THE IMPROVED VENTURI FLUME

By Ralph L. Parshall, Irrigation Engineer

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Based on data gathered under cooperative agreement between Bureau of Public Roads, United States Department of Agriculture, and Colorado Agricultural Experiment Station.

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By Ralph L. Parshall

Water is the most valuable asset of Western agriculture. Large expenditures have been made for works which carry it to farms. The preparation of land to be irrigated and the establishment of legal rights to the water have cost much additional money. Outlays already made and those which must be faced in the future emphasize the need for the conservation of water, and correct measurement is the basis of any plan of saving.

In many cases, the absence of suitable devices for measuring water is not an indication of indifference on the part of the users so much as an indication of their lack of knowledge of such devices. Measurement may be accomplished by various methods more or less suited to individual conditions, such as grade of canal or ditch, quantity of water, or interference by sand and silt.

The right to use water for irrigation is decreed by the courts which provide that definite amounts may be diverted from natural streams or water courses. Sometimes the measurement of the flow by some practical device is also stipulated. Without such measurement, the appropriator of water can not make a definite statement as to how much water he actually uses, and if a dispute should arise it would be difficult for him to furnish satisfactory proof of his established rights. In some of the Western States, because of the scarcity of water, it is of prime importance that its measurement be accurate. Where legal questions over water rights are involved, considerable advantage is to be gained by having definite records of measurements made by some practical device of recognized accuracy.

Sometimes because of faulty measurements, the farmer's water supply is so restricted as to interfere seriously with the maturing of his crops. Were dependable measurements made, the increase in value of the crops would more than pay for the expense of installing and maintaining a good, practical, measuring device.

It would be expected that large irrigation systems, like any large manufacturing or commercial business with many ramifications, would measure all water deliveries with at least approximate exactness, yet many of them still estimate deliveries or use faulty measuring devices. The principal asset of such irrigation enterprises is water, and their principal duty is the proper and economic distribution of the supply. Fairness to the water users and successful business management both demand that reliable measurements be made as a basis for all water transactions.

It is generally believed that the measurement of water is an intricate process, but accurate measurements can readily be made where the conditions are as specified for the proper setting or dimensions of the device. The water user himself, with little practice, should be able to measure the water delivered to him with a satisfactory degree of accuracy.

The measurement of water flowing in open channels is a matter of importance thruout the irrigated areas. The cost of the measuring structures is complained of in many instances, as well as the fact that the particular device installed may not be well suited to the conditions under which it must operate. Accumulations of debris in many devices have rendered the measurements either questionable or obviously of no value. Such failures have discouraged the installation of devices better suited to the conditions.

In the measurement of water in open channels, the weir has been most generally used for small-to-moderate flows. Laboratory tests indicate that it is the most accurate practical means for measuring water under favorable conditions but if the pool or channel section immediately upstream from the weir crest accumulates sediment, the required vertical depth of water below the crest is correspondingly reduced, thus interfering with the accuracy of the device.

Where the grade of the channel is not sufficient to permit the use of standard weirs, orifices have been used with varying success. Experiments seem to indicate that the constants which apply to give the true discharges are affected by the shape of the orifice as well as certain contraction distances which may or may not be correct, thus rendering the practical value of this device uncertain. However, its property of indicating the discharge with a relatively small loss in head is an advantage.

One of the devices most commonly used to measure large flows is the rating flume, which is a simple structure built in the channel where the floor is level, set to the grade line, and with its side walls either vertical or inclined. This flume is calibrated by current meter measurements, or by other means, where the rate of discharge varies with the depth of the stream, which is indicated by a staff gage set on the inside face of the flume. The ordinary rating flume is not altogether reliable. Often a deposit accumulates on the floor of the structure, thus cutting down the cross section of the water prism, which, in turn, affects the velocity. Flow conditions downstream from the rating flume may change, causing the gage readings to be affected to such an extent that certain readings will not give the true discharge. Trailing grass, weeds or willows in the water may affect the rate of flow, which causes error in the discharge readings. On the other hand, a smaller loss of head will suffice for measurements by means of the rating flume than for any other practical device, and for this reason it is the most commonly used.

The improved Venturi flume, as described in this bulletin, is believed to possess such characteristics as will obviate many of the objections to the weir, orifice, rating flume or other devices which are now in general use.

The use of the word "Venturi" is justified, since the flume, by having a contracted section between a converging and diverging section, is somewhat similar in principle to the Venturi tube or meter. The improved Venturi flume, under certain conditions of flow, does not operate according to the Venturi principle but more nearly according to the principle of discharge over a weir. However, as explained later, if the flow is submerged, the device operates in accordance with the Venturi principle.

Early in 1915, tests were conducted at the Fort Collins hydraulic laboratory of the Colorado Agricultural Experiment Station on a water-measuring device having a converging inlet, straight throat section, and a diverging outlet, with a level floor thruout. These tests were made to determine the most practical angles of convergence and divergence with relation to the contracted section, as well as the practical length of the structure. The walls of some of the tested structures were vertical; in others they inclined outward from the axis. After arriving at certain conclusions bearing upon the most practical dimensions to be used, a series of calibrations was made on flumes of various widths and of both these types. The first tests were reported in the Journal of Agricultural Research, Vol. IX, No. 4, p. 115, April, 1917. Because of the many apparent practical advantages of the device, more extensive investigations were made at the hydraulic laboratory, Cornell University, Ithaca, N. Y., where large flows were available.[1]

The water-measuring device herein described, called the improved Venturi flume, is thot to possess such characteristics as will make it meet general field conditions more successfully than did its predecessor, the Venturi flume.

Experience in the field, as well as laboratory tests with the old type of Venturi flume, seem to indicate that in order to operate the device successfully it is desirable that two depths H_a and H_b be observed simultaneously (See Fig. 20) and the mean values referred to a discharge diagram to determine the rate of flow. Tests and field observations on the new device show that, for free flow, the discharge may be determined by a single gage reading. For the determination of submerged flow, two gage readings are necessary, two of the four gages formerly required being eliminated. This report presents the

[1] These data, together with additional observations, were reported in Bul. 265 of the Colo. Agricultural Expt. Station, entitled "The Venturi Flume." 1921.

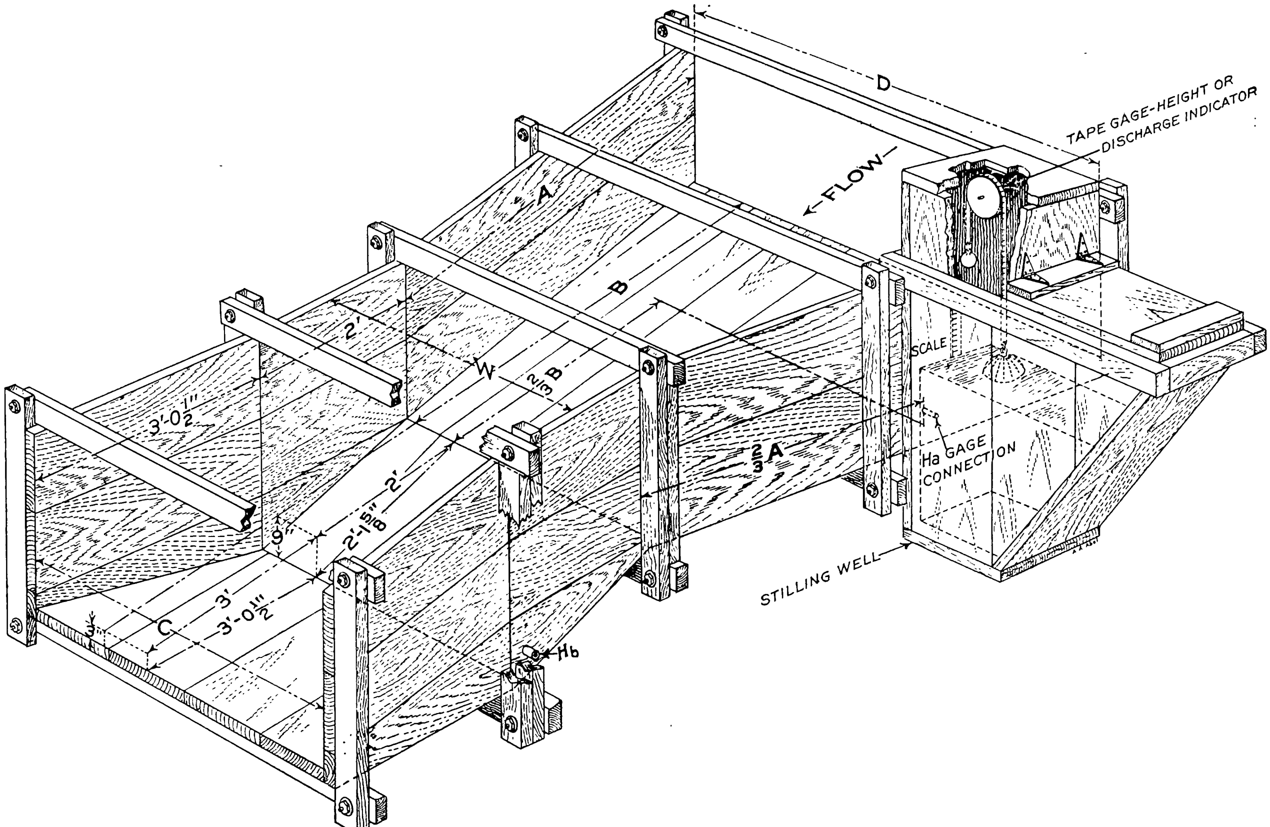

Figure 1.—Improved Venturi Flume, Including Stilling-well Equipped with Indicating Tape Device. Staff Gage in Well.

TABLE I.—STANDARD DIMENSIONS AND CAPACITIES OF IMPROVED VENTURI FLUME
(Letters refer to Figures 1 and 20)

Crest Length W	Dimensions in Feet and Inches						Free-flow Capacity			
							Maximum		Minimum	
	A	⅔A	B	⅔B	C	D	Head H_a	Disch.	Head H_a	Disch.
Feet							Feet	Sec.-Ft.	Feet	Sec.-Ft.
1	4′6″	3′0″	4′ 4⅞″	2′11¼″	2	2′ 9¼″	2.50	16.1	0.20	0.35
2	5′0″	3′4″	4′10⅞″	3′ 3¼″	3	3′11½″	2.50	33.1	0.20	0.66
3	5′6″	3′8″	5′ 4¾″	3′ 7⅛″	4	5′ 1⅞″	2.50	50.4	0.20	0.97
4	6′0″	4′0″	5′10⅝″	3′11⅛″	5	6′ 4¼″	2.50	67.9	0.20	1.26
5	6′6″	4′4″	6′ 4½″	4′ 3″	6	7′ 6⅝″	2.50	85.6	0.25	2.22
6	7′0″	4′8″	6′10⅜″	4′ 6⅞″	7	8′ 9″	2.50	103.5	0.25	2.63
7	7′6″	5′0″	7′ 4¼″	4′10⅞″	8	9′11⅜″	2.50	121.4	0.30	4.08
8	8′0″	5′4″	7′10⅛″	5′ 2¾″	9	11′ 1¾″	2.50	139.5	0.30	4.62
10	9′0″	6′0″	8′ 9⅞″	5′10⅝″	11	13′ 6⅜″	2.50	175.8	0.40	9.10

discharge data in tabular form, which is believed to be more convenient than that given in former reports on the Venturi flume.

The improved Venturi flume differs in design from the old type in the reduction of the convergence angle from 18° 26′ to 11° 19′ for its upstream or inlet section, a lengthening of the throat section from 1 foot to 2 feet, reduction of the divergence angle of the lower or outlet section from 18° 26′ to 9° 28′, and the placing of a depression in the floor at the throat section. The length of the side wall of the converging section is also changed in accordance with the arbitrary rule $A=\frac{W}{2}+4$.[2] The length of the converging side of the structure will be discussed more fully in another section of this bulletin. The length of the diverging section has been taken as 3 feet for all widths at the throat section from 1 to 8 feet inclusive.[2] In the old flume the floor was level thruout, whereas in the improved type the floor in the throat section slopes downward at a rate of 9 inches vertically to 24 inches horizontally. At the point where the diverging section begins, the floor slopes upward at a rate of 6 inches vertically to 36 inches horizontally. The floor at the lower end of the flume is 3 inches below the floor level of the upper or converging section. The small 6-inch flume discussed elsewhere is of special design.

HYDRAULIC LABORATORIES

Two hydraulic laboratories were used in developing this flume. At one, accurate and precise work is possible; the other is a field laboratory, of capacity such as to permit the study of flow thru structures of large size, and where the accuracy in measurement of flow is well within practical limits. The Fort Collins laboratory [3] has a capacity of about 16 second-feet, where the discharge is measured volumetrically. Outside, at an elevation above the laboratory floor, is the supply reservoir which has a capacity of three-fourths of an acre-foot. The water is led from this reservoir by means of a channel, into the laboratory, where the experimental structures are tested. There it is possible to maintain a specific depth or discharge long enough to determine quite closely the condition of flow. It has been found possible to make calibrations come within about 0.005 second-foot of the discharges determined volumetrically.

The volumetric tanks are of reinforced concrete. Their capacity is approximately that of the supply reservoir. The amount of water added to these tanks or basins for any particular test is determined by hookgage readings to a limit of accuracy of 0.001 foot. Electrically-

[2]The general dimensions of the flume as shown in Fig. 1 refer to the tabular dimensions given in Table I.

[3]For a more complete description, see Eng. News, Vol. 70, p. 662, Oct., 1913.

driven centrifugal pumps return the water to the supply reservoir for use again. The calibrations of the smaller Venturi flumes were made at this laboratory, where the discharges were measured to thousandths of second-feet, and the depths or heads affecting the discharge thru the flumes were determined by hookgage readings. These experimental structures were built of wood, accurate in dimension and of sufficient depth to cover a range of discharge such as would be found in actual service.

The field laboratory at Bellvue (Figure 2) is 8 miles west of Fort Collins at the headworks of the Jackson Ditch, on the Cache la Poudre River. It consists of a reinforced concrete channel 14 feet

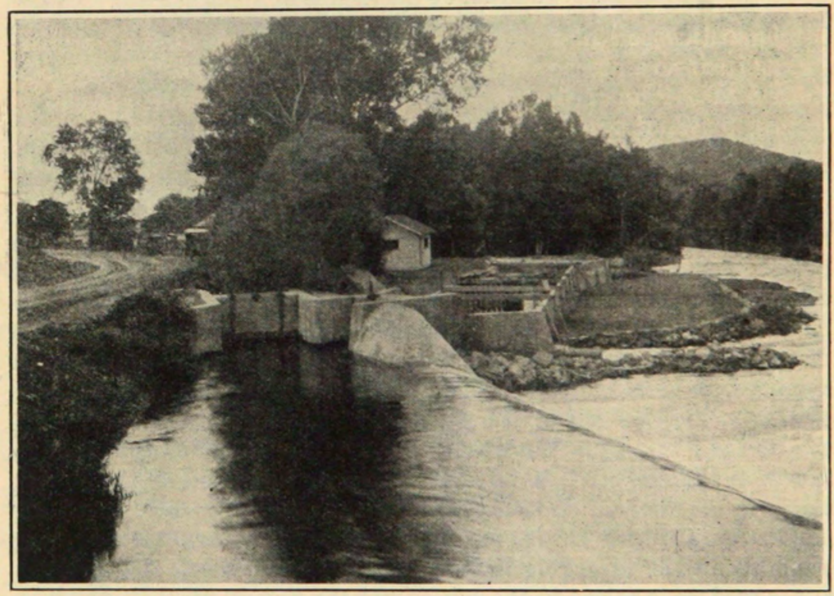

Figure 2.—Irrigation Hydraulic Laboratory at Bellvue.

wide and $6\frac{1}{2}$ feet deep, with a present length of about 150 feet. At the lower end of this channel is a weir box 25 feet wide and 10 feet deep, having in the end wall a 15-foot standard rectangular weir.

At this laboratory, in 1923, when the calibrations were made on the larger sizes of the improved Venturi flume, the concrete weir box was of the same width as the channel and had a depth of $7\frac{1}{2}$ feet for a distance of 24 feet. In the end wall of this weir box was a 10-foot standard rectangular weir, patterned after the 10-foot weir calibrated by J. B. Francis in the early '50s at Lowell, Mass. Because these weirs were of similar dimensions, the discharge curve for the weir used was based upon the results of Francis' experiments. The larger improved Venturi flumes were built in this concrete channel at a point upstream from the weir box. The water was admitted to this channel at its upper end, thence flowed thru the experimental structures, and finally was carefully measured over the standard weir. Hookgages were mounted on the model structures at such points as permitted careful measurement of the upper head, H_a, and throat head, H_b. The head on the standard weir was determined by means of two hookgage readings on opposite sides of the weir box (Figure 30). All hookgage readings were observed to a limit of accuracy of 0.001 foot. Downstream from the experimental flumes an adjustable baffle was provided which permitted the regulation of the degree of submergence. At this laboratory, calibrations were made for flows ranging from 5 second-feet to 90 second-feet.

ACTION OF THE IMPROVED VENTURI FLUME

The fundamental idea dictating the design of the flume is based upon the effect of the increasing velocity in the converging section, resulting from the constantly decreasing cross-section of the water prism. As the flowing stream reaches the crest, which is the junction of the upper level floor and throat floor, it has virtually attained its maximum velocity. For the free-flow condition, the stream is carried down the inclined floor of the throat and, with the momentum thus acquired, is carried upward over the inclined floor of the diverging section to the exit end of the structure. Because there is no obstruction to the flow as just described, this condition is called free flow, as shown in Figures 3, 11, 20 and 21. When the resistance to the flowing water in the channel downstream from the flume is great enough, the momentum thru the throat section is not sufficient to permit clearing smoothly in the diverging section. By thus restricting the flow, the water surface is raised in the exit end of the flume. In this transition of flow, the phenomenon occurs known as the "hydraulic jump." Because of the downward inclined floor of the throat section, this jump is produced at some distance downstream from the crest, and is, in effect, the means of warding off or holding back the resisting water in the diverging section. In the formation of the hydraulic jump, a portion of the velocity head of the stream passing the crest is converted into static head, which causes the stream to flow at a slower velocity but with greater depth beyond the point where the jump is formed. As the resistance to the flow in the diverging section is further increased, the jump is reduced in its effectiveness and at the same time crowded back into the throat section. As the jump moves upstream into the throat section, a condition of downstream depth is

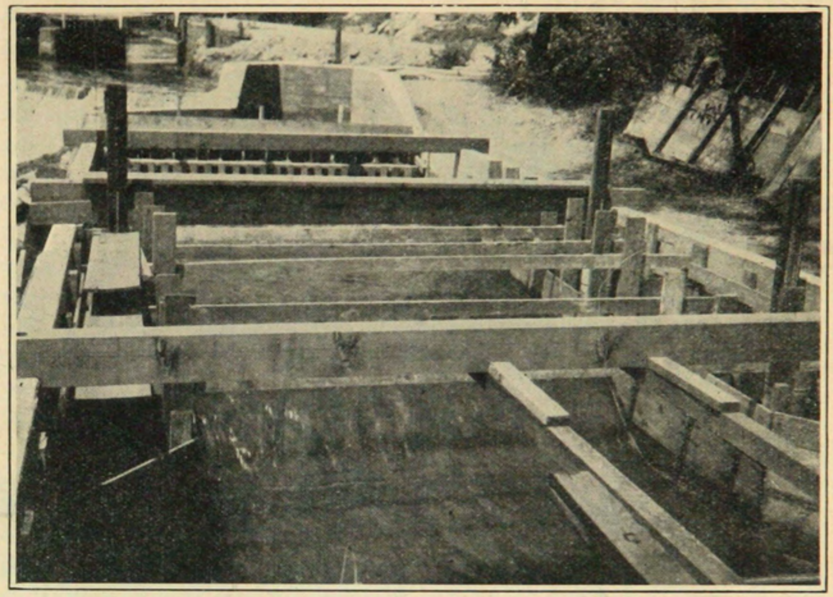

Figure 3.—Experimental 8-foot Improved Venturi Flume, Bellvue Laboratory. Free-flow Discharge. Note Arrangement of Hookgages to Determine the Upper Head on Opposite Sides of Flume and the Throat Head.

reached where the momentum or push of the water over the crest is reduced by the resistance to the point of decreasing the discharge. This point is called the limiting depth or critical degree of submergence and is important because it defines the limit of free-flow discharge. The amount of water flowing will be undiminished until the water surface at the lower or downstream edge of the throat has been raised to such a point that the depth here, or H_b, is approximately 0.7 of that in the converging section at the gage point H_a, where both these depths are referred to the crest elevation as the datum. When the resistance to the flow downstream from the structure is further increased, because of lack of grade or checking of the flow by means of flashboards, or otherwise raising the water surface beyond this limiting depth, a reduction in the discharge results. This condition is called submerged flow.

In this discussion the degree of submergence is the ratio of the throat gage H_b to the upper gage H_a expressed as a decimal fraction.

In the plan and elevation of the 2-foot flume (Figure 20), the lower water surface in the downstream section shows the condition of free flow, while the upper surface indicates the approximate elevation of the free-flow discharge limit. The elevation of this surface at any point between is within the free-flow zone, and the discharge for this range is a function of the flume's width or size and of the upper head, H_a, which is measured at the two-thirds point along the converging side of the structure.

CHARACTERISTICS OF THE FLUME.—The practical use of the improved Venturi flume has demonstrated that it possesses many desirable characteristics and is not subject to many of the disadvantages of other devices. It may be operated either as a free-flow, single-head device, or under submerged-flow conditions where two heads are involved. Because of the contracted section at the throat, the velocity of water flowing thru the structure is relatively greater than the natural flow of the stream, and for this reason any sand or silt in suspension or rolled along the bottom of the channel is carried thru, leaving the device free of deposit. Velocity of approach, which often becomes a serious factor in the operation of weirs, has little or no effect upon the rate of discharge of the flume. It is accurate enough for all irrigation purposes and since it remains clear of sediment the reliability of its measurement is believed to be greater than that of other devices. Usually, conditions found in the field will permit it to operate with a free-flow discharge, which is a function only of a single depth, as with a weir. The loss of head for the free-flow limit is found to be about 25 percent of that for the standard overpour weir. There is no easy way to alter the dimensions or cause a change in the device, modify the channel above or below the structure, or otherwise interfere with the original conditions for the purpose of increasing the discharge to effect a wilfully unfair measurement.

The design and action of this device have shown that it is capable of withstanding a high degree of submergence before the rate of discharge is reduced. Because of this fact it will operate successfully where the overpour weir fails because of the flat grade of the channel. A wide range of capacity of measurement has been provided in its calibration, and it is, therefore, adapted to use on the small farm lateral as well as channels of large capacity. The structure itself may be built of either wood or concrete, or, for the smaller flumes, of sheet-metal. The fact that the design specifies certain angles does not greatly increase the work of building, since all surfaces are plane; hence the material may be readily cut to fit properly. The practical operation of the device is simple, and any observer can make the necessary readings and apply them to the table and diagrams to determine the discharge. When the discharge is a function of a single depth, a graduated metal tape showing the flow in second-feet, miner's inches, or shares may be installed so that the discharge may be read direct. For this same condition of flow, that is, a single head as a function of the discharge, an integrating instrument operated by means of a float may be mounted over the stilling-well, which will positive including all values between +0.6 and +1.5 inclusive, and 1 percent negative all values between —1.4 and —0.5 inclusive. On this same basis the range of positive and negative values was extended to account for all the free-flow observations on the 1, 2, 3, 4, 6, and 8-foot flumes.[4] The height, or ordinate of the bars in the error diagram, Figure 4, shows the percentage of the total of 298 tests, limited in head, H_a, from 0.2 foot to 2.5 feet and with the limiting degree of submergence of 69.9 percent. For the distribution of the original 159 tests, it was found that approximately 97 percent of the total number fell within the limit of ±3 percent of the computed value of the discharge; while for the total of 298 tests, 89 percent were within this limit.

When the series of tests, consisting of 139 observations on the 1, 2, 4, 6 and 8-foot flumes, made at the Bellvue laboratory in 1926, was included with the original tests, a wider variation of the deviation between the observed and computed discharges was found to exist. In the original series of 1923 there were about twice as many tests made at the Fort Collins hydraulic laboratory, volumetric measurements, on the 1, 2 and 3-foot flumes, as were taken at the Bellvue laboratory. The 1926 tests were all made at the Bellvue laboratory where rectangular weirs, 18 inches, 48 inches and 15 feet in dimensions, were used to determine the observed discharge. (Figure 30.)

Table III, giving the free-flow discharge in second-feet thru the improved Venturi flume for sizes from 1 foot to 10 feet, is based on the formula $Q=4\ W\ H_a^{1.522W^{0.026}}$

Figures 5 and 6 show field installations of 1-foot and 2-foot improved Venturi flumes operating under free-flow conditions, each being equipped with a water-stage recording instrument giving a record of the upper head, H_a. There is practically no submergence in the case of the 1-foot flume, but in the 2-foot structure the degree of submergence is approximately 50 percent for a discharge of 5.7 second-feet. The loss of head in this structure was determined roughly in the field to be about 4½ inches, and by applying the data to the diagram, Figure 15, the loss is calculated to be slightly more than 5 inches.

[4] Of the total of 308 free-flow tests, two were excluded because of gross error, (6512, 3-foot flume, and 7043, 8-foot flume). Six special tests (7625-26, 7739-40, 2-foot flume, and 6525-26, 3-foot flume) were excluded. Tests 6476-77 were omitted because the value of H_a exceeded 2.5 feet. Summary as follows:

Test	W	H_a	H_b	Ratio $\frac{H_b}{H_a}$	Observed Q	Computed Q	Difference	Deviation
	Ft.	Ft.	Ft.		Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Percent
6476	1	2.722	1.795	0.659	18.13	18.36	+0.23	1.3
6477	1	2.641	1.726	.653	17.34	17.54	+ .20	1.2

accurately record the total discharge in acre-feet for any period of time. Where the flow thru the flume is submerged, and two heads or depths are observed, a graphic recording instrument may be used which indicates on a chart the value of the upper head and the difference in head between this upper depth and the head or depth at the throat. This recorded data, referred to the size of the flume, is sufficient to determine the total flow over any period of time. In the case of the integrating instrument, this total is read directly from a series of dials, while for the recording instrument subsequent calculations are necessary. (See discussion on page 58.)

CONSTRUCTION OF EXPERIMENTAL FLUMES AND METHOD OF OBSERVATION

The experimental test flumes at both the Fort Collins and Bellvue laboratories were of ordinary lumber. The sills and posts were 2 by 4-inch pieces, while the floor and walls were made of 1-inch boards, surfaced on both sides. In the building of these structures particular care was taken to have all dimensions exact. When the side walls and floor became wet they swelled, and due allowance was made in having the throat width or size of flume slightly greater than the nominal length in order that, when the structure was completely soaked, the swelling would bring the dimension close to the true value. Dimensions of the structure were checked occasionally to see whether or not they remained within practical limits.

The stilling wells were metal cans, about 10 inches in diameter and from 3 to 6 feet deep. The deeper cans were used at the Bellvue laboratory as a matter of convenience. In the mounting of hookgages, care was taken to have them securely fixed. At the Bellvue laboratory, a 2 by 6-inch plank was set vertically and rigidly fixed to insure against error in depth measurements, as shown in Figure 3. The metal stilling well was placed against the face of the plank, resting firmly upon a solid base. A ¾-inch pipe connection was provided at the bottom of the well, and from this was led a piece of common garden hose of the same diameter, connecting to the wall of the flume by a similar pipe connection at the desired point. In the concrete channel downstream from the model flume was a 22 by 22-inch metal gate, placed in a framework consisting of a set of flashboards. This gate and the flashboards made it possible to secure various degrees of submergence and to regulate the flow thru the test structure. Baffles were placed upstream from the model flume as well as downstream below the submergence bulkhead.

Each morning before operations were begun, all hookgage constants were determined by means of an engineer's level and rod. The mean elevation of the crest of the test flume was accuratly determined by several observations at different points. A light wooden rod with sliding target was placed at a point of mean elevation and the target set exactly at the line of sight of the instrument. This rod was then placed upon the various hooks of the gages and the gages were adjusted so that the target again agreed with the line of sight of the leveling instrument. The hookgage readings then gave the constant of correction for each gage. This same method was employed to determine the hookgage constants for the standard rectangular weirs.

Water was admitted to the concrete channel by means of the main regulating gate and after the flow had assumed a constant condition observations were taken as follows: An observer started by reading the upper head, or H_a, on the flume, calling this observation to a note-keeper who recorded it on a special form, and then read in proper order all other hookgages, calling the readings as they were observed. For the most part, five hookgages were observed, three on the experimental flume and two on the standard weir. A complete round of readings usually required about one and one-half minutes, and where the variations in the water surface were small, five complete sets were assumed to be sufficient to give the correct mean; otherwise, more observations were taken.

In the old type of Venturi flume it was found that the downstream flow conditions were such as to swing the current from one side to the other, apparently without cause. This swinging was found to affect the reading of head in the converging section. To determine whether or not heads observed on either side of the converging section of the improved Venturi flume were the same, approximately 200 observations were made in 1923 by having two hookgage connections, one on each side at the proper point. These observations show that the difference in the two readings was very small, and it can be safely assumed that the upper head, H_a, may be observed on either side with equal accuracy.

At the Bellvue laboratory, the loss of head thru the flume was determined by staff gages read direct, the zero of the gages being set at the elevation of the floor of the converging section. These gages were so situated that the elevation of the water above and below the flume could be determined quite accurately. At the Fort Collins laboratory, where calibrations were made on the smaller-sized flumes of small discharge, the loss of head was determined by means of hookgage readings.

FREE-FLOW FORMULA

The data upon which the free-flow formula is based consist of discharge in second-feet and the corresponding heads, H_a, for 159 tests, where the degree of submergence is less than 70 percent, these tests being divided according to size of flume as follows: 1-foot flume, 27 tests; 2-foot flume, 28 tests; 3-foot flume, 34 tests; 4-foot flume, 21 tests; 6-foot flume, 20 tests, and the 8-foot flume, 29 tests. The data obtained from the tests, when plotted to a logarithmic scale for the various discharges and corresponding heads, showed very nearly a straight-line variation for the various sizes of flumes tested. Upon adjusting a straight line to these individual sets of plottings, it was observed that the discharge intercepts for the upper head, H_a, at one foot are very closely proportional to four times the width of the flume in feet. The slope of the lines for the various sizes of flume is not the same, thus showing that the values of the exponent of the upper head, H_a, are not identical, and therefore vary with the width or size of flume. By careful inspection of the plotted data, values of the intercept and slope have been determined for each size of flume, as given in Table II.

TABLE II.—Values of Intercept J and Slope n, Log Plot, for Law of Free-flow Discharge Thru Different-sized Improved Venturi Flumes

Size of Flume W	COEFFICIENT J			EXPONENT n of H_a		
	Intercept Log plot	Computed Value 4W	Difference	Scaled Value Log plot	Computed Value of $1.522W^{0.026}$	Difference
Feet						
1	3.98	4.00	+0.02	1.527	1.522	−0.005
2	8.00	8.00	.00	1.552	1.550	− .002
3	11.96	12.00	+ .04	1.565	1.566	+ .001
4	16.02	16.00	− .02	1.574	1.578	+ .004
6	24.05	24.00	− .05	1.592	1.595	+ .003
8	32.00	32.00	.00	1.608	1.606	− .002

The fundamental law for the free-flow discharge thru the improved Venturi flume is:

$$Q = J\ H_a^{n}$$

where Q=Quantity in second-feet

J=Coefficient which is a function of the size of the flume

H_a=The upper head in feet observed at a point distant upstream from the crest two-thirds the length of the converging section

n=Exponent of the head, H_a

By inspection of the data in Table II, it is evident that, as an approximation, $J=4$ W, where W is the size of flume or width of throat, in feet. The relation of the slope n, and width of flume W has been established as $n=1.522W.^{0.026}$ Hence, the complete formula may be stated as

$$Q=4\ W\ H_a^{1.522W^{0.026}}$$

The form of expression employing the double exponent of H_a may at first appear to be complicated and unusual. However, when the simple operation is performed to reduce to the proper value of the exponent for the particular width of flume, the form of the expression for the discharge offers no more difficulty in its solution than the simple discharge formula for a standard weir or submerged orifice. This equation, being in the product form, is readily solved by means of logarithms.

Figure 4 shows graphically the agreement of the computed discharge, as determined by the free-flow formula, with the observed discharge as the base. This comparison includes, in addition to the

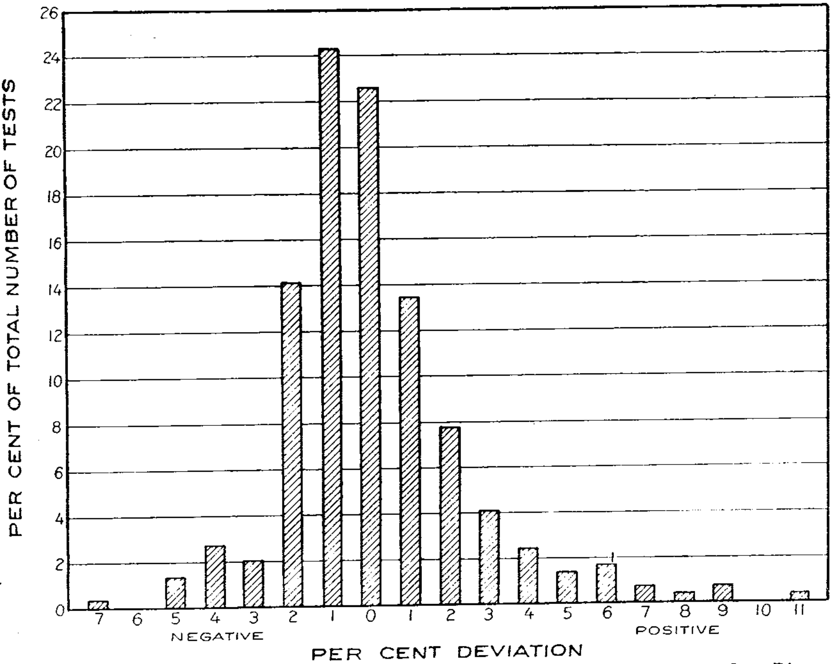

Figure 4.—Comparison in Percentage of Computed to Observed Free-flow Discharge Thru Experimental Flumes.

159 original tests made in 1923, the 139 check tests made in 1926. The data upon which this diagram is based were developed by expressing the deviation between the observed and computed discharge in percentage where the computed was greater than the observed discharge, the percentage was positive, and where the computed was less than the observed discharge the percentage was negative. A tabulation was then made of these values, in which zero deviation included all values between —0.4 and +0.5 inclusive; 1 percent

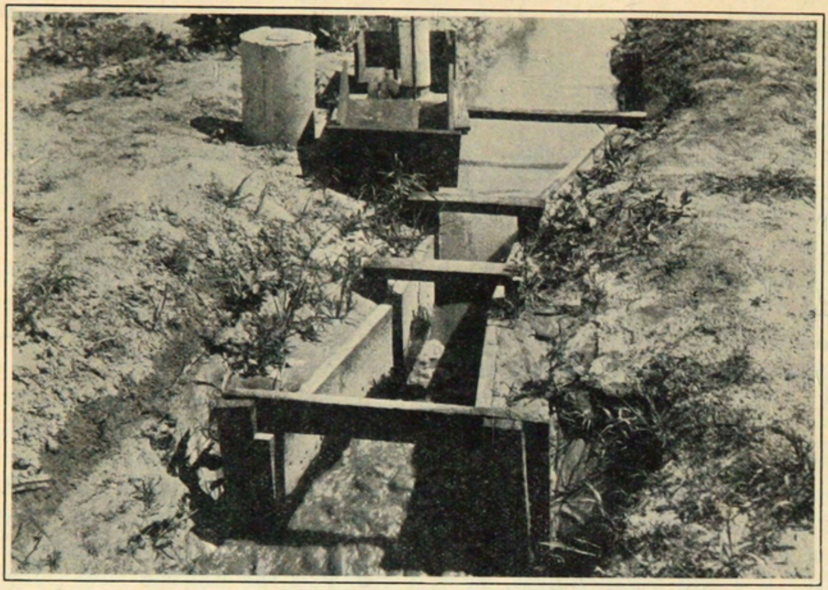

Figure 5.—One-foot Improved Venturi Flume, Experimental Farm, American Beet Sugar Company, Rocky Ford, Colorado. Free-flow Discharge of 1 Second-foot. Instrument Installed to Record Total Flow.

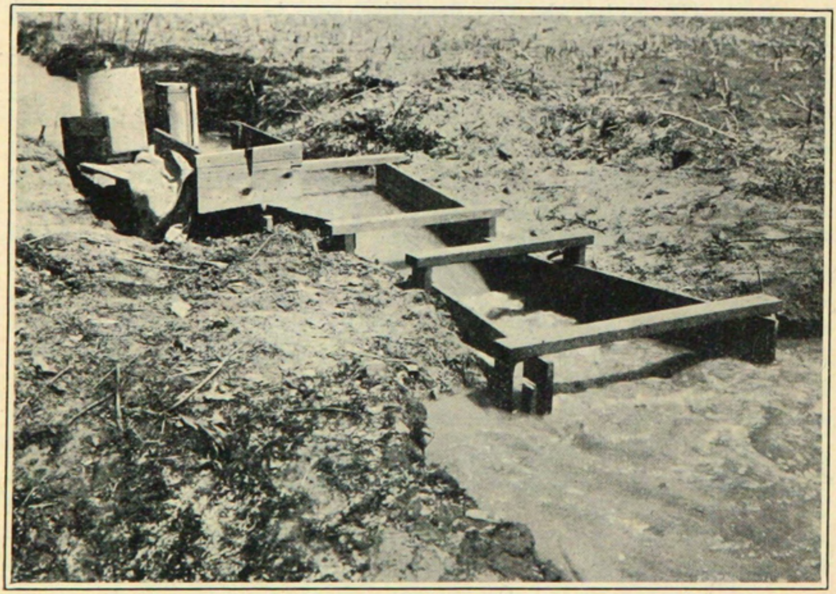

Figure 6.—Two-foot Improved Venturi Flume Discharging 5.7 Second-feet, Submergence 50 Percent, Loss of Head about 0.4 Foot. Mitchell Farm Lateral near Las Animas, Colorado.

TABLE III.—FREE-FLOW DISCHARGE FOR IMPROVED VENTURI FLUME

Computed from the formula $Q = 4\ W\ H_a^{1.522\ W^{0.026}}$

Upper Head H_a		Discharge per second for flumes of various throat widths								
		1 Foot	2 Feet	3 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet	10 Feet
Feet	Inches	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.
0.20	2⅜	0.35	0.66	0.97	1.26	....	....	....	....	....
.21	2½	.37	.71	1.04	1.36	....	....	....	....	....
.22	2⅝	.40	.77	1.12	1.47	....	....	....	....	....
.23	2¾	.43	.82	1.20	1.58	....	....	....	....	....
.24	2⅞	.46	.88	1.28	1.69	....	....	....	....	....
.25	3	.49	.93	1.37	1.80	2.22	2.63	....	....	....
.26	3⅛	.51	.99	1.46	1.91	2.36	2.80	....	....	....
.27	3¼	.54	1.05	1.55	2.03	2.50	2.97	....	....	....
.28	3⅜	.58	1.11	1.64	2.15	2.65	3.15	....	....	....
.29	3½	.61	1.18	1.73	2.27	2.80	3.33	....	....	....
.30	3⅝	.64	1.24	1.82	2.39	2.96	3.52	4.08	4.62	....
.31	3¾	.68	1.30	1.92	2.52	3.12	3.71	4.30	4.88	....
.32	3 13/16	.71	1.37	2.02	2.65	3.28	3.90	4.52	5.13	....
.33	3 15/16	.74	1.44	2.12	2.78	3.44	4.10	4.75	5.39	....
.34	4 1/16	.77	1.50	2.22	2.92	3.61	4.30	4.98	5.66	....
.35	4 3/16	.80	1.57	2.32	3.06	3.78	4.50	5.22	5.93	....
.36	4 5/16	.84	1.64	2.42	3.19	3.95	4.71	5.46	6.20	....
.37	4 7/16	.88	1.72	2.53	3.34	4.13	4.92	5.70	6.48	....
.38	4 9/16	.92	1.79	2.64	3.48	4.31	5.13	5.95	6.76	....
.39	4 11/16	.95	1.86	2.75	3.62	4.49	5.35	6.20	7.05	....
.40	4 13/16	.99	1.93	2.86	3.77	4.68	5.57	6.46	7.34	9.10
.41	4 15/16	1.03	2.01	2.97	3.92	4.86	5.80	6.72	7.64	9.47
.42	5 1/16	1.07	2.09	3.08	4.07	5.05	6.02	6.98	7.94	9.85
.43	5 3/16	1.11	2.16	3.20	4.22	5.24	6.25	7.25	8.24	10.23
.44	5¼	1.15	2.24	3.32	4.38	5.43	6.48	7.52	8.55	10.61
.45	5⅜	1.19	2.32	3.44	4.54	5.63	6.72	7.80	8.87	11.00
.46	5½	1.23	2.40	3.56	4.70	5.83	6.96	8.08	9.19	11.40
.47	5⅝	1.27	2.48	3.68	4.86	6.03	7.20	8.36	9.51	11.81
.48	5¾	1.31	2.57	3.80	5.03	6.24	7.44	8.65	9.84	12.22
.49	5⅞	1.35	2.65	3.92	5.20	6.45	7.69	8.94	10.17	12.63
.50	6	1.39	2.73	4.05	5.36	6.66	7.94	9.23	10.51	13.05
.51	6⅛	1.44	2.82	4.18	5.53	6.87	8.20	9.53	10.85	13.47
.52	6¼	1.48	2.90	4.31	5.70	7.09	8.46	9.83	11.19	13.90
.53	6⅜	1.52	2.99	4.44	5.88	7.30	8.72	10.14	11.54	14.34
.54	6½	1.57	3.08	4.57	6.06	7.52	8.98	10.45	11.89	14.78
.55	6⅝	1.62	3.17	4.70	6.23	7.74	9.25	10.76	12.24	15.22
.56	6¾	1.66	3.26	4.84	6.41	7.97	9.52	11.07	12.60	15.67
.57	6 13/16	1.70	3.35	4.98	6.59	8.20	9.79	11.39	12.96	16.13
.58	6 15/16	1.75	3.44	5.11	6.77	8.43	10.07	11.71	13.33	16.59
.59	7 1/16	1.80	3.53	5.25	6.96	8.66	10.35	12.03	13.70	17.05
.60	7 3/16	1.84	3.62	5.39	7.15	8.89	10.63	12.36	14.08	17.52
.61	7 5/16	1.88	3.72	5.53	7.34	9.13	10.92	12.69	14.46	17.99
.62	7 7/16	1.93	3.81	5.68	7.53	9.37	11.20	13.02	14.84	18.47
.63	7 9/16	1.98	3.91	5.82	7.72	9.61	11.49	13.36	15.23	18.96
.64	7 11/16	2.03	4.01	5.97	7.91	9.85	11.78	13.70	15.62	19.45
.65	7 13/16	2.08	4.11	6.12	8.11	10.10	12.08	14.05	16.01	19.94
.66	7 15/16	2.13	4.20	6.26	8.31	10.34	12.38	14.40	16.41	20.44
.67	8 1/16	2.18	4.30	6.41	8.51	10.59	12.68	14.75	16.81	20.94
.68	8 3/16	2.23	4.40	6.56	8.71	10.85	12.98	15.10	17.22	21.45
.69	8¼	2.28	4.50	6.71	8.91	11.10	13.28	15.46	17.63	21.96
.70	8⅜	2.33	4.60	6.86	9.11	11.36	13.59	15.82	18.04	22.48
.71	8½	2.38	4.70	7.02	9.32	11.62	13.90	16.18	18.45	23.00
.72	8⅝	2.43	4.81	7.17	9.53	11.88	14.22	16.55	18.87	23.52
.73	8¾	2.48	4.91	7.33	9.74	12.14	14.53	16.92	19.29	24.05
.74	8⅞	2.53	5.02	7.49	9.95	12.40	14.85	17.29	19.71	24.59

TABLE III.—FREE-FLOW DISCHARGE FOR IMPROVED VENTURI FLUME
Continued

Computed from the formula $Q = 4\,W\,H_a^{1.522\,W^{0.026}}$

Upper Head H_a		Discharge per second for flumes of various throat widths								
		1 Foot	2 Feet	3 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet	10 Feet
Feet	Inches	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.
.75	9	2.58	5.12	7.65	10.16	12.67	15.17	17.66	20.14	25.13
.76	9 1/8	2.63	5.23	7.81	10.38	12.94	15.49	18.04	20.57	25.67
.77	9 1/4	2.68	5.34	7.97	10.60	13.21	15.82	18.42	21.01	26.22
.78	9 3/8	2.74	5.44	8.13	10.81	13.48	16.15	18.81	21.46	26.77
.79	9 1/2	2.80	5.55	8.30	11.03	13.76	16.48	19.20	21.91	27.33
.80	9 5/8	2.85	5.66	8.46	11.25	14.04	16.81	19.59	22.36	27.89
.81	9 3/4	2.90	5.77	8.63	11.48	14.32	17.15	19.99	22.81	28.46
.82	9 13/16	2.96	5.88	8.79	11.70	14.60	17.49	20.39	23.26	29.03
.83	9 15/16	3.02	6.00	8.96	11.92	14.88	17.83	20.79	23.72	29.60
.84	10 1/16	3.07	6.11	9.13	12.15	15.17	18.17	21.18	24.18	30.18
.85	10 3/16	3.12	6.22	9.30	12.38	15.46	18.52	21.58	24.64	30.76
.86	10 5/16	3.18	6.33	9.48	12.61	15.75	18.87	21.99	25.11	31.35
.87	10 7/16	3.24	6.44	9.65	12.84	16.04	19.22	22.40	25.58	31.94
.88	10 9/16	3.29	6.56	9.82	13.07	16.33	19.57	22.82	26.06	32.53
.89	10 11/16	3.35	6.68	10.00	13.31	16.62	19.93	23.24	26.54	33.13
.90	10 13/16	3.41	6.80	10.17	13.55	16.92	20.29	23.66	27.02	33.74
.91	10 15/16	3.46	6.92	10.35	13.79	17.22	20.65	24.08	27.50	34.35
.92	11 1/16	3.52	7.03	10.53	14.03	17.52	21.01	24.50	27.99	34.96
.93	11 3/16	3.58	7.15	10.71	14.27	17.82	21.38	24.93	28.48	35.57
.94	11 1/4	3.64	7.27	10.89	14.51	18.13	21.75	25.36	28.97	36.19
.95	11 3/8	3.70	7.39	11.07	14.76	18.44	22.12	25.79	29.47	36.82
.96	11 1/2	3.76	7.51	11.26	15.00	18.75	22.49	26.22	29.97	37.45
.97	11 5/8	3.82	7.63	11.44	15.25	19.06	22.86	26.66	30.48	38.08
.98	11 3/4	3.88	7.75	11.63	15.50	19.37	23.24	27.10	30.98	38.72
.99	11 7/8	3.94	7.88	11.82	15.75	19.68	23.62	27.55	31.49	39.36
1.00	12	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	40.00
1.01	12 1/8	4.06	8.12	12.19	16.25	20.32	24.38	28.45	32.52	40.65
1.02	12 1/4	4.12	8.25	12.38	16.51	20.64	24.77	28.90	33.04	41.30
1.03	12 3/8	4.18	8.38	12.57	16.76	20.96	25.16	29.36	33.56	41.96
1.04	12 1/2	4.25	8.50	12.76	17.02	21.28	25.55	29.82	34.08	42.62
1.05	12 5/8	4.31	8.63	12.96	17.28	21.61	25.94	30.28	34.61	43.28
1.06	12 3/4	4.37	8.76	13.15	17.54	21.94	26.34	30.74	35.14	43.95
1.07	12 13/16	4.43	8.88	13.34	17.80	22.27	26.74	31.20	35.68	44.62
1.08	12 15/16	4.50	9.01	13.54	18.07	22.60	27.13	31.67	36.22	45.30
1.09	13 1/16	4.56	9.14	13.74	18.34	22.93	27.53	32.14	36.76	45.98
1.10	13 3/16	4.62	9.27	13.93	18.60	23.26	27.94	32.62	37.30	46.66
1.11	13 5/16	4.68	9.40	14.13	18.86	23.60	28.35	33.10	37.84	47.35
1.12	13 7/16	4.75	9.54	14.33	19.13	23.94	28.76	33.58	38.39	48.04
1.13	13 9/16	4.82	9.67	14.53	19.40	24.28	29.17	34.06	38.94	48.73
1.14	13 11/16	4.88	9.80	14.73	19.67	24.62	29.58	34.54	39.50	49.43
1.15	13 13/16	4.94	9.94	14.94	19.94	24.96	30.00	35.02	40.06	50.13
1.16	13 15/16	5.01	10.07	15.14	20.22	25.31	30.41	35.51	40.62	50.84
1.17	14 1/16	5.08	10.20	15.34	20.50	25.66	30.83	36.00	41.18	51.55
1.18	14 3/16	5.15	10.34	15.55	20.78	26.01	31.25	36.50	41.75	52.27
1.19	14 1/4	5.21	10.48	15.76	21.05	26.36	31.68	37.00	42.32	52.99
1.20	14 3/8	5.28	10.61	15.96	21.33	26.71	32.10	37.50	42.89	53.71
1.21	14 1/2	5.34	10.75	16.17	21.61	27.06	32.53	38.00	43.47	54.43
1.22	14 5/8	5.41	10.89	16.38	21.90	27.42	32.96	38.50	44.05	55.16
1.23	14 3/4	5.48	11.03	16.60	22.18	27.78	33.39	39.00	44.64	55.89
1.24	14 7/8	5.55	11.17	16.81	22.47	28.14	33.82	39.51	45.22	56.63
1.25	15	5.62	11.31	17.02	22.75	28.50	34.26	40.02	45.80	57.37
1.26	15 1/8	5.69	11.45	17.23	23.04	28.86	34.70	40.54	46.38	58.11
1.27	15 1/4	5.76	11.59	17.44	23.33	29.22	35.14	41.05	46.97	58.86
1.28	15 3/8	5.82	11.73	17.66	23.62	29.59	35.58	41.57	47.57	59.61
1.29	15 1/2	5.89	11.87	17.88	23.92	29.96	36.02	42.09	48.17	60.36

TABLE III.—FREE-FLOW DISCHARGE FOR IMPROVED VENTURI FLUME
Continued

Computed from the formula $Q = 4\ W\ H_a^{1.522\ W^{0.026}}$

Upper Head H_a		Discharge per second for flumes of various throat widths								
		1 Foot	2 Feet	3 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet	10 Feet
Feet	Inches	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.
1.30	15 5/8	5.96	12.01	18.10	24.21	30.33	36.47	42.62	48.78	61.12
1.31	15 3/4	6.03	12.16	18.32	24.50	30.70	36.92	43.14	49.38	61.88
1.32	15 13/16	6.10	12.30	18.54	24.80	31.07	37.37	43.67	49.99	62.65
1.33	15 15/16	6.18	12.44	18.76	25.10	31.44	37.82	44.20	50.60	63.42
1.34	16 1/16	6.25	12.59	18.98	25.39	31.82	38.28	44.73	51.22	64.19
1.35	16 3/16	6.32	12.74	19.20	25.69	32.20	38.74	45.26	51.84	64.96
1.36	16 5/16	6.39	12.89	19.42	25.99	32.58	39.20	45.80	52.46	65.74
1.37	16 7/16	6.46	13.03	19.64	26.30	32.96	39.66	46.35	53.08	66.52
1.38	16 9/16	6.53	13.18	19.87	26.60	33.34	40.12	46.89	53.70	67.31
1.39	16 11/16	6.60	13.33	20.10	26.90	33.72	40.58	47.44	54.33	68.10
1.40	16 13/16	6.68	13.48	20.32	27.21	34.11	41.05	47.99	54.95	68.90
1.41	16 15/16	6.75	13.63	20.55	27.52	34.50	41.52	48.54	55.58	69.70
1.42	17 1/16	6.82	13.78	20.78	27.82	34.89	41.99	49.09	56.22	70.50
1.43	17 3/16	6.89	13.93	21.01	28.14	35.28	42.46	49.64	56.86	71.30
1.44	17 1/4	6.97	14.08	21.24	28.45	35.67	42.94	50.20	57.50	72.11
1.45	17 3/8	7.04	14.23	21.27	28.76	36.06	43.42	50.76	58.14	72.92
1.46	17 1/2	7.12	14.38	21.70	29.07	36.46	43.89	51.32	58.78	73.73
1.47	17 5/8	7.19	14.54	21.94	29.38	36.86	44.37	51.88	59.43	74.55
1.48	17 3/4	7.26	14.69	22.17	29.70	37.26	44.85	52.45	60.08	75.37
1.49	17 7/8	7.34	14.85	22.41	30.02	37.66	45.34	53.02	60.74	76.19
1.50	18	7.41	15.00	22.64	30.34	38.06	45.82	53.59	61.40	77.02
1.51	18 1/8	7.49	15.16	22.88	30.66	38.46	46.31	54.16	62.06	77.85
1.52	18 1/4	7.57	15.31	23.12	30.98	38.87	46.80	54.74	62.72	78.69
1.53	18 3/8	7.64	15.47	23.36	31.30	39.28	47.30	55.32	63.38	79.53
1.54	18 1/2	7.72	15.62	23.60	31.63	39.68	47.79	55.90	64.04	80.37
1.55	18 5/8	7.80	15.78	23.84	31.95	40.09	48.28	56.48	64.71	81.21
1.56	18 3/4	7.87	15.94	24.08	32.27	40.51	48.78	57.06	65.38	82.06
1.57	18 13/16	7.95	16.10	24.32	32.60	40.92	49.28	57.65	66.06	82.91
1.58	18 15/16	8.02	16.26	24.56	32.93	41.35	49.78	58.24	66.74	83.77
1.59	19 1/16	8.10	16.42	24.80	33.26	41.75	50.28	58.83	67.42	84.63
1.60	19 3/16	8.18	16.58	25.05	33.59	42.17	50.79	59.42	68.10	85.49
1.61	19 6/16	8.26	16.74	25.30	33.92	42.59	51.30	60.02	68.79	86.36
1.62	19 7/16	8.34	16.90	25.54	34.26	43.01	51.81	60.62	69.48	87.23
1.63	19 9/16	8.42	17.06	25.79	34.60	43.43	52.32	61.22	70.17	88.10
1.64	19 11/16	8.49	17.22	26.04	34.93	43.86	52.83	61.82	70.86	88.97
1.65	19 13/16	8.57	17.38	26.29	35.26	44.28	53.34	62.42	71.56	89.85
1.66	19 15/16	8.65	17.55	26.54	35.60	44.70	53.86	63.03	72.26	90.73
1.67	20 1/16	8.73	17.72	26.79	35.94	45.13	54.38	63.64	72.96	91.62
1.68	20 3/16	8.81	17.88	27.04	36.28	45.56	54.90	64.25	73.66	92.51
1.69	20 1/4	8.89	18.04	27.30	36.62	46.00	55.42	64.86	74.37	93.40
1.70	20 3/8	8.97	18.21	27.55	36.96	46.43	55.95	65.48	75.08	94.29
1.71	20 1/2	9.05	18.38	27.80	37.30	46.86	56.48	66.10	75.79	95.19
1.72	20 5/8	9.13	18.54	28.06	37.65	47.30	57.00	66.72	76.50	96.09
1.73	20 3/4	9.21	18.71	28.32	38.00	47.74	57.53	67.34	77.22	96.99
1.74	20 7/8	9.29	18.88	28.57	38.34	48.17	58.06	67.96	77.94	97.90
1.75	21	9.38	19.04	28.82	38.69	48.61	58.60	68.59	78.66	98.81
1.76	21 1/8	9.46	19.21	29.08	39.04	49.05	59.13	69.22	79.38	99.72
1.77	21 1/4	9.54	19.38	29.34	39.39	49.50	59.67	69.85	80.10	100.6
1.78	21 3/8	9.62	19.55	29.60	39.74	49.94	60.20	70.48	80.83	101.5
1.79	21 1/2	9.70	19.72	29.87	40.10	50.38	60.74	71.11	81.56	102.4

TABLE III.—FREE-FLOW DISCHARGE FOR IMPROVED VENTURI FLUME
Continued

Computed from the formula $Q=4\,W\,H_a^{1.522\,W^{0.026}}$

Upper Head H_a		Discharge per second for flumes of various throat widths								
		1 Foot	2 Feet	3 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet	10 Feet
Feet	Inches	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.
1.80	21⅝	9.79	19.90	30.13	40.45	50.83	61.29	71.75	82.29	103.4
1.81	21¾	9.87	20.07	30.39	40.80	51.28	61.83	72.39	83.03	104.4
1.82	21 13/16	9.95	20.24	30.65	41.16	51.73	62.38	73.03	83.77	105.3
1.83	21 15/16	10.04	20.42	30.92	41.52	52.18	62.92	73.68	84.51	106.2
1.84	22 1/16	10.12	20.59	31.18	41.88	52.64	63.46	74.33	85.25	107.1
1.85	22 3/16	10.20	20.76	31.45	42.24	53.09	64.01	74.98	86.00	108.1
1.86	22 5/16	10.29	20.93	31.71	42.60	53.55	64.57	75.63	86.75	109.0
1.87	22 7/16	10.38	21.10	31.98	42.96	54.00	65.13	76.28	87.50	110.0
1.88	22 9/16	10.46	21.28	32.25	43.32	54.46	65.69	76.93	88.25	110.9
1.89	22 11/16	10.54	21.46	32.52	43.69	54.92	66.25	77.58	89.00	111.9
1.90	22 13/16	10.62	21.63	32.79	44.05	55.39	66.81	78.24	89.76	112.9
1.91	22 15/16	10.71	21.81	33.06	44.42	55.85	67.37	78.90	90.52	113.8
1.92	23 1/16	10.80	21.99	33.33	44.79	56.32	67.93	79.56	91.29	114.8
1.93	23 3/16	10.88	22.17	33.60	45.16	56.78	68.50	80.23	92.05	115.8
1.94	23¼	10.97	22.35	33.87	45.53	57.25	69.06	80.90	92.82	116.7
1.95	23⅜	11.06	22.53	34.14	45.90	57.72	69.63	81.57	93.59	117.7
1.96	23½	11.14	22.70	34.42	46.27	58.19	70.20	82.24	94.36	118.7
1.97	23⅝	11.23	22.88	34.70	46.64	58.67	70.78	82.91	95.14	119.7
1.98	23¾	11.31	23.06	34.97	47.02	59.14	71.35	83.58	95.92	120.6
1.99	23⅞	11.40	23.24	35.25	47.40	59.61	71.92	84.26	96.70	121.6
2.00	24	11.49	23.43	35.53	47.77	60.08	72.50	84.94	97.48	122.6
2.01	24⅛	11.58	23.61	35.81	48.14	60.56	73.08	85.62	98.26	123.6
2.02	24¼	11.66	23.79	36.09	48.52	61.04	73.66	86.30	99.05	124.6
2.03	24⅜	11.75	23.98	36.37	48.90	61.52	74.24	86.99	99.84	125.6
2.04	24½	11.84	24.16	36.65	49.29	62.00	74.83	87.68	100.6	126.6
2.05	24⅝	11.93	24.34	36.94	49.67	62.48	75.42	88.37	101.4	127.6
2.06	24¾	12.02	24.52	37.22	50.05	62.97	76.00	89.06	102.2	128.6
2.07	24 13/16	12.10	24.70	37.50	50.44	63.46	76.59	89.75	103.0	129.6
2.08	24 15/16	12.19	24.89	37.78	50.82	63.94	77.19	90.44	103.8	130.6
2.09	25 1/16	12.28	25.08	38.06	51.21	64.43	77.78	91.14	104.6	131.6
2.10	25 3/16	12.37	25.27	38.35	51.59	64.92	78.37	91.84	105.4	132.7
2.11	25 5/16	12.46	25.46	38.64	51.98	65.41	78.97	92.54	106.2	133.7
2.12	25 7/16	12.55	25.64	38.93	52.37	65.91	79.56	93.25	107.0	134.7
2.13	25 9/16	12.64	25.83	39.22	52.76	66.40	80.15	93.95	107.9	135.7
2.14	25 11/16	12.73	26.01	39.50	53.15	66.89	80.75	94.66	108.7	136.8
2.15	25 13/16	12.82	26.20	39.79	53.54	67.39	81.36	95.37	109.5	137.8
2.16	25 15/16	12.92	26.39	40.08	53.94	67.89	81.97	96.08	110.3	138.8
2.17	26 1/16	13.01	26.58	40.37	54.34	68.39	82.58	96.79	111.1	139.9
2.18	26 3/16	13.10	26.77	40.66	54.73	68.89	83.19	97.51	111.9	140.9
2.19	26¼	13.19	26.96	40.96	55.12	69.39	83.80	98.23	112.8	142.0
2.20	26⅜	13.28	27.15	41.25	55.52	69.90	84.41	98.94	113.6	143.0
2.21	26½	13.37	27.34	41.54	55.92	70.40	85.02	99.66	114.4	144.1
2.22	26⅝	13.46	27.54	41.84	56.32	70.90	85.63	100.0	115.3	145.1
2.23	26¾	13.56	27.73	42.13	56.72	71.41	86.25	101.1	116.1	146.2
2.24	26⅞	13.65	27.92	42.43	57.12	71.92	86.87	101.8	116.9	147.3
2.25	27	13.74	28.12	42.73	57.52	72.43	87.49	102.6	117.8	148.3
2.26	27⅛	13.84	28.31	43.02	57.93	72.94	88.11	103.3	118.6	149.4
2.27	27¼	13.93	28.50	43.32	58.34	73.46	88.73	104.0	119.5	150.5
2.28	27⅜	14.02	28.70	43.62	58.74	73.97	89.35	104.8	120.3	151.5
2.29	27½	14.12	28.90	43.92	59.15	74.49	89.98	105.5	121.2	152.6

TABLE III.—FREE-FLOW DISCHARGE FOR IMPROVED VENTURI FLUME
Concluded

Computed from the formula $Q = 4 W H_a^{1.522 W^{0.026}}$

Upper Head H_a		Discharge per second for flumes of various throat widths								
		1 Foot	2 Feet	3 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet	10 Feet
Feet	Inches	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.
2.30	27 5/8	14.21	29.09	44.22	59.56	75.01	90.61	106.2	122.0	153.7
2.31	27 3/4	14.30	29.29	44.52	59.96	75.52	91.24	107.0	122.9	154.8
2.32	27 13/16	14.40	29.49	44.83	60.37	76.04	91.87	107.7	123.7	155.8
2.33	27 15/16	14.49	29.69	45.13	60.79	76.57	92.50	108.5	124.6	156.9
2.34	28 1/16	14.59	29.89	45.43	61.20	77.09	93.14	109.2	125.4	158.0
2.35	28 3/16	14.68	30.08	45.74	61.61	77.61	93.77	110.0	126.3	159.1
2.36	28 5/16	14.78	30.28	46.04	62.03	78.13	94.41	110.7	127.2	160.2
2.37	28 7/16	14.87	30.48	46.35	62.44	78.66	95.05	111.5	128.0	161.3
2.38	28 9/16	14.97	30.69	46.66	62.86	79.19	95.69	112.2	128.9	162.4
2.39	28 11/16	15.07	30.89	46.96	63.27	79.72	96.33	113.0	129.8	163.5
2.40	28 13/16	15.16	31.09	47.27	63.69	80.25	96.97	113.7	130.7	164.6
2.41	28 15/16	15.26	31.29	47.58	64.11	80.78	97.62	114.5	131.5	165.7
2.42	29 1/16	15.35	31.49	47.89	64.53	81.31	98.27	115.3	132.4	166.8
2.43	29 3/16	15.45	31.68	48.20	64.95	81.84	98.91	116.0	133.3	168.0
2.44	29 1/4	15.55	31.89	48.51	65.38	82.38	99.56	116.8	134.2	169.1
2.45	29 3/8	15.64	32.10	48.82	65.80	82.92	100.2	117.6	135.1	170.2
2.46	29 1/2	15.74	32.30	49.13	66.23	83.45	100.9	118.3	135.9	171.3
2.47	29 5/8	15.89	32.50	49.45	66.65	83.99	101.5	119.1	136.8	172.4
2.48	29 3/4	15.94	32.70	49.76	67.07	84.54	102.2	119.9	137.7	173.6
2.49	29 7/8	16.03	32.90	50.08	67.50	85.07	102.8	120.6	138.6	174.7
2.50	30	16.13	33.11	50.39	67.93	85.62	103.5	121.4	139.5	175.8

SUBMERGED-FLOW FORMULA

In the development of a formula suitable for the determination of discharge thru the improved Venturi flume for submerged flow, various methods were attempted, a form of equation being sought that would follow consistently the trend of the data and at the same time not be so complicated as to be impracticable. The following was the manner of reasoning finally followed:

For degree of submergence below 70 percent, it is found that a simple expression will apply in determining the rate of discharge where only the upper head, H_a, and the width of the flume are involved. However, when the degree of submergence is 70 percent or more the free-flow discharge is diminished slightly at first, and as the degree of submergence increases the rate of decrease in flow is increased until, near the point of complete submergence, the flow is very greatly reduced. The determination of the rate of submerged flow is then based upon the application of a certain correction to the free flow for that particular head, H_a, and the corresponding ratio of the throat head to the upper head. As pointed out, this ratio must be greater than 70 percent before being effective in the discharge.

The experimental data upon which this correction was first based included the results of 228 tests made in 1923, where the degree of submergence ranged from 70 to more than 95 percent, and a range of H_a from 0.2 foot to slightly more than 2.5 feet. They were divided according to size of flume as follows: 1-foot flume, 46 tests; 2-foot flume, 41 tests; 3-foot flume, 65 tests; 4-foot flume, 21 tests; 6-foot flume, 18 tests, and 8-foot flume, 37 tests. In 1926 a series of submerged-flow tests, numbering 264, was made and when the results were compared with the original submergence data it was found that a slight adjustment in the correction was necessary. The combination of all the submerged-flow tests shows the following division according to size of flume: 1-foot flume, 80 tests; 2-foot flume, 84 tests; 3-foot flume, 61 tests; 4-foot flume, 64 tests; 6-foot flume, 65 tests, and 8-foot flume, 116 tests. In the final arrangement 21 tests were excluded from the 1923 series.[5]

After reviewing the combined series it was found that for high submergence, where the gage ratio H_b/H_a exceeded 0.95, little dependence could be placed upon the accuracy of the computed discharge; also, when the value of H_a was 0.2 foot, the deviation between the observed and computed discharge was quite large. In the use of a more complicated expression for the determination of the correction factor it would be possible to reduce the error for these low heads, but for the high submergence at any head, H_a, observations show marked inconsistencies.

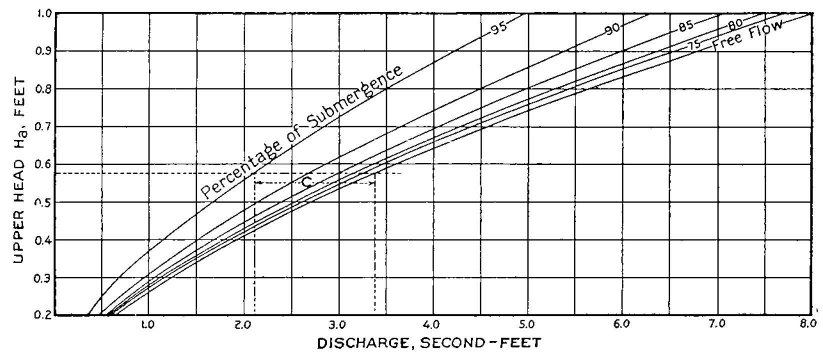

Figure 7.—Meaning of Correction Factor C in Second-feet, to be Subtracted from the Free-flow Discharge for a Definite Value of H_a and a Certain Degree of Submergence.

[5] For the 1-foot flume, test 6494 excluded because H_a exceeded 2.5 feet. Tests 6656-57, 6707-8 excluded because H_a=0.2 foot. Tests 6684, 6700, 6705 excluded because submergence exceeded 95 percent. For the 2-foot flume, test 6624 excluded because submergence exceeded 95 percent. Tests 6642-43 and 6646 excluded because H_a=0.2 ft.; 3-foot flume, test 6583 excluded because submergence exceeded 95 percent, and tests 6579-80-81 excluded because H_a=0.2 foot; 6-foot flume, tests 6342 and 7079 excluded because submergence exceeded 95 percent; 8-foot flume, tests 7020-29 excluded because submergence exceeded 95 percent. Of the 471 submerged-flow tests falling within the prescribed limits, test 6335 was excluded because of gross error.

These data were plotted as shown in Figure 7, where the several curved lines represent the degree of submergence. For any particular point on the submergence line there will be a definite value, C, as shown, which is the amount in second-feet to be subtracted from the free-flow value for that particular upper head, H_a, to give the submerged flow. It will be observed that as the value of H_a increases, the amount of the correction also increases for any particular degree of submergence. It is found that for the relation existing between the correction factor C for submergence and the upper head, H_a, for any degree of submergence, K, the general expression may be stated thus:

$$C_k = \left\{ \frac{H_a}{A} \right\}^{n} + B$$

where C_k is the correction in second-feet for the degree of submergence K, expressed as a decimal fraction, and H_a upper head in feet. A and B are values dependent on the gage ratio or degree of submergence, K, and n an exponent also dependent on K. Base equations were developed for various values of K, ranging from 0.70 to 0.95, and from these the law of variation of A, B and n was determined. This relation for the 1-foot flume is as follows:

$$C_k = \left\{ \frac{H_a}{\left\{ \frac{1.8}{K} \right\}^{1.8} - 2.45} \right\}^{4.57 - 3.14K} + 0.093K$$

For the other sizes of flume it was found by introducing a multiplying factor to the value of C that a practical agreement with the observed submerged flow was possible. This factor, M, varies with the width or size of flume W, according to the simple relation $M = W^{0.815}$

The following is the complete formula for computing the discharge thru the improved Venturi flume for submerged flow:

$$Q = 4\,W\,H_a^{1.522W^{0.026}} - \left\{ \left\{ \frac{H_a}{\left\{ \frac{1.8}{K} \right\}^{1.8} - 2.45} \right\}^{4.57 - 3.14K} + 0.093K \right\} W^{0.815}$$

This formula is not, in its complete statement, a simple expression; however, when the value of K, the degree of submergence expressed as a decimal fraction, is properly substituted, the formula, or that term representing the correction C, becomes much simplified. To facilitate the use of this expression for the value of C, it has been expanded in tabular form, as shown in Table IV.

To apply the correction C appearing in this table, it is necessary to multiply the tabular value C by a constant, as follows:

Size of flume W (feet)	Multiplier M
1	1.0
2	1.8
3	2.4
4	3.1
5	3.7
6	4.3
7	4.9
8	5.4

Figure 8 shows the agreement of the observed and computed discharges for submerged flow. The manner of compiling the data and constructing this diagram is identical with that given for the free-flow discharge. In the comparison of computed and observed discharges for the total 470 tests, it was found that 87 percent were within ±5 percent of the observed value.

In the comparison of the free-flow and submerged-flow error diagrams, it is evident that the accuracy of the measurement is greater where the device operates under a free-flow condition.

To determine the quantity of discharge thru the improved Venturi flume under submerged flow, reference should be made to Table IV, which is a base table applicable to the 1, 2, 3, 4, 5, 6, 7 and 8-foot flumes limited in range of upper head H_a from 0.3 foot to 2.5 feet, and to 95

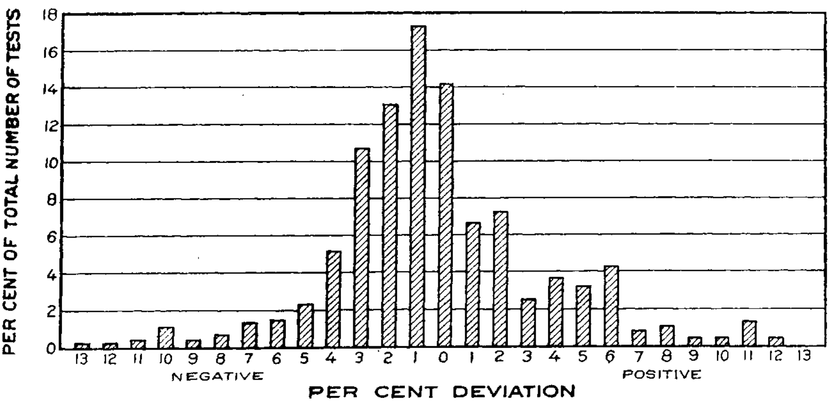

Figure 8.—Comparison in Percentage of Computed to Observed Submerged-flow Discharges Thru Experimental Flumes.

percent submergence. The following examples will illustrate the method of making computations for submerged conditions:

TABLE IV.—BASE TABLE FOR CALCULATING CORRECTIONS (C) TO DETERMINE SUBMERGED DISCHARGES FOR THE IMPROVED VENTURI FLUME FOR THROAT WIDTHS FROM ONE TO EIGHT FEET

Upper Head H_a		Gage Ratio or Degree of Submergence												
Feet	Inches	0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.79	0.80	0.81	0.82
0.30	3 5/8	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.10	0.11
.32	3 13/16	.07	.07	.07	.07	.08	.08	.08	.09	.09	.09	.10	.10	.11
.34	4 1/16	.07	.07	.07	.07	.08	.08	.08	.09	.09	.10	.10	.11	.11
.36	4 5/16	.07	.07	.07	.08	.08	.08	.09	.09	.09	.10	.11	.11	.12
.38	4 9/16	.07	.07	.07	.08	.08	.08	.09	.09	.10	.10	.11	.12	.13
.40	4 13/16	.07	.07	.08	.08	.08	.09	.09	.10	.10	.11	.11	.12	.13
.42	5 1/16	.07	.07	.08	.08	.08	.09	.09	.10	.10	.11	.12	.13	.14
.44	5 1/4	.07	.07	.08	.08	.09	.09	.10	.10	.11	.11	.12	.13	.14
.46	5 1/2	.07	.08	.08	.08	.09	.09	.10	.11	.11	.12	.13	.14	.15
.48	5 3/4	.07	.08	.08	.09	.09	.10	.10	.11	.12	.12	.13	.14	.16
.50	6	.08	.08	.08	.09	.09	.10	.11	.11	.12	.13	.14	.15	.16
.52	6 1/4	.08	.08	.09	.09	.09	.10	.11	.12	.12	.13	.14	.16	.17
.54	6 1/2	.08	.08	.09	.09	.10	.10	.11	.12	.13	.14	.15	.16	.18
.56	6 3/4	.08	.09	.09	.09	.10	.11	.11	.12	.13	.14	.16	.17	.19
.58	6 15/16	.08	.09	.09	.10	.10	.11	.12	.13	.14	.15	.16	.18	.19
.60	7 3/16	.08	.09	.09	.10	.11	.11	.12	.13	.14	.15	.17	.19	.20
.62	7 7/16	.09	.09	.10	.10	.11	.12	.13	.14	.15	.16	.18	.19	.21
.64	7 11/16	.09	.09	.10	.11	.11	.12	.13	.14	.15	.17	.18	.20	.22
.66	7 15/16	.09	.09	.10	.11	.12	.13	.13	.15	.16	.17	.19	.21	.23
.68	8 3/16	.09	.10	.10	.11	.12	.13	.14	.15	.17	.18	.20	.22	.24
.70	8 3/8	.09	.10	.11	.11	.12	.13	.14	.16	.17	.19	.21	.23	.25
.72	8 5/8	.09	.10	.11	.12	.13	.14	.15	.16	.18	.19	.21	.24	.26
.74	8 7/8	.10	.10	.11	.12	.13	.14	.15	.17	.18	.20	.22	.25	.27
.76	9 1/8	.10	.11	.11	.12	.13	.15	.16	.17	.19	.21	.23	.25	.28
.78	9 3/8	.10	.11	.12	.13	.14	.15	.17	.18	.20	.22	.24	.26	.29
.80	9 5/8	.11	.11	.12	.13	.14	.16	.17	.19	.21	.23	.25	.27	.30
.82	9 13/16	.11	.12	.13	.14	.15	.16	.18	.19	.21	.23	.26	.29	.32
.84	10 1/16	.11	.12	.13	.14	.15	.17	.18	.20	.22	.24	.27	.30	.33
.86	10 5/16	.11	.12	.13	.14	.16	.17	.19	.21	.23	.25	.28	.31	.34
.88	10 9/16	.12	.13	.14	.15	.16	.18	.19	.21	.23	.26	.29	.32	.35
.90	10 13/16	.12	.13	.14	.15	.17	.18	.20	.22	.24	.27	.30	.33	.37
.92	11 1/16	.12	.13	.14	.16	.17	.19	.21	.23	.25	.28	.31	.34	.38
.94	11 1/4	.13	.13	.15	.16	.18	.19	.21	.24	.26	.29	.32	.35	.39
.96	11 1/2	.13	.14	.15	.17	.18	.20	.22	.24	.27	.30	.33	.37	.41
.98	11 3/4	.13	.14	.16	.17	.19	.21	.23	.25	.28	.31	.34	.38	.42
1.00	12	.13	.15	.16	.18	.19	.21	.23	.26	.29	.32	.35	.39	.43
1.02	12 1/4	.14	.15	.17	.18	.20	.22	.24	.27	.30	.33	.36	.40	.45
1.04	12 1/2	.14	.15	.17	.19	.21	.23	.25	.28	.31	.34	.37	.42	.46
1.06	12 3/4	.15	.16	.17	.19	.21	.23	.26	.29	.32	.35	.39	.43	.48
1.08	12 15/16	.15	.16	.18	.20	.22	.24	.27	.29	.33	.36	.40	.44	.49
1.10	13 3/16	.15	.17	.18	.20	.22	.25	.27	.30	.34	.37	.41	.46	.51
1.12	13 7/16	.16	.17	.19	.21	.23	.25	.28	.31	.35	.38	.43	.47	.53
1.14	13 11/16	.16	.18	.19	.21	.24	.26	.29	.32	.36	.39	.44	.49	.54
1.16	13 15/16	.17	.18	.20	.22	.24	.27	.30	.33	.37	.41	.45	.50	.56
1.18	14 3/16	.17	.19	.21	.23	.25	.28	.31	.34	.38	.42	.47	.52	.57
1.20	14 3/8	.17	.19	.21	.23	.26	.29	.32	.35	.39	.43	.48	.53	.59
1.22	14 5/8	.18	.20	.22	.24	.27	.29	.33	.36	.40	.44	.49	.55	.61
1.24	14 7/8	.18	.20	.22	.25	.27	.30	.33	.37	.41	.46	.51	.56	.63
1.26	15 1/8	.19	.21	.23	.25	.28	.31	.34	.38	.42	.47	.52	.58	.65
1.28	15 3/8	.19	.21	.23	.26	.29	.32	.35	.39	.44	.48	.54	.60	.66
1.30	15 5/8	.20	.22	.24	.27	.30	.33	.36	.40	.45	.50	.55	.61	.68
1.32	15 13/16	.20	.22	.25	.27	.30	.34	.37	.41	.46	.51	.57	.63	.70
1.34	16 1/16	.21	.23	.25	.28	.31	.35	.38	.43	.47	.53	.58	.65	.72
1.36	16 5/16	.21	.23	.26	.29	.32	.36	.39	.44	.49	.54	.60	.67	.74
1.38	16 9/16	.22	.24	.27	.30	.33	.37	.41	.45	.50	.55	.62	.68	.76
1.40	16 13/16	.22	.25	.27	.30	.34	.37	.42	.46	.51	.57	.63	.70	.78
1.42	17 1/16	.23	.25	.28	.31	.35	.38	.43	.47	.53	.58	.65	.72	.80
1.44	17 1/4	.23	.26	.29	.32	.35	.39	.44	.49	.54	.60	.67	.74	.82
1.46	17 1/2	.24	.27	.29	.33	.36	.40	.45	.50	.55	.61	.68	.76	.84
1.48	17 3/4	.25	.27	.30	.34	.37	.41	.46	.51	.57	.63	.70	.78	.86
1.50	18	.25	.28	.31	.34	.38	.43	.47	.53	.58	.65	.72	.80	.88
1.52	18 1/4	.26	.29	.32	.35	.39	.44	.48	.54	.60	.66	.73	.82	.91
1.54	18 1/2	.26	.29	.33	.36	.40	.45	.50	.55	.61	.68	.75	.84	.93
1.56	18 3/4	.27	.30	.33	.37	.41	.46	.51	.57	.63	.69	.77	.86	.95
1.58	18 15/16	.28	.31	.34	.38	.42	.47	.52	.58	.64	.71	.79	.88	.97
1.60	19 3/16	.28	.31	.35	.39	.43	.48	.53	.59	.66	.73	.81	.90	.99
1.62	19 7/16	.29	.32	.36	.40	.44	.49	.55	.61	.67	.75	.83	.92	1.02
1.64	19 11/16	.30	.33	.37	.41	.45	.50	.56	.62	.69	.76	.85	.94	1.04
1.66	19 15/16	.30	.34	.37	.42	.46	.51	.57	.64	.71	.78	.87	.96	1.07
1.68	20 3/16	.31	.35	.38	.43	.47	.53	.59	.65	.72	.80	.89	.98	1.09
1.70	20 3/8	.32	.35	.39	.44	.49	.54	.60	.67	.74	.82	.91	1.01	1.11
1.72	20 5/8	.32	.36	.40	.45	.50	.55	.61	.68	.75	.84	.93	1.03	1.14
1.74	20 7/8	.33	.37	.41	.46	.51	.56	.63	.70	.77	.86	.95	1.05	1.16
1.76	21 1/8	.34	.38	.42	.47	.52	.58	.64	.71	.79	.87	.97	1.07	1.19
1.78	21 3/8	.35	.39	.43	.48	.53	.59	.65	.73	.81	.89	.99	1.10	1.21
1.80	21 5/8	.35	.39	.44	.49	.54	.60	.67	.74	.82	.91	1.01	1.12	1.24
1.82	21 13/16	.36	.40	.45	.50	.55	.62	.69	.76	.84	.93	1.03	1.14	1.26
1.84	22 1/16	.37	.41	.46	.51	.57	.63	.70	.78	.86	.95	1.05	1.17	1.29
1.86	22 5/16	.38	.42	.47	.52	.58	.64	.71	.79	.88	.97	1.08	1.19	1.32
1.88	22 9/16	.39	.43	.48	.53	.59	.66	.73	.81	.90	.99	1.10	1.22	1.34
1.90	22 13/16	.39	.44	.49	.54	.60	.67	.75	.83	.92	1.01	1.12	1.24	1.37
1.92	23 1/16	.40	.45	.50	.55	.62	.69	.76	.84	.93	1.03	1.15	1.27	1.40
1.94	23 1/4	.41	.46	.51	.57	.63	.70	.78	.86	.95	1.06	1.17	1.29	1.43
1.96	23 1/2	.42	.47	.52	.58	.64	.71	.79	.88	.97	1.08	1.19	1.32	1.45
1.98	23 3/4	.43	.48	.53	.59	.66	.73	.81	.90	.99	1.10	1.22	1.34	1.48
2.00	24	.44	.49	.54	.60	.67	.74	.83	.92	1.01	1.12	1.24	1.37	1.51
2.02	24 1/4	.45	.50	.55	.61	.68	.76	.84	.93	1.03	1.14	1.26	1.40	1.54
2.04	24 1/2	.46	.51	.56	.63	.70	.77	.86	.95	1.05	1.17	1.29	1.42	1.57
2.06	24 3/4	.46	.52	.58	.64	.71	.79	.88	.97	1.07	1.19	1.31	1.45	1.60
2.08	24 15/16	.47	.53	.59	.65	.73	.81	.89	.99	1.09	1.21	1.34	1.48	1.63
2.10	25 3/16	.48	.54	.60	.67	.74	.82	.91	1.01	1.12	1.23	1.36	1.50	1.66
2.12	25 7/16	.49	.55	.61	.68	.75	.84	.93	1.03	1.14	1.26	1.39	1.53	1.69
2.14	25 11/16	.50	.56	.62	.69	.77	.85	.95	1.05	1.16	1.28	1.41	1.56	1.72
2.16	25 15/16	.51	.57	.63	.71	.78	.87	.96	1.07	1.18	1.30	1.44	1.59	1.75
2.18	26 3/16	.52	.58	.65	.72	.80	.89	.98	1.09	1.20	1.33	1.47	1.62	1.78
2.20	26 3/8	.53	.59	.66	.73	.81	.90	1.00	1.11	1.22	1.35	1.49	1.65	1.81
2.22	26 5/8	.54	.60	.67	.75	.83	.92	1.02	1.13	1.25	1.38	1.52	1.67	1.84
2.24	26 7/8	.55	.62	.69	.76	.85	.94	1.04	1.15	1.27	1.40	1.55	1.70	1.88
2.26	27 1/8	.56	.63	.70	.77	.86	.95	1.06	1.17	1.29	1.43	1.57	1.73	1.91
2.28	27 3/8	.57	.64	.71	.79	.88	.97	1.08	1.19	1.31	1.45	1.60	1.76	1.94
2.30	27 5/8	.59	.65	.72	.80	.89	.99	1.10	1.21	1.34	1.48	1.63	1.79	1.97
2.32	27 13/16	.60	.66	.74	.82	.91	1.01	1.12	1.23	1.36	1.50	1.66	1.82	2.01
2.34	28 1/16	.61	.67	.75	.83	.93	1.03	1.14	1.26	1.39	1.53	1.69	1.85	2.04
2.36	28 5/16	.62	.69	.77	.85	.94	1.04	1.16	1.28	1.41	1.55	1.71	1.89	2.07
2.38	28 9/16	.63	.70	.78	.86	.96	1.06	1.18	1.30	1.43	1.58	1.74	1.92	2.11
2.40	28 13/16	.64	.71	.79	.88	.98	1.08	1.20	1.32	1.46	1.61	1.77	1.96	2.14
2.42	29 1/16	.65	.73	.81	.89	.99	1.10	1.22	1.35	1.48	1.63	1.80	1.98	2.18
2.44	29 1/4	.66	.74	.82	.91	1.01	1.12	1.24	1.37	1.51	1.66	1.83	2.01	2.21
2.46	29 1/2	.67	.75	.83	.93	1.03	1.14	1.26	1.39	1.53	1.69	1.86	2.05	2.25
2.48	29 3/4	.69	.76	.85	.94	1.05	1.16	1.28	1.41	1.56	1.72	1.89	2.08	2.28
2.50	30	.70	.78	.86	.96	1.06	1.18	1.30	1.44	1.58	1.76	1.92	2.11	2.32

Upper Head H_a	Gage Ratio or Degree of Submergence												
Feet	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95
0.30	0.11	0.12	0.13	0.14	0.15	0.16	0.18	0.20	0.22	0.24	0.27	0.30	0.34
.32	.12	.13	.14	.15	.16	.17	.19	.21	.23	.26	.29	.33	.37
.34	.12	.13	.14	.15	.17	.19	.20	.23	.25	.28	.31	.35	.40
.36	.13	.14	.15	.16	.18	.20	.22	.24	.27	.30	.33	.38	.43
.38	.13	.15	.16	.17	.19	.21	.23	.26	.29	.32	.36	.40	.46
.40	.14	.15	.17	.18	.20	.22	.25	.27	.30	.34	.38	.43	.49
.42	.15	.16	.18	.19	.21	.23	.26	.29	.32	.36	.41	.46	.52
.44	.15	.17	.19	.20	.22	.25	.28	.31	.34	.39	.43	.49	.55
.46	.16	.18	.20	.21	.24	.26	.29	.33	.36	.41	.46	.52	.59
.48	.17	.19	.21	.23	.25	.28	.31	.34	.39	.43	.49	.55	.62
.50	.18	.20	.22	.24	.26	.29	.33	.36	.41	.46	.51	.58	.66
.52	.19	.21	.23	.25	.28	.31	.34	.38	.43	.48	.54	.61	.70
.54	.20	.22	.24	.26	.29	.32	.36	.40	.45	.51	.57	.65	.73
.56	.21	.23	.25	.28	.31	.34	.38	.43	.48	.54	.60	.68	.77
.58	.21	.24	.26	.29	.32	.36	.40	.45	.50	.56	.63	.72	.81
.60	.22	.25	.27	.30	.34	.37	.42	.47	.53	.59	.67	.75	.85
.62	.23	.26	.29	.31	.35	.39	.44	.49	.55	.62	.70	.79	.89
.64	.24	.27	.30	.33	.37	.41	.46	.52	.58	.65	.73	.83	.93
.66	.25	.28	.31	.35	.39	.43	.48	.54	.61	.68	.76	.86	.98
.68	.27	.29	.33	.36	.40	.45	.50	.56	.63	.71	.80	.90	1.02
.70	.28	.31	.34	.38	.42	.47	.53	.59	.66	.74	.83	.94	1.07
.72	.29	.32	.35	.39	.44	.49	.55	.61	.69	.77	.87	.98	1.11
.74	.30	.33	.37	.41	.46	.51	.57	.64	.72	.81	.91	1.02	1.15
.76	.31	.35	.38	.43	.48	.53	.60	.67	.75	.84	.94	1.06	1.20
.78	.33	.36	.40	.45	.50	.55	.62	.69	.78	.87	.98	1.11	1.25
.80	.34	.37	.42	.46	.52	.58	.65	.72	.81	.91	1.02	1.15	1.30
.82	.35	.39	.43	.48	.54	.60	.67	.75	.84	.94	1.06	1.19	1.35
.84	.36	.40	.45	.50	.56	.62	.70	.78	.87	.98	1.10	1.23	1.39
.86	.38	.42	.47	.52	.58	.65	.72	.81	.90	1.01	1.14	1.28	1.44
.88	.39	.43	.48	.54	.60	.67	.75	.84	.94	1.05	1.18	1.33	1.49
.90	.41	.45	.50	.56	.62	.70	.78	.87	.97	1.09	1.22	1.37	1.55
.92	.42	.47	.52	.58	.65	.72	.81	.90	1.01	1.13	1.26	1.42	1.60
.94	.44	.48	.54	.60	.67	.75	.83	.93	1.04	1.17	1.30	1.47	1.65
.96	.45	.50	.56	.62	.69	.77	.86	.96	1.07	1.20	1.35	1.51	1.70
.98	.47	.52	.58	.64	.72	.80	.89	.99	1.11	1.24	1.39	1.56	1.76
1.00	.48	.54	.60	.67	.74	.83	.92	1.03	1.15	1.28	1.43	1.61	1.81
1.02	.50	.56	.62	.69	.77	.85	.95	1.06	1.18	1.32	1.48	1.66	1.87
1.04	.51	.57	.64	.71	.79	.88	.98	1.09	1.22	1.37	1.53	1.71	1.92
1.06	.53	.59	.66	.73	.81	.91	1.01	1.13	1.26	1.41	1.57	1.76	1.98
1.08	.55	.61	.68	.75	.84	.94	1.04	1.16	1.30	1.45	1.62	1.81	2.03
1.10	.57	.63	.70	.78	.87	.97	1.07	1.20	1.34	1.49	1.67	1.87	2.09
1.12	.58	.65	.72	.80	.89	.99	1.11	1.23	1.37	1.53	1.71	1.92	2.15
1.14	.60	.67	.74	.83	.92	1.02	1.14	1.27	1.41	1.58	1.76	1.97	2.21
1.16	.62	.69	.77	.85	.95	1.05	1.17	1.31	1.45	1.62	1.81	2.03	2.27
1.18	.64	.71	.79	.88	.98	1.09	1.21	1.34	1.50	1.67	1.86	2.08	2.33
1.20	.66	.73	.81	.90	1.00	1.12	1.24	1.38	1.54	1.71	1.91	2.13	2.39
1.22	.68	.75	.83	.93	1.03	1.15	1.28	1.42	1.58	1.76	1.96	2.19	2.45
1.24	.70	.77	.86	.95	1.06	1.18	1.31	1.46	1.62	1.81	2.01	2.25	2.51
1.26	.72	.79	.88	.98	1.09	1.21	1.35	1.50	1.66	1.85	2.06	2.30	2.58
1.28	.74	.82	.91	1.01	1.12	1.24	1.38	1.54	1.71	1.90	2.11	2.36	2.64
1.30	.76	.84	.93	1.04	1.15	1.28	1.42	1.58	1.75	1.95	2.17	2.42	2.70
1.32	.78	.86	.96	1.06	1.18	1.31	1.45	1.62	1.79	2.00	2.22	2.48	2.77
1.34	.80	.89	.98	1.09	1.21	1.35	1.49	1.66	1.84	2.05	2.27	2.53	2.83
1.36	.82	.91	1.01	1.12	1.24	1.38	1.53	1.70	1.89	2.10	2.33	2.59	2.90
1.38	.84	.93	1.04	1.15	1.28	1.41	1.57	1.74	1.93	2.15	2.38	2.65	2.96
1.40	.87	.96	1.06	1.18	1.31	1.45	1.61	1.78	1.98	2.20	2.44	2.71	3.03
1.42	.89	.98	1.09	1.21	1.34	1.49	1.65	1.83	2.02	2.25	2.49	2.78	3.10
1.44	.91	1.01	1.12	1.24	1.37	1.52	1.69	1.87	2.07	2.30	2.55	2.84	3.16
1.46	.93	1.03	1.15	1.27	1.41	1.56	1.73	1.91	2.12	2.35	2.61	2.90	3.23
1.48	.96	1.06	1.17	1.30	1.44	1.59	1.77	1.96	2.17	2.40	2.66	2.96	3.30
1.50	.98	1.08	1.20	1.33	1.47	1.63	1.81	2.00	2.21	2.46	2.72	3.03	3.37
1.52	1.00	1.11	1.23	1.36	1.51	1.67	1.85	2.05	2.26	2.51	2.78	3.09	3.44
1.54	1.03	1.14	1.26	1.39	1.54	1.71	1.89	2.09	2.31	2.56	2.84	3.15	3.51
1.56	1.05	1.16	1.29	1.43	1.58	1.75	1.93	2.14	2.36	2.62	2.90	3.22	3.58
1.58	1.08	1.19	1.32	1.46	1.61	1.78	1.97	2.18	2.41	2.67	2.96	3.28	3.65
1.60	1.10	1.22	1.35	1.49	1.65	1.82	2.01	2.23	2.46	2.73	3.02	3.35	3.72
1.62	1.13	1.25	1.38	1.53	1.69	1.86	2.06	2.28	2.51	2.78	3.08	3.42	3.80
1.64	1.15	1.27	1.41	1.56	1.72	1.90	2.10	2.32	2.57	2.84	3.14	3.48	3.87
1.66	1.18	1.30	1.44	1.59	1.76	1.94	2.15	2.37	2.62	2.90	3.20	3.55	3.94
1.68	1.21	1.33	1.47	1.63	1.80	1.98	2.19	2.42	2.67	2.95	3.27	3.62	4.02
1.70	1.23	1.36	1.50	1.66	1.83	2.03	2.23	2.47	2.73	3.01	3.33	3.69	4.09
1.72	1.26	1.39	1.53	1.70	1.87	2.07	2.28	2.52	2.78	3.07	3.39	3.75	4.17
1.74	1.29	1.42	1.57	1.73	1.91	2.11	2.33	2.57	2.83	3.13	3.45	3.82	4.24
1.76	1.31	1.45	1.60	1.77	1.95	2.15	2.37	2.62	2.89	3.19	3.52	3.89	4.32
1.78	1.34	1.48	1.63	1.80	1.99	2.19	2.42	2.67	2.94	3.25	3.58	3.96	4.39
1.80	1.37	1.51	1.67	1.84	2.03	2.24	2.47	2.72	3.00	3.31	3.65	4.03	4.47
1.82	1.40	1.54	1.70	1.88	2.07	2.28	2.51	2.77	3.05	3.37	3.71	4.11	4.55
1.84	1.43	1.57	1.73	1.91	2.11	2.32	2.56	2.82	3.11	3.43	3.78	4.18	4.63
1.86	1.46	1.60	1.77	1.95	2.15	2.37	2.61	2.87	3.17	3.49	3.85	4.25	4.71
1.88	1.49	1.64	1.80	1.99	2.19	2.41	2.66	2.93	3.22	3.55	3.91	4.32	4.79
1.90	1.51	1.67	1.84	2.03	2.23	2.46	2.71	2.98	3.28	3.61	3.98	4.40	4.87
1.92	1.54	1.70	1.87	2.07	2.28	2.50	2.75	3.03	3.34	3.68	4.05	4.47	4.95
1.94	1.57	1.73	1.91	2.11	2.32	2.55	2.80	3.09	3.39	3.74	4.12	4.54	5.03
1.96	1.60	1.77	1.95	2.15	2.36	2.60	2.85	3.14	3.45	3.80	4.19	4.62	5.11
1.98	1.63	1.80	1.98	2.19	2.40	2.64	2.91	3.20	3.51	3.87	4.26	4.69	5.19
2.00	1.67	1.83	2.02	2.23	2.45	2.69	2.96	3.25	3.57	3.93	4.33	4.77	5.27
2.02	1.70	1.87	2.06	2.27	2.49	2.74	3.01	3.31	3.63	4.00	4.40	4.85	5.35
2.04	1.73	1.90	2.09	2.31	2.53	2.79	3.06	3.36	3.69	4.06	4.47	4.92	5.44
2.06	1.76	1.94	2.13	2.35	2.58	2.83	3.11	3.42	3.75	4.13	4.54	5.00	5.52
2.08	1.79	1.98	2.17	2.39	2.62	2.88	3.16	3.48	3.82	4.19	4.61	5.08	5.60
2.10	1.83	2.01	2.21	2.43	2.67	2.93	3.22	3.53	3.88	4.26	4.68	5.15	5.69
2.12	1.86	2.04	2.25	2.47	2.71	2.98	3.27	3.59	3.94	4.33	4.75	5.23	5.77
2.14	1.89	2.08	2.29	2.51	2.76	3.03	3.32	3.65	4.00	4.40	4.83	5.31	5.86
2.16	1.93	2.12	2.33	2.56	2.81	3.08	3.38	3.71	4.07	4.46	4.90	5.39	5.94
2.18	1.96	2.15	2.37	2.60	2.85	3.13	3.43	3.77	4.13	4.53	4.97	5.47	6.03
2.20	1.99	2.19	2.41	2.64	2.90	3.18	3.49	3.83	4.19	4.60	5.05	5.55	6.12
2.22	2.03	2.23	2.45	2.69	2.95	3.23	3.54	3.89	4.26	4.67	5.12	5.63	6.20
2.24	2.06	2.27	2.49	2.73	2.99	3.28	3.60	3.95	4.32	4.74	5.20	5.71	6.29
2.26	2.10	2.30	2.53	2.78	3.04	3.33	3.65	4.01	4.39	4.81	5.27	5.79	6.38
2.28	2.13	2.34	2.57	2.82	3.09	3.39	3.71	4.07	4.45	4.88	5.35	5.87	6.47
2.30	2.17	2.38	2.61	2.87	3.14	3.44	3.77	4.13	4.52	4.95	5.43	5.96	6.56
2.32	2.21	2.42	2.65	2.91	3.19	3.49	3.82	4.19	4.58	5.02	5.50	6.04	6.65
2.34	2.24	2.46	2.70	2.96	3.24	3.55	3.88	4.25	4.65	5.09	5.58	6.13	6.74
2.36	2.28	2.50	2.74	3.00	3.29	3.60	3.94	4.31	4.72	5.17	5.66	6.21	6.83
2.38	2.31	2.54	2.78	3.05	3.34	3.65	4.00	4.37	4.79	5.24	5.74	6.29	6.92
2.40	2.35	2.58	2.83	3.10	3.39	3.71	4.05	4.44	4.85	5.31	5.82	6.38	7.01
2.42	2.39	2.62	2.87	3.14	3.44	3.76	4.11	4.50	4.92	5.39	5.89	6.46	7.10
2.44	2.43	2.66	2.91	3.19	3.49	3.82	4.17	4.57	4.99	5.46	5.97	6.55	7.19
2.46	2.47	2.70	2.96	3.24	3.54	3.87	4.23	4.63	5.06	5.54	6.05	6.63	7.29
2.48	2.50	2.74	3.00	3.29	3.60	3.93	4.29	4.69	5.13	5.61	6.13	6.72	7.38
2.50	2.54	2.78	3.05	3.34	3.65	3.99	4.35	4.76	5.20	5.68	6.21	6.81	7.47

(1) Let it be assumed that the flume has a throat width, W, of one foot, upper head, H_a, 1.50 feet, and the throat head, H_b, 1.29 feet. The ratio 1.29/1.50=0.86. In the left-hand column of the table under the head H_a, follow down to the value 1.50, the recorded upper head, and on this line follow out to the right to the column headed 0.86 where the constant 1.33 is found. In the free-flow discharge Table III for the 1-foot flume with the recorded head, H_a, of 1.50 feet, note that the discharge is 7.41 second-feet. The flow with a submergence of 86 percent under these conditions, will, therefore, be 7.41—1.33 =6.08 second-feet.

(2) What will be the discharge thru a 4-foot flume where the upper head, H_a, is 2.15 feet and the throat head, H_b, 1.71 feet? The ratio of heads 1.71/2.15 is very close to 0.795. In the submergence table the value sought will be found between certain given numbers, both for submergence and value of upper head, H_a. First, find the average value for the submergence 0.79 and 0.80 for an upper head, H_a, at 2.14 feet. This is 1.35. Now find the average value for these two submergences with an upper head of 2.16 feet. This is 1.37. The average values thus determined are for the submergence 0.795. The value of the correction for the upper head, H_a, 2.15 feet, will obviously be the average of 1.35 and 1.37, or 1.36. It is found that for the 4-foot flume, the multiplying factor M is 3.1, and this times 1.36 equals 4.22 second-feet, the correction or amount to be subtracted from the free-flow discharge. From the free-flow discharge table, 4-foot flume, H_a=2.15 feet, the discharge is observed to be 53.54 second-feet; hence the submerged flow for these conditions would be 53.54 − 4.22=49.32 second-feet. For this degree of submergence, it is readily determined that the free-flow discharge has been reduced approximately 8 percent.

For general field use it would be necessary only to express the ratio of throat head to the upper head, K, to the nearest hundredth.

Table V has been prepared to show the error for submerged discharge resulting from observing either the upper head, H_a, or the throat head, H_b, 0.01 foot too large or too small. The error in free-flow discharge caused by 0.01 foot error may be determined easily by noting the difference in the tabular values given in Table III for an increment of 0.01 foot.

In order to make a comparison between the computed discharge of an improved Venturi flume and an ordinary rating flume, there was built a 6-foot improved Venturi flume in a ditch at Rocky Ford, Colorado, as shown in Figure 9. This flume is provided with stilling wells for both the H_a and H_b gages. An index was fixed near the

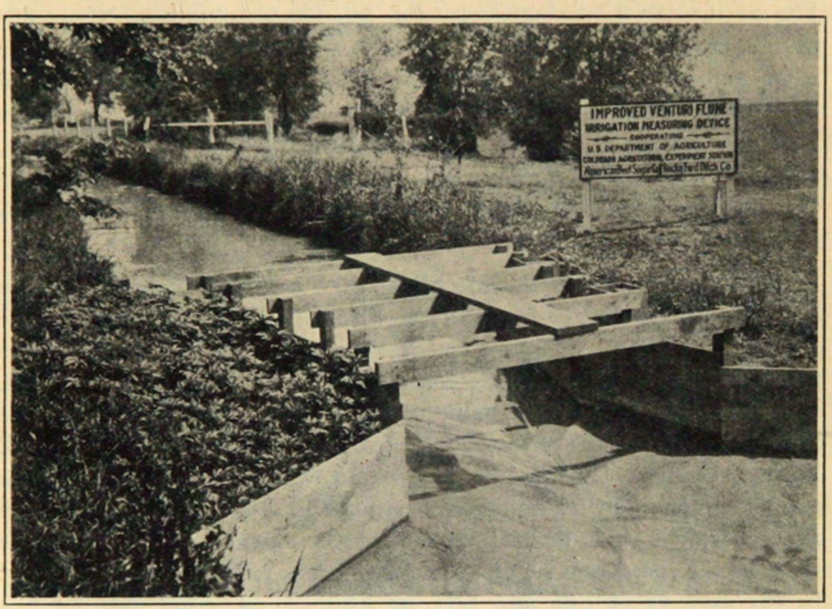

Figure 9.—Six-foot Improved Venturi Flume Showing a Discharge of About 50 Second-feet with a Submergence of 95 Percent, Rocky Ford, Colorado.

top of each well which made it possible to determine the heads to 0.01 foot by means of a depth gage. Reference points in the upstream and downstream wings of the structure were used to determine the loss of head.

An ordinary rating flume, previously constructed in the ditch at a point about 100 yards downstream, was calibrated by current-meter gagings and used to ascertain the discharge of the improved Venturi flume. The condition of flow thru the rating flume was satisfactory. Table VI gives a comparison between the computed discharge thru this 6-foot improved Venturi flume, as compared with the discharge as shown by the rating flume.

THE 6-INCH IMPROVED VENTURI FLUME

In the original investigation of this type of measuring device, the 1-foot flume was the smallest size tested, and because of the desirability of using this flume for smaller discharges than could be measured practically by use of the 1-foot size, a series of observations was made on a 6-inch structure having different dimensions than

TABLE V.—PERCENTAGE OF ERROR IN SUBMERGED DISCHARGE CAUSED BY 0.01 FOOT ERROR IN READING THE UPPER OR THROAT HEADS

Upper Head, H_a	Gage Ratio or Degree of Submergence 1-Foot Flume					Gage Ratio or Degree of Submergence 2-Foot Flume					Gage Ratio or Degree of Submergence 3-Foot Flume				
Feet	0.75	0.80	0.85	0.90	0.95	0.75	0.80	0.85	0.90	0.95	0.75	0.80	0.85	0.90	0.95
Where the throat head, H_b, is observed to be 0.01 foot less than the true value															
0.5	1	1	3	7	19	1	1	3	6	15	1	1	2	5	14
1.0	.	1	2	4	9	.	1	1	3	7	.	1	1	3	6
1.5	.	1	1	3	6	.	.	1	2	4	.	.	1	2	4
2.0	.	1	1	2	4	.	.	1	1	3	.	.	1	1	3
2.5	.	.	1	1	3	.	.	.	1	2	.	.	.	1	2
Where the throat head, H_b, is observed to be 0.01 foot more than the true value															
0.5	1	2	4	9	26	1	2	3	7	20	1	2	3	7	19
1.0	1	1	2	4	10	.	1	2	3	8	.	1	1	3	7
1.5	.	1	1	2	7	.	1	1	2	5	.	.	1	2	5
2.0	.	1	1	2	5	.	.	1	2	3	.	.	1	1	3
2.5	.	.	1	2	3	.	.	1	1	3	.	.	1	1	2
Where the upper head, H_a, is observed to be 0.01 foot less than the true value															
0.5	4	5	7	12	30	4	5	7	10	24	4	5	7	10	23
1.0	2	2	3	6	13	2	2	3	5	10	2	2	3	5	10
1.5	1	2	2	4	7	1	2	2	3	6	1	2	2	3	5
2.0	1	1	2	3	6	1	1	2	2	4	1	1	2	2	4
2.5	1	1	1	2	5	1	1	1	2	4	1	1	1	2	3
Where the upper head, H_a, is observed to be 0.01 foot more than the true value															
0.5	5	6	7	10	24	4	4	6	9	19	4	5	6	9	17
1.0	2	3	3	5	11	2	2	3	5	9	2	2	3	5	8
1.5	1	2	2	4	7	1	2	2	3	6	1	2	2	3	5
2.0	1	1	2	3	5	1	1	2	2	4	1	1	2	2	4
2.5	1	1	2	2	4	1	1	1	2	3	1	1	1	2	3

Upper Head, H_a	Gage Ratio or Degree of Submergence 4-Foot Flume					Gage Ratio or Degree of Submergence 6-Foot Flume					Gage Ratio or Degree of Submergence 8-Foot Flume				
Feet	0.75	0.80	0.85	0.90	0.95	0.75	0.80	0.85	0.90	0.95	0.75	0.80	0.85	0.90	0.95
Where the throat head, H_b, is observed to be 0.01 foot less than the true value															
0.5	1	1	2	5	13	1	1	2	5	13	1	1	2	5	13
1.0	.	1	1	3	6	.	1	1	3	6	.	1	1	2	6
1.5	.	.	1	2	4	.	.	1	2	4	.	.	1	2	3
2.0	.	.	1	1	2	.	.	1	1	2	.	.	1	1	2
2.5	.	.	.	1	2	.	.	.	1	2	.	.	.	1	2
Where the throat head, H_b, is observed to be 0.01 foot more than the true value															
0.5	1	2	3	7	18	1	2	3	7	18	1	2	3	6	17
1.0	.	1	1	3	7	.	1	1	3	7	.	1	1	3	6
1.5	.	.	1	2	4	.	.	1	2	4	.	.	1	2	4
2.0	.	.	1	1	3	.	.	1	1	3	.	.	1	1	3
2.5	.	.	1	1	2	.	.	1	1	2	.	.	1	1	2
Where the upper head, H_a, is observed to be 0.01 foot less than the true value															
0.5	4	5	6	10	22	4	5	6	10	22	4	5	6	10	21
1.0	2	2	3	5	9	2	2	3	5	9	2	2	3	5	9
1.5	1	2	2	3	5	1	2	2	3	5	1	2	2	3	5
2.0	1	1	1	2	4	1	1	1	2	4	1	1	1	2	4
2.5	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3
Where the upper head, H_a, is observed to be 0.01 foot more than the true value															
0.5	4	4	6	9	17	4	4	6	9	16	4	4	6	8	16
1.0	2	2	3	4	8	2	2	3	4	7	2	2	3	4	7
1.5	1	2	2	3	5	1	2	2	3	5	1	2	2	3	5
2.0	1	1	2	2	4	1	1	1	2	4	1	1	2	2	3
2.5	1	1	1	2	3	1	1	1	2	3	1	1	1	2	3

TABLE VI.—COMPARISON OF COMPUTED DISCHARGE THRU A 6-FOOT IMPROVED VENTURI FLUME WITH THAT DETERMINED BY MEANS OF A DISCHARGE CURVE FOR AN ORDINARY RATING FLUME, ROCKY FORD DITCH, ROCKY FORD, COLORADO

(The values of H_a and H_b are single observations; that is, they are not the mean of several trials in the determination of these heads.)

Date	Six-foot Improved Venturi Flume			Ratio H_b/H_a	Loss of Head	Computed Discharge	Rating Flume*		Difference	Deviation	Current Meter Gagings in Rating Flume†	
	H_a	H_b	H_d				Gage	Discharge			Gage	Discharge
1924	Ft.	Ft.	Ft.		Ft.	Sec.-Ft.	Ft.	Sec.-Ft.	Sec.-Ft.	Percent	Ft.	Sec.-Ft.
3/29	1.78	1.68	0.10	0.944	...	42.4	1.40	40.2	+2.2	5.5	...	....
3/29	1.73	1.65	.08	.954	0.12	38.6	1.40	40.2	−1.6	4.0	...	....
3/30	2.16	2.05	.11	.949	.15	56.7	1.83	54.0	+2.7	5.0	...	....
4/1	1.77	1.70	.07	.960	...	38.0	1.43	41.3	−3.3	8.0	...	....
4/2	1.26	1.22	.04	.968	.05	....	0.89	24.9	....	...	...	....
4/9	2.31	2.21	.10	.957	.18	61.1	1.99	59.5	+1.6	2.7	...	....
4/11	2.35	2.20	.15	.936	.17	68.2	2.00	59.7	+8.5	14.2	...	....
4/21	2.31	2.21	.10	.957	.18	61.1	1.99	59.5	+1.6	2.7	...	....
4/26	1.88	1.77	.11	.941	.11	46.9	1.53	44.3	+2.6	5.9	...	....
4/29	1.50	1.44	.06	.960	.02	29.5	1.19	33.8	−4.3	12.7	...	....
5/5	1.74	1.66	.08	.954	.11	38.7	1.41	40.5	−1.8	4.5	...	....
5/6	1.69	1.64	.05	.970	.10	....	1.37	39.3	....	...	1.40	40.3
5/12	1.84	1.80	.04	.978	.12	....	1.68	49.1	....	...	1.68	48.2
5/29	2.11	2.00	.11	.948	.14	54.8	1.76	51.8	+3.0	5.8	1.76	51.8
7/9	2.62	2.52	.10	.962	.18	....	2.38	72.5	....	...	2.38	73.5
7/10	2.99	2.87	.12	.960	.18	....	2.70	83.4	....	...	2.70	83.2
9/19	2.74	2.62	.12	.957	.14	....	2.46	75.3	....	...	...	....
10/6	1.88	1.77	.11	.941	.11	46.9	1.53	44.3	+2.6	5.9	...	....
10/8	2.14	2.04	.10	.953	.14	54.7	1.87	55.5	−0.8	1.4	...	....
11/26	1.92	1.84	.08	.958	...	47.1	1.60	46.6	+0.5	1.1	...	....
12/2	1.95	1.85	.10	.949	.07	44.9	1.61	47.0	−2.1	4.5	...	....
12/3	2.36	2.25	.11	.954	.11	63.7	2.05	61.3	+2.4	3.9	...	....
12/4	2.22	2.13	.09	.959	.11	57.0	1.92	57.0	0.0	0.0	...	....
12/11	2.17	2.08	.09	.959	.13	54.6	1.85	54.8	−0.3	0.5	...	....
1925												
9/28	2.16	2.05	.11	.949	.08	56.7	1.86	55.0	+1.7	3.1	...	....

* The gage indicated is the reading at the time the heads were observed on the improved Venturi flume. The corresponding discharge in second-feet was taken from a mean curve based on the current meter gagings given in this table. This rating flume is located in the same channel as the improved Venturi flume.

† Current meter gagings in rating flume in second-feet with corresponding gage in feet. These gagings made on dates indicated.

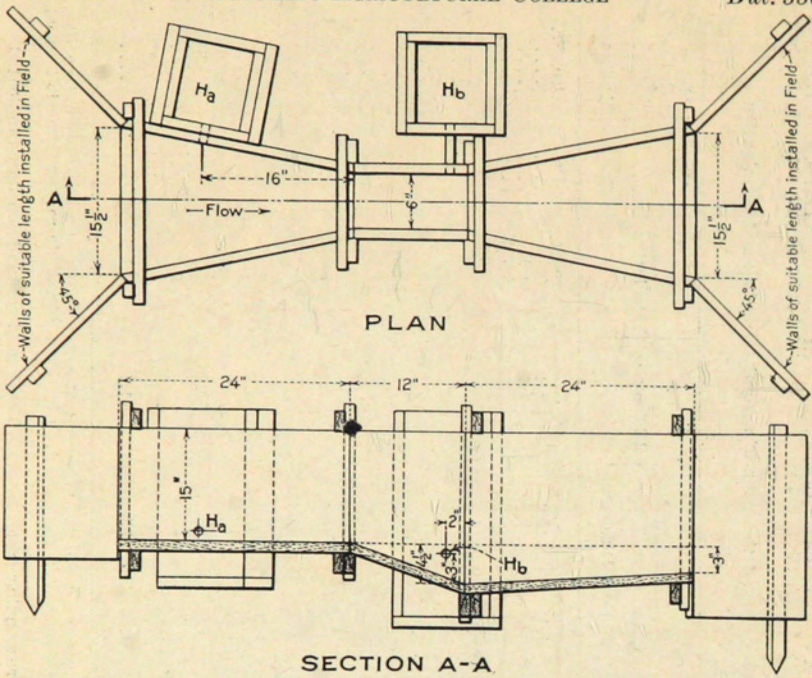

Figure 10.—Plan and Elevation of the 6-inch Improved Venturi Flume.

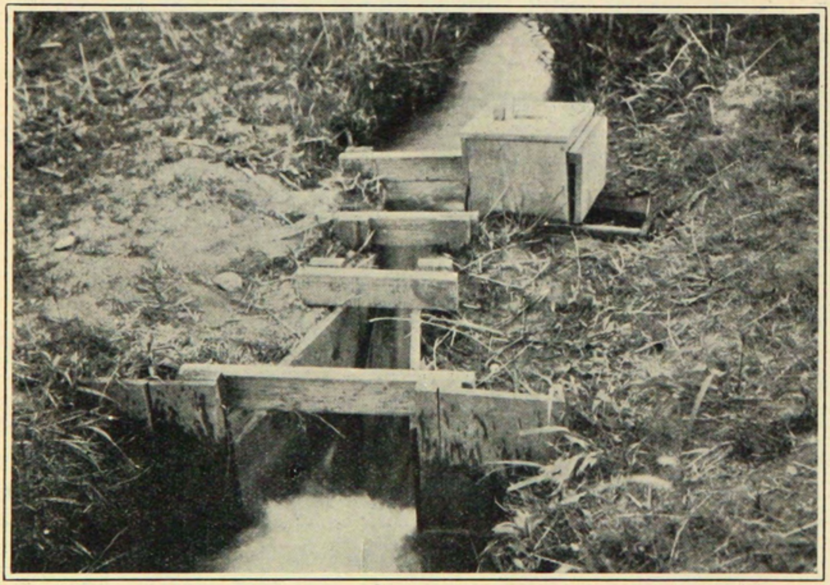

Figure 11.—Free-flow Discharge thru 6-inch Improved Venturi Flume Equipped with Discharge Indicating Tape Graduated in Shares. For Small Flumes the Downstream Wings May be at Right Angles as Shown. Flume on Farm Lateral near Boulder, Colorado.

those which governed in the larger sizes. The general dimensions of this small flume are given in Figure 10. A 6-inch flume, equipped with the discharge-indicating tape graduated to shares, is shown in Figure 11.

For the calibration of the flume, a wooden structure was installed at the Fort Collins hydraulic laboratory where the discharge was determined by means of a 90-degree notch weir with standard bottom and side contractions. The upper head, H_a, and throat head, H_b, and the head on the weir were ascertained by hookgages reading to 0.001 foot, while the loss of head thru the model structure was observed by noting the depths of water above and below the flume, as shown by staff gages on which the zero points agreed with the elevation of the level floor of the crest of the device. The calibration covered a complete range of free flow from 0.05 to 2.20 second-feet, as well as a sufficient number of submergence tests to determine the law for submerged flow. For the larger flumes, the degree of submergence was found to be about 70 percent before the free-flow discharge was affected, while for the 6-inch flume the flow was interfered with at about 50 percent submergence.

For free-flow in second-feet, thru this 6-inch flume, the formula $Q=2.06\ H_a^{1.58}$ gives quite close agreement thruout the range of calibration, where Q=second-feet, and H_a the upper head in feet. In Table XXI are shown the free-flow data upon which this expression is based, together with the deviation of the computed from the observed discharge. Table VII gives the free-flow discharge in second-feet thru the 6-inch improved Venturi flume and is based on the same formula. For submerged flow the formula becomes

$$Q=2.06\ H_a^{1.58}-C,$$

where the constant or correction C, as determined by the expres-

TABLE VII.—FREE-FLOW DISCHARGE THRU 6-INCH IMPROVED VENTURI FLUME

Based on $Q=2.06\ H_a^{1.58}$

Upper Head H_a	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
Feet	Sec-ft.	Sec-ft.	Sec-ft.	Sec-ft.	Sec-ft.	Sec-ft.	Sec-ft.	Sec-ft.	Sec-ft.	Sec-ft.
0.10	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.14	0.15
.20	.16	.18	.19	.20	.22	.23	.25	.26	.28	.29
.30	.31	.32	.34	.36	.38	.39	.41	.43	.45	.47
.40	.48	.50	.52	.54	.56	.58	.61	.63	.65	.67
.50	.69	.71	.73	.76	.78	.80	.82	.85	.87	.89
.60	.92	.94	.97	.99	1.02	1.04	1.07	1.10	1.12	1.15
.70	1.17	1.20	1.23	1.26	1.28	1.31	1.34	1.36	1.39	1.42
.80	1.45	1.48	1.50	1.53	1.56	1.59	1.62	1.65	1.68	1.71
.90	1.74	1.77	1.81	1.84	1.87	1.90	1.93	1.97	2.00	2.03

sion here given, is expanded in Table VIII which shows the correction in second-feet to be applied to the free-flow discharge to determine the submerged discharge in exactly the same manner as that described for the larger flumes. For the 6-inch flume the correction as given in the table applies directly and requires no multiplying factor.

The correction table for this small flume for submerged flow is based on the following formula:

$$C = \frac{0.072 H_a^{2.22}}{\left\{\frac{H_a+10}{10} - K\right\}^{1.44}} - \frac{H_a - 0.184}{8.17}$$

where C=correction in second-feet
H_a=upper head
K=ratio of throat head to upper head, or H_b/H_a, expressed as a decimal fraction.

The complete expression for computing the submerged discharge is:

$$Q = 2.06\, H_a^{1.58} - \left\{ \frac{0.072\, H_a^{2.22}}{\left\{\frac{H_a+10}{10} - K\right\}^{1.44}} - \frac{H_a - 0.184}{8.17} \right\}$$

SETTING OF THE FLUME

This device, like any other water-measuring structure, must be properly installed and maintained to give best results. Size must be considered first. Within certain limits of head, any specified discharge may be measured thru flumes of various sizes, and the selection of the proper size to use for the conditions imposed requires careful judgment. From the standpoint of economy, the smaller the flume, the less its cost, but to crowd the full discharge thru it may require too great a loss of head, which, in turn, would mean greater expense in strengthening the banks of the channel above the structure, as well as providing additional protection to the channel below if the flume operated under free-flow condition.

The flume's capacity, or quantity of water to be measured, must first be determined, due allowance being made for additional flow owing to floods or future enlargements of the channel. On the other hand, there is danger in selecting a flume having too wide a throat. If the structure operates under free-flow conditions, the change in upper head for given fluctuations in the discharge will be less for large than for small flumes. It might be feasible to operate a large flume as a free-flow structure for low discharges, and submerged for high dis-

TABLE VIII.—CORRECTIONS TO BE USED IN DETERMINING SUBMERGED DISCHARGE FOR 6-INCH IMPROVED VENTURI FLUME

Upper Head H_a		Ratio of Throat Head to Upper Head, or H_b/H_a																							
		0.50	0.52	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70	0.72	0.74	0.76	0.78	0.80	0.82	0.84	0.86	0.88	0.90	0.92	0.94	0.96
Feet	Inches	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.
0.20	2⅜	...	...	...	...	...	...	...	...	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.07	0.11
.22	2⅝	...	...	...	...	...	...	...	...	.01	.01	.01	.01	.01	.01	.01	.02	.02	.02	.03	.03	.04	.06	.08	.13
.24	2⅞	...	...	...	...	...	...	...	...	.01	.01	.01	.01	.01	.01	.02	.02	.02	.03	.04	.04	.05	.07	.10	.15
.26	3⅛	...	...	...	...	...	...	...	...	.01	.01	.01	.01	.01	.02	.02	.02	.03	.03	.04	.05	.06	.08	.12	.17
.28	3⅜	...	...	...	...	...	...	...	...	.01	.01	.01	.01	.01	.02	.02	.03	.03	.04	.05	.06	.07	.09	.13	.19
.30	3⅝	...	...	...	...	...	...	...	0.01	.01	.01	.01	.01	.02	.02	.02	.03	.03	.04	.05	.06	.08	.11	.15	.21
.32	3 13/16	...	...	...	...	...	...	...	.01	.01	.01	.01	.02	.02	.02	.03	.03	.04	.05	.06	.07	.09	.12	.17	.23
.34	4 1/16	...	...	...	...	...	...	...	.01	.01	.01	.01	.02	.02	.03	.03	.04	.04	.05	.06	.08	.10	.13	.18	.25
.36	4 5/16	...	...	...	...	...	...	...	.01	.01	.01	.01	.02	.02	.03	.03	.04	.05	.06	.07	.08	.10	.14	.19	.27
.38	4 9/16	...	...	...	...	...	...	...	.01	.01	.01	.01	.02	.02	.03	.03	.04	.05	.06	.07	.09	.11	.15	.21	.29
.40	4 13/16	...	...	...	...	...	...	0.01	.01	.01	.01	.02	.02	.02	.03	.04	.05	.05	.07	.08	.10	.13	.17	.23	.32
.42	5 1/16	...	...	...	...	...	...	.01	.01	.01	.02	.02	.02	.03	.03	.04	.05	.06	.07	.09	.11	.14	.19	.25	.34
.44	5¼	...	...	...	...	0.01	0.01	.01	.01	.02	.02	.03	.03	.04	.04	.05	.06	.07	.08	.10	.13	.16	.21	.28	.37
.46	5½	...	...	...	...	.01	.01	.01	.01	.02	.02	.03	.03	.04	.05	.05	.06	.08	.09	.11	.14	.17	.23	.30	.39
.48	5¾	...	...	...	...	.01	.01	.01	.02	.02	.02	.03	.03	.04	.05	.06	.07	.08	.10	.12	.15	.18	.24	.32	.41
.50	6	...	...	...	...	.01	.01	.01	.02	.02	.02	.03	.03	.04	.05	.06	.07	.09	.10	.12	.16	.19	.25	.34	.43
.52	6¼	...	...	...	0.01	.01	.01	.02	.02	.02	.03	.04	.04	.05	.06	.07	.08	.10	.12	.14	.17	.21	.27	.36	.46
.54	6½	...	...	...	.01	.01	.01	.02	.02	.03	.03	.04	.04	.05	.06	.07	.08	.10	.12	.15	.18	.23	.28	.38	.48
.56	6¾	...	...	0.01	.01	.01	.02	.02	.02	.03	.04	.04	.05	.06	.07	.08	.09	.11	.13	.16	.20	.25	.30	.41	.51
.58	6 15/16	...	...	.01	.01	.01	.02	.02	.03	.03	.04	.04	.05	.06	.07	.08	.10	.12	.14	.17	.21	.26	.32	.43	.54
.60	7 3/16	...	...	.01	.01	.01	.02	.02	.03	.04	.04	.05	.06	.07	.08	.09	.11	.13	.15	.18	.22	.27	.34	.45	.57
.62	7 7/16	...	0.01	.01	.01	.02	.02	.03	.03	.04	.05	.05	.06	.07	.09	.10	.12	.14	.17	.20	.24	.29	.36	.48	.60
.64	7 11/16	0.01	.01	.01	.02	.02	.03	.03	.04	.05	.05	.06	.07	.08	.10	.11	.13	.15	.18	.21	.25	.31	.38	.50	.63
.66	7 15/16	.01	.01	.01	.02	.02	.03	.04	.04	.05	.06	.07	.08	.09	.10	.12	.14	.16	.19	.22	.27	.33	.40	.52	.66
.68	8 3/16	.01	.01	.02	.02	.03	.03	.04	.04	.05	.06	.07	.08	.09	.11	.13	.15	.17	.20	.24	.28	.34	.42	.54	.69
.70	8⅜	.01	.01	.02	.02	.03	.03	.04	.05	.06	.07	.08	.09	.10	.12	.14	.16	.18	.21	.25	.30	.36	.44	.56	.72
.72	8⅝	.01	.02	.02	.03	.03	.04	.04	.05	.06	.07	.08	.09	.11	.13	.14	.16	.19	.22	.26	.32	.38	.46	.58	.75
.74	8⅞	.01	.02	.02	.03	.03	.04	.05	.06	.06	.07	.09	.10	.11	.14	.15	.17	.20	.23	.27	.33	.39	.48	.60	.78
.76	9⅛	.02	.02	.03	.03	.04	.04	.05	.06	.07	.08	.09	.10	.12	.14	.16	.18	.21	.24	.28	.34	.41	.50	.62	.80
.78	9⅜	.02	.02	.03	.03	.04	.05	.05	.06	.07	.08	.09	.11	.12	.14	.16	.19	.22	.25	.29	.35	.43	.52	.64	.83
.80	9⅝	.02	.03	.03	.04	.04	.05	.06	.07	.08	.09	.10	.12	.13	.15	.17	.20	.23	.27	.31	.37	.45	.54	.67	.86
.82	9 13/16	.03	.03	.03	.04	.05	.06	.06	.07	.08	.10	.11	.12	.14	.16	.18	.21	.24	.28	.33	.38	.47	.56	.69	.88
.84	10 1/16	.03	.03	.04	.04	.05	.06	.07	.08	.09	.10	.11	.13	.15	.17	.19	.22	.25	.29	.34	.40	.48	.58	.72	.91
.86	10 5/16	.03	.03	.04	.05	.05	.06	.07	.08	.09	.10	.12	.13	.15	.17	.20	.23	.26	.30	.35	.41	.49	.60	.74	.94
.88	10 9/16	.03	.04	.04	.05	.06	.07	.08	.09	.10	.11	.12	.14	.16	.18	.21	.24	.27	.32	.37	.43	.51	.63	.76	.97
.90	10 13/16	.03	.04	.05	.05	.06	.07	.08	.09	.10	.12	.13	.15	.17	.19	.22	.25	.29	.33	.39	.45	.54	.65	.79	.99
.92	11 1/16	.04	.04	.05	.06	.07	.08	.09	.10	.11	.13	.14	.16	.18	.20	.23	.26	.30	.35	.40	.47	.56	.67	.82	1.02
.94	11¼	.04	.05	.05	.06	.07	.08	.09	.10	.12	.13	.15	.17	.19	.21	.24	.27	.31	.36	.41	.49	.58	.69	.85	1.05
.96	11½	.04	.05	.06	.07	.08	.09	.10	.11	.12	.14	.16	.18	.20	.22	.25	.28	.32	.38	.43	.51	.59	.71	.87	1.08
.98	11¾	.05	.06	.06	.07	.08	.09	.10	.12	.13	.15	.16	.18	.21	.23	.26	.29	.34	.39	.45	.52	.61	.73	.89	1.10
1.00	12	.05	.06	.07	.08	.09	.10	.11	.12	.13	.15	.17	.19	.21	.24	.27	.31	.35	.40	.46	.54	.63	.76	.91	1.13

charges, because the depth in the channel below the flume may increase at a faster rate than the depth in the converging section. Figure 12 shows a 6-foot flume carrying 64 second-feet, where the loss in head is approximately 0.85 foot and the degree of submergence about 60 percent. This is considered an ideal condition because the degree of submergence is less than 70 percent, the discharge is a function of a single head or depth, and the exit velocity is moderate.

Figure 12.—Six-foot Improved Venturi Flume Discharging 64 Second-feet with a Submergence of 60 Percent. Farmers' Ditch, Boulder, Colorado.

To assist in the selection of the proper size of flume to meet certain requirements, there are shown in Figures 13, 14, 15, 16, 17, 18 and 19 the graphic charts for various sizes of flumes, giving the approximate loss of head in feet for various degrees of submergence and discharge. The vertical axis at the left of the diagram gives the depth of water in feet measured from the top side of the end of the floor of the diverging section, or the lower end of the floor of the flume. Along the horizontal axis is given the loss of head in feet for any particular discharge at a certain degree of submergence. This loss of head is the difference in feet between the water surface above and below the structure. The percentage of submergence is based upon the ratio of the throat head, H_b, to the upstream head in the converging section, H_a. The loss of head from various discharges and depths of water

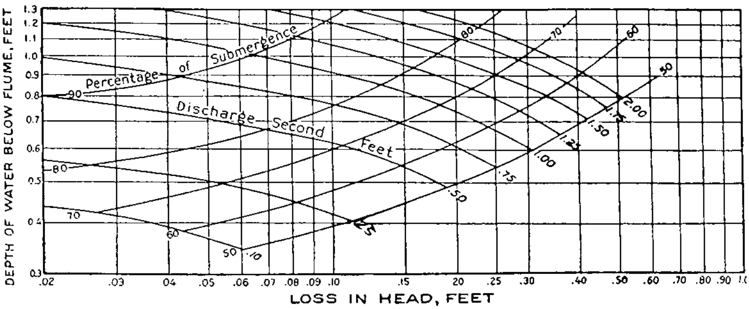

Figure 13.—Loss-of-head Diagram for the 6-inch Improved Venturi Flume.

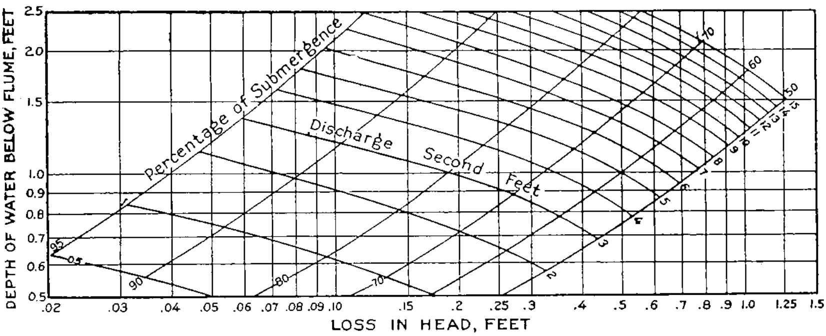

Figure 14.—Loss-of-head Diagram for the 1-foot Improved Venturi Flume.

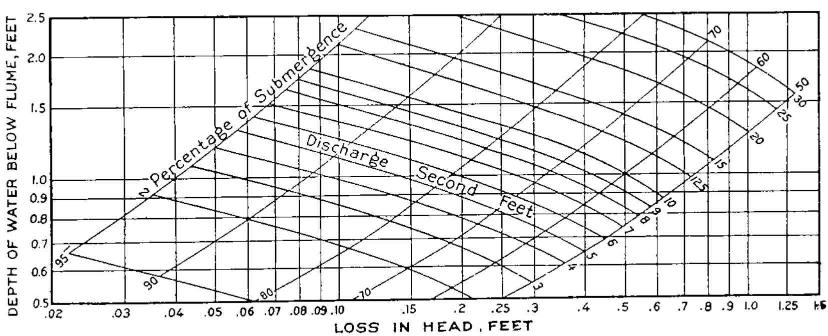

Figure 15.—Loss-of-head Diagram for the 2-foot Improved Venturi Flume.

below the flume are also given in tabular form in Tables IX, X, XI, XII, XIII, XIV and XV.

The following examples are given to guide in the selection of the proper flume to fulfill the requirements for the particular case in hand: Assume that the channel is 25 feet wide on the bottom, average depth of water 2.5 feet at the site of the structure, with the inside

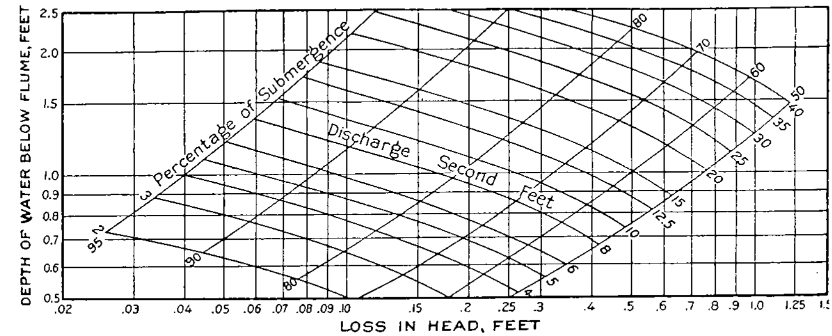

Figure 16.—Loss-of-head Diagram for the 3-foot Improved Venturi Flume.

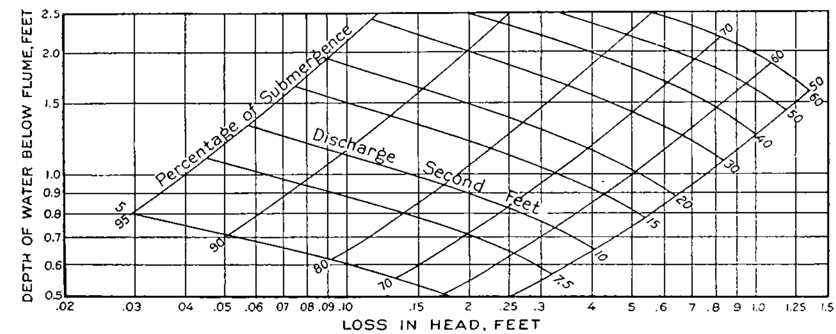

Figure 17.—Loss-of-head Diagram for the 4-foot Improved Venturi Flume.

slope of banks 1 to 1. The maximum discharge to be measured is 70 second-feet. For this condition it is found that the average velocity is approximately 1 foot per second; however, the velocity in this case is merely incidental and is mentioned here to call attention to the fact

TABLE IX.—LOSS OF HEAD THRU 6-INCH IMPROVED VENTURI FLUME

Depth Water Below Flume	Discharge (Second-Feet) 0.10	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00
Feet	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
0.3	0.08	....	....	....	....	....	....	....	....
0.4	.04	0.11	0.25	....	....	....	....	....	....
0.5	....	.05	.17	0.30	....	....	....	....	....
0.6	....	.01	.11	.21	0.31	0.40	....	....	....
0.7	....	....	.05	.14	.23	.32	0.43	0.53	....
0.8	....	....	.02	.08	.16	.24	.34	.43	0.52
0.9	....	....	....	.04	.11	.18	.26	.36	.42
1.0	....	....	....	.02	.07	.13	.19	.28	.35
1.1	....	....	....	....	.04	.09	.14	.21	.28
1.2	....	....	....	....	.02	.06	.10	.15	.22
1.3	....	....	....	....	....	.04	.07	.12	.17

TABLE X.—LOSS OF HEAD THRU 1-FOOT IMPROVED VENTURI FLUME

Depth Water Below Flume	Discharge (Second-Feet)															
	0.5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Feet	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
0.5	0.05	0.17	....	....	....	....	....	....	....	....	....	....	....	....	....	....
0.6	.03	.11	0.30	....	....	....	....	....	....	....	....	....	....	....	....	....
0.7	....	.06	.22	0.42	....	....	....	....	....	....	....	....	....	....	....	....
0.8	....	.04	.15	.34	0.51	....	....	....	....	....	....	....	....	....	....	....
0.9	....	....	.10	.26	.42	0.59	....	....	....	....	....	....	....	....	....	....
1.0	....	....	.07	.19	.34	.50	0.64	0.79	....	....	....	....	....	....	....	....
1.1	....	....	.05	.14	.27	.41	.55	.69	0.83	....	....	....	....	....	....	....
1.2	....	....	....	.10	.21	.34	.47	.60	.73	0.88	0.98	....	....	....	....	....
1.3	....	....	....	.07	.16	.27	.39	.52	.64	.79	.89	1.01	....	....	....	....
1.4	....	....	....	....	.12	.21	.32	.44	.56	.70	.80	.92	1.03	1.15	....	....
1.5	....	....	....	....	.09	.17	.26	.37	.49	.61	.72	.84	.94	1.05	1.16	1.28
1.6	....	....	....	....	.07	.13	.21	.31	.42	.54	.64	.76	.86	.96	1.06	1.18
1.7	....	....	....	....	....	.10	.17	.26	.36	.48	.57	.69	.78	.88	.98	1.09
1.8	....	....	....	....	....	.08	.14	.22	.31	.42	.51	.62	.70	.80	.90	1.00
1.9	....	....	....	....	....	....	.12	.19	.27	.37	.45	.56	.63	.73	.83	.92
2.0	....	....	....	....	....	....	.10	.16	.23	.32	.40	.50	.57	.66	.76	.85
2.1	....	....	....	....	....	....	....	.14	.20	.28	.35	.44	.51	.60	.70	.78
2.2	....	....	....	....	....	....	....	.12	.17	.24	.31	.39	.46	.55	.64	.72
2.3	....	....	....	....	....	....	....	.10	.15	.21	.27	.34	.41	.50	.59	.66
2.4	....	....	....	....	....	....	....	....	.13	.18	.24	.30	.37	.45	.54	.61
2.5	....	....	....	....	....	....	....	....	.12	.16	.22	.27	.35	.41	.50	.57

TABLE XI.—LOSS OF HEAD THRU 2-FOOT IMPROVED VENTURI FLUME

Depth Water Below Flume	Discharge (Second-Feet) 1	2	3	4	5	6	7	8	9	10	12.5	15	20	25	30
Feet	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
0.5	0.06	0.21	0.33	....	...	....	....	....	....	....	....	....	....	....	....
0.6	.03	.15	.25	0.37	....	....	....	....	....	....	....	....	....	....	....
0.7	.02	.09	.17	.26	0.34	0.44	....	....	....	....	....	....	....	....	....
0.8	....	.06	.12	.19	.26	.34	0.44	0.53	....	....	....	....	....	....	....
0.9	....	.04	.08	.14	.19	.26	.35	.43	0.51	0.60	....	....	....	....	....
1.0	....	....	.06	.10	.14	.20	.27	.35	.42	.50	0.70	....	....	....	....
1.1	....	....	....	.07	.10	.15	.21	.27	.34	.42	.60	0.80	....	....	....
1.2	....	....	....	...	.08	.11	.16	.21	.27	.34	.50	.70	....	....	....
1.3	....	....	....	....	.06	.08	.12	.16	.21	.27	.42	.60	0.97	....	....
1.4	....	....	....	...	...	.06	.09	.13	.17	.21	.35	.50	.87	....	....
1.5	....	....	....	....	...	....	.07	.10	.13	.17	.29	.42	.77	1.11	....
1.6	....	....	....	....	...	....	....	,08	.11	.14	.24	.35	.68	1.00	1.28
1.7	....	....	....	....	...	....	....	....	.09	.11	.20	.30	.59	.90	1.18
1.8	....	....	....	....	...	....	....	....	..	.09	.16	.25	.50	.82	1.08
1.9	....	....	....	....	...	....	....	....	....	....	.14	.21	.43	.74	.98
2.0	....	....	....	....	...	....	....	....	...	....	.12	.18	.38	.66	.90
2.1	....	....	....	....	....	....	....	....	...	....	.10	.15	.33	.58	.82
2.2	....	....	....	....	....	....	....	....	....	....	....	.13	.28	.50	.74
2.3	....	....	....	....	....	....	....	....	....	....	....	.11	.25	.44	.67
2.4	....	....	....	....	....	....	....	....	....	....	....	....	.22	.39	.60
2.5	....	....	....	....	....	....	....	....	....	....	....	....	.20	.35	.56

TABLE XII.—LOSS OF HEAD THRU 3-FOOT IMPROVED VENTURI FLUME

Depth Water Below Flume	Discharge (Second-Feet) 2	3	4	5	6	7	8	9	10	12.5	15	20	25	30	35	40
Feet	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
0.5	0.10	0.18	0.27	...	...	....	....	....	....	....	....	....	....	....	....	....
0.6	.06	.12	.19	0.27	0.35	....	....	....	....	....	....	....	....	....	....	....
0.7	.03	.08	.13	.19	.25	0.32	0.39	0.45	....	....	....	....	....	....	....	....
0.8	....	.05	.09	.14	.18	.24	.30	.36	0.42	0.58	....	....	....	....	....	....
0.9	....	.03	.06	.09	.13	.18	.23	.28	.33	.48	0.60	....	....	....	....	....
1.0	....	....	.04	.06	.09	.13	.17	.21	.26	.39	.50	0.78	....	....	....	....
1.1	....	....	....	....	.07	.09	.13	.16	.20	.31	.42	.67	0.90	....	....	....
1.2	....	....	....	....	.05	.07	.09	.12	.15	.24	.35	.58	.80	....	....	....
1.3	....	....	....	....	...	.05	.07	.09	.12	.20	.28	.49	.70	0.93	....	....
1.4	....	....	...	....	...	....	....	.07	.09	.16	.23	.42	.62	.83	1.06	....
1.5	....	....	....	....	....	....	....	....	.07	.13	.19	.35	.54	.74	.96	1.17
1.6	....	....	....	....	....	....	....	....	....	.10	.15	.30	.46	.65	.86	1.07
1.7	....	....	....	....	....	....	....	....	....	.08	.12	.25	.39	.56	.77	.97
1.8	....	....	....	....	....	....	....	....	....	....	.10	.21	.33	.49	.68	.88
1.9	....	....	....	...	....	....	....	....	....	....	....	.17	.28	.42	.59	.79
2.0	....	....	....	....	....	....	....	....	....	....	....	.14	.24	.36	.51	.70
2.1	....	....	....	....	....	....	....	....	....	....	....	.12	.21	.32	.45	.62
2.2	....	....	....	....	....	....	....	....	....	....	....	.10	.18	.27	.39	.54
2.3	....	....	....	....	....	....	....	....	....	....	....	....	.15	.23	.34	.47
2.4	....	....	....	....	....	....	....	....	....	....	....	....	.13	.20	.29	.40
2.5	....	....	....	....	....	....	....	....	....	....	....	....	.12	.18	.25	.36

TABLE XIII.—LOSS OF HEAD THRU 4-FOOT IMPROVED VENTURI FLUME

Depth Water Below Flume	Discharge (Second-Feet) 5	7.5	10	15	20	30	40	50	60
Feet	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
0.5	0.18	....	....	....	....	....	....	....	....
0.6	.10	0.29	....	....	....	....	....	....	....
0.7	.05	.21	0.36	....	....	....	....	....	....
0.8	.03	.14	.27	0.52	....	....	....	....	....
0.9	....	.09	.20	.42	0.62	....	....	....	....
1.0	....	.06	.14	.33	.52	....	....	....	....
1.1	....	....	.10	.26	.44	0.82	....	....	....
1.2	....	....	.08	.20	.36	.71	....	....	....
1.3	....	....	.06	.16	.30	.61	0.96	....	....
1.4	....	....	....	.13	.24	.52	.86	....	....
1.5	....	....	....	.10	.20	.44	.76	1.10	....
1.6	....	....	....	.08	.16	.38	.68	1.00	1.35
1.7	....	....	....	....	.13	.32	.60	.91	1.25
1.8	....	....	....	....	.11	.28	.52	.82	1.16
1.9	....	....	....	....	.09	.24	.46	.73	1.07
2.0	....	....	....	....	....	.20	.40	.64	.98
2.1	....	....	....	....	....	.17	.35	.56	.89
2.2	....	....	....	....	....	.15	.30	.49	.80
2.3	....	....	....	....	....	.13	.26	.42	.71
2.4	....	....	....	....	....	.11	.23	.37	.63
2.5	....	....	....	....	....	....	.20	.33	.56

TABLE XIV.—LOSS OF HEAD THRU 6-FOOT IMPROVED VENTURI FLUME

Depth Water Below Flume	Discharge (Second-Feet) 5	10	15	20	25	30	40	50	60	70
Feet	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
0.5	0.20	....	....	....	....	....	....	....	....	....
0.6	.13	0.30	....	....	....	....	....	....	....	....
0.7	.07	.21	0.38	....	....	....	....	....	....	....
0.8	.04	.14	.28	0.44	0.60	....	....	....	....	....
0.9	....	.09	.20	.34	.50	0.63	....	....	....	....
1.0	....	.06	.15	.26	.40	.53	0.79	....	....	....
1.1	....	....	.10	.19	.31	.44	.69	....	....	....
1.2	....	....	.07	.14	.24	.36	.59	0.84	....	....
1.3	....	....	....	.10	.18	.28	.50	.74	0.97	....
1.4	....	....	....	.07	.14	.22	.42	.65	.87	1.08
1.5	....	....	....	....	.10	.17	.35	.56	.77	.98
1.6	....	....	....	....	.08	.13	.29	.47	.67	.88
1.7	....	....	....	....	....	.10	.23	.40	.58	.79
1.8	....	....	....	....	....	.08	.19	.33	.49	.69
1.9	....	....	....	....	....	....	.15	.27	.41	.60
2.0	....	....	....	....	....	....	.12	.23	.34	.52
2.1	....	....	....	....	....	....	.10	.19	.29	.45
2.2	....	....	....	....	....	....	....	.15	.24	.39
2.3	....	....	....	....	....	....	....	.12	.20	.33
2.4	....	....	....	....	....	....	....	....	.17	.28
2.5	....	....	....	....	....	....	....	....	.15	.24

TABLE XV.—LOSS OF HEAD THRU 8-FOOT IMPROVED VENTURI FLUME

Depth Water Below Flume	Discharge (Second-Feet) 10	15	20	30	40	50	60	70	80	90
Feet	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
0.5	0.24	....	....	....	....	....	....	....	....	....
0.6	.15	0.32	....	....	....	....	....	....	....	....
0.7	.08	.22	0.37	....	....	....	....	....	....	....
0.8	.04	.14	.27	0.50	....	....	....	....	....	....
0.9	....	.08	.18	.40	0.60	....	....	....	....	....
1.0	....	.05	.12	.30	.50	0.70	....	....	....	....
1.1	....	....	.08	.23	.40	.60	0.77	....	....	....
1.2	....	....	.05	.17	.32	.50	.67	0.83	0.97	....
1.3	....	....	....	.13	.24	.40	.57	.72	.87	1.02
1.4	....	....	....	.09	.19	.32	.47	.62	.77	.92
1.5	....	....	....	.07	.15	.26	.38	.52	.67	.82
1.6	....	....	....	....	.12	.20	.31	.43	.58	.71
1.7	....	....	....	....	.09	.16	.25	.36	.49	.61
1.8	....	....	....	....	....	.14	.21	.30	.41	.52
1.9	....	....	....	....	....	.11	.18	.25	35	.45
2.0	....	....	....	....	....	.09	.15	.21	.30	.38
2.1	....	....	....	....	....	....	.13	.18	.25	.34
2.2	....	....	....	....	....	....	.11	.16	.21	.29
2.3	....	....	....	....	....	....	....	.13	.18	.24
2.4	....	....	....	....	....	....	....	.11	.16	.21
2.5	....	....	....	....	....	....	....	....	.14	.18

that it is low. Referring to Figure 18 for the 6-foot flume, for a depth of water below the flume of 2.5 feet and a discharge of 70 second-feet, it is found that the loss of head would be 0.25 foot and the submergence 90 percent. In this case, the discharge thru the flume will be determined by observing both the upper head, H_a, and the throat head, H_b, and then applying the proper correction factor as

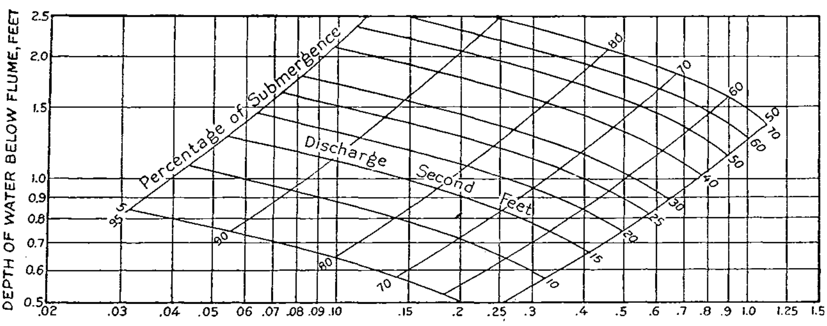

Figure 18.—Loss-of-head Diagram for the 6-foot Improved Venturi Flume.

determined from Table IV, and the multiplier given on page 26. The free-flow discharge is the more desirable, provided conditions will permit. To operate the 6-foot flume at a degree of submergence of 70 percent, 70 second-feet discharge, where the depth of water in the downstream channel is 2.5 feet, the loss of head will be approximately 0.7 foot and the depth of water at the outlet end of the structure 1.8

feet. In this case the structure would have to be raised 0.7 foot; that is, 2.5 feet minus 1.8 feet. Since the crest of the flume is 0.25 foot or 3 inches above the end of the outlet floor, the crest is 0.95 foot above the bottom of the channel. The depth of water in the channel being 2.5 feet and the loss of head 0.7 foot, gives a depth of 3.2 feet upstream from the flume, it being assumed that the bottom of the channel is level for the distance occupied by the structure. Since the level floor of the upstream or converging section of the flume is set up 0.95 foot above the bottom, the depth of water upstream now referred to this floor or crest would be 2.25 feet. For the discharge of 70 second-feet at a submergence of 70 percent or less, it is found in Table III that the corresponding H_a is 1.96 feet. This head subtracted from the depth 2.25 feet gives 0.29 foot, or the loss in head at gage H_a. If the materials of which the channel is composed will not withstand the velocity resulting from a submergence of 70 percent, or the increase in depth of water above the structure would require considerable expense in raising the banks to a safe height, then a higher degree of submergence will be necessary.

For the above conditions of channel and flow, what would be the effect of installing an 8-foot flume? Referring to Figure 19 it is found that if this structure be built with a floor of the outlet end of the

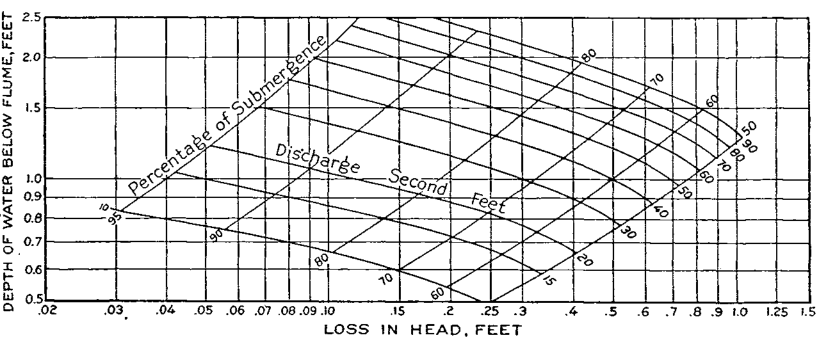

Figure 19.—Loss-of-head Diagram for the 8-foot Improved Venturi Flume.

flume at the bottom of the channel, or at the depth of 2.5 feet, the degree of submergence will be slightly in excess of 95 percent, or beyond the recommended limit. For this setting, the loss of head will be 0.10 foot. To have a loss of head of 0.25 foot, as in the first case of the 6-foot flume, the depth of water below the flume would need to be 1.9 feet; the lower end of the outlet floor of the flume would be set 0.6 foot above the bottom, and the crest elevation would be 0.85 foot above the bottom. To operate this larger flume at a submergence of 70 percent, it is found from the loss-of-head diagram that the depth below the flume would have to be 1.5 feet, or the end of the outlet floor would be 1.0 foot above the bottom and the crest or elevation of the level floor of the converging section would be 1.25 feet above the bottom of the channel. With the structure at this elevation, the loss of head or difference in elevation between the upper and lower water surfaces is observed to be approximately 0.5 foot. Assuming that the channel is level for the distance occupied by the structure, the depth of water immediately upstream from the flume will be 3.0 feet. Since the floor of the converging section is set at an elevation of 1.25 feet, it will give a water depth of 1.75 feet when referred to the level floor of the flume. From the free-flow discharge, Table III, it is found that for a discharge of 70.17 second-feet, the upper head, H_a, is 1.63 feet, thus giving a loss of head of only 0.12 foot at gage H_a.

For setting either the 6-foot or 8-foot flume, if no unusual hydraulic characteristics affect the channel downstream from the structure, the depth in the channel below the structure will increase faster than the head, H_a, in the converging section of the flume. It appears that as the discharge decreases from a maximum of 70 second-feet with a submergence of 70 percent, the percentage of submergence also decreases, which permits the flume to function properly as a single-head device thru the full range of the discharge.

Slightly more material would be required to construct the 8-foot flume, but other things being equal, the wing walls would require less material.

As previously determined, the loss of head thru the 8-foot flume is 0.2 foot less than for the 6-foot flume; however, this small difference may not be of serious consequence. The 8-foot flume is advantageous, since, with the lower exit velocity there would be less erosion in the channel immediately downstream. If the materials of the channel will withstand the imposed velocities and sufficient free-board is available, the 6-foot flume should be chosen for free-flow discharge or degree of submergence of 70 percent. If the loss of head is too great thru this smaller flume, the loss may be reduced by installing the 8-foot flume. If free-flow conditions are not permissible in either case, because of excessive erosion, then the 6-foot structure should be built and so set in elevation that the resulting submergence will be the least, consistent with safe exit velocity.

After having fully decided upon the location of the flume, its size, and the elevation of the crest which will insure that the flume will operate at free-flow or some predetermined degree of submergence, consideration must be given to the fixing of the longitudinal axis of the structure. The site of the flume should be in a reasonably straight section of the channel. It is suggested that a stake be set in the middle of the channel 100 feet upstream, and another at the same distance downstream, from the proposed site. Reference points should then be established at convenient distances near the two ends of the structure and in line with the two more distant points. A line stretched between the two latter points will locate the axis of the flume or the midpoints of the floor sills. For structures of moderate size carrying less than 50 second-feet, possibly no great pains need be taken to have the structure carefully aligned, but for greater discharges care must be taken in order that the flow below the structure will be uniformly distributed thruout the channel.

CONSTRUCTION OF THE FLUME

The building of this structure should offer no great difficulty. No warped surfaces have been introduced into the design other than the suggested curved entrance at the inlet of the large flumes. These structures may be made of lumber, concrete, or sheet metal.

Figure 1 suggests a wooden framing for the larger flumes, while for the smaller sizes, Figure 20 illustrates a practical design in which the walls and floor are of 1-inch or 2-inch material, and the sills, posts and ties of 2-by-4-inch pieces. Two-inch commercial lumber is recommended for the floor and walls of the larger flumes, while the sills and posts may be of 4-by-4-inch pieces or heavier, as conditions warrant. In the building of the framed structures it is suggested that the pieces which compose the floor and walls be laid with sufficient space between them to allow for swelling when wet, as otherwise the swelling may be sufficient to warp the surfaces seriously and interfere with the proper functioning of the device. Ordinarily if the cracks between the planks or boards be one-eighth to three-sixteenths inch wide, the swelling will not cause distortion and yet will make a tight joint.

Let it be assumed that the elevation of the crest of the flume has been fixed by the characteristics of the channel in which the flume is to be built. It is then necessary to set the crest sill at its proper elevation, as well as in the correct transverse position. For the smaller sizes, the fact that the longitudinal axis of the structure is not exactly coincident with that of the channel is of little importance where only moderate flows have to be cared for, but the large flumes should be so set that this axis is approximately correct to permit the stream to approach and leave the structure without undue distortion. Hence the site of the flume should not be in a decided bend of the channel.

The crest sill having been set and securely fixed in position, the other floor sills may be placed at their proper intervals and elevations, after which the posts and ties may be set. The posts must be set

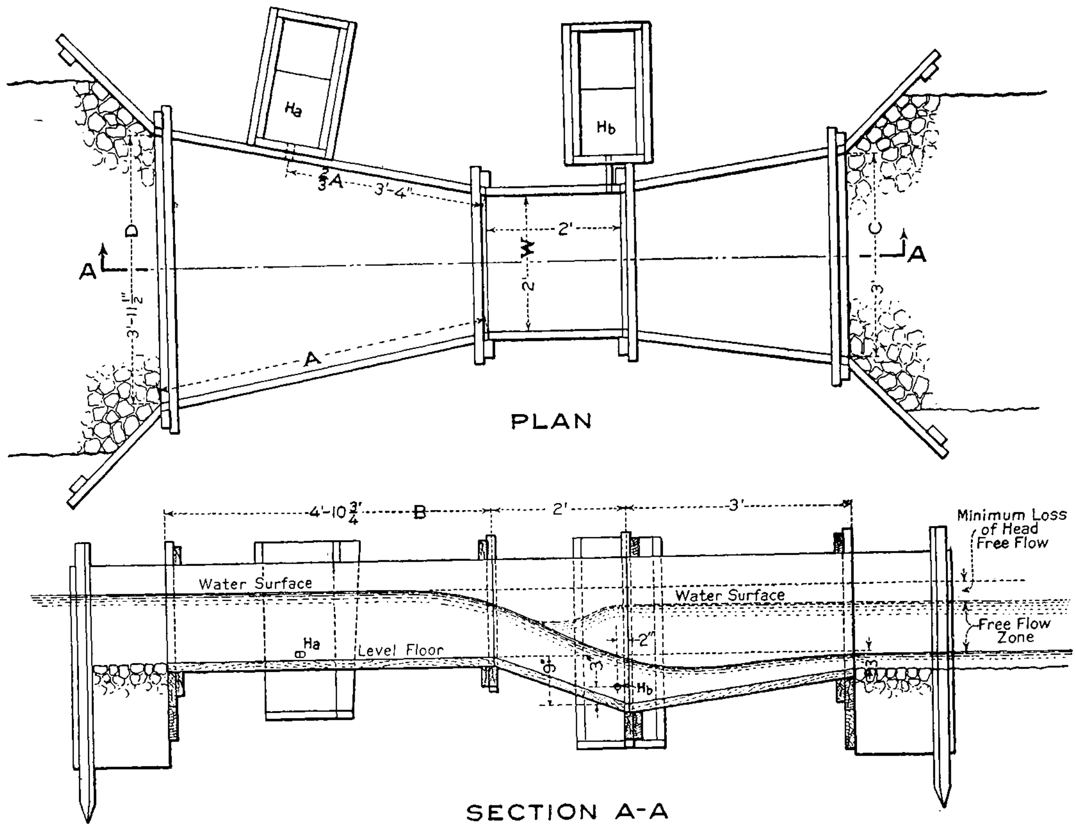

Figure 20.—Plan and Elevation of 2-foot Improved Venturi Flume Showing Suggestions as to Construction.

back the thickness of the wall to give the flume its proper inside width when completed. The walls of the structure may then be secured to the vertical posts.

The walls of the converging section are of straight framing. Two methods may be used in cutting the pieces for the throat walls. One is shown in Figure 1 where the pieces are rectangular and the cracks between them horizontal. If it is desired to have the cracks parallel the slope of the floor, the pieces composing the throat walls would be cut at parallelograms with end cuts on a skew of the ratio 9/24. As the top of the wall will then have a slope equal to that of the floor, the downstream end will be low by 9 inches. If the flume is to be operated under free-flow condition, the height of walls in the diverging section may be less than the converging or upstream part, and, therefore, the top of these walls may be made to agree with the low point of slope of the throat wall. This method of building will reduce the amount of material in the structure. It is suggested, however, that the bottom pieces in the walls of the downstream or diverging section be so cut that the top edges will be level, thus leaving the finished top horizontal.

After the walls have been placed, the floor is laid. Since the floors of the upstream and downstream sections taper, special pieces will need to be cut to fit. The lower end of the level floor, which forms the crest, should be smooth and even. At this point the throat floor is joined and the pieces forming this inclined floor should be cut on a bevel of 9/24 which will fit closely to the ends of the level floor. The placing of the floor after the walls have been set holds the bottom course of the walls in position and prevents the outside earth pressure from dislodging or crowding the walls and altering the inside dimensions. The tendency of the larger wooden structures to float should be given consideration, and it is recommended that posts or piling be driven down to tie the sills securely. The cut-off walls set at each end of the structure will aid in holding the flume in place. A plank laid along the outside of the flume walls on the ends of the sills will resist the uplift after back filling has been placed. Where the discharge thru the flume is 50 second-feet or more, the contraction effect set up by the water entering the flume where the 45-degree wings are attached, causes a disturbance. A better entrance condition is secured by setting these wings back from the flume and then joining them to it by a sheet metal section rolled to a radius of 30 to 60 inches. The downstream 45-degree wings may be attached directly to the structure.

For moderate flows thru the smaller flumes, the downstream wings may be placed at right angles to the axis of the flume, as shown in Figure 11. For the larger discharges, some protection to the bottom of the channel immediately upstream from the flume may be necessary. Large, flat stones or heavy gravel would, under ordinary conditions, provide ample protection. For free-flow conditions, the exit velocity is quite high, and where the channel is in earthy section, ample protection must be provided. To prevent bottom scour, a wire mattress filled with cobble stones and brush has been used successfully. This mattress is attached to the lower end of the structure and laid transversely to the axis of the channel. The top and bottom web of the mattress should be securely wired together. These vertical wires will prevent the material within the mattress from collecting at the lower side. Being flexible, the mattress will sag down if any cutting occurs and form a protection for the lower end of the structure. Bank protection may be provided in the same manner downstream from the outlet of the flume.

The improved Venturi flume may be constructed of concrete, as shown in Figure 21. The construction of large concrete flumes is similar to that of any ordinary reinforced structure. Because of the flume's relatively short length it is not necessary to provide expansion joints, but to increase stability, braces should be added to tie the walls at the top. As the crest of the flume is an important part of the structure it is suggested that an angle iron be cast in the floor at this point with its top face flush with the plane of the level floor; the

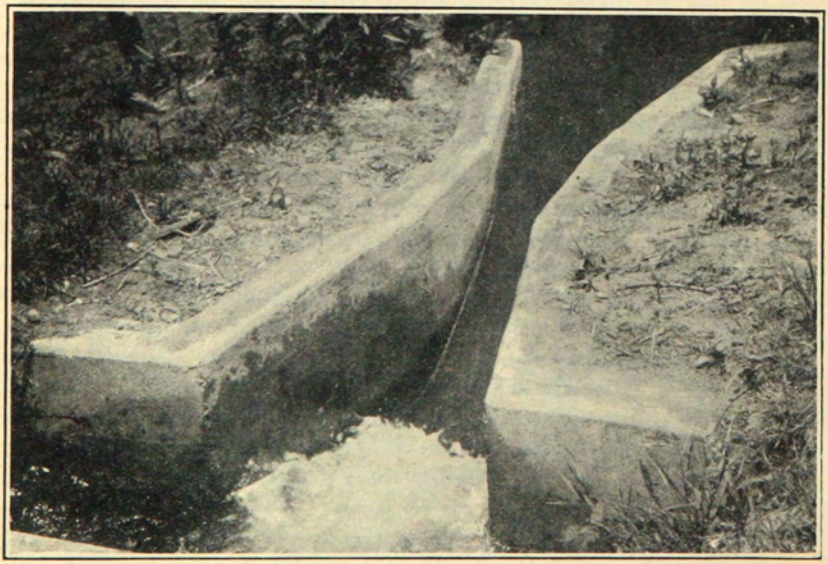

Figure 21.—One-foot Reinforced Concrete Improved Venturi Flume, Free-flow Discharge of 4 Second-feet. Lake Canal, near Fort Collins, Colorado.

corner of the angle iron forming the true crest. The stilling wells for the concrete flumes may be of either wood or concrete, and since the water level in the well is the real index to the water surface within the flume itself, it is essential that the leakage be a minimum to insure the correct reading of the effective depth. Wooden stilling wells carefully made, when once tight after swelling, are dependable but can not be expected to last indefinitely. Wells of small cross section are impractical, because of the difficulty experienced in cleaning them. They should be of ample size with the side opposite the flume sloping outward at the top, to permit easy cleaning as well as for easy and accurate reading of a staff gage set on the far side of the well, as shown in Figure 22.

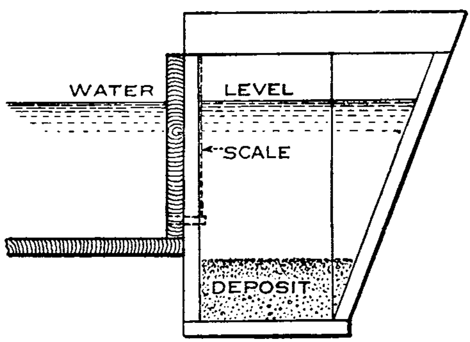

Figure 22.—Suggested Construction of Open Stilling-well with Staff Gage or Scale Inside the Well.

For the 6-inch and 1-foot flumes, where a number are to be installed, precast concrete members may be made and installed in the field. To accomplish this, the design for the casting of the several pieces must be such that each will not be too heavy to be handled conveniently. It is recommended that the floor of the converging or upstream section and the floor of the throat section be cast as one piece, with a light angle-iron cast into the face at the crest. A rib should be cast longitudinally along the center line on the bottom side to strengthen the members while they are being handled, and a groove should be formed at the proper distance along the sides, top face, to locate and fix the position of the side walls. Each of these side walls should be cast as a flat slab of the proper dimensions with a projecting tongue on the sides to engage the grooves of adjacent members. Stub bolts cast into the top face of wall members will fix crossbars or struts to resist displacement after the structure has been assembled. Tubes should be cast at the proper points, both in the converging and throat walls, to which stilling wells may be attached for the measurement of heads. The wells may be made of lumber (Figure 9) set to fit the tube connections, or for moderate depths of flow, they may be of ordinary sewer tile set into a concrete base with the connecting tube reaching thru a hole in the side. (Sections of old stave pipe may be used as stilling wells.) This arrangement will not permit the use of a vertical scale in the tile or pipe to determine the head, but a scale measuring down to the water surface from a fixed point at the top may be used. This distance subtracted from the elevation of the fixed point above the crest of the flume will give the effective head.

In building a concrete flume in place, a suitable foundation is first prepared in the bottom of the channel. The forms for the floor are set to a grade such that, when struck off, the floor of the converging section is level and the floor of the throat and diverging section have properly inclined slopes. For all structures built in a channel, it is necessary to guard against the possibility of the water washing beneath the structure. It is recommended that in preparing the foundtion a trench be cut crosswise, which, when filled with concrete, will form a cut-off wall at each end of the structure and be made a part of the floor itself, and the concrete wings be set down deep enough and into the banks far enough to prevent the water from cutting around the sides. The lower parts of the wing walls should be cast at the same time as the floor system. In building small structures, before the concrete sets, short pieces of reinforcing bars or scrap iron may be placed at intervals along the edges of the floor in such manner that when the walls are cast they will strengthen the structure against possible cracking or rupturing at the floor line. After the floor has set hard enough to permit work to be done on it, the forms for the side walls are placed and braced securely to prevent possible displacement. Before pouring the walls, the surface of the floor which is in contact with the new wall should be cleaned thoroly in order that a proper bond may be secured.

The smaller sizes of flumes may be made of sheet metal, as shown in Figure 23. This 6-inch flume was assembled in the shop ready for setting in the field. It was built rigidly of 16-gage galvanized sheet steel and, exclusive of the stilling well, weighed 65 pounds.

Small flumes built of sheet metal have long life, are easy to set, may be readily moved and relocated, can not be harmed by burning weeds or trash in ditch-cleaning operations, do not leak, and are easily built true to specified dimensions.

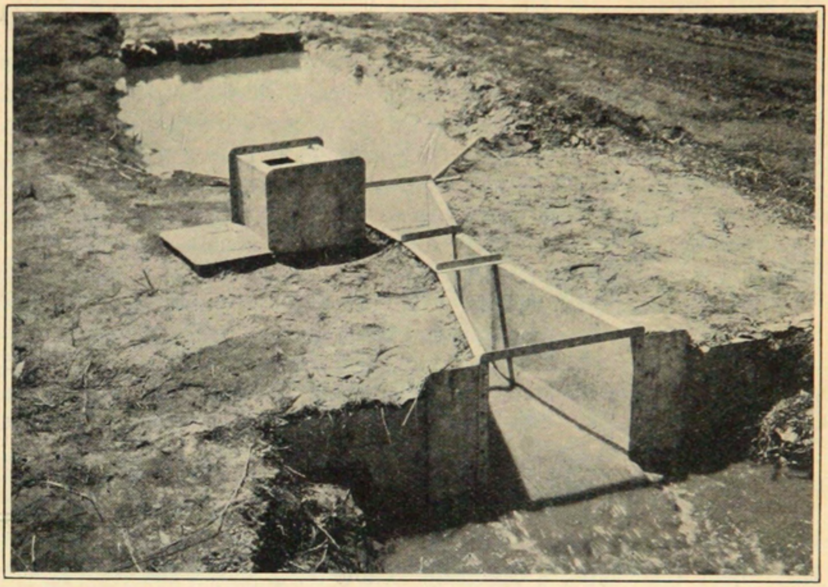

Figure 23.—Six-inch Improved Venturi Flume Constructed of Sheet Metal, with Stilling-well Equipped with Discharge Indicating Tape Graduated in Second-feet. Typical Field Installation on Farm Lateral.

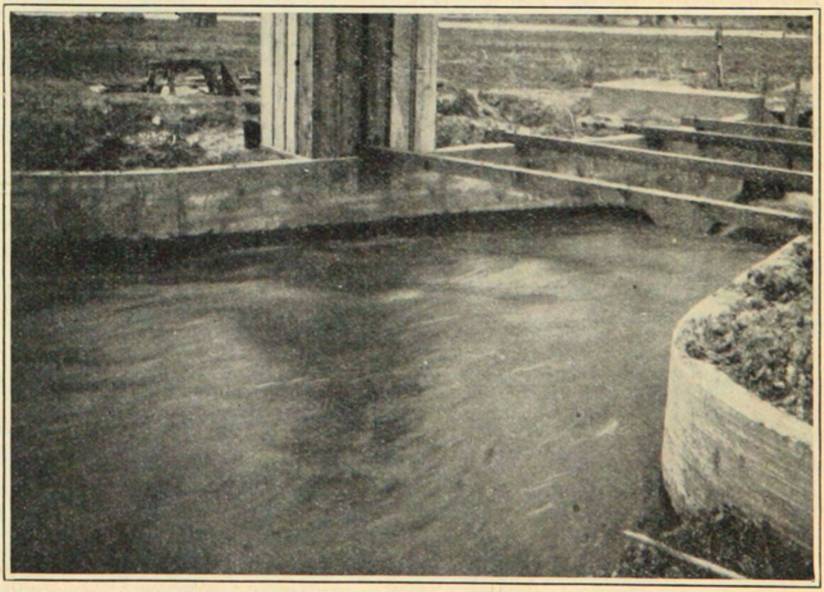

Figure 24.—Ten-foot Reinforced Concrete Improved Venturi Flume Discharging 200 Second-feet. Dye Lake Outlet, near Rocky Ford, Colorado.

LARGE IMPROVED VENTURI FLUME

Because of limited laboratory facilities, it has not been possible to investigate the flow thru the larger sizes of flumes, but such flumes installed in the field have permitted study of conditions typical of those encountered in actual service. In Figure 24 is shown a discharge of 200 second-feet thru a 10-foot reinforced concrete improved Venturi flume on the Dye Lake Outlet near Rocky Ford, Colorado. This structure was designed to carry a maximum discharge of 400 second-feet. Because of this large capacity the dimensions were altered from those of the standard design. The throat length was made 4 feet instead of 2 feet as in the standard; the length of converging side was made 20.39 feet instead of 9.00 feet; the structure was made 18 feet wide at the upstream end instead of 13.53 feet and the dip in the throat was 18 inches. The angles of convergence, divergence and the dip are the same as for the standard plan. The gage, H_a, was set at a point ⅔, the distance along the converging side from the crest.

In Figure 25 are shown 120 second-feet flowing thru a standard 10-foot improved Venturi flume on the Las Animas Consolidated Ditch near Las Animas, Colorado. Table XVI shows the comparison of current-meter gagings with the discharge as computed by the free-flow formula. The head, H_a, in this case was determined by observing

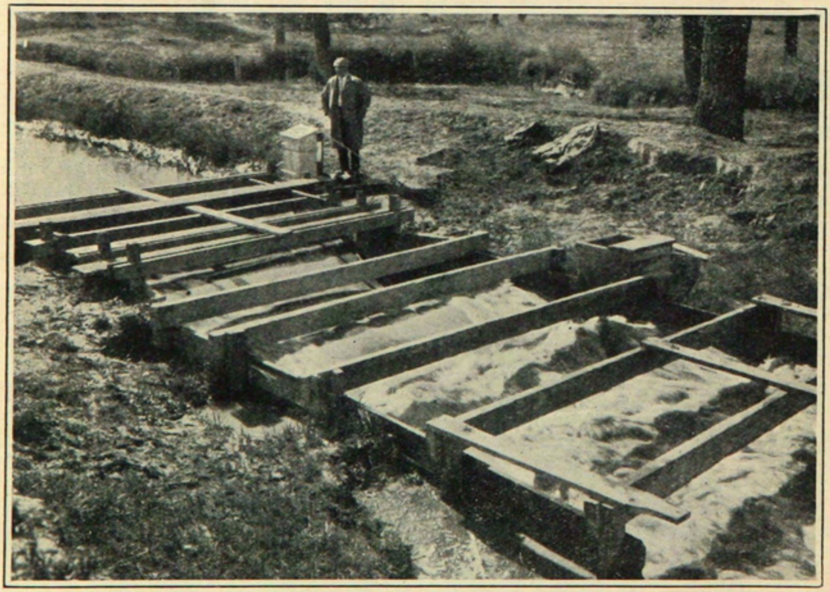

Figure 25.—Ten-foot Improved Venturi Flume Discharging 120 Second-feet Free-flow. Las Animas Consolidated Ditch, near Las Animas, Colorado.

TABLE XVI.—Comparison of Current Meter Gagings and Computed Discharge, Standard 10-foot Improved Venturi Flume, Las Animas Consolidated Ditch, Las Animas, Colorado

Date	H_a	DISCHARGE		Differ-ence	Devia-tion	Method of Gaging	Hydro-grapher
		Current Meter	Com-puted				
	Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft	Per cent		
5-12-26	1.15	49.5	50.1	+0.6	1.2	V. I.	C. Rohwer
5-13-26	1.71	96.1	95.2	−0.9	0.9	V. I.	C. Rohwer
5-13-26	1.99	120.4	121.6	+1.2	1.0	V. I.	C. Rohwer
7-26-26	1.16	50.2	50.8	+0.6	1.2	V. I.	R. L. Parshall
9-17-26	0.48	13.2	12.2	−1.0	7.6	0.6	Thos. Curtis
9-20-26	0.51	14.5	13.5	−1.0	6.9	0.6	Thos. Curtis
9-22-26	0.43	10.4	10.2	−0.2	1.9	0.6	Thos. Curtis
7- 1-27	2.05	126.1	127.6	+1.5	1.2	V. I.	C. Rohwer

V. I. = Vertical Integration.

the depth on a staff gage set vertically on the inside face of the flume at the correct distance back from the crest. The current-meter gagings were made in the converging section of the structure at the section of the gage, H_a.

In Figure 26 is shown a discharge of 40 second-feet thru a standard 12-foot improved Venturi flume built in the channel of Box Elder Creek, near Fort Collins, Colorado. Table XVII shows the comparison of current meter gagings with the computed discharge, as determined

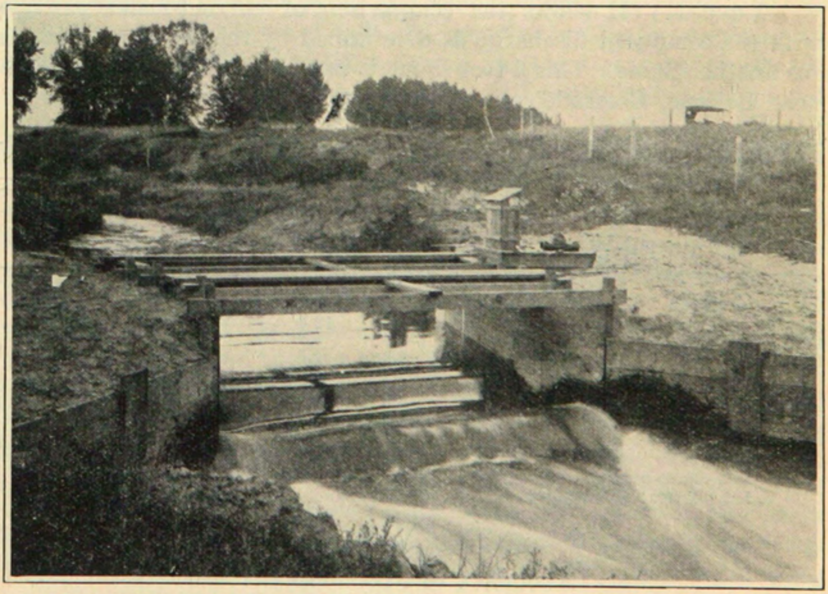

Figure 26.—Twelve-foot Improved Venturi Flume Discharging about 40 Second-feet, Free-flow. Box Elder Creek, near Fort Collins, Colorado.

TABLE XVII.—COMPARISON OF CURRENT METER GAGINGS AND COMPUTED DISCHARGE, STANDARD 12-FOOT IMPROVED VENTURI FLUME, BOX ELDER CREEK, FORT COLLINS, COLORADO

Date	H_a	Discharge		Difference	Deviation	Method of Gaging	Hydrographer
		Current Meter	Computed				
	Feet	Sec.-Ft.	Sec.-Ft.	Sec. Ft.	Per cent		
8-3-26	0.89	37.6	39.7	+2.1	5.6	V.I.	C. Rohwer
8-3-26	.89	38.8	39.7	+0.9	2.3	V.I.	R. L. Parshall
8-3-26	.95	42.1	44.2	+2.1	5.0	V.I.	C. Rohwer
8-4-26	.93	41.9	42.7	+0.8	1.9	V.I.	C. Rohwer
8-5-26	.66	23.6	24.4	+0.8	3.4	V.I.	C. Rohwer
8-17-26	1.19	60.3	63.7	+3.4	5.6	V.I.	R. L. Parshall
8-17-26	1.19	61.0	63.7	+2.7	4.4	V.I.	R. L. Parshall
8-19-26	1.04	48.4	51.2	+2.8	5.8	V.I.	R. L. Parshall
8-31-26	.86	38.1	37.6	−0.5	1.3	V.I.	R. L. Parshall
7-26-27	1.28	72.7	71.7	−1.0	1.4	V.I.	R. L. Parshall
8-26-27	1.44	87.4	86.8	−0.6	0.7	V.I.	C. Rohwer

V. I.=Vertical Integration.

by the free-flow formula. This structure settled during construction in such a way that the end of crest, on the side of channel where H_a was observed, was 0.03 foot lower than the opposite end. The computed discharge was based on the head, H_a, read on a vertical staff gage on the inside of the wall of the converging section, where the zero of the gage was assumed to agree with the mean elevation of the crest. The current-meter gagings were made within the converging section of the structure in a section slightly upstream from the gage, H_a.

Table XVIII shows the comparison of current-meter gagings with the computed discharge as determined by the free-flow formula for another flume. This 6-foot flume is installed in the Jackson Ditch near Bellvue, Colorado, and operates with no submergence.

TABLE XVIII.—COMPARISON OF CURRENT METER GAGINGS AND COMPUTED DISCHARGE, STANDARD 6-FOOT IMPROVED VENTURI FLUME, JACKSON DITCH, BELLVUE, COLORADO

Date	H_a	Discharge		Difference	Deviation	Method of Gaging	Hydrographer
		Current Meter	Computed				
	Feet	Sec.-Ft.	Sec.-Ft	Sec.-Ft.	Per-cent		
5-15-26	0.635	10.3	11.6	+1.3	12.6	V.I.	C. Rohwer
5-19-26	1.455	44.1	43.7	−0.4	0.9	V.I.	C. Rohwer
5-21-26	1.375	40.1	39.9	−0.2	0.5	V.I.	C. Rohwer
5-31-26	1.575	52.2	49.5	−2.7	5.2	V.I.	C. Rohwer
8-10-26	1.125	29.2	29.0	−0.2	0.7	V.I.	R. L. Parshall
6-14-27	1.47	45.3	44.4	−0.9	2.0	V.I.	R. L. Parshall
6-14-27	1.49	45.0	45.3	+0.3	0.7	V.I.	L. R. Brooks
6-15-27	1.54	48.1	47.8	−0.3	0.6	V.I.	R. L. Parshall
7- 7-27	1.155	30.5	30.2	−0.3	1.0	V.I.	R. L. Parshall

V. I.=Vertical Integration.

EFFECT OF VELOCITY OF APPROACH ON THE ACCURACY OF MEASUREMENT

To test the effect of velocity of approach, a series of observations was made on the 2-foot improved flume at the Bellvue laboratory.

The floor of the channel immediately above the flume structure was built level, of 1-inch boards, this floor being in reality merely an extension of the floor of the converging section of the experimental flume. Vertical wing walls were placed at an angle of 45 degrees to the longitudinal axis of the flume from the upper ends of its converging section, these wings extending back on each side to the concrete walls of the laboratory channel. Movable partitions were set up in a vertical position on the floor of the approach section, one on each side of and parallel to the axis of the channel with the lower or downstream ends against the wings. Tests were made with widths of approach channel varying from a maximum of 11.1 feet to a minimum of 6.0 feet. The results of this series of observations for free-flow conditions are given in Table XIX.

In the last column of this table showing ratio of velocities in percentages, it appears that for the narrow channel, 6-foot width, the increase in velocity of approach is practically 85 percent of that for the standard condition of 11.1 feet. To determine these values, the velocity of approach in feet per second was carefully plotted against the upper head, H_a, where the width of channel was 11.1 feet. The mean curve was drawn thru these points, which gave the values near 100 percent as indicated. Then for the other widths of channel, the velocity of approach for the corresponding head was determined from this mean curve and this value was compared with the actual velocity of approach. These tests indicate that the maximum increase of 85 percent in the velocity of approach does not cause a significant change in the discharge, as the variation is less than the experimental error.

The effect on the discharge over standard weirs caused by filling the basin upstream from the crest with sediment or deposit, or reducing this depth by improper construction, possibly may not be fully appreciated. For proper measurement by the use of the standard overpour weir, it has been found by experiment that the bottom depth or vertical distance from the crest to bottom should equal twice the maximum head, and the distance out to the sides of the box or banks be equal to three times this head; or the bottom depth be three times the head and the side or end distance be twice the head. With these limitations of bottom and side distances, the velocity of approach should be about one-third foot per second, and the error from this source about 1 percent of the discharge. To take the extreme case where the bottom and side distance are each one-half foot for a 1-foot rectangular weir with a head of 0.6 foot, the error in discharge due to the velocity of approach is found to be 4.6 percent. For these same distances and head, but with a 4-foot rectangular weir, the error in discharge is 10.5 percent. For a 1-foot and a 4-foot weir, with 1

TABLE XIX.—EFFECT OF VELOCITY OF APPROACH ON DISCHARGE THRU 2-FOOT IMPROVED VENTURI FLUME

H_a	Discharge		Difference	Deviation	Area Water Prism, Channel of Approach	Velocity in Channel of Approach	Ratio of Velocities
	Observed	Computed					
Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Percent	Sq. Ft.	Feet per Second	Per-cent
			Width of Approach Channel 11.1 Feet				
2.65	35.84	36.23	–0.39	–1.1	32.2	1.11	100
2.56	33.48	34.34	–0.86	–2.5	31.2	1.07	101
2.52	33.03	33.52	–0.49	–1.5	30.8	1.07	101
2.52	33.43	33.52	–0.09	–0.3	30.1	1.11	103
2.35	29.94	30.08	–0.14	–0.5	28.8	1.04	100
2.09	25.03	25.08	–0.05	–0.2	25.6	0.98	100
1.79	19.90	19.72	+0.18	+0.9	21.9	0.91	100
1.53	14.90	15.47	–0.57	–3.8	18.4	0.81	103
1.51–	15.12	15.08	+0.04	+0.3	18.2	0.83	101
1.13	9.59	9.67	–0.08	–0.8	13.6	0.70	100
0.97	7.50	7.63	–0.13	–1.7	11.7	0.64	100
0.97–	7.47	7.57	–0.10	–1.3	11.7	0.64	100
0.75	4.99	5.12	–0.13	–2.6	9.1	0.55	100
				Mean –1.1			
			Width of Approach Channel 10.0 Feet				
2.66	36.20	36.45	–0.25	–0.7	29.4	1.23	111
2.36	30.33	30.28	+0.05	–0.2	25.9	1.17	112
2.05	24.51	24.34	+0.17	+0.7	22.6	1.08	111
1.68–	17.93	17.80	+0.13	+0.7	18.5	0.97	111
1.23	11.11	11.03	+0.08	+0.7	13.5	0.82	112
1.08–	8.89	8.94	–0.05	–0.6	11.7	0.76	112
0.75	4.99	5.12	–0.13	–2.6	8.1	0.62	113
				Mean –0.3			
			Width of Approach Channel 8.0 Feet				
2.56	34.28	34.34	–0.06	–0.2	22.7	1.51	139
2.31–	29.13	29.25	–0.12	–0.4	20.4	1.43	139
1.97	23.05	22.88	+0.17	+0.7	17.4	1.33	139
1.50–	15.05	14.92	+0.13	+0.9	13.2	1.14	138
1.16	9.98	10.07	–0.09	–0.9	10.1	0.99	139
0.98	7.68	7.75	–0.07	–0.9	8.6	0.89	138
0.75–	4.97	5.07	–0.10	–2.0	6.6	0.75	136
				Mean –0.4			
			Width of Approach Channel 6.0 Feet				
2.39	30.76	30.89	–0.13	–0.4	15.9	1.93	184
2.19	27.01	26.96	+0.05	+0.2	14.6	1.85	184
2.02	23.89	23.79	+0.10	+0.4	13.3	1.80	187
1.71	18.41	18.38	+0.03	+0.2	11.3	1.63	184
1.38–	13.16	13.10	+0.06	+0.5	9.1	1.45	185
1.05	8.52	8.63	–0.11	–1.3	6.8	1.25	185
0.75	4.97	5.12	–0.15	–3.0	4.9	1.02	186
				Mean –0.5			

TABLE XX.—COMPARISON OF LOSS OF HEAD IN FEET FOR VARIOUS DISCHARGES THRU THE IMPROVED VENTURI FLUME AND THE SAME DISCHARGE OVER WEIRS

Discharge	Improved Venturi Flume				Standard Rectangular Weir				Standard Cipolletti Weir				90° Triangular Notch Weir
	6-inch	1-foot	2-foot	4-foot	6-inch	1-foot	2-foot	4-foot	6-inch	1-foot	2-foot	4-foot	
Second-ft.	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet
0.10	0.06	...	...	...	0.15	...	...	...	0.15	...	...	...	0.27
0.50	0.16	0.08	...	...	0.46	0.29	0.18	...	0.43	0.28	0.18	...	0.52
1.00	0.25	0.12	0.08	...	0.74	0.46	0.29	0.18	0.64	0.44	0.28	0.18	0.69
2.00	0.41	0.19	0.12	0.08	1.16	0.75	0.46	0.29	0.96	0.69	0.45	0.28	0.92
3.00	...	0.25	0.16	0.11	...	0.99	0.61	0.38	...	0.88	0.58	0.37	1.08
5.00	...	0.35	0.22	0.14	...	...	0.86	0.53	...	...	0.82	0.52	1.32
7.50	...	0.45	0.29	0.19	...	...	1.13	0.70	...	...	1.06	0.68	...
10.00	...	0.55	0.35	0.22	...	...	...	0.85	...	...	1.27	0.83	...
12.50	...	0.63	0.40	0.26	...	...	...	0.99	...	...	...	0.96	...
15.00	...	...	0.45	0.29	...	...	...	1.12	...	...	...	1.08	...
20.00	...	...	0.54	0.35	...	...	...	1.36	...	...	...	1.31	...

foot head and the bottom and side distances each at 1 foot, the error in discharge is 2.8 percent and 6.8 percent, respectively. As the head increases, the error also increases, assuming the bottom and side distances to remain fixed. For this fixed condition the error increases as the length of crest is increased.

COMPARISON OF LOSS OF HEAD FOR VARIOUS DISCHARGES OVER STANDARD WEIRS AND THRU THE IMPROVED VENTURI FLUME

Table XX has been prepared to show the relative loss of head in feet for various discharges thru the improved Venturi flume and over weirs. For the 6-inch flume the degree of submergence at 50 percent was taken as the limit of free-flow, while for the 1, 2 and 4-foot flumes the limiting percentage was taken at 70. It is to be noted in this comparison that the values given under the headings for the various weirs represent the actual head on the crest to give the corresponding discharge. The loss of head is, in reality, greater than that indicated by the distance between the water surface downstream from the weir and the crest. This additional fall is necessary to permit the free passage of air underneath the nappe, or overpouring stream of water, and may be assumed to be from 0.05 to 0.10 foot.

ACCESSORIES

The discharge-indicating tape is graduated according to the free-flow discharge formula and may show either cubic-feet per second, miner's inches, rights or shares, for equal increments in depth, or it may be graduated in cubic-feet per second, miner's inches, or shares as whole numbers, the increment in depth decreasing as this depth increases.

The principle of this device is shown in Figure 1. The graduated metal tape, passing over the flat-faced wheel, is directly under a fixed index or pointer observed thru a small opening which permits accuracy and ease in reading. With this arrangement, the amount of discharge may be read directly from the tape. As the moving system is a unit, it will not get out of order. The numbers showing the value of the graduations should be outlined by perforations, thus insuring against obliteration by wear or erasure or fraudulent changing of the number. The stilling well as designed and shown in Figure 22 features a very desirable improvement over the old straight well, as the inclined wall makes cleaning easy. Sediment which accumulates in the stilling well is deposited in a space provided below the inlet tube. The process of cleaning is accomplished by raising a hinged lid and drawing the deposit upward along the inclined side of the well by means of a garden hoe. This cleaning is done without interference with the indicating mechanism.

For small flows thru the improved Venturi flume, a staff gage set flush with the inside face of the converging section at the proper distance back from the crest may be found satisfactory to determine the upper head, H_a, for free-flow. If the flow is submerged, the throat gage on the inside face will be found unsatisfactory because of the roughness of the water surface. As the degree of submergence increases, the water becomes less disturbed, but for high submergence the error in reading the head may cause a large error in the computed discharge even tho the reading may be carefully observed. It is thot, however, that more satisfactory results will be obtained by placing the staff gages, or scales, in the stilling wells as suggested in Figures 1 and 22.

An automatic recording instrument has been perfected to be used in connection with the measurement of the discharge thru any device where depth and difference in depth are to be recorded. This instrument is readily adapted to use in connection with the improved Venturi flume, but further calculations from the record would be necessary to make the submerged-flow table adaptable to this type of device. Such an instrument (Figure 27) consists of a horizontal

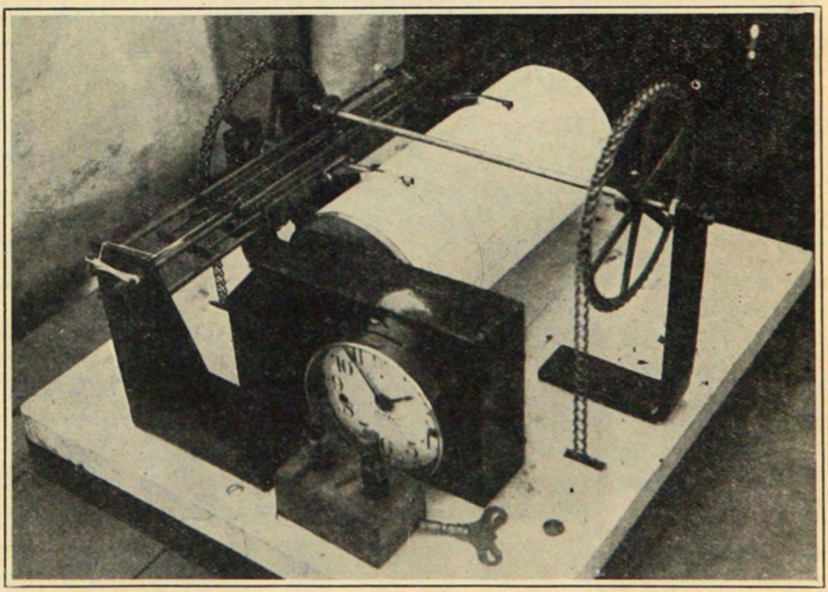

Figure 27.—The Improved Venturi Flume Register which Records Graphically the Upper Head, H_a, and the Difference in Head, $H_a - H_b$.

cylinder turned at the rate of one revolution in 8 days. The graduated-record chart on this cylinder has for the ordinate, depth in feet, and time in hours as the abscissa. Two pens moved by floats trace out the elevation and difference in elevation of the water surface in the stilling wells, which are directly communicated to the desired points in the structure. In order that the total discharge in acre-feet thru such a device may be determined from this instrument record, it is necessary to calculate such values from the tables, the record being used as an index.

To eliminate the necessity of making office computations to determine the total discharge, a recording instrument has been designed and built which is capable of mechanically integrating or summing up the total discharge thru the improved Venturi flume under free-flow condition for any period of time. Figure 28 is a front view

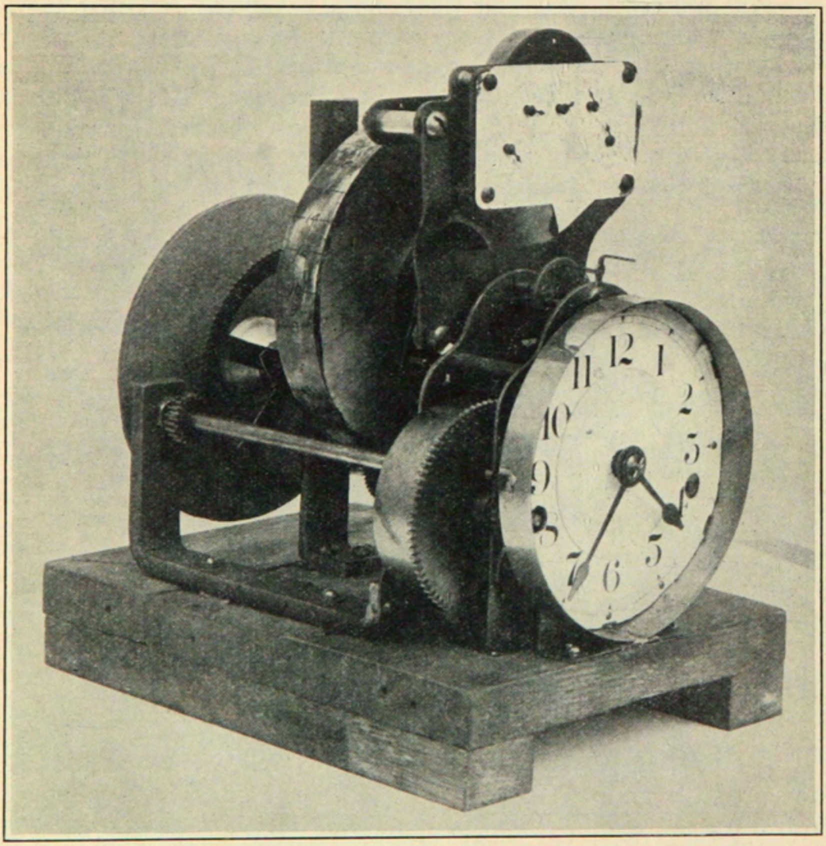

Figure 28.—Acre-foot Integrating Instrument.

showing the general working parts. The total number of acre-feet is read on the series of dials immediately above the clock face. When the case is in place, a window is provided at the top thru which the rate of discharge in second-feet at any particular time may be observed on the graduations appearing on the edge of the disc wheel. On the back part of the instrument is a circular chart upon which is inscribed the variation of the depth of water. This graphic chart, however, is not intended to be used to compute discharge and only serves as an indication of the variation of the flow as well as to show the time the water was turned in or out of the channel. Altho the instrument is designed to operate in connection with the improved Venturi flume, free-flow condition, it may be attached to any measuring device where the discharge is a function of one head, such as a weir, rating flume, or free-flow orifice. With any of these devices the law of discharge must be known, in order that the regulating cam may be properly designed.

GENERAL COMMENT AND NOTES CONCERNING ORIGINAL DATA

The original data given in Tables XXI to XXXV constitute the results of the complete series of both free-flow and submerged-flow tests used in the determination of the discharge formulas for these two conditions.

Tests 6295 to 6494 were made in 1923 at the Bellvue laboratory, where a standard 10-foot rectangular weir was used to determine the observed discharge thru the various sizes of experimental improved Venturi flumes. For the smaller discharges, model flumes of 1, 2 and 3-foot sizes were tested at the Fort Collins hydraulic laboratory as indicated in the tables which follow.

Tests 7015 to 7138 were made in the fall of 1924 at the Bellvue laboratory where the 10-foot standard rectangular weir was used to obtain the observed discharge. Only a limited number of this series of tests was used in the comparison because they were purposely run at high submergence and H_a depths greater than 2.5 feet. The few tests considered were made a part of the 1923 series, as they were used in the original derivation of the discharge formulas.

Tests 7285 to 7554 were made in 1926 at the Bellvue laboratory, where a standard 15-foot rectangular weir was used to determine the

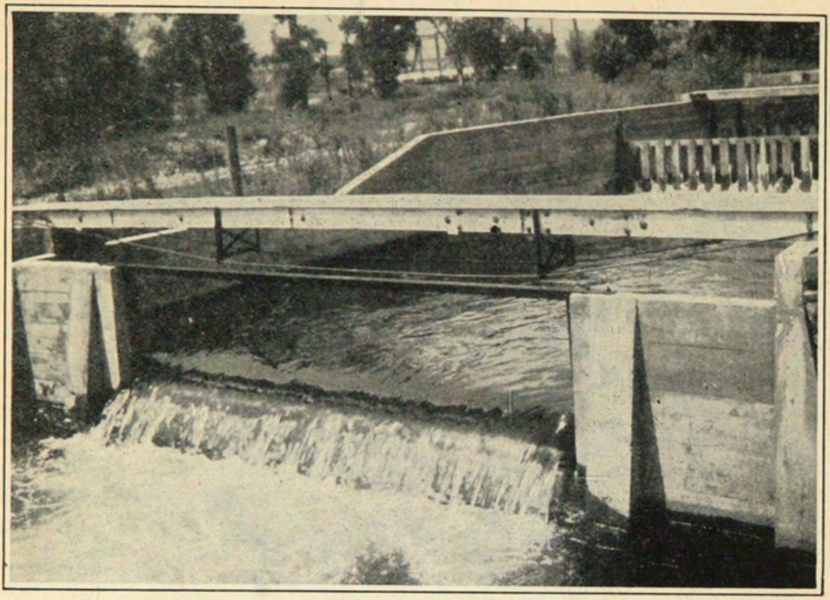

Figure 29.—Fifteen-foot Standard Rectangular Weir at the Bellvue Hydraulic Laboratory. Discharge 40 Second-feet. Actual Length of Crest, 14.98 feet.

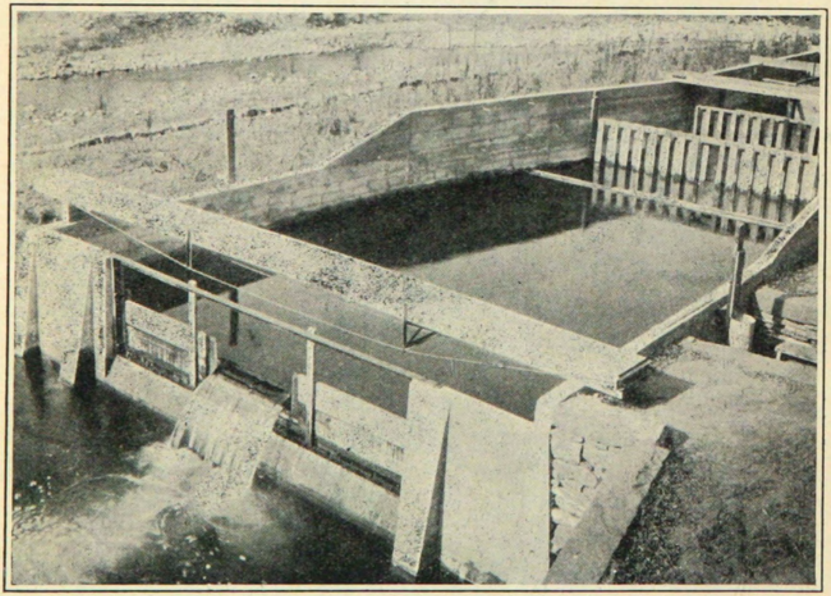

Figure 30.—Weir Basin at the Bellvue Hydraulic Laboratory with a 4-foot Rectangular Weir Mounted on the 15-foot Crest. The Headon Weirs Determined by Two Hookgages as Shown. Discharge Over the 4-foot Weir, 7.67 Second-feet.

observed discharge, Figure 29. Tests 7555 to 7615 were also made at the Bellvue laboratory, but apply to a different device. A standard 4-foot rectangular weir was used in tests 7616 to 7712, Figure 30, while for tests 7713 to 7756 an 18-inch rectangular weir was used. Tests 7757 to 7773 were made where the 15-foot weir was used to determine the discharge. It will be found for tests on the 2-foot flume that four different-sized weirs, as well as volumetric determinations of discharge, were used in the calibration.

The computed discharges for tests 7674 to 7683, 1-foot flume, were reduced by 2 percent because the dimension of width of throat was incorrect.

Tests 7379 to 7388 were made on the 8-foot improved Venturi flume as special observations to determine the effect of increasing the length of the converging section of the structure. In this case the length of side was increased from the standard dimension of 8 feet to 14.5 feet. This increase of length of side gave a width of structure at the front end of 14.0 feet. It will be noted that the computed discharges for both the free-flow and submerged flow agree quite closely with the observed discharge. The hydraulic condition of flow within or thru this setting was very good. See Table XXXV.

The series of tests at the Bellvue laboratory in 1923 was for the most part made with duplicate readings of the upper head, H_a, on the model flumes; that is, the head was determined at corresponding points on opposite sides of the converging section and the value of the mean used as the effective head. The throat head, H_b, was a single determination. The 1926 series of tests at the Bellvue laboratory was made with duplicate readings of both H_a and H_b and the means determined as the effective heads. It was found that the upper head, H_a, as observed on either side of the flume, gave very consistent agreement, while the two throat gages gave results that were more discordant. Examination of the mean values of H_b shows that for the 8-foot flume these differ as a maximum as much as 0.07 foot for a discharge of 80 second-feet, and for submergence between 50 and 80 percent. These maximum differences in the H_b mean readings indicate that one gage was consistently high, but in general it was found that either one may be greater. As the size of flume decreases the maximum difference in the throat gages also decreases, but the tendency is for greater differences to show for the lower degree of submergence. These inconsistencies under laboratory settings would warrant the conclusion that for field conditions where only approximate methods are used to determine the heads, an accurate determination of the computed submerged-flow discharge would not be expected. However, it is believed on the whole, that submerged-flow measurements in the field are possible, allowing for these apparent inconsistencies of the throat-gage reading.

The first nine tests, free-flow, on the 8-foot flume, series of 1926, showed a difference of 0.03 to 0.05 foot in the H_a gages. Examination of the floor disclosed an irregularity near the gage opening at one side. The removal of this obstruction appeared to correct the difficulty, and thereafter very close agreement with the opposite, H_a, reading was obtained. Elevations taken on the crest of this 8-foot flume at the beginning showed one end to be approximately 0.03 foot low. Commencing with test 7310, the floor in the converging section had been removed and the crest adjusted to within about 0.005 foot. Free-flow discharge for succeeding tests showed better agreement. The general trend of all tests on this 8-foot setting was for the observed discharge, as determined by the 15-foot standard rectangular weir, to be in excess of the computed discharge. The mean width of throat at the conclusion of test 7388 was 7.98 feet. Computed discharges for this 8-foot setting were corrected accordingly. After completing the tests on the 4-foot flume the apparatus was again adjusted to an 8-foot size and tests 7518 to 7554 were made. This short series shows a better agreement between the computed and observed discharges.

Tests on the 6-foot flume, 7389 to 7455, series of 1926, show fair agreement. These tests were made by four different observers. For discharges of 75 to 85 second-feet, free-flow, the contraction effect caused by the water flowing past the upstream end of the converging section resulted in a pronounced dip or depression at the point vertically above the piezometer opening to H_a gage stilling wells. This depression was estimated to be about 3 inches below the general slope of the inclined water surface. The law of the discharge is based upon stilling-well depths, and the fact that the static head is reduced by the contraction does not vitiate the results of this seemingly erratic condition. Gage staffs or scales placed on the inside face of the converging section to permit the head, H_a, to be read would be unsatisfactory for large free-flow discharges.

For the 4-foot settings, test 7501, the discharge was free-flow; that is, unrestricted by back water, similar to that shown in Figure 3. This test showed a gage ratio of approximately 74 percent, and even tho being strictly free flow it was classified as a submerged test and corrected accordingly. At this discharge the throat was filled to such an extent that the gage at this point registered a depth of more than the free-flow limit. Had this test been considered as free-flow, the deviation between the observed and computed discharges would have been approximately 1.1 percent.

Profiles of the water surfaces were taken along the longitudinal axis of the flume for tests 7511-7517. It was found for these tests that the gage, H_a, agreed reasonably well with measured depth in the flume; however, in all cases the stilling-well depth exceeded the profile in amounts ranging from 0.01 to 0.03 foot. Greater variation was found to exist in the H_b hookgage readings.

Nothing of unusual importance was observed in connection with these tests on the 2-foot flume. Test 7763, free-flow discharge, gave the maximum flow thru this size structure in 1926, this test being limited to the total supply available in the river. At the Bellvue laboratory in 1923, a test was made on the 2-foot flume where the upper head, H_a, was 2.65 feet and the gage ratio 72 percent. This condition of flow was similar to test 7501 for the 4-foot flume. Assuming the condition as free-flow, it was found that the deviation of computed and observed discharge was approximately 1.1 percent, the computed discharge being in excess for both these maximum flows.

It was found in testing the 1-foot flume that the computed discharges for tests 7674 to 7683 had to be reduced by 2 percent, due to reduction in mean length of crest.

Ice was a troublesome factor at the Bellvue laboratory in 1926 during the time tests were being made on the 1-foot and 2-foot flumes. It is believed, however, that it had little or no effect upon the accuracy of the work.

SUMMARY

The improved Venturi flume has shown in field operation that it is practical under conditions which make a standard weir or rating flume impractical, either because of silting trouble or insufficient grade.

The accuracy of measurement with this device is entirely within practical limits. The observed discharge, free-flow, was within ± 3 percent of the computed amount in 89 percent of the tests. For the submerged flow, 85 percent of the observed discharges were within ± 5 percent of the computed amounts.

The range of capacity of discharge from a minimum of less than 0.10 second-foot thru the 6-inch flume to a maximum of 200 second-feet thru the 10-foot flume, as limited by present investigations, is sufficient to meet ordinary requirements.

This device operates successfully with relatively small loss of head, and for free flow this loss in a standard weir is approximately four times that in the flume.

The flume will withstand a high degree of submergence without affecting the rate of free-flow discharge.

Because of the increased velocity of the water, it will operate successfully in sand- or silt-laden streams. Since the floor of the structure is constantly swept clean of all deposit, constancy of condition is maintained.

Operation is simple because it has no adjustable or moving parts.

Its dimensions are not easily altered so as to cause wilfully unfair measurement of the discharge. The filling of a weir box upstream from the crest, by natural deposit from the stream, causes the weir to over-register and consequently there is no incentive on the part of the water user to correct this condition. Discharge thru rating flumes may be changed to the advantage of the user by altering downstream conditions.

Velocity of approach of the stream to the entrance of this device has little or no effect upon the rate of discharge.

Plane surfaces in the structure make it easy to construct. For moderately large flows the upper ends of the converging section should be rounded off by means of sheet-metal pieces rolled to a radius of 4 or 5 feet.

The structure may be built of wood, concrete or sheet metal. Precast concrete members may be made and assembled in the field for the small-sized flumes. Sheet-metal flumes, portable because of their light weight, are entirely practical for the small sizes.

Recording instruments may be operated in connection with this device to register heads or total discharge.

The indicating tape gives the discharge direct, making it unnecessary to refer to tables; discharge may be indicated in second-feet, miner's inches, rights or shares. The tape will not get out of order.

Where the degree of submergence exceeds about 95 percent, the indicated discharge thru the flume is not wholly dependable. If conditions permit, the discharge should be free flow or with the least possible degree of submergence.

For free flow, the flume's measurement of discharge depends on a single head or depth only, it being similar in this respect to a standard weir or rating flume.

The upper head in the converging section, or the throat head, may be read on either side of the flume with equal accuracy.

Scales or gages attached to the inside of the flume for the purpose of determining the head are not recommended except for small flows or moderate depth and free-flow condition. Better results are obtained if the heads are observed in stilling wells outside the structure.

For free flow the exit velocity is relatively high, and bottom as well as bank protection must be provided to pervent erosion. Where the materials are of such a nature as to withstand a high velocity, such as heavy gravel or rock, then no attention need be given to protection.

The improved Venturi flume has the advantage over the old type Venturi flume in that the angles of convergence and divergence are such as to eliminate the effect of the switching of the current in the diverging section, which, in the old flume, affected the discharge. The elimination of this effect made possible the determination of the discharge by means of single, upper and throat heads; in the old flume it was recommended that these heads be observed on both sides and the mean reading used as the basis of computing the discharge. The dip in the floor at the throat section permits the formation of a hydraulic jump downstream from the throat section, thus leaving the conditions of flow in the converging section unaffected by submergence until the degree of the submerged flow reaches 70 percent, or where the ratio of the upper head, H_a, and throat head, H_b, both referred to the crest as the datum, has a value of 0.7.

ACKNOWLEDGMENT

The author wishes to acknowledge the assistance and cooperation of the Jackson Ditch Company, of Laporte, Colorado, in permitting the use of their diversion dam and headworks in connection with the operation of the irrigation hydraulic laboratory at Bellvue. To those who have made valuable suggestions and criticisms, he wishes to extend his most sincere thanks.

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TABLE XXI.—ORIGINAL FREE-FLOW DISCHARGE DATA FOR 6-INCH IMPROVED VENTURI FLUME, 1926

Test	Flume Heads		Ratio H_b/H_a	Head on Weir	Discharge		Difference	Deviation
	H_a	H_b			Obs.	Comp.		
	Feet	Feet		Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
7214	0.215	....	....	0.352	0.186	0.182	−0.004	2.2
7215	.398	....	....	.517	.483	.481	− .002	0.4
7216	.612	0.095	0.155	.678	.947	.948	+ .001	0.1
7217	.825	.284	.344	.815	1.500	1.520	+ .020	1.3
7218	.971	.404	.416	.908	1.960	1.966	+ .006	0.3
7219	.123	....	....	.244	.075	.075	.000	0.0
7220	.204	....	....	.338	.168	.167	− .001	0.6
7221	.303	....	....	.436	.316	.312	− .004	1.3
7222	.391	....	....	.513	.475	.467	− .008	1.7
7223	.520	.012	.023	.615	.745	.733	− .012	1.6
7224	.595	.077	.129	.669	.917	.907	− .010	1.1
7225	.708	.178	.251	.745	1.200	1.194	− .006	0.5
7226	.909	.348	.383	.870	1.760	1.772	+ .012	0.7
7227	.716	.194	.271	.750	1.220	1.215	− .005	0.4
7228	.809	.275	.340	.810	1.480	1.474	− .006	0.4
7229	1.011	.441	.436	.936	2.110	2.096	− .014	0.7
7230	1.116	.524	.470	.988	2.420	2.450	+ .030	1.2
7231	.137	....	....	.260	.088	.089	+ .001	1.1
7232	.093	....	....	.208	.051	.048	− .003	5.9
7233	.509	.139	.273	.608	.723	.709	− .014	1.9

TABLE XXII.—ORIGINAL FREE-FLOW DISCHARGE DATA FOR 1-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio H_b/H_a	Head on Weir	Discharge		Difference	Deviation
	H_a	H_b			Obs.	Comp.		
	Feet	Feet		Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
6478	2.516	1.615	0.642	0.623	16.13	16.29	+0.16	1.0
6479	2.404	1.512	.629	.595	15.09	15.20	+ .11	0.7
6480	2.420	1.543	.638	.594	15.05	15.35	+ .30	2.0
6481	2.419	1.578	.653	.595	15.09	15.34	+ .25	1.7
6484	2.132	1.268	.595	.528	12.66	12.66	.00	0.0
6485	1.828	.976	.534	.453	10.05	10.02	− .03	0.3
6486	1.168	.251	.215	.284	5.04	5.07	+ .03	0.6
6487	1.516	.662	.436	.373	7.53	7.54	+ .01	0.1
6491	1.852	1.160	.626	.450	9.95	10.22	+ .27	2.7
6647	1.302	.491	.377	V. M.*	6.04	5.97	− .07	1.2
6648	1.199	.376	.314	V. M.	5.32	5.27	− .05	0.9
6649	.500	−.193	....	V. M.	1.37	1.39	+ .02	1.5
6650	1.099	.262	.238	V. M.	4.65	4.61	− .04	0.9
6651	1.000	.147	.147	V. M.	4.01	4.00	− .01	0.2
6652	.899	.029	.032	V. M.	3.39	3.40	+ .01	0.3
6653	.402	−.155	....	V. M.	.96	1.00	+ .04	4.2
6654	.301	−.133	....	V. M.	.62	.64	+ .02	3.2
6655	.201	−.143	....	V. M.	.33	.35	+ .02	6.0
6659	1.802	1.011	.562	V. M.	9.82	9.81	− .01	0.1
6660	1.699	.910	.536	V. M.	8.94	8.96	+ .02	0.2
6661	1.603	.813	.507	V. M.	8.20	8.20	.00	0.0
6662	1.501	.709	.472	V. M.	7.45	7.42	− .03	0.4
6663	1.399	.599	.428	V. M.	6.69	6.67	− .02	0.3
6664	.801	−.086	....	V. M.	2.84	2.85	+ .01	0.4
6665	.701	−.200	....	V. M.	2.30	2.33	+ .03	1.3
6666	.601	−.308	....	V. M.	1.83	1.84	+ .01	0.5
6703	.398	.276	.694	V. M.	.91	.98	+ .07	7.7
Check Tests, Bellvue Laboratory, 1926								
7662	1.182	....	....	0.549	5.26	5.16	−0.10	1.9
7667	1.189	0.724	0.609	.540	5.13	5.20	+ .07	1.4
7668	1.881	....	....	.883	10.59	10.47	− .12	1.1
7672	.619	....	....	.273	1.88	1.92	+ .04	2.1
7674	.294	....	....	.120	.57	.62	+ .05	8.8
7679	.289	.144	.498	.118	.55	.61	+ .06	10.9
7680	.499	....	....	.213	1.31	1.39	+ .08	6.1
7684	.273	....	....	.111	.51	.55	+ .04	7.8
7689	.584	....	....	.255	1.70	1.77	+ .07	4.1
7692	1.187	....	....	.545	5.20	5.19	− .01	0.2
7695	2.451	....	....	1.167	15.96	15.65	− .31	1.9
7699	2.150	....	....	1.009	12.89	12.82	− .07	0.5
7703	1.563	....	....	.731	8.02	7.89	− .13	1.6
7704	1.592	1.082	.679	.726	7.94	8.12	+ .18	2.3
7708	.950	....	....	.428	3.64	3.70	+ .06	1.6
7712	.392	....	....	.165	.91	.96	+ .05	5.5
7713	.683	....	....	.602	2.21	2.24	+ .03	1.4
7714	.519	....	....	.455	1.47	1.48	+ .01	0.7
7715	.409	....	....	.349	.99	1.03	+ .04	4.0
7716	.332	....	....	.284	.74	.75	+ .01	1.4
7717	.275	....	....	.226	.53	.56	+ .03	5.7
7718	.278	....	....	.228	.53	.57	+ .04	7.5
7725	.585	.332	.568	.506	1.71	1.77	+ .06	3.5
7730	.315	....	....	.262	.65	.69	+ .04	6.2
7731	.476	....	....	.407	1.25	1.29	+ .04	3.2
7732	.605	....	....	.526	1.82	1.86	+ .04	2.2
7733	.739	....	....	.653	2.49	2.52	+ .03	1.2
7734	.588	....	....	.510	1.73	1.79	+ .06	3.5
7735	.335	....	....	.285	.74	.75	+ .01	1.4

* Volumetric measurements, Hydraulic Laboratory, Fort Collins.

TABLE XXIII.—ORIGINAL FREE-FLOW DISCHARGE DATA FOR 2-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio H_b/H_a	Head on Weir	Discharge		Difference	Deviation
	H_a	H_b			Obs.	Comp.		
	Feet	Feet		Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
6435	2.350	1.640	0.698	0.943	29.94	30.08	+0.14	0.5
6438	2.094	1.368	.653	.836	25.03	25.16	+ .13	0.5
6443	1.794	1.048	.584	.717	19.90	19.79	− .11	0.6
6444	1.505	.719	.478	.596	15.12	15.08	− .04	0.3
6448	1.129	.256	.227	.439	9.59	9.66	+ .07	0.7
6449	.965	.042	.044	.371	7.47	7.57	+ .10	1.3
6450	.973	.239	.246	.372	7.50	7.67	+ .17	2.3
6453	.752	−.244	....	.282	4.99	5.14	+ .15	3.0
6587	1.000	.147	.147	V. M.*	8.10	8.00	− .10	1.2
6588	.901	.018	.020	V. M.	6.83	6.81	− .02	0.3
6589	.799	−.109	....	V. M.	5.65	5.65	.00	0.0
6590	.701	−.234	....	V. M.	4.59	4.61	+ .02	0.4
6591	.601	−.157	....	V. M.	3.59	3.63	+ .04	1.1
6592	.500	−.112	....	V. M.	2.69	2.73	+ .04	1.5
6593	.399	−.106	....	V. M.	1.89	1.92	+ .03	1.6
6594	.301	−.107	....	V. M.	1.22	1.25	+ .03	2.5
6595	.202	−.127	....	V. M.	.65	.67	+ .02	3.1
6596	1.101	.274	.249	V. M.	9.40	9.28	− .12	1.3
6597	1.200	.401	.334	V. M.	10.76	10.61	− .15	1.4
6598	1.587	.858	.540	V. M.	16.63	16.37	− .26	1.6
6599	1.501	.762	.508	V. M.	15.16	15.02	− .14	0.9
6600	1.303	.523	.401	V. M.	12.19	12.06	− .13	1.1
6601	1.400	.644	.460	V. M.	13.73	13.48	− .25	1.8
6605	1.606	.872	.543	V. M.	16.73	16.68	− .05	0.3
6611	1.604	.480	.299	V. M.	16.89	16.64	− .25	1.5
6636	.399	.223	.559	V. M.	1.86	1.92	+ .06	3.2
6637	.402	.281	.699	V. M.	1.87	1.95	+ .08	4.3
6645	.201	.140	.697	V. M.	.62	.66	+ .04	6.5
Check Tests, Bellvue Laboratory, 1926								
7616	0.348	....	....	0.233	1.49	1.56	+0.07	4.7
7617	.936	....	....	.675	7.13	7.21	+ .08	1.1
7618	.937	....	....	.676	7.15	7.23	+ .08	1.1
7619	.942	....	....	.689	7.34	7.29	− .05	0.7
7620	.470	....	....	.323	2.40	2.48	+ .08	3.3
7621	.312	....	....	.208	1.26	1.31	+ .05	4.0
7622	.296	....	....	.195	1.15	1.21	+ .06	5.2
7623	.794	....	....	.572	5.59	5.59	.00	0.0
7624	.195	....	....	.125	.60	.63	+ .03	5.0
7627	.295	....	....	.196	1.16	1.21	+ .05	4.3
7628	.300	....	....	.196	1.16	1.24	+ .08	6.9
7630	.321	....	....	.215	1.33	1.38	+ .05	3.8
7633	.498	....	....	.344	2.64	2.71	+ .07	2.7
7637	.759	....	....	.546	5.21	5.22	+ .01	0.2
7642	.598	....	....	.422	3.57	3.60	+ .03	0.8
7644	.747	....	....	.538	5.10	5.09	− .01	0.2
7648	1.214	....	....	.909	11.05	10.81	− .24	2.2
7655	1.028	....	....	.758	8.46	8.35	− .11	1.3
7656	1.372	....	....	1.035	13.38	13.06	− .32	2.4
7661	.856	....	....	.624	6.35	6.29	− .06	0.9
7736	.415	....	....	.566	2.02	2.05	+ .03	1.5
7737	.328	....	....	.445	1.42	1.43	+ .01	0.7
7738	.210	....	....	.276	.71	.71	.00	0.0
7741	.265	....	....	.356	1.02	1.02	.00	0.0
7745	.512	....	....	.713	2.83	2.84	+ .01	0.4
7750	.849	....	....	1.221	6.21	6.21	.00	0.0
7757	.968	....	....	.286	7.62	7.61	− .01	0.1
7758	1.776	....	....	.529	19.09	19.48	+ .39	2.0
7759	.834	....	....	.245	6.07	6.04	− .03	0.5
7762	2.142	....	....	.654	26.18	26.05	− .13	0.5
7763	2.250	....	....	.689	28.30	28.12	− .18	0.6
7768	1.575	....	....	.478	16.40	16.18	− .22	1.3
7773	1.135	....	....	.339	9.81	9.74	− .07	0.7

* Volumetric Measurements, Hydraulic Laboratory, Fort Collins.

TABLE XXIV.—ORIGINAL FREE-FLOW DISCHARGE DATA FOR 3-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio H_b/H_a	Head on Weir	Discharge		Difference	Deviation
	H_a	H_b			Obs.	Comp.		
	Feet	Feet		Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
6409	2.138	1.470	0.688	1.136	39.57	39.45	−0.12	0.3
6410	1.962	1.283	.654	1.042	34.78	34.48	− .30	0.9
6415	1.712	1.012	.591	.905	28.15	27.85	− .30	1.1
6416	1.597	.870	.545	.840	25.21	24.98	− .23	0.9
6421	1.377	.582	.423	.718	19.95	19.80	− .15	0.8
6422	1.154	.277	.240	.595	15.09	15.02	− .07	0.5
6423	1.167	.779	.668	.594	15.05	15.28	+ .23	1.5
6427	.916	−.047	....	.460	10.28	10.46	+ .18	1.7
6428	.719	−.306	....	.355	7.01	7.15	+ .14	2.0
6432	.590	−.082	....	.285	5.07	5.25	+ .18	3.5
6495	.800	−.146	....	V.M.*	8.62	8.46	− .16	1.9
6496	.800	.440	.550	V.M.	8.52	8.46	− .06	0.7
6497	.800	.547	.684	V.M.	8.40	8.46	+ .06	0.7
6500	.892	−.017	....	V.M.	10.24	10.03	− .21	2.0
6501	.696	−.277	....	V.M.	6.87	6.80	− .07	1.0
6502	.588	−.410	....	V.M.	5.29	5.22	− .07	1.3
6503	.532	−.475	....	V.M.	4.51	4.47	− .04	0.9
6504	.391	−.189	....	V.M.	2.78	2.76	− .02	0.7
6505	.327	−.146	....	V.M.	2.09	2.09	.00	0.0
6506	.209	−.142	....	V.M.	1.03	1.03	.00	0.0
6507	1.202	.783	.651	V.M.	16.27	16.00	− .27	1.7
6513	.703	.463	.659	V.M.	6.85	6.91	+ .06	0.9
6518	.502	−.077	....	V.M.	4.08	4.08	.00	0.0
6519	.499	.256	.513	V.M.	4.02	4.04	+ .02	0.5
6527	.399	−.064	....	V.M.	2.86	2.85	− .01	0.4
6533	.601	.103	.171	V.M.	5.45	5.40	− .05	0.9
6542	.999	.124	.124	V.M.	12.27	11.98	− .29	2.4
6554	.600	.373	.622	V.M.	5.29	5.39	+ .10	1.9
6564	1.098	.242	.220	V.M.	14.00	13.89	− .11	0.8
6572	1.200	.836	.697	V.M.	15.99	15.96	− .03	0.2
6574	.299	.073	.244	V.M.	1.77	1.81	+ .04	2.3
7118	2.391	1.629	.682	1.262	46.20	46.99	+ .79	1.7
7137	1.843	1.131	.614	.973	31.38	31.26	− .12	0.4
7138	1.141	.444	.389	.588	14.83	14.75	− .08	0.5

* Volumetric Measurements, Hydraulic Laboratory, Fort Collins.

TABLE XXV.—ORIGINAL FREE-FLOW DISCHARGE DATA FOR 4-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads H_a	Flume Heads H_b	Ratio H_b/H_a	Head on Weir	Discharge Obs.	Discharge Comp.	Difference	Deviation
	Feet	Feet		Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
6371	1.658	0.938	0.566	1.075	36.46	35.53	−0.93	2.5
6372	1.644	1.070	.651	1.060	35.69	35.06	− .63	1.8
6378	1.470	.704	.479	.952	30.38	29.38	−1.00	3.3
6379	2.001	1.309	.654	1.293	47.91	47.81	− .10	0.2
6380	1.994	1.300	.652	1.291	47.80	47.55	− .25	0.5
6381	1.973	1.286	.652	1.277	47.03	46.75	− .28	0.6
6386	2.219	1.548	.698	1.435	55.90	56.28	+ .38	0.7
6387	1.853	1.159	.626	1.202	43.00	42.35	− .65	1.5
6388	1.334	.516	.387	.850	25.66	25.22	− .44	1.7
6389	1.335	.525	.393	.845	25.44	25.25	− .19	0.7
6390	1.340	.828	.618	.848	25.57	25.39	− .18	0.7
6391	1.459	.694	.476	.935	29.56	29.04	− .52	1.8
6396	1.163	.271	.233	.730	20.45	20.30	− .15	0.7
6397	.958	−.008	....	.590	14.90	14.95	+ .05	0.3
6398	.966	.599	.620	.590	14.90	15.15	+ .25	1.7
6402	.738	−.293	....	.448	9.88	9.91	+ .03	0.3
6403	.595	−.456	....	.354	6.98	7.05	+ .07	1.0
6404	.485	−.029	....	.283	5.02	5.11	+ .09	1.8
6405	.598	.333	.557	.354	6.98	7.11	+ .13	1.9
7116	.864	−.186	....	.538	13.02	12.70	− .32	2.5
7117	1.295	.423	.326	.829	24.73	24.06	− .67	2.7
Check Tests, Bellvue Laboratory, 1926								
7456	0.729	....	....	0.340	9.85	9.72	−0.13	1.3
7461	.512	....	....	.232	5.60	5.56	− .04	0.7
7467	.264	....	....	.111	1.94	1.96	+ .02	1.0
7471	1.750	....	....	.855	39.05	38.69	− .36	0.9
7476	1.552	....	....	.760	32.75	32.01	− .74	2.3
7482	1.706	....	....	.837	37.83	37.16	− .67	1.8
7483	1.331	....	....	.642	25.47	25.13	− .34	1.3
7488	1.881	....	....	.922	43.71	43.36	− .35	0.8
7493	1.999	....	....	.981	47.95	47.73	− .22	0.5
7498	2.313	....	....	1.136	59.70	60.08	+ .38	0.6
7499	2.346	....	....	1.152	60.96	61.45	+ .49	0.8
7500	2.488	....	....	1.224	66.71	67.41	+ .70	1.0
7506	1.089	....	....	.519	18.55	18.31	− .24	1.3
7512	1.049	.675	.644	.493	17.18	17.25	+ .07	0.4
7517	1.607	1.058	.659	.779	33.99	33.82	− .17	0.5

TABLE XXVI.—ORIGINAL FREE-FLOW DISCHARGE DATA FOR 6-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio H_b/H_a	Head on Weir	Discharge		Difference	Deviation
	H_a	H_b			Obs.	Comp.		
	Feet	Feet		Feet	Sec.-Ft	Sec.-Ft	Sec.-Ft.	Per-cent
6338	1.550	0.757	0.489	1.318	49.29	48.28	−1.01	2.1
6344	1.812	1.090	.601	1.548	62.54	61.94	− .60	1.0
6345	1.458	.640	.439	1.232	44.59	43.80	− .79	1.8
6346	1.368	.518	.379	1.153	40.46	39.57	− .89	2.2
6351	1.260	.379	.301	1.053	35.33	34.70	− .63	1.8
6352	1.139	.208	.183	.947	30.14	29.54	− .60	2.0
6357	1.005	.019	.019	.828	24.68	24.19	− .49	2.0
6358	.892	−.134	....	.725	20.24	20.00	− .24	1.2
6364	.737	−.332	....	.588	14.83	14.75	− .08	0.5
6365	.570	−.501	....	.445	9.79	9.79	.00	0.0
6369	.465	−.013	....	.356	7.03	7.08	+ .05	0.7
6370	.382	−.035	....	.287	5.12	5.17	+ .05	1.0
7070	2.158	1.476	.684	1.839	80.81	81.85	+1.04	1.3
7071	2.017	1.321	.655	1.722	73.31	73.49	+ .18	0.2
7072	1.844	1.105	.599	1.567	63.70	63.68	− .02	0.3
7073	1.660	.858	.517	1.415	54.76	53.86	− .90	1.6
7074	1.498	.685	.457	1.270	46.64	45.72	− .92	2.0
7075	1.090	.121	.111	.904	28.10	27.53	− .57	2.0
7083	1.678	.870	.518	1.422	55.15	54.80	− .35	0.6
7084	1.511	.663	.438	1.250	45.55	46.36	+ .81	1.8
Check Tests, Bellvue Laboratory, 1926								
7389	0.326	....	....	0.186	4.04	4.02	−0.02	0.5
7394	.628	....	....	.376	11.45	11.43	− .02	0.2
7399	.742	....	....	.448	14.88	14.91	+ .03	0.2
7400	.755	0.524	0.694	.447	14.83	15.33	+ .50	3.4
7403	.756	....	....	.460	15.48	15.36	− .12	0.8
7408	.899	....	....	.552	20.33	20.25	− .08	0.4
7417	1.023	....	....	.636	25.11	24.89	− .22	0.9
7418	1.151	....	....	.722	30.34	30.04	− .30	1.0
7428	2.239	1.556	.695	1.444	85.29	86.81	+1.52	1.8
7433	2.142	1.445	.675	1.382	79.92	80.87	+ .95	1.2
7434	2.114	1.475	.698	1.352	77.36	79.21	+1.85	2.4
7438	1.975	1.262	.639	1.272	70.66	71.07	+ .41	0.6
7443	1.792	1.041	.581	1.149	60.72	60.85	+ .13	0.2
7446	1.570	....	....	1.014	50.39	49.28	−1.11	2.2
7451	1.375	....	....	.878	40.63	39.89	− .74	1.8

TABLE XXVII.—ORIGINAL FREE-FLOW DISCHARGE DATA FOR 8-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio H_b/H_a	Head on Weir	Discharge		Difference	Deviation
	H_a	H_b			Obs.	Comp.		
	Feet	Feet		Feet	Sec.-Ft	Sec.-Ft	Sec.-Ft.	Per-cent
6295	1.400	0.905	0.646	1.400	53.90	54.95	+1.05	2.0
6300	1.318	.436	.331	1.323	49.57	49.87	+ .30	0.6
6301	1.239	.315	.254	1.240	45.01	45.16	+ .15	0.3
6302	1.235	.540	.437	1.237	44.85	44.93	+ .08	0.2
6303	1.244	.728	.585	1.244	45.23	45.45	+ .22	0.5
6304	1.246	.871	.689	1.242	45.12	45.57	+ .45	1.0
6309	1.101	.109	.099	1.097	37.58	37.35	− .23	0.6
6310	1.049	.047	.045	1.044	34.88	34.56	− .32	0.9
6311	1.052	.533	.507	1.046	34.98	34.72	− .26	0.7
6312	1.056	.624	.591	1.048	35.08	34.93	− .15	0.4
6317	.975	−.060	....	.961	30.81	30.73	− .08	0.3
6318	.858	−.218	....	.838	25.12	25.02	− .10	0.4
6319	.859	.220	.256	.841	25.26	25.06	− .20	0.8
6320	.860	.448	.522	.840	25.21	25.11	− .10	0.4
6321	.863	.526	.651	.837	25.08	25.25	+ .17	0.7

TABLE XXVII.—ORIGINAL FREE-FLOW DISCHARGE DATA FOR 8-FOOT IMPROVED VENTURI FLUME, 1923—Concluded

Test	Flume Heads		Ratio H_b/H_a	Head on Weir	Discharge		Difference	Deviation
	H_a	H_b			Obs.	Comp.		
6324	.748	.096	.128	.726	20.28	20.05	− .23	1.1
6325	.625	.049	.078	.596	15.12	15.03	− .09	0.6
6326	.625	.235	.376	.596	15.12	15.03	− .09	0.6
6330	.479	.010	.021	.449	9.92	9.81	− .11	1.1
6332	.314	−.044	....	.282	4.99	4.98	− .01	0.2
6333	.369	−.102	....	.340	6.57	6.45	− .12	1.8
6336	1.443	.925	.641	1.470	57.92	57.69	− .23	0.4
6337	1.313	.397	.302	1.326	49.74	49.56	− .18	0.4
7044	.452	.131	.290	.422	9.04	8.93	− .11	1.2
7045	.611	.317	.519	.586	14.75	14.50	− .25	1.7
7060	1.660	1.124	.677	1.689	71.23	72.26	+1.03	1.4
7064	1.567	1.082	.690	1.598	65.59	65.86	+ .27	0.4
7066	1.296	.380	.293	1.295	48.02	48.54	+ .52	1.1
7067	1.513	.944	.624	1.519	60.80	62.26	+1.46	2.4
Check Tests, Bellvue Laboratory, 1926								
Mean Width of Throat 7.98 Feet								
7285	1.517	....	....	1.204	65.10	62.36	−2.74	4.2
7286	1.489	....	....	1.180	63.18	60.52	−2.66	4.2
7290	1.084	....	....	.840	38.03	36.34	−1.69	4.4
7291	1.066	....	....	.824	36.96	35.37	−1.59	4.3
7292	1.063	....	....	.824	36.96	35.21	−1.75	4.7
7293	.822	....	....	.635	25.06	23.29	−1.77	7.1
7294	.828	....	....	.631	24.82	23.54	−1.28	5.2
7295	1.425	....	....	1.124	58.76	56.40	−2.36	4.0
7300	.446	....	....	.324	9.17	8.72	− .45	4.9
7301	.448	.064	.143	.324	9.17	8.79	− .38	4.1
7302	.449	.192	.428	.326	9.25	8.82	− .43	4.7
7303	.452	.315	.697	.326	9.25	8.93	− .32	3.5
7306	.746	....	....	.560	20.77	19.91	− .86	4.2
7307	.755	.523	.693	.555	20.50	20.31	− .19	0.9
7310	.443	....	....	.313	8.71	8.63	− .08	0.9
7311	.762	....	....	.564	20.99	20.61	− .38	1.8
7312	.986	....	....	.744	31.73	31.21	− .52	1.6
7317	1.153	....	....	.883	40.98	40.13	− .85	2.1
7322	1.410	....	....	1.099	56.82	55.44	−1.38	2.4
7327	1.508	.814	.540	1.176	62.86	61.78	−1.08	1.7
7328	1.515	1.001	.661	1.176	62.86	62.23	− .63	1.0
7338	1.570	.975	.621	1.220	66.39	65.90	− .49	0.7
7346	.343	−.079	....	.240	5.89	5.73	− .16	2.7
7347	.344	.221	.642	.240	5.89	5.76	− .13	2.2
7350	.628	.167	.266	.458	15.38	15.11	− .27	1.8
7351	.629	.364	.579	.458	15.38	15.15	− .23	1.5
7353	.634	.429	.677	.459	15.43	15.35	− .08	0.5
7355	1.404	.800	.570	1.090	56.13	55.06	−1.07	1.9
7358	1.402	.832	.594	1.078	55.21	54.94	− .27	0.5
7359	1.806	.976	.540	1.416	82.85	82.52	− .33	0.4
7364	1.696	.849	.500	1.332	75.67	74.61	−1.06	1.4
7369	.730	....	....	.539	19.63	19.24	− .39	2.0
7378	.788	....	....	.581	21.94	21.77	− .17	0.8
Mean Width of Throat 8.00 Feet								
7518	1.289	....	....	0.992	48.76	48.11	−0.65	1.3
7519	1.500	....	....	1.152	60.96	61.40	+ .44	0.7
7523	1.345	....	....	1.031	51.66	51.53	− .13	0.3
7524	1.351	0.818	0.605	1.027	51.36	51.90	+ .54	1.1
7528	1.116	....	....	.842	38.17	38.17	.00	0.0
7529	1.119	.608	.544	.845	38.37	38.33	− .04	0.1
7534	.978	....	....	.730	30.84	30.88	+ .04	0.1
7535	.980	.629	.642	.730	30.84	30.98	+ .14	0.5
7540	.861	....	....	.638	25.23	25.16	− .07	0.3
7541	.858	.570	.664	.633	24.94	25.02	+ .08	0.3
7545	.609	....	....	.438	14.39	14.42	+ .03	0.2
7550	.389	....	....	.273	7.12	7.02	− .10	1.4
7553	.262	....	....	.178	3.79	3.72	− .07	1.8
7554	.306	....	....	.212	4.91	4.78	− .13	2.6

TABLE XXVIII.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 6-INCH IMPROVED VENTURI FLUME, 1926

Test	Flume Heads		Ratio H_b/H_a	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b		Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
7234	0.515	0.263	0.511	0.22	0.23	0.611	0.72	0.72	0.00	0.0
7235	.508	.344	.678	.15	.15	.598	.68	.68	.00	0.0
7236	.533	.411	.771	.10	.10	.603	.69	.69	.00	0.0
7237	.558	.449	.805	.05	.09	.583	.64	.73	+ .09	14.1
7238	.566	.510	.901	.02	.02	.534	.52	.58	+ .06	11.5
7239	.588	.556	.946	.01	...	.503	.44	.42	− .02	4.6
7240	.561	.510	.909	.02	.02	.515	.50	.55	+ .05	10.0
7241	.850	.509	.599	.33	.34	.829	1.52	1.53	+ .01	0.7
7242	.834	.575	.690	.25	.25	.810	1.44	1.44	.00	0.0
7243	.869	.651	.750	.20	.21	.819	1.48	1.48	.00	0.0
7244	.862	.698	.810	.15	.16	.795	1.38	1.38	.00	0.0
7245	891	.766	.860	.10	.12	.788	1.35	1.33	− .02	1.5
7246	.895	.815	.911	.07	.06	.743	1.17	1.14	− .03	2.6
7247	.945	.879	.930	.05	.05	.738	1.15	1.13	− .02	1.7
7248	.926	.871	.940	.04	.03	.712	1.05	1.00	− .05	4.8
7249	.940	.878	.933	.05	.05	.731	1.12	1.08	− .04	3.6
7250	.320	.146	.457	.13	.15	.453	.34	.34	.00	0.0
7251	.322	.217	.674	.06	.09	.447	.33	.33	.00	0.0
7252	.336	.281	.836	.03	.02	.426	.29	.32	+ .03	10.3
7253	.351	.328	.934	...	...	.385	.23	.22	− .01	4.4
7254	.217	.173	.798	.01	.02	.331	.16	.16	.00	0.0
7255	.219	.163	.745	...	...	.339	.17	.18	+ .01	5.9
7256	.219	.151	.690	.03	.04	.344	.17	.18	+ .01	5.9
7257	.217	.146	.673	.05	.05	.350	.18	.18	.00	0.0
7258	.218	.135	.618	.06	.06	.350	.18	.19	+ .01	5.6
7259	.217	.103	.475	.08	.09	.352	.18	.19	+ .01	5.6
7260	.219	.207	.945	.01	...	.264	.09	.10	+ .01	11.1
7261	.216	.184	.852	.01	.01	.313	.14	.16	+ .02	14.3
7262	.216	.195	.902	.00	...	.293	.12	.14	+ .02	16.7
7263	.461	.275	.597	.17	.16	.569	.60	.60	.00	0.0
7264	.458	.246	.537	.19	.20	.569	.60	.60	.00	0.0
7265	.460	.343	.745	.10	.10	.556	.56	.57	+ .01	1.8
7266	.459	.385	.839	.07	.05	.541	.52	.52	.00	0.0
7267	.462	.429	.928	.01	...	.457	.34	.35	+ .01	2.9
7268	.456	.437	.958	.01	...	.401	.25	.22	− .03	12.0
7269	.721	.550	.762	.17	.16	.730	1.11	1.10	− .01	0.9
7270	.724	.488	.674	.21	.22	.745	1.17	1.17	.00	0.0
7271	.721	.414	.574	.30	.29	.753	1.20	1.20	.00	0.0
7272	.720	.614	.853	.10	.10	.703	1.02	.99	− .03	2.9
7273	.720	.588	.817	.13	.12	.714	1.05	1.04	− .01	1.0
7274	.715	.643	.899	...	.05	.654	.84	.84	.00	0.0
7275	.718	.664	.924	.02	.03	.609	.71	.74	+ .03	4.2
7276	.997	.493	.495	.52	.52	.925	2.01	2.00	− .01	0.5
7277	.995	.632	.635	.37	.36	.912	1.93	1.93	.00	0.0
7278	1.002	.701	.700	.30	.30	.905	1.89	1.89	.00	0.0
7279	1.001	.779	.779	.22	.22	.885	1.79	1.79	.00	0.0
7280	.998	.819	.820	.16	.17	.868	1.70	1.71	+ .01	0.6
7281	.999	.884	.884	.11	.11	.827	1.51	1.50	− .01	0.7
7282	.999	.915	.915	.06	.06	.779	1.31	1.33	+ .02	1.5
7283	1.005	.952	.947	.02	.02	.721	1.08	1.09	+ .01	0.9
7284	.997	.928	.928	...	.04	.745	1.17	1.23	+ .06	5.1

TABLE XXIX.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 1-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b	H_b/H_a	Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft	Sec.-Ft.	Sec.-Ft.	Per-cent
6482	2.524	1.926	0.763	0.65	0.65	0.593	15.01	15.01	0.00	0.0
6488	1.564	1.203	.770	.50	.40	.371	7.47	7.33	− .14	1.9
6489	1.779	1.522	.856	.23	.25	.375	7.59	7.88	+ .29	3.8
6490	2.130	1.966	.924	.12	.15	.371	7.47	8.10	+ .63	8.4
6492	2.012	1.637	.814	.43	.39	.449	9.92	10.15	+ .23	2.3
6493	2.196	1.916	.873	.28	.30	.451	9.98	10.27	+ .29	2.9
6667	.600	.424	.707	.17	.17	V.M.*	1.74	1.75	+ .01	0.6
6668	.598	.513	.858	.09	.09	V.M.	1.61	1.54	− .07	4.3
6669	1.800	1.262	.701	.64	.58	V.M.	9.50	9.44	− .06	0.6
6670	1.799	1.394	.775	.47	.46	V.M.	9.05	9.00	− .05	0.6
6671	1.799	1.514	.842	.32	.30	V.M.	8.48	8.24	− .24	2.8
6672	1.801	1.712	.950	.08	.09	V.M.	5.54	5.33	− .21	3.8
6674	1.604	1.126	.702	.54	.52	V.M.	7.98	7.92	− .06	0.8
6675	1.603	1.200	.749	.46	.42	V.M.	7.73	7.71	− .02	0.3
6676	1.597	1.360	.852	.28	.25	V.M.	7.02	6.78	− .24	3.4
6677	1.602	1.514	.945	.07	.08	V.M.	4.86	4.66	− .20	4.1
6679	1.405	1.096	.780	.34	.33	V.M.	6.24	6.20	− .04	0.6
6680	1.400	1.000	.714	.43	.42	V.M.	6.43	6.43	.00	0.0
6681	1.402	1.205	.860	.21	.20	V.M.	5.74	5.52	− .22	3.8
6682	1.402	1.333	.950	.06	.07	V.M.	3.79	3.66	− .13	3.4
6686	1.202	.857	.713	.37	.37	V.M.	5.10	5.09	− .01	0.2
6687	1.199	.914	.763	.31	.31	V.M.	4.98	4.94	− .04	0.8
6688	1.199	1.024	.854	.18	.18	V.M.	4.58	4.42	− .16	3.5
6689	1.001	.759	.758	.26	.25	V.M.	3.78	3.78	.00	0.0
6690	1.000	.714	.714	.30	.30	V.M.	3.83	3.85	+ .02	0.5
6691	1.000	.850	.850	.12	.15	V.M.	3.33	3.40	+ .07	2.1
6692	.998	.948	.950	.04	.06	V.M.	2.34	2.18	− .16	6.8
6694	.802	.605	.754	.21	.21	V.M.	2.69	2.70	+ .01	0.4
6695	.801	.568	.709	.24	.24	V.M.	2.72	2.75	+ .03	1.1
6696	.800	.681	.851	.10	.12	V.M.	2.32	2.43	+ .11	4.8
6699	.599	.448	.748	.15	.15	V.M.	1.71	1.73	+ .02	1.2
6702	.402	.307	.764	.09	.11	V.M.	.91	.90	.01	1.1
6704	.398	.349	.877	.05	.06	V.M.	.78	.77	− .01	1.3
6709	1.801	1.392	.772	.48	.46	V.M.	9.11	9.04	− .07	0.8
6710	1.002	.708	.706	.31	.30	V.M.	3.86	3.87	+ .01	0.3
6712	.800	.677	.846	.10	.11	V.M.	2.33	2.45	+ .12	5.1
6713	.801	.633	.790	.17	.17	V.M.	2.63	2.63	.00	0.0

* Volumetric Measurements, Hydraulic Laboratory, Fort Collins.

TABLE XXIX.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 1-FOOT IMPROVED VENTURI FLUME, 1923—Concluded

Check Tests, Bellvue Laboratory, 1926

Test	Flume Heads		Ratio H_b/H_a	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b		Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft	Sec.-Ft.	Sec.-Ft	Per cent
7663	1.447	1.349	0.932	0.11	0.10	0.487	4.41	4.39	−0.02	0.5
7664	1.381	1.250	.905	.11	.13	.497	4.54	4.70	+ .16	3.5
7665	1.276	1.081	.848	.20	.19	.521	4.87	4.91	+ .04	0.8
7666	1.233	1.000	.811	.28	.25	.530	4.99	4.93	− .06	1.2
7669	1.964	1.613	.822	.44	.38	.844	9.91	9.69	− .22	2.2
7670	1.928	1.494	.775	.57	.49	.861	10.21	9.97	− .24	2.3
7671	2.078	1.857	.894	.17	.24	.781	8.84	8.90	+ .06	0.7
7673	.641	.462	.721	.16	.17	.268	1.83	1.93	+ .10	5.5
7675	.330	.277	.840	.05	.06	.123	.59	.60	+ .01	1.7
7676	.343	.300	.875	.07	.05	.124	.60	.59	− .01	1.7
7677	.344	.302	.878	.07	.05	.124	.60	.58	− .02	3.3
7678	.353	.315	.892	.07	.05	.124	.60	.58	− .02	3.3
7681	.514	.409	.796	.13	.12	.210	1.28	1.32	+ .04	3.1
7682	.516	.420	.814	.12	.11	.210	1.28	1.30	+ .02	1.6
7683	.556	.495	.890	.05	.07	.201	1.21	1.26	+ .05	4.1
7685	.290	.245	.845	.07	.05	.107	.48	.48	.00	0.0
7686	.283	.209	.739	.08	.08	.113	.52	.52	.00	0.0
7687	.337	.312	.926	.04	.03	.103	.45	.46	+ .01	2.2
7688	.337	.310	.920	.05	.03	.109	.49	.48	− .01	2.0
7690	.622	.482	.775	.12	.14	.255	1.70	1.79	+ .09	5.3
7691	.690	.627	.909	.07	.06	.244	1.59	1.63	+ .04	2.5
7693	1.456	1.332	.915	.09	.12	.508	4.69	4.86	+ .17	3.6
7694	1.512	1.412	.934	.10	.10	.498	4.55	4.62	+ .07	1.5
7696	2.496	2.087	.836	.56	.45	1.054	13.74	13.42	− .32	2.3
7697	2.489	2.245	.902	.24	.25	.913	11.12	11.20	+ .08	0.7
7698	2.486	2.319	.933	.14	.16	.815	9.42	9.66	+ .24	2.5
7700	2.284	1.968	.862	.38	.33	.925	11.34	11.18	− .16	1.4
7701	2.393	2.182	.912	.16	.20	.844	9.91	10.18	+ .27	2.7
7702	2.235	1.826	.817	.53	.41	.955	11.89	11.79	− .10	0.8
7705	1.758	1.540	.876	.20	.23	.682	7.24	7.37	+ .13	1.8
7706	1.950	1.831	.940	.11	.11	.624	6.35	6.48	+ .13	2.0
7707	1.612	1.188	.737	.53	.46	.723	7.89	7.85	− .04	0.5
7709	1.213	1.130	.932	.07	.08	.404	3.35	3.37	+ .02	0.6
7710	1.101	.941	.855	.12	.16	.425	3.61	3.89	+ .28	7.7
7711	1.015	.825	.813	.24	.20	.432	3.70	3.67	− .03	0.8
7719	.298	.246	.826	.06	.05	.227	.53	.52	− .01	1.9
7722	.474	.406	.856	.09	.08	.364	1.06	1.07	+ .01	0.9
7723	.447	.320	.716	.14	.14	.368	1.07	1.10	+ .03	2.8
7724	.635	.531	.836	.11	.10	.498	1.67	1.74	+ .07	4.2
7726	.755	.619	.820	.16	.14	.630	2.36	2.32	− .04	1.7
7727	.869	.787	.906	.09	.08	.617	2.29	2.35	+ .06	2.6
7728	1.463	1.191	.815	.34	.28	1.243	6.37	6.33	− .04	0.6
7729	1.651	1.494	.905	.12	.15	1.177	5.89	6.10	+ .21	3.6

TABLE XXX.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 2-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio H_b/H_a	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b		Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
6434	2.516	1.791	0.712	...	...	1.007	33.03	31.97	−1.06	3.2
6436	2.495	1.956	.784	0.67	0.62	.949	30.23	30.03	− .20	0.7
6439	2.260	1.792	.793	.51	.52	.835	24.99	25.66	+ .67	2.7
6440	2.370	1.964	.829	.35	.39	.834	24.95	26.37	+1.42	5.7
6445	1.528	1.090	.714	.48	.48	.590	14.90	14.88	− .02	0.1
6446	1.738	1.442	.831	.21	.28	.592	14.97	16.51	+1.54	10.3
6447	2.168	2.042	.943	.10	13	.583	14.64	16.47	+1.83	12.5
6451	1.204	1.076	.894	.10	.14	.371	7.47	8.29	+ .82	11.0
6454	2.517	1.788	.711	...	..	1.015	33.43	32.01	−1.42	4.2
6602	1.403	1.038	.741	.41	.39	V.M.*	13.23	12.91	− .32	2.4
6603	1.397	1.187	.850	.20	.21	V.M.	11.30	11.53	+ .23	2.0
6604	1.003	.859	.856	.16	.16	V.M.	6.90	6.89	− .01	0.1
6606	1.002	.707	.706	.31	.31	V.M.	7.89	7.77	− .12	1.5
6607	1.000	.768	.768	.26	.25	V.M.	7.70	7.55	− .15	2.0
6608	.999	.860	.860	.16	.15	V.M.	6.85	6.79	− .06	0.9
6609	1.000	.948	.948	.06	.06	V.M.	5.06	4.81	− .25	5.0
6612	1.602	1.127	.704	.51	.52	V.M.	16.51	16.09	− .42	2.5
6613	1.593	1.217	.764	.42	.42	V.M.	15.89	15.48	− .41	2.6
6614	1.604	1.359	.847	.22	.24	V.M.	14.24	14.26	+ .02	0.1
6615	1.602	1.499	.936	.12	.10	V.M.	10.99	10.80	− .19	1.7
6617	1.598	1.350	.845	.24	.25	V.M.	14.35	14.23	− .12	0.8
6618	1.407	1.333	.947	.09	.08	V.M.	8.52	8.28	− .24	2.8
6620	1.200	.905	.754	.32	.33	V.M.	10.32	10.07	− .25	2.4
6621	1.402	1.000	.714	.43	.43	V.M.	13.46	13.04	− .42	3.1
6622	1.206	.875	.726	.35	.36	V.M.	10.50	10.29	− .21	2.0
6623	1.203	1.026	.853	.19	.18	V.M.	9.21	9.14	− .07	0.8
6626	.802	.584	.728	.22	.23	V.M.	5.51	5.45	− .06	1.1
6627	.802	.618	.770	.19	.20	V.M.	5.45	5.34	− .11	2.0
6628	.802	.692	.863	.10	.12	V.M.	4.60	4.83	+ .23	5.0
6629	.803	.758	.944	.05	.05	V.M.	3.50	3.51	+ .01	0.3
6631	.598	.421	.704	.16	.19	V.M.	3.49	3.46	− .03	0.9
6632	.602	.456	.757	.13	.17	V.M.	3.38	3.42	+ .04	1.2
6633	.601	.514	.855	.09	.10	V.M.	3.06	3.11	+ .05	1.6
6634	.596	.562	.943	.04	.04	V.M.	2.29	2.16	− .13	5.7
6637	.402	.281	.700	.12	.13	V.M.	1.87	1.82	− .05	2.7
6638	.402	.298	.741	.10	.11	V.M.	1.82	1.81	− .01	0.6
6639	.400	.352	.880	.06	.06	V.M.	1.60	1.53	− .07	4.4

* Volumetric Measurements, Hydraulic Laboratory, Fort Collins.

TABLE XXX.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 2-FOOT IMPROVED VENTURI FLUME, 1923—Concluded

Check Tests, Bellvue Laboratory, 1926

Test	Flume Heads		Ratio H_b/H_a	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b		Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft	Per-cent
7629	0.319	0.272	0.853	0.06	0.05	0.194	1.14	1.11	−0.03	2.6
7631	.334	.260	.779	.09	.08	.214	1.32	1.30	− .02	1.5
7632	.372	.339	.912	.04	.04	.212	1.30	1.21	− .09	6.9
7634	.515	.371	.720	.15	.16	.345	2.66	2.70	+ .04	1.5
7635	.561	.487	.868	.04	.08	.342	2.62	2.73	+ .11	4.2
7636	.627	.581	.927	.06	.05	.337	2.56	2.64	+ .08	3.1
7638	.804	.599	.745	.19	.22	.544	5.19	5.43	+ .24	4.6
7639	.847	.705	.832	.13	.14	.540	5.13	5.51	+ .38	7.4
7640	.978	.907	.928	.08	.07	.524	4.91	5.30	+ .39	7.9
7641	1.634	1.535	.940	.10	.09	.846	9.94	10.89	+ .95	9.6
7643	.653	.544	.834	.11	.12	.416	3.49	3.67	+ .18	5.2
7644	.788	.599	.760	.17	.20	.533	5.03	5.22	+ .19	3.8
7646	.822	.683	.831	.14	.14	.532	5.02	5.27	+ .25	5.0
7647	1.057	.927	.877	.12	.14	.650	6.75	7.16	+ .41	6.1
7649	1.276	.998	.782	.28	.31	.896	10.82	10.86	+ .04	0.4
7650	1.374	1.180	.859	.17	.20	.875	10.45	11.06	+ .61	5.8
7651	1.149	.938	.817	.18	.20	.758	8.46	9.01	+ .55	6.5
7652	1.112	.877	.789	.21	.25	.749	8.31	8.75	+ .44	5.3
7653	1.241	1.131	.912	.11	.11	.714	7.74	8.19	+ .45	5.8
7654	1.203	1.084	.901	.11	.13	.708	7.65	8.13	+ .48	6.3
7657	1.582	1.405	.888	.15	.18	.963	12.03	12.80	+ .77	6.4
7658	1.635	1.492	.913	.12	.14	.934	11.50	12.39	+ .89	7.7
7659	1.023	.935	.915	.10	.09	.584	5.76	6.02	+ .26	4.5
7660	.906	.692	.764	.20	.23	.610	6.14	6.49	+ .35	5.7
7742	.275	.219	.797	.09	.06	.351	1.00	.92	− .08	8.0
7743	.285	.245	.860	.06	.05	.351	1.00	.91	− .09	9.0
7744	.311	.286	.920	.03	.03	.348	.98	.86	− .12	12.2
7746	.529	.419	.792	.13	.14	.709	2.80	2.73	− .07	2.5
7747	.535	.414	.774	.13	.14	.711	2.82	2.81	− .01	0.4
7748	.548	.451	.823	.06	.11	.709	2.80	2.81	+ .01	0.4
7749	.621	.572	.921	.08	.06	.697	2.74	2.70	− .04	1.5
7751	.902	.697	.773	.20	.22	1.211	6.14	6.41	+ .27	4.4
7752	1.056	.975	.923	.10	.09	1.171	5.85	6.10	+ .25	4.3
7753	.984	.869	.884	.12	.12	1.191	5.99	6.27	+ .28	4.7
7754	.922	.750	.814	.18	.18	1.202	6.07	6.42	+ .35	5.8
7755	.880	.660	.750	.25	.24	1.213	6.15	6.24	+ .09	1.5
7756	.943	.792	.840	.15	.15	1.203	6.08	6.45	+ .37	6.1
7760	1.009	.917	.909	.10	.09	.237	5.78	6.04	+ .26	4.5
7761	1.018	.930	.914	.10	.09	.237	5.78	5.99	+ .21	3.6
7764	2.380	1.981	.833	.45	.40	.650	25.94	26.43	+ .49	1.9
7765	2.488	2.185	.879	.26	.31	.624	24.41	25.81	+1.40	5.7
7766	2.454	2.266	.924	.18	.18	.550	20.22	21.88	+1.66	8.2
7767	2.330	1.886	.810	.57	.47	.658	26.42	26.36	− .06	0.2
7769	1.603	1.305	.814	.30	.30	.440	14.49	14.94	+ .45	3.1
7770	1.704	1.518	.892	.19	.19	.417	13.37	14.15	+ .78	5.8
7771	1.770	1.636	.925	.14	.14	.400	12.56	13.28	+ .72	5.7
7772	1.379	1.050	.762	.46	.36	.400	12.56	12.40	− .16	1.3

TABLE XXXI.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 3-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio H_b/H_a	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b		Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
6408	2.358	1.697	0.720	...	...	1.252	45.66	44.13	−1.53	3.3
6411	2.039	1.509	.741	0.52	0.58	1.051	35.23	34.95	− .28	0.8
6412	2.179	1.773	.815	.40	.43	1.053	35.33	36.55	+1.22	3.5
6413	2.332	2.042	.875	.20	.30	1.042	34.78	37.10	+2.32	6.7
6417	1.653	1.227	.743	.43	.47	.838	25.12	25.24	+ .12	0.5
6418	1.750	1.413	.807	.30	.36	.841	25.26	26.35	+1.09	4.3
6419	2.080	1.913	.920	.15	.16	.847	25.53	27.72	+2.19	8.6
6424	1.266	1.006	.794	.23	.28	.595	15.09	16.19	+1.10	7.3
6425	1.623	1.536	.946	.05	.09	.597	15.16	16.84	+1.68	11.1
6429	.733	.532	.726	.20	.21	.356	7.03	7.09	+ .06	0.9
6430	.896	.836	.933	.08	.07	.353	6.95	7.10	+ .15	2.2
6498	.800	.615	.769	.20	.21	V.M.*	8.09	8.00	− .09	1.1
6499	.807	.715	.886	.13	.11	V.M.	7.07	7.07	.00	0.0
6508	.900	.708	.787	.20	.22	V.M.	9.46	9.55	+ .09	1.0
6509	1.040	.982	.945	.05	.07	V.M.	8.64	8.41	− .23	2.7
6510	.900	.674	.749	.23	.24	V.M.	9.69	9.74	+ .05	0.5
6511	.900	.795	.884	.13	.13	V.M.	8.49	8.42	− .07	0.8
6514	.699	.499	.714	.21	.22	V.M.	6.74	6.61	− .13	1.9
6515	.710	.607	.855	.12	12	V.M.	6.12	6.15	+ .03	0.5
6516	.697	.622	.892	.09	.09	V.M.	5.58	5.52	− .06	1.1
6517	.712	.676	.949	.06	.04	V.M.	4.01	4.46	+ .45	11.2
6520	.503	.379	.754	.12	.14	V.M.	3.93	3.85	− .08	2.0
6521	.500	.389	.778	.12	.13	V.M.	3.78	3.76	− .02	0.5
6522	.498	.442	.887	.07	.07	V.M.	3.43	3.25	− .18	5.2
6523	.499	.461	.924	.06	.05	V.M.	3.14	2.89	− .25	8.0
6528	.399	.297	.744	.11	.11	V.M.	2.75	2.66	− .09	3.3
6529	.399	.324	.812	.08	.08	V.M.	2.64	2.56	− .08	3.0
6530	.401	.353	.881	.06	.06	V.M.	2.43	2.34	− .09	3.7
6531	.399	.372	.932	.04	.04	V.M.	2.14	1.92	− .22	10.3
6534	.595	.446	.750	.15	.16	V.M.	5.13	5.06	− .07	1.4
6535	1.141	.914	.801	.27	.27	V.M.	13.97	13.70	− .27	1.9
6536	1.096	.957	.873	.16	.16	V.M.	11.58	11.73	+ .15	1.3
6537	1.097	1.030	.939	.10	.07	V.M.	9.56	9.44	− .12	1.3
6538	1.199	1.065	.889	.16	.15	V.M.	13.06	12.99	− .07	0.5
6543	.996	.710	.713	.34	.31	V.M.	11.84	11.57	− .27	2.3
6544	1.004	.799	.796	.28	.24	V.M.	11.79	11.26	− .53	4.5
6545	.999	.865	.864	.17	.16	V.M.	10.30	10.30	.00	0.0
6547	1.000	.942	.942	.09	.07	V.M.	8.37	8.04	− .33	3.9
6550	.801	.757	.945	.07	.05	V.M.	5.67	5.55	− .12	2.1
6553	.900	.647	.720	.30	.28	V.M.	10.09	9.84	− .25	2.5
6556	.600	.466	.776	.15	.15	V.M.	5.13	5.06	− .07	1.4
6657	.597	.508	.851	.11	.10	V.M.	4.94	4.70	− .24	4.9
6558	.599	.569	.950	.06	.04	V.M.	3.75	3.34	− .41	10.9
6560	.981	.757	.772	.29	.25	V.M.	11.34	11.05	− .29	2.6
6561	.999	.769	.770	.30	.25	V.M.	11.92	11.36	− .56	4.7
6562	1.002	.952	.950	.08	.06	V.M.	7.88	7.68	− .20	2.5
6563	1.000	.754	.754	.31	.28	V.M.	11.81	11.47	− .34	2.9
6565	1.196	1.024	.856	.19	.19	V.M.	13.66	13.82	+ .16	1.2
6566	1.387	1.304	.940	.12	.09	V.M.	13.07	13.63	+ .56	4.3
6569	1.596	1.484	.930	.15	.13	V.M.	17.73	17.73	.00	0.0
6570	1.400	1.215	.867	.21	.22	V.M.	16.93	17.27	+ .34	2.0
6571	1.418	1.322	932	.12	11	V.M.	14.42	14.63	+ .21	1.5
6575	.298	.221	.742	09	09	V.M.	1.71	1.64	− .07	4.1
6576	.299	.255	.853	06	05	V.M.	1.59	1.51	− .08	5.0
6577	.300	.281	.937	.03	.02	V.M.	1.21	1.12	− .09	7.4
7123	2.520	2.200	.873	.30	.33	1.097	37.58	41.89	+4.31	11.5
7124	2.197	1.958	.892	.18	.24	.924	29.04	32.64	+3.60	12.4
7131	1.211	1.103	.911	.12	.12	.492	11.39	12.40	+1.01	8.9
7132	1.068	.852	.798	...	...	.500	11.67	12.39	+ .72	6.2
7133	1.477	1.216	.824	.23	.27	.690	18.78	19.94	+1.16	6.2
7136	2.456	2.292	.934	.16	.15	.932	29.42	34.00	+4.58	15.6

* Volumetric Measurements, Hydraulic Laboratory, Fort Collins.

TABLE XXXII.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 4-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio H_b/H_a	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b		Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
6373	1.702	1.293	0.760	0.39	0.45	1.055	35.44	35.17	−0.27	0.8
6374	1.804	1.519	.842	.22	.30	1.050	35.18	35.79	+ .61	1.7
6375	2.088	1.955	.937	.12	.14	1.022	33.78	35.72	+1.94	5.7
6382	2.008	1.475	.735	.49	.59	1.264	46.31	46.09	− .22	0.5
6383	2.082	1.688	.810	.30	.42	1.252	45.66	46.32	+ .66	1.4
6384	2.280	2.064	.905	.16	.24	1.210	43.42	45.53	+2.11	4.9
6393	1.624	1.508	.929	.11	.13	.822	24.42	24.91	+ .49	2.0
6394	1.421	1.177	.828	.26	.25	.825	24.55	25.15	+ .60	2.4
6395	1.339	.977	.730	.33	.38	.825	24.55	24.49	− .06	0.2
6399	1.014	.791	.780	.19	.24	.595	15.09	15.42	+ .33	2.2
6400	1.248	1.180	.946	.09	.08	.603	15.38	15.13	− .25	1.6
7096	2.372	1.687	.711	...	...	1.522	60.98	60.32	− .66	1.1
7100	1.998	1.614	.808	.45	.43	1.227	44.32	43.55	− .77	1.7
7101	2.303	2.096	.910	.25	.24	1.221	44.00	45.64	+1.64	3.7
7102	2.059	1.931	.938	.20	.14	1.025	33.93	34.79	+ .86	2.5
7109	1.807	1.683	.931	.16	.13	.888	27.37	29.20	+1.83	6.7
7110	1.429	1.099	.769	.39	.38	.881	27.06	26.64	− .42	1.6
7111	1.783	1.517	.851	.29	.27	1.025	33.93	34.73	+ .80	2.4
7112	1.174	1.097	.934	.10	.08	.573	14.28	14.61	+ .33	2.3
7115	1.064	.943	.886	.13	.13	.577	14.42	14.63	+ .21	1.5
Check Tests, Bellvue Laboratory, 1926										
7457	0.734	0.536	0.730	0.21	0.21	0.336	9.68	9.45	−0.23	2.4
7458	.753	.604	.802	.17	.17	.332	9.51	9.52	+ .01	0.1
7459	.811	.728	.898	.10	.09	.335	9.64	9.26	− .38	3.9
7460	.870	.811	.932	.08	.07	.334	9.59	9.15	− .44	4.6
7462	.545	.390	.715	.16	.14	.242	5.96	5.89	− .07	1.2
7463	.587	.428	.729	.17	.16	.261	6.66	6.59	− .07	1.0
7464	.600	.486	.810	.14	.12	.260	6.62	6.56	− .06	0.9
7465	.626	.558	.891	.09	.08	.256	6.47	6.24	− .23	3.6
7466	.644	.590	.916	.09	.06	.254	6.40	6.07	− .33	5.2
7468	.270	.214	.792	.07	...	.111	1.94	1.75	− .19	9.8
7469	.312	.292	.936	.02	...	.110	1.92	1.62	− .30	15.6
7470	.272	.224	.824	.06	...	.111	1.94	1.74	− .20	10.3
7472	1.779	1.276	.717	.60	.58	.854	38.98	38.40	− .58	1.5
7473	1.794	1.487	.829	.37	.34	.821	36.76	36.06	− .70	1.9
7474	1.856	1.655	.892	.25	.28	.784	34.31	34.24	− .07	0.2
7475	1.928	1.782	.924	.20	.16	.756	32.11	33.15	+1.04	3.2
7477	1.582	1.175	.743	.47	.46	.747	31.92	31.65	− .27	0.8
7478	1.675	1.440	.860	.28	.27	.736	31.22	31.09	− .13	0.4
7479	1.750	1.578	.902	.22	.20	.722	30.34	30.48	+ .14	0.5
7480	1.859	1.748	.941	.16	.13	.696	28.73	29.26	+ .53	1.8
7481	1.861	1.751	.942	.17	.13	.696	28.73	29.22	+ .49	1.7
7484	1.352	.984	.728	.42	.40	.639	25.29	24.91	− .38	1.5
7485	1.414	1.153	.816	.28	.26	.627	24.59	25.25	+ .66	2.7
7486	1.526	1.376	.902	.18	.18	.629	24.70	24.66	− .04	0.2
7489	1.875	1.393	.744	.57	.58	.902	42.30	41.22	−1.08	2.6
7490	1.920	1.597	.832	.43	.37	.884	41.05	39.92	−1.13	2.8
7491	2.013	1.801	.895	.30	.23	.843	38.23	38.55	+ .32	0.8
7492	2.114	1.984	.938	.17	.15	.805	35.69	36.30	+ .61	1.7
7494	1.981	1.429	.721	.68	.63	.962	46.57	45.39	−1.18	2.5
7495	2.031	1.629	.802	.51	.46	.957	46.21	44.91	−1.30	2.8
7496	2.142	1.889	.882	.36	.29	.926	44.00	43.65	− .35	0.8
7497	2.243	2.070	.922	.23	.19	.893	41.67	42.24	+ .57	1.4
7501	2.517	1.857	.738	...	...	1.239	67.94	65.37	−2.57	3.8
7502	2.305	1.803	.782	.64	.59	1.097	56.67	55.51	−1.16	2.0
7503	2.546	2.318	.911	.32	.25	1.056	53.54	53.20	− .34	0.6
7507	1.127	.865	.767	.27	.29	.516	18.39	18.38	− .01	0.1
7508	1.143	.922	.806	.27	.25	.515	18.34	18.29	− .05	0.3
7509	1.194	1.045	.875	.20	.17	.508	17.96	17.91	− .05	0.3
7510	1.286	1.213	.943	.11	.09	.474	16.19	16.20	+ .01	0.1
7511	1.051	.743	.707	.37	.34	.492	17.12	16.85	− .27	1.6
7513	1.081	.830	.767	.25	.26	.490	17.02	17.23	+ .21	1.2
7514	1.604	1.164	.726	.51	.48	.764	33.01	32.57	− .44	1.3
7515	1.613	1.185	.735	.53	.48	.771	33.47	32.75	− .72	2.1
7516	1.635	1.245	.761	.38	.44	.773	33.60	33.02	− .58	1.7

TABLE XXXIII.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 6-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio H_b/H_a	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b		Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft	Sec.-Ft.	Sec.-Ft.	Per-cent
6339	1.562	1.120	0.717	0.49	0.50	1.322	49.51	47.50	–2.01	4.1
6340	1.617	1.273	.787	.31	.40	1.332	50.07	48.56	–1.51	3.0
6341	1.774	1.564	.882	.16	.24	1.348	50.97	50.29	– .68	1.3
6347	1.396	1.065	.763	.34	.39	1.148	40.20	39.01	–1.19	3.0
6348	1.492	1.303	.873	.19	.22	1.146	40.09	38.95	–1.14	2.8
6353	1.143	.803	.702	.39	.48	.945	30.04	29.02	–1.02	3.4
6354	1.171	.905	.773	.20	.31	.943	29.94	29.36	– .58	1.9
6355	1.357	1.270	.936	.10	.10	.945	30.04	28.40	–1.64	5.5
6359	.900	.678	.753	.24	.25	.722	20.11	19.52	– .59	2.9
6360	.941	.784	.833	.16	.17	.723	20.16	19.85	– .31	1.5
6361	1.037	.961	.927	.08	.08	.726	20.28	19.11	–1.17	5.8
6366	.590	.487	.825	.11	.11	.445	9.79	9.47	– .32	3.3
7080	2.111	1.936	.917	.25	.18	1.499	59.61	61.06	+1.45	2.4
7085	1.669	1.457	.873	.27	.24	1.248	45.44	46.46	+1.02	2.2
7089	1.227	1.092	.890	.19	.15	.906	28.20	27.71	– .49	1.7
7093	1.384	1.316	.950	.13	.08	.897	27.78	27.53	– .25	0.9
Check Tests, Bellvue Laboratory, 1926										
7390	0.330	0.232	0.703	0.13	0.13	0.186	4.04	3.80	–0.24	5.9
7391	.378	.357	.944	.03	.03	.178	3.79	3.28	– .51	13.4
7392	.342	.292	.854	.08	.07	.186	4.04	3.74	– .30	7.4
7395	.646	.498	.771	.20	.17	.376	11.45	11.36	– .09	0.8
7396	.666	.560	.841	.15	.12	.374	11.36	11.36	.00	0.0
7397	.690	.611	.886	.16	.10	.372	11.27	11.17	– .10	0.9
7398	.704	.636	.903	.13	.08	.371	11.23	11.09	– .14	1.2
7401	.784	.655	.836	.18	.14	.447	14.83	14.77	– .06	0.4
7402	.862	.794	.921	.11	.08	.442	14.59	14.55	– .04	0.3
7404	.772	.550	.713	.26	.24	.458	15.38	15.46	+ .08	0.5
7405	.788	.642	.815	.21	.17	.456	15.28	15.21	– .07	0.5
7406	.830	.737	.888	.15	.11	.454	15.18	14.95	– .23	1.5
7407	.893	.834	.934	.12	.07	.451	15.03	14.62	– .41	2.7
7409	.921	.666	.723	.26	.28	.550	20.22	20.45	+ .23	1.1
7410	.940	.755	.804	.26	.20	.552	20.33	20.33	.00	0.0
7411	1.004	.900	.896	.15	.13	.545	19.95	19.89	– .06	0.3
7412	1.083	1.017	.939	.14	.07	.538	19.57	19.56	– .01	0.1
7413	1.216	1.134	.932	.15	.08	.614	23.83	24.18	+ .35	1.5
7414	1.151	1.036	.900	.18	.13	.622	24.30	24.49	+ .19	0.8
7415	1.078	.890	.825	.23	.20	.630	24.76	24.81	+ .05	0.2
7416	1.046	.762	.728	.29	.31	.634	25.00	24.97	– .03	0.1
7419	1.166	.832	.713	.39	.37	.719	30.15	29.89	– .26	0.9
7420	1.194	.939	.786	.29	.29	.717	30.02	30.09	+ .07	0.2
7421	1.302	1.184	.910	.20	.14	.706	29.34	29.04	– .30	1.0
7422	1.390	1.308	.941	.15	.09	.689	28.30	28.90	+ .60	2.1
7423	2.296	1.612	.702	. . .	. . .	1.480	88.46	87.82	– .64	0.7
7424	2.315	1.709	.738	.84	.70	1.468	87.40	87.72	+ .32	0.4
7425	2.464	2.196	.887	.45	.42	1.439	84.85	83.36	–1.49	1.8
7427	2.348	1.878	.800	.68	.55	1.463	86.96	86.34	– .62	0.7
7429	2.245	1.574	.701	. . .	. . .	1.443	85.20	84.82	– .38	0.4
7430	2.304	1.867	.810	.59	.52	1.429	83.98	83.16	– .82	1.0
7432	2.483	2.258	.908	.37	.29	1.387	80.35	80.70	+ .35	0.4
7435	2.141	1.705	.796	.57	.50	1.328	75.33	74.96	– .37	0.5
7436	2.280	2.049	.898	.35	.28	1.302	73.15	72.15	–1.00	1.4
7437	2.446	2.315	.946	.24	.15	1.222	66.55	70.00	+3.45	5.2
7439	1.972	1.379	.700	.77	.66	1.254	69.17	69.04	– .13	0.2
7440	2.004	1.600	.798	.58	.47	1.254	69.17	67.53	–1.64	2.4
7441	2.146	1.941	.905	.36	.23	1.206	65.26	64.58	– .68	1.0
7442	2.304	2.171	.942	.22	.15	1.168	62.22	64.63	+2.41	3.9
7444	1.827	1.285	.703	.70	.62	1.166	62.06	61.17	– .89	1.4
7445	1.866	1.496	.801	.49	.42	1.150	60.80	60.22	– .58	1.0
7447	1.590	1.132	.712	.56	.52	1.006	49.79	48.95	– .84	1.7
7448	1.615	1.285	.796	. . .	. . .	1.004	49.65	48.11	–1.54	3.1
7449	1.718	1.528	.889	.29	.22	.981	47.95	47.22	– .73	1.5
7450	1.850	1.737	.940	.20	.13	.942	45.13	45.91	+ .78	1.7
7452	1.391	.995	.715	.49	.43	.870	40.08	39.51	– .57	1.4
7453	1.441	1.179	.818	.34	.28	.868	39.94	39.55	– .39	1.0
7454	1.527	1.365	.894	.25	.18	.857	39.19	38.81	– .38	1.0
7455	1.598	1.483	.928	.20	.12	.847	38.51	38.01	– .50	1.3

TABLE XXXIV.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 8-FOOT IMPROVED VENTURI FLUME, 1923

Test	Flume Heads		Ratio	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b	H_b/H_a	Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft	Per-cent
6296	1.522	1.305	0.857	0.20	0.23	1.421	55.10	55.73	+0.63	1.1
6297	1.554	1.351	.870	.15	.21	1.432	55.72	56.51	+ .79	1.4
6298	1.608	1.464	.910	.12	.15	1.429	55.55	55.25	− .30	0.5
6299	1.686	1.576	.935	.08	.12	1.423	55.12	55.45	+ .33	0.6
6305	1.270	.937	.738	.25	.34	1.244	45.23	45.46	+ .23	0.5
6306	1.320	1.125	.852	.14	.20	1.244	45.23	44.70	− .53	1.2
6307	1.480	1.383	.935	.08	.10	1.265	46.37	44.91	−1.46	3.2
6313	1.064	.774	.727	.25	.30	1.048	35.08	34.39	− .69	2.0
6314	1.124	.954	.849	.17	.17	1.055	35.44	34.78	− .66	1.9
6315	1.225	1.142	.932	.08	.09	1.050	35.18	33.44	−1.74	4.9
6322	.939	.839	.894	.10	.12	.840	25.21	24.22	− .99	3.9
6327	.690	.630	.913	.07	.07	.592	14.97	14.06	− .91	6.1
6334	.403	.291	.722	...	...	.349	6.83	7.00	+ .17	2.5
7015	2.100	1.952	.930	.13	.15	1.765	76.04	80.16	+4.12	5.4
7016	2.099	1.948	.929	.14	.15	1.763	75.91	80.29	+4.38	5.8
7017	2.415	2.276	.942	.12	.15	1.987	90.64	96.47	+5.83	6.4
7018	2.427	2.294	.945	.13	.15	2.000	91.52	96.26	+4.74	5.2
7019	2.199	2.076	.945	...	...	1.829	80.16	82.04	+1.88	2.3
7021	1.903	1.773	.932	.13	.14	1.620	66.93	68.01	+1.08	1.6
7022	2.006	1.868	.931	.14	.14	1.692	71.42	74.24	+2.82	4.0
7023	1.755	1.629	.928	.13	.14	1.516	60.62	60.50	− .12	0.2
7024	1.441	1.312	.910	.13	.14	1.284	47.41	46.38	−1.03	2.2
7025	1.365	1.237	.906	.15	.14	1.225	44.22	42.94	−1.28	2.9
7026	1.693	1.566	.925	.15	.15	1.473	58.09	57.57	− .52	0.9
7034	1.576	1.436	.911	.14	.15	1.390	53.33	53.35	+ .02	0.0
7035	2.026	1.878	.927	.14	.15	1.702	72.05	76.30	+4.25	5.9
7039	1.127	.992	880	.14	.15	1.039	34.63	33.38	−1.25	3.6
7046	1.097	.883	805	.18	.23	1.046	34.98	34.82	− .16	0.5
7054	.883	.737	.835	.14	.16	.829	24.73	23.99	− .74	3.(
7057	1.958	1.497	.765	.44	.49	1.972	89.62	89.73	+ .11	0.1
7058	1.903	1.430	.751	.45	.50	1.924	86.39	86.32	− .07	0.1
7059	1.766	1.249	.707	.50	.53	1.792	77.77	77.81	+ .04	0.1
7062	1.941	1.540	.793	.36	.42	1.940	87.46	87.01	− .45	0.5
7063	1.753	1.302	.743	.44	.48	1.775	76.68	75.96	− .72	0.9
7065	1.873	1.454	.776	.39	.49	1.877	83.28	83.14	− .14	0.2

TABLE XXXIV.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 8-FOOT IMPROVED VENTURI FLUME, 1923—Continued

Check Tests, Bellvue Laboratory, 1926

Mean Width of Throat 7.98 Feet, Tests 7285 to 7388, inclusive

Test	Flume Heads		Ratio H_b/H_a	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b		Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
7287	1.538	1.236	0.804	0.38	0.33	1.185	63.58	59.70	−3.88	6.1
7288	1.544	1.255	.813	.37	.32	1.185	63.58	59.61	−3.97	6.2
7289	1.664	1.531	.920	.22	.16	1.135	59.62	56.83	−2.79	4.7
7296	1.493	1.235	.827	.31	.28	1.114	57.98	55.85	−2.13	3.7
7299	1.444	1.047	.726	.52	.44	1.109	57.59	56.09	−1.50	2.6
7304	.458	.353	.771	.12	.11	.324	9.17	8.54	− .63	6.9
7305	.544	.515	.946	.06	.03	.320	9.00	8.20	− .80	8.9
7308	.772	.623	.807	.30	.17	.556	20.55	19.75	− .80	3.9
7309	.841	.774	.920	.11	.08	.557	20.61	18.94	−1.67	8.1
7313	1.000	.707	.707	.38	.32	.751	32.17	31.16	−1.01	3.1
7314	1.029	.833	.810	.28	.22	.744	31.73	31.22	− .51	1.6
7315	1.088	.965	.886	.19	.14	.744	31.73	31.12	− .61	1.9
7316	1.212	1.145	.945	.13	.08	.729	30.78	31.09	+ .31	1.0
7318	1.166	.900	.772	.34	.29	.863	39.60	39.02	− .58	1.5
7319	1.198	.992	.827	.25	.22	.862	39.53	39.22	− .31	0.8
7320	1.269	1.138	.897	.11	.14	.862	39.53	38.87	− .66	1.7
7321	1.387	1.306	.942	.14	.09	.852	38.85	39.30	+ .45	1.2
7323	1.425	1.016	.713	.50	.44	1.093	56.36	55.00	−1.36	2.4
7324	1.471	1.199	.815	.34	.29	1.083	55.59	54.98	− .61	1.1
7325	1.580	1.430	.905	24	.17	1.073	54.83	54.24	− .59	1.1
7326	1.726	1.640	.949	.16	.10	1.047	52.86	54.38	+1.52	2.9
7329	1.522	1.080	.710	.56	.49	1.179	63.10	61.13	−1.97	3.1
7330	1.529	1.120	.733	.50	.45	1.174	62.70	61.22	−1.48	2.4
7331	1.548	1.192	.770	.44	.40	1.175	62.78	61.41	−1.37	2.2
7332	1.565	1.255	.802	.42	.34	1.171	62.46	61.30	−1.16	1.9
7333	1.669	1.502	.900	.25	.18	1.148	60.64	59.83	− .81	1.3
7334	1.726	1.595	.924	.23	.15	1.134	59.54	59.29	− .25	0.4
7335	1.554	1.329	.855	.30	.24	1.130	59.23	57.55	−1.68	2.8
7336	1.553	1.323	.852	.29	.24	1.131	59.31	57.70	−1.61	2.7
7337	1.482	1.055	.712	.53	.47	1.142	60.17	58.61	−1.56	2.6
7339	1.624	1.356	.835	.34	.28	1.210	65.58	63.17	−2.41	3.7
7341	1.640	1.384	.844	.34	.27	1.211	65.66	63.46	−2.20	3.3
7342	1.783	1.664	.934	.19	.14	1.184	63.50	60.70	−2.80	4.4
7343	1.734	1.573	.908	.24	.18	1.180	63.18	62.45	− .73	1.2
7344	1.670	1.445	.866	.26	.25	1.217	66.15	63.57	−2.58	3.9
7345	1.634	1.336	.818	.37	.32	1.219	66.31	64.84	−1.47	2.2
7348	.359	.310	.864	.07	.05	.239	5.85	5.24	− .61	10.4
7349	.390	.361	.926	.04	.02	.236	5.75	5.14	− .61	10.6
7352	.653	.544	.833	.15	.11	.459	15.43	14.74	− .69	4.5
7354	.728	.680	.934	.09	.05	.453	15.13	14.15	− .98	6.5
7356	1.501	1.306	.870	.25	.22	1.074	54.90	53.40	−1.50	2.7
7357	1.427	1.075	.754	.41	.38	1.080	55.36	54.37	− .99	1.8
7360	1.829	1.294	.708	.64	.58	1.434	84.42	82.13	−2.29	2.7
7361	1.874	1.510	.806	...	...	1.419	83.11	81.34	−1.77	2.1
7362	2.038	1.830	.898	.25	.22	1.379	79.66	82.45	+2.79	3.5
7363	2.130	1.974	.927	.22	.15	1.362	78.21	82.50	+4.29	5.5
7365	1.700	1.215	.715	.57	.51	1.313	74.07	72.90	−1.17	1.6
7366	1.754	1.422	.811	...	...	1.296	72.65	72.99	+ .34	0.5
7367	1.886	1.686	.894	.19	.22	1.295	72.57	73.51	+ .94	1.3
7368	2.089	1.972	.944	.17	.13	1.281	71.40	75.62	+4.22	5.9
7370	.745	.549	.737	...	...	.537	19.52	19.18	− .34	1.7
7371	.760	.630	.829	.15	.14	.536	19.46	18.85	− .61	3.1
7372	.844	.786	.931	.10	.07	.530	19.14	18.26	− .88	4.6
7373	.864	.813	.941	.06	.06	.526	18.92	18.18	− .74	3.9
7374	.916	.856	.934	.11	.06	.569	21.27	20.67	− .60	2.8

TABLE XXXIV.—ORIGINAL SUBMERGED-FLOW DISCHARGE DATA FOR THE 8-FOOT IMPROVED VENTURI FLUME, 1923—Concluded

Check Tests, Bellvue Laboratory, 1926

Mean Width of Throat 7.98 Feet. Tests 7285 to 7388, inclusive

Test	Flume Heads		Ratio H_b/H_a	Loss of Head		Head on Weir	Discharge		Difference	Deviation
	H_a	H_b		Obs.	Comp.		Obs.	Comp.		
	Feet	Feet		Feet	Feet	Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
7375	.880	.795	.903	.11	.09	.574	21.54	21.31	− .23	1.1
7376	.803	.616	.767	.21	.20	.580	21.88	21.48	− .40	1.8
7377	.796	.559	.702	.27	.26	.581	21.94	21.54	− .40	1.8
7520	1.510	1.112	.736	.47	.43	1.145	60.41	60.06	− .35	0.6
Mean Width of Throat 8.00 Feet, Tests 7518 to 7554, inclusive										
7521	1.664	1.502	0.903	0.21	0.18	1.133	59.46	59.31	−0.15	0.3
7522	1.712	1.588	.927	.18	.13	1.105	57.29	58.27	+ .98	1.7
7525	1.370	1.021	.746	.43	.38	1.028	51.43	51.19	− .24	0.5
7526	1.453	1.263	.869	.26	.20	1.022	50.98	50.88	− .10	0.2
7527	1.557	1.441	.925	.18	.12	1.010	50.09	50.33	+ .24	0.5
7530	1.155	.914	.791	.29	.26	.843	38.23	38.13	− .10	0.3
7531	1.188	1.013	.853	21	.18	.841	38.10	37.73	− .37	1.0
7532	1.267	1.162	.917	.17	.11	.829	37.29	37.02	− .27	0.7
7533	1.324	1.245	.940	.12	.09	.821	36.76	36.78	+ .02	0.1
7536	.998	.758	.760	.31	.25	.728	30.71	30.66	− .05	0.2
7537	1.019	.837	.822	.24	.19	.726	30.59	30.51	− .08	0.3
7538	1.086	.985	.907	.16	.11	.718	30.09	29.68	− .41	1.4
7539	1.136	1.061	.934	.11	.08	.712	29.71	29.40	− .31	1.1
7542	.965	.893	.925	.13	.08	.617	24.01	23.25	− .76	3.2
7543	.916	.828	.904	.13	.10	.602	23.14	22.77	− .37	1.6
7544	.859	.706	.822	.22	.16	.605	23.31	23.17	− .14	0.6
7546	.620	.445	.718	.21	.18	.442	14.59	14.30	− .29	2.0
7547	.628	.504	.803	.17	.13	.439	14.44	14.18	− .26	1.8
7548	.687	.628	.914	.09	.06	.436	14.29	13.89	− .40	2.8
7549	.734	.695	.947	.08	.04	.431	14.05	13.52	− .53	3.8
7551	.406	.349	.860	.08	.06	.272	7.08	6.55	− .53	7.5
7552	.420	.378	.900	.08	.04	.272	7.08	6.37	− .71	10.0

TABLE XXXV.—SPECIAL TESTS ON 8-FOOT IMPROVED VENTURI FLUME TO SHOW THE EFFECT ON DISCHARGE BY INCREASING THE LENGTH OF CONVERGING SECTION. MEASUREMENT OF HEADS IN FLUME AT THE STANDARD POINTS.

Test	Flume Heads		Ratio H_b/H_a	Head on Weir	Discharge		Difference	Deviation
	H_a	H_b			Obs.	Comp.		
	Feet	Feet		Feet	Sec.-Ft.	Sec.-Ft.	Sec.-Ft.	Per-cent
7379	0.618	....	....	0.446	14.78	14.72	−0.06	0.4
7380	.756	....	....	.556	20.55	20.35	− .20	1.0
7381	.963	....	....	.720	30.21	30.05	− .16	0.5
7382	1.147	....	....	.869	40.01	39.79	− .22	0.6
7383	1.314	....	....	1.005	49.72	49.50	− .22	0.4
7384	1.440	....	....	1.107	57.44	57.36	− .08	0.1
7385	1.161	0.825	0.711	.871	40.15	39.61	− .54	1.3
7386	1.194	.951	.796	.862	39.53	39.97	+ .44	1.1
7387	1.276	1.155	.904	.850	38.71	38.59	− .12	0.3
7388	1.350	1.263	.936	.839	37.96	38.46	+ .50	1.3