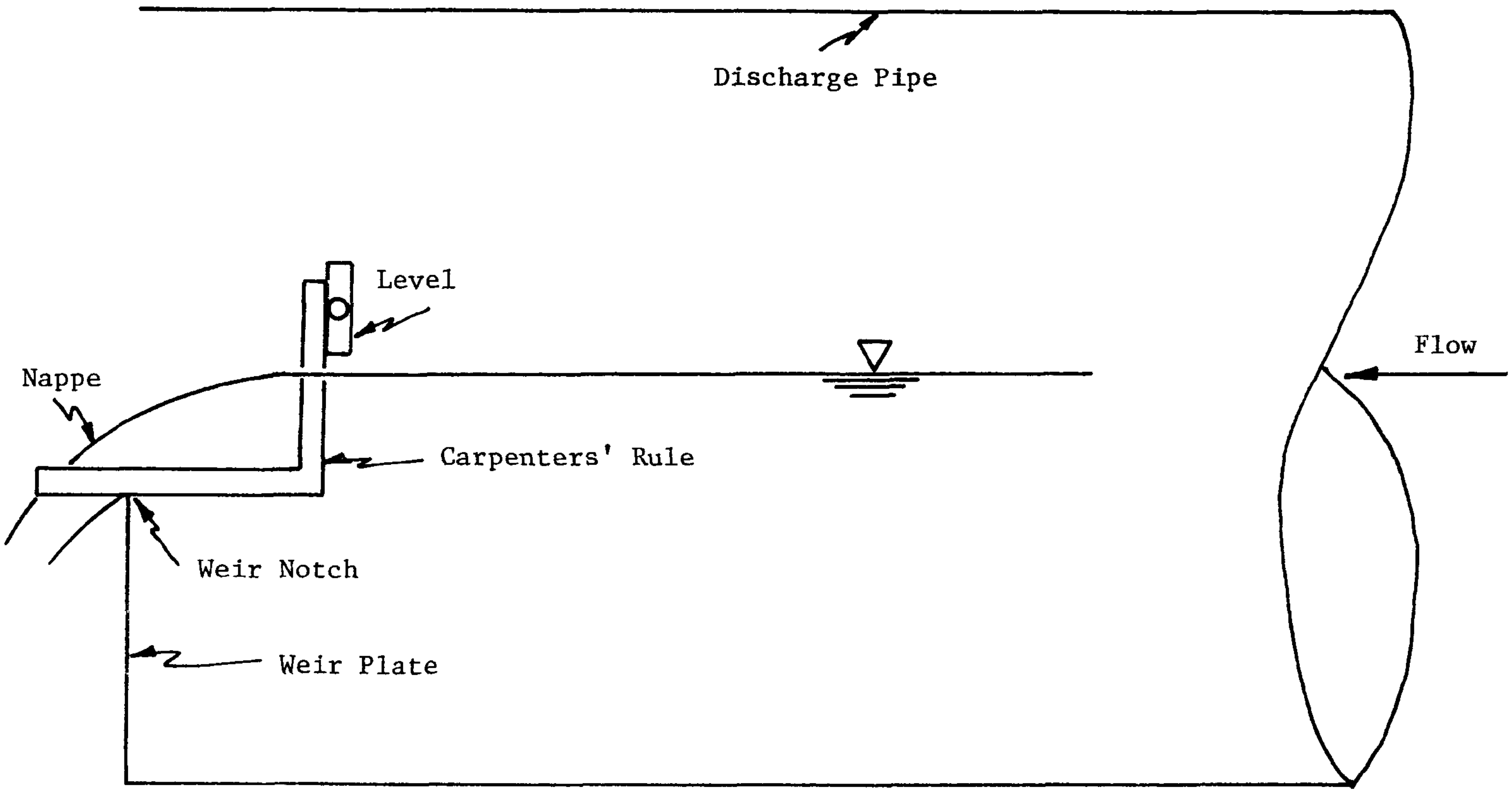

Figure 1. Carpenters' Square Technique Used by EPA

SECTION 6

EXPERIMENTAL APPARATUS

During the design phase of the project, it was decided that the experimental apparatus should be constructed to duplicate previous laboratory weir calibration apparatus and to satisfy installation requirements for standard weirs as specified in design manuals (2). These criteria include the following items:

(1) The upstream face of the bulkhead should be smooth and in a vertical plane perpendicular to the axis of the channel.

(2) The upstream face of the weir plate should be smooth, straight, and flush with the upstream face of the bulkhead.

(3) The thickness of the crest, measured in the direction of flow, should be between 0.03 and 0.08 inch. The sides of the notch should be inclined 45^o from the vertical.

(4) The upstream corners of the notch must be sharp. They should be machined or filed perpendicular to the upstream face, free of burrs or scratches, and not smoothed off with abrasive cloth or paper. Knife edges should be avoided because they are difficult to maintain.

(5) The downstream edges of the notch should be relieved by chamfering if the plate is thicker than the prescribed crest width. This chamfer should be at an angle of 45^o or more to the surface of the crest.

(6) The distance of the crest from the bottom of the approach channel should preferably be not less than twice the depth of water above the crest and in no case less than one foot.

(7) The minimum distances of the sides of the weir from the sides of the channel should be at least twice the head on the weir, and should be measured from the intersection points of the maximum water surface with the edges of the weir.

(8) The overflow sheet (nappe) should touch only the upstream edges of the crest and sides.

(9) Air should circulate freely both under and on the sides of the nappe.

(10) The measurement of head on the weir should be taken at the difference in elevation between the notch and the water surface at a point upstream from the weir a distance of four times the maximum head on the weir face.

(11) The cross-sectional area of the approach channel should be at least 8 times that of the overflow sheet at the crest for a distance upstream from 15 to 20 times the depth of the sheet.

Other criteria for weir box construction are in the Water Measurement Manuel (2). Since a typical field installation weir was also calibrated, the above criteria for weir plate construction was not followed for tests simulating field conditions.

The experimental apparatus consists of three major systems, the weir and weir box, the water supply system and recirculation system. While these systems are integrated into the whole calibration system, examination of their respective design and construction will provide an adequate description of the entire experimental apparatus. Flow ranges were anticipated to range from 0.0 - 5.0 c.f.s. corresponding to a maximum average flow velocity of approximately 0.2 ft./sec. at 5 c.f.s. The system was designed to accomodate the upper range of flows, and to meet criteria previously outlined.

The first system to be designed and constructed was the weir and weir box system. There were several major objectives to be met during its planning. First, the dimensions of the weir box had to satisfy standard parameters of 90° V-notch weir installation for the upper range of flows. It also had to be large enough to include an adequate turbulence suppression system, and small enough to fit into the lab. The weir plate had to be of corrosion resistant material to limit any corrosive damage to the machined surfaces. It also had to be large enough to contain a notch of dimensions suitable for anticipated flows, and strong enough to resist any deflections that might occur in the bulkhead of the weir box.

The final weir box design was to place 3/4" thick exterior grade plywood over 2" x 10" bracing. The interior box dimensions are 20 ft. long, 7 ft. wide, and 4 ft. deep (see Figures 2 and 3). The floor bracing was placed directly on the laboratory floor. This bracing was placed 12 inches center to center to carry the anticipated maximum load of approximately 250 pounds per square foot. The box sides are reinforced with vertical 2" x 6" struts (see Figure 4).

Care was taken to ensure the watertightness of the box during construction. Prior to assembly, all exterior and interior wood surfaces were sealed with a wood preservative. During assembly, all joints and seams were calked with a butyl rubber compound. After assembly, all interior joints and seams were covered with fiberglass mat and resin. The exterior edges were reinforced with 1-1/4" x 1-1/4" x 1/8" angle iron notched into the bracing. To prevent any movement of the structure as a whole, both ends of the box are

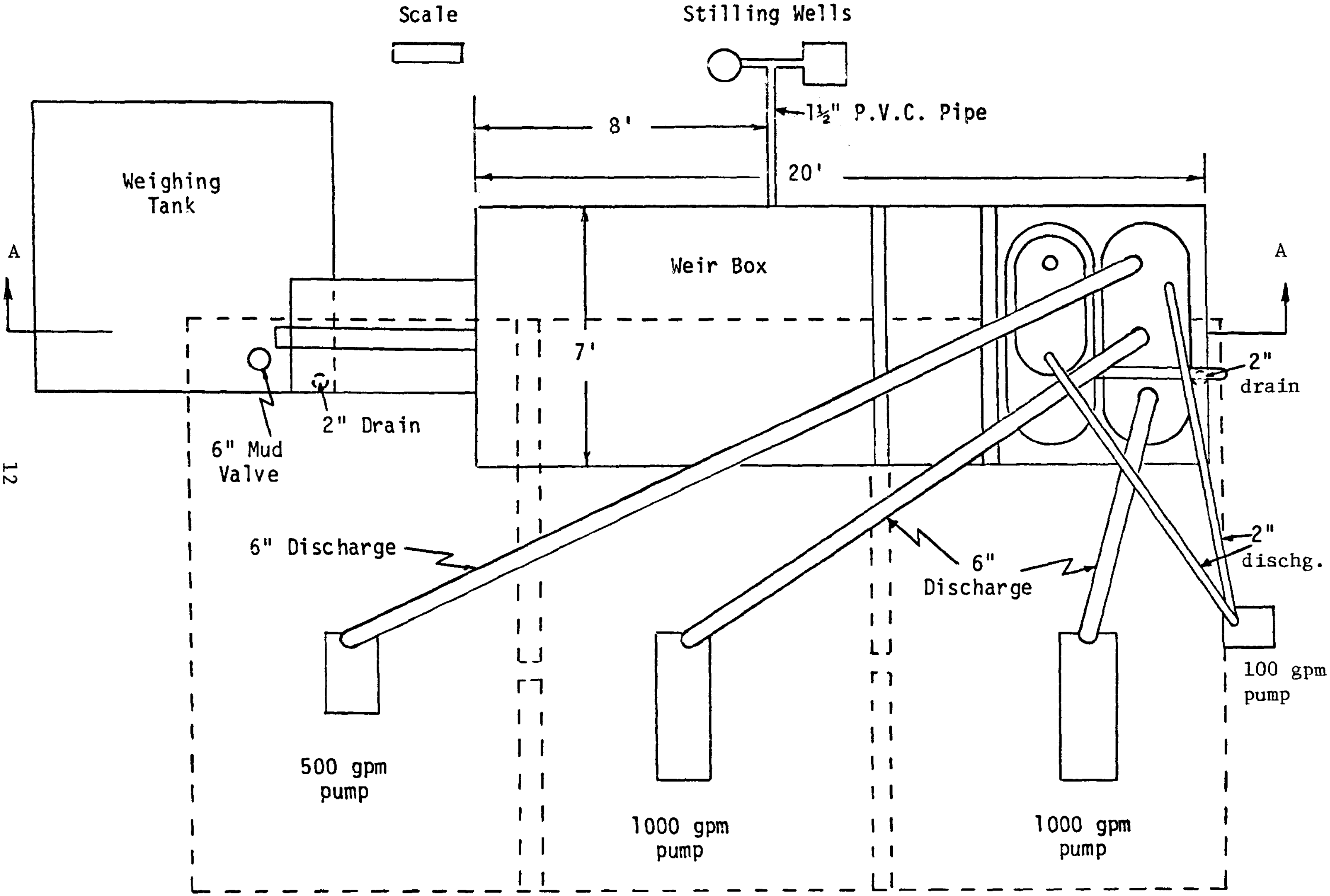

Figure 2. Plan View of Testing Apparatus

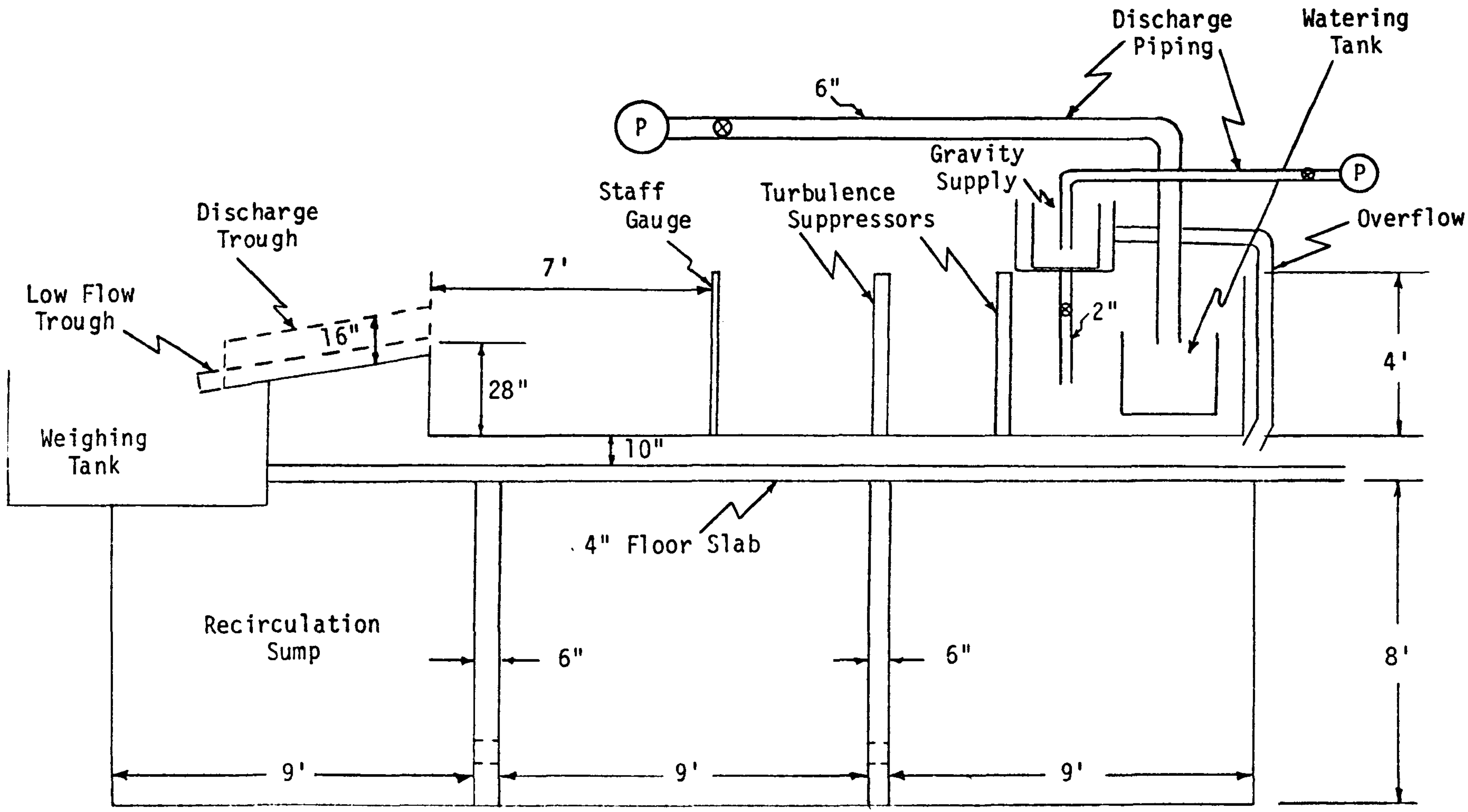

Figure 3. Section A-A of Plan View Shown in Figure 2

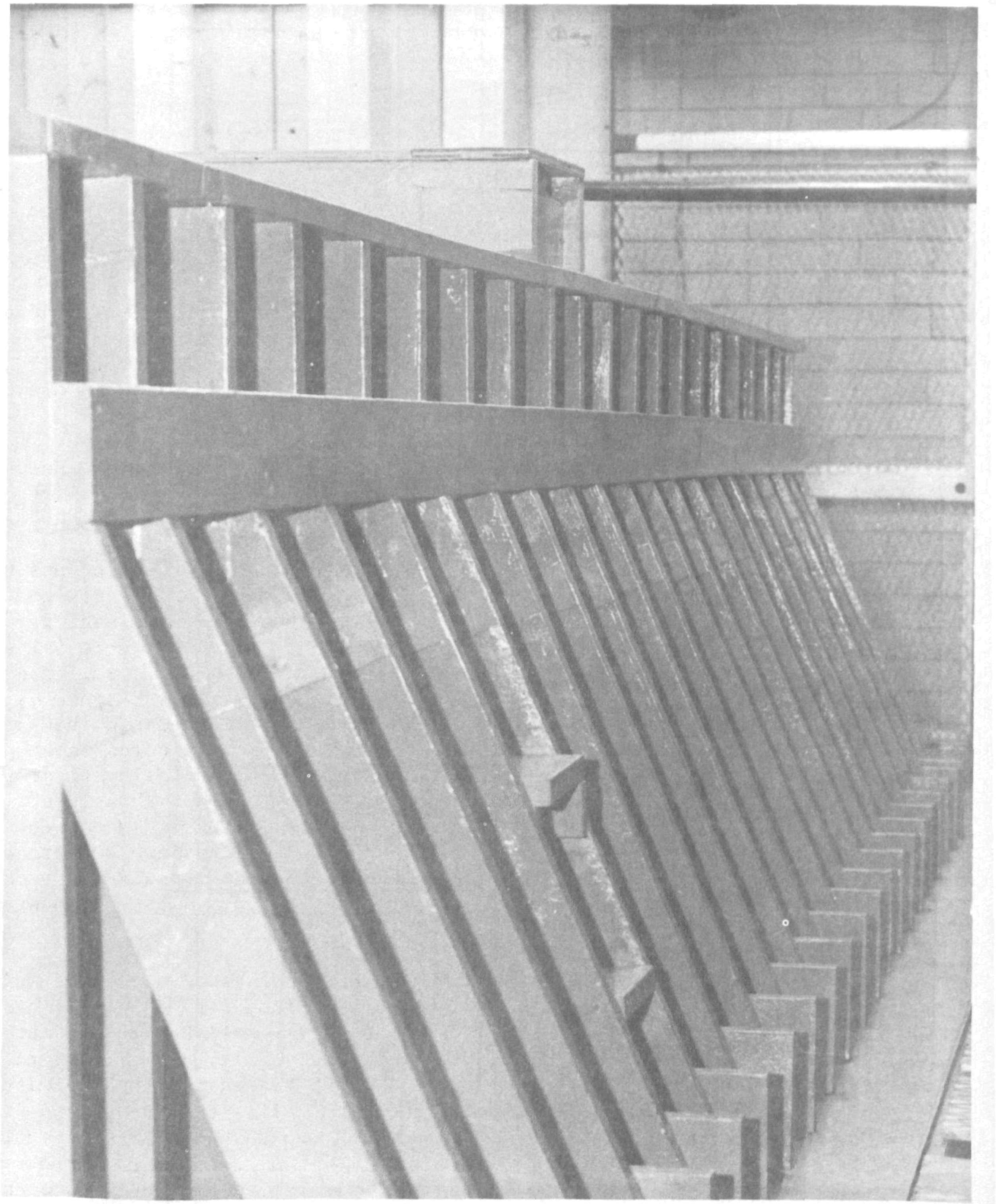

Figure 4. View of Weir Box Side Bracing

fastened to 4" x 4" x 1/4" angle iron which is mounted to the lab floor with anchor bolts. When assembly was completed, the box interior was primed with exterior primer, then painted with two coats of epoxy enamel.

The precision machined weir plate is 1/4" thick brass measuring 30" x 36". The notch is 16 inches deep with an upstream crest width of 1/16" (see Figure 5). A machined chamfer of 30^{o} was chosen as an appropriate bevel. The plate is mounted to the bulkhead of the box with woodscrews. The box exterior has extra bracing at the points of attachment to help insure adequate stiffness. After installation, a smooth bead of calking was applied around the plate to seal the interface and to preclude turbulence formation.

Gary Bryant of the EPA Wheeling, West Virginia field office supplied an aluminum weir plate of the type encountered in field applications. The dimensions and configuration of this weir plate is shown in Figure 6. The weir notch was straight cut (no bevel) from 1/8 inch thick aluminum plate. This weir plate was also to be used in the calibration experiments.

Water is supplied to the system from three 8,078 gallon concrete sumps situated underneath the lab floor. In turn, they are filled by a 2" line carrying city water. The sumps are connected by 8" lines.

The four pumps were selected to provide flexibility of operation and to cover the selected range of testing. These pumps are mounted directly to the lab floor and are located above the sumps. The basic premise behind pump operation assumed that flow could be regulated by placing a gate valve on the discharge side to choke flow. Two pumps are 1,000 g.p.m. Bell and Gossett pumps with six inch intake and six inch discharge lines (Figure 7). One pump is a 500 g.p.m. Weinmar pump with six inch intake and six inch discharge lines. The fourth pump is a 100 g.p.m. pump with a three inch intake and a two inch discharge line. Intake lines are all steel with attached footvalves. Discharge lines are schedule 40 plastic pipe with solvent weld fittings on the larger pumps, and steel on the small pump. Metal to metal joints are flange or threaded. Plastic discharge lines are supported overhead by hangers connected to ceiling trusses. All the pumps are fitted with 1/4 inch copper priming lines with air relief valves. Figure 8 shows the line of pumps adjacent to the stilling basin.

Water is introduced into the weir box at the end farthest from the weir plate for flows in excess of 0.02 c.f.s. Overhead lines turn downward into a 190 gallon galvanized tank (Figure 9). The tank was selected to act as a preliminary turbulence suppressor because of its durability and ability to accept surges. The tank is open at the top and perforated on one side with multiple 1-1/2 inch holes. Water leaving the pipes fills the trough and passes through the sieve-like trough wall towards two turbulence suppressors. These suppressors, mounted three feet apart, consist of rubberized horsehair mounted on a wire and wood framework (Figure 10). They fit exactly into the cross-sectional dimensions of the weir box. Rubberized horsehair was selected due to its porosity, durability, and convenience in mounting. This material passes water readily enough to avoid any accumulation of head in the rear of the weir box, dampens wave motion, and effectively straightens flow.

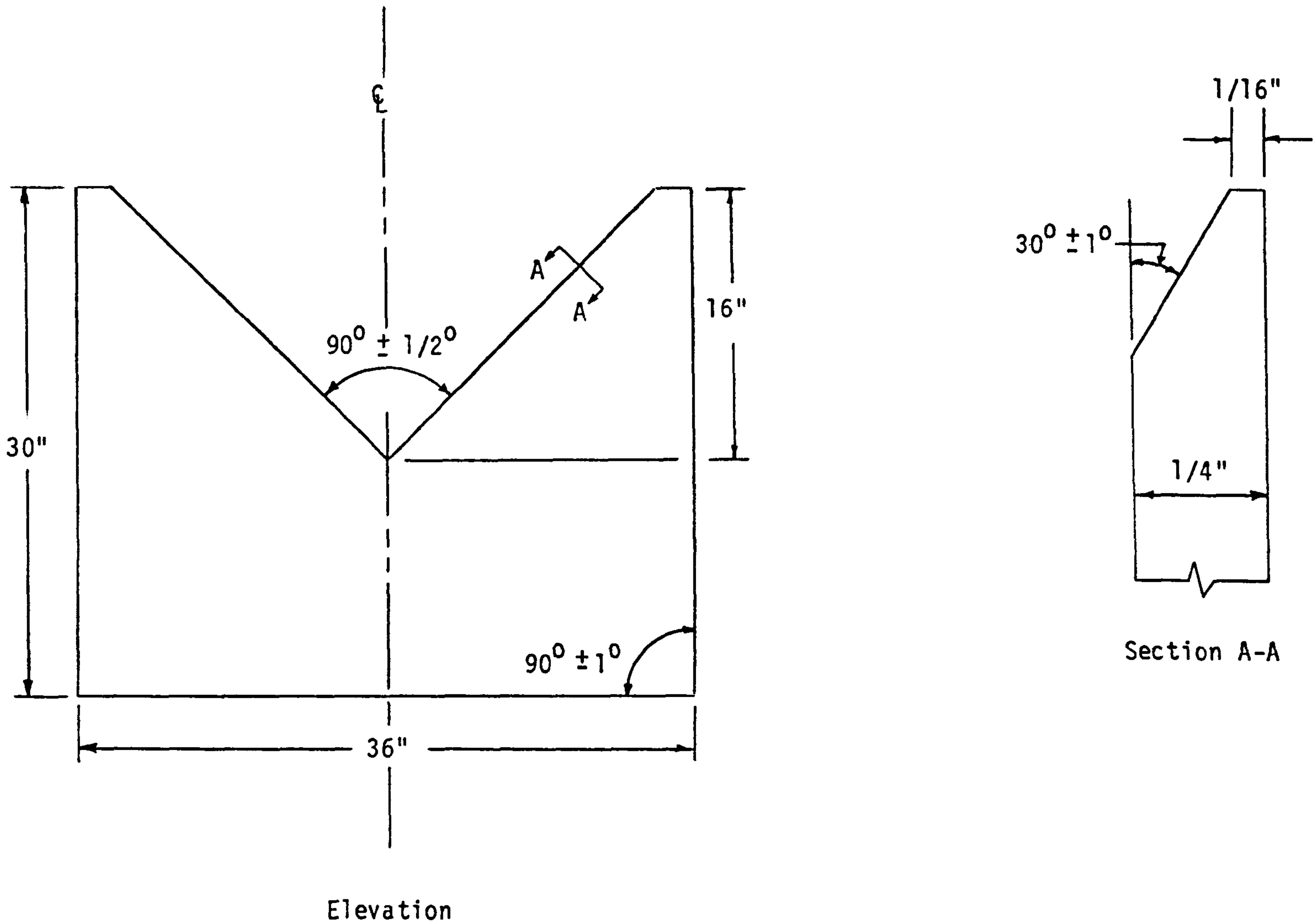

Figure 5. Precision Machined Brass Weir Plate Details

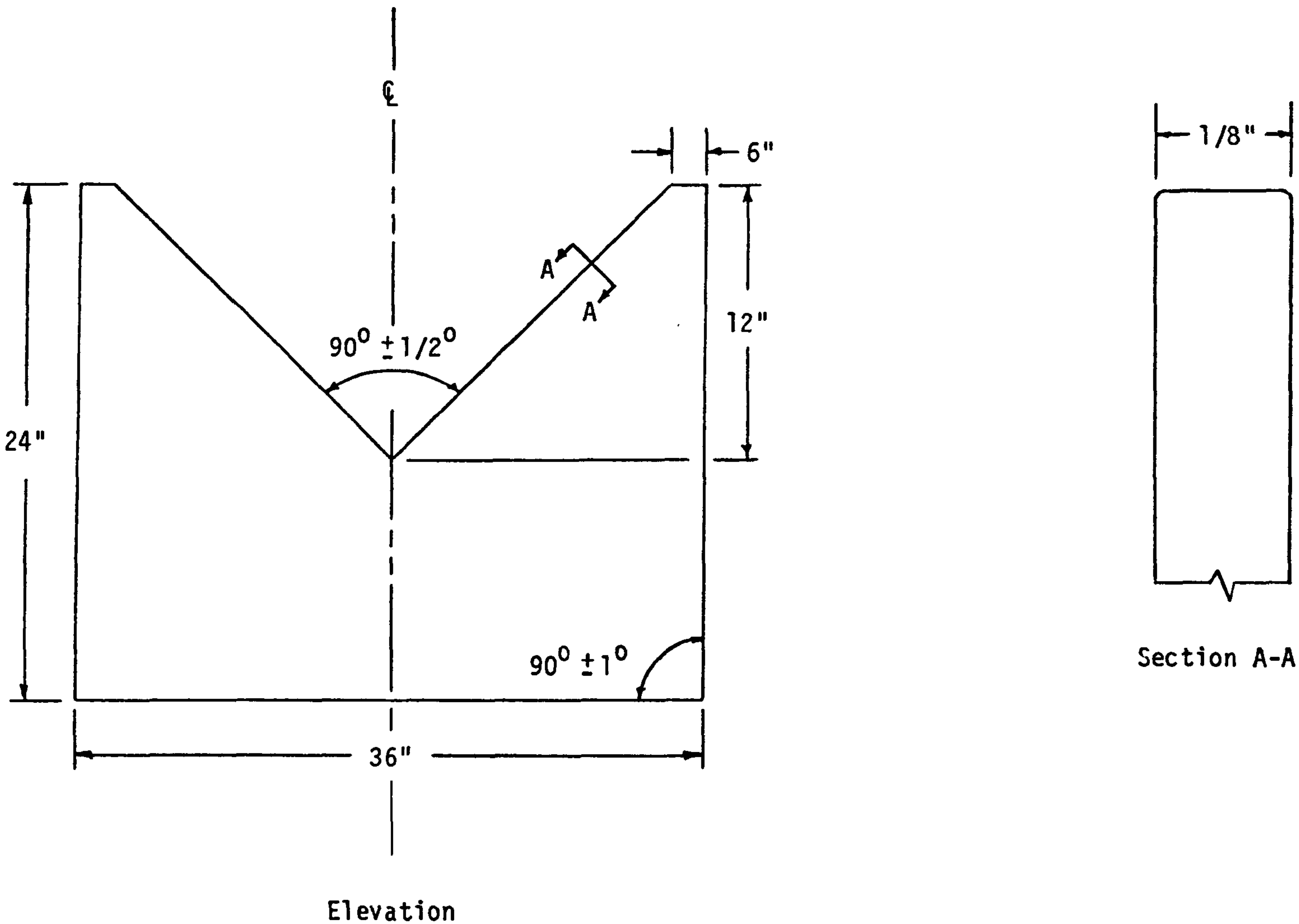

Figure 6. Square-Cut Aluminum Field Weir Plate Details

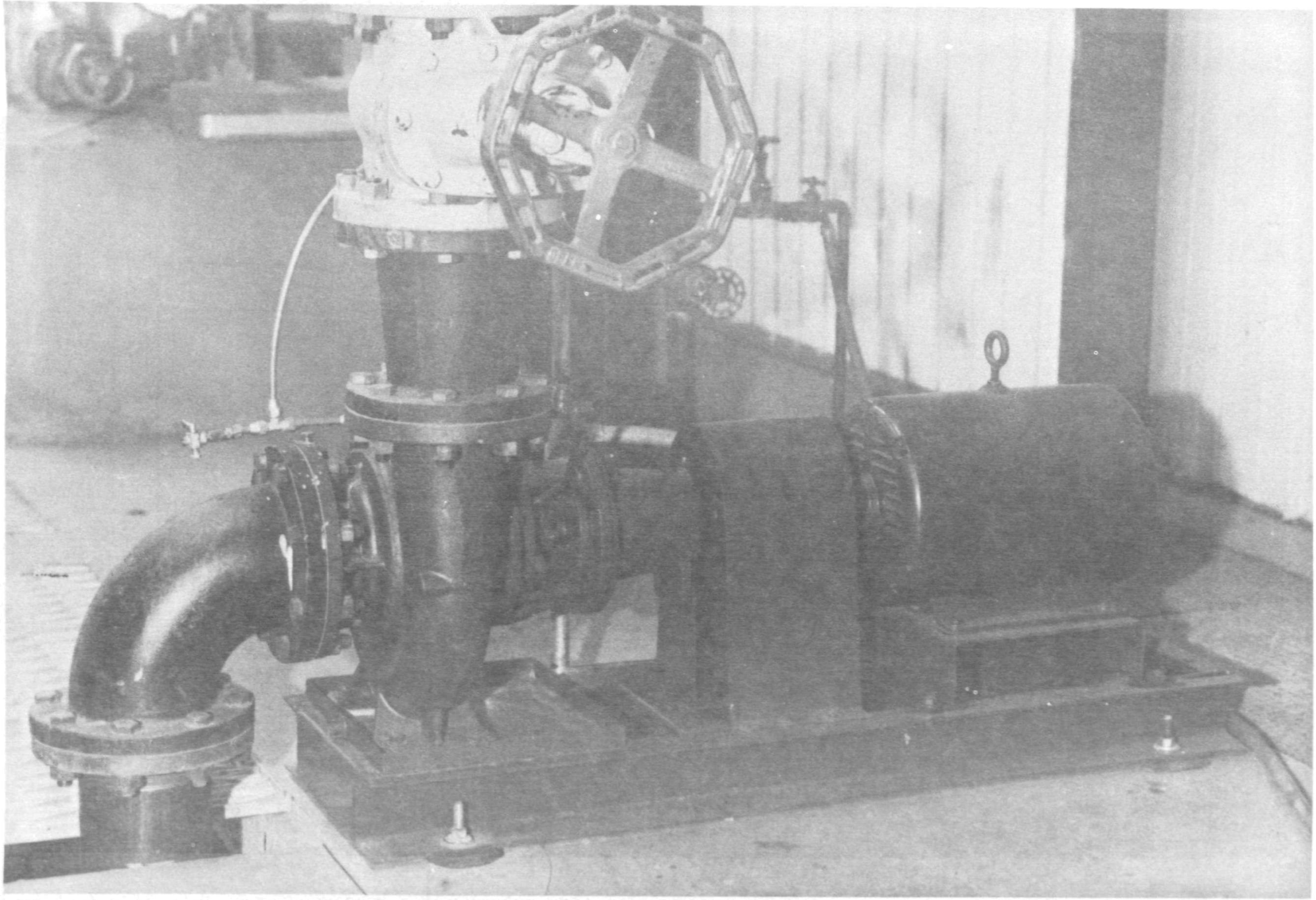

Figure 7. 1,000 gpm Bell and Gossett Pump, One of Two

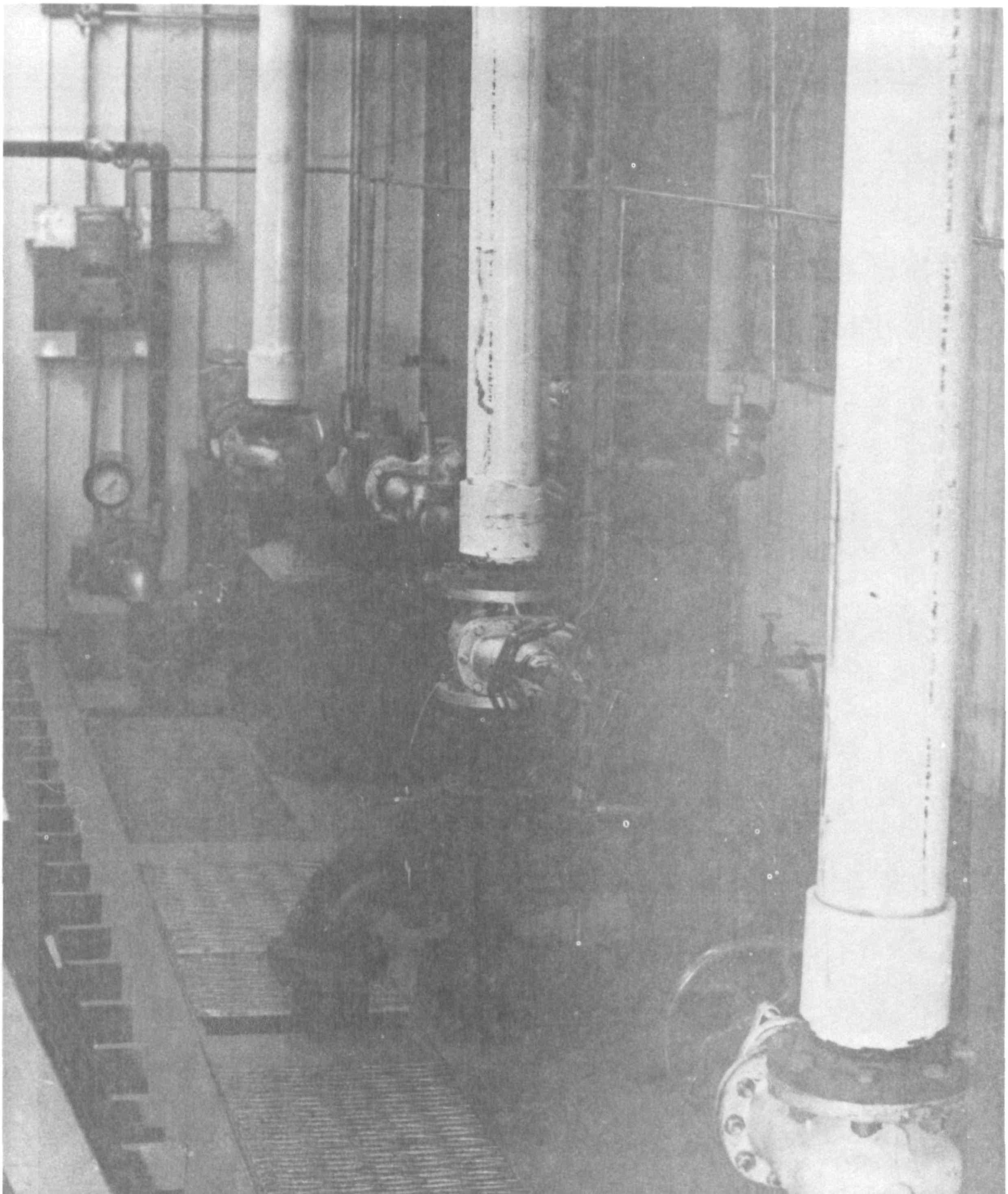

Figure 8. Line of Pumps Feeding the Weir Box

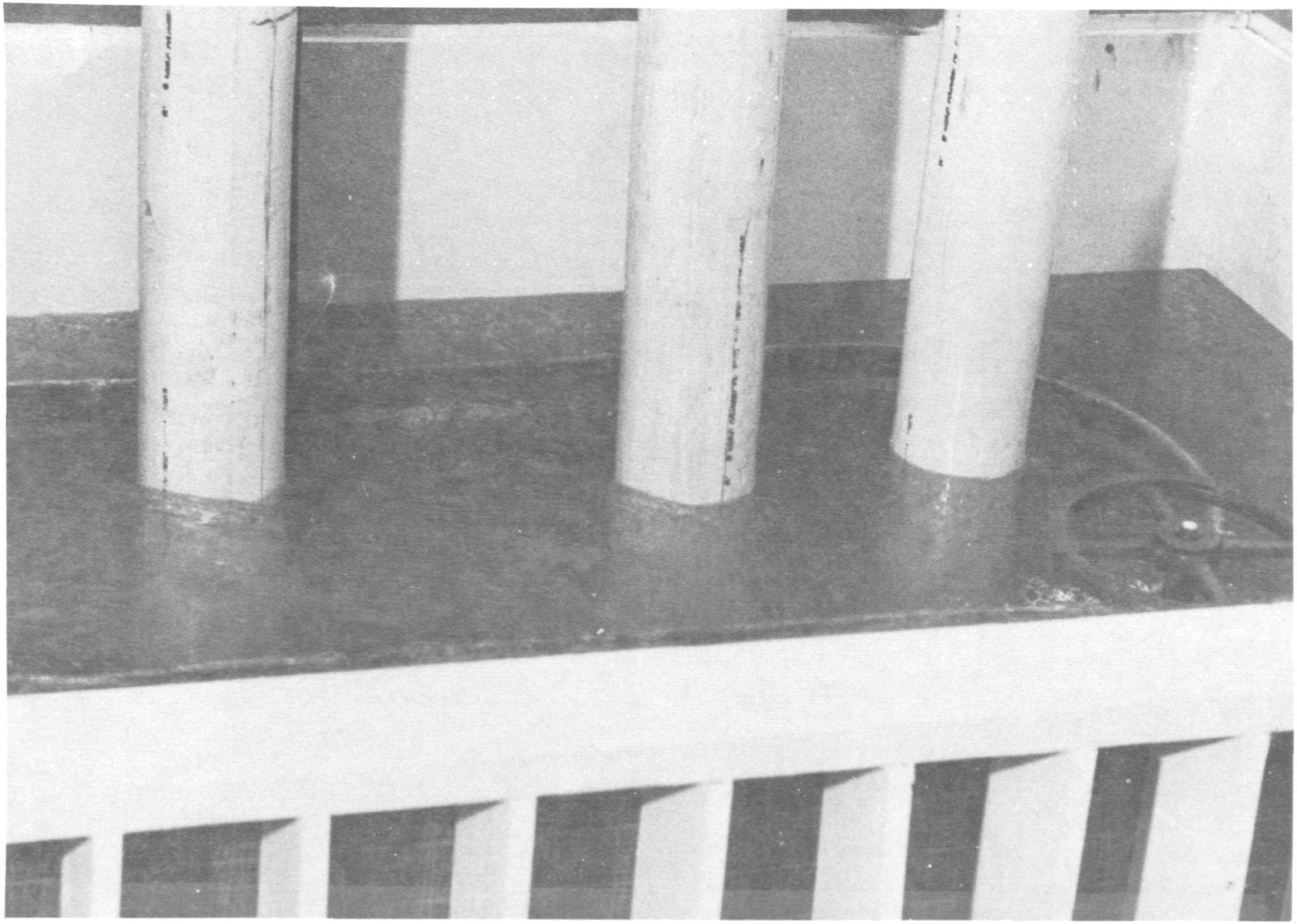

Figure 9. Water Supply Lines Leading Into Turbulence Suppressor Tank

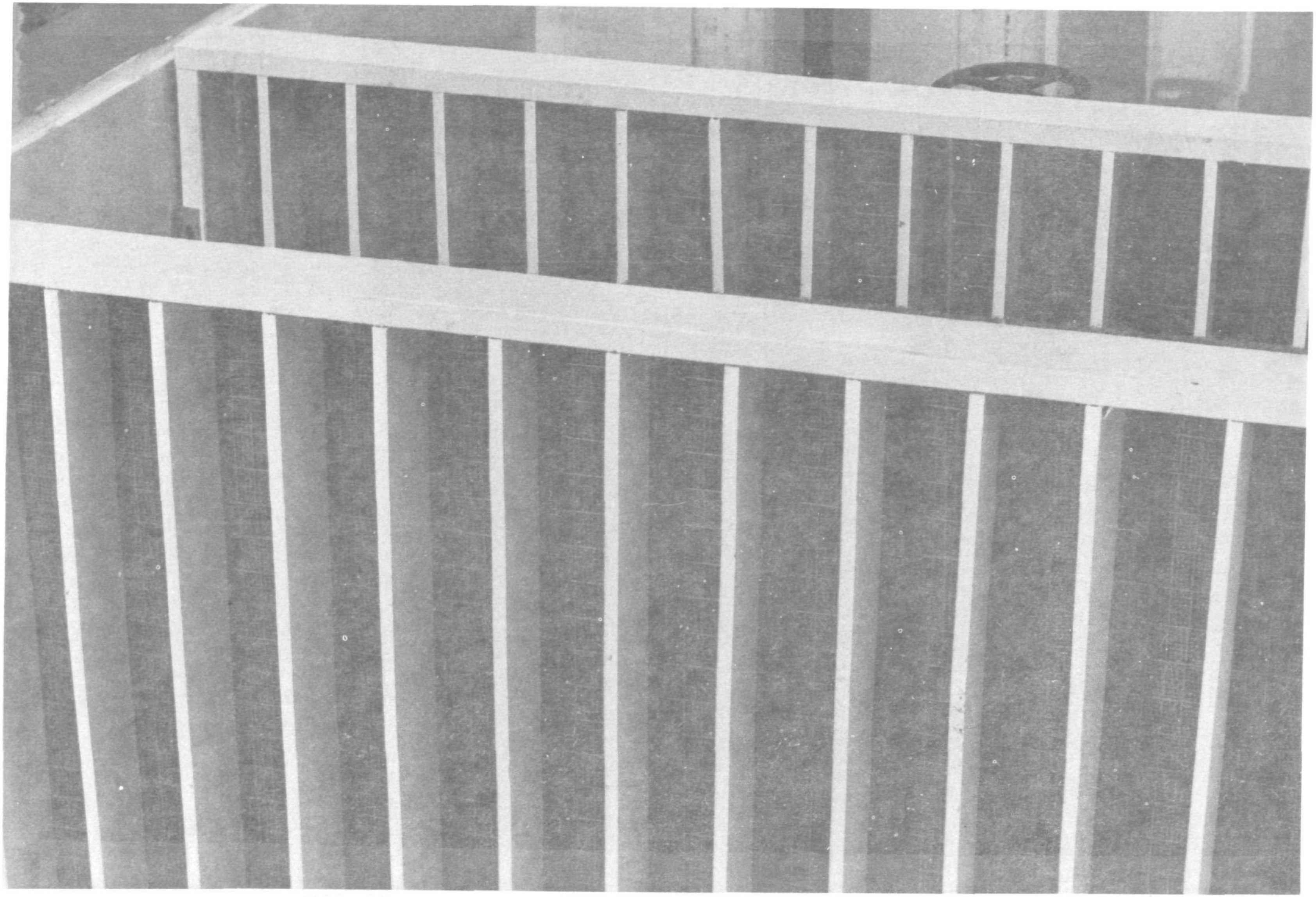

Figure 10. Turbulence Suppressors, Rubberized Horsehair Mounted on Wood Frame

Flow leaving the turbulence suppressors is smooth and glassy (Figure 11). It passes over the weir plate, down a chute, and into the weighing tank. Water is recirculated back into the pumps via several means. The weighing tank has a six inch mud valve drain and a 2 ft. x 2 ft. diversion box. The chute spanning the distance between weir box and weighing tank directs water either into the weighing tank or into the diversion box when the aluminum cover is removed (Figures 12 and 13).

Because of unsteady flow conditions produced when the small pump was choked too much by the gate valve on the discharge side, low flow calibrations could not be performed using water directly supplied by the small pump. To facilitate low flow calibrations a storage tank was installed above the flume which could feed the flume by gravity flow (Figure 14). This system consists of two open galvanized tanks similar to the one used as a turbulence suppressor in the flume. These tanks are 190 gallon and 100 gallon in size. The smaller tank is situated inside the larger tank as shown in Figure 15. The water is supplied by an additional 2 inch discharge line from the 100 g.p.m. pump and enters the smaller inner tank. Both discharge lines from the 100 g.p.m. pump are equipped with gate valves for flexibility of operation. This configuration provides a constant head water supply to the flume via the smaller tank. Excess flow from the pump spills over the lip of the smaller tank into the outer larger tank which acts as a catch basin to direct the overflow back to the sumps (Figure 15). The inner smaller tank drains vertically through a 2 inch PVC discharge pipe down to within 18 inches of the flume bottom, just upstream of the turbulence suppressors.

The basic recirculation scheme is to allow the weighing tank to fill during a test run (valve and diversion box closed). Then, water is diverted into the diversion box while the weighing tank is drained to allow another run to begin. Weir box valves are used in emergency overflow situations and to drain the weir box when it's not in use.

The instrumentation/flow measurement system was designed to allow flexibility in parameter testing and to provide checks of the reliability of flow measurement schemes currently practiced. The basic apparatus consists of a tank to collect water, a scale to weigh the water in the tank, and an electronic timer to measure weight/unit time intervals. Weight/unit time can be converted into volume/unit time knowing the density of water at various temperatures. In order to decrease the chance of human error, the electronic timer can be triggered by the scale hand passing over a photo switching transitor mounted in the face of the scale (Figure 16). Figure 17 illustrates the light-activated phototransistor relay circuit used to time 2000 lb. increments at high discharge rates. A standard 35 mm projector is used as an intense light source. The incoming light strikes a phototransitor (Figure 17: Q1) which when broken by the scale hand activates the relay, RY1, which closes a circuit to a Heathkit digital stop watch. Thus, for high discharges the stop watch is activated on the first pass of the hand and deactivated on the next pass corresponding to a 2000 lb. increment on the scale. At high discharge rates the scale hand is moving rapidly and it is impossible to accurately start and stop the stop watch by hand. The electronic switching circuit was found to eliminate this problem, giving repeatability between runs within 0.04 second.

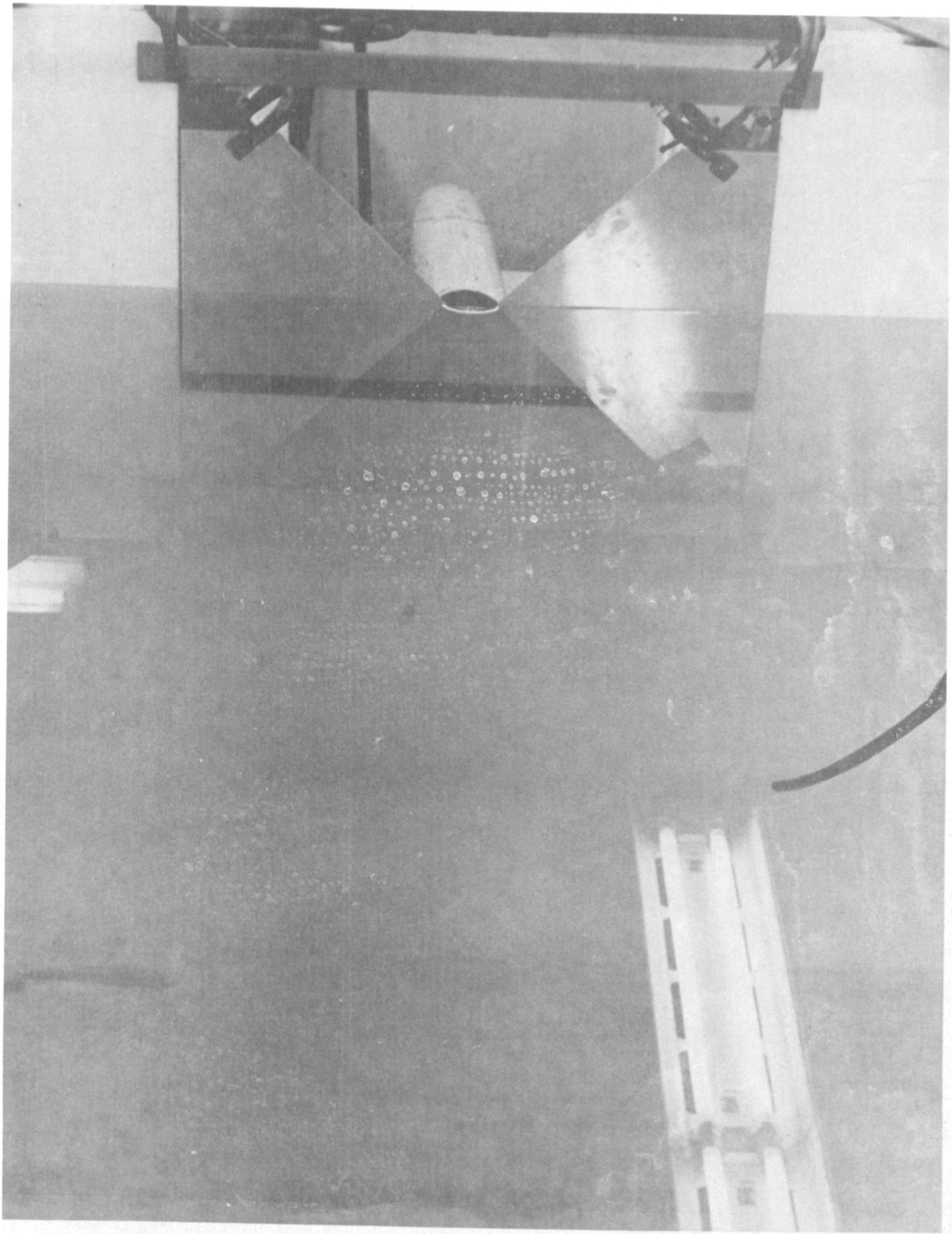

Figure 11. Effectiveness of Turbulence Suppression System in Producing a Smooth Water Surface

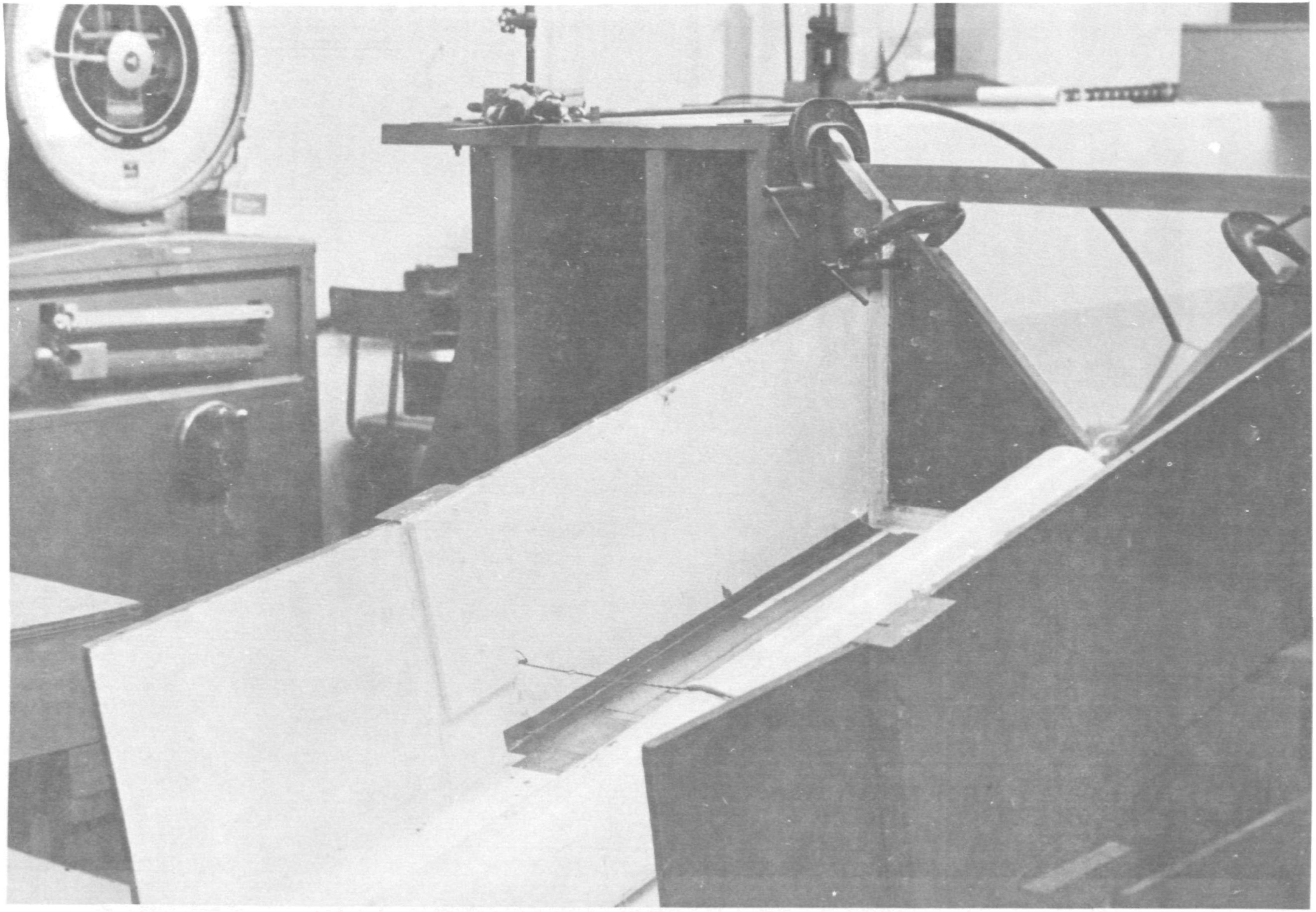

Figure 12. Outlet Chute Leading From Weir Plate to Weighing Tank

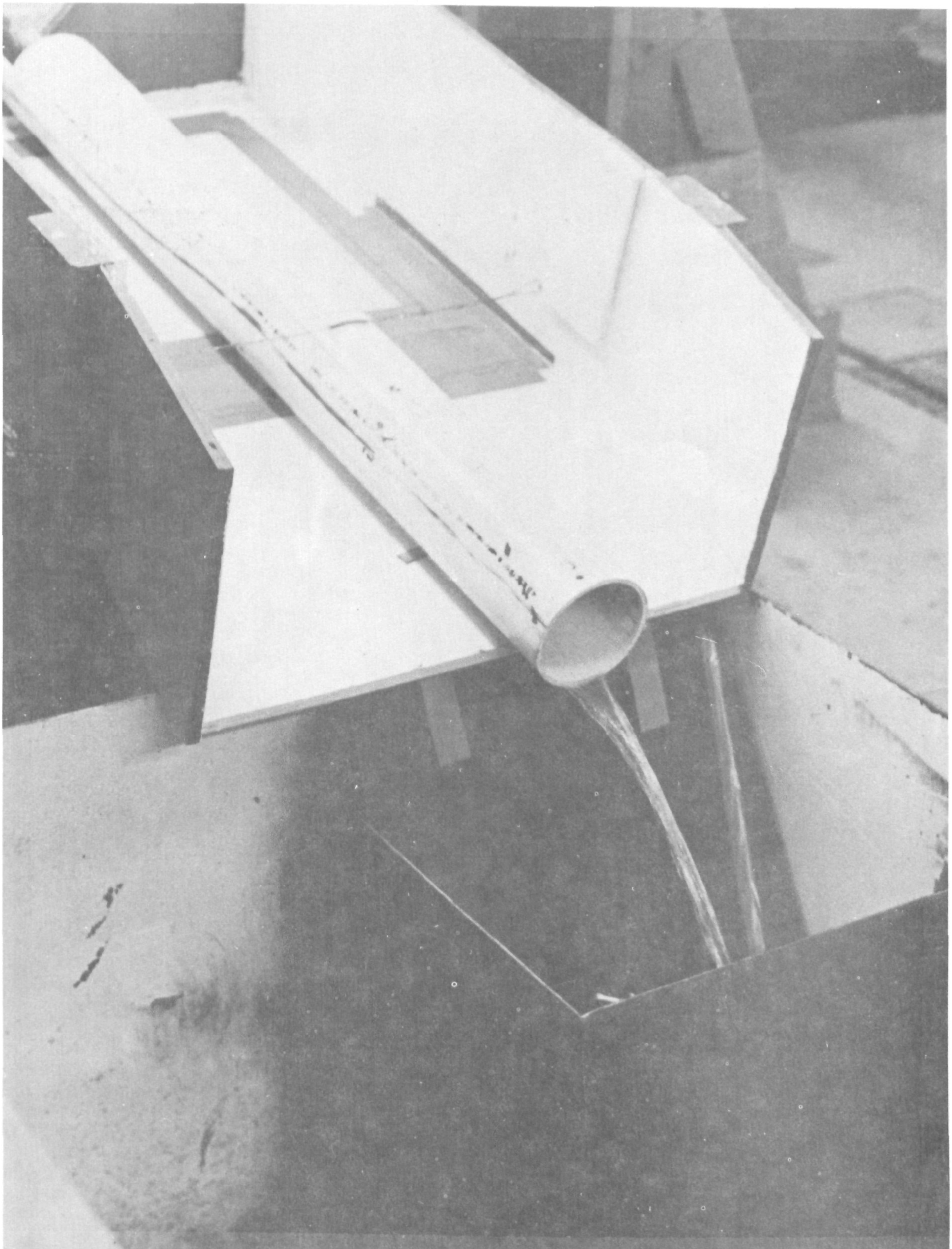

Figure 13. Weighing Tank Diversion Box With Cover Removed

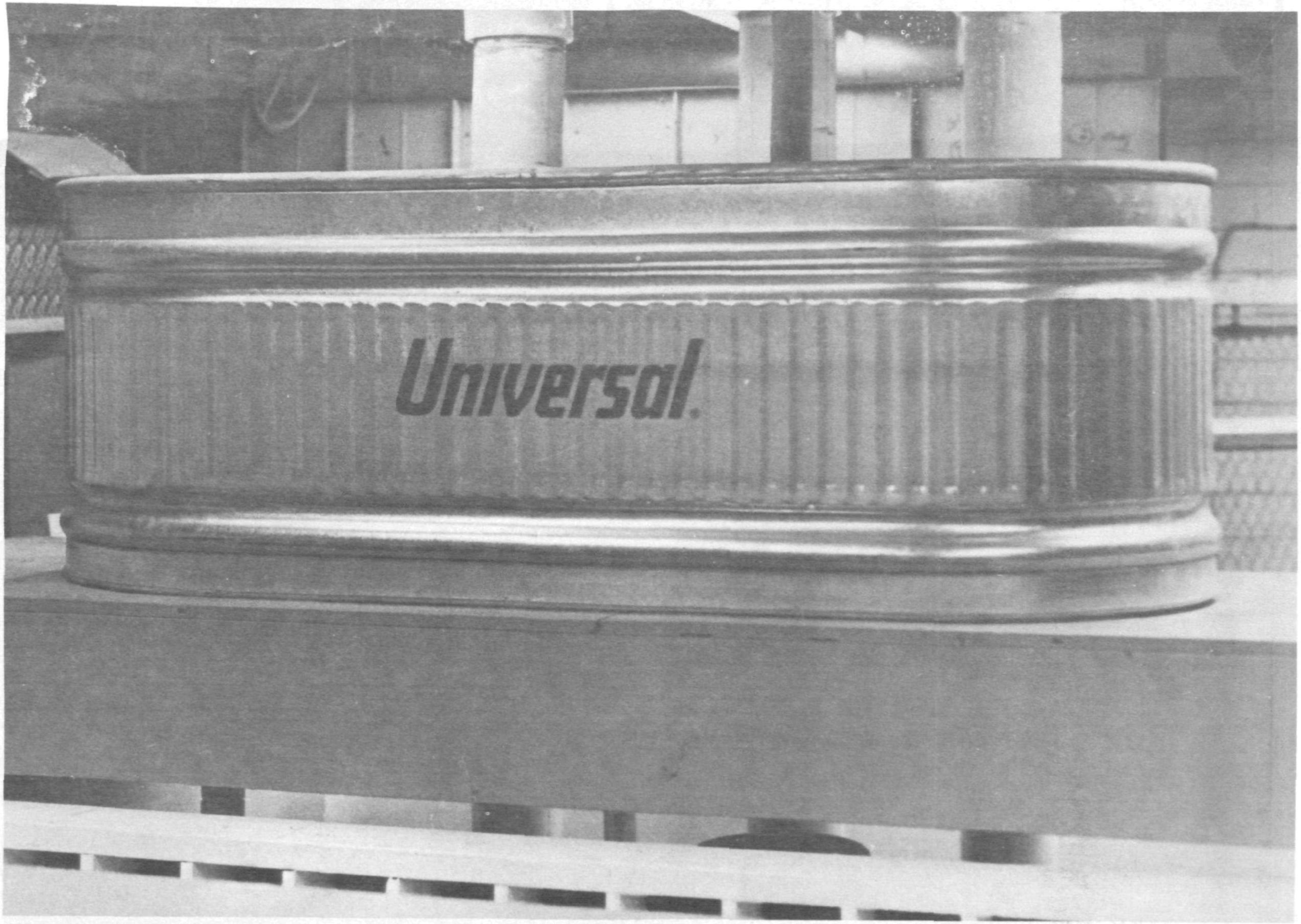

Figure 14. Storage Tank Installation for Use as a Constant Head Water Supply

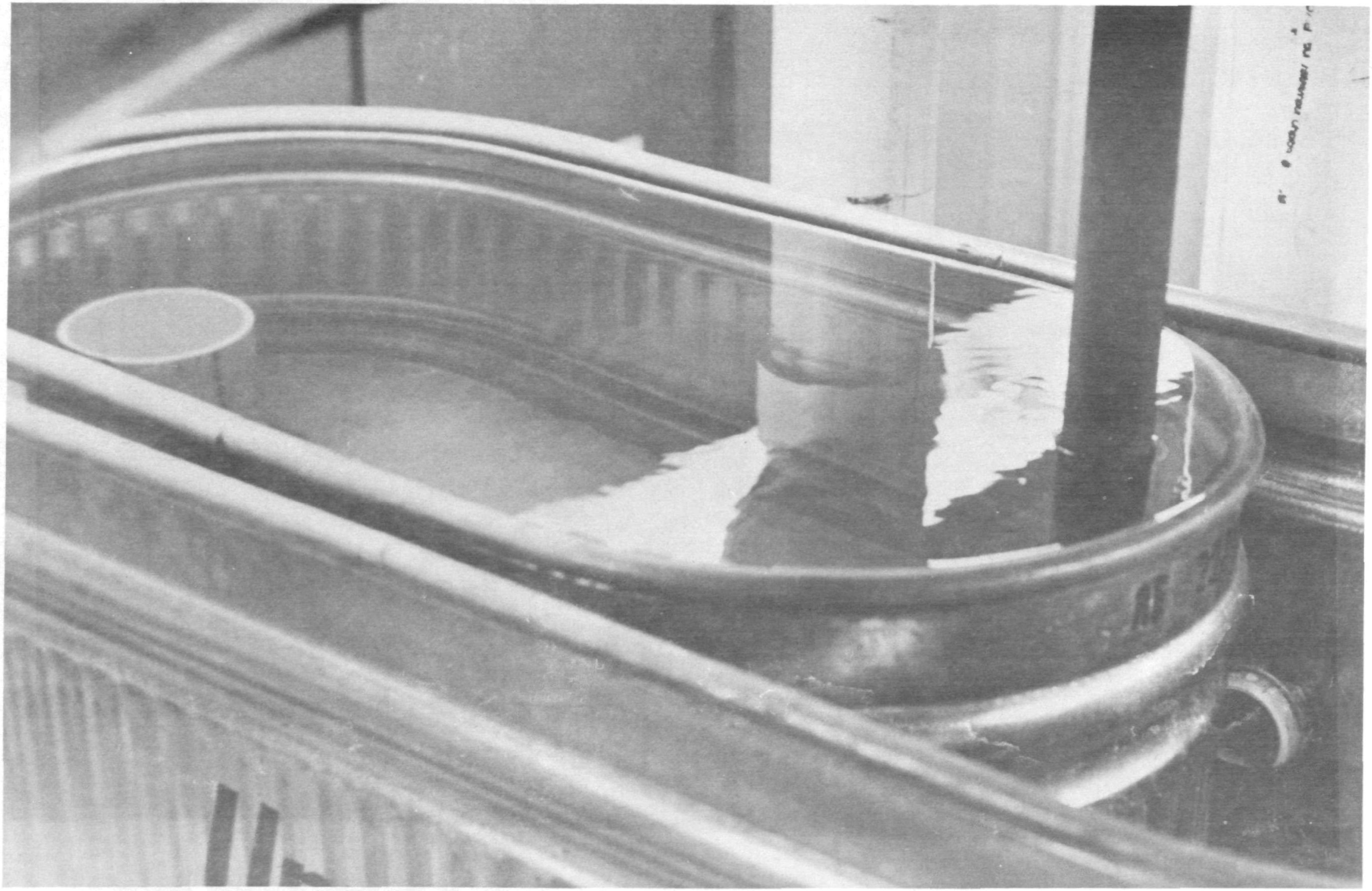

Figure 15. Detail of Constant Head Tank and Its Containing Outer Overflow Tank

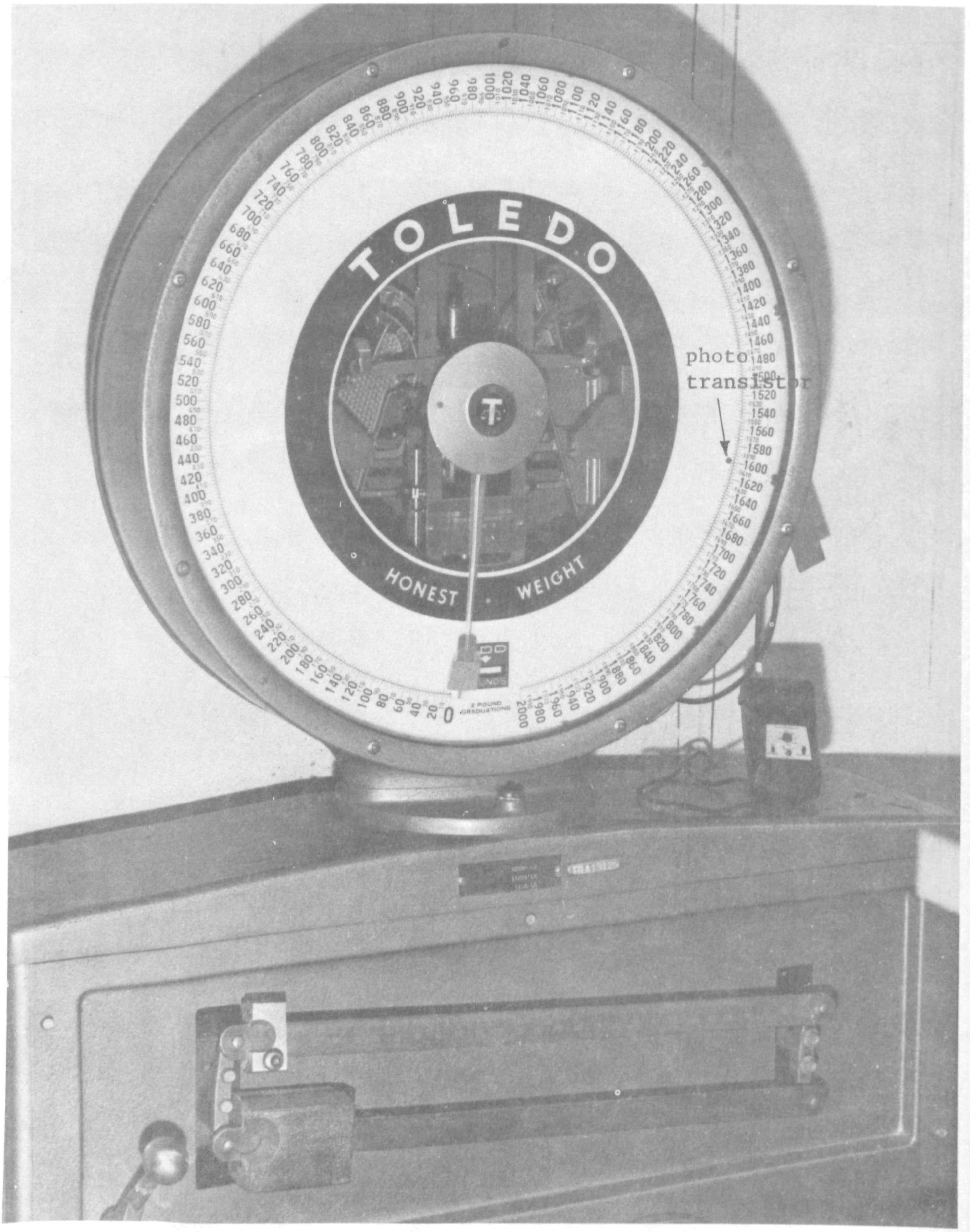

Figure 16. Weighing Scale Showing Location of Photo Transistor

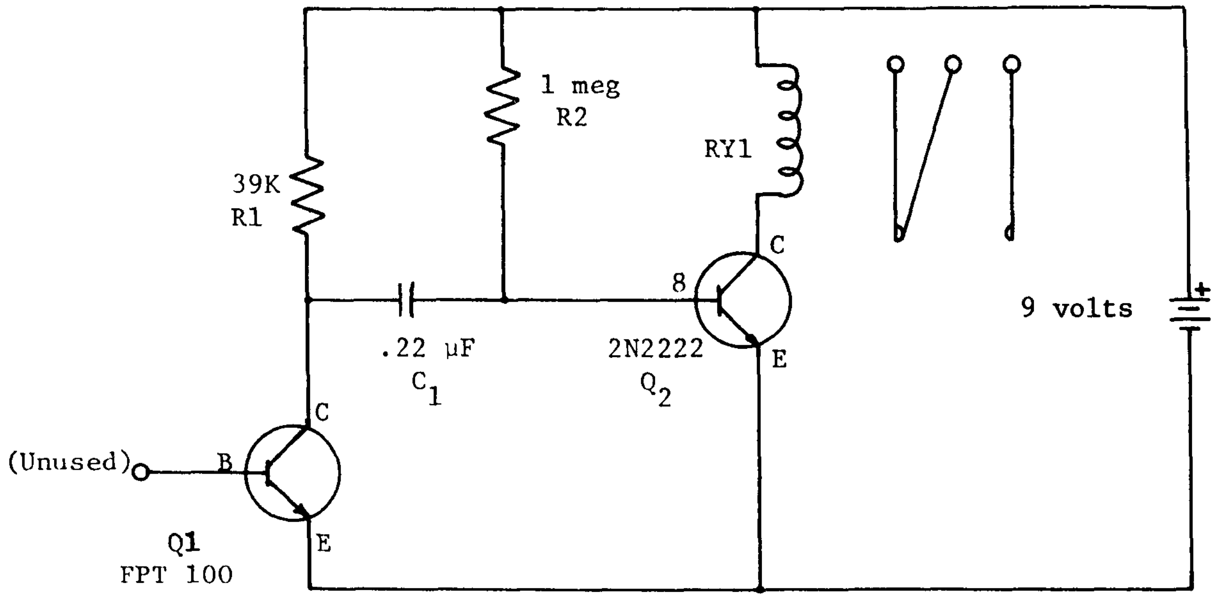

Figure 17. Light-Activated Phototransistor Relay Circuit

Two stilling wells are mounted on the scale side of the weir box. They are constructed out of clear plexiglass in order to allow visual inspection of the water level (Figures 18 and 19). One stilling well houses a hook gauge, calibrated in .001 foot increments. The other contains a 12 inch stainless steel ball which is the float for a Fisher-Porter stage recording gauge accurate to 0.001 foot. The float gauge is designed to provide direct flow measurement, in million gallons per day, for 90^{o} V-notch weirs. Its scale ranges from zero to four million gallons per day.

A staff gauge is mounted in the interior of the weir box. It provides a visual means of estimating the upstream head. Intervals of 0.01 feet can be read. The installation of a staff gauge was incorporated to check the accuracy of measurement practices currently in use.

Two venturi meters were installed in two separate pump discharge lines. (The central 1,000 g.p.m. pump and the 500 g.p.m. pump). They were included to provide flexibility in future experimentation, and are currently not in use.

The overall purpose of the flow measurement system is to allow comparison of several established flow measurement schemes, (i.e., upstream head on hook and staff gauge, float gauge) to actual weight per unit time measurements, and to allow comparison of other flow parameters, (i.e., depth and

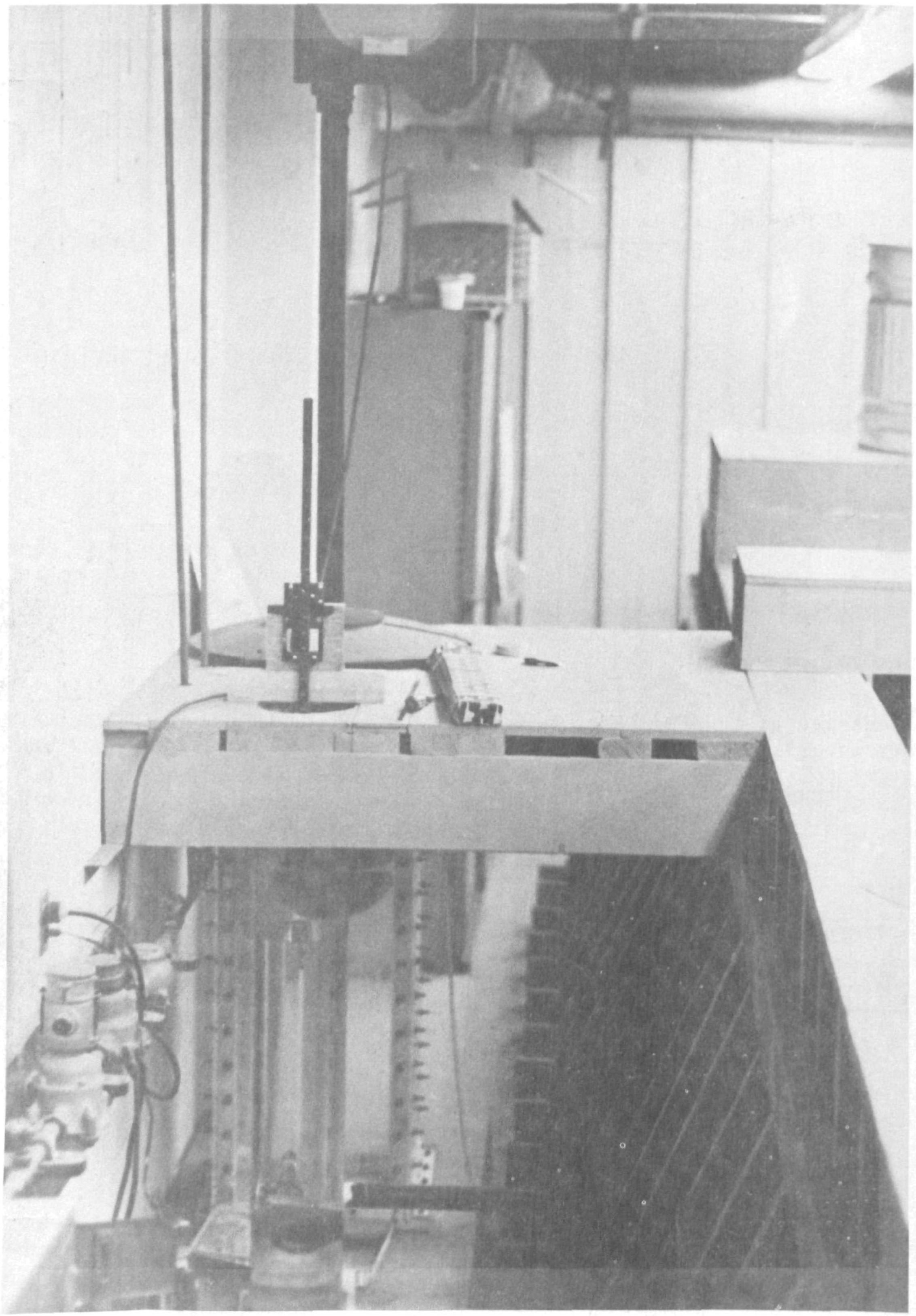

Figure 18. Stilling Well Installation Showing Hook Gauge and Recording Gauge

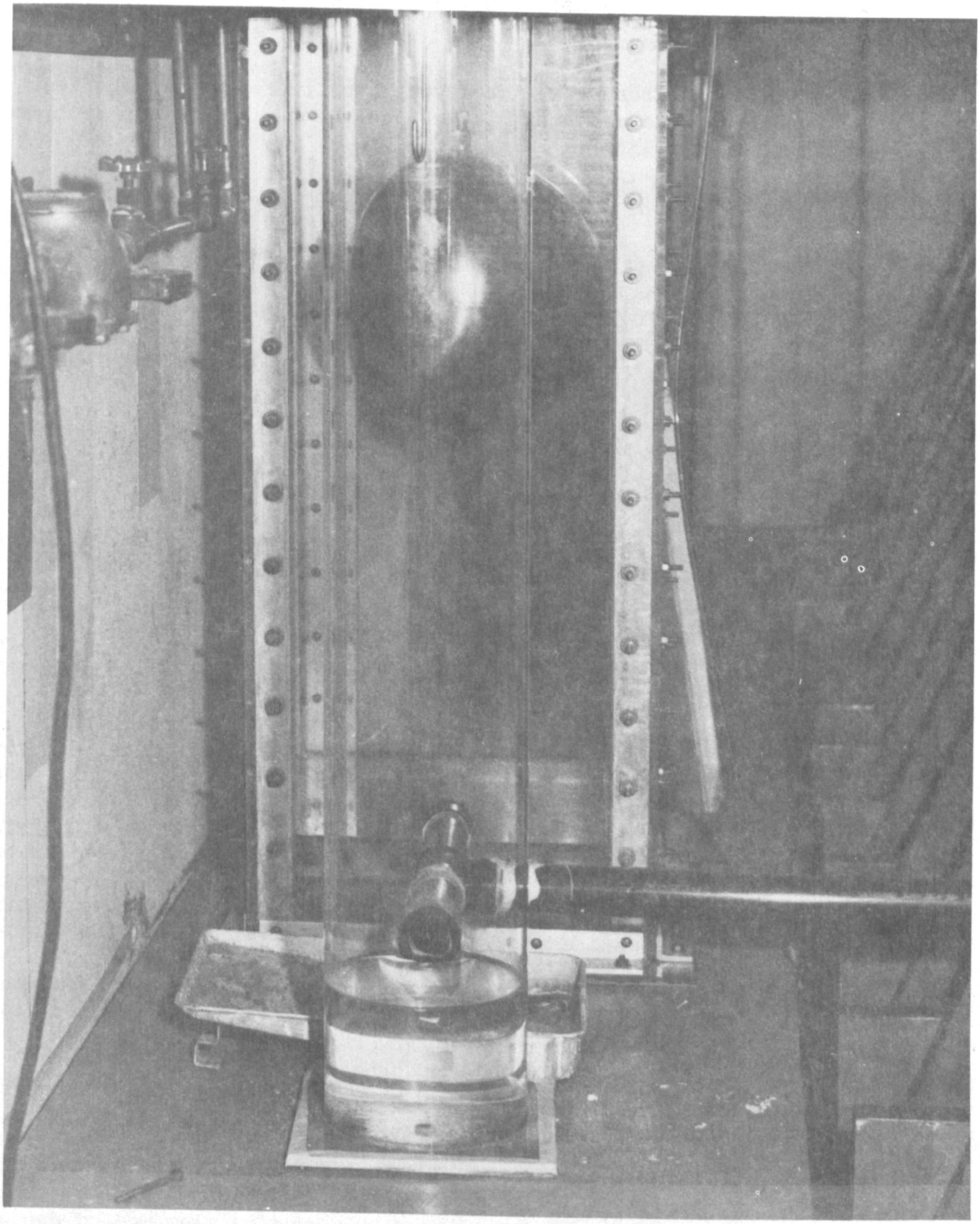

Figure 19. Plexiglass Stilling Wells, Hook Gauge:Foreground, Float Gauge:Rear

width of water at the weir face), with actual weight per unit time measurements and existing flow measurement schemes. The design of the measurement systems followed standard practice. Instruments were checked for accuracy and recalibrated as necessary.

In summary, the apparatus as a whole was constructed to provide leak-free operation and durable service. It was designed to meet standard criteria and to provide flexibility in testing.

SECTION 7

EXPERIMENT PROCEDURES

The goal of this research was to establish testing parameters for 90° V-notch weir discharge that are readily measured under field conditions and provide accurate flow calculations. In particular, it was thought that parameters obtainable at the weir face would be of primary interest. Two obvious parameters are the depth of water above the notch, and the width of the water surface above the notch.

Simple measuring devices were chosen to make measurements of these parameters. A Lufkin meter rule (part no. 1261ME), also calibrated in inches with divisions of 1/16 inch, was selected to determine the water depth above the notch. The technique selected to perform this measurement is also simple. The rule is inserted in the notch with the zero end resting on the bottom of the V. The calibrated edge is pointed upstream. A metal bar, clamped directly to the plate above the notch, serves as a stop for the rule when it reaches a vertical position. The rule is kept plumb by eye, and readings are made to the nearest 1/32 of an inch (estimated). Figure 20 demonstrates this technique.

As shown in Figures 21 and 22 small disturbance waves are created as a result of the presence of the rule in the water. These small waves are standing waves and are positioned directly in front of rule. At first, there was considerable concern about reading the rule in a consistent manner, given the presence of the waves and the curvature of the water surface. However, after many trials with different people (see Section 8, Results) it was determined that the eye could easily ignore the small waves and extrapolate back along the sides of the rule such that repeatable measurements could be made to the nearest 1/32 of an inch. This process of extrapolating back by eye is illustrated in Figure 23. During the course of the research, everyone involved with this particular measurement found it very easy to make and repeat.

Even though the measurement technique outlined above was easy to master in the laboratory it seemed reasonable to suspect that access to a field weir might be very limited which would cause the taking of these measurements to be quite difficult. A person measuring depth at the notch must be able to get within an arms reach of the weir in order to measure the depth of water at the notch. They must also be able to get their eyes close enough to the weir to make the depth reading. After considering this problem, it was concluded that the depth of water at the notch could be taken much more easily, and perhaps more accurately, by covering the ruler with a

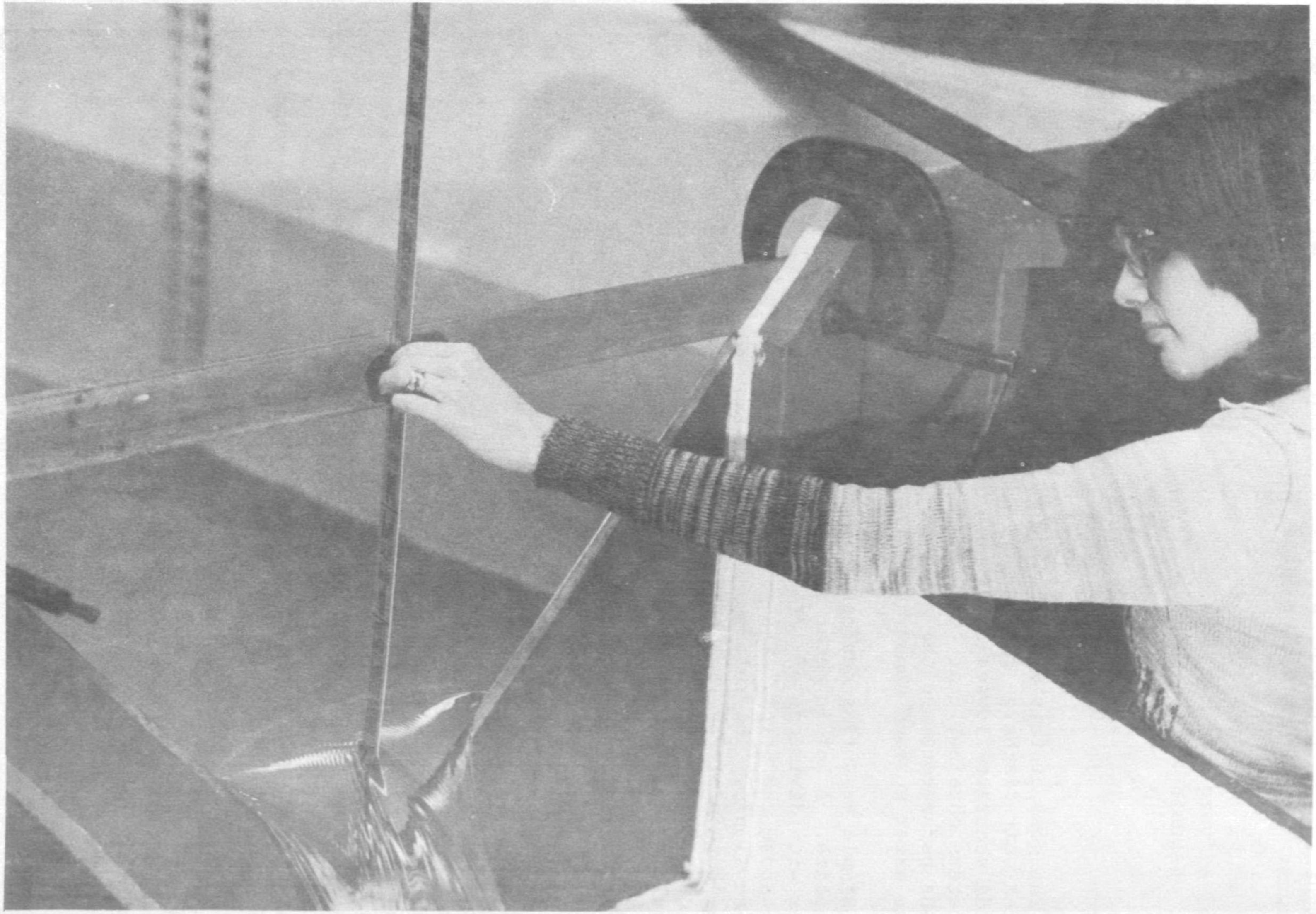

Figure 20. Placement of the Rule When Measuring Depth of Flow at the Weir Notch

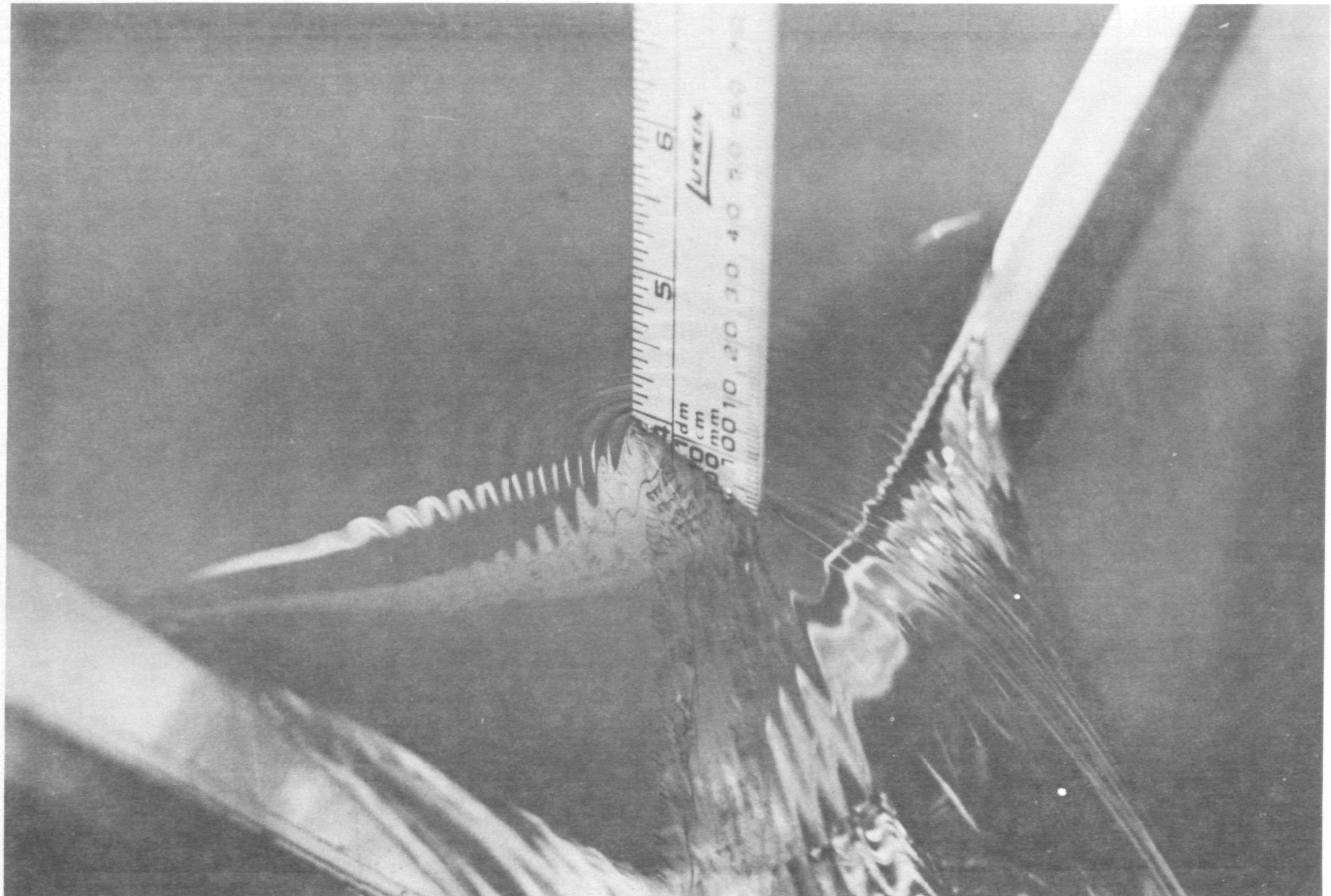

Figure 21. View of Small Disturbance Waves Looking Upstream

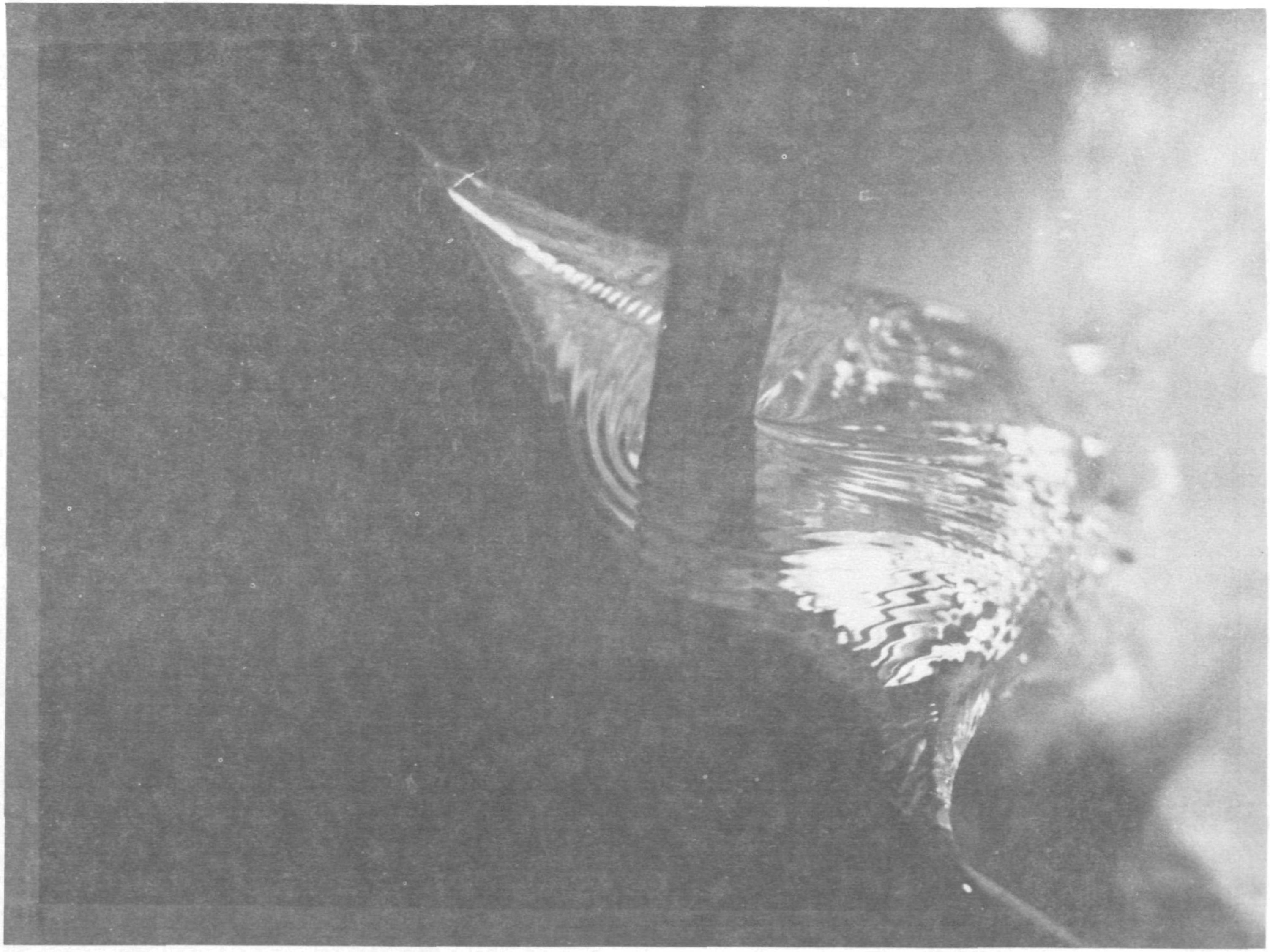

Figure 22. View of Small Disturbance Wave When Viewed From Above the Weir

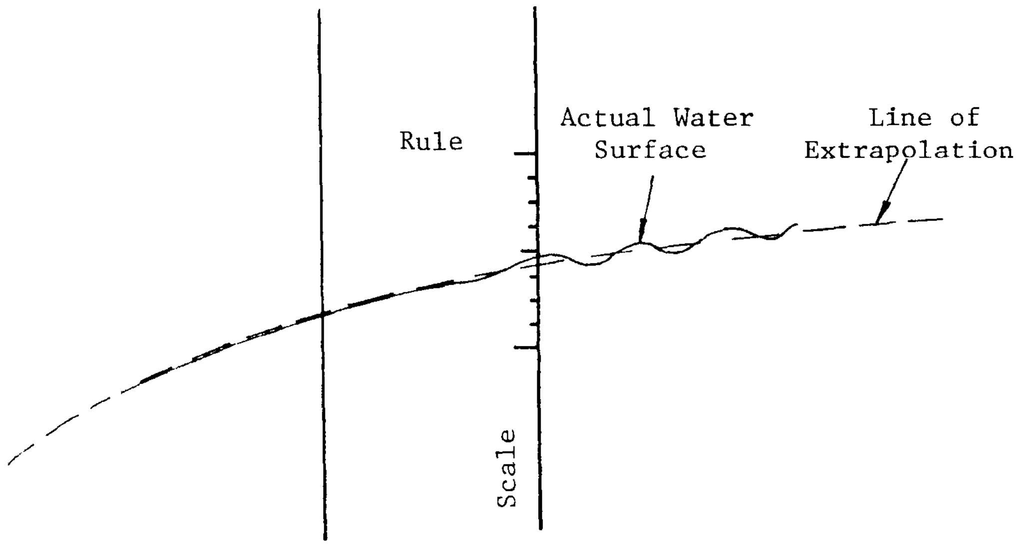

Figure 23. Method of Reading the Rule by Extrapolation of Water Surface to Scale Markings

powdery substance which would be washed away by the water leaving a distinct water mark.

Using an indicating marker, such as a powder, would eliminate the need for getting close to the weir plate to measure the depth of water. The field person need only be able to reach the apex of the weir notch with a measuring device such as the Lufkin rule utilized in this work. Although the person would have to be able to view the plate and be close enough to position and steady the rule, they would not need to be close enough to read the rule in position. The rule could be pulled from the notch and the depth read at the powder marker water line.

Many various powders and dusts were considered for use as the marking agent. Some requirements of the material were that it be inexpensive, easily obtainable, and hydrophobic (water repelling). If the material were not hydrophobic, the wetting action of the water may have made the water line difficult to determine with accuracy.

With the above requirements in mind, common baby powder (talc powder) was chosen as the marking material. The powder was sprinkled on the rule and the excess was knocked off by tapping the rule against a solid object such as the weir box. A very thin layer of powder remained on the rule after tapping. The rule was placed in the apex of the weir notch and positioned as previously described for the optical reading. However, in this case the rule was not read in place, but rather it was removed as soon as it was positioned properly and the depth of water at the notch was determined by the water line on the rule (Figure 24). It was found that the waterline was sharply defined and

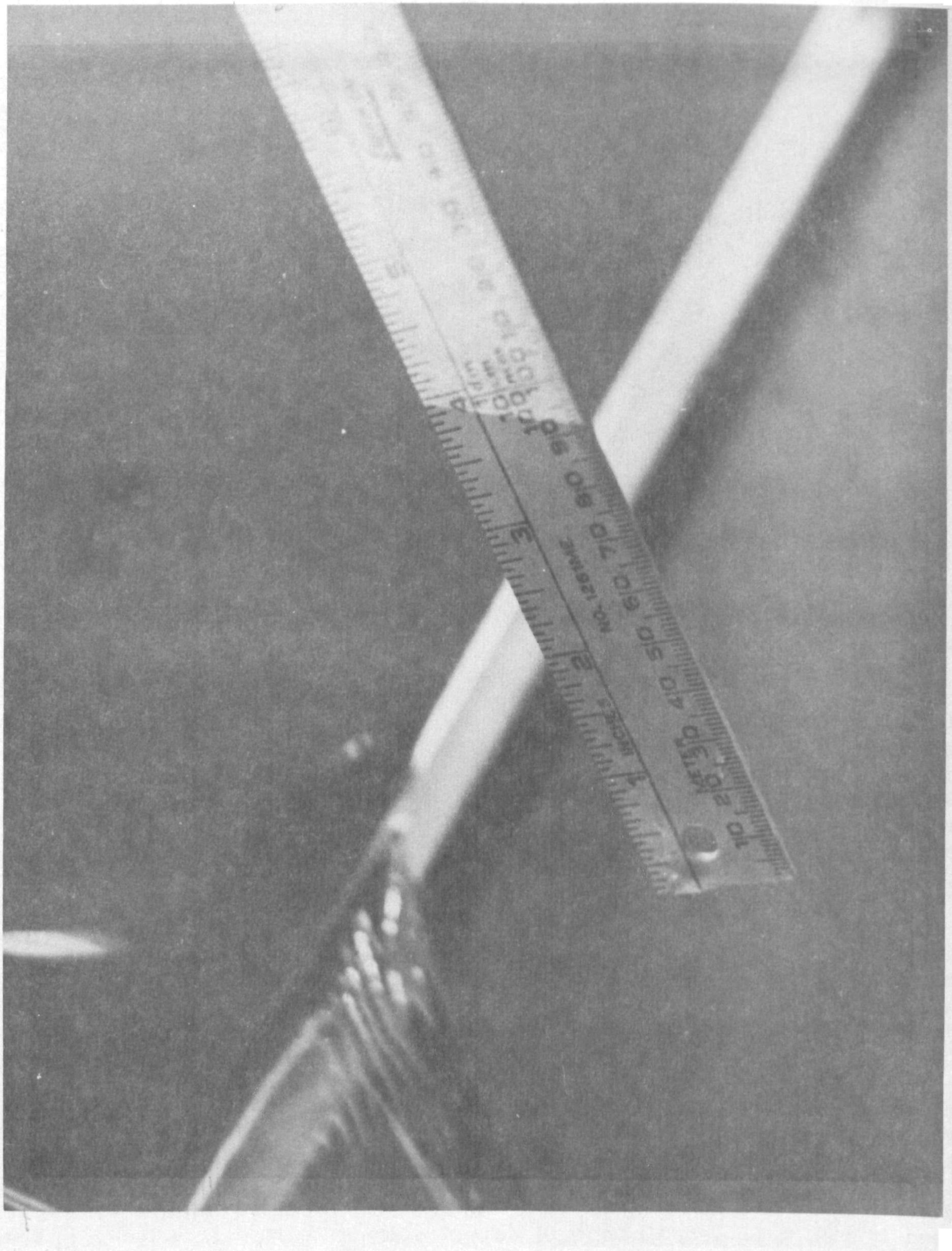

Figure 24. Use of Common Baby Powder to Produce a High Water Mark on the Rule

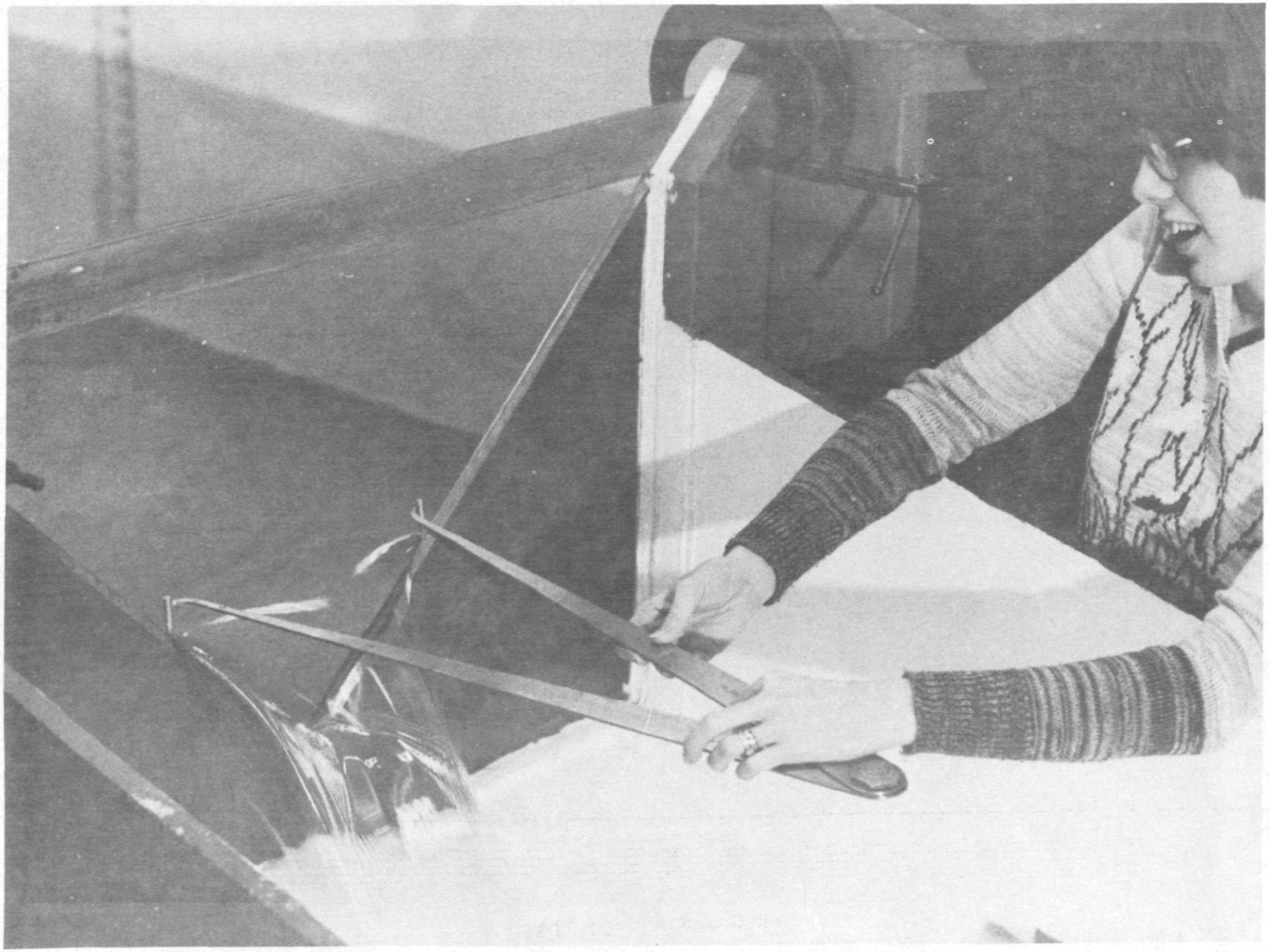

Figure 25. Positioning of Caliper to Perform Measurement of Flow Width at Weir Crest

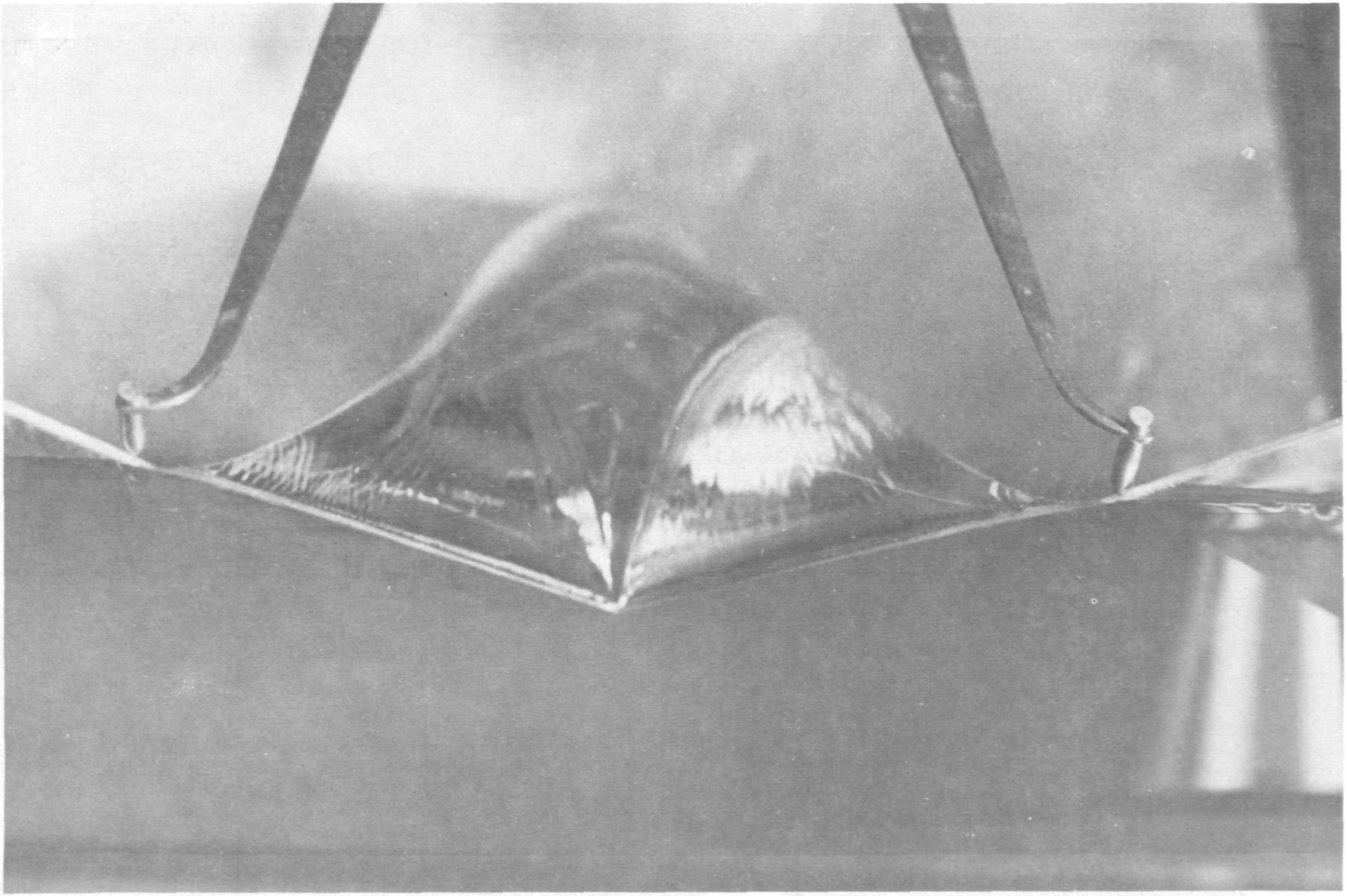

Figure 26. Placement of the Caliper as Viewed From Above

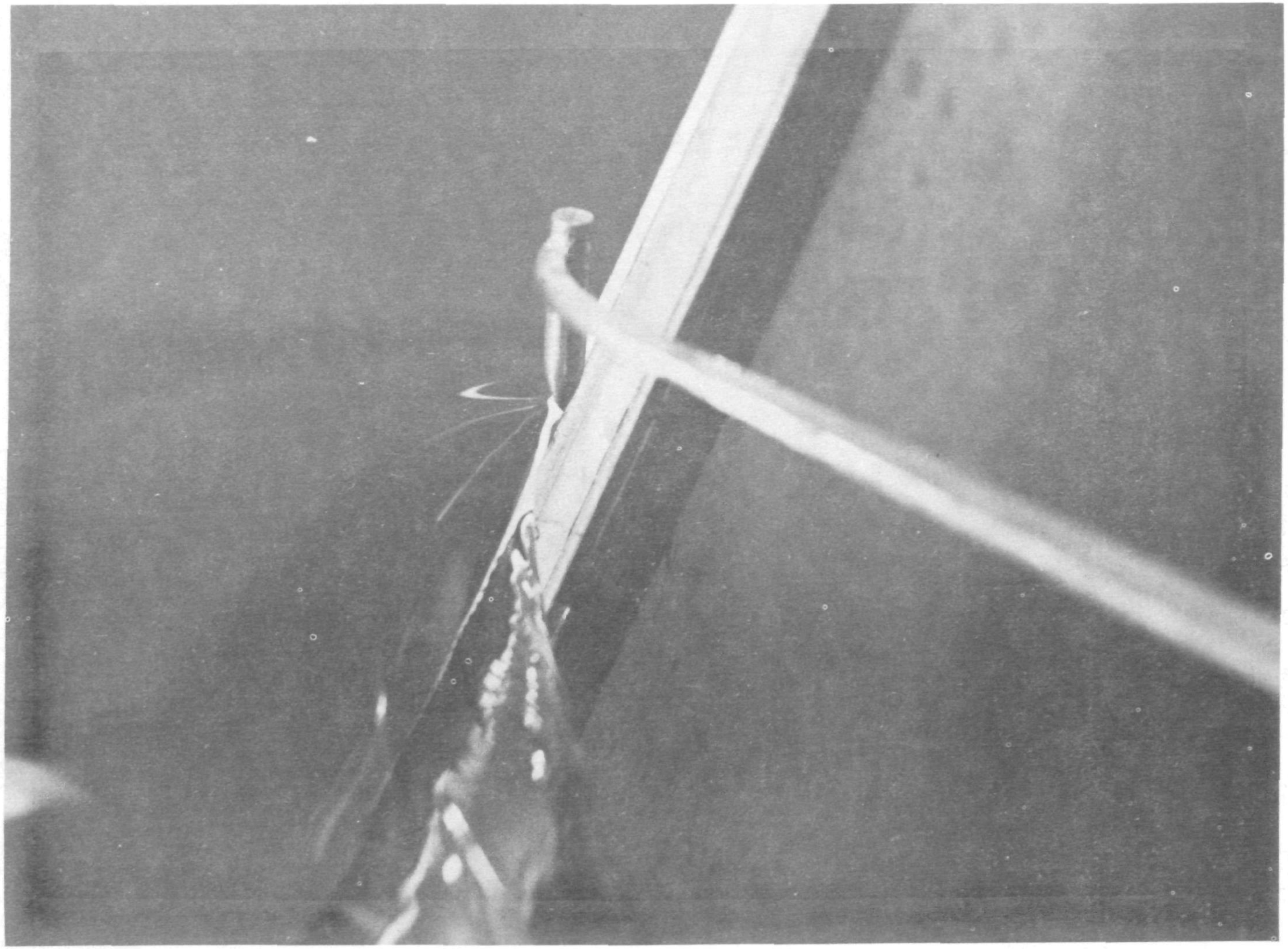

Figure 27. View of a Single Caliper Tip as Properly Positioned at the Intersection of the Weir Crest and Water Surface

much easier to accurately read than when the rule is in place.

A machinist's caliper was selected to measure the width of water above the notch. Points were attached to the ends of the caliper to facilitate measurement. The points are approximately 1 inch long, and are 1/8 inch brass rod with conical points. The caliper points are set at width of water at the upstream side of the weir plate (Figure 25). Although the use of the caliper is more difficult to accomplish then the depth measurement using the rule, it is not as difficult or as inaccurate as one might think. Figures 26 and 27 show two different views of the placement of the caliper. The technique is to locate the point of the caliper such that it centers on the water crossing the weir crest as shown in Figure 28.

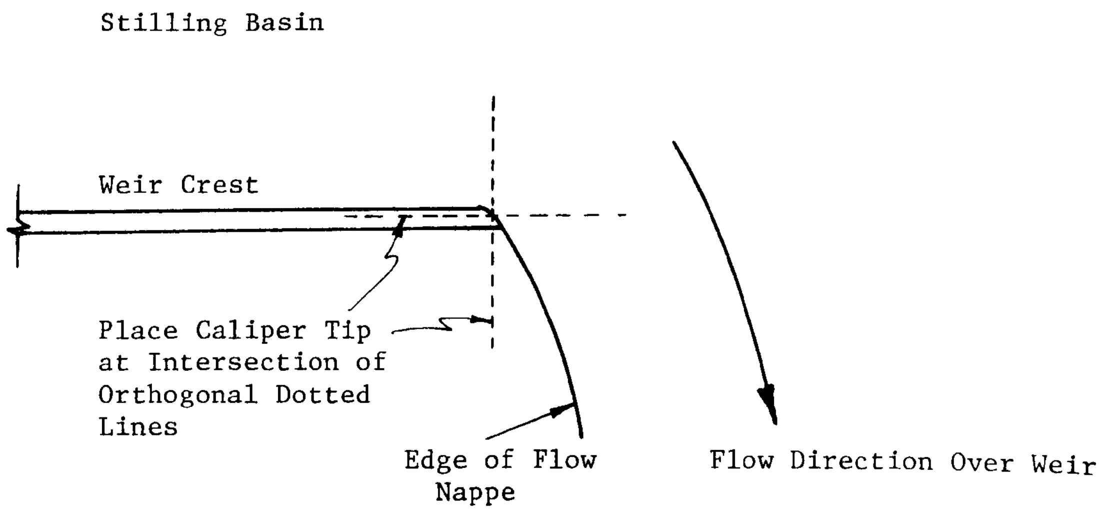

Figure 28. Location of Caliper Tip at Intersection of the Weir Crest and the Flow Nappe

The design of the caliper points is not critical as long as the points will contact the weir crest as shown in Figure 28, without any other part of the caliper coming in contact with the water surface. The water surface is curved at the weir plate such that a standard ruler or other direct measurement device will not work without contacting the nappe and disrupting the flow. After the caliper is set to the width of flow at the weir plate, it is removed and the width determined. Measurements are taken on a Lufkin rule identical to the one used to measure the depth of water. However, in this case the rule is mounted on a short piece of aluminum channel. A small indentation was drilled in the channel at exactly the zero point of the rule. To make a measurement, one caliper point is placed in this hole and the caliper is rotated until the other point intersects the rule. Measurements are taken to the nearest 1/32 of an inch (Figure 29).

The weir box was designed to meet standard specifications for the anticipated range of flows (2). The general scheme of testing was based upon previous work (10,11,12). Therefore, a secondary purpose of testing was to check the apparatus and experimental technique against previous data and formulas, particularly the Cone formula.

The basic components of the testing scheme can be delineated as follows:

1) Water is drawn out of the sumps by a pump and introduced into the rear of the weir box or into the constant head tank (Figure 4).

2) Water flows through the turbulence suppressors, across the weir and into the weighing tank or diversion chute (Figures 12 and 13).

3) Measurements of weight and time are taken with the electronic timer, triggered manually or with the light sensitive switching circuit, and the scale (Figures 16 and 17).

4) Measurements of head are done with the hook gauge mounted in the stilling well, and read from the staff gauge mounted on the interior weir box wall.

5) Parameter measurements are taken as previously described.

After the construction phase of the project was completed, a general shakedown of the various systems was done to check for leaks and operational problems. The initial filling of the weir box was done by the smallest pump. The weir box had no leaks, and there was no evidence of deflections of the weir box structure under full load. All pumps and piping performed properly, with the exception of some small leaks that developed around the choke valve packing glands and an elbow joint. The packing gland screws were tightened to correct the valve leaks. Silicon rubber was used to calk the faulty elbow joint. The mud valves in the weir box and weighing tank had to be fitted with rubber gaskets to stop minor leakage. The entire pump/pipe and weir box leakage was reduced to a few drips per minute, and therefore regarded as a negligible source of experimental error.

The turbulence suppression system worked extremely well. Flow through the weir box was varied over the test ranges, and the water surface approaching the weir was always smooth and glassy. It was discovered that all the pumps are capable of producing flows well in excess of their rated capacities. This is primarily due to the lower than expected discharge head (probably less than 10 feet of water). Essentially, any two pumps could supply enough flow to cover the test discharge range. This simplified operational procedures.

Problems developed in the flow diversion and flow measurement systems. The original diverting trap door had significant leakage and had to be sealed so that testing could be carried on (Figure 30). A diversion box was finally

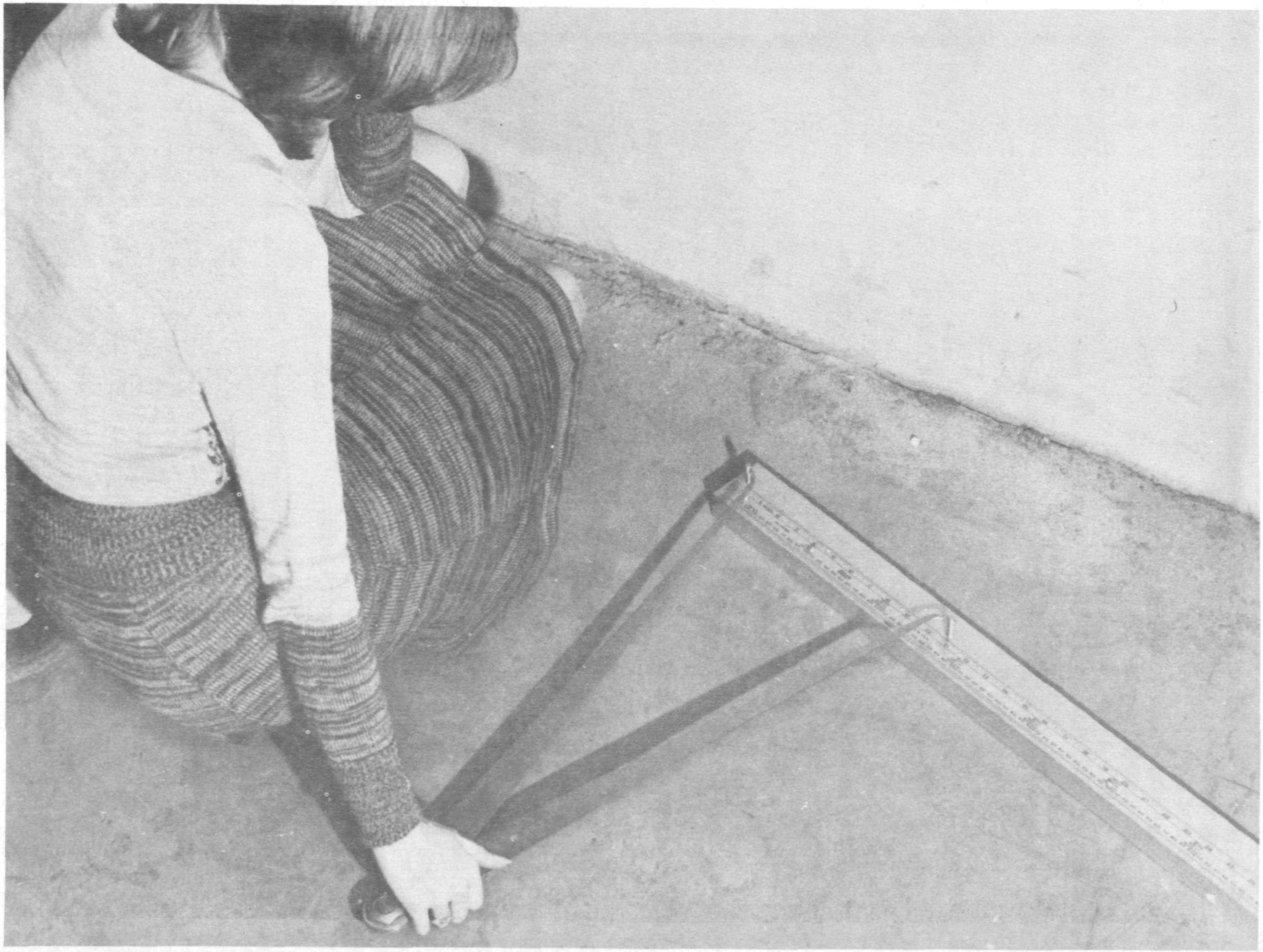

Figure 29. Aluminum Channel With Attached Meter Stick for Measuring Caliper Width

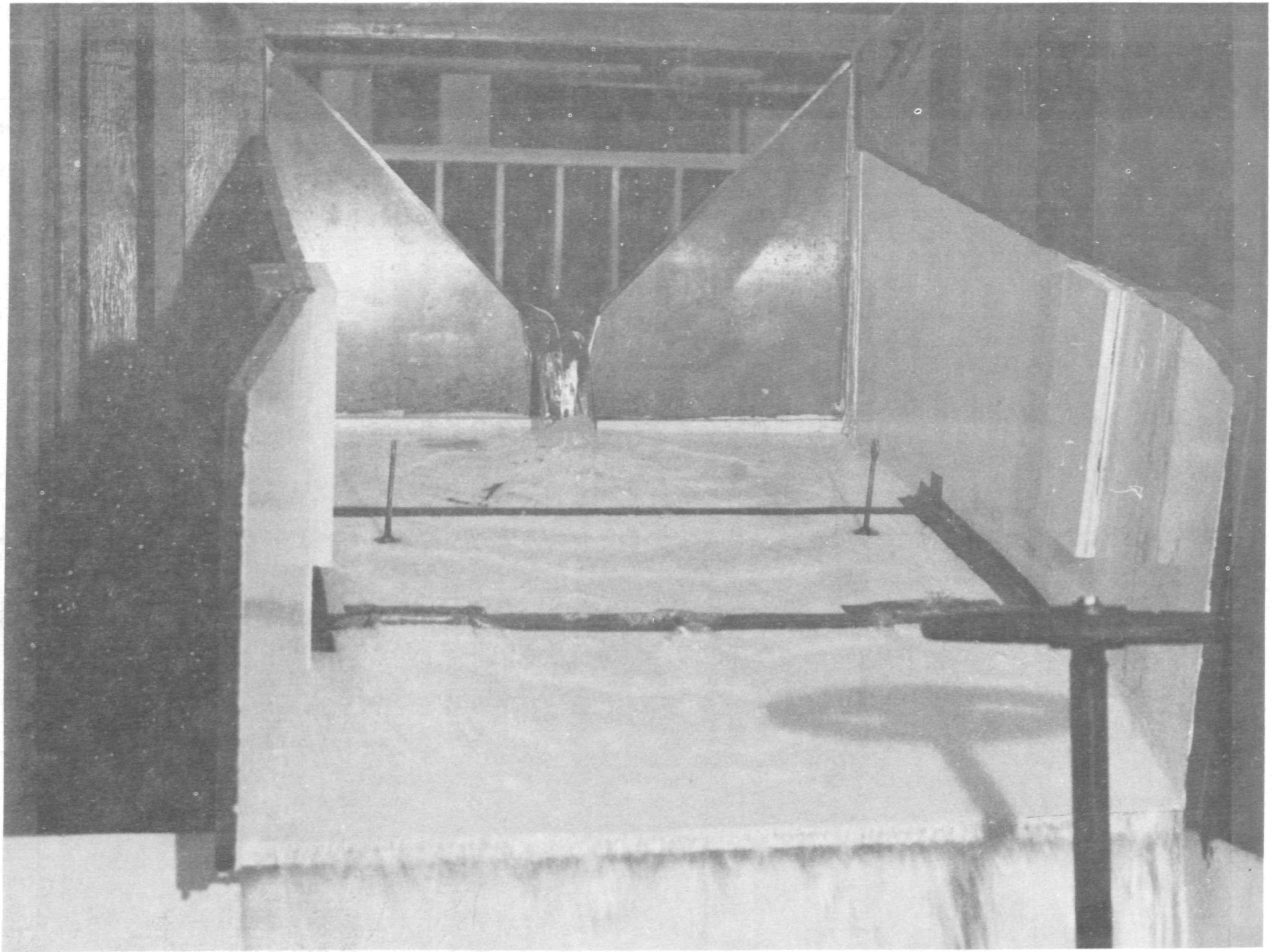

Figure 30. Flow Chute Leading From Weir to Weighing Tank -- Trap Door Diversion Sealed

designed and incorporated into the weighing tank (Figure 13). The diversion box has a removable cover which when in place allows the weighing tank to fill, and when removed, it diverts the flow through a hole in the bottom of the tank. This allows the weighing tank to be drained at higher flow rates.

Light intensity in the lab area was not great enough to trigger the light sensitive switching circuit for the electronic timer. The light intensity of a standard 35 mm slide projector provided sufficient light to trigger the circuit, and was added as part of the measuring apparatus. Cardboard tags were attached to the scale hand to provide a greater contrast of light and dark, thus more clearly defining the point of activation for the switching circuit. With the addition of the light source and tags, weight per unit time measurements typically agree to within ±0.03 sec. over 2000 pound intervals.

The hook gauge, float gauge, and stilling wells all functioned satisfactorily. Laboratory physical constraints created minor difficulties in installation of the float gauge, which required its placement slightly off the center of the stilling well. However, this slight variation did not affect its operation.

Once the system shakedown was completed, the point of zero head was established. It was originally intended to use the same method of zeroing set forth by the literature. This method requires the utilization of two hook gauges; one at the weir plate and another in a stilling well. With the water level in the weir box exactly even with the weir notch, both gauges are read. They are moved, then readjusted for another reading. The intent is to check the relative difference in readings for each gauge against the other in order to define any discrepancies in gauge calibration or measurement technique.

It was discovered that by carefully filling the weir box with water up to the bottom of the notch, good calibration could be achieved by simply observing the point at which the water level exactly coincided with the bottom of the notch. Surface tension effects did not interfere with the observation as might be expected. At this point, the hook gauge in the stilling well was read. The float gauge was set at zero with an adjustment screw. This procedure was repeated prior to each day's operation.

Testing began at relatively low flow rates. Originally it was thought that the float gauge would indicate variations in flow and head fluctuations. However, due to its calibration scale (0-4 MGD), it proved to be too insensitive to slight variations. Float gauge readings are not included in this report. Since steady flow is an essential condition for accurate discharge, another indicator was required.

The device most sensitive to flow variations is the scale/weighing tank system. With the valves open in the weighing tank, an equilibrium is reached where water entering the weighing tank equals the water leaving the tank plus a residual pool. At low flow rates the scale clearly indicates equilibrium, with readings remaining constant, typically within plus or minus 2 pounds. Since scale readings remain steady, pump discharge is constant at any valve setting. This indicated that the pumps operated without significant head or discharge fluctuations in the lower flow ranges (but greater than 0.02 c.f.s.). At flows near zero c.f.s. (less than 0.02 c.f.s.) the constant head tank was used in conjunction with multiple runs to assure equilibrium flow rates. At higher flow rates the point gage was used to assume that equilibrium flow conditions had been reached. While design considerations indicated that pump flow would be constant, test verification was necessary.

The constant head tank (Figures 14 and 15) was used to obtain very low flow rates, less than 0.02 c.f.s. The tank was maintained at overflowing to provide the constant head. Equipped with the 2-inch discharge line and gate valve, the gravity tank supplied very constant low flows. The tank was used to obtain flows up to approximately 0.02 c.f.s. Above this point the flow was pumped directly to the flume from the 100 gpm pump and controlled by the gate valve on that discharge line.

Because of the extended time involved with obtaining a measurable incremental weight of flow in the weighing tank, flows less than 0.01 c.f.s. were caught in a bucket by hand and weighed on a platform scale. This procedure was utilized for the low flows on both the machined brass and the aluminum weir plates. To improve accuracy, the elapsed time of catching water with the bucket method was greater than 60 seconds. Timing was done with a mechanical stopwatch. No less than 7 catches were made for each flow rate. Specifically, timed catches were made periodically and weighed to determine if the flow rate was constant.

An attempt to measure the velocity profile in the weir box was made with a Gurley Pygmy Current Meter, Model 625. This meter is suitable for use between velocities of 0.05 to 3.00 feet per second. Using the continuity equation, $Q = AV$, (Q = flow, A = cross-sectional area, V = velocity) the mean velocity in the weir box should be near 0.12 to 0.15 feet per second. However, the current meter failed to turn, indicating either that it was not as sensitive to low velocities as rated, or that the velocity of flow in the weir box was not as great as calculated. In either case, the velocity was too small to have any significant impact (velocity head was less than 0.001 ft.), and the attempt to define a velocity profile was abandoned.

In summary, the testing procedure was developed as a result of a trial and error process and designed to be as efficient and accurate as conditions would permit. The first step of the procedure was to determine the zero points for the hook and staff gauges. This is the reading on the gauges corresponding to the same water level as the apex of the V-notch. This was accomplished by filling the weir box to the level where the water just touched the apex of the notch. The direct line from the smallest (100 gpm) pump was used to bring the water level up close to the apex. Then the direct line was shut off and the gravity tank was used for fine adjustment of the water level. When the water level reached the same level as the apex, the hook and staff gauges were read.

The flow rates of approximately 0.02 c.f.s. and above were allowed to flow into the weighing tank to determine the weight flow rate. The temperature of the water was taken every day so that a volume flow rate could be determined. When using the weighing tank, the determination of constant flow was accomplished by leaving the draining valve open and monitoring the scale arm for equilization. That is, when the scale arm was stationary it indicated that the flow rate was constant. At this point the timed weighings were started and checked for consistency. No less than 5 timings were made for each flow rate up to 1.0 c.f.s. After the timing runs were completed, the various parameters were measured, including upstream head (hook and staff gauges), head at the weir crest (directly by eye and powdered rule), and width of water at the crest (caliper).

After the flow rate passed 1.0 c.f.s., the timing was performed with an electronic stopwatch which was controlled by a photo switching transistor mounted on the face of the scale. The watch was started and stopped by the photo transistor which was activated by the scale hand passing over it. This technique could only be used to time 2000 pound increments, which was equivalent to one revolution of the scale hand. When utilizing the electronic timer, the number of timings at each flow rate was reduced to two or three. This was done for two reasons. First, the electronic timer provided a higher accuracy, never varying more than 0.04 seconds between runs. Secondly, the weighing tank was becoming difficult to drain between runs even when utilizing the diversion chute. The tank draining process often took 5 minutes.

SECTION 8

RESULTS

INTRODUCTION

The results are presented in two parts consistent with the performance of research over a period of 2.5 years. The first 1.5 years were fully funded by the Environmental Protection Agency and involved flow calibration with the precision machined brass weir (Figure 5). After the contract period was completed (December 31, 1978), work continued using the same equipment plus suitable modifications to permit very low flow calibrations (less than 0.06 c.f.s.) and the inclusion of a full range calibration using a typical aluminum straight cut field weir (Figure 6). To maintain continuity, the results of the original funded study are presented first, with the extended research being presented second.

PRECISION BRASS WEIR, MODERATE TO HIGH FLOWS

The original calibration runs on the precision brass weir covered the range of 0.06 to 3.89 c.f.s. Data collected during thirty-two runs is tabulated in the Appendix, Table A-1, and is summarized along with selected calculations in Table 2. It was intended that flow rates covered during these test runs, (0.06 - 3.89 c.f.s.), would prove or disprove the suitability of the new measurement techniques. The test parameters were measured only once per run since no variability could be detected during a run using the new measurement techniques. For flow rates less than 1 c.f.s., at least five weight/unit time measurements were taken per run. For discharges greater than 1 c.f.s. only two to three measurements were made due to the difficulty in flow diversion and weighing operations at very high flow rate. However, accuracy was so good using the electronic timing system that repeatability was obtained between the two or three runs within ±0.04 seconds. Therefore, the automatic electronic timing system made multiple runs unnecessary at high flow rates.

As can be seen from Table 2, measured flow rates correspond to those calculated by the Cone formula table values (2) within plus or minus 5%. This essentially substantiates the basic accuracy of the experimental apparatus and measurement techniques since the cone formula has been considered acceptable by most (1,2). Standard deviation values for individual runs indicate that greater error in measurement is present at higher flow rates as would be expected with manual timing. Even this insignificant error is substantially removed when the light switching circuit is used during high flow rate runs. Run number 20 has a standard deviation of almost 0.02 c.f.s.

TABLE 2. WEIR CALIBRATION DATA SUMMARY, MODERATE TO HIGH FLOWS, BRASS WEIR

Run No.	Measured Flow Rate: Mean Flow (cfs)	Measured Flow Rate: Standard Dev. (cfs)	Measured Parameters: Hook Gauge Head (ft)	Rule (in.)	Rule (ft.)	Caliper (in.)	Caliper (ft.)	Staff Gauge Head (ft.)	Calc. Table Value ** (cfs)
1	0.060	0.0009	0.220	2.50	0.208	5.28	0.440	0.23	0.058
2	0.076	0.0005	0.244	2.75	0.229	5.75	0.479	0.25	0.075
3	0.090	0.0009	0.262	2.94	0.245	6.25	0.521	0.26	0.090
4	0.103	0.0007	0.278	3.13	0.261	6.47	0.539	0.28	0.104
5	0.117	0.0009	0.292	3.25	0.271	6.84	0.570	0.29	0.118
6	0.140	0.0010	0.314	3.50	0.292	7.38	0.615	0.32	0.141
7	0.178	0.0018	0.348	3.89	0.324	7.94	0.662	0.35	0.182
8	0.219	0.0015	0.378	4.25	0.354	8.97	0.748	0.38	0.223
9	0.262	0.0024	0.408	4.59	0.383	9.59	0.799	0.41	0.270
10	0.324	0.0023	0.444	4.97	0.414	10.56	0.880	0.44	0.332
11	0.355	0.0029	0.460	5.19	0.432	11.00	0.917	0.46	0.363
12	0.446	0.0039	0.503	5.66	0.472	11.94	0.995	0.50	0.453
13	0.480	0.0037	0.518	5.81	0.484	12.50	1.042	0.52	0.487
14	0.525	0.0061	0.534	5.97	0.497	12.38	1.032	0.54	0.525
15	0.629	0.0095	0.575	6.38	0.532	13.47	1.123	0.58	0.631
16	0.698	0.0102	0.597	6.69	0.557	14.19	1.183	0.60	0.699
17	0.770	0.0078	0.613	6.94	0.578	14.94	1.245	0.63	0.740
18	0.853	0.0089	0.650	7.22	0.602	15.22	1.268	0.65	0.856
19	0.921	0.0110	0.670	7.50	0.625	15.75	1.313	0.68	0.922
20	1.029	0.0195	0.701	7.78	0.648	16.38	1.365	0.70	1.032

** calculated from the Cone Formula

continued

TABLE 2 (continued)

	Measured Flow Rate		Measured Parameters						Calc. Table Value *
Run No.	Mean Flow (cfs)	Standard Dev. (cfs)	Hook Gauge Head (ft)	Rule (in.)	Rule (ft.)	Caliper (in.)	Caliper (ft.)	Staff Gauge Head (ft.)	(cfs)
21	1.094	0.0017	0.721	8.00	0.666	16.78	1.398	0.72	1.106
22	1.228	*	0.748	8.41	0.701	17.50	1.458	--	1.212
23	1.463	*	0.811	9.00	0.750	19.19	1.599	0.81	1.481
24	1.542	*	0.821	9.19	0.766	19.41	1.618	0.83	1.527
25	1.872	*	0.888	9.94	0.828	21.09	1.758	0.89	1.855
26	1.953	*	0.906	10.06	0.838	21.44	1.787	0.90	1.949
27	2.195	*	0.947	10.56	0.880	22.50	1.875	0.95	2.175
28	2.330	*	0.973	10.81	0.901	23.12	1.927	0.98	2.375
29	2.428	*	0.993	11.00	0.917	23.25	1.938	0.99	2.447
30	2.815	*	1.054	11.66	0.972	24.78	2.065	1.06	2.837
31	3.324	*	1.121	12.44	1.037	26.63	2.219	1.13	3.305
32	3.888	*	1.192	13.25	1.104	28.09	2.341	1.20	3.849

*insufficient sample size to compute standard deviation

The timer was operated manually during this run. Run number 21 has a standard deviation of .002 c.f.s., which reflects the use of the light switching circuit in obtaining time intervals at that flow rate and above. Therefore the light switching circuit operates very satisfactorily, and increases precision of measurement. The net result of using electronic timing on high flow rate runs is the maintenance of high accuracy in spite of high flow rates.

Staff gauge readings correspond to the hook gauge readings within plus or minus 5%. This indicates that the staff gauge may be a reasonable indicator of head in spite of poor resolution typical of these gauges. However, these readings were obtained at a close range of observation in good light. Field conditions might well limit reading accuracy.

Weir discharge was calculated as follows:

$$Q = W \times \gamma$$

where:

W = the weight rate of flow, lb/sec (determined experimentally)

γ = the weight per unit volume, lb/ft^3 (temperature dependent, see Appendix A, Figure A-1, for correction curve)

Figure 31 shows fitted curves of head, staff, rule, and caliper readings plotted against measured weir discharge. By inspection, all curves have the same general shape. This is to be expected since the same physical phenomena is being measured in each case. That is, discharge over the weir is being related to a length measurement, either a depth or a width which are both closely related. The cross-sectional area of flow over a 90^o V-notch weir is approximately triangular in shape. The base width of the triangle (corresponding to the water surface) changes by an amount proportional to the altitude of the triangle (the depth over the notch). Since there is similar behavior between depth over the weir notch and weir head it is not surprising that all the measurements behave in manners described adequately by a power curve similar to the Cone formula.

The above argument led to the following analysis of data: the Cone formula $Q = 2.49\ H^{2.48}$ can be written in a generalized form:

$y = a\ x^b$ where a and b are regression coefficients. Since all the curves appear to have the same general shape, they should all be described by the same general equation with different coefficients.

This shape of curve is known generally as a power curve. Regression coefficients can be found as follows:

$$a = \exp\left[\frac{\Sigma \ln y_i}{n} - b\,\frac{\Sigma \ln x_i}{n}\right]$$

$$b = \frac{\Sigma(\ln x_i)(\ln y_i) - \frac{(\Sigma \ln x_i)(\Sigma \ln y_i)}{n}}{\Sigma(\ln x_i)^2 - \frac{(\Sigma \ln x_i)^2}{n}}$$

and

$$r^2 = \frac{\left[\Sigma(\ln x_i)(\ln y_i) - \frac{(\Sigma \ln x_i)(\Sigma \ln y_i)}{n}\right]^2}{\left[\Sigma(\ln x_i)^2 - \frac{(\Sigma \ln x_i)^2}{n}\right]\left[\Sigma(\ln y_i)^2 - \frac{(\Sigma \ln y_i)^2}{n}\right]}$$

where r is the correlation coefficient

x_i = parameter measured, run_i

y_i - flow, run_i

A regression analysis was performed on data in an attempt to describe the curves. The following equations were obtained:

Hook gage: $Q = 2.49\ H_h^{2.48}$ where H_h is the actual head over the weir as measured by the hook gage.

Rule: $Q = 3.01\ H_r^{2.51}$ where H_r is the measured vertical water height in the weir notch.

Caliper: $Q = 0.46\ H_c^{2.48}$ where H_c is the measured horizontal water surface width at the weir notch.

A measure of goodness of fit is the correlation coefficient, r. A perfect fit would correspond to a correlation of 1. The curve fits resulting from the above regression coefficients were extremely good as is listed in the table below:

Measurement	a	b	r
Hook gage	2.49	2.48	0.99993
Rule	3.01	2.51	0.99992
Caliper	0.46	2.48	0.99972

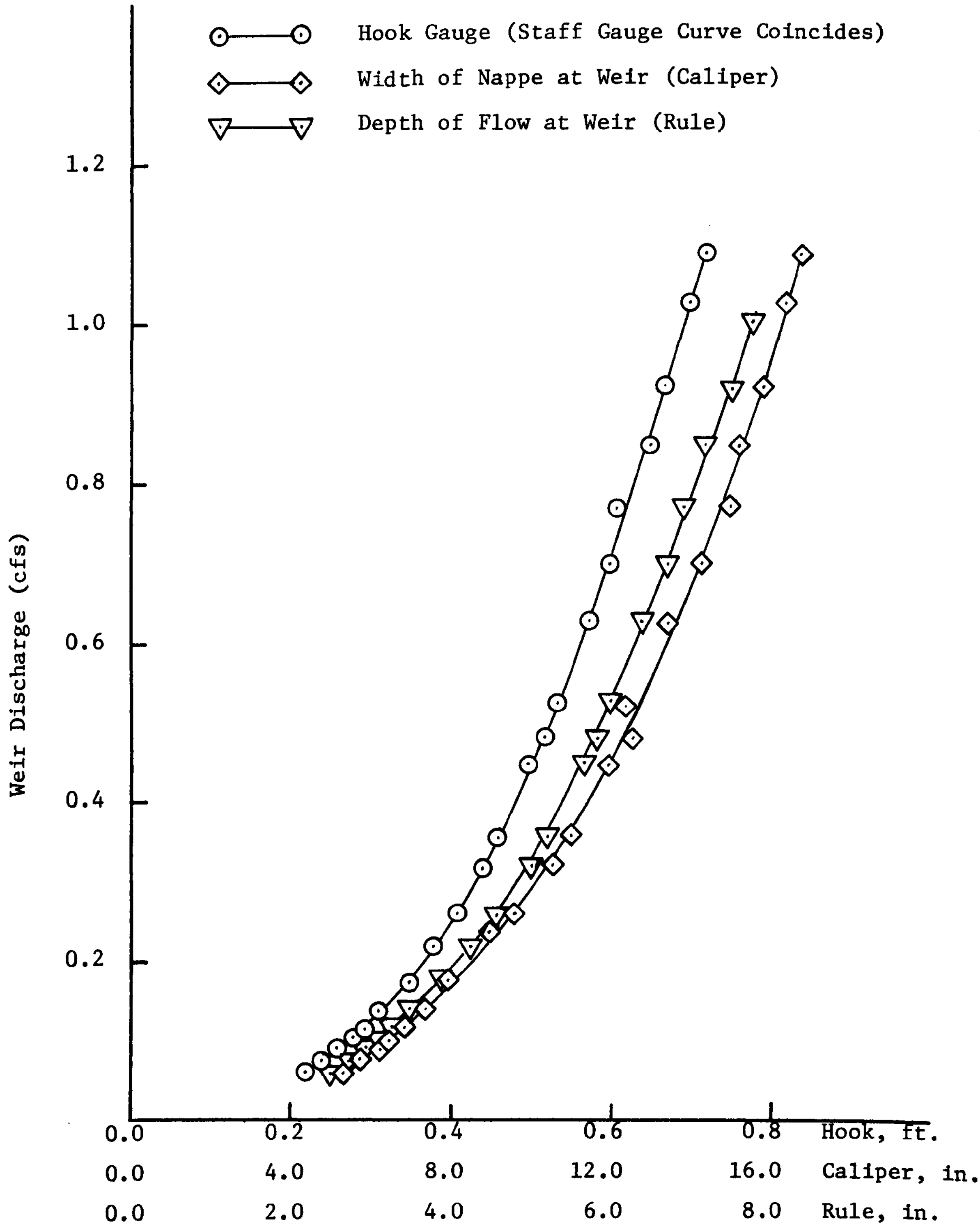

Figure 31. Head Versus Measurement Parameters for Moderate to High Flows, Brass Weir

It is interesting to note that the regression coefficients given in the cone formula were duplicated. This is a good indication that the experimental apparatus was set up and operated properly, duplicating the work of others. Care should be taken in applying these relations in cases when the approach velocity is not negligible.

During test runs, caliper measurements were the most difficult to take. The water level at the crest was very hard to see and the caliper was unwieldly to spread. The brass tips had a tendency to draw the water further up the notch by altering the surface tension effects. Given these difficulties in using the calipers, the close fit of the curve to the data points is surprising.

No difficulties were encountered in measuring depths at the weir notch by use of the rule. However, significant blockage of the flow occurs at low flow rates due to the presence of the rule. This effect is noticable at flow rates, less than approximately 0.02 c.f.s. (below calibration levels listed in Table 2). Table 3 illustrates the effect of the rule on discharge in the vicinity of 0.02 c.f.s. The effect is more pronounced as discharge drops below this level. However, the blocking effect has no impact on the accuracy of the flow measurement since the weight rate of flow is measured without the rule being placed in the notch. Thus the correlation between depth over the notch and discharge is as accurate as before. When the rule is placed in the notch the discharge is momentarily reduced but the flow rate is so low that the head over the weir will not have time to react significantly during the reading. The volume is so great in the stilling basin that flows less than 0.02 c.f.s. will not produce measurable head changes during any practical period of measurement. For example, based on the data in Table 3 showing an approximate 8% reduction in discharge, only 0.08 x 0.02 x 10 = 0.016 cubic feet of water would be blocked over a typical 10 second measuring period. In a stilling basin of 7 ft. x 8 ft. this would correspond to a 0.003 inch increase in depth over the 10 second period. Maximum measurement resolution on the rule is 0.0312 inch, a factor of 10 greater. Therefore, even under more critical conditions it is highly unlikely that this blockage effect would ever be a significant factor.

An important consideration in evaluating the new measurement techniques is the repeatability of the measurement when comparing different people performing the measurement. An experiment was devised to determine the variation due to different observers performing the same measurement. Two laboratory sections of an undergraduate hydraulics course were used to provide sample size. An average of 11 people made calibration measurements for six different discharges. The only guidance provided was a brief verbal description of how to conduct each measurement. The discharge was then stabilized and the students made measurements of flow depth at the weir using the rule, as well as the flow width using the caliper. The raw results, listed in Table A-2 of Appendix A were subjected to statistical analysis. The statistical parameters computed are listed in Table 4. Sample sizes were too small to gain much useful information from the higher order moments. However, the mean and standard deviation are useful parameters. Of interest is the error in discharge measurements induced by ± twice the standard deviation of the new calibration parameters. These calculations are summarized in Table 5.

TABLE 3. BLOCKING EFFECT OF THE RULE AT LOW DISCHARGES - WEIR BOX INFLOW HELD CONSTANT

Presence of Rule in Notch	Individual run times for Δw=20 lbs, sec	Average time, sec	Mean disch., cfs
Rule in Notch	16.95 16.12 17.06 16.19 16.71	16.61	0.0193
No rule in notch	15.52 15.16 15.15 15.01 15.45	15.26	0.0210
Rule in notch	16.21 16.13 15.76 16.48 16.06	16.13	0.0199
No rule in notch	14.90 15.09 14.79 14.51 15.80	15.02	0.0214

TABLE 4. STATISTICAL ANALYSIS PARAMETERS OF DEPTH AND WIDTH AT WEIRS, MULTIOBSERVER TESTS.

Sec/ Run No.	n	"Caliper" (width at weir), inches					"Rule" (depth at weir), inches					
		$\bar{x}$	S_x	γ_x	k_x	v_x	$\bar{y}$	S_y	γ_y	k_y	v_y	r_{xy}
M/1	10	6.538	0.087	-0.650	2.031	1.405	3.063	0.014	-0.068	-7.615	0.485	-0.164
M/3	11	9.739	0.177	1.008	2.812	1.901	4.546	0.051	-1.537	5.610	1.169	-0.580
M/7	8	12.961	0.157	0.889	2.135	1.293	6.086	0.046	1.126	3.272	0.813	-0.092
T/1	12	6.182	0.068	-0.356	1.734	1.156	2.896	0.037	0.064	1.333	1.335	0.075
T/4	12	9.657	0.134	0.202	2.005	1.446	4.586	0.059	-1.455	3.927	1.332	0.071
T/7	12	12.060	0.091	-0.925	2.830	0.784	5.716	0.058	-0.511	2.154	1.056	0.233

n = Sample Size
$\bar{x}$ = Mean (Caliper)
S_x = Standard Deviation
γ_x = Skew Coefficient
k_x = Kurtosis
v_x = Coefficient of Variation
$\bar{y}$ = Mean (Rule)
S_y = Standard Deviation
γ_y = Skew Coefficient
k_y = Kurtosis
v_y = Coefficient of Variation
r_{xy} = Correlation Coefficient

TABLE 5. EXPECTED ERROR IN FLOW MEASUREMENT BASED ON STATISTICAL PARAMETER ANALYSIS RESULTS OF MULTIOBSERVER TESTS

Sec/ Run No.	Sample Size, n	"Caliper" (width at weir), inches					"Rule" (depth at weir), inches				
		$\bar{x}$	S_x	ΔQ_s ±	ΔQ_{2s} ±	%* Error	$\bar{y}$	S_y	ΔQ_s ±	ΔQ_{2s} ±	%* Error
M/1	10	6.538	0.087	0.0034	0.0067	3/7	3.063	0.014	0.0011	0.0022	1/2
M/3	11	9.739	0.177	0.0124	0.0247	5/9	4.546	0.051	0.0074	0.0148	3/6
M/7	8	12.961	0.157	0.0167	0.0335	3/6	6.086	0.046	0.0104	0.0208	2/4
T/1	12	6.182	0.068	0.0024	0.0048	3/5	2.896	0.037	0.0027	0.0054	3/6
T/4	12	9.657	0.134	0.0092	0.0185	3/7	4.586	0.059	0.0087	0.0174	3/6
T/7	12	12.060	0.091	0.0087	0.0174	2/4	5.716	0.058	0.0119	0.0238	3/5

$\bar{x}, \bar{y}$ = sample mean

S_x, S_y = sample standard deviation

ΔQ_s = Average discharge variation for one standard deviation

ΔQ_{2s} = Average discharge variation for two standard deviations

*% error in discharge, one standard deviation/two standard deviation

Even though the measurements were made by untrained students in a hurried atmosphere, the error on all measurement parameters was less than 10% at ± two standard deviations. By the laws of probability it can be expected that 95% of all measurements made will fall within the two standard deviation range. Therefore, the experimental evidence indicates that both of the new measurement parameters, the width and depth of water at the weir face, can be measured accurately using the technique described.

Precision Brass Weir, Low Flows

After completion of the original moderate to high flow calibration runs using the brass weir, additional calibration runs were conducted in the very low flow range (less than 0.06 c.f.s.). At very low flows the nappe sticks to the weir plate, effectively changing the discharge coefficient and necessitating a separate determination of discharge coefficients by regression analysis. Also, in this range the blockage effect previously discussed must be considered and rule measurements should be taken as rapidly as possible to avoid significant head increases (preferably in less than 10 seconds).

Modifications to equipment were required to avoid surging problems with the small 100 gpm pump at highly choked low flows. The constant head tank was installed as outlined in Section 6 and the discharge trough was modified as shown in Figure 32 by installing a section of pipe to collect the flow so that a bucket could be used to determine the weight rate of flow for conversion into discharge. The pipe was notched and sealed against the weir plate as shown in Figure 33.

The raw data for flow rates between 0.0009 and 0.06 c.f.s. are included in Appendix B, Table B-1. The regression coefficients a and b are listed in Appendix C, Table C-1, both in feet and inches.

Straight-Cut Aluminum Field Weir, All Flows

The aluminum field weir plate was attached to the back of the brass weir such that the notch was approximately one inch above the notch in the brass weir. This resulted in an approximate one inch extension of the aluminum weir crest above that of the brass weir plate such that the brass weir did not interfere with the flow over the aluminum crest. At very low flows the aluminum weir flow nappe did not cling to the weir face as had occurred with the brass weir, Therefore, only one regression analysis was conducted for each of the measurement parameters. The powdered rule measurement was added to the list of measurements with the aluminum field weir since it proved to be easier to accomplish the reading using the meter stick in this manner (Section 7). All regression coefficients for both feet and inches are included in Appendix C, Table C-1.

Flow Calibration Tables for Field Use

Flow calibration tables for field use are included in Appendix C. Four tables are provided for convenience. The precision machined brass weir (Tables C-2 and C-3) will probably not often be encountered in the field due to the expense in machining the beveled crest. The values of discharge cover

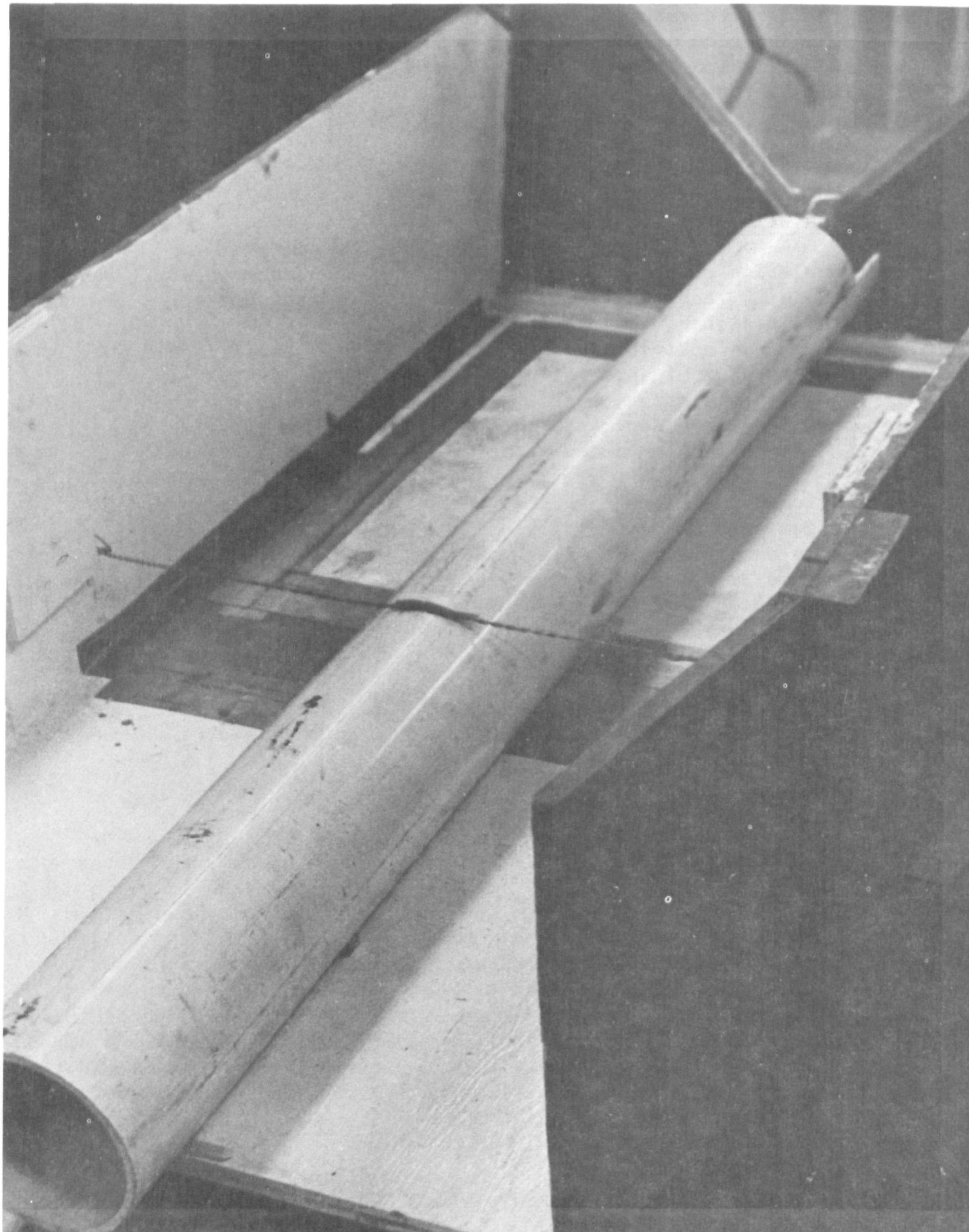

Figure 32. Installation of Plastic Pipe Section in Flow Trough to Facilitate Low Flow Measurements

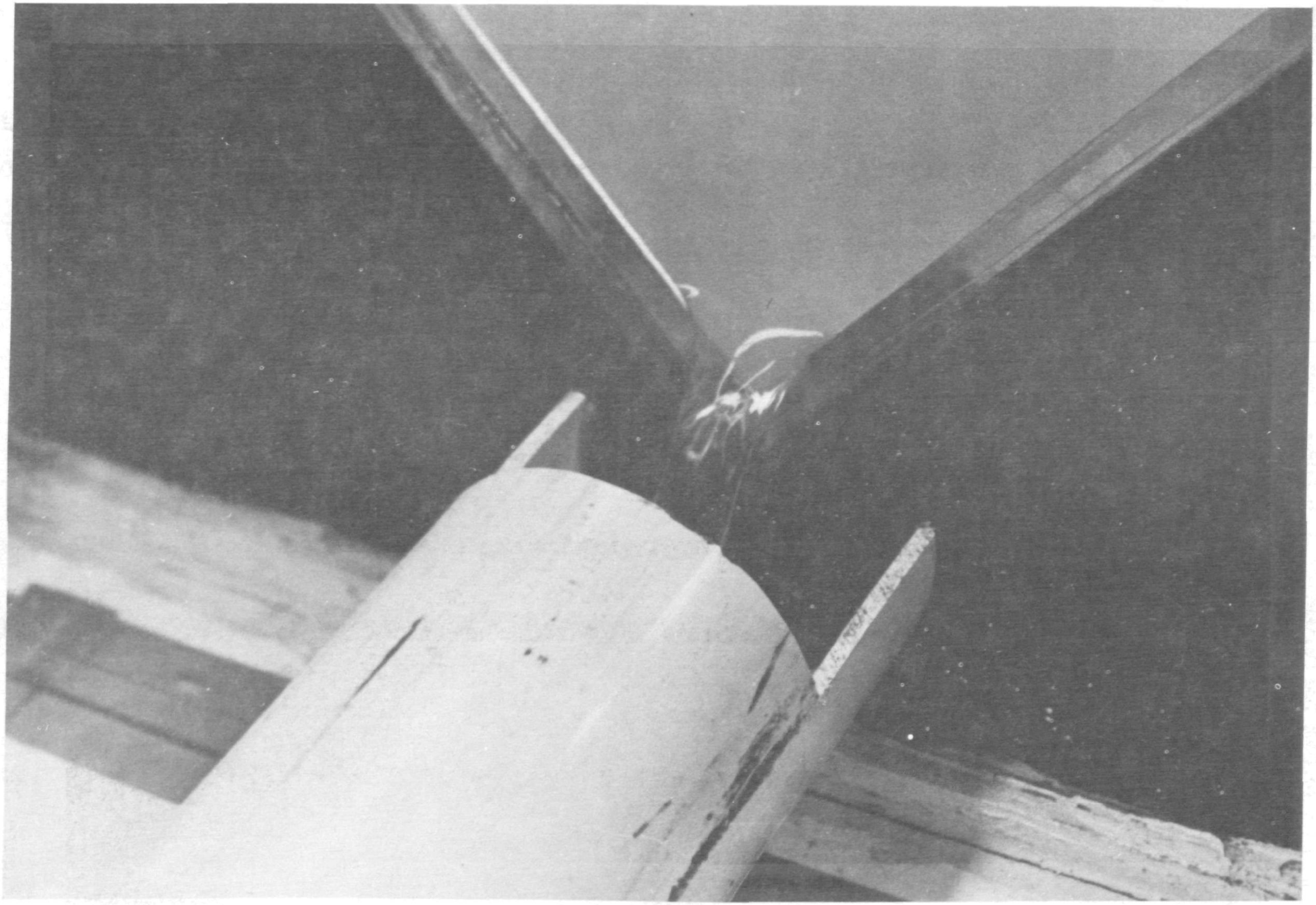

Figure 33. Close-up View of Notch in Plastic Pipe to Contain Flow Nappe

an approximate range from 0.001 to 4.500 c.f.s. The discharge values were calculated using the regression coefficients listed in Table C-1. The brass weir tables make use of low flow regression coefficients in the range from 0 to 0.06 c.f.s., approximately, and moderate to high flow coefficients above 0.06 c.f.s. The aluminum field weir uses one set of coefficients for the entire flow range. The tables are provided in both feet and inches. The "rule" measurement for the aluminum weir uses the coefficients for the direct read approach, not the "powdered" rule method. However, if the powdered rule method is used in the field, then the tables will still be adequate for use since the regression coefficients are very similar and no appreciable error will result. Theoretically, both techniques should result in the same regression coefficients. The only explanation for variation between coefficients is sampling error.

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APPENDIX A

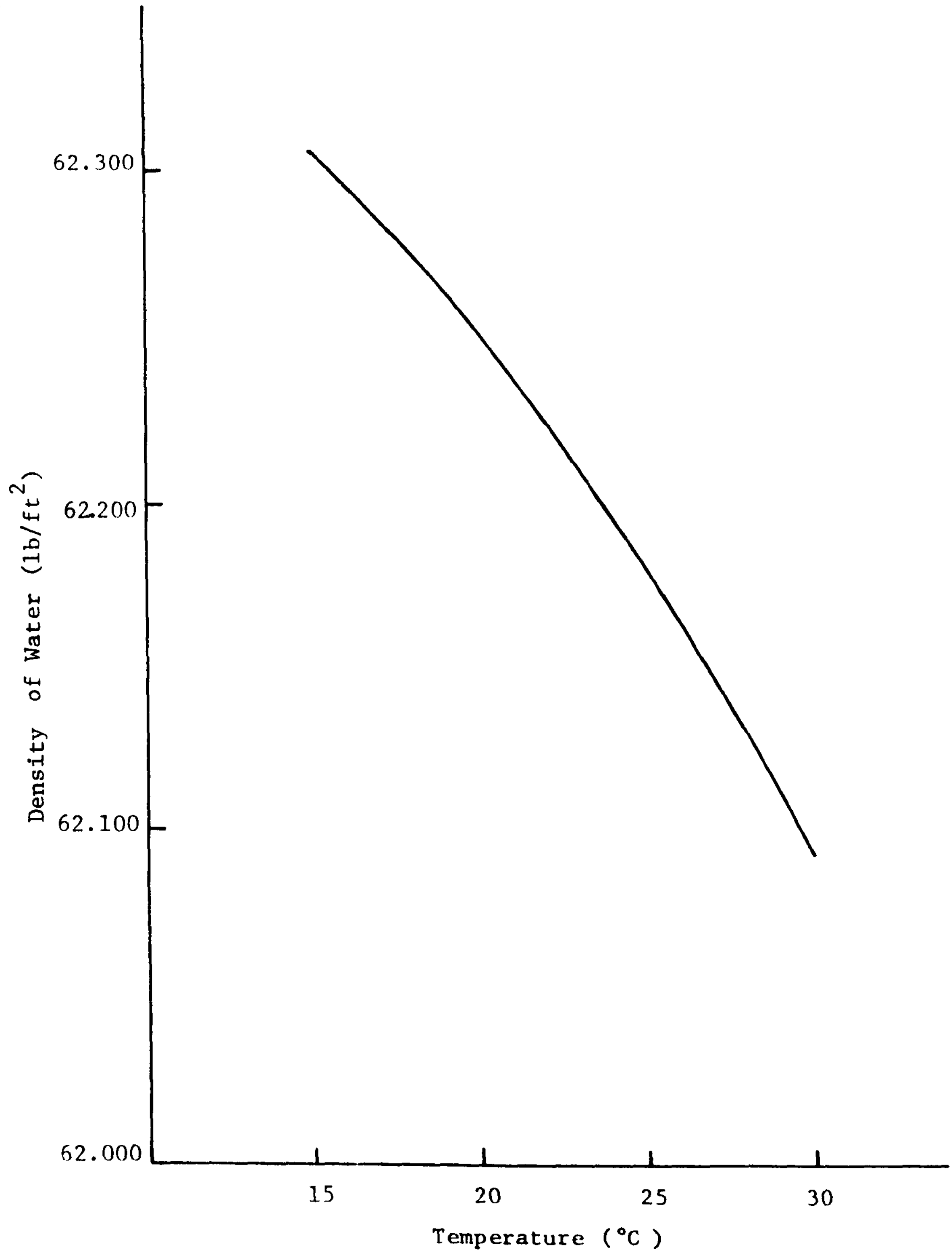

Figure A-1. Density of Water as a Function of Temperature

TABLE A-1. RAW DATA, BRASS WEIR, MODERATE TO HIGH FLOW CALIBRATION RUNS

Run No.	Water Temp.	Increment Weight Measured (lb)	Elapsed Time (sec)	Cubic Feet per second	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
1	20.4°C	100	27.00	0.060	1.033	2-16/32	5-9/32	2.93
			26.63	0.060				
			26.98	0.060		Knapp sticking to plate		
			27.22	0.059				
			27.11	0.059		on both sides		
			26.87	0.060		Hook Gauge Zero = 0.813		
			27.66	0.058				
			26.57	0.061		Staff Gauge Zero = 2.00		
2	20.5°C	100	21.07	0.076	1.057	2-24/32	5-24/32	2.25
			21.02	0.076				
			21.11	0.076				
			21.34	0.075		Knapp sticking to plate		
			21.26	0.076				
			21.18	0.076		on both sides		
			21.39	0.075				
			21.10	0.076				
3	20.5°C	100	17.68	0.091	1.075	2-30/32	6-8/32	2.265
			17.67	0.091				
			17.66	0.091				
			18.14	0.089				
			17.95	0.090		Knapp sticking to plate		
			17.87	0.090		on both sides		
			17.96	0.089				
			17.70	0.091				

continued

TABLE A-1 (continued)

Run No.	Water Temp.	Increment Weight Measured (lb)	Elapsed Time (sec)	Cubic Feet per second	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
4	20.5°C	200	31.15	0.103	1.091	3-4/32	6-15/32	2.28
			30.94	0.104				
			31.29	0.103				
			31.34	0.103	Clings to bevel.			
			30.99	0.104	Almost springs free.			
			31.30	0.103				
			31.23	0.103				
			31.59	0.102				
5	20.3°C	200	27.45	0.117	1.105	3-8/32	6-27/32	2.29
			27.27	0.118				
			27.52	0.117	Clings to bevel.			
			27.54	0.117				
			27.30	0.118	Springs free inter-			
			27.63	0.116	mittently.			
			27.57	0.117				
			27.95	0.115				
6	20.0°C	200	22.78	0.141	1.127	3-16/32		
			22.71	0.142				
			22.96	0.140				
			22.83	0.141				
			22.86	0.141				
			23.02	0.140	Springs free inter-			
			23.18	0.139	mittently.			
			23.16	0.139				
			23.15	0.139				
			22.93	0.140				
			23.04	0.139				

continued

TABLE A-1 (continued)

Run No.	Water Temp.	Increment Weight Measured (lb)	Elapsed Time (sec)	Cubic Feet per second	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
7	17.0°C	200	17.97	0.179	1.161	3-28/32	7-30/32	2.35
			18.18	0.177				
			18.21	0.176				
			17.68	0.182		Water springs free periodically.		
			18.17	0.177				
			18.09	0.178				
			18.21	0.176				
			18.15	0.177				
8	17.0°C	200	14.63	0.220	1.191	4-8/32	8-31/32	2.38
			14.45	0.222				
			14.69	0.219				
			14.68	0.219		Water springs free. Sticks to bevel periodically.		
			14.59	0.220				
			14.79	0.217				
			14.64	0.219				
			14.59	0.220				
9	17.0°C	200	12.03	0.267	1.221	4-19/32	9-19/32	2.405
			12.26	0.262				
			12.32	0.261				
			12.25	0.262		Water springs free.		
			12.36	0.260				
			12.39	0.259				
			12.20	0.263				
			12.31	0.261				

continued

TABLE A-1 (continued)

Run No.	Water Temp.	Increment Weight Measured (lb)	Elapsed Time (sec)	Cubic Feet per second	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
10	17.0°C	300	14.70	0.328	1.257	4-31/32	10-18/32	2.445
			14.82	0.325				
			14.96	0.322				
			14.87	0.324				
			14.84	0.325	Water springing free.			
			14.88	0.324				
			15.07	0.320				
			14.87	0.324				
11	17.0°C	400	17.78	0.361	1.273	5-6/32	11-00/32	2.46
			18.21	0.353				
			18.07	0.355				
			17.96	0.358				
			18.07	0.355	Water springing free.			
			18.18	0.353				
			18.08	0.355				
			18.20	0.353				
12	15.9°C	500	17.80	0.451	1.316	5-21/32	11-30/32	2.50
			17.83	0.450				
			18.10	0.443				
			18.02	0.445				
			17.95	0.447	Water springing free.			
			18.25	0.440				
			18.05	0.445				

continued

TABLE A-1 (continued)

Run No.	Water Temp.	Increment Weight Measured (lb)	Elapsed Time (sec)	Cubic Feet per second	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
13	15.5°C	500	16.59	0.484	1.331	5-26/32	12-16/32	2.52
			16.58	0.481				
			16.51	0.486				
			16.73	0.480	Water springing free.			
			16.66	0.479				
			16.75	0.479				
			16.89	0.475				
			16.86	0.476				
14	17.2°C	500	15.25	0.526	1.347	5-31/32	12-12/32	2.54
			15.48	0.519				
			15.37	0.522				
			15.17	0.529				
			15.37	0.522	Water springing free.			
			15.38	0.522				
			14.94	0.537				
			15.44	0.520				
15	17.3°C	500	12.64	0.635	1.388	6-12/32	13-15/32	2.575
			12.84	0.625				
			12.84	0.625				
			12.50	0.642				
			12.86	0.624	Water springing free.			
			12.91	0.622				
			12.48	0.643				
			12.99	0.618				

continued

TABLE A-1 (continued)

Run No.	Water Temp.	Increment Weight Measured (lb)	Elapsed Time (sec)	Cubic Feet per second	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
16	17.3°C	600	13.91	0.693	1.412	6-22/32	14-6/32	2.595
			13.59	0.709				
			13.92	0.692				
			13.95	0.691				
			13.52	0.713	Water springing free.			
			13.89	0.694				
			14.05	0.686				
			13.60	0.708				
17	17.3°C	600	12.57	0.766	1.426	6-30/32	14-30/32	2.63
			12.44	0.774				
			12.47	0.773	Water springing free;			
			12.71	0.758	Tank becoming difficult			
			12.39	0.777	to drain between runs.			
			13.17	0.975				
			13.06	0.983				
18	17.3°C	700	13.18	0.975	1.463	7-7/32	15-7/32	2.65
			13.07	0.983				
			13.40	0.959	Water springing free.			
			13.83	1.045				
			14.08	1.026				

continued

TABLE A-1 (continued)

Run No.	Water Temp.	Increment Weight Measured (lb)	Elapsed Time (sec)	Cubic Feet per second	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
19	17.3°C	800	13.77	1.049	1.483	7-16/32	15-24/32	2.675
			14.09	1.026				
			13.83	1.045				
			14.14	1.022	Water springing free.			
			15.80	1.016				
			15.09	1.064				
20	17.5°C	1000	15.70	1.023	1.514	7-25/32	16-12/32	2.70
			15.57	1.031				
			15.53	1.034	Water springing free.			
			15.93	1.008				
			29.41	1.092				
21	18°C	2000	29.32	1.095	1.534	8-00/32	16-25/32	2.72
			29.35	1.094				
					Light sensitive switch activated. Trap door activated excessive leakage.			

continued

TABLE A-1 (continued)

Run No.	Water Temp.	Increment Weight Measured (lb)	Elapsed Time (sec)	Cubic Feet per second	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
22	$12.5^{\circ}C$	2000	26.13 26.12*	1.228	1.571	8-13/32	17-16/32	--
23	$15^{\circ}C$	2000	21.94 21.94	1.463	1.628	9-00/32	19-6/32	2.81
24	$12.5^{\circ}C$	2000	20.81 20.81	1.542	1.644	9-6/32	19-13/32	2.83
25	$12.5^{\circ}C$	2000	17.12 17.16 17.14	1.872	1.711	9-30/32	21-3/32	2.89
26	$13^{\circ}C$	2000	16.46 16.42 16.43	1.953	1.728	10-2/32	21-4/32	2.90
27	$12.5^{\circ}C$	2000	14.61 14.63	2.195	1.770	10-18/32	22-16/32	2.95
28	$13^{\circ}C$	2000	13.76 13.79 13.78	2.330	1.795	10-26/32	23-4/32	2.98

continued

TABLE A-1 (continued)

Run No.	Water Temp.	Increment Weight Measured (lb)	Elapsed Time (sec)	Cubic Feet per second	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
29	13°C	2000	13.21 13.23	2.428	1.810	11-00/32	23-8/32	2.99
30	13°C	2000	11.41 11.39	2.815	1.871	11-21/32	24-25/32	3.06
31	13°C	2000	9.65 9.66	3.324	1.943	12-14/32	26-20/32	3.13
32	13°C	2000	8.27 8.24	3.888	2.014	13-8/32	28-3/32	3.20

TABLE A-2. RAW DATA, MULTIOBSERVER EXPERIMENT

Run No.	Caliper (in)	Meter Stick (in)	Hook Gauge (ft)	Average Time (sec)	Weight Difference (lb)	Discharge (cfs)
M-1	6 19/32	3 1/32	1.085	16.42	100	.0972
	6 19/32	3 2/32				
	6 17/32	3 3/32				
	6 13/32	3 2/32				
	6 16/32	3 2/32				
	6 20/32	3 2/32				
	6 16/32	3 2/32				
	6 16/32	3 2/32				
	6 12/32	3 2/32				
	6 20/32	3 2/32				
	6 20/32	3 2/32				
M-3	10 2/32	4 13/32	1.221	6.05	100	.2653
	9 22/32	4 18/32				
	9 24/32	4 18/32				
	9 25/32	4 17/32				
	9 24/32	4 17/32				
	9 17/32	4 18/32				
	9 20/32	4 18/32				
	9 21/32	4 17/32				
	9 18/32	4 18/32				
	10 3/32	4 18/32				
	9 20/32	4 20/32				

continued

TABLE A-2 (continued)

Run No.	Caliper (in)	Meter Stick (in)	Hook Gauge (ft)	Average Time (sec)	Weight Difference (lb)	Discharge (cfs)
M-7	12 29/32	6 2/32	1.359	11.60	400	.5535
	12 26/32	6 6/32				
	12 27/32	6 1/32				
	13 6/32	6 4/32				
	12 26/32	6 3/32				
	12 30/32	6 2/32				
	12 30/32	6 2/32				
	13 8/32	6 2/32				
T-1	6 8/32	2 30/32	1.070	18.92	100	.0848
	6 8/32	2 30/32				
	6 6/32	2 38/32				
	6 8/32	2 30/32				
	6 8/32	2 28/32				
	6 4/32	2 28/32				
	6 4/32	2 27/32				
	6 7/32	2 27/32				
	6 3/32	2 28/32				
	6 4/32	2 30/32				
	6 2/32	2 30/32				
	6 8/32	2 28/32				

continued

TABLE A-2 (continued)

Run No.	Caliper (in)	Meter Stick (in)	Hook Gauge (ft.)	Average Time (sec)	Weight Difference (lb)	Discharge (cfs)
T-4	9 14/32	4 18/32	1.224	17.91	300	.2689
	9 18/32	4 18/32				
	9 22/32	4 20/32				
	9 16/32	4 20/32				
	9 24/32	4 19/32				
	9 20/32	4 20/32				
	9 24/32	4 20/32				
	9 28/32	4 20/32				
	9 28/32	4 16/32				
	9 18/32	4 14/32				
	9 18/32	4 20/32				
	9 22/32	4 20/32				
T-7	11 30/32	5 23/32	1.326	13.50	400	.4756
	12 00/32	5 23/32				
	12 04/32	5 26/32				
	11 30/32	5 24/32				
	12 04/32	5 20/32				
	11 28/32	5 20/32				
	12 04/32	5 20/32				
	12 04/32	5 24/32				
	12 04/32	5 24/32				
	12 03/32	5 24/32				
	12 04/32	5 23/32				
	12 04/32	5 24/32				

TABLE B-1. RAW DATA, LOW FLOW CALIBRATION, BRASS WEIR

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
1	20.0	6.875	120.2	0.00092	0.041	7/16	1	0.04
			120.4	0.00092				
			120.7	0.00091				
			120.3	0.00092				
			120.3	0.00092		Nappe sticking to plate		
			120.4	0.00092				
			120.9	0.00091				
			120.1	0.00092				
2	20.0	17.94	60.5	0.00476	0.078	27/32	1-13/16	0.08
		17.97	60.2	0.00479				
		17.97	60.2	0.00479				
		18.09	60.5	0.00480				
		18.19	60.6	0.00482				
		18.06	60.2	0.00482		Nappe sticking to plate		
		18.12	60.4	0.00482				
		18.03	60.0	0.00482				
3	20.0	80	120.9	0.01062	0.112	1- 1/4	2-10/16	0.11
			121.5	0.01057				
			119.8	0.01072				
			120.4	0.01066		Nappe sticking, half		
			118.6	0.01082		free on one side		
			120.7	0.01064				
			120.6	0.01064				
			120.0	0.01070				

continued

TABLE B-1 (continued)

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
4	20.0	80	85.8	0.0150	0.13	1-13/32	2-27/32	0.13
			86.3	0.0149				
			87.7	0.0146				
			85.0	0.0151		Nappe sticking, half free on both sides		
			86.0	0.0149				
			85.7	0.0150				
			87.5	0.0147				
			86.4	0.0149				
5	20.0	80	64.9	0.0198	0.141	1- 9/16	3- 6/16	0.145
			64.6	0.0199				
			65.1	0.0197				
			65.3	0.0197		Nappe sticking, half free on both sides		
			65.1	0.0197				
			64.8	0.0198				
			64.2	0.0200				
			64.8	0.0198				
6	20.0	80	49.5	0.0259	0.157	1-25/32	3-23/32	0.16
			50.5	0.0254				
			50.1	0.0256				
			49.5	0.0259		Nappe sticking, half free on both sides		
			49.8	0.0258				
			49.5	0.0259				
			50.0	0.0257				
			49.9	0.0257				

continued

TABLE B-1 (continued)

Run No.	Water Temp. (^oC)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
7	20.0	80	47.0	0.0273	0.164	1-14/16	3- 13/16	0.17
			46.0	0.0279				
			46.2	0.0278				
			46.1	0.0278		Nappe sticking, half free on both sides		
			46.7	0.0275				
			46.5	0.0276				
			46.1	0.0278				
			46.2	0.0278				
8	20.0	80	36.4	0.0353	0.183	2- 1/16	3-15/16	0.18
			35.8	0.0359				
			35.3	0.0364				
			35.6	0.0361				
			35.1	0.0366		Nappe free on one side		
			35.7	0.0360				
			35.7	0.0360				
			36.0	0.0357				
9	20.0	80	32.6	.0394	0.191	2- 5/32	4- 5/32	0.19
			32.3	.0397				
			31.8	.0404				
			31.8	.0404		Water springing free		
			31.5	.0408		Knapp sticking on one side		
			32.5	.0395				
			32.2	.0399				
			32.0	.0401				

continued

TABLE B-1 (continued)

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)
10	20.0	80	30.2	.0425	0.197	2- 3/16	4- 9/32	0.20
			29.8	.0431				
			29.6	.0434				
			29.4	.0437		Water springing free		
			29.6	.0434		both sides		
			29.4	.0437				
			30.2	.0425				
			29.7	.0432				
11	20.0	80	25.2	.0509	0.211	2- 6/16	4- 9/16	0.21
			25.1	.0512				
			25.3	.0507				
			25.2	.0509				
			25.0	.0514		Water springing free		
			25.0	.0514		both sides		
			25.3	.0507				
			25.0	.0514				
12	20.0	100	30.0	.0535	0.217	2-13/32	4-27/32	0.22
			29.6	.0542				
			29.3	.0548				
			29.1	.0552		Water springing free		
			29.0	.0553		both sides		
			29.3	.0548				
			29.4	.0546				
			29.3	.0548				

TABLE B-2. RAW DATA, CALIBRATION RUNS, ALUMINUM WEIR

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
1	19.4	10.25	60.3	0.00272	0.061	11/16	1- 8/16	0.07	11/16
		10.12	60.2	0.00270					
		10.06	60.3	0.00268					
		10.19	60.3	0.00271				Water springing	
		10.19	60.4	0.00271				free with trickle	
		10.12	60.3	0.00269				from notch.	
		10.06	60.2	0.00268					
		10.00	59.9	0.00268					
2	19.4	80	130.0	0.00987	0.104	1- 3/16	2- 2/16	0.11	1- 5/32
			130.0	0.00987					
			128.0	0.01003					
			130.9	0.00981				Water springing	
			129.2	0.00994				free with trickle	
			127.0	0.01011				from notch.	
			132.0	0.00972					
3	19.4	80	26.0	0.0494	0.201	2- 4/16	4-11/32	0.205	2- 9/32
			25.6	0.0501					
			25.5	0.0503					
			25.6	0.0501				Water springing	
			25.2	0.0509				free with trickle	
			25.6	0.0501				from notch.	
			25.8	0.0498					
			25.7	0.0499					

continued

TABLE B-2 (continued)

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
4	19.0	12.06	30.2	0.00641	0.085	1	1-27/32	0.08	1
		12.06	30.0	0.00645					
		12.12	30.2	0.00644					
		12.06	30.0	0.00645				Water springing free with trickle from notch.	
		12.06	29.8	0.00649					
		12.31	30.5	0.00648					
		12.12	29.9	0.00650					
		12.31	30.4	0.00650					
5	19.0	80	53.7	0.0239	0.146	1-11/16	3- 2/16	0.14	1-11/16
			53.4	0.0240					
			53.2	0.0241					
			52.7	0.0243				Water springing free with trickle from notch.	
			52.8	0.0243					
			53.1	0.0242					
			52.0	0.0247					
			52.2	0.0246					
6	19.0	80	39.6	0.0324	0.166	1-29/32	3- 9/16	0.16	1-29/32
			39.5	0.0325					
			39.3	0.0327					
			38.8	0.0331				Water springing free with trickle from notch.	
			39.6	0.0324					
			38.9	0.0330					
			38.6	0.0332					
			38.9	0.0330					

continued

TABLE B-2 (continued)

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
7	18.0	80	31.9	0.0402	0.186	2- 1/16	3-14/16	0.185	2- 1/16
			31.3	0.0410					
			32.0	0.0401					
			31.2	0.0411					
			31.9	0.0402				Water springing free with trickle from notch.	
			31.7	0.0405					
			31.9	0.0402					
			31.3	0.0410					
8	18.0	100	25.9	0.0619	0.222	2-15/32	4-10/16	0.215	2- 8/16
			25.8	0.0622					
			25.8	0.0622					
			25.5	0.0629					
			25.6	0.0627				Water springing free with trickle from notch.	
			26.1	0.0615					
			25.6	0.0627					
			25.4	0.0632					
9	18.0	100	22.8	0.0704	0.232	2-19/32	5- 1/16	0.225	2-10/16
			22.9	0.0700					
			22.7	0.0707					
			23.2	0.0691					
			22.7	0.0707				Water springing free with trickle from notch.	
			22.9	0.0700					
			23.0	0.0697					
			22.8	0.0704					

continued

TABLE B-2 (continued)

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
10	17.5	100	20.5	0.0782	0.241	2-11/16	5- 5/16	0.235	2-11/16
			20.5	0.0782					
			20.8	0.0771				Water springing free with trickle from notch.	
			20.6	0.0779					
			20.8	0.0771					
			21.0	0.0764					
			21.0	0.0764					
11	17.5	100	17.6	0.0911	0.258	2-14/16	5-12/16	0.255	2-14/16
			17.4	0.0922					
			17.6	0.0911					
			17.6	0.0911				Water springing free with trickle from notch.	
			17.7	0.0906					
			18.0	0.0891					
			17.8	0.0901					
			18.4	0.0872					
12	17.5	200	28.5	0.113	0.280	3- 2/16	6- 3/16	0.275	3- 2/16
			28.8	0.111					
			29.2	0.110					
			30.3	0.106				Water springing free completely.	
			30.0	0.107					
			29.6	0.108					
			29.0	0.111					
			28.7	0.112					

continued

TABLE B-2 (continued)

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
13	17.5	200	23.7	0.135	0.303	3- 6/16	6-11/16	0.300	3- 6/16
			24.1	0.133					
			25.0	0.128					
			24.7	0.130				Water springing free.	
			24.3	0.132					
			23.8	0.135					
			24.0	0.134					
			24.3	0.132					
14	17.5	200	19.2	0.167	0.331	3-11/16	7- 7/16	0.325	3-11/16
			19.3	0.166					
			20.0	0.160					
			19.5	0.164					
			19.1	0.168				Water springing free.	
			19.0	0.169					
			19.2	0.167					
			19.7	0.163					
15	17.5	200	16.3	0.197	0.354	3-15/16	8	0.35	3-15/16
			16.4	0.196					
			16.9	0.190					
			16.6	0.193				Water springing free.	
			16.3	0.197					
			16.2	0.198					
			16.3	0.197					
			16.6	0.193					

continued

TABLE B-2 (continued)

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
16	18.0	200	15.1	0.212	0.371	4- 2/16	8-13/32	0.365	4- 2/16
			14.7	0.218					
			14.5	0.221					
			14.5	0.221				Water springing free.	
			14.7	0.218					
			15.3	0.210					
			15.3	0.210					
			14.9	0.215					
17	18.0	200	12.5	0.257	0.403	4-15/32	9- 1/16	0.400	4-15/32
			12.3	0.261					
			12.0	0.267					
			12.0	0.267				Water springing free.	
			11.9	0.270					
			12.2	0.263					
			12.5	0.257					
			12.2	0.263					
18	18.0	300	15.4	0.312	0.429	4-12/16	9-21/32	0.425	4-25/32
			15.2	0.317					
			15.3	0.314					
			15.8	0.305					
			15.6	0.308				Water springing free.	
			15.2	0.317					
			15.2	0.317					
			16.0	0.301					

continued

TABLE B-2 (continued)

Run No.	Water Temp. (^oC)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
19	18.0	400	17.6	0.365	0.460	5- 3/32	10- 6/16	0.455	5- 2/16
			17.2	0.373					
			17.2	0.373					
			17.8	0.360				Water springing	
			17.3	0.371				free.	
			17.3	0.371					
			17.9	0.358					
			17.4	0.369					
20	18.0	500	19.0	0.422	0.486	5-13/32	10-31/32	0.485	5-13/32
			18.6	0.431					
			19.3	0.416					
			18.6	0.413					
			19.1	0.420				Water springing	
			19.1	0.420				free.	
			18.7	0.429					
			19.2	0.418					
			18.7	0.429					
21	18.0	500	17.8	0.451	0.501	5- 9/16	11- 7/16	0.495	5-10/16
			17.3	0.464					
			17.9	0.448					
			17.4	0.461					
			18.0	0.446				Water springing	
			17.9	0.448				free.	
			17.9	0.448					
			17.5	0.458					

continued

TABLE B-2 (continued)

Run No.	Water Temp. (^oC)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
22	18.0	500	15.6	0.514	0.529	5-14/16	11-14/16	0.520	5-14/16
			15.1	0.531					
			15.7	0.511				Water springing free.	
			15.1	0.531					
			15.6	0.514					
			15.6	0.514				Begin operating 500 gpm pump.	
			15.3	0.524					
			15.2	0.528					
23	18.0	600	16.2	0.594	0.559	6- 3/16	12-10/16	0.550	6- 7/32
			16.2	0.594					
			16.3	0.590					
			16.0	0.602				Water springing free.	
			16.4	0.587					
			16.3	0.590					
			16.4	0.587					
			16.1	0.598					
24	18.0	600	14.9	0.646	0.573	6- 6/16	13- 1/16	0.565	6- 6/16
			15.2	0.633					
			15.1	0.637					
			15.0	0.642				Water springing free.	
			15.1	0.637					
			14.9	0.646					
			15.1	0.637					
			15.1	0.637					

continued

TABLE B-2 (continued)

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
25	18.0	600	13.2	0.729	0.600	6-11/16	13-13/16	0.600	6-11/16
			13.6	0.708					
			13.3	0.724					
			13.5	0.713			Water springing free.		
			13.5	0.713					
			13.4	0.718					
			13.5	0.713					
			13.4	0.718					
26	18.0	600	11.8	0.816	0.633	7	14-15/32	0.625	7
			11.7	0.823					
			11.8	0.816					
			11.7	0.823					
			11.8	0.816			Water springing free.		
			12.0	0.802					
			11.7	0.823					
			11.8	0.816					
27	18.0	700	12.1	0.928	0.667	7-13/32	15- 5/16	0.665	7- 7/16
			12.1	0.928					
			12.3	0.913					
			12.0	0.936			Water springing free.		
			12.2	0.920					
			12.1	0.928					
			12.1	0.928					

continued

TABLE B-2 (continued)

Run No.	Water Temp. (°C)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
28	15.0	2000	30.88	1.038	0.701	7-12/16	16	0.695	7-13/16
			30.88	1.038					
			30.88	1.038				Water springing free. Begin Electronic Timing.	
29	15.0	2000	27.46	1.168	0.735	8- 2/16	16-12/16	0.730	8- 3/16
			27.49	1.167				Water springing free.	
			27.46	1.168					
30	15.0	2000	24.16	1.333	0.775	8- 9/16	17-12/16	0.770	8-10/16
			24.15	1.328				Water springing free.	
			24.16	1.333					
31	15.0	2000	20.63	1.554	0.826	9- 2/16	18-29/32	0.825	9- 3/16
			20.61	1.556				Water springing free.	

continued

TABLE B-2 (continued)

Run No.	Water Temp. (^oC)	Increment of Weight (lb)	Elapsed Time (sec)	Flow Rate (cfs)	Hook Gauge (ft)	Rule (in)	Caliper (in)	Staff (ft)	Powdered Rule (in)
32	15.0	2000	18.36	1.747	0.866	9-17/32	19-14/16	0.865	9-11/16
			18.39	1.744				Water springing free.	
33	15.0	2000	16.67	1.924	0.901	9-15/16	20- 9/16	0.900	10- 1/16
			16.63	1.928				Water springing free. Limit of 500 gpm pump.	
34	15.0	2000	15.04	2.132	0.938	10-11/32	21- 8/16	0.940	---
			15.01	2.136				Water springing free. Powdered rule too difficult to read.	
35	15.0	2000	13.63	2.353	0.977	10-25/32	22-10/16	0.975	---
			13.62	2.354				Water springing free. 500 plus 100 gpm pumps.	

APPENDIX C

TABLE C-1. REGRESSION COEFFICIENTS FOR WEIR MEASUREMENT PARAMETERS USING THE RELATION $Q=aH^b$

Weir type and conditions	Measurement type	a	b	r, correlation coefficient
bevel crest brass, low flow (0-0.06 c.f.s.)	Hook, inches	0.0053	2.441	0.99964
	Staff, inches	0.0053	2.410	0.99954
	Rule, inches	0.0066	2.361	0.99943
	Caliper, inches	0.0009	2.598	0.99788
bevel crest brass, low flow (0-0.06 c.f.s.)	Hook, feet	2.287	2.441	0.99967
	Staff, feet	2.122	2.410	0.99958
	Rule, feet	2.343	2.361	0.99946
	Caliper, feet	0.594	2.598	0.99790
bevel crest brass, moderate to high flows (0.06-4.50 c.f.s.)	Hook, inches	0.0053	2.469	0.99991
	Staff, inches	0.0049	2.505	0.99986
	Rule, inches	0.0059	2.507	0.99989
	Caliper, inches	0.0010	2.483	0.99965
bevel crest brass, moderate to high flows (0.06-4.50 c.f.s.)	Hook, feet	2.491	2.480	0.99993
	Staff, feet	2.482	2.504	0.99990
	Rule, feet	3.013	2.506	0.99992
	Caliper, feet	0.464	2.484	0.99970
aluminum straight cut field weir all flows (0.0-4.50 c.f.s.)	Hook, inches	0.0060	2.428	0.99992
	Staff, inches	0.0060	2.446	0.99879
	Rule, inches	0.0070	2.466	0.99996
	Powdered rule, inches	0.0067	2.453	0.99995
	Caliper, inches	0.0010	2.366	0.99897
aluminum straight cut field weir, all flows (0.0-4.50 c.f.s.)	Hook, feet	2.454	2.428	0.99993
	Staff, feet	2.541	2.447	0.99880
	Rule, feet	3.052	2.466	0.99992
	Powdered rule, feet	2.984	2.453	0.99997
	Caliper, feet	0.529	2.366	0.99900

TABLE C-2. 90° V-NOTCH WEIR CALIBRATION TABLE
MACHINED BRASS PLATE

Head Over Weir (Hook) (ft)	Discharge (cfs)	Water Width at Weir (ft)	Discharge (cfs)	Head at Weir (Rule) (ft)	Discharge (cfs)
0.01	---	0.02	---	0.01	---
0.02	---	0.04	---	0.02	---
0.03	---	0.06	---	0.03	0.001
0.04	0.001	0.08	0.001	0.04	0.001
0.05	0.002	0.10	0.001	0.05	0.002
0.06	0.002	0.12	0.002	0.06	0.003
0.07	0.003	0.14	0.004	0.07	0.004
0.08	0.005	0.16	0.005	0.08	0.006
0.09	0.006	0.18	0.007	0.09	0.008
0.10	0.008	0.20	0.009	0.10	0.010
0.11	0.010	0.22	0.012	0.11	0.013
0.12	0.013	0.24	0.015	0.12	0.016
0.13	0.016	0.26	0.018	0.13	0.019
0.14	0.019	0.28	0.022	0.14	0.023
0.15	0.022	0.30	0.026	0.15	0.027
0.16	0.026	0.32	0.031	0.16	0.031
0.17	0.030	0.34	0.036	0.17	0.036
0.18	0.035	0.36	0.037	0.18	0.041
0.19	0.040	0.38	0.042	0.19	0.046
0.20	0.045	0.40	0.048	0.20	0.052
0.21	0.051	0.42	0.054	0.21	0.059
0.22	0.057	0.44	0.060	0.22	0.068
0.23	0.063	0.46	0.067	0.23	0.076
0.24	0.072	0.48	0.075	0.24	0.084
0.25	0.080	0.50	0.083	0.25	0.093
0.26	0.088	0.52	0.091	0.26	0.103
0.27	0.097	0.54	0.100	0.27	0.113
0.28	0.106	0.56	0.110	0.28	0.124
0.29	0.115	0.58	0.120	0.29	0.135
0.30	0.125	0.60	0.130	0.30	0.147
0.31	0.136	0.62	0.142	0.31	0.160
0.32	0.147	0.64	0.153	0.32	0.173
0.33	0.159	0.66	0.165	0.33	0.187
0.34	0.171	0.68	0.178	0.34	0.202
0.35	0.184	0.70	0.191	0.35	0.217
0.36	0.197	0.72	0.205	0.36	0.233
0.37	0.211	0.74	0.220	0.37	0.249
0.38	0.225	0.76	0.235	0.38	0.267
0.39	0.240	0.78	0.250	0.39	0.285

(continued)

TABLE C-2 (continued)

Head Over Weir (Hook) (ft)	Discharge (cfs)	Water Width at Weir (ft)	Discharge (cfs)	Head at Weir (Rule) (ft)	Discharge (cfs)
0.40	0.255	0.80	0.267	0.40	0.303
0.41	0.271	0.82	0.283	0.41	0.323
0.42	0.288	0.84	0.301	0.42	0.343
0.43	0.305	0.86	0.319	0.43	0.363
0.44	0.323	0.88	0.338	0.44	0.385
0.45	0.341	0.90	0.357	0.45	0.407
0.46	0.360	0.92	0.377	0.46	0.430
0.47	0.380	0.94	0.398	0.47	0.454
0.48	0.400	0.96	0.419	0.48	0.479
0.49	0.421	0.98	0.441	0.49	0.504
0.50	0.443	1.00	0.464	0.50	0.530
0.51	0.465	1.02	0.487	0.51	0.557
0.52	0.488	1.04	0.511	0.52	0.585
0.53	0.511	1.06	0.536	0.53	0.614
0.54	0.536	1.08	0.562	0.54	0.643
0.55	0.560	1.10	0.588	0.55	0.674
0.56	0.586	1.12	0.615	0.56	0.705
0.57	0.612	1.14	0.642	0.57	0.737
0.58	0.639	1.16	0.671	0.58	0.769
0.59	0.666	1.18	0.700	0.59	0.803
0.60	0.695	1.20	0.730	0.60	0.838
0.61	0.724	1.22	0.760	0.61	0.873
0.62	0.753	1.24	0.792	0.62	0.909
0.63	0.784	1.26	0.824	0.63	0.947
0.64	0.815	1.28	0.857	0.64	0.985
0.65	0.846	1.30	0.890	0.65	1.024
0.66	0.879	1.32	0.925	0.66	1.064
0.67	0.912	1.34	0.960	0.67	1.104
0.68	0.946	1.36	0.996	0.68	1.146
0.69	0.981	1.38	1.033	0.69	1.189
0.70	1.016	1.40	1.070	0.70	1.233
0.71	1.053	1.42	1.109	0.71	1.277
0.72	1.090	1.44	1.148	0.72	1.323
0.73	1.127	1.46	1.188	0.73	1.369
0.74	1.166	1.48	1.229	0.74	1.417
0.75	1.205	1.50	1.270	0.75	1.465
0.76	1.245	1.52	1.313	0.76	1.515
0.77	1.286	1.54	1.356	0.77	1.565
0.78	1.328	1.56	1.400	0.78	1.617

(continued)

TABLE C-2 (continued)

Head Over Weir (Hook) (ft)	Discharge (cfs)	Water Width at Weir (ft)	Discharge (cfs)	Head at Weir (Rule) (ft)	Discharge (cfs)
0.79	1.370	1.58	1.445	0.79	1.669
0.80	1.413	1.60	1.491	0.80	1.722
0.81	1.457	1.62	1.538	0.81	1.777
0.82	1.502	1.64	1.586	0.82	1.832
0.83	1.548	1.66	1.634	0.83	1.889
0.84	1.594	1.68	1.683	0.84	1.946
0.85	1.642	1.70	1.734	0.85	2.005
0.86	1.690	1.72	1.785	0.86	2.065
0.87	1.739	1.74	1.837	0.87	2.125
0.88	1.788	1.76	1.890	0.88	2.187
0.89	1.839	1.78	1.943	0.89	2.250
0.90	1.890	1.80	1.998	0.90	2.314
0.91	1.943	1.82	2.054	0.91	2.379
0.92	1.996	1.84	2.110	0.92	2.445
0.93	2.050	1.86	2.168	0.93	2.512
0.94	2.105	1.88	2.226	0.94	2.580
0.95	2.160	1.90	2.285	0.95	2.650
0.96	2.217	1.92	2.345	0.96	2.720
0.97	2.274	1.94	2.407	0.97	2.792
0.98	2.333	1.96	2.469	0.98	2.864
0.99	2.392	1.98	2.532	0.99	2.938
1.00	2.452	2.00	2.596	1.00	3.013
1.01	2.513	2.02	2.661	1.01	3.089
1.02	2.575	2.04	2.727	1.02	3.166
1.03	2.638	2.06	2.794	1.03	3.245
1.04	2.701	2.08	2.861	1.04	3.324
1.05	2.766	2.10	2.930	1.05	3.405
1.06	2.831	2.12	3.000	1.06	3.487
1.07	2.898	2.14	3.071	1.07	3.570
1.08	2.965	2.16	3.143	1.08	3.654
1.09	3.033	2.18	3.215	1.09	3.739
1.10	3.102	2.20	3.289	1.10	3.826
1.11	3.173	2.22	3.364	1.11	3.914
1.12	3.244	2.24	3.440	1.12	4.002
1.13	3.316	2.26	3.516	1.13	4.093
1.14	3.389	2.28	3.594	1.14	4.184
1.15	3.462	2.30	3.673	1.15	4.277
1.16	3.537	2.32	3.753	1.16	4.370
1.17	3.613	2.34	3.834	1.17	4.465

(continued)

TABLE C-2 (continued)

Head Over Weir (Hook) (ft)	Discharge (cfs)	Water Width at Weir (ft)	Discharge (cfs)	Head at Weir (Rule) (ft)	Discharge (cfs)
1.18	3.690	2.36	3.916	1.18	4.562
1.19	3.767	2.38	3.999	1.19	4.659
1.20	3.846	2.40	4.083	1.20	4.758
1.21	3.926	2.42	4.168	1.21	4.858
1.22	4.006	2.44	4.254	1.22	4.959
1.23	4.088	2.46	4.341	1.23	5.062
1.24	4.170	2.48	4.429	1.24	5.165
1.25	4.254	2.50	4.518	1.25	5.270

TABLE C-3. 90° V-NOTCH WEIR CALIBRATION TABLE
MACHINED BRASS PLATE

Head Over Weir (Hook) (in)	Discharge (cfs)	Water Width at Weir (in)	Discharge (cfs)	Head at Weir (Rule) (in)	Discharge (cfs)
0.10	---	0.20	---	0.10	---
0.20	---	0.40	---	0.20	---
0.30	---	0.60	---	0.30	---
0.40	0.001	0.80	0.001	0.40	0.001
0.50	0.001	1.00	0.001	0.50	0.001
0.60	0.002	1.20	0.001	0.60	0.002
0.70	0.002	1.40	0.002	0.70	0.003
0.80	0.003	1.60	0.003	0.80	0.004
0.90	0.004	1.80	0.004	0.90	0.005
1.00	0.005	2.00	0.005	1.00	0.007
1.10	0.007	2.20	0.007	1.10	0.008
1.20	0.008	2.40	0.009	1.20	0.010
1.30	0.010	2.60	0.011	1.30	0.012
1.40	0.012	2.80	0.013	1.40	0.015
1.50	0.014	3.00	0.016	1.50	0.017
1.60	0.017	3.20	0.018	1.60	0.020
1.70	0.019	3.40	0.022	1.70	0.023
1.80	0.022	3.60	0.025	1.80	0.026
1.90	0.025	3.80	0.029	1.90	0.030
2.00	0.029	4.00	0.033	2.00	0.034
2.10	0.032	4.20	0.037	2.10	0.038
2.20	0.036	4.40	0.042	2.20	0.042
2.30	0.040	4.60	0.047	2.30	0.047
2.40	0.045	4.80	0.053	2.40	0.052
2.50	0.050	5.00	0.059	2.50	0.057
2.60	0.055	5.20	0.060	2.60	0.063
2.70	0.060	5.40	0.066	2.70	0.071
2.80	0.067	5.60	0.072	2.80	0.078
2.90	0.073	5.80	0.079	2.90	0.085
3.00	0.080	6.00	0.086	3.00	0.093
3.10	0.087	6.20	0.093	3.10	0.101
3.20	0.094	6.40	0.100	3.20	0.109
3.30	0.101	6.60	0.108	3.30	0.118
3.40	0.109	6.80	0.117	3.40	0.127
3.50	0.117	7.00	0.125	3.50	0.136
3.60	0.125	7.20	0.135	3.60	0.146
3.70	0.134	7.40	0.144	3.70	0.157
3.80	0.143	7.60	0.154	3.80	0.168
3.90	0.153	7.80	0.164	3.90	0.179
4.00	0.162	8.00	0.175	4.00	0.191

(continued)

Table C-3 (continued)

Head Over Weir (Hook) (in)	Discharge (cfs)	Water Width at Weir (in)	Discharge (cfs)	Head at Weir (Rule) (in)	Discharge (cfs)
4.10	0.173	8.20	0.186	4.10	0.203
4.20	0.183	8.40	0.197	4.20	0.215
4.30	0.194	8.60	0.209	4.30	0.229
4.40	0.206	8.80	0.221	4.40	0.242
4.50	0.217	9.00	0.234	4.50	0.256
4.60	0.229	9.20	0.247	4.60	0.271
4.70	0.242	9.40	0.261	4.70	0.286
4.80	0.255	9.60	0.275	4.80	0.301
4.90	0.268	9.80	0.289	4.90	0.317
5.00	0.282	10.00	0.304	5.00	0.334
5.10	0.296	10.20	0.319	5.10	0.351
5.20	0.311	10.40	0.335	5.20	0.368
5.30	0.325	10.60	0.351	5.30	0.386
5.40	0.341	10.80	0.368	5.40	0.405
5.50	0.357	11.00	0.385	5.50	0.424
5.60	0.373	11.20	0.403	5.60	0.443
5.70	0.390	11.40	0.421	5.70	0.463
5.80	0.407	11.60	0.440	5.80	0.484
5.90	0.424	11.80	0.459	5.90	0.505
6.00	0.442	12.00	0.478	6.00	0.527
6.10	0.461	12.20	0.498	6.10	0.549
6.20	0.479	12.40	0.519	6.20	0.572
6.30	0.499	12.60	0.540	6.30	0.595
6.40	0.518	12.80	0.561	6.40	0.619
6.50	0.539	13.00	0.583	6.50	0.644
6.60	0.559	13.20	0.606	6.60	0.669
6.70	0.581	13.40	0.629	6.70	0.695
6.80	0.602	13.60	0.652	6.80	0.721
6.90	0.624	13.80	0.677	6.90	0.748
7.00	0.647	14.00	0.701	7.00	0.775
7.10	0.670	14.20	0.726	7.10	0.803
7.20	0.693	14.40	0.752	7.20	0.832
7.30	0.717	14.60	0.778	7.30	0.861
7.40	0.742	14.80	0.805	7.40	0.891
7.50	0.767	15.00	0.832	7.50	0.922
7.60	0.792	15.20	0.860	7.60	0.953
7.70	0.818	15.40	0.888	7.70	0.985
7.80	0.845	15.60	0.917	7.80	1.017
7.90	0.872	15.80	0.947	7.90	1.050
8.00	0.899	16.00	0.977	8.00	1.084
8.10	0.928	16.20	1.007	8.10	1.118

(continued)

TABLE C-3 (continued)

Head Over Weir (Hook) (in)	Discharge (cfs)	Water Width at Weir (in)	Discharge (cfs)	Head at Weir (Rule) (in)	Discharge (cfs)
8.20	0.956	16.40	1.039	8.20	1.153
8.30	0.985	16.60	1.070	8.30	1.188
8.40	1.015	16.80	1.103	8.40	1.225
8.50	1.045	17.00	1.136	8.50	1.262
8.60	1.075	17.20	1.169	8.60	1.299
8.70	1.106	17.40	1.203	8.70	1.337
8.80	1.138	17.60	1.238	8.80	1.376
8.90	1.170	17.80	1.273	8.90	1.416
9.00	1.203	18.00	1.309	9.00	1.456
9.10	1.236	18.20	1.345	9.10	1.497
9.20	1.270	18.40	1.382	9.20	1.538
9.30	1.305	18.60	1.420	9.30	1.581
9.40	1.339	18.80	1.458	9.40	1.624
9.50	1.375	19.00	1.497	9.50	1.667
9.60	1.411	19.20	1.536	9.60	1.712
9.70	1.447	19.40	1.576	9.70	1.757
9.80	1.485	19.60	1.617	9.80	1.802
9.90	1.522	19.80	1.658	9.90	1.849
10.00	1.561	20.00	1.700	10.00	1.896
10.10	1.599	20.20	1.743	10.10	1.944
10.20	1.639	20.40	1.786	10.20	1.993
10.30	1.679	20.60	1.829	10.30	2.042
10.40	1.719	20.80	1.874	10.40	2.092
10.50	1.760	21.00	1.919	10.50	2.143
10.60	1.802	21.20	1.965	10.60	2.194
10.70	1.844	21.40	2.011	10.70	2.247
10.80	1.887	21.60	2.058	10.80	2.300
10.90	1.931	21.80	2.106	10.90	2.353
11.00	1.975	22.00	2.154	11.00	2.408
11.10	2.019	22.20	2.203	11.10	2.463
11.20	2.064	22.40	2.252	11.20	2.519
11.30	2.110	22.60	2.303	11.30	2.576
11.40	2.157	22.80	2.354	11.40	2.633
11.50	2.204	23.00	2.405	11.50	2.692
11.60	2.251	23.20	2.458	11.60	2.751
11.70	2.299	23.40	2.510	11.70	2.811
11.80	2.348	23.60	2.564	11.80	2.871
11.90	2.398	23.80	2.618	11.90	1.933
12.00	2.448	24.00	2.673	12.00	2.995
12.10	2.498	24.20	2.729	12.10	3.058
12.20	2.550	24.40	2.785	12.20	3.121

(continued)

TABLE C-3 (continued)

Head Over Weir (Hook) (in)	Discharge (cfs)	Water Width at Weir (in)	Discharge (cfs)	Head at Weir (Rule) (in)	Discharge (cfs)
12.30	2.602	24.60	2.842	12.30	3.186
12.40	2.654	24.80	2.900	12.40	3.251
12.50	2.707	25.00	2.959	12.50	3.317
12.60	2.761	25.20	3.018	12.60	3.384
12.70	2.816	25.40	3.077	12.70	3.452
12.80	2.871	25.60	3.138	12.80	3.521
12.90	2.926	25.80	3.199	12.90	3.590
13.00	2.983	26.00	3.261	13.00	3.660
13.10	3.040	26.20	3.324	13.10	3.731
13.20	3.097	26.40	3.387	13.20	3.803
13.30	3.155	26.60	3.451	13.30	3.876
13.40	3.214	26.80	3.516	13.40	3.949
13.50	3.274	27.00	3.582	13.50	4.023
13.60	3.334	27.20	3.648	13.60	4.099
13.70	3.395	27.40	3.715	13.70	4.174
13.80	3.456	27.60	3.782	13.80	4.251
13.90	3.519	27.80	3.851	13.90	4.329
14.00	3.581	28.00	3.920	14.00	4.407
14.10	3.645	28.20	3.990	14.10	4.487
14.20	3.709	28.40	4.061	14.20	4.567
14.30	3.774	28.60	4.132	14.30	4.648
14.40	3.839	28.80	4.204	14.40	4.730
14.50	3.906	29.00	4.277	14.50	4.813
14.60	3.972	29.20	4.350	14.60	4.896
14.70	4.040	29.40	4.425	14.70	4.981
14.80	4.108	29.60	4.500	14.80	5.066
14.90	4.177	29.80	4.576	14.90	5.153
15.00	4.247	30.00	4.652	15.00	5.240

TABLE C-4. 90° V-NOTCH WEIR CALIBRATION TABLE
ALUMINUM, ROUGH CUT PLATE

Head Over Weir (Hook) (ft)	Discharge (cfs)	Water Width at Weir (ft)	Discharge (cfs)	Head at Weir (Rule) (ft)	Discharge (cfs)
0.01	---	0.02	---	0.01	---
0.02	---	0.04	---	0.02	---
0.03	---	0.06	0.001	0.03	0.001
0.04	0.001	0.08	0.001	0.04	0.001
0.05	0.002	0.10	0.002	0.05	0.002
0.06	0.003	0.12	0.004	0.06	0.003
0.07	0.004	0.14	0.005	0.07	0.004
0.08	0.005	0.16	0.007	0.08	0.006
0.09	0.007	0.18	0.009	0.09	0.008
0.10	0.009	0.20	0.012	0.10	0.010
0.11	0.012	0.22	0.015	0.11	0.013
0.12	0.014	0.24	0.018	0.12	0.016
0.13	0.017	0.26	0.022	0.13	0.020
0.14	0.021	0.28	0.026	0.14	0.024
0.15	0.025	0.30	0.031	0.15	0.028
0.16	0.029	0.32	0.036	0.16	0.033
0.17	0.033	0.34	0.041	0.17	0.039
0.18	0.038	0.36	0.047	0.18	0.044
0.19	0.044	0.38	0.054	0.19	0.051
0.20	0.049	0.40	0.061	0.20	0.058
0.21	0.055	0.42	0.068	0.21	0.065
0.22	0.062	0.44	0.076	0.22	0.073
0.23	0.069	0.46	0.084	0.23	0.081
0.24	0.077	0.48	0.093	0.24	0.090
0.25	0.085	0.50	0.103	0.25	0.100
0.26	0.093	0.52	0.113	0.26	0.110
0.27	0.102	0.54	0.123	0.27	0.121
0.28	0.112	0.56	0.134	0.28	0.132
0.29	0.121	0.58	0.146	0.29	0.144
0.30	0.132	0.60	0.158	0.30	0.157
0.31	0.143	0.62	0.171	0.31	0.170
0.32	0.154	0.64	0.184	0.32	0.184
0.33	0.166	0.66	0.198	0.33	0.198
0.34	0.179	0.68	0.212	0.34	0.213
0.35	0.192	0.70	0.227	0.35	0.229
0.36	0.205	0.72	0.243	0.36	0.246
0.37	0.220	0.74	0.259	0.37	0.263

(continued)

TABLE C-4 (continued)

Head Over Weir (Hook) (ft)	Discharge (cfs)	Water Width at Weir (ft)	Discharge (cfs)	Head at Weir (Rule) (ft)	Discharge (cfs)
0.38	0.234	0.76	0.276	0.38	0.281
0.39	0.249	0.78	0.294	0.39	0.299
0.40	0.265	0.80	0.312	0.40	0.319
0.41	0.282	0.82	0.331	0.41	0.339
0.42	0.299	0.84	0.350	0.42	0.359
0.43	0.316	0.86	0.370	0.43	0.381
0.44	0.334	0.88	0.391	0.44	0.403
0.45	0.353	0.90	0.412	0.45	0.426
0.46	0.372	0.92	0.434	0.46	0.450
0.47	0.392	0.94	0.457	0.47	0.474
0.48	0.413	0.96	0.480	0.48	0.499
0.49	0.434	0.98	0.504	0.49	0.526
0.50	0.456	1.00	0.529	0.50	0.552
0.51	0.478	1.02	0.554	0.51	0.580
0.52	0.502	1.04	0.580	0.52	0.608
0.53	0.525	1.06	0.607	0.53	0.638
0.54	0.550	1.08	0.635	0.54	0.668
0.55	0.575	1.10	0.663	0.55	0.699
0.56	0.600	1.12	0.692	0.56	0.730
0.57	0.627	1.14	0.721	0.57	0.763
0.58	0.654	1.16	0.752	0.58	0.797
0.59	0.682	1.18	0.783	0.59	0.831
0.60	0.710	1.20	0.814	0.60	0.866
0.61	0.739	1.22	0.847	0.61	0.902
0.62	0.769	1.24	0.880	0.62	0.939
0.63	0.799	1.26	0.914	0.63	0.977
0.64	0.830	1.28	0.949	0.64	1.015
0.65	0.862	1.30	0.984	0.65	1.055
0.66	0.895	1.32	1.020	0.66	1.095
0.67	0.928	1.34	1.057	0.67	1.137
0.68	0.962	1.36	1.095	0.68	1.179
0.69	0.997	1.38	1.133	0.69	1.222
0.70	1.032	1.40	1.173	0.70	1.266
0.71	1.068	1.42	1.213	0.71	1.312
0.72	1.105	1.44	1.254	0.72	1.358
0.73	1.143	1.46	1.295	0.73	1.405
0.74	1.181	1.48	1.337	0.74	1.452

(continued)

TABLE C-4 (continued)

Head Over Weir (Hook) (ft)	Discharge (cfs)	Water Width at Weir (ft)	Discharge (cfs)	Head at Weir (Rule) (ft)	Discharge (cfs)
0.75	1.220	1.50	1.381	0.75	1.501
0.76	1.260	1.52	1.425	0.76	1.551
0.77	1.301	1.54	1.469	0.77	1.602
0.78	1.342	1.56	1.515	0.78	1.654
0.79	1.385	1.58	1.561	0.79	1.707
0.80	1.427	1.60	1.608	0.80	1.760
0.81	1.471	1.62	1.656	0.81	1.815
0.82	1.516	1.64	1.705	0.82	1.871
0.83	1.561	1.66	1.755	0.83	1.928
0.84	1.607	1.68	1.805	0.84	1.985
0.85	1.654	1.70	1.856	0.85	2.044
0.86	1.702	1.72	1.909	0.86	2.104
0.87	1.750	1.74	1.961	0.87	2.165
0.88	1.799	1.76	2.015	0.88	2.227
0.89	1.849	1.78	2.070	0.89	2.290
0.90	1.900	1.80	2.125	0.90	2.354
0.91	1.952	1.82	2.182	0.91	2.419
0.92	2.004	1.84	2.239	0.92	2.485
0.93	2.058	1.86	2.297	0.93	2.552
0.94	2.112	1.88	2.356	0.94	2.620
0.95	2.167	1.90	2.415	0.95	2.689
0.96	2.222	1.92	2.476	0.96	2.760
0.97	2.279	1.94	2,537	0.97	2.831
0.98	2.337	1.96	2.600	0.98	2.904
0.99	2.395	1.98	2.663	0.99	2.977
1.00	2.454	2.00	2.727	1.00	3.052
1.01	2.514	2.02	2.792	1.01	3.128
1.02	2.575	2.04	2.858	1.02	3.205
1.03	2.637	2.06	2.925	1.03	3.283
1.04	2.699	2.08	2.992	1.04	3.362
1.05	2.763	2.10	3.061	1.05	3.442
1.06	2.827	2.12	3.130	1.06	3.524
1.07	2.892	2.14	3.200	1.07	3.606
1.08	2.958	2.16	3.272	1.08	3.690
1.09	3.025	2.18	3.344	1.09	3.775
1.10	3.093	2.20	3.417	1.10	3.861
1.11	3.162	2.22	3.491	1.11	3.948

(continued)

TABLE C-4 (continued)

Head Over Weir (Hook) (ft)	Discharge (cfs)	Water Width at Weir (ft)	Discharge (cfs)	Head at Weir (Rule) (ft)	Discharge (cfs)
1.12	3.231	2.24	3.566	1.12	4.036
1.13	3.302	2.26	3.641	1.13	4.125
1.14	3.373	2.28	3.718	1.14	4.216
1.15	3.445	2.30	3.796	1.15	4.308
1.16	3.519	2.32	3.874	1.16	4.401
1.17	3.593	2.34	3.954	1.17	4.495
1.18	3.668	2.36	4.034	1.18	4.590
1.19	3.744	2.38	4.115	1.19	4.687
1.20	3.820	2.40	4.198	1.20	4.784
1.21	3.898	2.42	4.281	1.21	4.883
1.22	3.977	2.44	4.365	1.22	4.983
1.23	4.056	2.46	4.450	1.23	5.085
1.24	4.137	2.48	4.536	1.24	5.187
1.25	4.218	2.50	4.623	1.25	5.291

TABLE C-5. 90^0 V-NOTCH WEIR CALIBRATION TABLE
ALUMINUM, ROUGH CUT PLATE

Head Over Weir (Hook) (in)	Discharge (cfs)	Water Width at Weir (in)	Discharge (cfs)	Head at Weir (Rule) (in)	Discharge (cfs)
0.10	---	0.20	---	0.10	---
0.20	---	0.40	---	0.20	---
0.30	---	0.60	---	0.30	---
0.40	0.001	0.80	0.001	0.40	0.001
0.50	0.001	1.00	0.001	0.50	0.001
0.60	0.002	1.20	0.002	0.60	0.002
0.70	0.003	1.40	0.002	0.70	0.003
0.80	0.003	1.60	0.003	0.80	0.004
0.90	0.005	1.80	0.004	0.90	0.005
1.00	0.006	2.00	0.005	1.00	0.007
1.10	0.008	2.20	0.006	1.10	0.009
1.20	0.009	2.40	0.008	1.20	0.011
1.30	0.011	2.60	0.010	1.30	0.013
1.40	0.014	2.80	0.011	1.40	0.016
1.50	0.016	3.00	0.013	1.50	0.019
1.60	0.019	3.20	0.016	1.60	0.022
1.70	0.022	3.40	0.018	1.70	0.026
1.80	0.025	3.60	0.021	1.80	0.030
1.90	0.029	3.80	0.024	1.90	0.034
2.00	0.032	4.00	0.027	2.00	0.039
2.10	0.036	4.20	0.030	2.10	0.044
2.20	0.041	4.40	0.033	2.20	0.049
2.30	0.045	4.60	0.037	2.30	0.055
2.40	0.050	4.80	0.041	2.40	0.061
2.50	0.056	5.00	0.045	2.50	0.067
2.60	0.061	5.20	0.049	2.60	0.074
2.70	0.067	5.40	0.054	2.70	0.081
2.80	0.073	5.60	0.059	2.80	0.089
2.90	0.080	5.80	0.064	2.90	0.097
3.00	0.086	6.00	0.069	3.00	0.105
3.10	0.094	6.20	0.075	3.10	0.114
3.20	0.101	6.40	0.081	3.20	0.123
3.30	0.109	6.60	0.087	3.30	0.133
3.40	0.117	6.80	0.093	3.40	0.143
3.50	0.126	7.00	0.100	3.50	0.154
3.60	0.135	7.20	0.107	3.60	0.165
3.70	0.144	7.40	0.114	3.70	0.176
3.80	0.153	7.60	0.121	3.80	0.188

(continued)

TABLE C-5 (continued)

Head Over Weir (Hook) (in)	Discharge (cfs)	Water Width at Weir (in)	Discharge (cfs)	Head at Weir (Rule) (in)	Discharge (cfs)
3.90	0.163	7.80	0.129	3.90	0.201
4.00	0.174	8.00	0.137	4.00	0.214
4.10	0.184	8.20	0.145	4.10	0.227
4.20	0.196	8.40	0.154	4.20	0.241
4.30	0.207	8.60	0.163	4.30	0.255
4.40	0.219	8.80	0.172	4.40	0.270
4.50	0.231	9.00	0.181	4.50	0.286
4.60	0.244	9.20	0.191	4.60	0.302
4.70	0.257	9.40	0.201	4.70	0.318
4.80	0.271	9.60	0.211	4.80	0.335
4.90	0.284	9.80	0.221	4.90	0.352
5.00	0.299	10.00	0.232	5.00	0.370
5.10	0.313	10.20	0.243	5.10	0.389
5.20	0.329	10.40	0.255	5.20	0.408
5.30	0.344	10.60	0.267	5.30	0.428
5.40	0.360	10.80	0.279	5.40	0.448
5.50	0.376	11.00	0.291	5.50	0.469
5.60	0.393	11.20	0.304	5.60	0.490
5.70	0.411	11.40	0.317	5.70	0.512
5.80	0.428	11.60	0.330	5.80	0.534
5.90	0.446	11.80	0.344	5.90	0.557
6.00	0.465	12.00	0.358	6.00	0.581
6.10	0.484	12.20	0.372	6.10	0.605
6.20	0.504	12.40	0.386	6.20	0.630
6.30	0.524	12.60	0.401	6.30	0.655
6.40	0.544	12.80	0.417	6.40	0.681
6.50	0.565	13.00	0.432	6.50	0.708
6.60	0.586	13.20	0.448	6.60	0.735
6.70	0.608	13.40	0.464	6.70	0.762
6.80	0.630	13.60	0.481	6.80	0.791
6.90	0.653	13.80	0.498	6.90	0.820
7.00	0.676	14.00	0.515	7.00	0.849
7.10	0.700	14.20	0.532	7.10	0.880
7.20	0.724	14.40	0.550	7.20	0.910
7.30	0.749	14.60	0.569	7.30	0.942
7.40	0.774	14.80	0.587	7.40	0.974
7.50	0.799	15.00	0.606	7.50	1.007
7.60	0.826	15.20	0.626	7.60	1.040
7.70	0.852	15.40	0.645	7.70	1.074

(continued)

TABLE C-5 (continued)

Head Over Weir (Hook) (in)	Discharge (cfs)	Water Width at Weir (in)	Discharge (cfs)	Head at Weir (Rule) (in)	Discharge (cfs)
7.80	0.879	15.60	0.665	7.80	1.109
7.90	0.907	15.80	0.686	7.90	1.145
8.00	0.935	16.00	0.706	8.00	1.181
8.10	0.964	16.20	0.727	8.10	1.217
8.20	0.993	16.40	0.749	8.20	1.255
8.30	1.023	16.60	0.771	8.30	1.293
8.40	1.053	16.80	0.793	8.40	1.332
8.50	1.083	17.00	0.815	8.50	1.371
8.60	1.115	17.20	0.838	8.60	1.411
8.70	1.146	17.40	0.861	8.70	1.452
8.80	1.179	17.60	0.885	8.80	1.493
8.90	1.211	17.80	0.909	8.90	1.536
9.00	1.245	18.00	0.933	9.00	1.579
9.10	1.278	18.20	0.958	9.10	1.622
9.20	1.313	18.40	0.983	9.20	1.666
9.30	1.348	18.60	1.008	9.30	1.711
9.40	1.383	18.80	1.034	9.40	1.757
9.50	1.419	19.00	1.061	9.50	1.804
9.60	1.456	19.20	1.087	9.60	1.851
9.70	1.493	19.40	1.114	9.70	1.899
9.80	1.531	19.60	1.141	9.80	1.947
9.90	1.569	19.80	1.169	9.90	1.997
10.00	1.607	20.00	1.197	10.00	2.047
10.10	1.647	20.20	1.226	10.10	2.098
10.20	1.687	20.40	1.255	10.20	2.149
10.30	1.727	20.60	1.284	10.30	2.202
10.40	1.768	20.80	1.314	10.40	2.255
10.50	1.810	21.00	1.344	10.50	2.309
10.60	1.852	21.20	1.374	10.60	2.363
10.70	1.894	21.40	1.405	10.70	2.419
10.80	1.938	21.60	1.437	10.80	2.475
10.90	1.982	21.80	1.468	10.90	2.532
11.00	2.026	22.00	1.500	11.00	2.589
11.10	2.071	22.20	1.533	11.10	2.648
11.20	2.117	22.40	1.566	11.20	2.707
11.30	2.163	22.60	1.599	11.30	2.767
11.40	2.210	22.80	1.633	11.40	2.828
11.50	2.257	23.00	1.667	11.50	2.889
11.60	2.305	23.20	1.701	11.60	2.952

(continued)

TABLE C-5 (continued)

Head Over Weir (Hook) (in)	Discharge (cfs)	Water Width at Weir (in)	Discharge (cfs)	Head at Weir (Rule) (in)	Discharge (cfs)
11.70	2.353	23.40	1.736	11.70	3.015
11.80	2.403	23.60	1.771	11.80	3.079
11.90	2.452	23.80	1.807	11.90	3.143
12.00	2.503	24.00	1.843	12.00	3.209
12.10	2.554	24.20	1.880	12.10	3.275
12.20	2.605	24.40	1.917	12.20	3.342
12.30	2.657	24.60	1.954	12.30	3.410
12.40	2.710	24.80	1.992	12.40	3.479
12.50	2.763	25.00	2.030	12.50	3.549
12.60	2.817	25.20	2.069	12.60	3.619
12.70	2.872	25.40	2.108	12.70	3.690
12.80	2.927	25.60	2.147	12.80	3.762
12.90	2.983	25.80	2.187	12.90	3.835
13.00	3.039	26.00	2.228	13.00	3.909
13.10	3.097	26.20	2.268	13.10	3.984
13.20	3.154	26.40	2.309	13.20	4.059
13.30	3.213	26.60	2.351	13.30	4.135
13.40	3.272	26.80	2.393	13.40	4.212
13.50	3.331	27.00	2.436	13.50	4.290
13.60	3.391	27.20	2.478	13.60	4.369
13.70	3.452	27.40	2.522	13.70	4.449
13.80	3.514	27.60	2.566	13.80	4.529
13.90	3.576	27.80	2.610	13.90	4.611
14.00	3.639	28.00	2.654	14.00	4.693
14.10	3.702	28.20	2.699	14.10	4.776
14.20	3.766	28.40	2.745	14.20	4.860
14.30	3.831	28.60	2.791	14.30	4.945
14.40	3.896	28.80	2.837	14.40	5.031
14.50	3.962	29.00	2.884	14.50	5.117
14.60	4.029	29.20	2.931	14.60	5.205
14.70	4.096	29.40	2.979	14.70	5.293
14.80	4.164	29.60	3.027	14.80	5.382
14.90	4.233	29.80	3.076	14.90	5.472
15.00	4.302	30.00	3.125	15.00	5.563

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

Traditional calibration of 90° V-Notch Weirs has involved the establishment of a head-discharge relationship where the head is measured upstream of weir drawdown effects. This parameter is often difficult to measure in field weir installations. Two other parameters are proposed for use as correlation parameters to weir discharge. These parameters are depth and width of flow at the weir notch. Techniques for measuring these parameters are proposed that result in less than 10% error in discharge at the 95% probability level in the laboratory environment.

17. KEY WORDS AND DOCUMENT ANALYSIS

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