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THE PARSHALL MEASURING FLUME

# ~~THE IMPROVED VENTURI FLUME~~

by

~~By~~ RALPH L. PARSHALL
Senior Irrigation Engineer

Colorado State College

COLORADO EXPERIMENT STATION
COLORADO AGRICULTURAL COLLEGE
FORT COLLINS, COLORADO

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| Free Flow | | | Submerged | | |
|---|---|---|---|---|---|
| XI | 3-inch | | XX | 3-inch | |
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Footnote bottom page 3

* This bulletin is a revision of Colo. Agri. Exp. Bul. 336 entitled "The Improved Venturi Flume", issued March 1928.

The Parshall Measuring Flume

# ~~THE IMPROVED VENTURI FLUME~~

by

~~By~~ RALPH L. PARSHALL, Senior Irrigation Engineer

Prepared under the direction of W. W. McLaughlin, ~~Associate~~ Chief, Division of Agricultural Engineering, United States Department of Agriculture, ~~Bureau of Public Roads. Thomas H. MacDonald, Chief~~. Bureau of Agricultural Engineering

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

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Water is the most valuable asset of Western agriculture. Large expenditures have been made in the development of irrigation works and canal systems to furnish water to farms; these with the cost in the preparation of large areas of lands to be irrigated, and the establishment of legal rights to the use of water, ~~represents~~ represent a vast irrigation investment. The extensive outlays already made ~~together with those~~ and which must be faced in the future emphasize the great need for the conservation of irrigation supplies, and in this relation correct measurements of flow should be the basis of any plan of saving.

The water-measuring device herein described, called the Parshall * measuring flume, * is believed to possess the characteristics which will make it meet general field conditions more successfully than did its predecessor, the Venturi flume, as well as obviate many of the objections to the weir, orifice, rating flume or other measuring devices which are now in general use. This measuring flume is intended primarily to meet general field conditions where extreme accuracy in the measurement is not required. It is assumed that the accuracy of the indicated discharge will be well within the limits of 2 to 5 percent when the flume is operating under normal conditions.

Footnote * This measuring device, at the suggestion of the Irrigation Committee of the American Society of Civil Engineers with the approval of the Bureau of Agricultural Engineering, United States Department of Agriculture and the Colorado Agricultural Experiment Station, [has been named the Parshall Measuring Flume.]

The Parshall Measuring Flume*

# ~~THE IMPROVED VENTURI FLUME~~

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.

Recast

In many cases, the absence of suitable ~~devices~~ means for measuring flowing 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.

reliable

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.

Too many "devices"

It is generally believed that the measurement of water is an intricate process, but accurate measurements can readily be made

*

methods of measurement

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.

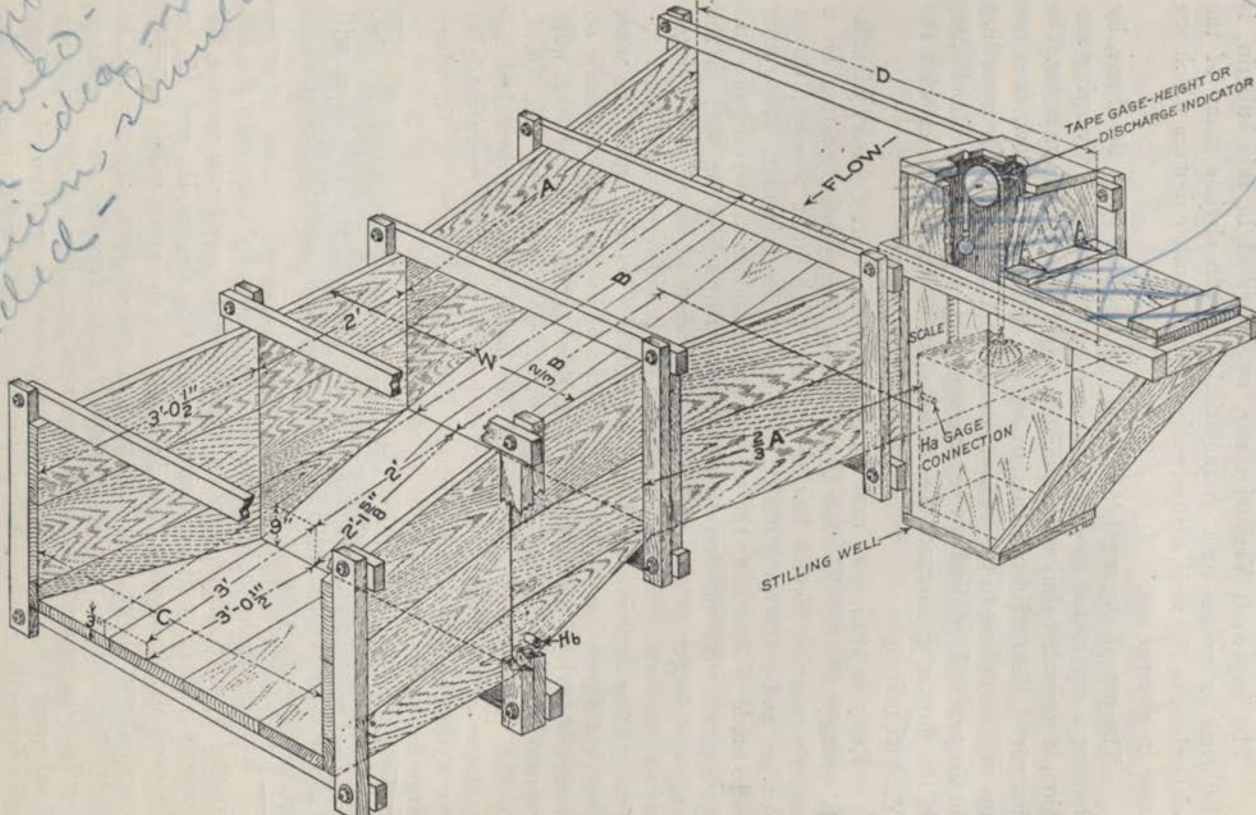


Figure 1.—~~Improved Venturi Flume.~~ Including Stilling-well ~~Equipped with Indicating Tape Device. Staff Gage in Well.~~

Figure 1. The Parshall measuring flume with stilling well provided with staff gage inside capable of more accurate head readings

Take out

This figure may be improved - tape indicator idea made no impression, should be discarded -

the Parshall measuring flume

TABLE 1.—STANDARD DIMENSIONS AND CAPACITIES OF ~~IMPROVED VENTURI FLUME~~
(Letters refer to Figure 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~~ |

(For flumes of larger size see Experiment Station Bulletin 386 Parshall Flumes of Large Size.

(Suggest that this bulletin be limited to the 8-foot flume as bul. 386 continues with 10 to 50 foot sizes.)

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 pump 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

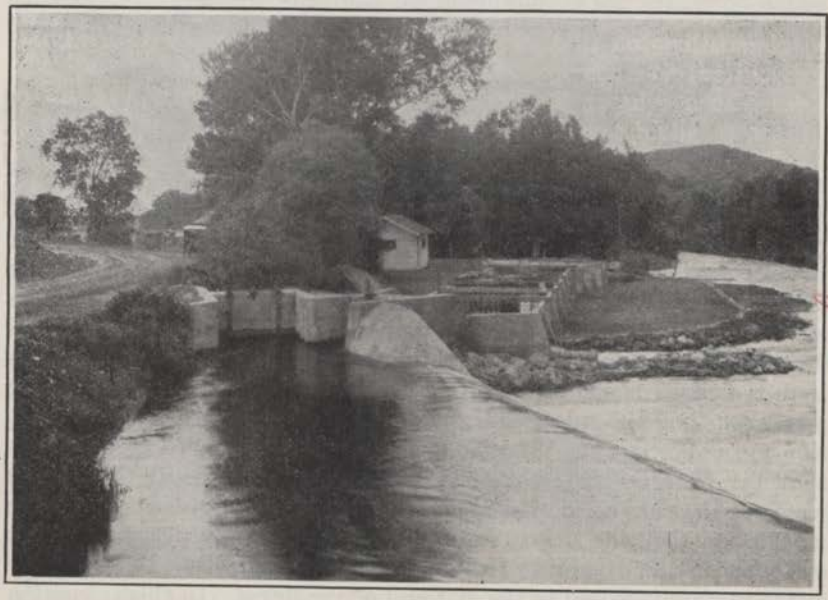

**Figure 2.—Irrigation Hydraulic Laboratory at Bellvue.**

wide and 6½ 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 7½ 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

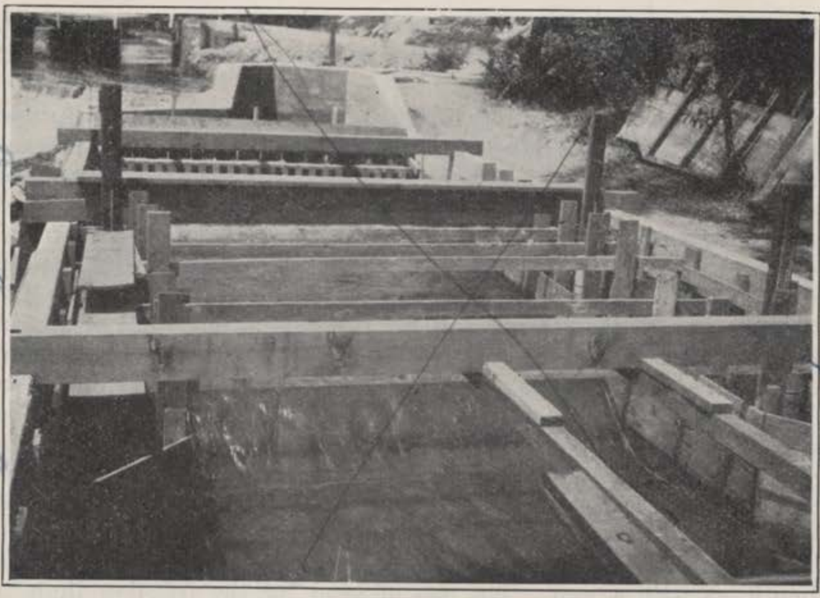

**Figure 3.—Experimental 8-foot Improved Venturi Flume, Bellvue Laboratory. Free-flow Discharge. Note Arrangement of Hookgages to Determine the Upper Head on Opposite Sides of Flume and the Throat Head.**

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 13), 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

(see discussion page —)



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

* Bul. 386, Parshall Flumes of Large Size, Colo. Agri. Expt Sta, 1932, discusses flume of larger size, maximum throat width of 50 feet and having a capacity of 3000 second-feet.

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

these two heads (see figure 28)

test experimental

(15)

experimental

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

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

Ha

Parshall measuring flumes

Parshall

measuring

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Smaller case but larger than

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

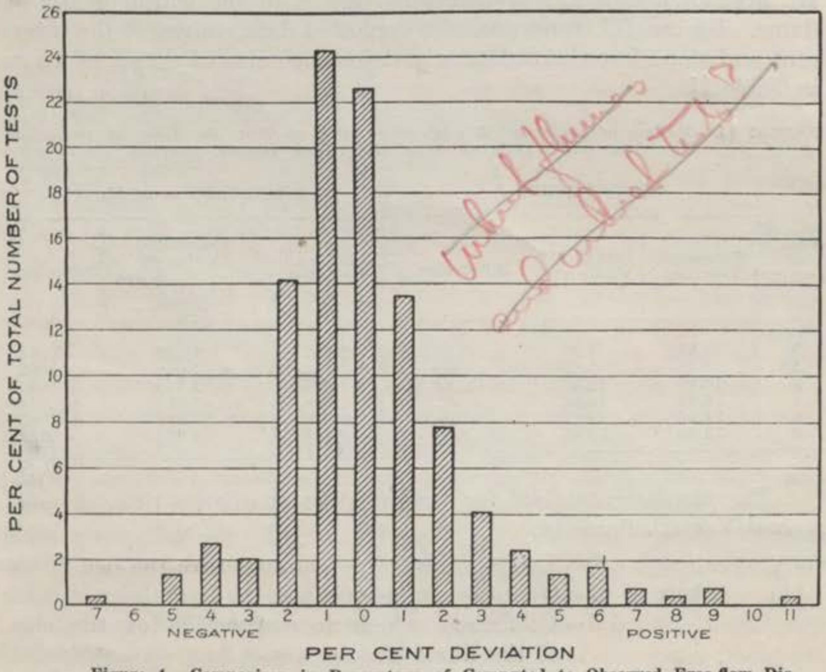


**Figure 4.—Comparison in Percentage of Computed to Observed Free-flow Discharge Thru Experimental Flumes.**

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

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 18, 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 |

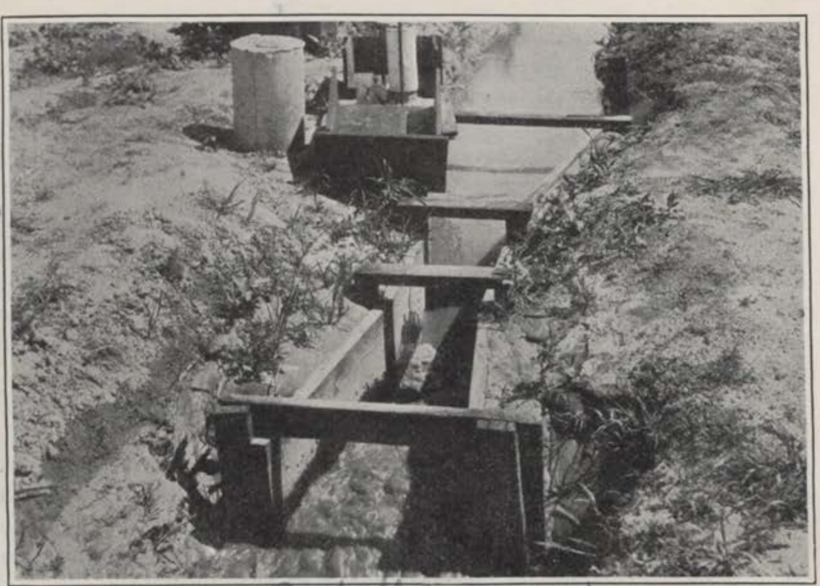

Figure 5.—One-foot ~~Improved Venturi~~ Flume, Experimental Farm, American Beet Sugar Company, Rocky Ford, Colorado. Free-flow Discharge of 1 Second-foot. Instrument Installed to Record Total Flow.

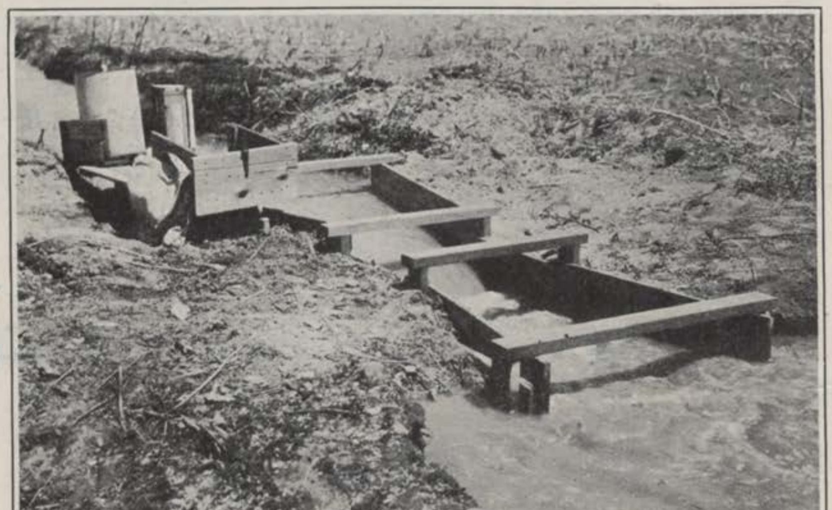

Figure 6.—Two-foot ~~Improved Venturi~~ Flume Discharging 5.7 Second-feet, Submergence 50 Percent, Loss of Head about 0.4 Foot. Mitchell Farm Lateral near Las Animas, Colorado.

Check table for typographical errors



TABLE III.—FREE-FLOW DISCHARGE FOR ~~IMPROVED VENTURI FLUME~~ Parshall Measuring 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 | 6.05 | 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 |

3.20

8.46

11.89

12.68

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 | 9.15 | 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 |

8.46
8.63
8.79
8.96
9.13

12.00
12.19
12.38
12.57
12.76

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 | 15⅝ | 5.96 | 12.01 | 18.10 | 24.21 | 30.33 | 36.47 | 42.62 | 48.78 | 61.12 |
| 1.31 | 15¾ | 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 | 17¼ | 6.97 | 14.08 | 21.24 | 28.45 | 35.67 | 42.94 | 50.20 | 57.50 | 72.11 |
| 1.45 | 17⅜ | 7.04 | 14.23 | 21.27 | 28.76 | 36.06 | 43.42 | 50.76 | 58.14 | 72.92 |
| 1.46 | 17½ | 7.12 | 14.38 | 21.70 | 29.07 | 36.46 | 43.89 | 51.32 | 58.78 | 73.73 |
| 1.47 | 17⅝ | 7.19 | 14.54 | 21.94 | 29.38 | 36.86 | 44.37 | 51.88 | 59.43 | 74.55 |
| 1.48 | 17¾ | 7.26 | 14.69 | 22.17 | 29.70 | 37.26 | 44.85 | 52.45 | 60.08 | 75.37 |
| 1.49 | 17⅞ | 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 | 18⅛ | 7.49 | 15.16 | 22.88 | 30.66 | 38.46 | 46.31 | 54.16 | 62.06 | 77.85 |
| 1.52 | 18¼ | 7.57 | 15.31 | 23.12 | 30.98 | 38.87 | 46.80 | 54.74 | 62.72 | 78.69 |
| 1.53 | 18⅜ | 7.64 | 15.47 | 23.36 | 31.30 | 39.28 | 47.30 | 55.32 | 63.38 | 79.53 |
| 1.54 | 18½ | 7.72 | 15.62 | 23.60 | 31.63 | 39.68 | 47.79 | 55.90 | 64.04 | 80.37 |
| 1.55 | 18⅝ | 7.80 | 15.78 | 23.84 | 31.95 | 40.09 | 48.28 | 56.48 | 64.71 | 81.21 |
| 1.56 | 18¾ | 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 5/16 | 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 | 20¼ | 8.89 | 18.04 | 27.30 | 36.62 | 46.00 | 55.42 | 64.86 | 74.37 | 93.40 |
| 1.70 | 20⅜ | 8.97 | 18.21 | 27.55 | 36.96 | 46.43 | 55.95 | 65.48 | 75.08 | 94.29 |
| 1.71 | 20½ | 9.05 | 18.38 | 27.80 | 37.30 | 46.86 | 56.48 | 66.10 | 75.79 | 95.19 |
| 1.72 | 20⅝ | 9.13 | 18.54 | 28.06 | 37.65 | 47.30 | 57.00 | 66.72 | 76.50 | 96.09 |
| 1.73 | 20¾ | 9.21 | 18.71 | 28.32 | 38.00 | 47.74 | 57.53 | 67.34 | 77.22 | 96.99 |
| 1.74 | 20⅞ | 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 | 21⅛ | 9.46 | 19.21 | 29.08 | 39.04 | 49.05 | 59.13 | 69.22 | 79.38 | 99.72 |
| 1.77 | 21¼ | 9.54 | 19.38 | 29.34 | 39.39 | 49.50 | 59.67 | 69.85 | 80.10 | 100.6 |
| 1.78 | 21⅜ | 9.62 | 19.55 | 29.60 | 39.74 | 49.94 | 60.20 | 70.48 | 80.83 | 101.5 |
| 1.79 | 21½ | 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 | 27⅝ | 14.21 | 29.09 | 44.22 | 59.56 | 75.01 | 90.61 | 106.2 | 122.0 | 153.7 |
| 2.31 | 27¾ | 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 | 29¼ | 15.55 | 31.89 | 48.51 | 65.38 | 82.38 | 99.56 | 116.8 | 134.2 | 169.1 |
| 2.45 | 29⅜ | 15.64 | 32.10 | 48.82 | 65.80 | 82.92 | 100.2 | 117.6 | 135.1 | 170.2 |
| 2.46 | 29½ | 15.74 | 32.30 | 49.13 | 66.23 | 83.45 | 100.9 | 118.3 | 135.9 | 171.3 |
| 2.47 | 29⅝ | 15.89 | 32.50 | 49.45 | 66.65 | 83.99 | 101.5 | 119.1 | 136.8 | 172.4 |
| 2.48 | 29¾ | 15.94 | 32.70 | 49.76 | 67.07 | 84.54 | 102.2 | 119.9 | 137.7 | 173.6 |
| 2.49 | 29⅞ | 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.

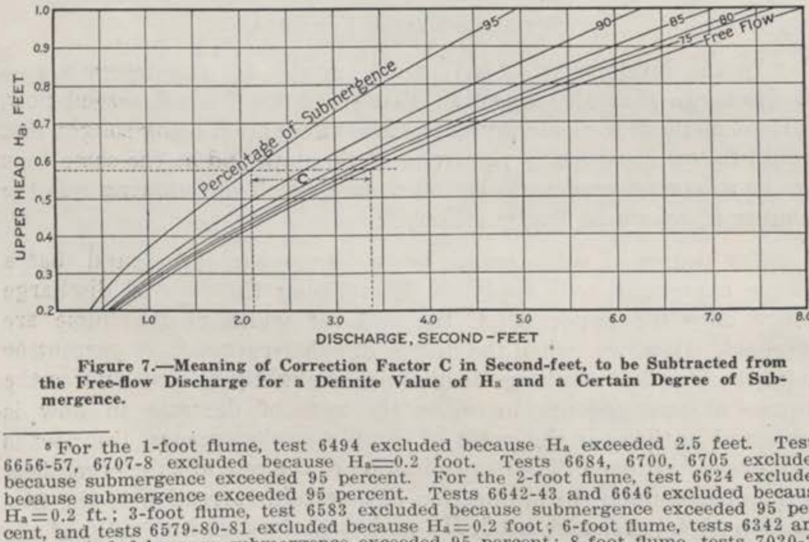


**Figure 7.—Meaning of Correction Factor C in Second-feet, to be Subtracted from the Free-flow Discharge for a Definite Value of $H_a$ and a Certain Degree of Submergence.**

[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.

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¶ To facilitate the use of this submerged flow correction formula the values of C for a 1-foot flume may be taken directly from the diagram, figure 8. To determine the submerged flow correction for other sizes of flume multiply this correction by the factor M as given in the following tabulation before subtracting from the corresponding free flow for that particular Ha head.

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

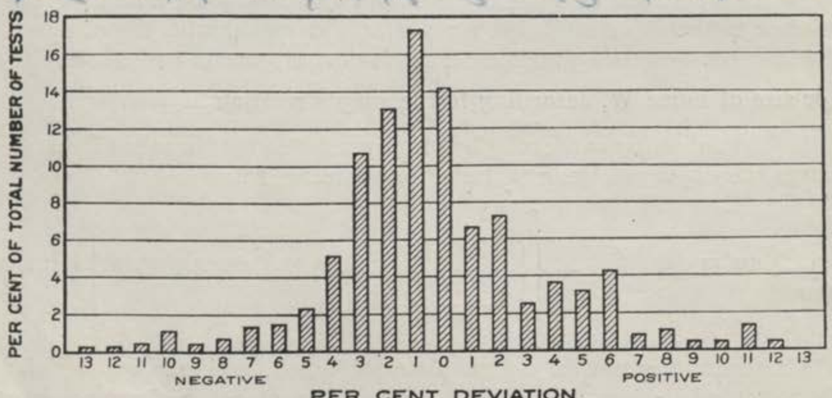


**Figure 8.—Comparison in Percentage of Computed to Observed Submerged-flow Discharges Thru Experimental Flumes.**

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

K

To determine the quantity of discharge through the Parshall measuring flume under submerged flow the following examples are given to illustrate the method of computation:

See Bul 386 page 44
for better form of
of tabulation of W and
M.

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(1) Let is be assumed that the flume has a throat width of one foot, upper head, Ha, 1.50 feet and the throat head, Hb, 1.20 feet. The ratio 1.20/1.50 = 0.80 Enter diagram figure 8 at the left hand side on the Ha line 1.5, follow this horizontal line to the right until reaching the curved line "80". Vertically beneath this intersection observe the ~~approximate~~ reading 0.71 which is the correction in second-feet due to the submergence. In the free flow discharge table III for the 1-foot flume with the recorded head, Ha, of 1.50 feet, note that the discharge is 7.41 second-feet. The flow with a submergence of 80 percent under these conditions, will, therefore be 7.41 − 0.71 = 6.70 second-feet.

(2) What will be the discharge through a 4-foot flume where the upper head Ha is 1.98 feet and the throat head, Hb is 1.80 feet? The ratio 1.80/1.98 is very closely 0.91. As before enter the correction diagram at the left, however, in this case follow to the right along the horizontal line indicating Ha = 2.0 until the point is reached midway between curved lines 90 and

92. It is to be kept in mind that the line Ha=2 is slightly above the true value of the upper head which is 1.98 feet. At this corrected point move vertically downward to the base of the diagram and estimate the value on this scale at 3.50 second-feet, which is the correction for submergence for a 1-foot flume. It will be noted in the previous tabulation that the multiplying factor M for the 4-foot flume is 3.1. This factor times the correction in second feet is 10.85 second-feet or the amount to be deducted from the free flow through the 4-foot flume for an upper head Ha of 1.98 feet. The computed submerged flow is therefore ~~found to be~~ 36.17 second-feet.

(3) ~~For example~~, Suppose the upper head, Ha,
1 of an 8-foot flume is 0.69 foot and the
4 throat head Hb is 0.60 foot, what would
8 be the submerged flow discharge? The ratio
of the two heads will be 0.60/0.69 or very closely 0.87
As before enter the correction diagram at the
left and follow horizontally to the right on
the line 0.7 to a point about midway between
the curved lines 86 and 88. Since the value

of the Ha head is 0.69 foot it will be necessary to select the true point about one tenth the interval below the 0.7 Ha line. Vertically below this final location of the true point there will be found, on the base of the diagram the ~~approximate~~ value of 0.41 second feet as the correction for submergence for the 1-foot flume. The multiplying factor M for the 8-foot flume is 5.4, hence the full correction for this flume will be 0.41 × 5.4 or 2.21 second feet. The free-flow discharge through the 8-foot flume for an upper head, Ha, of 0.69 foot is 17.63 second-feet. The computed submerged flow will therefore be 17.63 − 2.21 = 15.42 second-feet. For this degree of submergence, it is readily determined that the free-flow discharge has been reduced approximately ~~[illegible]~~ 12.5 percent.

Replace with diagram
see Bulletin #1683 page 12 ✓
Change text to conform.

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 | 0.83 | 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 | 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 | 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 | 3 13/16 | .07 | .07 | .07 | .07 | .08 | .08 | .08 | .09 | .09 | .09 | .10 | .10 | .11 | .12 | .13 | .14 | .15 | .16 | .17 | .19 | .21 | .23 | .26 | .29 | .33 | .37 |
| .34 | 4 1/16 | .07 | .07 | .07 | .07 | .08 | .08 | .08 | .09 | .09 | .10 | .10 | .11 | .11 | .12 | .13 | .14 | .15 | .17 | .19 | .20 | .23 | .25 | .28 | .31 | .35 | .40 |
| .36 | 4 5/16 | .07 | .07 | .07 | .08 | .08 | .08 | .09 | .09 | .09 | .10 | .11 | .11 | .12 | .13 | .14 | .15 | .16 | .18 | .20 | .22 | .24 | .27 | .30 | .33 | .38 | .43 |
| .38 | 4 9/16 | .07 | .07 | .07 | .08 | .08 | .08 | .09 | .09 | .10 | .10 | .11 | .12 | .13 | .13 | .15 | .16 | .17 | .19 | .21 | .23 | .26 | .29 | .32 | .36 | .40 | .46 |
| .40 | 4 13/16 | .07 | .07 | .08 | .08 | .08 | .09 | .09 | .10 | .10 | .11 | .11 | .12 | .13 | .14 | .15 | .17 | .18 | .20 | .22 | .25 | .27 | .30 | .34 | .38 | .43 | .49 |
| .42 | 5 1/16 | .07 | .07 | .08 | .08 | .08 | .09 | .09 | .10 | .10 | .11 | .12 | .13 | .14 | .15 | .16 | .18 | .19 | .21 | .23 | .26 | .29 | .32 | .36 | .41 | .46 | .52 |
| .44 | 5 1/4 | .07 | .07 | .08 | .08 | .09 | .09 | .10 | .10 | .11 | .11 | .12 | .13 | .14 | .15 | .17 | .19 | .20 | .22 | .25 | .28 | .31 | .34 | .39 | .43 | .49 | .55 |
| .46 | 5 1/2 | .07 | .08 | .08 | .08 | .09 | .09 | .10 | .11 | .11 | .12 | .13 | .14 | .15 | .16 | .18 | .20 | .21 | .24 | .26 | .29 | .33 | .36 | .41 | .46 | .52 | .59 |
| .48 | 5 3/4 | .07 | .08 | .08 | .09 | .09 | .10 | .10 | .11 | .12 | .12 | .13 | .14 | .16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .34 | .39 | .43 | .49 | .55 | .62 |
| .50 | 6 | .08 | .08 | .08 | .09 | .09 | .10 | .11 | .11 | .12 | .13 | .14 | .15 | .16 | .18 | .20 | .22 | .24 | .26 | .29 | .33 | .36 | .41 | .46 | .51 | .58 | .66 |
| .52 | 6 1/4 | .08 | .08 | .09 | .09 | .09 | .10 | .11 | .12 | .12 | .13 | .14 | .16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .34 | .38 | .43 | .48 | .54 | .61 | .70 |
| .54 | 6 1/2 | .08 | .08 | .09 | .09 | .10 | .10 | .11 | .12 | .13 | .14 | .15 | .16 | .18 | .20 | .22 | .24 | .26 | .29 | .32 | .36 | .40 | .45 | .51 | .57 | .65 | .73 |
| .56 | 6 3/4 | .08 | .09 | .09 | .09 | .10 | .11 | .11 | .12 | .13 | .14 | .16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .34 | .38 | .43 | .48 | .54 | .60 | .68 | .77 |
| .58 | 6 15/16 | .08 | .09 | .09 | .10 | .10 | .11 | .12 | .13 | .14 | .15 | .16 | .18 | .19 | .21 | .24 | .26 | .29 | .32 | .36 | .40 | .45 | .50 | .56 | .63 | .72 | .81 |
| .60 | 7 3/16 | .08 | .09 | .09 | .10 | .11 | .11 | .12 | .13 | .14 | .15 | .17 | .19 | .20 | .22 | .25 | .27 | .30 | .34 | .37 | .42 | .47 | .53 | .59 | .67 | .75 | .85 |
| .62 | 7 7/16 | .09 | .09 | .10 | .10 | .11 | .12 | .13 | .14 | .15 | .16 | .18 | .19 | .21 | .23 | .26 | .29 | .31 | .35 | .39 | .44 | .49 | .55 | .62 | .70 | .79 | .89 |
| .64 | 7 11/16 | .09 | .09 | .10 | .11 | .11 | .12 | .13 | .14 | .15 | .17 | .18 | .20 | .22 | .24 | .27 | .30 | .33 | .37 | .41 | .46 | .52 | .58 | .65 | .73 | .83 | .93 |
| .66 | 7 15/16 | .09 | .09 | .10 | .11 | .12 | .12 | .13 | .15 | .16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .35 | .39 | .43 | .48 | .54 | .61 | .68 | .76 | .86 | .98 |
| .68 | 8 3/16 | .09 | .10 | .10 | .11 | .12 | .13 | .14 | .15 | .17 | .18 | .20 | .22 | .24 | .27 | .29 | .33 | .36 | .40 | .45 | .50 | .56 | .63 | .71 | .80 | .90 | 1.02 |
| .70 | 8 3/8 | .09 | .10 | .11 | .11 | .12 | .13 | .14 | .16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .34 | .38 | .42 | .47 | .53 | .59 | .66 | .74 | .83 | .94 | 1.07 |
| .72 | 8 5/8 | .09 | .10 | .11 | .12 | .13 | .14 | .15 | .16 | .18 | .19 | .21 | .24 | .26 | .29 | .32 | .35 | .39 | .44 | .49 | .55 | .61 | .69 | .77 | .87 | .98 | 1.11 |
| .74 | 8 7/8 | .10 | .10 | .11 | .12 | .13 | .14 | .15 | .17 | .18 | .20 | .22 | .25 | .27 | .30 | .33 | .37 | .41 | .46 | .51 | .57 | .64 | .72 | .81 | .91 | 1.02 | 1.15 |
| .76 | 9 1/8 | .10 | .11 | .11 | .12 | .13 | .15 | .16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .35 | .38 | .43 | .48 | .53 | .60 | .67 | .75 | .84 | .94 | 1.06 | 1.20 |
| .78 | 9 3/8 | .10 | .11 | .12 | .13 | .14 | .15 | .17 | .18 | .20 | .22 | .24 | .26 | .29 | .33 | .36 | .40 | .45 | .50 | .55 | .62 | .69 | .78 | .87 | .98 | 1.11 | 1.25 |
| .80 | 9 5/8 | .11 | .11 | .12 | .13 | .14 | .16 | .17 | .19 | .21 | .23 | .25 | .27 | .30 | .34 | .37 | .42 | .46 | .52 | .58 | .65 | .72 | .81 | .91 | 1.02 | 1.15 | 1.30 |
| .82 | 9 13/16 | .11 | .12 | .13 | .14 | .15 | .16 | .18 | .19 | .21 | .23 | .26 | .29 | .32 | .35 | .39 | .43 | .48 | .54 | .60 | .67 | .75 | .84 | .94 | 1.06 | 1.19 | 1.35 |
| .84 | 10 1/16 | .11 | .12 | .13 | .14 | .15 | .17 | .18 | .20 | .22 | .24 | .27 | .30 | .33 | .36 | .40 | .45 | .50 | .56 | .62 | .70 | .78 | .87 | .98 | 1.10 | 1.23 | 1.39 |
| .86 | 10 5/16 | .11 | .12 | .13 | .14 | .16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .34 | .38 | .42 | .47 | .52 | .58 | .65 | .72 | .81 | .90 | 1.01 | 1.14 | 1.28 | 1.44 |
| .88 | 10 9/16 | .12 | .13 | .14 | .15 | .16 | .18 | .19 | .21 | .23 | .26 | .29 | .32 | .35 | .39 | .43 | .48 | .54 | .60 | .67 | .75 | .84 | .94 | 1.05 | 1.18 | 1.33 | 1.49 |
| .90 | 10 13/16 | .12 | .13 | .14 | .15 | .17 | .18 | .20 | .22 | .24 | .27 | .30 | .33 | .37 | .41 | .45 | .50 | .56 | .62 | .70 | .78 | .87 | .97 | 1.09 | 1.22 | 1.37 | 1.55 |
| .92 | 11 1/16 | .12 | .13 | .14 | .16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .34 | .38 | .42 | .47 | .52 | .58 | .65 | .72 | .81 | .90 | 1.01 | 1.13 | 1.26 | 1.42 | 1.60 |
| .94 | 11 1/4 | .13 | .13 | .15 | .16 | .18 | .19 | .21 | .24 | .26 | .29 | .32 | .35 | .39 | .44 | .48 | .54 | .60 | .67 | .75 | .83 | .93 | 1.04 | 1.17 | 1.30 | 1.47 | 1.65 |
| .96 | 11 1/2 | .13 | .14 | .15 | .17 | .18 | .20 | .22 | .24 | .27 | .30 | .33 | .37 | .41 | .45 | .50 | .56 | .62 | .69 | .77 | .86 | .96 | 1.07 | 1.20 | 1.35 | 1.51 | 1.70 |
| .98 | 11 3/4 | .13 | .14 | .16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .34 | .38 | .42 | .47 | .52 | .58 | .64 | .72 | .80 | .89 | .99 | 1.11 | 1.24 | 1.39 | 1.56 | 1.76 |
| 1.00 | 12 | .13 | .15 | .16 | .18 | .19 | .21 | .23 | .26 | .29 | .32 | .35 | .39 | .43 | .48 | .54 | .60 | .67 | .74 | .83 | .92 | 1.03 | 1.15 | 1.28 | 1.43 | 1.61 | 1.81 |
| 1.02 | 12 1/4 | .14 | .15 | .17 | .18 | .20 | .22 | .24 | .27 | .30 | .33 | .36 | .40 | .45 | .50 | .55 | .62 | .69 | .77 | .85 | .95 | 1.06 | 1.18 | 1.32 | 1.48 | 1.66 | 1.87 |
| 1.04 | 12 1/2 | .14 | .15 | .17 | .19 | .21 | .22 | .25 | .28 | .31 | .34 | .37 | .42 | .46 | .51 | .57 | .64 | .71 | .79 | .88 | .98 | 1.09 | 1.22 | 1.37 | 1.53 | 1.71 | 1.92 |
| 1.06 | 12 3/4 | .15 | .16 | .17 | .19 | .21 | .23 | .26 | .29 | .32 | .35 | .39 | .43 | .48 | .53 | .59 | .66 | .73 | .81 | .91 | 1.01 | 1.13 | 1.26 | 1.41 | 1.57 | 1.76 | 1.98 |
| 1.08 | 12 15/16 | .15 | .16 | .18 | .20 | .22 | .24 | .27 | .29 | .33 | .36 | .40 | .44 | .49 | .55 | .61 | .68 | .75 | .84 | .94 | 1.04 | 1.16 | 1.30 | 1.45 | 1.62 | 1.81 | 2.03 |
| 1.10 | 13 3/16 | .15 | .17 | .18 | .20 | .22 | .25 | .27 | .30 | .34 | .37 | .41 | .46 | .51 | .57 | .63 | .70 | .78 | .87 | .97 | 1.07 | 1.20 | 1.34 | 1.49 | 1.67 | 1.87 | 2.09 |
| 1.12 | 13 7/16 | .16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .35 | .38 | .43 | .47 | .53 | .58 | .65 | .72 | .80 | .89 | .99 | 1.11 | 1.23 | 1.37 | 1.53 | 1.71 | 1.92 | 2.15 |
| 1.14 | 13 11/16 | .16 | .18 | .19 | .21 | .24 | .26 | .29 | .32 | .36 | .39 | .44 | .49 | .54 | .60 | .67 | .74 | .83 | .92 | 1.02 | 1.14 | 1.27 | 1.41 | 1.58 | 1.76 | 1.97 | 2.21 |
| 1.16 | 13 15/16 | .17 | .18 | .20 | .22 | .24 | .27 | .30 | .33 | .37 | .41 | .45 | .50 | .56 | .62 | .69 | .77 | .85 | .95 | 1.05 | 1.17 | 1.31 | 1.45 | 1.62 | 1.81 | 2.03 | 2.27 |
| 1.18 | 14 3/16 | .17 | .19 | .21 | .23 | .25 | .28 | .31 | .34 | .38 | .42 | .47 | .52 | .57 | .64 | .71 | .79 | .88 | .98 | 1.09 | 1.21 | 1.34 | 1.50 | 1.67 | 1.86 | 2.08 | 2.33 |
| 1.20 | 14 3/8 | .17 | .19 | .21 | .23 | .26 | .29 | .32 | .35 | .39 | .43 | .48 | .53 | .59 | .66 | .73 | .81 | .90 | 1.00 | 1.12 | 1.24 | 1.38 | 1.54 | 1.71 | 1.91 | 2.13 | 2.39 |
| 1.22 | 14 5/8 | .18 | .20 | .22 | .24 | .27 | .29 | .33 | .36 | .40 | .44 | .49 | .55 | .61 | .68 | .75 | .83 | .93 | 1.03 | 1.15 | 1.28 | 1.42 | 1.58 | 1.76 | 1.96 | 2.19 | 2.45 |
| 1.24 | 14 7/8 | .18 | .20 | .22 | .25 | .27 | .30 | .33 | .37 | .41 | .46 | .51 | .56 | .63 | .70 | .77 | .86 | .95 | 1.06 | 1.18 | 1.31 | 1.46 | 1.62 | 1.81 | 2.01 | 2.25 | 2.51 |
| 1.26 | 15 1/8 | .19 | .21 | .23 | .25 | .28 | .31 | .34 | .38 | .42 | .47 | .52 | .58 | .65 | .72 | .79 | .88 | .98 | 1.09 | 1.21 | 1.35 | 1.50 | 1.66 | 1.85 | 2.06 | 2.30 | 2.58 |
| 1.28 | 15 3/8 | .19 | .21 | .23 | .26 | .29 | .32 | .35 | .39 | .44 | .48 | .54 | .60 | .66 | .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 | 15 5/8 | .20 | .22 | .24 | .27 | .30 | .33 | .36 | .40 | .45 | .50 | .55 | .61 | .68 | .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 | 15 13/16 | .20 | .22 | .25 | .27 | .30 | .34 | .37 | .41 | .46 | .51 | .57 | .63 | .70 | .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 | 16 1/16 | .21 | .23 | .25 | .28 | .31 | .35 | .38 | .43 | .47 | .53 | .58 | .65 | .72 | .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 | 16 5/16 | .21 | .23 | .26 | .29 | .32 | .36 | .39 | .44 | .49 | .54 | .60 | .67 | .74 | .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 | 16 9/16 | .22 | .24 | .27 | .30 | .33 | .37 | .41 | .45 | .50 | .55 | .62 | .68 | .76 | .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 | 16 13/16 | .22 | .25 | .27 | .30 | .34 | .37 | .42 | .46 | .51 | .57 | .63 | .70 | .78 | .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 | 17 1/16 | .23 | .25 | .28 | .31 | .35 | .38 | .43 | .47 | .53 | .58 | .65 | .72 | .80 | .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 | 17 1/4 | .23 | .26 | .29 | .32 | .35 | .39 | .44 | .49 | .54 | .60 | .67 | .74 | .82 | .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 | 17 1/2 | .24 | .27 | .29 | .33 | .36 | .40 | .45 | .50 | .55 | .61 | .68 | .76 | .84 | .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 | 17 3/4 | .25 | .27 | .30 | .34 | .37 | .41 | .46 | .51 | .57 | .63 | .70 | .78 | .86 | .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 | 18 | .25 | .28 | .31 | .34 | .38 | .43 | .47 | .53 | .58 | .65 | .72 | .80 | .88 | .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 | 18 1/4 | .26 | .29 | .32 | .35 | .39 | .44 | .48 | .54 | .60 | .66 | .73 | .82 | .91 | 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 | 18 1/2 | .26 | .29 | .33 | .36 | .40 | .45 | .50 | .55 | .61 | .68 | .75 | .84 | .93 | 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 | 18 3/4 | .27 | .30 | .33 | .37 | .41 | .46 | .51 | .57 | .63 | .69 | .77 | .86 | .95 | 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 | 18 15/16 | .28 | .31 | .34 | .38 | .42 | .47 | .52 | .58 | .64 | .71 | .79 | .88 | .97 | 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 | 19 3/16 | .28 | .31 | .35 | .39 | .43 | .48 | .53 | .59 | .66 | .73 | .81 | .90 | .99 | 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 | 19 7/16 | .29 | .32 | .36 | .40 | .44 | .49 | .55 | .61 | .67 | .75 | .83 | .92 | 1.02 | 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 | 19 11/16 | .30 | .33 | .37 | .41 | .45 | .50 | .56 | .62 | .69 | .76 | .85 | .94 | 1.04 | 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 | 19 15/16 | .30 | .34 | .37 | .42 | .46 | .51 | .57 | .64 | .71 | .78 | .87 | .96 | 1.07 | 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 | 20 3/16 | .31 | .35 | .38 | .43 | .47 | .53 | .59 | .65 | .72 | .80 | .89 | .98 | 1.09 | 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 | 20 3/8 | .32 | .35 | .39 | .44 | .49 | .54 | .60 | .67 | .74 | .82 | .91 | 1.01 | 1.11 | 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 | 20 5/8 | .32 | .36 | .40 | .45 | .50 | .55 | .61 | .68 | .75 | .84 | .93 | 1.03 | 1.14 | 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 | 20 7/8 | .33 | .37 | .41 | .46 | .51 | .56 | .63 | .70 | .77 | .86 | .95 | 1.05 | 1.16 | 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 | 21 1/8 | .34 | .38 | .42 | .47 | .52 | .58 | .64 | .71 | .79 | .87 | .97 | 1.07 | 1.18 | 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 | 21 3/8 | .35 | .39 | .43 | .48 | .53 | .59 | .65 | .73 | .81 | .89 | .99 | 1.10 | 1.21 | 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 | 21 5/8 | .35 | .39 | .44 | .49 | .54 | .60 | .67 | .74 | .82 | .91 | 1.01 | 1.12 | 1.24 | 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 | 21 13/16 | .36 | .40 | .45 | .50 | .55 | .62 | .69 | .76 | .84 | .93 | 1.03 | 1.14 | 1.26 | 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 | 22 1/16 | .37 | .41 | .46 | .51 | .57 | .63 | .70 | .78 | .86 | .95 | 1.05 | 1.17 | 1.29 | 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 | 22 5/16 | .38 | .42 | .47 | .52 | .58 | .64 | .72 | .79 | .88 | .97 | 1.08 | 1.19 | 1.32 | 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 | 22 9/16 | .39 | .43 | .48 | .53 | .59 | .66 | .73 | .81 | .90 | .99 | 1.10 | 1.22 | 1.34 | 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 | 22 13/16 | .39 | .44 | .49 | .54 | .60 | .67 | .75 | .83 | .92 | 1.01 | 1.12 | 1.24 | 1.37 | 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 | 23 1/16 | .40 | .45 | .50 | .55 | .62 | .69 | .76 | .84 | .93 | 1.03 | 1.15 | 1.27 | 1.40 | 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 | 23 1/4 | .41 | .46 | .51 | .57 | .63 | .70 | .78 | .86 | .95 | 1.06 | 1.17 | 1.29 | 1.43 | 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 | 23 1/2 | .42 | .47 | .52 | .58 | .64 | .71 | .79 | .88 | .97 | 1.08 | 1.19 | 1.32 | 1.45 | 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 | 23 3/4 | .43 | .48 | .53 | .59 | .66 | .73 | .81 | .90 | .99 | 1.10 | 1.22 | 1.34 | 1.48 | 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 | 24 | .44 | .49 | .54 | .60 | .67 | .74 | .83 | .92 | 1.01 | 1.12 | 1.24 | 1.37 | 1.51 | 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 | 24 1/4 | .45 | .50 | .55 | .61 | .68 | .76 | .84 | .93 | 1.03 | 1.14 | 1.26 | 1.40 | 1.54 | 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 | 24 1/2 | .46 | .51 | .56 | .63 | .70 | .77 | .86 | .95 | 1.05 | 1.17 | 1.29 | 1.42 | 1.57 | 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 | 24 3/4 | .46 | .52 | .58 | .64 | .71 | .79 | .88 | .97 | 1.07 | 1.19 | 1.31 | 1.45 | 1.60 | 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 | 24 15/16 | .47 | .53 | .59 | .65 | .73 | .81 | .89 | .99 | 1.09 | 1.21 | 1.34 | 1.48 | 1.63 | 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 | 25 3/16 | .48 | .54 | .60 | .67 | .74 | .82 | .91 | 1.01 | 1.12 | 1.23 | 1.36 | 1.50 | 1.66 | 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 | 25 7/16 | .49 | .55 | .61 | .68 | .75 | .84 | .93 | 1.03 | 1.14 | 1.26 | 1.39 | 1.53 | 1.69 | 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 | 25 11/16 | .50 | .56 | .62 | .69 | .77 | .85 | .95 | 1.05 | 1.16 | 1.28 | 1.41 | 1.56 | 1.72 | 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 | 25 15/16 | .51 | .57 | .63 | .71 | .78 | .87 | .96 | 1.07 | 1.18 | 1.30 | 1.44 | 1.59 | 1.75 | 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 | 26 3/16 | .52 | .58 | .65 | .72 | .80 | .89 | .98 | 1.09 | 1.20 | 1.33 | 1.47 | 1.62 | 1.78 | 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 | 26 3/8 | .53 | .59 | .66 | .73 | .81 | .90 | 1.00 | 1.11 | 1.22 | 1.35 | 1.49 | 1.65 | 1.81 | 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 | 26 5/8 | .54 | .60 | .67 | .75 | .83 | .92 | 1.02 | 1.13 | 1.25 | 1.38 | 1.52 | 1.67 | 1.84 | 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 | 26 7/8 | .55 | .62 | .69 | .76 | .85 | .94 | 1.04 | 1.15 | 1.27 | 1.40 | 1.55 | 1.70 | 1.88 | 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 | 27 1/8 | .56 | .63 | .70 | .77 | .86 | .95 | 1.06 | 1.17 | 1.29 | 1.43 | 1.57 | 1.73 | 1.91 | 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 | 27 3/8 | .57 | .64 | .71 | .79 | .88 | .97 | 1.08 | 1.19 | 1.31 | 1.45 | 1.60 | 1.76 | 1.94 | 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 | 27 5/8 | .59 | .65 | .72 | .80 | .89 | .99 | 1.10 | 1.21 | 1.34 | 1.48 | 1.63 | 1.79 | 1.97 | 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 | 27 13/16 | .60 | .66 | .74 | .82 | .91 | 1.01 | 1.12 | 1.23 | 1.36 | 1.50 | 1.66 | 1.82 | 2.01 | 2.21 | 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 | 28 1/16 | .61 | .67 | .75 | .83 | .93 | 1.03 | 1.14 | 1.26 | 1.39 | 1.53 | 1.69 | 1.85 | 2.04 | 2.24 | 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 | 28 5/16 | .62 | .69 | .77 | .85 | .94 | 1.04 | 1.16 | 1.28 | 1.41 | 1.55 | 1.71 | 1.89 | 2.07 | 2.28 | 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 | 28 9/16 | .63 | .70 | .78 | .86 | .96 | 1.06 | 1.18 | 1.30 | 1.43 | 1.58 | 1.74 | 1.92 | 2.11 | 2.31 | 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 | 28 13/16 | .64 | .71 | .79 | .88 | .98 | 1.08 | 1.20 | 1.32 | 1.46 | 1.61 | 1.77 | 1.95 | 2.14 | 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 | 29 1/16 | .65 | .73 | .81 | .89 | .99 | 1.10 | 1.22 | 1.35 | 1.48 | 1.63 | 1.80 | 1.98 | 2.18 | 2.39 | 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 | 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 | 2.43 | 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 | 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 | 2.47 | 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 | 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 | 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 | 30 | .70 | .78 | .86 | .96 | 1.06 | 1.18 | 1.30 | 1.44 | 1.58 | 1.75 | 1.92 | 2.11 | 2.32 | 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 |

(G)

The error in calculating the submerged flow discharge resulting from observing either the upper head or the throat head 0.01 foot two large or two small is found to be for Ha heads of 0.5 foot and submergences 75 to 90 percent to range from about 1 to 10 percent while for 95 percent submergence this error may be 20 to 30 percent. For Ha heads of about 2 feet this error for submergences, 75 to 95 percent, would be 5 percent or less.

(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 10. This flume is provided with stilling wells for both the $H_a$ and $H_b$ gages. An index was fixed near the

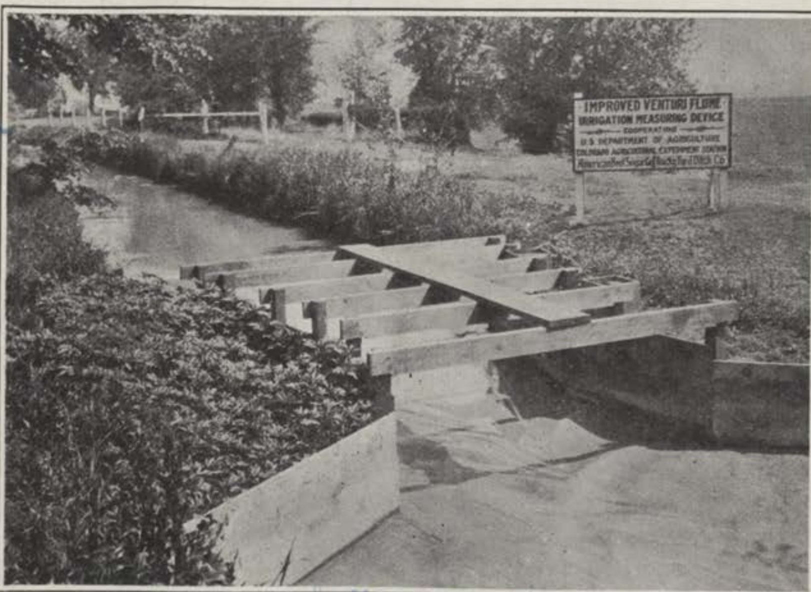


**Figure 9.—Six-foot Improved Venturi Flume Showing a Discharge of About 50 Second-feet with a Submergence of 95 Percent, Rocky Ford, Colorado.**

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 IV 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

Replace with short paragraph of text

Discuss inside and outside gages in converging section

(G) The error in calculating the submerged flow discharge resulting from observing either the upper head or the throat head 0.01 foot too large or too small is found to be about 20 percent for heads approximately 0.5 foot while for heads of about 2 feet the error is less than 5 percent. } Expand

extended

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 |

both free and submerged flows

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IV

TABLE VI.—COMPARISON OF COMPUTED DISCHARGE THRU A 6-FOOT ~~IMPROVED VENTURI~~ Parshall measuring 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~~ Parshall measuring 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 | 54.5 | 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~~ Parshall measuring 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~~ (6-foot) flume.

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

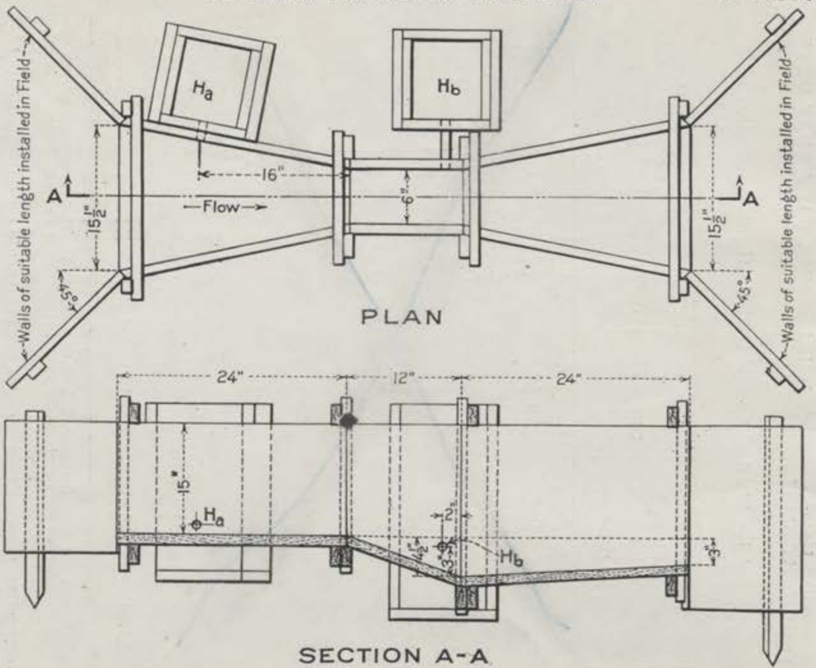


**Figure 10.—Plan and Elevation of the 6-inch Improved Venturi Flume.**

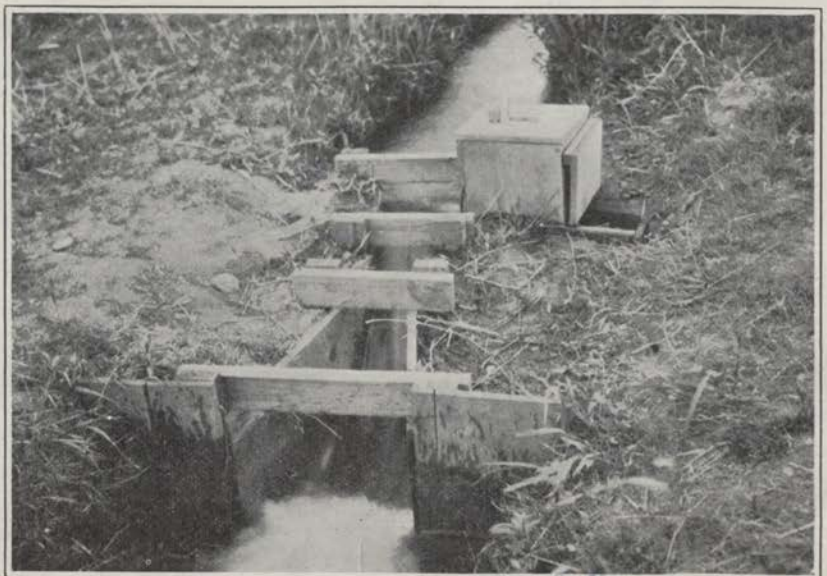

**Figure 11.—Free-flow Discharge thru 6-inch Improved Venturi Flume Equipped with Discharge Indicating Tape Graduated in Shares. For Small Flumes the Downstream Wings May be at Right Angles as Shown. Flume on Farm Lateral near Boulder, Colorado.**

TABLE ~~5~~ V.—*Dimensions and capacities of the Parshall measuring flume, for ~~various crest lengths~~* the 3, 6 and 9 inch crest lengths

(Letters refer to Figure 2)

| W | A | ⅔ A | B | C | D | E | F | G | K | N | X | Y | Free-flow capacity | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Maximum | Minimum |
| ~~Feet~~ Inch | Ft. in. | Ft. in. | Ft. in. | Ft. in. | Ft. in. | Ft. in. | Ft. | Ft. | In. | In. | In. | In. | Sec. ft. | Sec. ft. |
| 3 0.25 | 1 6⅜ | 1 ¼ | 1 6 | 7 | 10 3/16 | 1 3 | ½ | 1 | 1 | 2¼ | 1 | 1½ | 1.2 | 0.03 |
| 6 .50 | 2 7/16 | 1 4 5/16 | 2 | 1 3½ | 1 3½ | 1 6 | 1 | 2 | 3 | 4½ | 2 | 3 | 2.9 | .05 |
| 9 .75 | 2 10⅝ | 1 11⅛ | 2 10 | 1 3 | 1 10⅝ | 2 | 1 | 1½ | 3 | 4½ | 2 | 3 | 5.7 | .1 |
| ~~1~~ | ~~4 6~~ | ~~3~~ | ~~4 4⅞~~ | ~~2~~ | ~~2 9¼~~ | ~~3~~ | ~~2~~ | ~~3~~ | ~~3~~ | ~~9~~ | ~~2~~ | ~~3~~ | ~~16~~ | ~~.4~~ |
| ~~2~~ | ~~5~~ | ~~3 4~~ | ~~4 10⅞~~ | ~~3~~ | ~~3 11½~~ | ~~3~~ | ~~2~~ | ~~3~~ | ~~3~~ | ~~9~~ | ~~2~~ | ~~3~~ | ~~33~~ | ~~.7~~ |
| ~~3~~ | ~~5 6~~ | ~~3 8~~ | ~~5 4¾~~ | ~~4~~ | ~~5 1⅞~~ | ~~3~~ | ~~2~~ | ~~3~~ | ~~3~~ | ~~9~~ | ~~2~~ | ~~3~~ | ~~50~~ | ~~1.0~~ |
| ~~4~~ | ~~6~~ | ~~4~~ | ~~5 10⅝~~ | ~~5~~ | ~~6 4¼~~ | ~~3~~ | ~~2~~ | ~~3~~ | ~~3~~ | ~~9~~ | ~~2~~ | ~~3~~ | ~~68~~ | ~~1.3~~ |

(13

those which governed in the larger sizes. The general dimensions of these small flumes are given in Table V. Figure 11 shows the plan and elevation of the 6-inch framed Parshall measuring flume. Figure 12 shows the installation of the 6-inch flume in a farm lateral.

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For the 3-inch flume the rate of discharge was determined by ~~the use of~~ volumetric measurements. The 90-degree notch weir was employed ~~to~~ in the calibration of the 6-inch flume, while for the 9-inch flume the 2-foot Cipolletti weir and ~~was used for some of the tests~~ volumetric measurements were used ~~in the calibration~~.

(A) · The free flow discharge in second-feet for the 3, 6 and 9-inch flumes is given in tables VI, VII, and VIII respectively.

From the calibrations of the small flumes the following free-flow discharge formulas have been developed:

3-inch flume $Q = 0.992\, Ha^{1.547}$

6-inch " $Q = 2.06\, Ha^{1.58}$

9-inch " $Q = 3.07\, Ha^{1.53}$

where Q is the discharge in second-feet and Ha the head taken in feet at the proper gage point in the converging section as specified in table V

A → No attempt has been made to develop the submerged flow formulas for the 3 and 9-inch flumes. The computed values of the submerged flow for these two small flumes as are given in tables XX and XXII were taken from the correction diagrams Figure 14 and Figure 16. The ~~computed~~ computed values of the submerged flow for the 6-inch flume as given in table XXI are based on the formula

$$Q = 2.06\, Ha^{1.58} - \left\{ \frac{0.0772\, Ha^{2.22}}{\left(\frac{Ha+10}{10} - K\right)^{1.44}} - \frac{Ha - 0.184}{8.17} \right\}$$

where Q = The discharge in second-feet

Ha = The upper head in feet

K = The ratio, throat head to upper head, or Hb/Ha, expressed as a decimal.

Over

~~For convenience the submerged-flow correction factor for the 6-inch flume is~~

The submerged-flow correction factor C for the 6-inch flume is given in the diagram, Figure 15.

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 [illegible].

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-

Replace with diagram

see Bulletin # 1683 p 12

also 3" and 9" flumes.

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 |

(1) This may need considerable editing

Page 33 To assist in the selection of the proper size of flume to meet certain requirements ~~the loss of head there is given~~ diagram shown on figure 18 is given. [This loss of head is the difference in feet vertically between the water surface above and below the structure.] The use of this diagram may best be illustrated by an example. ~~as follows~~; Let it be required to find the loss of head through a 2-foot flume operating at a submergence of 85 percent and discharging 20 second-feet of water. Enter the diagram at the lower left and follow vertically on the line 85 until the curved discharge line 20 is reached. At this point move horizontally to the right until the sloping line 2 is intersected and then drop vertically to the base line and note the loss of head to be 0.33 foot

( ~~See bottom page 34~~ )

(2)

~~The following problem is given to [illegible]~~ example?

The following discussion is presented citing a ~~more or less~~ practical case as would be found in the field in ~~the~~ selecting ~~of the proper~~ the size and setting ~~of~~ the Parshall measuring flume ~~to~~ best ~~suited~~ suited to meet the following requirements; assume that ~~the~~ channel is 10 feet wide with ~~having~~ the inside ~~side~~ slope of the banks ~~are~~ 1 to 1, the depth of water ~~being~~ 2 feet and the maximum discharge to be measured ~~being~~ 50 second-feet. ~~of water.~~ It is required to select the proper size of flume, to determine its proper setting in elevation with reference to the grade of the channel and to approximate the condition of flow up-stream from the flume after it has been installed.

Generally, the width of the throat of the flume will be from one-third to one half the width of the channel, however, for wide shallow channels or deep narrow ones ~~are often found in [illegible]~~ this general statement would not hold.

③

The size of channel, depth of water, extent of free board, together with other limiting factors must all be considered in the final selection of the most practical size of structure. For the 10-foot channel, as assumed, the proper ~~size of flume~~ width of throat will probably be ~~either~~ 3, 4 or 5 feet.

④ Jan 36 - Bob will be 70.

~~either a 3, 4 or 5-foot flume~~. From the diagram, Fig. 18, for the 3-foot flume operating at a limiting submergence of 70 percent and a discharge of 50 second-feet it will be noted that the loss of head through the structure will be 0.86 foot, or about 10 1/4 inches. For this condition of flow the depth of water ~~surface~~ upstream from the flume, when discharging the 50 second-feet, will be 0.86 foot greater than that downstream or ~~[illegible]~~ a total ~~[illegible]~~ of 2.86 feet. On this basis it will be necessary to ~~[illegible]~~ examine into the matter of a safe free board for that portion of the channel upstream from the flume, as well as, to determine whether or not this increase in depth will interfere with diverting ~~the~~ flow through the head gates if ~~[illegible]~~ the location of the flume is near the point of diversion. If a submergence of 90 percent is taken as the limit, then the loss of head will be reduced to about 0.32 foot. It is to be pointed out for the case of this high submergence, ~~[illegible]~~, that both the Ha and Hb heads will have to be observed in order to compute the discharge, whereas, for the submergence of 70 percent only the Ha head would be required. ¶ Investigating a 4-foot flume setting for 70 percent submergence and a discharge of 50 second feet, it is found from the diagram that the loss of head will be 0.70 foot or about 8½ inches. The loss of head through the 5-foot flume for these same conditions will be 0.60 foot or about 7¼ inches. Comparing these values of loss of head it will be noted that by increasing the size of flume from 3 to 5 feet the loss of head decreased from .86 to .60 foot ~~[illegible]~~ or ~~an equivalent of~~ about 3 inches. It is usually found that a saving of an inch or so in the loss of head does not warrant the selection of the larger flume because of the increased cost of the structure. It is recommended in the selection of the proper size of flume that possibly ~~a top~~ ~~percent limit of~~ a submergence of 60 percent be taken as the more practical limit to use in approximating the size of structure because for this degree of submergence a moderate range in the fluctuation of the depth of water down stream from the flume may be tolerated without exceeding the free flow limit of submergence of 70 percent.

providing it is intended to operate the flume as a single head device

6/

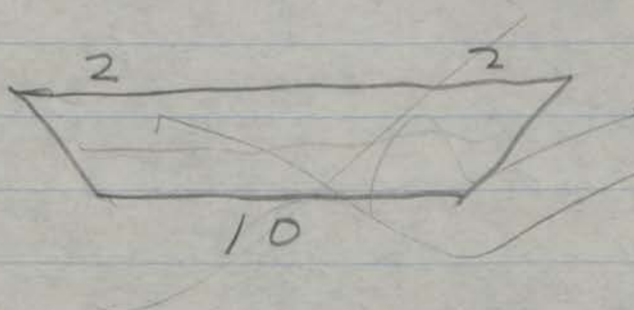
It appears that the use of the ~~may appear~~
~~From the above discussion it is assumed~~
~~that the~~ 3-foot flume would result in too great a loss of head, and by the use of the 5-foot flume when operating under like conditions of a flow of 50 second-feet and 70 percent submergence, a saving in loss of head of 3 inches ~~may~~ would be gained. In either case this saving of 3 inches may not be of any great importance, whereas, the cost of the 3 and 5-foot flumes would differ materially. If conditions will permit, it is obvious that the 3-foot structure should be selected, primarily from a cost standpoint, however it must be appreciated that when passing 50 second-feet through a ~~3-foot~~ throat 3 feet wide the velocity of the stream would be relatively high and adequate protection against scour downstream from the structure would be required. As the size of the flume increases the loss of head will decrease, and likewise the velocity of the stream through the throat will be less. If the 8-foot flume was considered the

loss of head would be reduced to slightly less than 6 inches and the velocity likewise lessened, but the saving in loss of head, no doubt, would not warrant the extra expense of construction. The 3-foot flume, unless conditions of operation are well suited, may be considered too small because of the greatest loss of head and maximum scouring effect. The 5-foot flume will probably be more acceptable because of the lesser loss in head and the more favorable velocity through the throat. The 8-foot flume is best suited because of the least loss of head and at the same time having the most favorable exit velocity of the stream in passing through the structure. This large flume with favorable hydraulic characteristics will be objectional from the standpoint of cost, and it is obvious therefore

(a)

that a compromise must be effected which, for the sake of argument it is assumed, will place the choice between, say the 4 and 5-foot flumes. Further examination more into the limitations of this hypothetical case may in the final analysis

(a) The 8-foot flume from the standpoint of loss of head and velocity through the structure is ~~best~~ the best suited, but because of the greater cost would ~~may~~ be found objectionable and therefore ~~the selection of made~~ ~~a compromise made in the use of a smaller flume as a more practical size~~ the smaller flume would be selected as a more practical size.




$\frac{50}{24} =$

~~definitely fix the selection of the~~ 5-foot ~~flume.~~

The setting of the flume to ~~a~~ the proper elevation with respect to the channel is a matter of importance in order to have the device operate as previously discussed. From table III the Ha head for a free-flow discharge of 50 second-feet through a 5-foot flume is found to be 1.78 feet. Since the degree of submergence is taken as the ratio, Hb/Ha, it is readily determined that the Hb gage reading would be about 1.25 feet for this limiting submergence of 70 percent. In figure 19 is shown the depth D or water depth down stream from the structure. This depth minus the value of Hb will give the elevation of the crest above the bottom of the channel. For this particular ~~free flow~~ case ~~[illegible]~~ this elevation will be 2.00 - 1.25 or 0.75 foot. Th~~is~~e crest of the 5-foot flume set 0.75 foot or 9 inches above the bed of the channel will increase the water depth upstream ~~only~~ about 7 inches.

Conditions of the channel or limiting

(7) 9/

restrictions of operation may in some cases require that the discharge through the flume be submerged. It has been found by experiment that the degree of submergence should not exceed about 95 percent and ~~therefore~~ it may therefore be necessary to very carefully determine the crest elevation of the structure in order to limit the submergence at a point not to exceed 95 percent.

~~How is this setting made so the sub will not be more than 95%?~~

charges, because the depth in the channel below the flume may increase at a faster rate than the depth in the converging section. Figure 17 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.

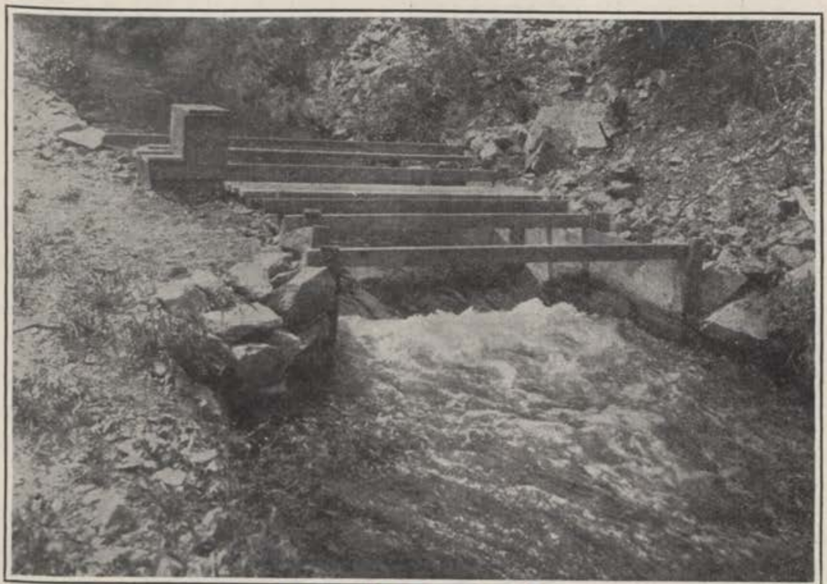


**Figure 12.—Six-foot Improved Venturi Flume Discharging 64 Second-feet with a Submergence of 60 Percent. Farmers' Ditch, Boulder, Colorado.**

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

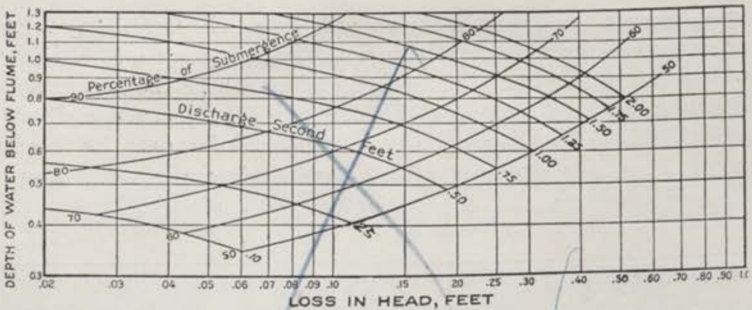



**Figure 13.—Loss-of-head Diagram for the 6-inch Improved Venturi Flume.**

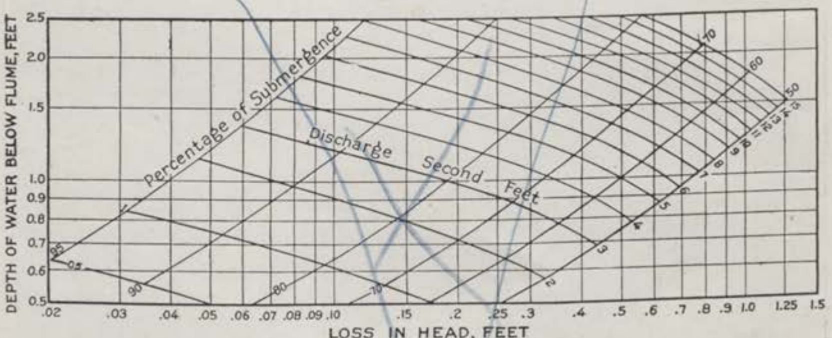



**Figure 14.—Loss-of-head Diagram for the 1-foot Improved Venturi Flume.**

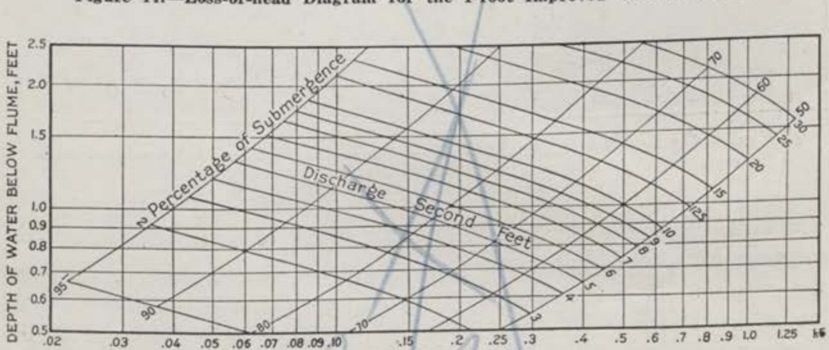



**Figure 15.—Loss-of-head Diagram for the 2-foot Improved Venturi Flume.**

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

Replace with one diagram, similar to Fig. 23 - Sta Bul 386, loss of head for 1-2-3-4-5-6-7 and 8, the following:

Figs 13, 14, 15, 16, 17, 18 and 19, also

Tables 9, 10, 11, 12, 13, 14, and 15

Add loss of head diagram for the 3, 6 and 9 inch

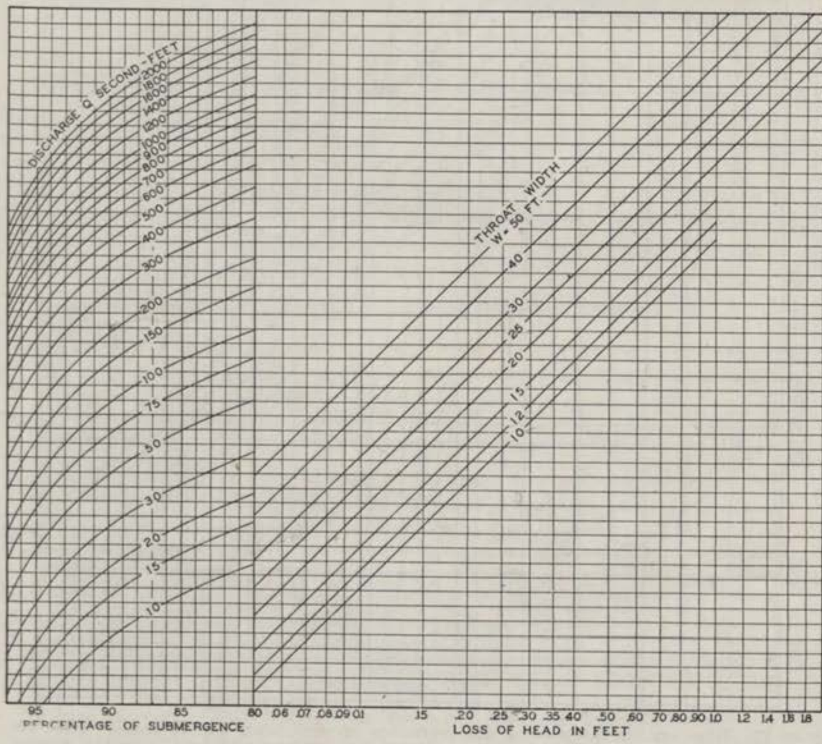



**Figure 23.—Diagram for determining the total loss of head thru large Parshall Measuring Flumes.**

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 | 0.36 | .... | .... | .... | .... | .... |
| 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 |

3. 6 and 9 inch

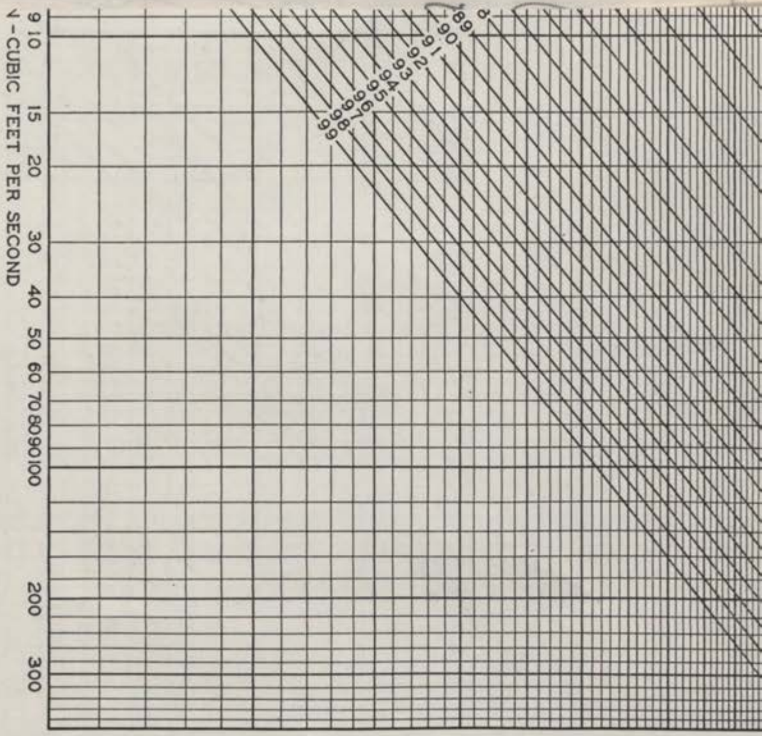



Figure 22.—Diagram for determining the correction in second-feet per 10 feet of cr… submerged-flow discharge. (This diagram, enlarged to a scale of 10.5 by 17.5 inches, … on heavy stock, is available at 25 cents per copy upon application to the Colorado A… tural Experiment Station.

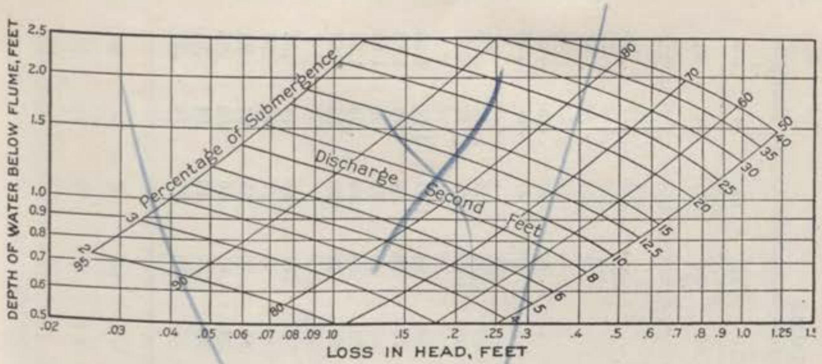



**Figure 16.—Loss-of-head Diagram for the 3-foot Improved Venturi Flume.**

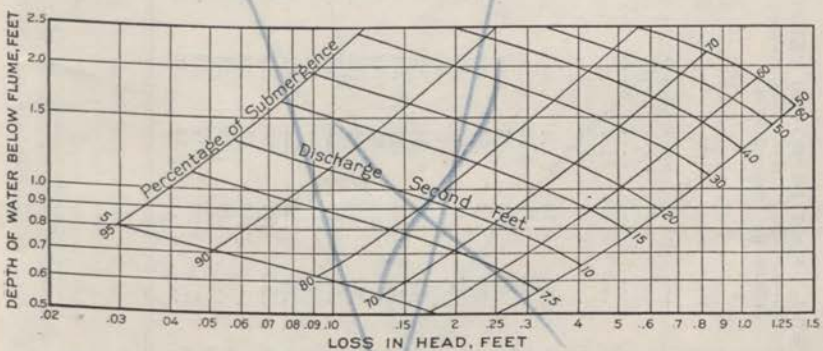



**Figure 17.—Loss-of-head Diagram for the 4-foot Improved Venturi Flume.**

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

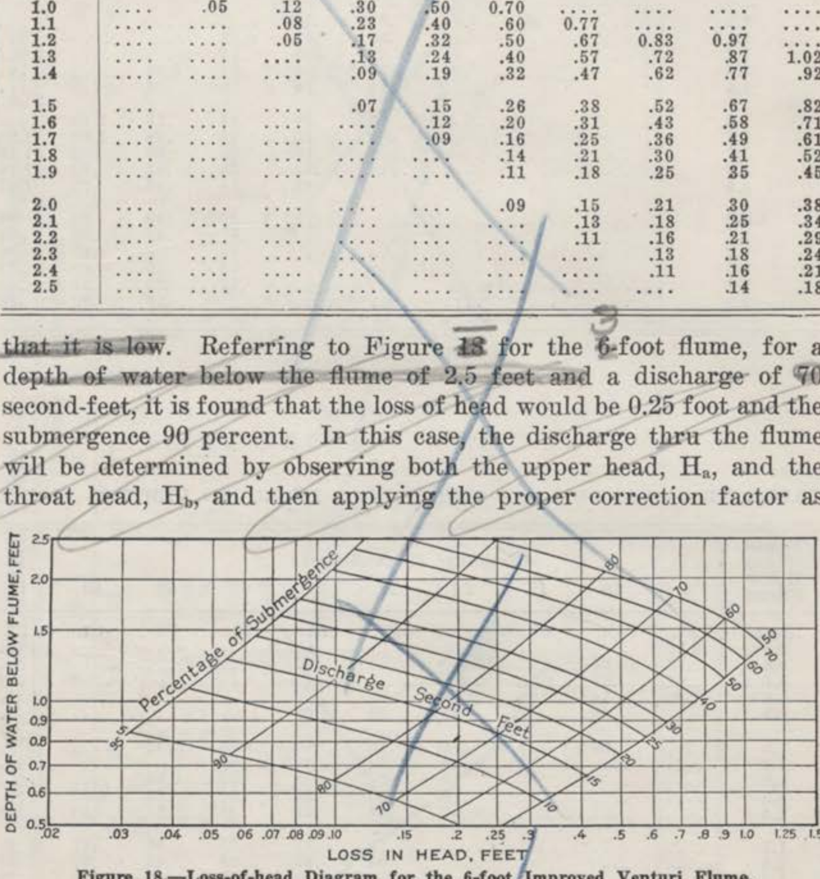



Figure 18.—Loss-of-head Diagram for the 6-foot Improved Venturi Flume.

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

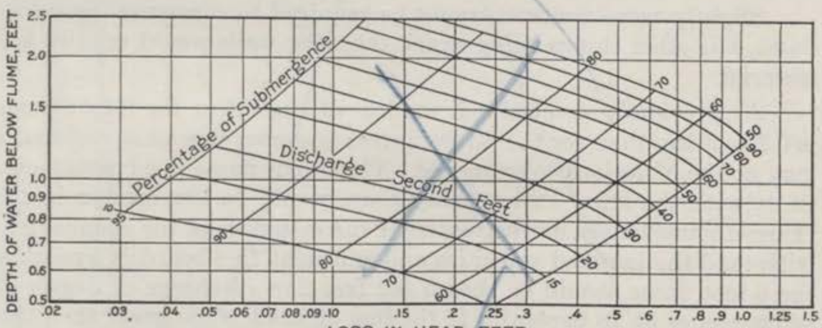



**Figure 19.—Loss-of-head Diagram for the 8-foot Improved Venturi Flume.**

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

Paragraph ending top of page 43

¶ Ordinarily when using the Parshall measuring flumes of the smaller sizes to measure farm deliveries it is recommended that the device should not be placed two close to the turn out gate. However, because of very limited or cramped conditions such flumes have been located close up to the head gate as shown in Fig 20. In this case a concrete 1-foot flume on the Lake Canal near Fort Collins was set where the upper end of the converging section is about 12 feet downstream from the head gate. This flume has operated very satisfactorily 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 11 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

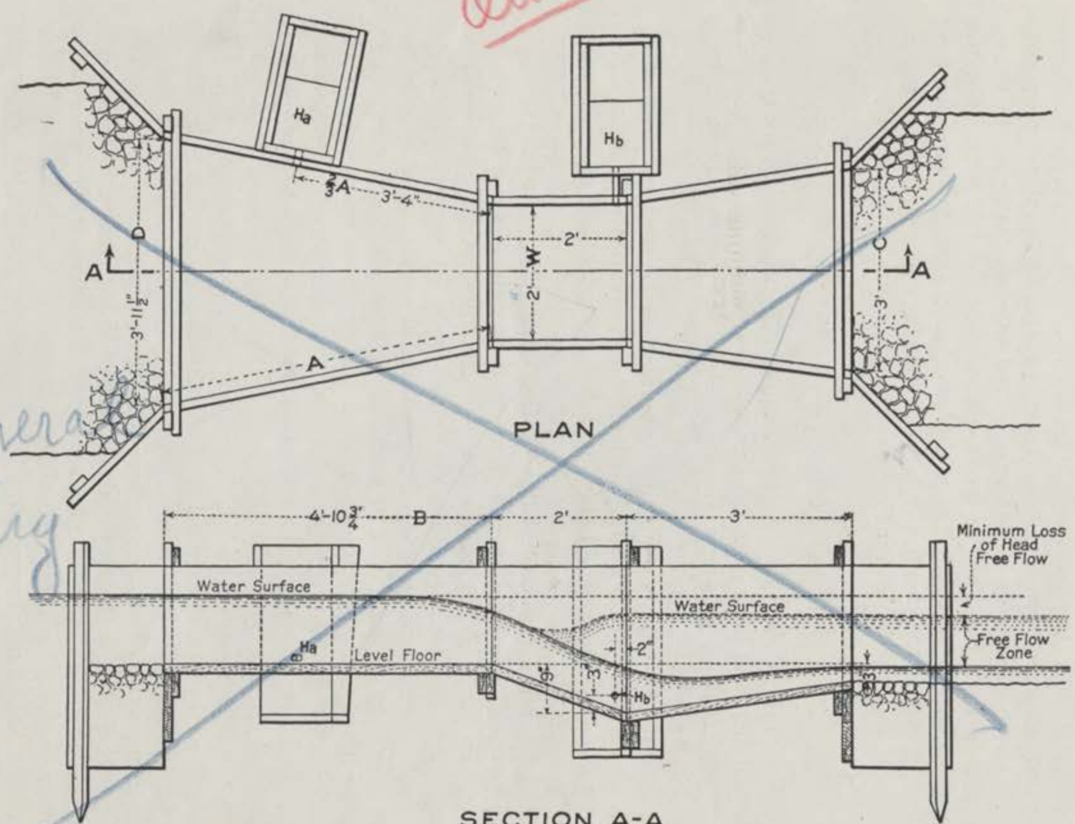



**Figure 20.—Plan and Elevation of 2-foot Improved Venturi Flume Showing Suggestions as to Construction.**

(X) It is desirable to use an angle iron crest for the framed structure. This metal piece is to be dapped in at the down stream end of the level floor of the converging section and made flush with the floor line. This should be set before placing the throat floor.

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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 12. 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 . 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

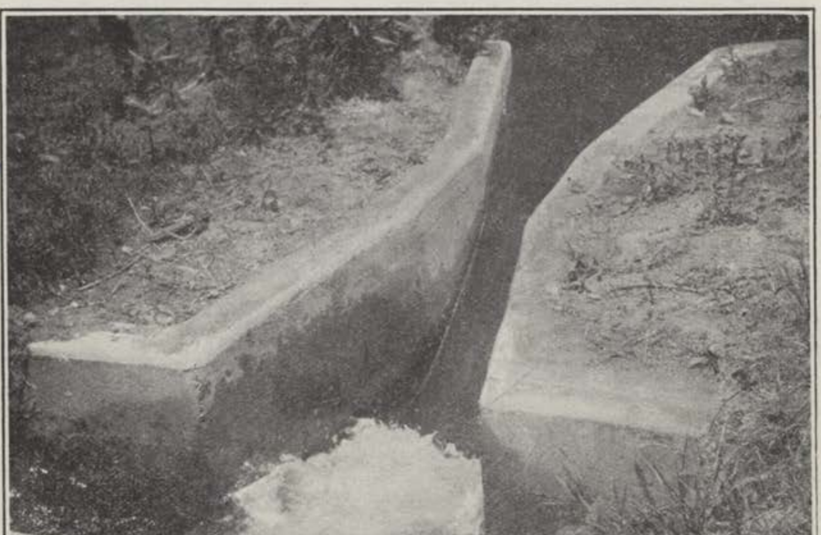

Figure 21.—One-foot Reinforced Concrete Improved Venturi Flume, Free-flow Discharge of 4 Second-feet. Lake Canal, near Fort Collins, Colorado.

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 1. A typical reinforced concrete flume is shown in Fig. 23

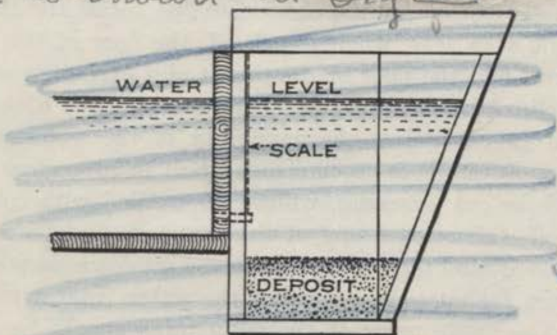


**Figure 22.—Suggested Construction of Open Stilling-well with Staff Gage or Scale Inside the Well.**

For the ~~6-inch and 1-foot~~ 3, 6, 9 or 12-inch 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 2. 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.

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~~Omit figure 22 and refer directly to Fig 1 - general drawing~~

Bottom of

Page - 48 (B)

The metal flume has been used in sizes up to 4-foot. Fig. 27 shows a 3-foot Parshall measuring flume installed in the outlet of one of the main sewer lines of the city of Colorado Springs.

~~Page - 45 - end of H middle of page~~

K Figure 24 shows a flow of 13 second-feet passing through a 3-foot concrete flume at a submergence of about 50 percent. Where the flow is not submerged it has been found a practical expedient to place the Ha staff gage at the proper point on the wall of the converging section as shown. Figure 25 also shows ~~the flow passing through~~ a 3-foot concrete flume operating ~~flume~~ at a submergence of about 50 percent.

for small flows

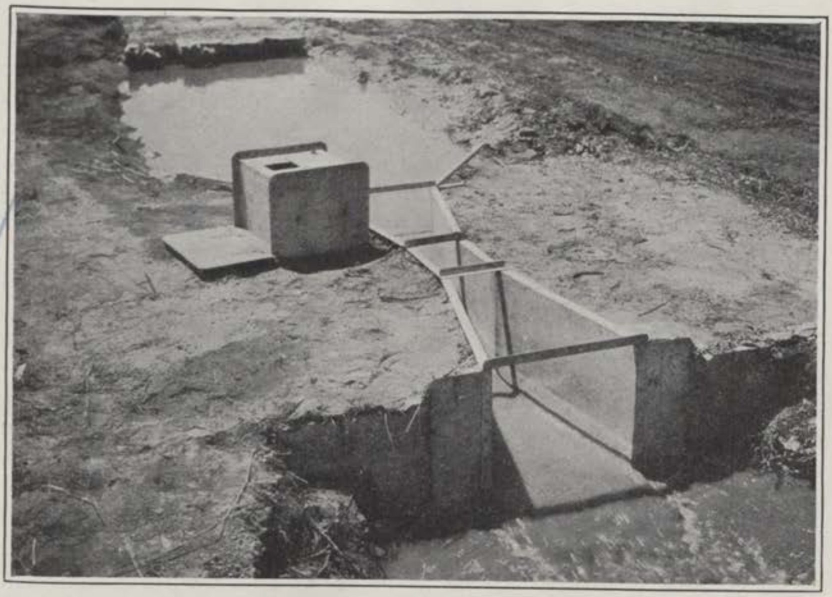

**Figure 23.—Six-inch Improved Venturi Flume Constructed of Sheet Metal, with Stilling-well Equipped with Discharge Indicating Tape Graduated in Second-feet. Typical Field Installation on Farm Lateral.**

**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

Maybe we can get a better picture—

**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

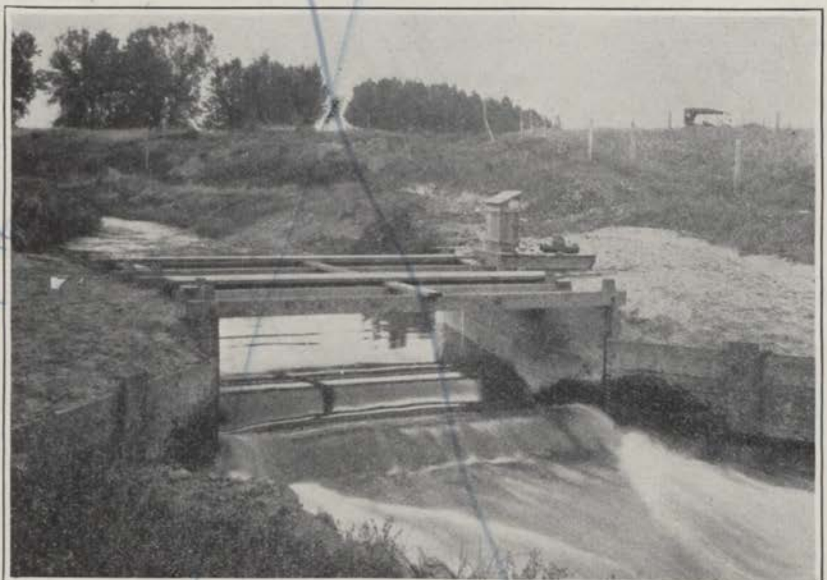

**Figure 26.—Twelve-foot Improved Venturi Flume Discharging about 40 Second-feet, Free-flow. Box Elder Creek, near Fort Collins, Colorado.**

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.

(A) 53

In 1932 further tests were made ~~in~~ the laboratory on the standard 2-foot Parshall measuring flume where there movable partitions were set with the downstream ends against the up stream ends of the converging section, or set apart ~~over a distance~~ 6 3.96 feet ~~3 feet 11½ inches between the partition~~.

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 | | | |
| | | | Width of approach channel 3.96 feet (Bellvue Laboratory, 1932) * | | | | |
| 1.50+ | 15.01 | 15.00 | +0.01 | +0.1 | 6.14 | 2.44 | 296 |
| 1.00 | 7.95 | 8.00 | −0.05 | −0.6 | 4.08 | 1.95 | 295 |
| 0.55 | 3.01 | 3.17 | −0.16 | −5.3 | 2.22 | 1.36 | 293 |
| | | | | Mean −1.9 | | | |

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Parshall Measuring

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 (Parshall Measuring) | | | | 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 | ... |

To be Recomputed based on new diagram.

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 X 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

Ha

Accessories

( ~~Staff gage~~ — )

¶ * For important installations of the Parshall measuring flume where permanent records of the flow are desired there has been designed a special double head indicating and recording instrument for use in connection with this type of measuring device. Field use has proven this ~~instrument~~ recorder to be of practical design and well suited to the purpose.

( see page 31 - 38b - and prepare text for revised bulletin as corrected)

This instrument Figure 28 has a etc — — —

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⊗ For higher heads it has been found inadvisable to use the staff gage placed on the inside face of the flume.

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 Figure 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

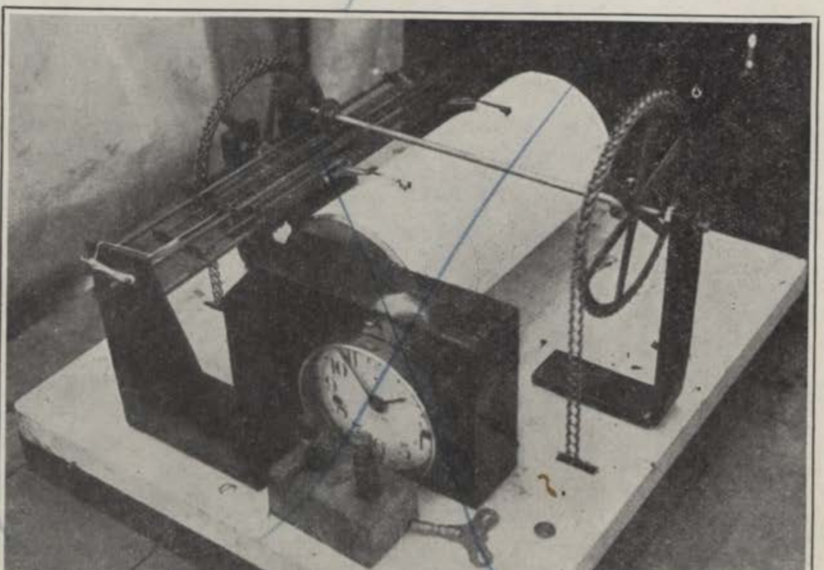

**Figure 27.—The Improved Venturi Flume Register which Records Graphically the Upper Head, $H_a$, and the Difference in Head, $H_a - H_b$.**

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

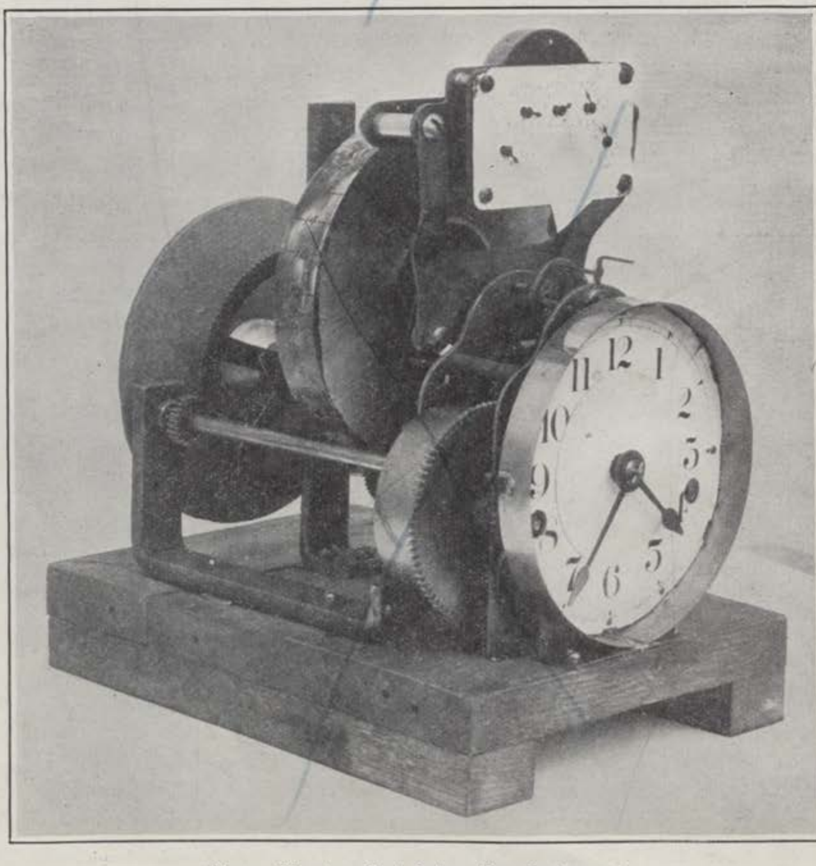

Figure 28.—Acre-foot Integrating Instrument.

Omit
and replace with double head recorder
~~also~~ integrator

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

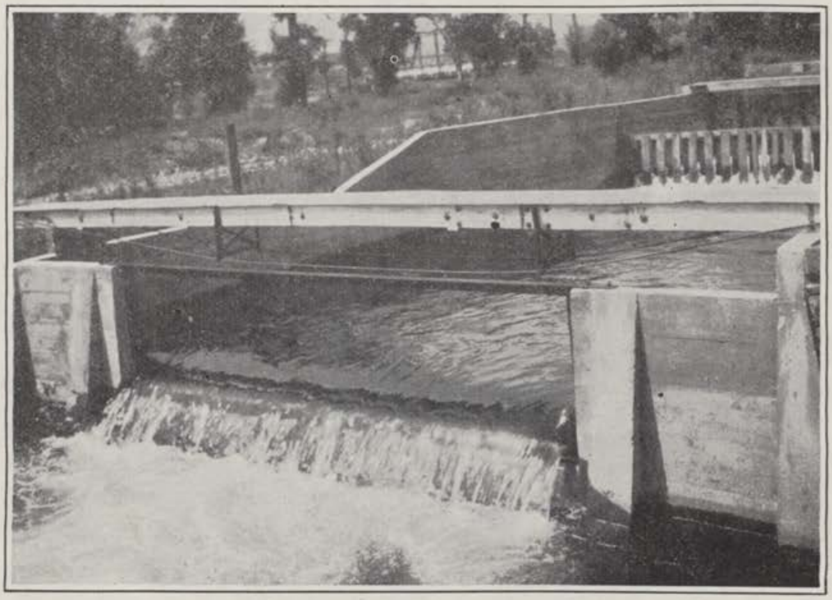

Figure 29.—Fifteen-foot Standard Rectangular Weir at the Bellvue Hydraulic Laboratory. Discharge 40 Second-feet. Actual Length of Crest, 14.98 feet.

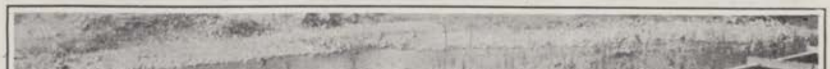

Figure 30.—Weir Basin at the Bellvue Hydraulic Laboratory with a 4-foot Rectangular Weir Mounted on the 15-foot Crest. The Headon Weirs Determined by Two Hookgages as Shown. Discharge Over the 4-foot Weir, 7.67 Second-feet.

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.

(X)
4 The calibration of the 3 and 9-inch flumes was made under laboratory settings. In both cases the experimental flumes were made of galvanised sheet metal carefully dimensioned.

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~~ Parshall measuring 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. and for this reason it is recommended to provide the $H_b$ stilling well to gain the full efficiency of the flume.

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 4 (?)

# Original Free Flow Data For 3-Inch ~~Improved Venturi Flume~~ Parshall Measuring Flume, 1930

| Test | Flume Heads Ha (Feet) | Flume Heads Hb (Feet) | Ratio Hb/Ha | Head on Weir | Discharge Obs (Sec Ft) | Discharge Comp (Sec Ft) | Diff (Sec Ft) | Deviation (Percent) |
|---|---|---|---|---|---|---|---|---|
| 8201 | 1.110 | 0.667 | 0.600 | V.M* | 1.181 | 1.166 | -0.015 | 1.3 |
| 8211 | 1.049 | .633 | .603 | V.M. | 1.070 | 1.068 | -0.002 | 0.2 |
| 8212 | 1.048 | .634 | .604 | V.M | 1.068 | 1.067 | -0.001 | 0.1 |
| 8173 | .988 | .591 | .598 | V.M. | .974 | .974 | .000 | 0.0 |
| 8213 | .951 | .577 | .607 | V.M | .914 | .918 | +.004 | 0.4 |
| 8210 | .949 | .573 | .604 | V.M | .912 | .915 | +.003 | 0.3 |
| 8174 | .897 | .539 | .601 | V.M. | .840 | .838 | -.002 | 0.2 |
| 8209 | .849 | .511 | .603 | V.M. | .764 | .770 | +.006 | 0.8 |
| 8175 | .797 | .475 | .596 | V.M. | .697 | .698 | +.001 | 0.1 |
| 8208 | .748 | .447 | .598 | V.M. | .624 | .633 | +.009 | 1.4 |
| 8187 | .704 | .417 | .592 | V.M | .574 | .576 | +.002 | 0.4 |
| 8176 | .700 | .408 | .583 | V.M. | .568 | .571 | +.003 ~~+.004~~ | 0.5 ~~0.7~~ |
| 8207 | .651 | .379 | .582 | V.M | .512 | .510 | -.002 | 0.4 ~~0.2~~ |
| 8177 | .600 | .335 | .558 | V.M. | .447 | .450 | +.003 | 0.7 |
| 8206 | .550 | .302 | .549 | V.M. | .390 | .393 | +.003 | 0.8 |
| 8178 | .500 | .255 | .510 | V.M. | .341 | .339 ~~.340~~ | -.002 | 0.6 ~~0.3~~ |
| 8205 | .451 | .220 | .488 | V.M. | .290 | .290 | .000 | 0.0 |
| 8179 | .400 | .170 | .425 | V.M. | .244 | .240 | -.003 ~~-.004~~ | 1.2 ~~1.6~~ |
| 8191 | .399 | .252 | .632 | V.M. | .237 | .240 ~~.239~~ | +.003 | 1.3 ~~0.8~~ |
| 8204 | .350 | .133 | .380 | V.M. | .197 | .196 | -.001 | 0.5 |
| 8180 | .300 | .076 | .253 | V.M. | .156 | .154 | -.002 | 1.3 |
| 8203 | .249 | .035 | .141 | V.M | .116 | .116 ~~.115~~ | -.000 | 0.0 |
| 8181 | .201 | -.025 | — | V.M | .083 | .083 | .000 | 0.0 |
| 8202 | .160 | — | — | V.M. | .058 | .058 | .000 | 0.0 |
| 8182 | .100 | — | — | V.M. | .028 | .028 | .000 | 0.0 |

* Volumetric measurements

Hydraulic Laboratory, Fort Collins.

OK

✓ 3/21/35

A BILL

for

AN ACT

To Regulate the Use of Artesian and Deep wells and to Prevent the Waste and Contamination of Subterranean Waters in this State, and Prescribing Penalties for a Violation of the Provisions Hereof.

Be It Enacted by the General Assembly of the State of Colorado:

SECTION 1. That Chapter 114, Compiled Laws of Colorado, 1921 be and the same is hereby repealed.

SECTION 2. Artesian well defined.- An artesian well is defined for the purposes of this act, to be an artificial well penetrating one or more water bearing formations which exist under pressure such that, if properly cased, the waters of any one formation will rise above the bottom of the first overlying and confining impervious stratum; Provided that nothing in this act shall be construed to apply to water flowing from a mining shaft.

SECTION 3. Deep Well defined.- A deep well is defined for the purposes of this act to be an artificial well which penetrates consolidated material such as shale, sandstone or other rock before encountering one or more water yielding formations. The water pressure may or may not be sufficient to cause the water in that particular water bearing stratum to rise above the point at which water is first encountered. This includes such wells drilled through more than one water yielding formation where water might pass from an upper to a lower stratum if not tightly cased.

SECTION 4. Wells must be properly cased and controlled.- Any artesian well which is not tightly cased to prevent the escape of water into a pervious stratum, either containing water or not containing water or provided with a valve or other mechanical contrivance that will effectively prevent and control the artesian flow of water at the ground surface is hereby declared to be a public nuisance. Any deep well which is not properly cased to prevent contamination of a potable water by salts or polluted waters originating from an underground or surface source is hereby considered to be a public nuisance. Any person, company, corporation, municipality or association owning, controlling or occupying the land upon which such well is situated, who causes, permits or suffers such public nuisance or suffers or permits it to remain or continue 30 days or such other reasonable specified time after notification from the state engineer to place such well in proper order is guilty of a misdemeanor.

SECTION 5. Unnecessary flow and waste forbidden.- Any person, company, corporation, municipality or association owning, controlling,

# Table — Original Submerged Flow Data
## 3-Inch Parshall Measuring Flume 1930

✓ 3/21/35

| Test | Flume Heads Ha | Flume Heads Hb | Ratio Hb/Ha | Loss of Head Obs | Loss of Head Comp | Head on Weir | Discharge Obs. | Discharge Comp | Diff. | Deviation |
|---|---|---|---|---|---|---|---|---|---|---|
| | Feet | Feet | | | | Feet | Sec. Ft. | Sec. Ft | Sec. Ft | Percent |
| 8186 | 1.000 | 0.951 | 0.951 | 0.04 | 0.04 | V.M * | 0.506 | 0.510 ** | +0.004 | 0.8 |
| 83 | 1.000 | .906 | .906 | — | .08 | V.M | .657 | .657 | .000 | 0.0 |
| 84 | .999 | .810 | .810 | .23 | .24 | V.M | .826 | .828 | +.002 | 0.2 |
| 85 | .999 | .698 | .698 | .41 | .42 | V.M | .940 | .940 | .000 | 0.0 |
| 95 | .702 | .665 | .947 | .02 | .03 | V.M | .296 | .306 | +.010 | 3.4 |
| 8190 | .704 | .633 | .899 | .07 | .06 | V.M | .404 | .404 | .000 | 0.0 |
| 89 | .700 | .563 | .804 | .15 | .15 | V.M | .491 | .493 | +.002 | 0.4 |
| 88 | .701 | .510 | .727 | .23 | .23 | V.M | .530 | .538 | +.008 | 1.5 |
| 94 | .401 | .376 | .938 | .02 | — | V.M | .138 | .145 | +.007 | 5.1 |
| 93 | .401 | .341 | .850 | .06 | .06 | V.M | .204 | .201 | −.003 | 1.5 |
| 8192 | .400 | .309 | .772 | .09 | .09 | V.M | .221 | .223 | +.002 | 0.9 |
| 8191 | .399 | .252 | .632 | .14 | .17 | V.M | .237 | .240 | +.003 | 1.3 |
| 8197 | .202 | .195 | .965 | .01 | – | V.M. | .038 | .039 | +.001 | 2.6 |
| 8200 | .198 | .179 | .904 | .02 | – | V.M. | .056 | .060 | +.004 | 7.1 |
| 8196 | .201 | .169 | .841 | .03 | – | V.M | .074 | .073 | −.001 | 1.4 |
| 8199 | .199 | .151 | .759 | .05 | – | V.M | .078 | .078 | .000 | 0.0 |
| 8198 | .200 | .141 | .705 | .05 | – | V.M | .080 | .081 | −.001 | 1.2 |

* Volumetric measure… ments, Hydraulic Laboratory, Fort Collins

** The computed dischar… ge determined from diagram Fig 14

Table—Original Submerged Flow Data for 9-inch Parshall Measuring Flume, 1930

| Test | Flume Heads Ha | Flume Heads Hb | Ratio Hb/Ha | Head on Weir | Discharge Obs. | Discharge Comp | Diff. | Deviation |
|---|---|---|---|---|---|---|---|---|
| | Feet | Feet | | Feet | Sec. Ft | Sec. Ft | Sec. Ft | Percent |
| 8500 | 0.233 | 0.164 | .704 | 0.122 | 0.30 | .30* | .00 | 0.0 |
| 8501 | .300 | .272 | .906 | .122 | .30 | .30 | -.00 | 0.0 |
| 02 | .242 | .175 | .723 | .121 | .29 | .31 | +.02 | 6.9 |
| 03 | .291 | .263 | .904 | .120 | .29 | .28 | -.01 | 3.4 |
| 04 | .271 | .232 | .856 | .120 | .29 | .29 | .00 | 0.0 |
| 05 | .252 | .202 | .802 | .119 | .29 | .29 | .00 | 0.0 |
| 06 | .244 | .187 | .766 | .119 | .29 | .30 | +.01 | 3.4 |
| 07 | .343 | .322 | .939 | .122 | .30 | .32 | +.02 | 6.7 |
| 08 | .226 | .144 | .637 | .122 | .30 | .29 | -.01 | 3.3 |
| 09 | .627 | .544 | .869 | .294 | 1.06 | 1.13 | +.07 | 6.6 |
| 8510 | .527 | .354 | .672 | .300 | 1.10 | 1.11 | +.01 | 0.9 |
| 11 | .578 | .464 | .802 | .296 | 1.08 | 1.16 | +.08 | 7.4 |
| 12 | .512 | .331 | .646 | .292 | 1.05 | 1.08 | +.03 | 2.8 |
| 13 | .625 | 548 | .877 | .285 | 1.02 | 1.11 | +.09 | 8.8 |
| 14 | .745 | .693 | .931 | .302 | 1.11 | 1.12 | +.01 | 0.9 |
| 8515 | .528 | .375 | .710 | .297 | 1.08 | 1.09 | +.01 | 0.9 |
| 16 | .525 | .388 | .739 | .294 | 1.06 | 1.06 | .00 | 0.0 |
| 17 | .545 | .433 | .794 | .300 | 1.10 | 1.08 | -.02 | 1.8 |
| 18 | .951 | .794 | .835 | .515 | 2.48 | 2.41 | -.07 | 2.8 |
| 19 | .993 | .857 | .864 | .513 | 2.46 | 2.39 | -.07 | 2.8 |
| 8520 | 1.044 | .927 | .888 | .500 | 2.37 | 2.38 | +.01 | 0.4 |
| 21 | 1.206 | 1.100 | .912 | .508 | 2.43 | 2.64 | +.21 | 8.6 |
| 22 | 1.257 | 1.175 | .934 | .498 | 2.36 | 2.45 | +.09 | 3.8 |
| 23 | .866 | .545 | .630 | .506 | 2.41 | 2.42 | +.01 | 0.4 |
| 24 | .913 | .721 | .790 | .512 | 2.45 | 2.47 | +.02 | 0.8 |
| 8526 | .855 | .577 | .675 | .499 | 2.36 | 2.37 | +.01 | 0.4 |
| 27 | .940 | .772 | .821 | .508 | 2.43 | 2.43 | .00 | 0.0 |
| 28 | .924 | .753 | .815 | .500 | 2.37 | 2.39 | +.02 | 0.8 |
| 29 | .859 | .618 | .720 | .497 | 2.35 | 2.33 | -.02 | 0.9 |
| 31 | .886 | .697 | .786 | .499 | 2.36 | 2.33 | -.03 | 1.3 |
| 8533 | .556 | .413 | .743 | .313 | 1.17 | 1.16 | -.01 | 0.9 |
| 34 | .641 | .548 | .855 | .309 | 1.15 | 1.23 | +.08 | 7.0 |
| 35 | .309 | .240 | .777 | .168 | .46 | .44 | -.02 | 4.3 |
| 36 | .446 | .419 | .939 | .167 | .46 | .47 | +.01 | 2.2 |
| 37 | .334 | .267 | .799 | .169 | .47 | .48 | +.01 | 2.1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 37 | .334 | .267 | .799 | .169 | .47 | .48 | +.01 | 2.1 |
| | | | | | | | | |
| 8538 | .446 | .292 | .655 | .263 | .91 | .86 | -.05 | 5.5 |
| 39 | .515 | .429 | .833 | .252 | .85 | .93 | +.08 | 9.4 |
| 40 | .461 | .348 | .755 | .247 | .83 | .85 | +.02 | 2.4 |
| 41 | .787 | .672 | .854 | .380 | 1.57 | 1.73 | +.16 | 10.2 |
| 42 | .648 | .456 | .704 | .369 | 1.49 | 1.51 | +.02 | 1.3 |
| | | | | | | | | |
| 8543 | .666 | .544 | .817 | .374 | 1.53 | 1.43 | -.10 | 6.5 |
| 44 | .820 | .734 | .895 | .376 | 1.54 | 1.55 | +.01 | 0.6 |
| 45 | .869 | .800 | .920 | .375 | 1.54 | 1.52 | -.02 | 1.3 |
| 46 | .519 | .406 | .782 | .271 | .95 | 1.01 | +.06 | 6.3 |
| 47 | .632 | .576 | .911 | .270 | .94 | .96 | +.02 | 2.1 |
| | | | | | | | | |
| 8548 | .253 | .216 | .853 | .116 | .28 | .27 | -.01 | 3.6 |
| 8549 | .272 | .244 | .897 | .116 | .28 | .27 | -.01 | 3.6 |
| | | | ✓ | | ✓ | ✓ | ✓ | ✓ |

* The computed discharge determined from diagram Fig. —.

✓

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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. | Percent |
| 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 |

Data on 3" and 9" flumes.

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 | .935 | .... | .... | .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 VENTU~~RI 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 | | 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. | Percent |
| 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 VENTU~~RI 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 | 20.98 | 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 |

Blue → to free flow table.



## 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 $H_b/H_a$ | 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 |
| 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 | | Differ-ence | Devia-tion |
|---|---|---|---|---|---|---|---|---|---|---|
| | $H_a$ | $H_b$ | | 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 | Percent |
| 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 |
| 7645 | .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 |
| 7666 | .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 | 2.5 |
| 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 | .750 | 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 $H_b/H_a$ | 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 |
| 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 $H_a$ | Flume Heads $H_b$ | Ratio $H_b/H_a$ | Loss of Head Obs. | Loss of Head Comp. | Head on Weir | Discharge Obs. | Discharge Comp. | Difference | Deviation |
|---|---|---|---|---|---|---|---|---|---|---|
| | 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 $H_a$ | 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 |
| 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 |

Table – Original Free Flow Data for 9-inch Parshall Measuring Flume, 1930

| Test | Flume Heads Ha | Flume Heads Hb | Ratio Hb/Ha | Head on Weir | Discharge Obs | Discharge Comp | Diff | Deviation |
|---|---|---|---|---|---|---|---|---|
| | Feet | Feet | | Feet | Sec. Ft. | Sec. Ft | Sec. Ft | Percent |
| 7999 | 0.113 | — | — | V.M. | 0.109 | .109 | .000 | 0.0 |
| 8000 | .210 | — | — | V.M | .278 | .282 | +.004 | 1.4 |
| 8001 | .310 | — | — | V.M | .501 | .513 | +.012 | 2.4 |
| 8002 | .494 | — | — | V.M | 1.041 | 1.043 | +.002 | 0.2 |
| 8003 | .717 | — | — | V.M | 1.881 | 1.845 | -.036 | 1.9 |
| 8004 | .922 | — | — | V.M | 2.763 | 2.711 | -.052 | 1.9 |
| 8005 | 1.120 | — | — | V.M | 3.696 | 3.651 | -.045 | 1.2 |
| 8006 | 1.228 | — | — | V.M | 4.260 | 4.204 | -.056 | 1.3 |
| 8007 | .443 | — | — | V.M | .884 | .884 | -.000 | 0.0 |
| 8008 | .573 | — | — | V.M | 1.320 | 1.310 | -.010 | 0.8 |
| 8009 | .744 | — | — | V.M | 1.982 | 1.952 | -.030 | 1.5 |
| 8491 | .347 | — | — | 0.199 | .596 | .608 | +.012 | 2.0 |
| 8492 | .546 | — | — | .324 | 1.234 | 1.215 | -.019 | 1.5 |
| 8493 | .727 | — | — | .435 | 1.920 | 1.885 | -.035 | 1.8 |
| 8494 | .878 | — | — | .525 | 2.550 | 2.517 | -.033 | 1.3 |
| 8495 | 1.002 | — | — | .600 | 3.130 | 3.080 | -.050 | 1.6 |
| 8496 | 1.153 | — | — | .695 | 3.910 | 3.815 | -.095 | 2.4 |
| 8497 | 1.287 | .613 | .477 | .773 | 4.607 | 4.517 | -.090 | 2.0 |
| 8498 | .374 | — | — | .217 | .675 | .682 | +.007 | 1.0 |
| 8499 | .219 | — | — | .122 | .296 | .301 | +.005 | 1.7 |
| 8525 | .853 | .486 | .570 | .505 | 2.405 | 2.407 | +.002 | 0.1 |
| 8530 | .836 | .465 | .556 | .494 | 2.328 | 2.333 | +.005 | 0.2 |
| 8532 | .540 | — | — | .316 | 1.186 | 1.194 | +.008 | 0.7 |

✓ 3/21/35 – OK ✓

Parshall, R.L. — 1932. Measuring
Water in Irrigation Channels.
U.S.D.A. Farmer's Bulletin 1683.

Parshall, R.L. – 1932 Parshall
Flumes of Large Size. Colo.
Agr. Exp. Sta. Bul. 386.

4 Copies 6"

Table — ~~See title Bul 336 page 31~~ Free Flow Discharge Through 6-Inch Parshall Measuring Flume. Based on $Q = 2.06 Ha^{1.58}$

| Upper Head Ha | 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 | | | | | | | | | | |
| .20 | | | | | | | | | | |
| .30 | | | | | | | | | | |
| .40 | | | | | | | | | | |
| .50 | | | | | | | | | | |
| .60 | | | | | | | | | | |
| .70 | | | | | | | | | | |
| .80 | | | | | | | | | | |
| .90 | | | | | | | | | | |
| 1.00 | 2.06 | 2.09 | 2.12 | 2.16 | 2.19 | 2.22 | 2.26 | 2.29 | 2.32 | 2.36 |
| 1.10 | 2.40 | 2.43 | 2.46 | 2.50 | 2.53 | 2.57 | 2.60 | 2.64 | 2.68 | 2.71 |
| 1.20 | 2.75 | 2.78 | 2.82 | 2.86 | 2.89 | 2.93 | 2.97 | 3.01 | 3.04 | 3.08 |

✓

Table — ~~Preliminary~~ Free-Flow Discharge ~~Table for the~~ Through the 9-inch ~~Improved~~ Parshall ~~Venturi~~ Measuring Flume

~~United States Department of Agriculture - Colorado Agricultural Experiment Station, Fort Collins~~

~~Computed from the formula~~ Based on $Q = 3.07\ Ha^{1.53}$

| Upper Head Ha | 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. |
| .10 | 0.09 | 0.10 | 0.12 | 0.14 | 0.15 | 0.17 | 0.19 | 0.20 | 0.22 | 0.24 |
| .20 | .26 | .28 | .30 | .32 | .35 | .37 | .39 | .41 | .44 | .46 |
| .30 | .49 | .51 | .54 | .56 | .59 | .62 | .64 | .67 | .70 | .73 |
| .40 | .76 | .78 | .81 | .84 | .87 | .90 | .94 | .97 | 1.00 | 1.03 |
| .50 | 1.06 | 1.10 | 1.13 | 1.16 | 1.20 | 1.23 | 1.26 | 1.30 | 1.33 | 1.37 |
| .60 | 1.40 | 1.44 | 1.48 | 1.51 | 1.55 | 1.59 | 1.63 | 1.66 | 1.70 | 1.74 |
| .70 | 1.78 | 1.82 | 1.86 | 1.90 | 1.94 | 1.98 | 2.02 | 2.06 | 2.10 | 2.14 |
| .80 | 2.18 | 2.22 | 2.27 | 2.31 | 2.35 | 2.39 | 2.44 | 2.48 | 2.52 | 2.57 |
| .90 | 2.61 | 2.66 | 2.70 | 2.75 | 2.79 | 2.84 | 2.88 | 2.93 | 2.98 | 3.02 |
| 1.00 | 3.07 | 3.12 | 3.17 | 3.21 | 3.26 | 3.31 | 3.36 | 3.40 | 3.45 | 3.50 |
| 1.10 | 3.55 | 3.60 | 3.65 | 3.70 | 3.75 | 3.80 | 3.85 | 3.90 | 3.95 | 4.01 |
| 1.20 | 4.06 | 4.11 | 4.16 | 4.22 | 4.27 | 4.32 | 4.37 | 4.43 | 4.48 | 4.53 |
| 1.30 | 4.59 | 4.64 | 4.69 | 4.75 | 4.80 | 4.86 | 4.92 | 4.97 | 5.03 | 5.08 |
| 1.40 | 5.14 | 5.19 | 5.25 | 5.31 | 5.37 | 5.42 | 5.48 | 5.54 | 5.59 | 5.65 |
| 1.50 | 5.71 | 5.77 | 5.83 | 5.89 | 5.94 | 6.00 | 6.06 | 6.12 | 6.18 | 6.24 |

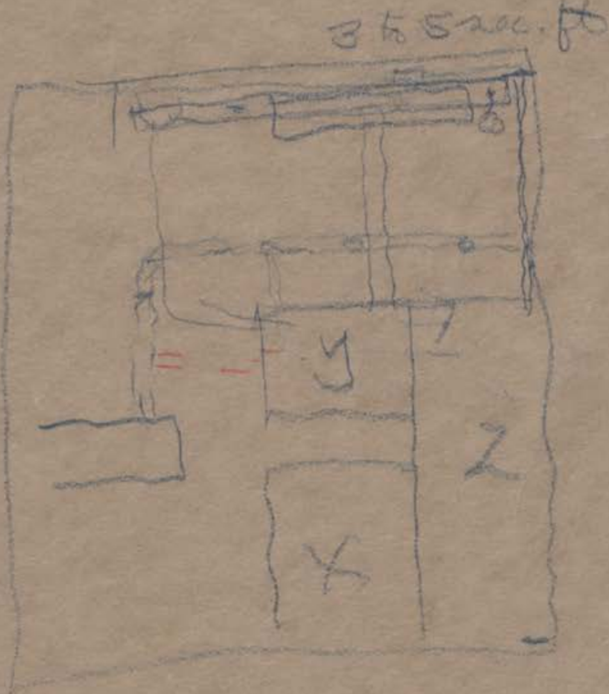
(1044)

Table — FREE-FLOW DISCHARGE ~~TABLE FOR~~ Through 3-Inch ~~IMPROVED VENTURI FLUME~~ Parshall Measuring Flume

Based on ~~Formula~~ $Q = 0.992 H_a^{1.547}$

| Upper Head $H_a$ | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | Upper head $H_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feet | Sec.ft | Sec.ft | " | ~~S e c o n d - f e e t~~ | | | " | " | " | " | Feet |
| 0.10 | .028 | .033 | .037 | .042 | .047 | .053 | .058 | .064 | .070 | .076 | 0.10 |
| .20 | .082 | .089 | .095 | .102 | .109 | .117 | .124 | .131 | .138 | .146 | .20 |
| .30 | .154 | .162 | .170 | .179 | .187 | .196 | .205 | .213 | .222 | .231 | .30 |
| .40 | .241 | .250 | .260 | .269 | .279 | .289 | .299 | .309 | .319 | .329 | .40 |
| .50 | .339 | .350 | .361 | .371 | .382 | .393 | .404 | .415 | .427 | .438 | .50 |
| .60 | .450 | .462 | .474 | .485 | .497 | .509 | .522 | .534 | .546 | .558 | .60 |
| .70 | .571 | .584 | .597 | .610 | .623 | .636 | .649 | .662 | .675 | .689 | .70 |
| .80 | .702 | .716 | .730 | .744 | .757 | .771 | .786 | .800 | .814 | .828 | .80 |
| .90 | .843 | .858 | .872 | .887 | .902 | .916 | .931 | .946 | .961 | .977 | .90 |
| 1.00 | .992 | 1.007 | 1.023 | 1.038 | 1.054 | 1.070 | 1.086 | 1.102 | 1.118 | 1.134 | 1.00 |

Omit



345 sq. ft
y
z
x

092-38-9122

Free-Flow Discharge Table for

PARSHALL MEASURING FLUME *

As Developed by the U. S. Department of Agriculture
Irrigation Investigations
Colorado Experiment Station, Cooperating

| Discharge in Cubic Feet Per Second | | | | | |
|---|---|---|---|---|---|
| Upper Gage Height Ha | | Width of Flume at Throat | | | |
| Feet | Inches | 1-Foot | 2-Feet | 3-Feet | 4-Feet |
| .20 | 2-3/8 | 0.4 | 0.7 | 1.0 | 1.3 |
| .25 | 3- | 0.5 | 0.9 | 1.4 | 1.8 |
| .20 | 3-5/8 | 0.6 | 1.2 | 1.8 | 2.4 |
| .35 | 4-1/4 | 0.8 | 1.6 | 2.3 | 3.1 |
| .40 | 4-3/4 | 1.0 | 1.9 | 2.9 | 3.8 |
| .45 | 5-3/8 | 1.2 | 2.3 | 3.4 | 4.5 |
| .50 | 6- | 1.4 | 2.7 | 4.0 | 5.4 |
| .55 | 6-5/8 | 1.6 | 3.2 | 4.7 | 6.2 |
| .60 | 7-1/4 | 1.8 | 3.6 | 5.4 | 7.2 |
| .65 | 7-3/4 | 2.1 | 4.1 | 6.1 | 8.1 |
| .70 | 8-3/8 | 2.3 | 4.6 | 6.9 | 9.1 |
| .75 | 9- | 2.6 | 5.1 | 7.6 | 10.2 |
| .80 | 9-5/8 | 2.8 | 5.7 | 8.5 | 11.2 |
| .85 | 10-1/4 | 3.1 | 6.2 | 9.3 | 12.4 |
| .90 | 10-3/4 | 3.4 | 6.8 | 10.2 | 13.6 |
| .95 | 11-3/8 | 3.7 | 7.4 | 11.1 | 14.8 |
| 1.00 | 12- | 4.0 | 8.0 | 12.0 | 16.0 |
| 1.05 | 12-5/8 | 4.3 | 8.6 | 13.0 | 17.3 |
| 1.10 | 13-1/4 | 4.6 | 9.3 | 13.9 | 18.6 |
| 1.15 | 13-3/4 | 4.9 | 9.9 | 14.9 | 19.9 |
| 1.20 | 14-3/8 | 5.3 | 10.6 | 16.0 | 21.3 |
| 1.25 | 15- | 5.6 | 11.3 | 17.0 | 22.8 |
| 1.30 | 15-5/8 | 6.0 | 12.0 | 18.1 | 24.2 |
| 1.35 | 16-1/4 | 6.3 | 12.7 | 19.2 | 25.7 |
| 1.40 | 16-3/4 | 6.7 | 13.5 | 20.3 | 27.2 |
| 1.45 | 17-3/8 | 7.0 | 14.2 | 21.5 | 28.8 |
| 1.50 | 18- | 7.4 | 15.0 | 22.6 | 30.3 |
| 1.55 | 18-5/8 | 7.8 | 15.8 | 23.8 | 32.0 |
| 1.60 | 19-1/4 | 8.2 | 16.6 | 25.0 | 33.6 |
| 1.65 | 19-3/4 | 8.6 | 17.4 | 26.3 | 35.3 |
| 1.70 | 20-3/8 | 9.0 | 18.2 | 27.6 | 37.0 |
| 1.75 | 21- | 9.4 | 19.0 | 28.8 | 38.7 |
| 1.80 | 21-5/8 | 9.8 | 19.9 | 30.1 | 40.4 |
| 1.85 | 22-1/4 | 10.2 | 20.8 | 31.4 | 42.2 |
| 1.90 | 22-3/4 | 10.6 | 21.6 | 32.8 | 44.0 |
| 1.95 | 23-3/8 | 11.1 | 22.5 | 34.1 | 45.9 |
| 2.00 | 24- | 11.5 | 23.4 | 35.5 | 47.8 |
| 2.05 | 24-5/8 | 11.9 | 24.3 | 36.9 | 49.7 |
| 2.10 | 25-1/4 | 12.4 | 25.3 | 38.4 | 51.6 |
| 2.15 | 25-3/4 | 12.8 | 26.2 | 39.8 | 53.5 |
| 2.20 | 26-3/8 | 13.3 | 27.2 | 41.2 | 55.5 |
| 2.25 | 27- | 13.7 | 28.1 | 42.7 | 57.5 |
| 2.30 | 27-5/8 | 14.2 | 29.1 | 44.2 | 59.6 |
| 2.35 | 28-1/4 | 14.7 | 30.1 | 45.7 | 61.6 |
| 2.40 | 28-3/4 | 15.2 | 31.1 | 47.3 | 63.7 |
| 2.45 | 29-3/8 | 15.6 | 32.1 | 48.8 | 65.8 |
| 2.50 | 30- | 16.1 | 33.1 | 50.4 | 67.9 |

* This condensed table was prepared by the Engineering Department of the Colorado Water Conservation Board from the Discharge Tables published in Bulletin 423 of the Colorado Experiment Station of Colorado State College at Fort Collins, Colorado.

Free-Flow Discharge Table for

PARSHALL MEASURING FLUME *

As Developed by the U. S. Department of Agriculture
Irrigation Investigations
Colorado Experiment Station, Cooperating

| Discharge in Cubic Feet Per Second | | | | | |
|---|---|---|---|---|---|
| Width of Flume at Throat | | | | Upper Gage Height Ha | |
| 5-Feet | 6-Feet | 7-Feet | 8-Feet | Inches | Feet |
| --- | --- | --- | --- | 2-3/8 | .20 |
| 2.2 | 2.6 | --- | --- | 3- | .25 |
| 3.0 | 3.5 | 4.1 | 4.6 | 3-5/8 | .30 |
| 3.8 | 4.5 | 5.2 | 5.9 | 4-1/4 | .35 |
| 4.7 | 5.6 | 6.5 | 7.3 | 4-3/4 | .40 |
| 5.6 | 6.7 | 7.8 | 8.9 | 5-3/8 | .45 |
| 6.7 | 7.9 | 9.2 | 10.5 | 6- | .50 |
| 7.7 | 9.2 | 10.8 | 12.2 | 6-5/8 | .55 |
| 8.9 | 10.6 | 12.4 | 14.1 | 7-1/4 | .60 |
| 10.1 | 12.1 | 14.0 | 16.0 | 7-3/4 | .65 |
| 11.4 | 13.6 | 15.8 | 18.0 | 8-3/8 | .70 |
| 12.7 | 15.2 | 17.7 | 20.1 | 9- | .75 |
| 14.0 | 16.8 | 19.6 | 22.4 | 9-5/8 | .80 |
| 15.5 | 18.5 | 21.6 | 24.6 | 10-1/4 | .85 |
| 16.9 | 20.3 | 23.7 | 27.0 | 10-3/4 | .90 |
| 18.4 | 22.1 | 25.8 | 29.5 | 11-3/8 | .95 |
| 20.0 | 24.0 | 28.0 | 32.0 | 12- | 1.00 |
| 21.6 | 25.9 | 30.3 | 34.6 | 12-5/8 | 1.05 |
| 23.3 | 27.9 | 32.6 | 37.3 | 13-1/4 | 1.10 |
| 25.0 | 30.0 | 35.0 | 40.1 | 13-3/4 | 1.15 |
| 26.7 | 32.1 | 37.5 | 42.9 | 14-3/8 | 1.20 |
| 28.5 | 34.3 | 40.0 | 45.8 | 15- | 1.25 |
| 30.3 | 36.5 | 42.6 | 48.8 | 15-5/8 | 1.30 |
| 32.2 | 38.7 | 45.3 | 51.8 | 16-1/4 | 1.35 |
| 34.1 | 41.0 | 48.0 | 55.0 | 16-3/4 | 1.40 |
| 36.1 | 43.4 | 50.8 | 58.1 | 17-3/8 | 1.45 |
| 38.1 | 45.8 | 53.6 | 61.4 | 18- | 1.50 |
| 40.1 | 48.3 | 56.5 | 64.7 | 18-5/8 | 1.55 |
| 42.2 | 50.8 | 59.4 | 68.1 | 19-1/4 | 1.60 |
| 44.3 | 53.3 | 62.4 | 71.6 | 19-3/4 | 1.65 |
| 46.4 | 56.0 | 65.5 | 75.1 | 20-3/8 | 1.70 |
| 48.6 | 58.6 | 68.6 | 78.7 | 21- | 1.75 |
| 50.8 | 61.3 | 71.8 | 82.9 | 21-5/8 | 1.80 |
| 53.1 | 64.0 | 75.0 | 86.0 | 22-1/4 | 1.85 |
| 55.4 | 66.8 | 78.2 | 89.8 | 22-3/4 | 1.90 |
| 57.7 | 69.6 | 81.6 | 93.6 | 23-3/8 | 1.95 |
| 60.1 | 72.5 | 84.9 | 97.5 | 24- | 2.00 |
| 62.5 | 75.4 | 88.4 | 101.4 | 24-5/8 | 2.05 |
| 64.9 | 78.4 | 91.8 | 105.4 | 25-1/4 | 2.10 |
| 67.4 | 81.4 | 95.4 | 109.5 | 25-3/4 | 2.15 |
| 69.9 | 84.4 | 98.9 | 113.6 | 26-3/8 | 2.20 |
| 72.4 | 87.5 | 102.6 | 117.8 | 27- | 2.25 |
| 75.0 | 90.6 | 106.2 | 122.0 | 27-5/8 | 2.30 |
| 77.6 | 93.8 | 110.0 | 126.3 | 28-1/4 | 2.35 |
| 80.2 | 97.0 | 113.7 | 130.7 | 28-3/4 | 2.40 |
| 82.9 | 100.2 | 117.6 | 135.1 | 29-3/8 | 2.45 |
| 85.6 | 103.5 | 121.4 | 139.5 | 30- | 2.50 |

* This condensed table was prepared by the Engineering Department of the Colorado Water Conservation Board from the Discharge Tables published in Bulletin 423 of the Colorado Experiment Station of Colorado State College at Fort Collins, Colorado.

092-38-9123 BILL OF MATERIAL For PARSHALL MEASURING FLUMES*

| Width "W" | Item | Size of Piece to Order | No. | Feet B.M. | Width "W" | Item | Size of Piece to Order | No. | Feet B. M. |
|---|---|---|---|---|---|---|---|---|---|
| 1' | Sidewalls | 2" x 12" x 10' | 9 | 180 | 5' | Sidewalls | 2" x 12" x 12' | 12 | 288 |
| | Floor | 2" x 12" x 10' | 2 | 40 | | Floor | 2" x 12" x 12' | 7 | 168 |
| | Sills | 4" x 4" x 10' | 2 | 27 | | Sills | 6" x 6" x 16' | 3 | 144 |
| | Posts | 4" x 4" x 12' | 3 | 48 | | Posts | 4" x 6" x 16' | 3 | 96 |
| | Ties | 2" x 6" x 8' | 2 | 16 | | Ties | 4" x 6" x 16' | 3 | 96 |
| | Piling | 2" x 12" x 12' | 2 | 48 | | Piling | 2" x 12" x 12' | 6 | 144 |
| | Anchors | 2" x 4" x 12' | 3 | 24 | | Anchors | 4" x 4" x 12' | 4 | 64 |
| | Bolts | 3/8"x 6" | 10 | | | Bolts | 1/2" x 8" | 10 | |
| | Nails | 30 penny | 20# | | | Nails | 40 penny | 40# | |
| | 1-1/4"x0'-2"G.I.Pipe Nipples | | 2 | | | 1-1/4"x0'-2"G.I.Pipe Nipples | | 2 | |
| | Steel Angle-2x2x1/4x1'-0" | | 1 | | | Steel Angle-2x2x1/4x5'-0" | | 1 | |
| | Total | | | 383 | | Total | | | 1000 |
| 2' | Sidewalls | 2" x 12" x 10' | 9 | 180 | 6' | Sidewalls | 2" x 12" x 12' | 12 | 288 |
| | Floor | 2" x 12" x 10' | 3 | 60 | | Floor | 2" x 12" x 12' | 8 | 192 |
| | Sills | 4" x 4" x 10' | 3 | 40 | | Sills | 6" x 6" x 16' | 3 | 144 |
| | Posts | 4" x 4" x 12' | 3 | 48 | | Posts | 4" x 6" x 16' | 3 | 96 |
| | Ties | 2" x 6" x 10' | 3 | 30 | | Ties | 4" x 6" x 16' | 3 | 96 |
| | Piling | 2" x 12" x 12' | 3 | 72 | | Piling | 2" x 12" x 12' | 6 | 144 |
| | Anchors | 2" x 4" x 12' | 3 | 24 | | Anchors | 4" x 4" x 12' | 5 | 80 |
| | Bolts | 3/8" x 6" | 10 | | | Bolts | 1/2" x 8" | 10 | |
| | Nails | 30 penny | 25# | | | Nails | 40 penny | 45# | |
| | 1-1/4"x0'-2"G.I.Pipe Nipples | | 2 | | | 1-1/4"x0'-2"G.I.Pipe Nipples | | 2 | |
| | Steel Angle-2x2x1/4x2' | | 1 | | | Stoel Angle 2x2x1/4x6'-0" | | 1 | |
| | Total | | | 454 | | Total | | | 1040 |
| 3' | Sidewalls | 2" x 12" x 12' | 11 | 264 | 7' | Sidewalls | 2" x 12" x 14' | 12 | 336 |
| | Floor | 2" x 12" x 12' | 4 | 96 | | Floor | 2" x 12" x 14' | 9 | 252 |
| | Sills | 4" x 4" x 16' | 2 | 43 | | Sills | 6" x 6" x 12' | 5 | 180 |
| | Posts | 4" x 4" x 16' | 3 | 64 | | Posts | 4" x 6" x 16' | 3 | 96 |
| | Ties | 2" x 6" x 16' | 2 | 32 | | Ties | 4" x 6" x 12' | 5 | 120 |
| | Piling | 2" x 12" x 12' | 3 | 72 | | Piling | 2" x 12" x 12' | 7 | 168 |
| | Anchors | 4" x 4" x 12' | 4 | 64 | | Anchors | 4" x 4" x 12' | 5 | 80 |
| | Bolts | 1/2" x 6" | 10 | | | Bolts | 1/2" x 8" | 10 | |
| | Nails | 30 penny | 30# | | | Nails | 40 penny | 50# | |
| | 1-1/4"x0'-2"G.I.Pipe Nipples | | 2 | | | 1-1/4"x0'-2"G.I.Pipe Nipples | | 2 | |
| | Steel Angle-2x2x1/4x3'-0" | | 1 | | | Steel Angle-2x2x1/4x7'-0" | | 1 | |
| | Total | | | 635 | | Total | | | 1232 |
| 4' | Sidewalls | 2" x 12" x 12' | 11 | 264 | 8' | Sidewalls | 2" x 12" 14' | 13 | 364 |
| | Floor | 2" x 12" x 12' | 5 | 120 | | Floor | 2" x 12" x 14' | 10 | 280 |
| | Sills | 6" x 6" x 14' | 3 | 126 | | Sills | 8" x 8" x 14' | 5 | 373 |
| | Posts | 4" x 6" x 16' | 3 | 96 | | Posts | 4" x 6" x 16' | 3 | 96 |
| | Ties | 2" x 6" x 14' | 3 | 42 | | Ties | 4" x 6" x 12' | 5 | 120 |
| | Piling | 2" x 12" x 12' | 4 | 96 | | Piling | 2" x 12" x 12' | 8 | 192 |
| | Anchors | 4" x 4" x 12' | 4 | 64 | | Anchors | 4" x 4" x 12' | 5 | 80 |
| | Bolts | 1/2" x 6" | 10 | | | Bolts | 1/2" x 8" | 10 | |
| | Nails | 40 penny | 35# | | | Nails | 40 penny | 55# | |
| | 1-1/4"x0'-2"G.I.Pipe Nipples | | 2 | | | 1-1/4"x0'-2"G.I.Pipe Nipples | | 2 | |
| | Steel Angle-2x2x1/4x4'-0" | | 1 | | | Steel Angle-2x2x1/4x8'-0" | | 1 | |
| | Total | | | 808 | | Total | | | 1505 |

NOTE: All timber shall be sound and first class material, straight and free from loose knots. All planks used in the floor and walls shall be surfaced.

To determine the size to which each piece should be cut, refer to plan and table of dimensions. Plank for wing walls is included with "Sidewalls". For sills allow minimum of 24 inches over width of flume; for posts allow minimum of 9" over height of side walls.

Side walls 2 feet (two 2 x 12 boards) in height are adequate for the small flumes. 3-foot side walls (three 2 x 12 boards) high are required for flumes from 3 to 8 feet in width. All above Bills of Material are figured on this basis.

Stilling wells are to be constructed of 2" plank. Minimum inside dimension of stilling wells to be 18" square. Material for one stilling well (two 2 x 12-12') is included in the above Bills of Material under "Sidewalls".

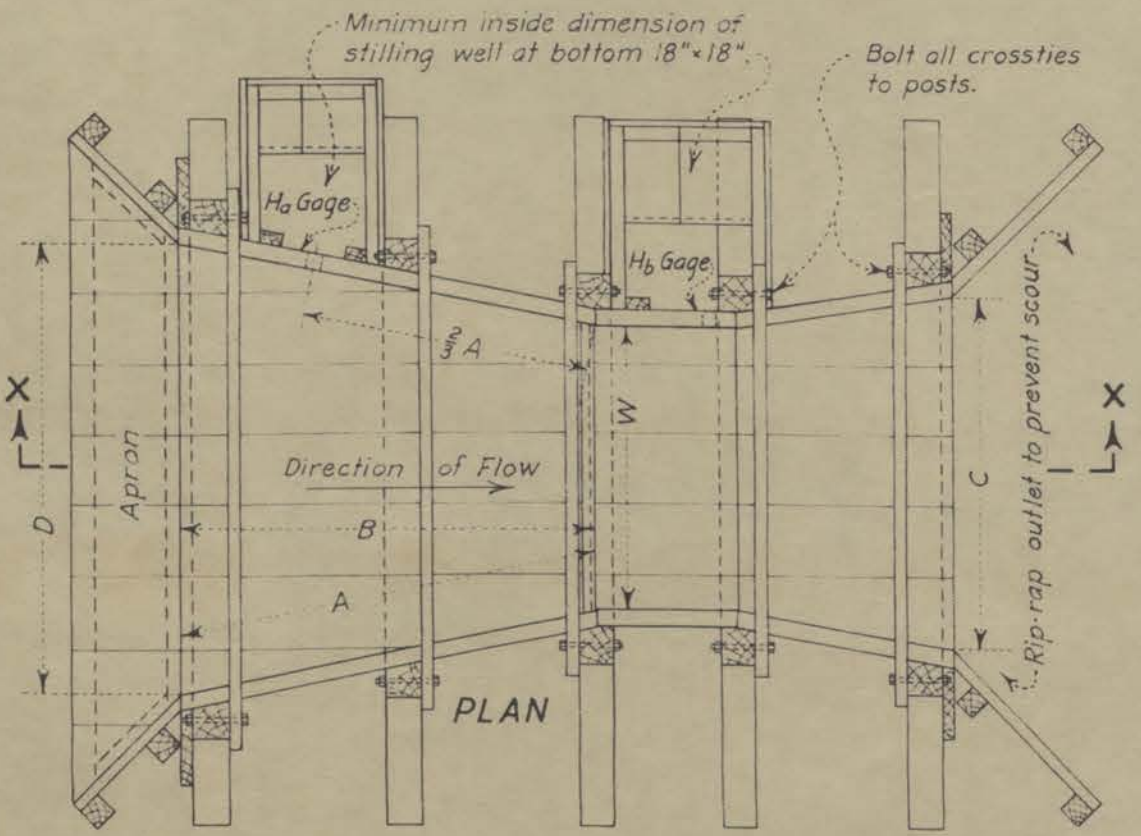
For greater permanence, all plank and timbers should be treated with creosote. The dimensions of timbers and plank shown on these Bills of Material are the minimum desirable for a satisfactory installation. Reinforced concrete can be used at some additional cost over cost of wooden structures.

*Prepared by the Engineering Department of the Colorado Water Conservation Board in accordance with "The Parshall Measuring Flume" as described in Bulletin 423 of the Colorado State College Experiment Station, Fort Collins, Colorado.

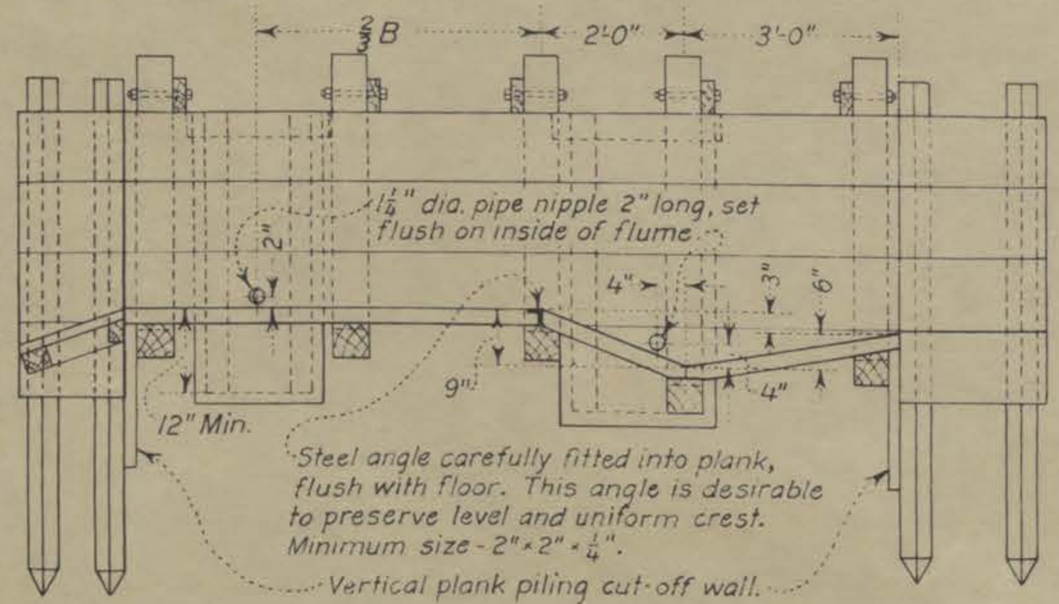
# PARSHALL MEASURING FLUME

## WOODEN CONSTRUCTION *

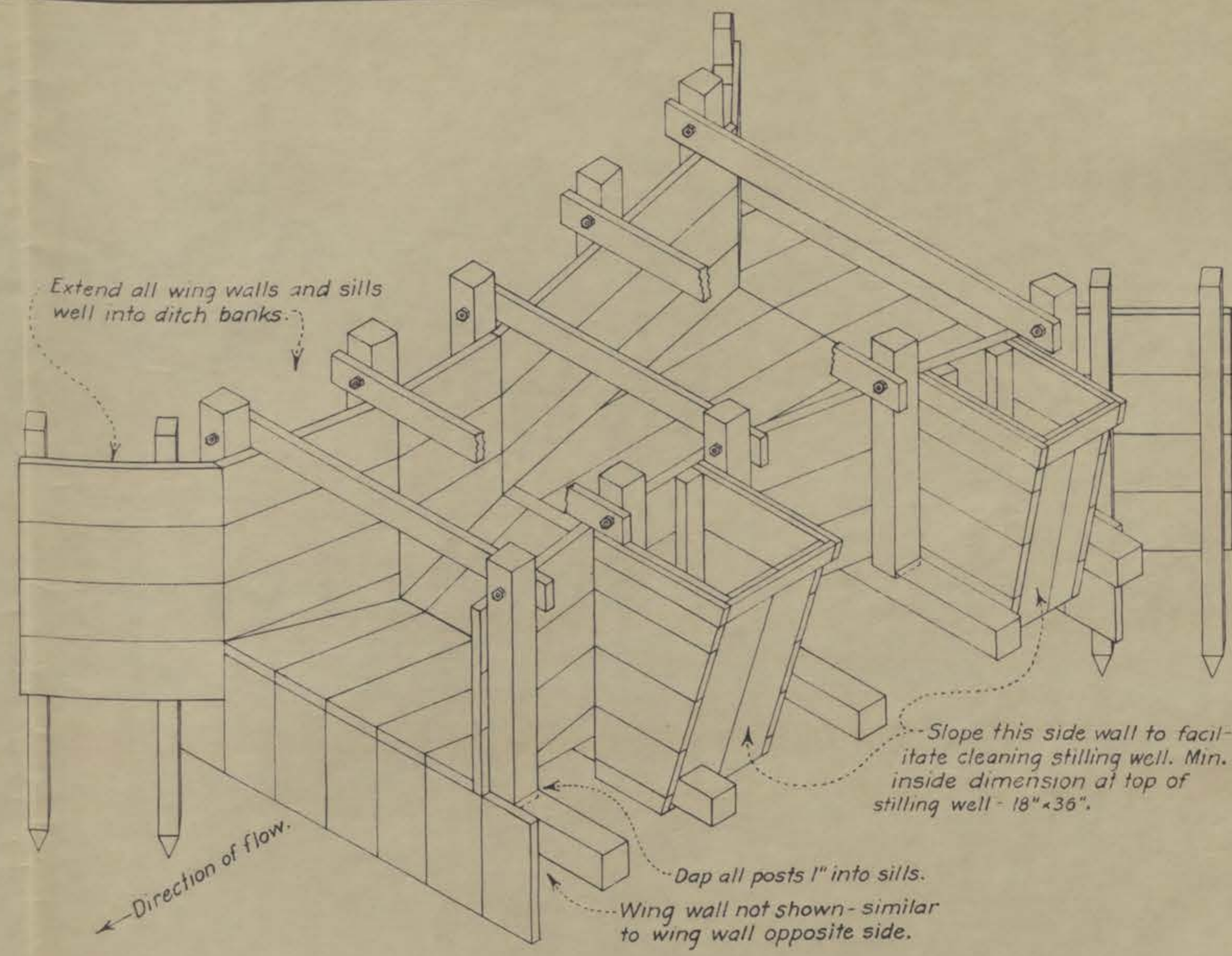
* Prepared by the Engineering Department of the Colorado Water Conservation Board in accordance with "The Parshall Measuring Flume" as described in Bulletin 423 of the Colorado State College Experiment Station, Fort Collins, Colorado.




PLAN




SECTION X-X




## STANDARD DIMENSIONS AND CAPACITIES *

Dimensions in Feet — Capacities in Second Feet

| WIDTH OF THROAT SECTION W | LENGTH OF SIDEWALL INLET SECT. A | LOCATION OF STAFF GAGE ⅔ A | LENGTH OF FLOOR INLET SECT. B | WIDTH OF INLET SECTION D | WIDTH OF OUTLET SECTION C | MINIMUM | | MAXIMUM | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | HEAD AT ⅔ A $H_a$ | FLOW IN SEC. FT. | HEAD AT ⅔ A $H_a$ | FLOW IN SEC. FT. |
| 1 | 4'-6" | 3'-0" | 4'-4⅞" | 2'-9¼" | 2' | 0.20 | 0.35 | 1.50 | 7.4 |
| 2 | 5'-0" | 3'-4" | 4'-10¾" | 3'-11½" | 3' | 0.20 | 0.66 | 1.50 | 15.0 |
| 3 | 5'-6" | 3'-8" | 5'-4¾" | 5'-1⅞" | 4' | 0.20 | 0.97 | 2.00 | 35.5 |
| 4 | 6'-0" | 4'-0" | 5'-10⅝" | 6'-4¼" | 5' | 0.20 | 1.26 | 2.50 | 67.9 |
| 5 | 6'-6" | 4'-4" | 6'-4½" | 7'-6⅝" | 6' | 0.25 | 2.22 | 2.50 | 85.6 |
| 6 | 7'-0" | 4'-8" | 6'-10⅜" | 8'-9" | 7' | 0.25 | 2.63 | 2.50 | 103.5 |
| 7 | 7'-6" | 5'-0" | 7'-4¼" | 9'-11⅜" | 8' | 0.30 | 4.08 | 2.50 | 121.4 |
| 8 | 8'-0" | 5'-4" | 7'-10⅛" | 11'-1¾" | 9' | 0.30 | 4.62 | 2.50 | 139.5 |

Note: Lengths of throat section and outlet section remain the same for all throat widths W.

| | | | | |
|---|---|---|---|---|
| Drawn R.M.G. Traced C.R.R. Checked A.C.S. | Issued April 18, 1938 Revised | Recommended 4-15-38 [signature] Assistant Engineer | Approved 4/18/38 [signature] Chief Engineer | 092-38-9210 |

Bulletin 386 May, 1932

# PARSHALL FLUMES OF LARGE SIZE

By R. L. Parshall, Senior Irrigation Engineer

Twenty-foot Parshall Measuring Flume, for Bijou Canal, South Platte River Valley, near Greeley, Colorado.

Based on data gathered under cooperative agreement between the Bureau of Agricultural Engineering, U. S. Department of Agriculture, and the Colorado Agricultural Experiment Station.

Colorado Agricultural College
Colorado Experiment Station
Fort Collins

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FORT COLLINS, COLORADO



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# PARSHALL FLUMES OF LARGE SIZE[1]

By R. L. PARSHALL, Senior Irrigation Engineer, Division of Irrigation, Bureau of Agricultural Engineering, United States Department of Agriculture.

Whenever the demand for water available for beneficial uses encroaches upon supply, the water acquires a value that makes rights to use it subject to restrictions by customs, laws, rules and regulations. Thruout the West generally water used for irrigating agricultural crops has long since become so valuable that its equitable distribution has been a matter of public concern, and laws providing administrative officers and methods of control have been enacted. Among such laws are those relating to the measurement of water.

It is of vital importance to all concerned that those charged with and held responsible for the distribution of public water supplies shall know, as nearly as it is practically feasible, not only the amounts carried in artificial channels and distributed therefrom for individual beneficial uses but also the amount diverted from the stream, lake or other primary source of supply by each one of such channels, in order that distribution may be made in accordance with the lawfully established priority rights of appropriators.

Measuring water in irrigation channels is discussed briefly in a recent publication[2]. Measuring large amounts necessarily calls for greater outlays of both care and expense in building the required structures than does the measurement of small flows and this report has been prepared with a view to furnishing assistance in such cases, altho the controlling principles involved are the same for both groups. This bulletin, therefore, deals more particularly with the measurement of the larger amounts of water diverted from streams and reservoirs rather than the smaller amounts.

Rating flumes of the type commonly recommended and constructed in the past[3] have very often been found unsatisfactory because of the adverse local conditions encountered. Moss, weeds, willows and other growths, accumulations of sand, and other obstructions of various kinds retard the flow of the water and reduce the carrying capacity of the channel. When the discharge of a channel thus obstructed is computed by using a rating flume of the usual type, the actual discharge is likely to vary materially

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[1]Prepared under the direction of W. W. McLaughlin, Chief, Division of Irrigation, Bureau of Agricultural Engineering, and in cooperation with the Colorado Agricultural Experiment Station.

[2]Measuring Water in Irrigation Channels, by R. L. Parshall (U. S. Dept. Agr. Farmers' Bulletin 1683), 1932.

[3]Early Biennial Reports of Colorado State Engineers, especially the Third (1885-1886), Fourth (1886-1887), and Eleventh (1901-1902).

from that indicated by the gage height. Many Western streams carry heavy burdens of silt, sand and gravel, especially at high-water stages, and experience has demonstrated that in such cases the ordinary rating flume is wholly unreliable as a measuring device unless frequent attention is given to its calibration. It has long been evident, therefore, that some more dependable measuring device, of reasonable simplicity and cost, was needed, and for several years investigations have been carried on at the Colorado Agricultural Experiment Station, with a view to filling this need. The Parshall flume is the present outcome of these investigations.

The Parshall flume is an improved form of what was originally called the "Venturi flume"[4,5] and, until 1930, was called the "improved Venturi flume."[6] It is designed as a practical device for meeting the adverse conditions ordinarily encountered in measuring the discharge of streams of water of any size up to 2000 or more second-feet, and this report describes a number of the installations of large size that have been made in Colorado, especially in the Arkansas Valley.

In Colorado, the Arkansas River and its tributaries are especially burdened with sediment during high, and even mean water stages. In some cases the channels of Arkansas Valley canals have changed so much thru the alternate filling in and scouring out of the sediment that within short periods of time the rates of flow for the same gage heights have been nearly halved or doubled. In the Holbrook Canal near Rocky Ford, for example, sand as much as 2.5 feet in depth has been found on the floor of the old rating flume, a structure 32 feet wide and 7 feet deep.

In the Arkansas Valley, therefore, the state hydrographic force has been obliged, owing to the frequent changes in flow conditions, to devote much of its time to measuring the amounts of water drawn from the streams and preparing rating tables to govern the regulation of the headgates of the canals, and even then it was found practically impossible in many cases to determine the actual discharge accurately. Naturally, this condition of affairs was very unsatisfactory to water users and officials alike.

In operating a canal, the superintendent and his assistants make certain arrangements for the delivery of the water to the farmer by setting the delivery gates according to the amounts flowing in the various sections of the canal. It was not unusual, after such settings had been made, to have the official hydro-

[4]The Venturi Flume, by V. M. Cone (U. S. Dept. Agr. Journal of Agricultural Research, Vol. IX, No. 4, pages 115-129). 1917.
[5]The Venturi Flume, by R. L. Parshall and Carl Rohwer (Colo. Agr. Exp. Sta. Bul. 265), 1921.
[6]The Improved Venturi Flume, by R. L. Parshall (Colo. Agr. Exp. Sta. Bul. 336).

grapher check the flow at the head of the main canal and find the actual discharge either too great or too small, thus requiring a change in the amount of discharge to agree with lawful or rightful diversion according to priority. Such changes would require immediate resetting and adjustment of farm headgates along the canal, and the decrease in the flow would naturally cause dissatisfaction on the part of the users, particularly when there was a shortage of water at times of extreme need. In some instances temporary checks in the channel some distance downstream from the rating flume were required to raise the water enough to accommodate adjacent high lands by diversion thru a headgate. This check usually raised the water surface in the rating flume, thus shifting the rating curve to agree with a temporary condition. Furthermore, the operating of a water-stage recording instrument in connection with the rating flume, as required by state law, was in some instances somewhat unsatisfactory because of the deposits accumulating in the float well.

## THE PARSHALL MEASURING FLUME

Experiments on a device called the Venturi flume were made in 1915 by V. M. Cone at the hydraulic laboratory of the Colorado Agricultural Experiment Station. Later experiments on the same device were made by Carl Rohwer and the writer in 1920 at both the hydraulic laboratory at Fort Collins and the Bellvue laboratory on the Cache la Poudre River, 8 miles west of Fort Collins. This device had converging entrance and diverging outlet sections, joined by an intermediate throat. The walls were either vertical or inclined outward, and the floor was level. In 1922 the writer proposed somewhat radical changes in the design of this device—the angles of convergence and divergence were changed, the lengths of these sections were altered, and the floor in the throat was sloped downward, forming a fixed crest and control at the junction of the converging section and the throat. The walls were made vertical and the floor of the converging section level, while the floor of the diverging section inclined upward to the lower end of the structure. It is this device that the Irrigation Committee of the American Society of Civil Engineers has named the Parshall Measuring Flume. The development of the larger flumes, however, during the years 1926 to 1930, inclusive, has been largely thru the design of structures for particular locations, especially in the Arkansas River valley.

The general ratio of dimensions that applies to the small-sized flumes has not been followed for the large flumes. In Table I are given the main dimensions for sizes ranging from 10 to 50

Table 1.—Relative dimensions for Parshall measuring flumes of large size.

| Size-throat width | Free-flow capacity | | Axial length | | | Width | | Wall depth converging section | Vertical distance below crest | | $H_A$ gage distance (not axial)* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Converging | Throat | Diverging | Upstream end | Downstream end | | Dip at throat | Lower end flume | |
| Feet | Sec.-ft. | Sec.-ft. | Feet | Feet | Feet | Feet | Feet | Feet | Feet | Inches | Feet |
| 10 | 200 | 6 | 14 | 3 | 6 | 15′ 7.25″ | 12′ 0″ | 4 | 1′ 1.5″ | 6 | 6′ 0″ |
| 12 | 350 | 8 | 16 | 3 | 8 | 18′ 4.75″ | 14′ 8″ | 5 | 1′ 1.5″ | 6 | 6′ 8″ |
| 15 | 600 | 8 | 25 | 4 | 10 | 25′ 0″ | 18′ 4″ | 6 | 1′ 6″ | 9 | 7′ 8″ |
| 20 | 1000 | 10 | 25 | 6 | 12 | 30′ 0″ | 24′ 0″ | 7 | 2′ 3″ | 12 | 9′ 4″ |
| 25 | 1200 | 15 | 25 | 6 | 13 | 35′ 0″ | 29′ 4″ | 7 | 2′ 3″ | 12 | 11′ 0″ |
| 30 | 1500 | 15 | 26 | 6 | 14 | 40′ 4.75″ | 34′ 8″ | 7 | 2′ 3″ | 12 | 12′ 8″ |
| 40 | 2000 | 20 | 27 | 6 | 16 | 50′ 9.5″ | 45′ 4″ | 7 | 2′ 3″ | 12 | 16′ 0″ |
| 50 | 3000 | 25 | 27 | 6 | 20 | 60′ 9.5″ | 56′ 8″ | 7 | 2′ 3″ | 12 | 19′ 4″ |

Note: For all these sizes the $H_B$ gage is located 12 inches upstream from, and 9 inches above the floor at, the downstream edge of throat.

*$H_A$ gage distance is measured along flume wall, upstream from the crest line.

feet in throat widths and having maximum capacities from 200 to 3,000 second-feet under conditions of free-flow discharge.[7] The flumes may successfully measure greater flows than those indicated as the maximum in Table I (see Tables II to X, pages 36 to 43 and 49 to 52, but under ordinary channel-capacity conditions the size of flume and the related maximum flow are approximately as shown in the first table. For example, in a channel having 600 second-feet capacity, it is probable that under average conditions the 15-foot flume would be suitable, provided a free-flow discharge could be secured.

In small flumes the length of the wall of the converging section is $\frac{W}{2} + 4$, in feet, W being the length of crest or size of flume in feet, and the point of observing the upper head, $H_A$, is two-thirds of the length of the wall measured back from the flume crest. For the large flumes, the length of the converging section generally has been made considerably longer than $\frac{W}{2} + 4$, in order to obtain a smoother flow as the water passes thru this part of the structure. The location of the gage point, $H_A$, however, is maintained at $2/3\ (\frac{W}{2} + 4)$ back from the crest. The lower gage, $H_B$, is located near the downstream end of the throat section (see Table I and Figures 9 and 13), and the head there is communicated to the $H_B$ stilling well thru a pipe of ample size which is also a part of the flushing system. For both the $H_A$ and $H_B$ gages, the zero point is at the elevation of the crest. Thus the depth or water pressure indicated by the $H_B$ gage is depth above the crest, and not the full depth of water at the pressure orifice.

## REPRESENTATIVE LARGE FLUME INSTALLATIONS

The first attempt made in the Arkansas River Valley to improve conditions of measurement was in the installation of a 10-foot Parshall measuring flume on the Las Animas Consolidated Ditch near Las Animas. (Fig. 1.) This experimental structure was built of untreated common fir lumber in March, 1926, and has been in constant use since that time. The condition to be met was the correcting of an unstable relation between discharge and gage height in the old rating flume, and also to provide against the backwater effect of a check located downstream.

[7]Discharge is "submerged" or "free flow," respectively, according to whether the depth of water in the throat of the flume is or is not sufficient to retard the flow; the stage at which increasing depth begins to retard the flow is the "critical degree of submergence." (See pages 34 and 44 and following.)

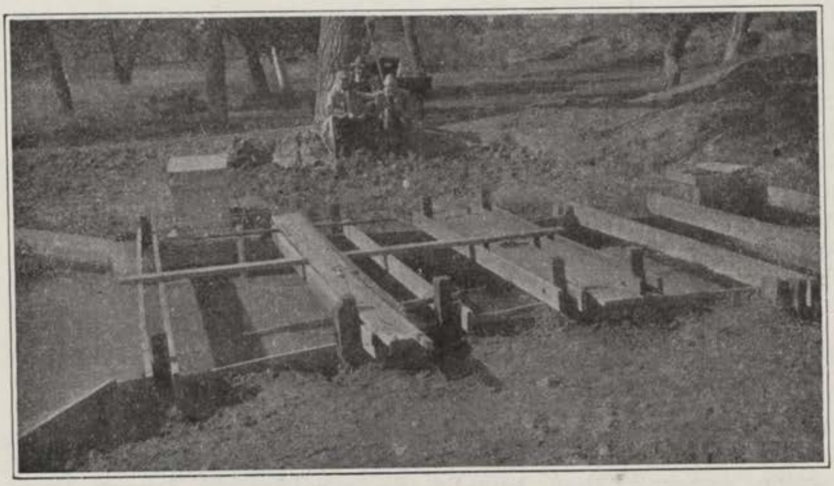

Figure 1.—Ten-foot timber Parshall Measuring Flume, discharge 96 second-feet, Las Animas Consolidated Canal (See Table X).

After the new device was in operation, the discharge was found to be independent of backwater caused by the check, and sand or silt had no effect upon the indicated rate of discharge. The ordinary flow thru this flume is 50 second-feet, and numerous check measurements by means of the current meter indicate that the rates of discharge from about 12 second-feet to nearly 130 second-feet agree with the computed discharge, within practical limits. (See Table X.) Five years' experience with this improved method of measuring indicates that it has been successful. The operation of this first flume, which was of moderate capacity, was watched with much interest by irrigation men and water officials. So completely and satisfactorily was this problem met that other canal companies became interested enough to solicit assistance in solving their measuring problems.

The next large flume of this type was a 20-foot reinforced concrete structure in the Holbrook Canal near Rocky Ford. (Fig. 2.) Like many others in the valley, this canal was subject to erratic variation in the relation of discharge to gage height in the old rating flume. The new flume, built in November, 1927, with a capacity of about 1,000 second-feet, has met successfully the trying conditions of variation in discharge due to filling in and scouring out of the channel whether upstream or downstream from the new structure.

The Fort Lyon Canal, the largest irrigation canal in Colorado, having a capacity of about 1,800 second-feet, was subject to unstable flow conditions. Since the distribution of water in

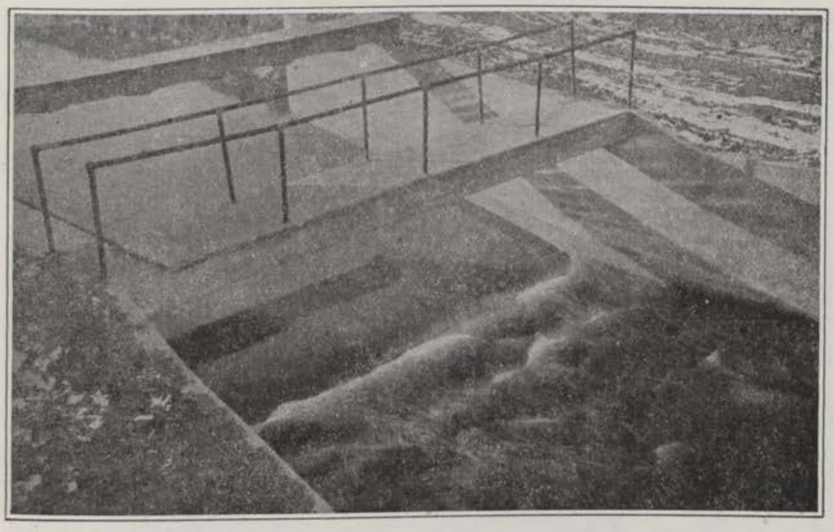

Figure 2.—Twenty-foot Parshall Measuring Flume, Holbrook Canal, discharge 75 second-feet, submergence 82 percent. (See Table X.)

the river depends largely upon the draft of this canal, the accuracy of discharge measurements is relatively important. Formerly the almost constant attention of one hydrographer was required in gaging the flow. The success of the 20-foot flume on the Holbrook Canal is believed to be largely responsible for the final approval by the Fort Lyon Canal Company and state water officials of the installation, near the canal headworks, of a 40-foot reinforced concrete Parshall measuring flume. This is the largest device of this type thus far constructed. (Figs. 3 and 4.) This structure, having a capacity of more than 2,000 second-feet, was built in December, 1928, and since then numerous current-meter check measurements have been made of flows ranging from approximately 130 to 1,460 second-feet. A maximum discharge of 1,800 second-feet has been passed thru this large structure. The measurements made have been found to agree remarkably well with the law of flow that was developed before the flume was built. (See Table X.) This flume has proved very satisfactory in its operation, has solved a very perplexing measuring problem and also has relieved friction and occasional strained relations between the several appropriators along the river.

The successful operation of the large Parshall flumes on several canals has been sufficient to show the practicability and reliability of this new type of measuring device, and now virtually every diversion from the Arkansas River, between Pueblo and the

Kansas state line, has been provided with a suitable flume of this type. These flumes are being used officially in the measurement of water diverted from streams in various irrigated sections of Colorado and other Western States.

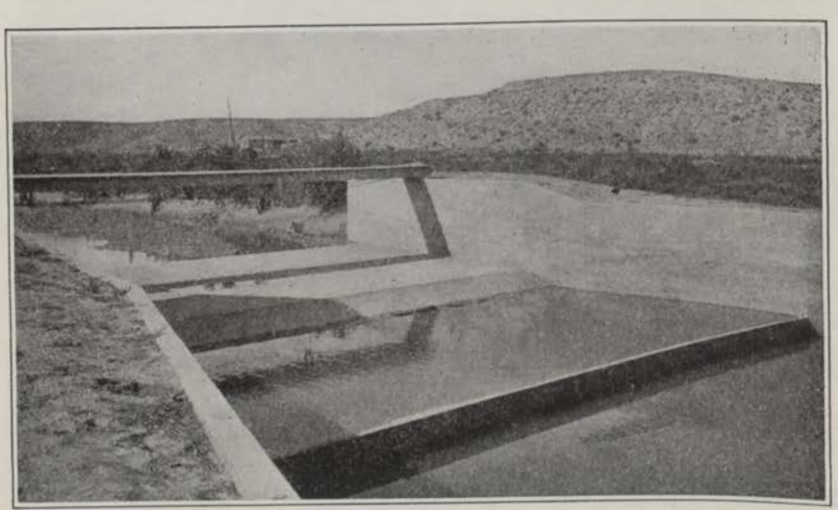

Figure 3.—Forty-foot Parshall Measuring Flume, Fort Lyon Canal.

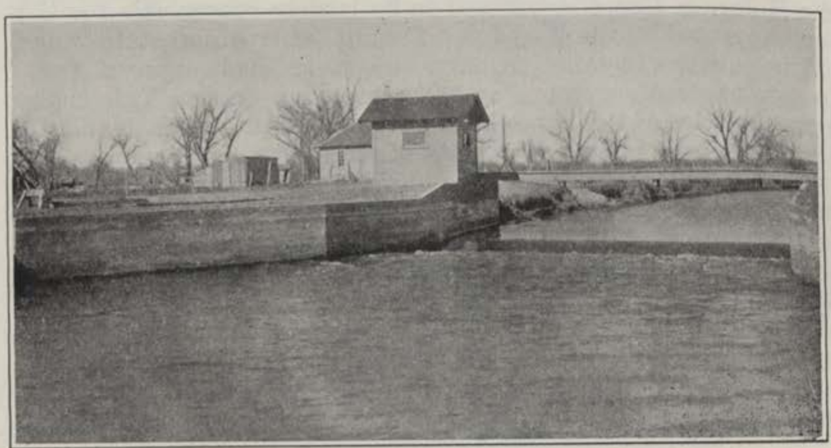

Figure 4.—Forty-foot Parshall Measuring Flume, discharge 177 second-feet, no submergence, Fort Lyon Canal. (See Table X.)

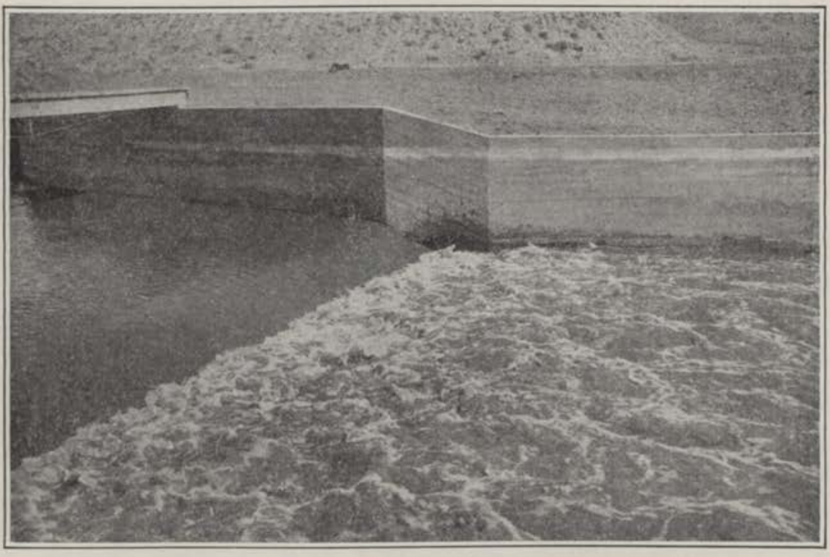

Figure 5.—Smoothness of flow in converging section thru 40-foot Parshall Measuring Flume discharging 177 second-feet, with no submergence. Fort Lyon Canal. (See Table X.)

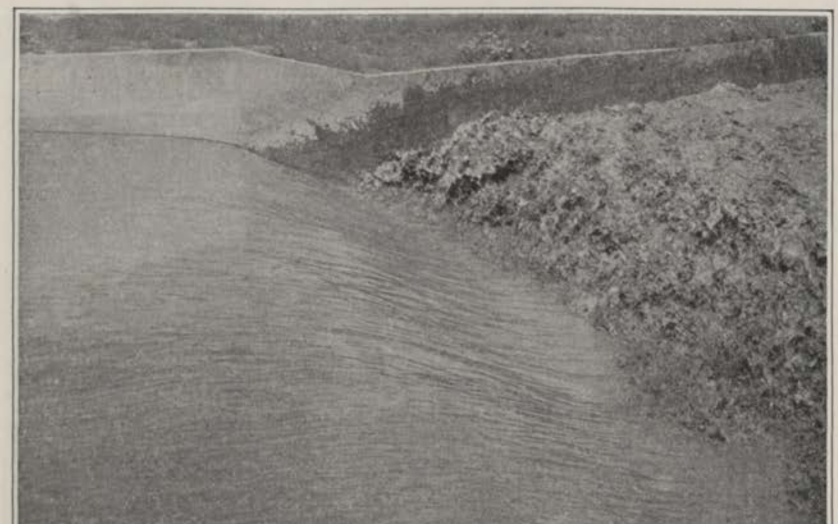

Figure 6.—Forty-foot Parshall Measuring Flume, discharge 1390 second-feet, with submergence not effective, in Fort Lyon Canal. (See Table X.)

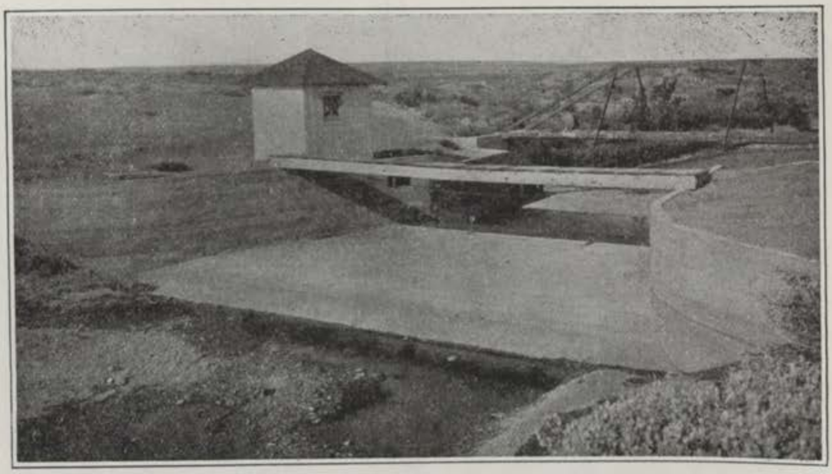

Figure 7.—Thirty-foot Parshall Measuring Flume, in Colorado Canal.

Figure 8.—Thirty-foot Parshall Measuring Flume, discharge 803 second-feet, submergence 89 percent, in Colorado Canal. (See Table X.)

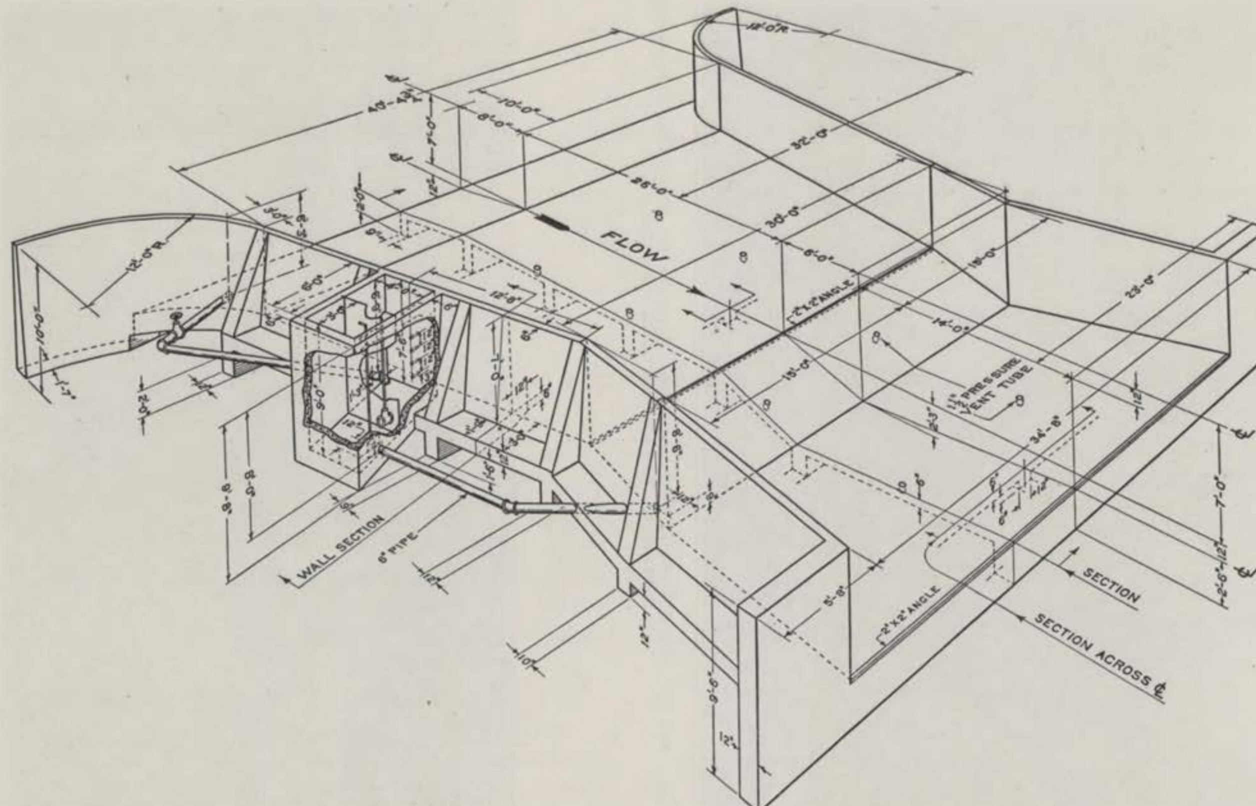


Figure 9.—Large Parshall Measuring Flume of reinforced concrete, with 30-foot throat.

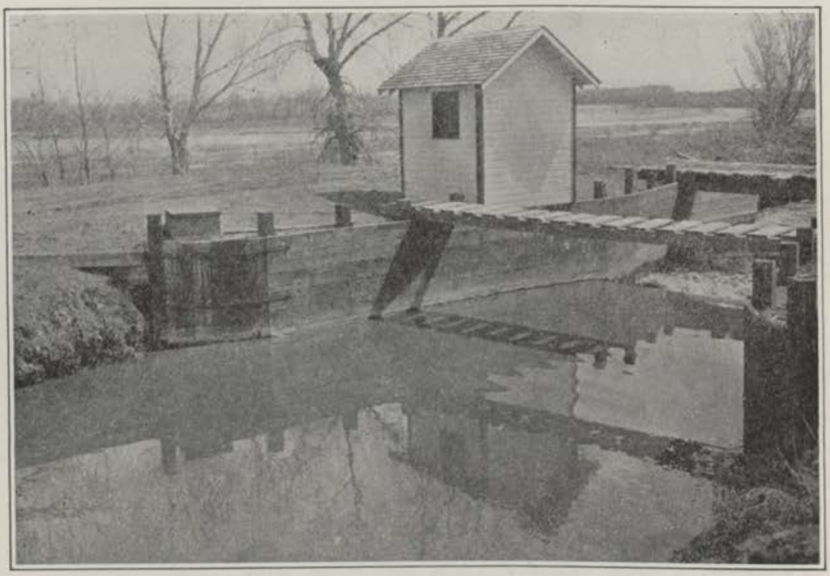

Figure 10.—Fifteen-foot Parshall Measuring Flume, discharge 101 second-feet, submergence 19 percent, Rocky Ford Highline Canal. (See Table X.)

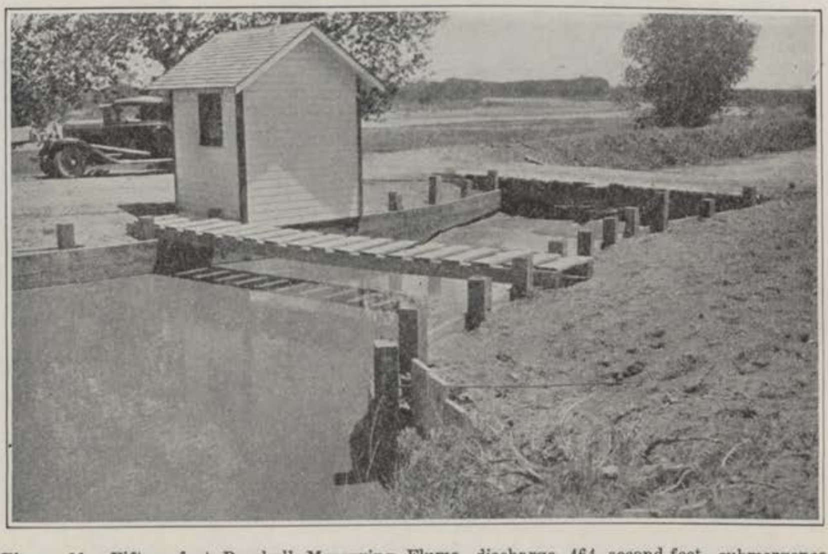

Figure 11.—Fifteen-foot Parshall Measuring Flume, discharge 464 second-feet, submergence 95 percent, Rocky Ford Highline Canal. (See Table X.)

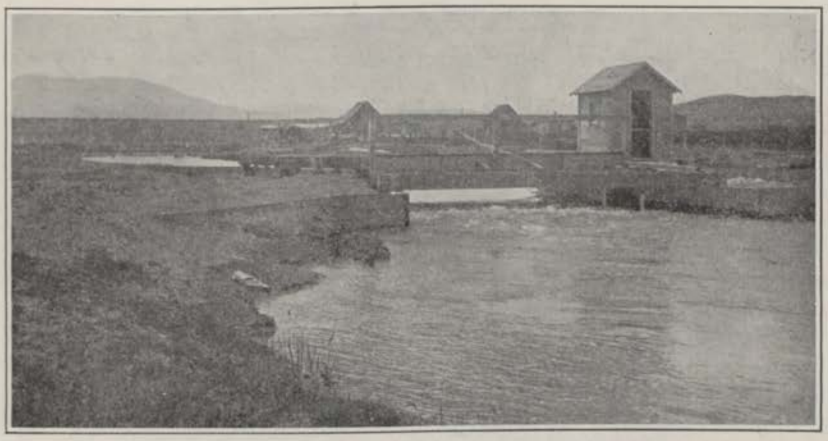

Figure 12.—Twenty-foot Parshall Measuring Flume, discharge 239 second-feet, submergence 69 percent, Antero Reservoir outlet, upper South Platte River. (See Table X.)

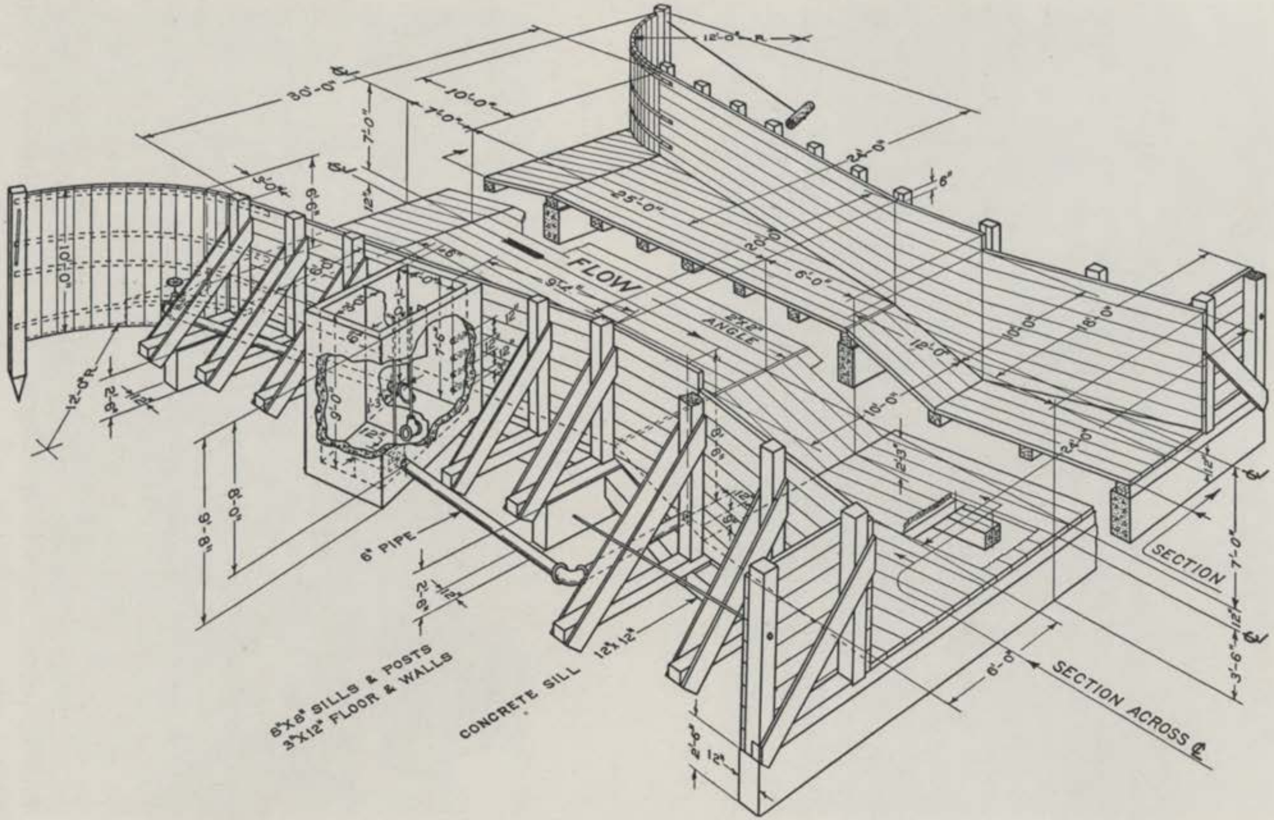


Figure 13.—Large Parshall Measuring Flume of timber construction, with 20-foot throat.

## THE SETTING OF LARGE FLUMES

For the successful operation of the larger flumes, it is important to have the crest set at the proper elevation with reference to the grade line of the channel. It will be found more convenient to set the flume so as to operate at less than the critical degree of submergence, which will eliminate the effect of backwater and thus having the rate of discharge a function of the size of flume and the upper head, $H_A$. Quite often, however, such a setting results in too much loss in head, and at the same time gives to large discharges high exit velocities which erode the downstream section of the channel. Often particular attention must be given to the increased depth of water upstream from the flume after it has been installed. The freeboard of canal banks must be considered, as well as the possibility of interfering with the diversion thru the headgates of the full capacity of the canal. In irrigation practice it is sometimes found necessary to determine the flow accurately for the smaller discharges while when the supply in the river is ample to provide a full head in the canal accuracy of measurement is not so important. To meet such conditions, the practice in establishing the proper elevation of the crest has been to provide a free-flow condition for the lower flows and allow a submerged flow condition for the greater discharges. This setting is desirable because of the lessened exit velocities for the larger flows and minimum loss of head thru the structure.

To illustrate the method used in determining the proper elevation of crest, an example applicable to a reasonably large canal is given. The discharge curve for the old rating flume on the Holbrook Canal, shown in Figure 14, was based on a few current-meter gagings that established a rating curve that was approximate only, because of the changing conditions of the channel, but was accurate enough for use in determining the crest elevation of the new flume. Previous attempts to establish a dependable rating curve based on current-meter gagings had been entirely unsatisfactory. At times more than 2 feet of sand had been observed on the floor of this flume, while later this deposit had been scoured out and moved downstream. In one observed instance, a depth of more than 1 foot of sand was deposited upon the floor in less than 2 hours. Because of this constantly shifting condition, the uncertainty of determining the flow by use of the rating curve was apparent, and the setting of the crest elevation of the new flume to meet such conditions, likewise, could not be accurately determined.

The first appropriation right of the Holbrook canal to the

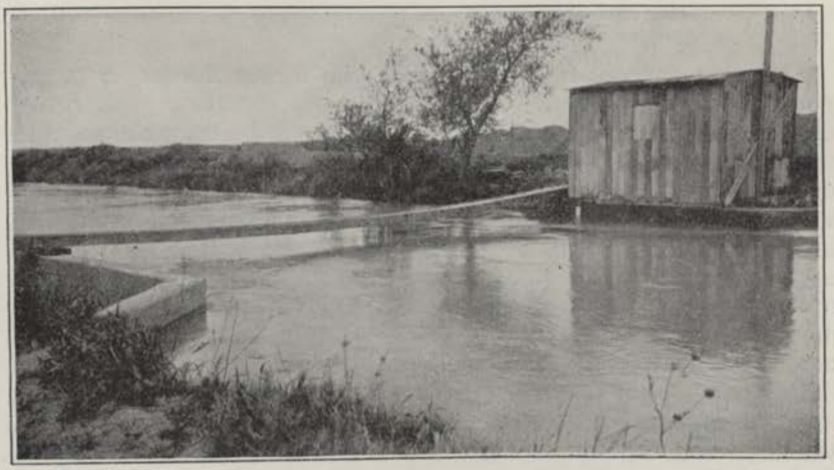

Figure 14.—Old concrete rating flume and gage house on Holbrook Canal, typical of many old structures replaced by Parshall Measuring Flumes.

use of water from the Arkansas River is 155 second-feet. In this case it was required to set the crest so that this discharge would be free flow and maximum discharge would be delivered under submerged-flow conditions. A width of 20 feet was chosen as the best size of structure and it was decided to place the new flume just upstream from the old concrete rating flume, so that the old structure would serve as a protection against erosion. From current-meter gagings made previous to the installation of the new flume, it was found that for a discharge of 155 second-feet thru the rating flume the depth of water on the staff gage was, on the average, about 2.25 feet. Had this been approximately a fixed stage, the crest elevation for the 20-foot flume with respect to the staff gage, computed from the free-flow discharge formula $Q = 76.25\ H_A^{1.6}$ (Table V, p. 39), should have been about 1 foot for the limiting submerged flow of about 80 percent.

To arrive at the elevation of 1 foot, refer to Figure 15. It will be observed from the discharge given in Table V for a 20-

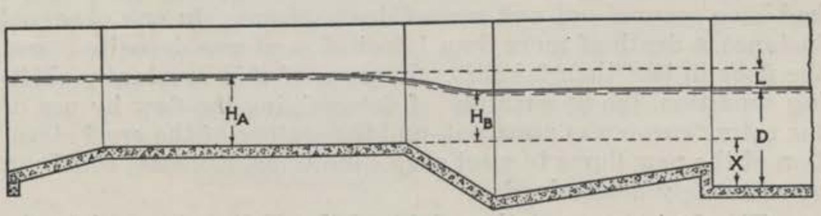


Figure 15.—Section of flume as an aid in the determination of the proper crest elevation.

foot flume, that the $H_A$ head for a discharge of 155 second-feet is about 1.56 feet. For a setting of limiting submergence at 80 percent, the $H_B$ gage would be about 80 percent of 1.56 feet, or 1.25 feet. At this degree of submergence, the water surface downstream from the $H_B$ gage is essentially level, and the loss of head or grade to the staff gage in the rating flume may be neglected. Since the average staff-gage reading is taken as 2.25 feet with the $H_B$ gage estimated to be 1.25 feet, the difference (X in Fig. 15) of 1 foot will be the elevation of the crest above the zero point of the rating-flume gage.

Because of the wide range of gage heights in the rating flume, with the discharge remaining approximately constant, it is better to base the elevation of crest on the condition of maximum rating-flume gage. For this condition, the depth or staff-gage reading in the rating flume may exceed 3 feet, and for such a limiting stage the crest of the new structure would be about 2 feet above the floor of the old rating flume to measure 155 second-feet under free flow—that is, with the degree of submergence not exceeding 80 percent.

After approximating the elevation of the crest of the flume at 2 feet, for a discharge of 155 second-feet at about 80 percent submergence, it is necessary to determine the condition of flow for large discharges. On June 1, 1924, about 3 years before this new 20-foot flume was built, there was a period when there was a discharge of 558 second-feet, as determined by a current-meter gaging with a staff-gage reading of 6.04 feet in the rating flume. With the crest set at 2 feet, the $H_B$ gage would be approximately 4.04 feet, and by use of the submergence correction diagram (Fig. 22, p. 45) it is found that for this discharge the degree of submergence will be about 95 percent, and the $H_A$ gage will read 4.25 feet. Therefore, the crest of the new Holbrook flume was set 2 feet higher in elevation than the zero of the staff gage in the old rating flume.

In planning such large flumes it is necessary to know, within reasonable limits, the depth of water in the channel for any particular discharge. As previously mentioned, it is not unusual to find that one or more limitations in measurement are imposed; that is, if conditions warrant, the lower rates of discharge should not be submerged, or, if submergence is necessary, it should be in the least possible amount and for maximum discharge the degree of submergence should not exceed from 95 to 98 percent with the lower percentage preferred. To meet these requirements, it is necessary to investigate the problem where various sizes of flumes are considered, as well as the cost of the proposed new structure.

Let it be assumed that it is required to provide a flume of the proper size and setting in a channel 50 feet wide, whose capacity is 950 second-feet, with submergence not exceeding 80 percent for a discharge of 500 second-feet, and with depth and discharge relationships at the site of the installation as follows:

| Gage height Feet | Discharge Sec.-ft. | Gage height Feet | Discharge Sec.-ft. |
|---|---|---|---|
| 0 | 0 | 3.5 | 398 |
| 0.5 | 18 | 4.0 | 500 |
| 1.0 | 45 | 4.5 | 607 |
| 1.5 | 86 | 5.0 | 718 |
| 2.0 | 145 | 5.5 | 832 |
| 2.5 | 218 | 6.0 | 949 |
| 3.0 | 303 | | |

First, consider a 20-foot flume. For a free-flow discharge of 500 second-feet the $H_A$ gage will be 3.24 feet and the $H_B$ gage 2.59 feet at 80 percent submergence, as illustrated in Figure 16.

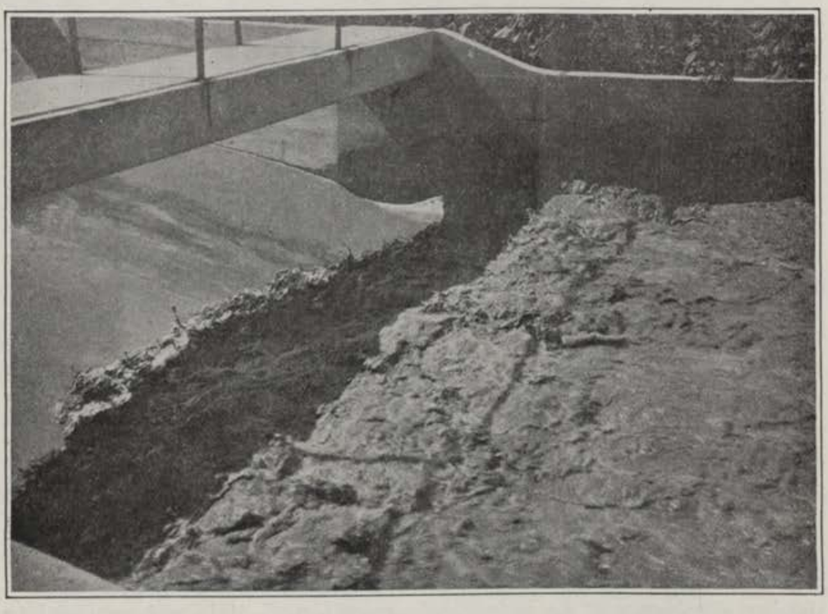

Figure 16.—A discharge of 550 second-feet passing thru the throat section of the 20-foot flume on the Holbrook Canal with 80 percent submergence. (See Table X.)

In the foregoing tabulation a depth of 4.0 feet downstream from the proposed flume is required for this discharge. Since for this submergence the water surface at the $H_B$ gage point is practically at the same elevation as it is downstream, X, the elevation of crest above bottom of channel (Fig. 15), is 1.4 feet. For the maximum discharge of 950 second-feet with this setting and size of flume, it is necessary to determine the degree of submerged flow. For a discharge of 950 second-feet the flow will be submerged. To determine the actual condition quickly, first assume the submergence to be 90 percent. Since the $H_B$ gage will be approximately 6.0—1.4, or 4.6 feet, for 90 percent submergence $H_A$ will be 5.11 feet, and the corresponding free-flow discharge 1,037 second-feet. (See discussion, pages 44 to 46). From the correction diagram (Fig. 22) it is found that this correction is about 145 second-feet, giving computed discharge of 1,037—145, or 892 second-feet. For 88 percent submergence, the $H_A$ gage is 5.23 feet and the computed discharge is 972 second-feet. At 89 percent submergence, the computed submerged flow is 934 second-feet. For a 20-foot flume set 1.4 feet above the bottom of the channel and discharging 950 second-feet, with a submergence of slightly more than 89 percent, the loss of head is about 1 foot. In this case, therefore, the depth upstream from the proposed structure would be 1 foot more, which might seriously reduce the freeboard of the canal banks and also interfere with the diversion or entrance conditions.

For a 25-foot flume to measure 500 second-feet at 80 percent submergence, it is found that the height of crest above the bottom of the canal should be about 1.7 feet. At this elevation of crest it is also found that the maximum discharge of 950 second-feet will occur when submergence is 91 percent. From the diagram shown in Figure 23 (page 46), it is found that the loss of head for this maximum condition of discharge and submergence is about 0.7 foot. The decision as to which size of flume to select depends largely upon whether or not the loss of head of 1 foot for the 20-foot flume is too great for economical operation, or whether, on the other hand, the cost of a 25-foot flume of similar construction would be excessive. It will be noted that the larger flume must be set higher, but the loss of head would be less. Either size of flume would satisfactorily measure the flow.

As in the case of the Holbrook flume, there naturally arises the problem of increasing the depth of water upstream from the new structure, due to raising the crest 2 feet and decreasing the width of the channel from about 40 feet to a throat section of 20 feet. Referring to Table X, it is noted that two discharges of approximately 550 second-feet were measured thru this 20-foot flume, with submergences of 63 and 81 percent and the upper gage ($H_A$) at about 3.5 feet. For the condition of 81 percent submergence, the loss of head from the $H_A$ gage point to the upper end of the converging section of the flume is about 0.33 foot. The difference $H_A—H_B$ is 0.66, with a total loss of head of about 1 foot. The upstream water surface would now be about

5.8 feet or 0.2 foot less in depth for 550 second-feet than it would have been on June 1, 1924, for approximately the same discharge with reference to the old rating-flume gage. This comparison shows that in the previous case the filling in of sand in the channel caused the water to assume a maximum, whereas the raising of the 20-foot flume 2 feet and reducing the channel to a 20-foot throat shows a lesser depth upstream after the new flume was installed. This condition is cited merely to indicate that under actual normal shifting conditions on this particular canal, the change in depth was greater than that caused by the installation of the 20-foot flume.

## CONSTRUCTION OF LARGE FLUMES

Reinforced concrete has been used very largely in the construction of the larger flumes. Figure 9 gives a design showing the principal dimensions for a concrete 30-foot flume, and Figure 13 gives a design for a frame structure having a throat width of 20 feet.

The concrete structures are of ordinary monolithic construction, with reinforcing steel bars cast into the walls and floor. (Fig. 17.) Because of the wide span, it is not practical to provide cross bracing or struts between the tops of walls, and coun-

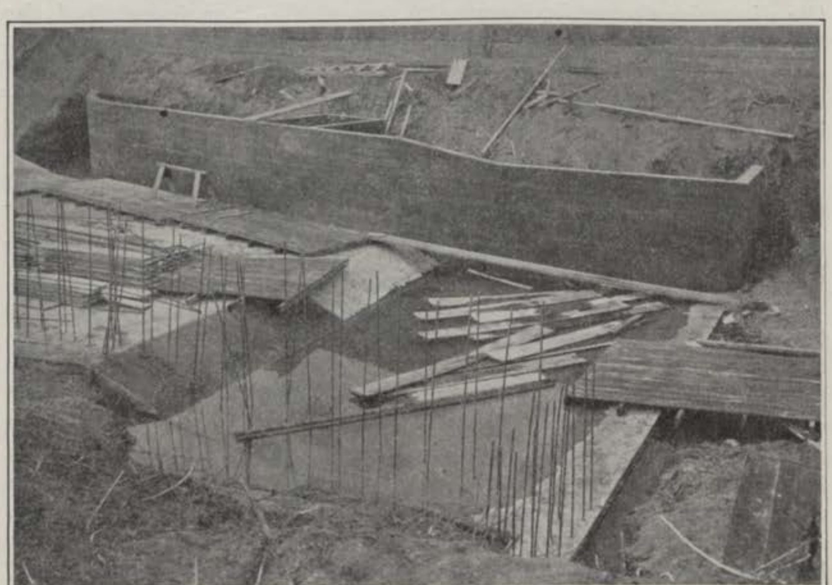

Figure 17.—Partly completed reinforced concrete 20-foot Parshall Measuring Flume on the Bijou Canal, South Platte River, near Greeley, Colo.

terforts have proved to be satisfactory for supporting 7-foot walls in 20-, 30- and 40-foot flumes, at the same time providing ample strength to sustain the backfill pressure. (Fig. 18.) It

Figure 18.—Flume wall, with counterfort bracing, of the 20-foot flume on Bijou Canal.

will be noted in Figure 9 that substantial footings are shown. The bases for such footings should be firm and well prepared, and with the entire floor of the structure acting as a base, little or no settlement has been observed in the large concrete structures. The longitudinal and transverse beams under the floor should have U-shaped lengths of short pieces of reinforcing bar, properly bent, inserted in the top surface of these beams at suitable intervals so that the bars in the floor may be threaded thru them to secure rigid contact between the beam and floor. These beams provide strength against heaving or bulging of the floor surface.

The essential feature in the building of the flumes is to have the finished dimensions and alignment correct. The floor of the converging section should be level. The downward-sloping floor in the throat should be a plane surface, pitched to the proper dimensions as shown. The floor of the diverging section slopes upward, the line of intersection of these two surfaces being level transversely. The most important feature of these flumes is the uniformly level floor of the converging section, and especially the uniformly level, straight crest at the junction of this floor and the floor of the throat. To provide a sharp and definite edge to serve as the crest, it is recommended that a straight, substantial angle iron be leveled and securely fixed in the proper position. For concrete structures this may be cast in the floor where the ends of the angle iron extend 2 or 3 inches back into the side walls of the structure. Holes provided thru the vertical leg of the angle iron at about 2-foot intervals, thru which short pieces of reinforcing steel or bolts may be inserted and cast into the floor, will securely anchor the crest in place. It is recommended that an angle iron be placed at the downstream end of the diverging section also, if the structure is built of concrete, as a protection to the exposed edge. The inside faces of the walls should be smooth, straight and vertical, and the outside faces should have the required batter. The floors of concrete structures should also be provided with pressure vent tubes, as indicated in Figure 9. The inclined apron at the upstream end of the flume, as well as the curved walls reaching back to the banks of the channel which serve to lead the stream of water into the entrance of the flume with slight loss of head, should all be smooth and regular to insure good flow conditions.

The utility of the structure lies in the accurate measurement of the discharge. As the rate of flow is a function of the relationship of the depths of water at the upper and lower gage points in the flume, it is important that the proper distances to these points be carefully determined. Table I gives the distances to the upper gage, $H_A$, in feet, measuring back from the end of the crest along the wall of the converging section. This point may be located on either side of the structure. Figures 9 and 13 show inlet tubes leading from the inside face of the wall into the $H_A$ gage well, where this well is cast as an integral part of the structure. These inlet points are located in a vertical line, 12 inches apart, with the bottom one about 3 inches above the floor line. The lower or throat gage, $H_B$, is at a point near the downstream edge of the throat. (See note, Table I.) The inlet openings into the flume for both $H_A$ and $H_B$ gages must be set flush with the inside face of the wall, and must be permanently fixed in position and neatly finished.

To insure better alignment for the frame structure along the floor line, it is recommended that the first courses of wall planks be set and the floor planks then be carefully fitted into place. This arrangement insures against the bulging or crowding inward of the bottom wall planks, due to the hydrostatic and earth pressure against the outside face of the flume wall. Also, experience teaches that the planks should not be matched too closely, as the swelling of the wood may cause the floors to warp or heave, thus making an irregular surface. There should be left a crack one-eighth- to one-fourth-inch wide between adjacent planks. Parting stop fillets to prevent leakage are thought to be unnecessary.

As for the concrete flume, an angle-iron crest is highly desirable. After setting the floor of the converging section with the ends of the planks at the crest line smooth and even, the angle-iron crest should be set flush with the floor surface and held firmly in place with substantial lag screws. The heads of these lag screws, set at about 2-foot intervals, may project above the surface without material interference with the proper working of the flume. If properly set, this angle-iron crest will be straight, at right angles to the axis of the flume, with its surface level thruout.

For the frame structure (Fig. 13) the curved transition at the entrance is formed of 3- by 6-inch pieces set on end and held in place by one-fourth- by 3-inch steel bands, properly spaced, with one end securely bolted to the upstream end of the wall of the converging section and the other to a post firmly set in the bank of the channel. These bands, when in place, form a smooth curve to support the vertical pieces and are held in place by the backfill. The framing of the large structures can be accomplished by any experienced carpenter. After the work has been completed, it is desirable to trim the tops of the posts to a uniform height as a matter of general appearance. As a measure of economy the use of lumber pressure-treated with creosote or other preservative is fully warranted.

Wooden flumes in ditches carrying water during the winter season have been subject to scoring due to angular pieces of ice striking against the side walls of the lower end of the converging section. For this reason it is thought advisable to protect the angle at the junction of the walls of the throat and converging section by means of a vertical strip of heavyweight sheet steel, shaped to the proper angle, so that when in place it will fit snugly against the side walls. It has also been the practice to provide a substantial footbridge spanning the converging section at a point about three-quarters the length of this section, measured back from the crest. This bridge is to provide a means of crossing and may be used in making current-meter gagings.

It is not possible to state the cost of these structures, as many factors are involved which influence the final figure. From the designs submitted, it is possible to approximate the amount of material, either in lumber or concrete. The local market prices are then used to estimate the cost of materials. The excavation required, accessibility, transportation, and other features ultimately enter into the cost. Treated-lumber flumes should cost somewhat less than those made of concrete. In some instances, however, the difference in cost for the two types has been small.

## STILLING WELLS

For making accurate discharge measurements in large flumes, it has been found necessary to determine carefully the effective heads $H_A$ and $H_B$. A staff gage for the determination of the $H_A$ reading, if attached to the inside face of the flume wall, can be read only approximately because of the fluctuations of the water surface, and the turbulent condition of the water within the throat of the structure makes it quite impossible to obtain accurate $H_B$ readings by means of a staff gage located in that section of the flume. In order to obtain reliable and accurate gage readings, a double stilling well (Fig. 19) is provided at a point where the gage inlet tubes will pass directly into the $H_A$ compartment, while the head for the $H_B$ gage is brought back to the other compartment thru a suitable pipe leading from the proper point in the throat section. A reinforced concrete stilling well with a quarter-inch steel plate diaphragm cast into the walls and bottom of the well to provide the water-tight $H_A$ and $H_B$ compartments is recommended. A ladder way for each compartment, improvised by fixing U-shaped pieces of reinforcing steel in the walls of the wells at suitable places, is also suggested.

Because of the depth of the wells, it has been found difficult, if not impracticable, to clean out the deposit of mud and sand by means of bucket and rope. Under some conditions, where the water passing thru the flume is heavily laden with silt, sand and suspended matter, the stilling wells soon become fouled. As a practical means of clearing the wells, a flushing system has been developed which has been found to be effective and suitable. Leading from the curved wing wall at the upstream end of the structure is a 6-inch metal pipe which discharges into the $H_A$ stilling well. This pipe has a substantial gate valve, located as shown in Figures 9 and 13. At the outlet end in the well is an elbow pointed downward. In the steel diaphragm is a 6-inch circular opening near the floor line, and attached is another similar gate valve. The 6-inch pipe leading from the $H_B$ well to the throat of the flume completes the system. To flush the wells, open the valve on the inlet pipe and the valve on the steel diaphragm, and raise the slide gate in the $H_B$ well. Unless the submergence thru the flume is very high, the hydrostatic head between the inlet and outlet ends of this flushing system is sufficient to provide a good scouring velocity thru the two wells. The elbow, pointed downward in the $H_A$ well, will move the deposit on the inclined floor toward the opening thru the diaphragm, and since the outlet from the $H_B$ well is at a low elevation, the deposits will tend to move to this point and eventually be carried out and discharged back into the throat section of the flume. Under extreme silt or sand conditions, a 5- or 10-minute flushing every day should maintain the wells in good order. When

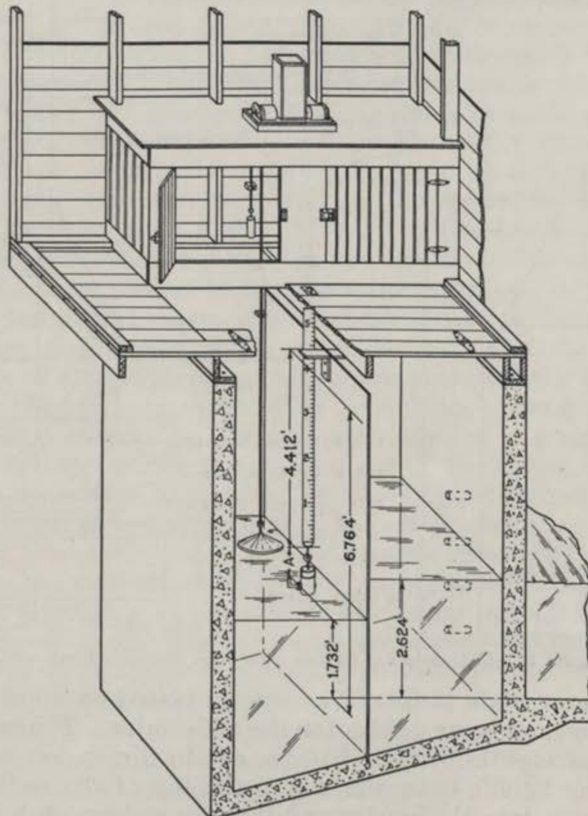


Figure 19.—Method of determining actual values of the $H_A$ and $H_B$ heads in feet, for comparison with indicated values on instrument drums.

all the valves are closed the water levels in the two wells will readily assume their normal elevations.

It will be noted that the valve in the pipeline leading to the $H_A$ well is shown set back at some distance from the inlet end. For winter operation, the danger of damage to the valve by freezing is lessened by having this valve well back from the exposed wall surface. For convenience in the operation of the valve, a pit may be provided with a trap door and lock, or a key stem may extend to the ground surface.

The slide gate at the upper end of the outlet pipe from the $H_B$ well will not need to be a close-fitting valve. A simple gate may be constructed (Fig. 20) by using a standard 6-inch cast-iron flange loosely turned on the projecting end of the pipe. A

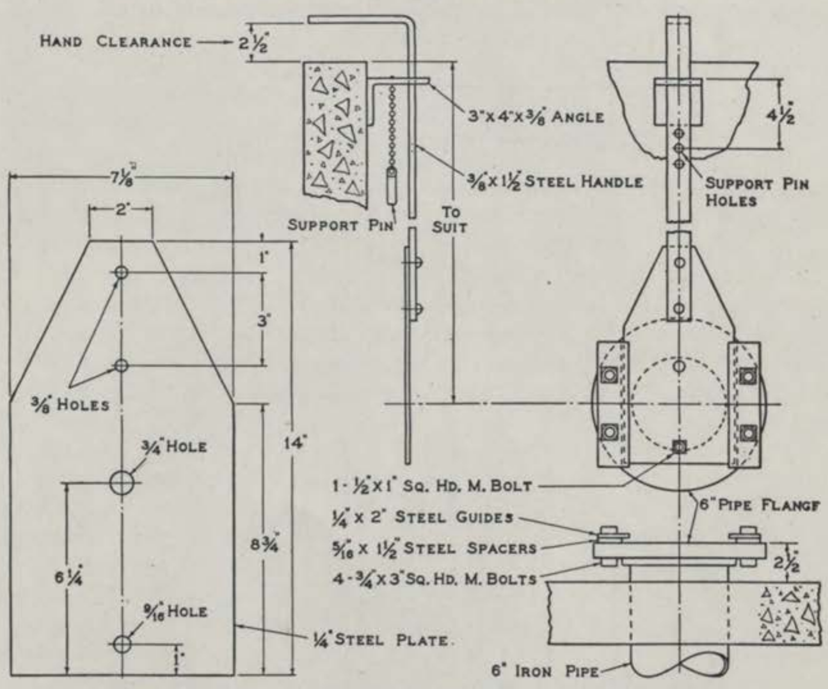


Figure 20.—Slide gate for flushing pipe from the $H_B$ stilling well.

lug and cover plate prepared as shown, bolted on opposite sides of the flange, serve as guides for the slide valve. The latter may be made of eighth-inch steel plate, cut to dimension as shown, with a long handle extending up to the top of the wall. Insert the slide gate into the guides and then fix a short stub bolt thru the lower hole in the slide. This bolt head will then come in contact with the bottom edge of the inside of the pipe and stop the gate in its proper position, and will, in like manner, prevent the gate from being withdrawn from the guides. When this slide valve is in normal position, the three-quarter-inch hole is near the top side of the pipe opening and is intended to damp down the pulsations caused by the roughness of the water in the throat of the flume. If sediment is deposited in the 6-inch pipeline, it will occupy the lowest portion leaving some space at the top for the communication of the water pressure.

### GAGE HOUSE AND INSTRUMENT

The gage house built over the stilling wells is not indispensable as a shelter for the instrument, but is in keeping with the utility of the installation. Experience shows that the convenience afforded by providing a suitable shelter warrants its cost. As shown in the several illustrations of large flumes, the gage houses are built of drop siding, with a shingle or metal roof, hard pine floor, 4-light windows and a well-painted exterior, and are of neat appearance. Some have been finished inside with paneled wallboard, and each one has a built-in cabinet over the gage wells on which the recording instrument is mounted. The height of the top of the cabinet above the crest should be sufficient to prevent the counterweight from striking the top of the float when the maximum stage or depth of water in the flume is reached. For a range of 5 feet in depth the base of the instrument should be not less than 10 feet higher than the crest of the flume. In general, the height above the crest should be somewhat more than twice the maximum $H_A$ gage height. The plane of the front side of this cabinet agrees approximately with the center line thru the two gage wells. The remaining area of the top of these wells is covered by a trap door, hinged at the edge so that the opened door will lie flat on the floor of the house, disclosing, within easy reach, a hand wheel on an extended stem for operating the 6-inch gate valve on the steel diaphragm, and also the handle of the slide gate. The ladder into the wells should be located on the wall or across the corner near the trap-door opening. The front side of the cabinet should be provided with two doors, hinged at the sides and equipped with a cupboard latch. When these doors and the trap door are open, enough light enters the wells to permit making observations.

The double-head indicating and recording instrument, especially designed for use in connection with the Parshall measuring flumes of large size (Fig. 21), has proved to be of practical design and well suited to the purpose. This instrument has a base of 8 by 21.5 inches and is 17.5 inches high, equipped with a vertical clock cylinder which turns one revolution in 7.5 days and carries an especially designed, convenient chart. The recording gage-height range is 5 feet. The clock used is a high-grade movement, arranged so that a friction gear permits the chart to be set to the correct time by merely turning the cylinder in place as desired. On two independent rotating shafts, suitably mounted on the base of the instrument, drums are fixed which indicate the $H_A$

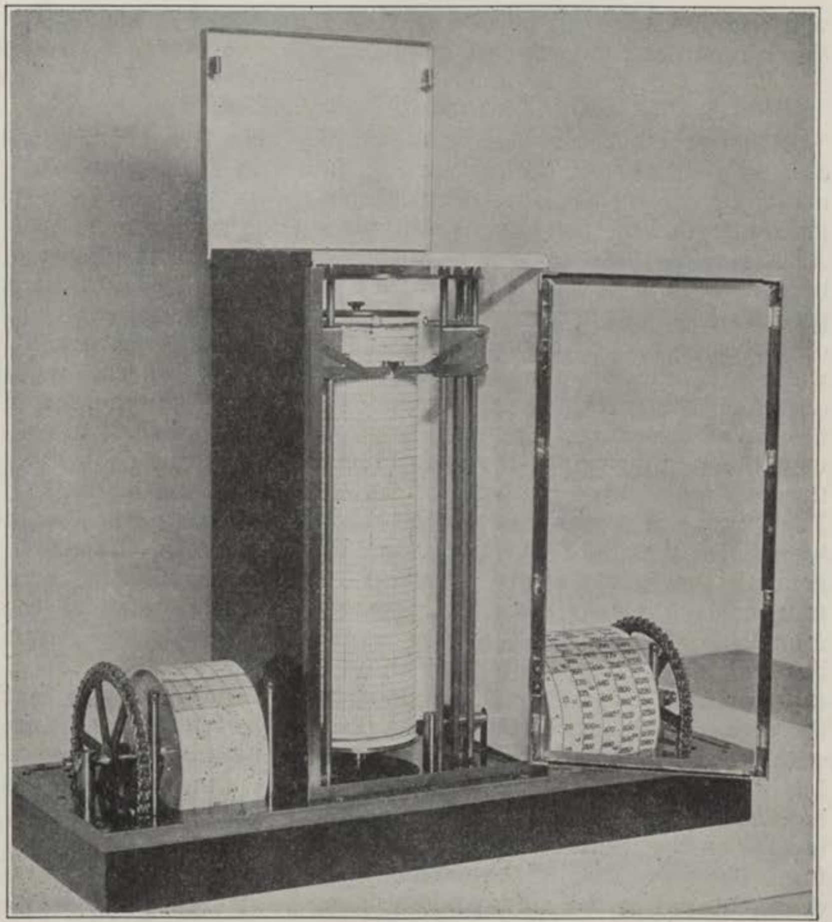

Figure 21.—Double-head recording and indicating instrument designed for use in connection with Parshall Measuring Flumes of large size.

and $H_B$ gage heights. Each of these is moved by a sprocket wheel and chain, the latter being attached to a float in the well, and the system is balanced by a counterweight. The $H_A$ and $H_B$ gage heights are read on continuous spiraled scales, graduated in feet, on the surface of the drums. The scales are of neat, clear-cut marking, printed on white pyralin strips which are afterward formed into cylinders of the proper diameter and provided with heavy pyralin heads, securely fixed to the sprocket wheel shaft. Mounted on a brass support is a strip of clear pyralin with a fine black-etched line spanning across the face of each cylinder. Any change or variation of the water surface in the wells is indicated by the movement of the scale beneath this

(A) These instruments are designated as "right hand" or "left hand" according ~~as~~ to whether the Ha drum is at the right or left when facing the instrument. This arrangement is necessary as a convenience to operation ~~as to~~ depending on whether the stilling wells are located on the right or left hand side of the flume.

(Add this as part of the paragraph.)

index line. The drum at the left gives the value of the $H_B$ head, and at the right is a wider-faced drum bearing two sets of graduations, one set giving the $H_A$ readings and the other showing in bold-faced type the rate of free-flow discharge in second-feet. The $H_A$ drum with its discharge graduations is especially designed for any particular size of flume.

Each pen used to scribe the graphs on the graduated chart is mounted on a suitable head block carried at the upper end of a vertical rack, meshing with a small gear of proper diameter attached to the shaft carrying the sprocket wheel and indicating drum.

Parallel guide rods direct the pens vertically along the hour line of the chart. Each pen is synchronized to the drum reading for gage height, and, since the index line crosses more than one line of graduations, it is only necessary to read approximately the indicated chart reading and then observe to close limits the actual value of the head as shown on the drum.

In the operation of this instrument, the only manipulation necessary is to remove the cylinder, wind the clock and change the chart. To remove the cylinder, the $H_A$ and $H_B$ pens are lifted from the chart by a suitable lever arrangement, and the cylinder is then lifted vertically from its pivot support. The key for winding is attached to the clock movement and extends to the top of the cylinder. An ornamental cover fits snugly over the top as a protection. The blank chart, cut to fit, is laid around the cylinder and rests against a ring projection at the bottom. Rubber bands are used to hold the sheet in place. Paste may be used to seal the edges if desired.

The distance between sprocket wheels is 18 inches, and where 12-inch floats are used only 6 inches are available to clear the vertical diaphragm in the float wells. If a concrete partition wall is used to separate the $H_A$ and $H_B$ compartments, it is found that with a practical thickness of wall there is not sufficient safe margin or clearance for the travel of the floats. The metal diaphragm, with horizontal angle-iron stiffeners, occupying only about 2.5 inches, is much more suitable. To locate properly the position of the instrument on the cabinet, it is necessary to plumb carefully from the diaphragm up to the under side of the top of the cabinet and there drive thru a nail. From the point thus obtained on the top, the places for the holes for the sprocket chains and those thru which the penracks are to pass may be marked. To provide ample clearance, 1-inch auger holes are recommended. The instrument base is now shifted to position and firmly fixed by screws at the ends. The sprocket chains are threaded thru, and the float and counterweight are attached.

The mounting and setting of the instrument require no special expert mechanical skill.

By carefully determining the mean crest elevation, using an engineer's level and rod, a reference point, or bench mark, is set over each well. The elevation of these marks above the mean elevation of the crest is calculated to 0.001 foot and posted at each point. A special weighted hook gage attached to a light-weight steel tape, graduated to 0.01 foot, is used to determine the vertical distance between the water surface and the fixed reference point. (Fig. 19.) To use the hook-gage plumb bob, attach it to the ring of the steel tape and lower it into the water in the well until the point is submerged. Carefully raise until the point just appears, and then read tape at the reference point. This tape reading will, of course, be the distance to the zero point of the tape. To this must be added the distance, A, from the point of the hook to the zero point of the tape. The sum is the distance from the reference point to the water surface, and this sum subtracted from the elevation of the reference point will be the actual effective head. The drum reading on the instrument is observed at the same time that the hook-gage reading is taken, the resulting difference indicating the error in the instrument reading.

In setting the instrument for the first time, a material error may be expected. By moving the chain on the sprocket, large corrections may be made until a fair agreement is attained. Several hook-gage and drum readings should next be taken simultaneously. The difference between the means of these observations will indicate the extent of the correction which must be made by adjusting the lock nut attachment at the float. The comparison of both drums and final adjustments must be made before actual discharge calculations are possible.[8]

## FREE-FLOW DISCHARGE

The free-flow discharge thru the Parshall measuring flume for all sizes is defined as that condition of flow where the degree of submergence does not retard or resist the rate of discharge. As the water passes thru the throat section, it may assume two different and distinct stages; first, where the velocity below the flume is high and the stream flattens out and conforms very closely with the dip at the downstream end of the throat section; second, where the depth of water in the channel downstream from the structure is such as to cause a hydraulic jump or standing wave to form in the lower portion of the throat. As the de-

[8]Further information concerning the double-head indicating instrument may be obtained by addressing the Colorado Experiment Station, Fort Collins.

gree of submergence becomes greater, the standing wave moves upstream in the throat until it becomes "drowned" and the rate of flow is retarded. For all conditions of flow up to this limiting degree of submergence, the rate of discharge is unrestricted, constant and fixed; hence, owing to the application of a definite law of flow, this range is called "free-flow." For very small flumes, such as the 3- to 9-inch sizes, this limiting degree of submergence is approximately 50 percent, while for the 10- to 50-foot flumes, the practical limit is about 80 percent.

The free-flow discharge formula for small flumes (1- to 8-foot size), $Q = 4WH_A^{1.522W^{0.026}}$, when extended to large structures is found to give a discharge in excess of the actual flow. In developing the general discharge formula for the large flumes, a more simplified expression has been found to be applicable to flumes ranging in size from 8- to 40-feet. This general discharge formula is $Q = (3.6875W + 2.5)\ H_A^{1.6}$, where Q is the rate of discharge in second feet, W, the throat width in feet, and $H_A$, the upper gage in feet. The free-flow discharge computed by this formula for an 8-foot flume differs by less than 1 percent from the general expression applicable to the smaller flumes.

Tables II to IX, inclusive, give the discharge in second-feet for throat widths of 10, 12, 15, 20, 25, 30, 40 and 50 feet, respectively. In these tables it is possible, by estimation, to read the free-flow discharge in second-feet with an error of less than 1 percent.

TABLE II

FREE-FLOW DISCHARGE 10-FOOT PARSHALL MEASURING FLUME

FORMULA $Q = 39.38\ H_A^{1.6}$

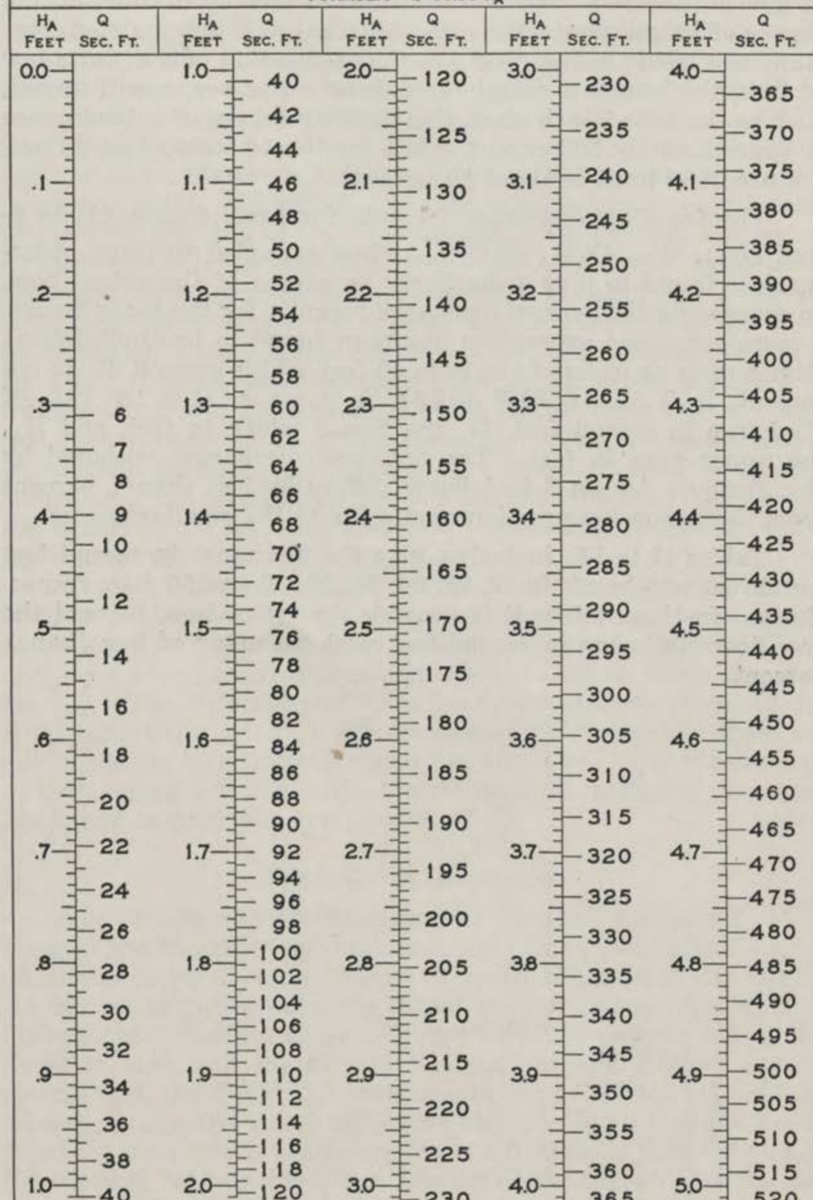

TABLE III

FREE-FLOW DISCHARGE 12-FOOT PARSHALL MEASURING FLUME

FORMULA $Q=46.75\ H_A^{1.6}$

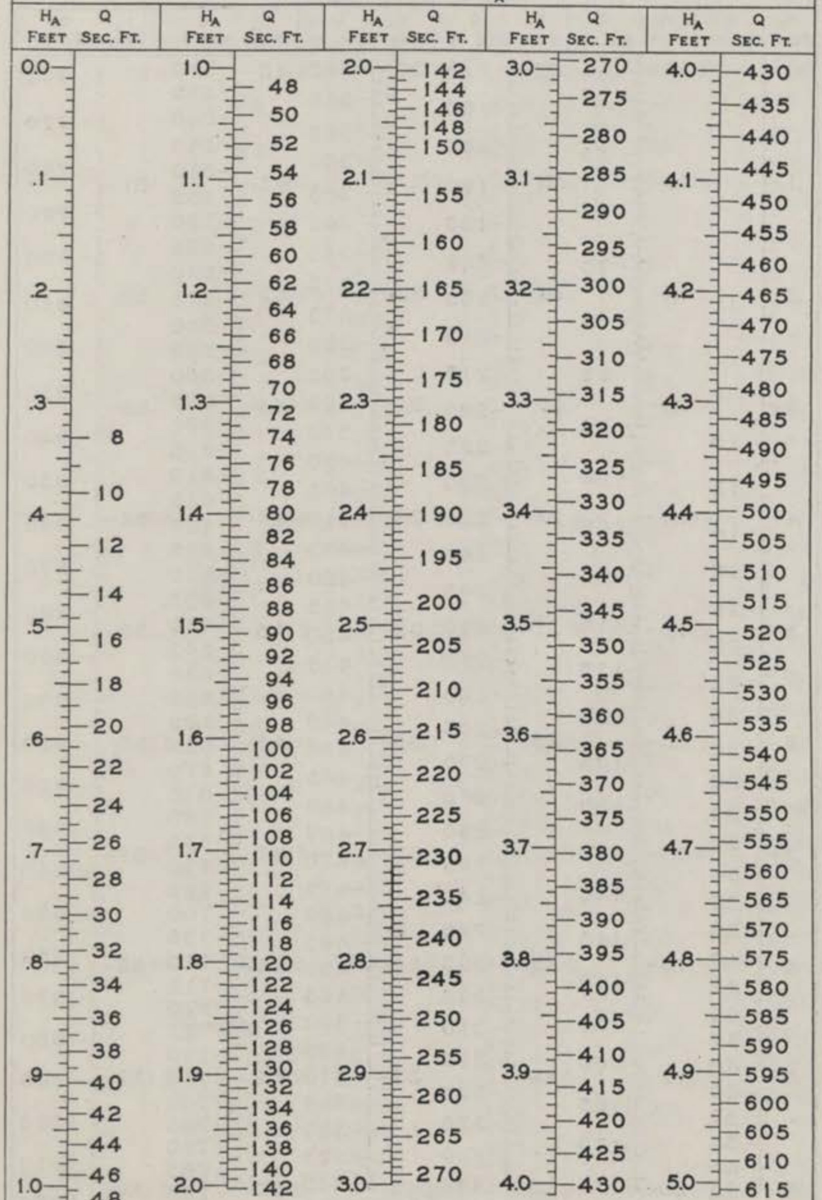

TABLE IV

FREE-FLOW DISCHARGE 15-FOOT PARSHALL MEASURING FLUME

FORMULA $Q = 57.81 H_A^{1.6}$

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 0.0 | |
| .1 | |
| .2 | |
| .3 | 8 |
| | 10 |
| | 12 |
| .4 | 14 |
| | 16 |
| | 18 |
| .5 | 20 |
| | 22 |
| | 24 |
| .6 | 26 |
| | 28 |
| | 30 |
| .7 | 32 |
| | 34 |
| | 36 |
| | 38 |
| .8 | 40 |
| | 42 |
| | 44 |
| | 46 |
| | 48 |
| .9 | 50 |
| | 52 |
| | 54 |
| | 56 |
| 1.0 | 58 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 1.0 | 58 |
| | 60 |
| | 65 |
| 1.1 | |
| | 70 |
| | 75 |
| 1.2 | |
| | 80 |
| | 85 |
| 1.3 | |
| | 90 |
| | 95 |
| 1.4 | 100 |
| | 105 |
| 1.5 | 110 |
| | 115 |
| | 120 |
| 1.6 | |
| | 125 |
| | 130 |
| 1.7 | 135 |
| | 140 |
| | 145 |
| 1.8 | 150 |
| | 155 |
| 1.9 | 160 |
| | 165 |
| | 170 |
| 2.0 | 175 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 2.0 | 175 |
| | 180 |
| | 185 |
| 2.1 | 190 |
| | 195 |
| | 200 |
| 2.2 | 205 |
| | 210 |
| | 215 |
| 2.3 | 220 |
| | 225 |
| | 230 |
| 2.4 | 235 |
| | 240 |
| | 245 |
| 2.5 | 250 |
| | 255 |
| | 260 |
| | 265 |
| 2.6 | |
| | 270 |
| | 275 |
| | 280 |
| 2.7 | 285 |
| | 290 |
| | 295 |
| 2.8 | 300 |
| | 305 |
| | 310 |
| | 315 |
| 2.9 | |
| | 320 |
| | 325 |
| | 330 |
| 3.0 | 335 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 3.0 | 335 |
| | 340 |
| | 345 |
| | 350 |
| 3.1 | 355 |
| | 360 |
| | 365 |
| | 370 |
| 3.2 | 375 |
| | 380 |
| | 385 |
| 3.3 | 390 |
| | 395 |
| | 400 |
| | 405 |
| 3.4 | 410 |
| | 415 |
| | 420 |
| | 425 |
| 3.5 | 430 |
| | 435 |
| | 440 |
| | 445 |
| 3.6 | 450 |
| | 455 |
| | 460 |
| | 465 |
| 3.7 | 470 |
| | 475 |
| | 480 |
| | 485 |
| 3.8 | 490 |
| | 495 |
| | 500 |
| | 505 |
| 3.9 | 510 |
| | 515 |
| | 520 |
| | 525 |
| 4.0 | 530 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 4.0 | 530 |
| | 535 |
| | 540 |
| | 545 |
| | 550 |
| 4.1 | 555 |
| | 560 |
| | 565 |
| | 570 |
| 4.2 | 575 |
| | 580 |
| | 585 |
| | 590 |
| 4.3 | 595 |
| | 600 |
| | 605 |
| | 610 |
| | 615 |
| 4.4 | 620 |
| | 625 |
| | 630 |
| | 635 |
| 4.5 | 640 |
| | 645 |
| | 650 |
| | 655 |
| | 660 |
| 4.6 | 665 |
| | 670 |
| | 675 |
| | 680 |
| | 685 |
| 4.7 | 690 |
| | 695 |
| | 700 |
| | 705 |
| 4.8 | 710 |
| | 715 |
| | 720 |
| | 725 |
| | 730 |
| 4.9 | 735 |
| | 740 |
| | 745 |
| | 750 |
| | 755 |
| 5.0 | 760 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 5.0 | 760 |
| | 770 |
| | 780 |
| 5.1 | |
| | 790 |
| | 800 |
| 5.2 | 810 |
| | 820 |
| | 830 |
| 5.3 | |
| | 840 |
| | 850 |
| 5.4 | 860 |
| | 870 |
| | 880 |
| 5.5 | |
| | 890 |
| | 900 |
| 5.6 | 910 |
| | 920 |
| | 930 |
| 5.7 | |
| | 940 |
| | 950 |
| | 960 |
| 5.8 | |
| | 970 |
| | 980 |
| 5.9 | 990 |
| | 1000 |
| | 1010 |
| 6.0 | 1020 |

TABLE V
FREE-FLOW DISCHARGE 20-FOOT PARSHALL MEASURING FLUME
FORMULA $Q = 76.25 H_A^{1.6}$

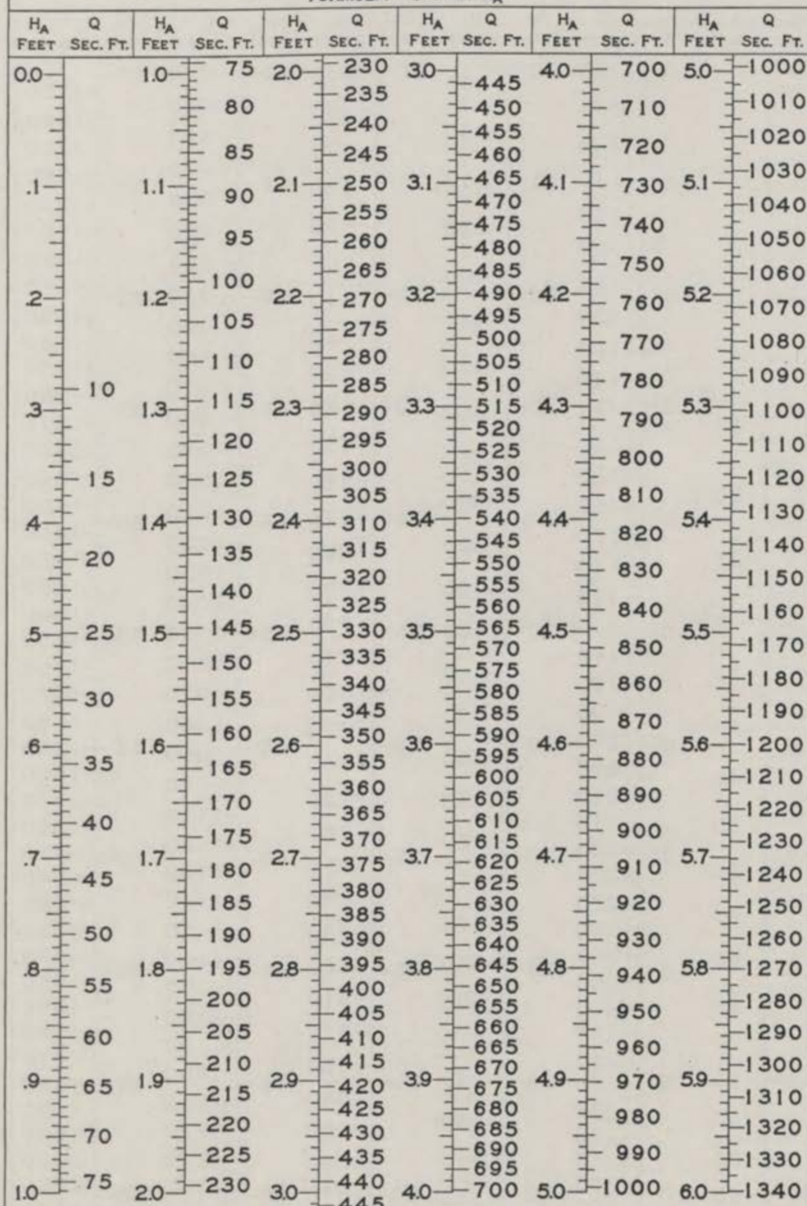

TABLE VI

FREE-FLOW DISCHARGE 25-FOOT PARSHALL MEASURING FLUME

FORMULA $Q=94.69\ H_A^{1.6}$

| $H_A$ FEET | Q SEC. FT. |
|---|---|
| 0.0 | |
| .1 | |
| .2 | |
| .3 | |
| | 15 |
| | 20 |
| .4 | |
| | 25 |
| .5 | 30 |
| | 35 |
| | 40 |
| .6 | |
| | 45 |
| | 50 |
| .7 | 55 |
| | 60 |
| .8 | 65 |
| | 70 |
| | 75 |
| .9 | 80 |
| | 85 |
| | 90 |
| 1.0 | 95 |

| $H_A$ FEET | Q SEC. FT. |
|---|---|
| 1.0 | 95 |
| | 100 |
| | 105 |
| 1.1 | 110 |
| | 115 |
| | 120 |
| 1.2 | 125 |
| | 130 |
| | 135 |
| | 140 |
| 1.3 | 145 |
| | 150 |
| | 155 |
| 1.4 | 160 |
| | 165 |
| | 170 |
| | 175 |
| 1.5 | 180 |
| | 185 |
| | 190 |
| | 195 |
| 1.6 | 200 |
| | 205 |
| | 210 |
| | 215 |
| 1.7 | 220 |
| | 225 |
| | 230 |
| | 235 |
| 1.8 | 240 |
| | 245 |
| | 250 |
| | 255 |
| | 260 |
| 1.9 | 265 |
| | 270 |
| | 275 |
| | 280 |
| 2.0 | 285 |
| | 290 |

| $H_A$ FEET | Q SEC. FT. |
|---|---|
| 2.0 | 290 |
| | 300 |
| 2.1 | 310 |
| | 320 |
| | 330 |
| 2.2 | |
| | 340 |
| | 350 |
| 2.3 | 360 |
| | 370 |
| | 380 |
| 2.4 | |
| | 390 |
| | 400 |
| 2.5 | 410 |
| | 420 |
| | 430 |
| 2.6 | 440 |
| | 450 |
| | 460 |
| 2.7 | |
| | 470 |
| | 480 |
| 2.8 | 490 |
| | 500 |
| | 510 |
| 2.9 | 520 |
| | 530 |
| | 540 |
| 3.0 | 550 |

| $H_A$ FEET | Q SEC. FT. |
|---|---|
| 3.0 | 550 |
| | 560 |
| | 570 |
| 3.1 | 580 |
| | 590 |
| | 600 |
| 3.2 | 610 |
| | 620 |
| | 630 |
| 3.3 | 640 |
| | 650 |
| | 660 |
| 3.4 | 670 |
| | 680 |
| | 690 |
| 3.5 | 700 |
| | 710 |
| | 720 |
| | 730 |
| 3.6 | 740 |
| | 750 |
| | 760 |
| 3.7 | 770 |
| | 780 |
| | 790 |
| 3.8 | 800 |
| | 810 |
| | 820 |
| | 830 |
| 3.9 | |
| | 840 |
| | 850 |
| | 860 |
| 4.0 | 870 |

| $H_A$ FEET | Q SEC. FT. |
|---|---|
| 4.0 | 870 |
| | 880 |
| | 890 |
| | 900 |
| 4.1 | |
| | 910 |
| | 920 |
| | 930 |
| 4.2 | 940 |
| | 950 |
| | 960 |
| | 970 |
| 4.3 | 980 |
| | 990 |
| | 1000 |
| 4.4 | 1010 |
| | 1020 |
| | 1030 |
| | 1040 |
| 4.5 | 1050 |
| | 1060 |
| | 1070 |
| | 1080 |
| 4.6 | 1090 |
| | 1100 |
| | 1110 |
| | 1120 |
| 4.7 | 1130 |
| | 1140 |
| | 1150 |
| 4.8 | 1160 |
| | 1170 |
| | 1180 |
| | 1190 |
| 4.9 | 1200 |
| | 1210 |
| | 1220 |
| | 1230 |
| 5.0 | 1240 |
| | 1250 |

| $H_A$ FEET | Q SEC. FT. |
|---|---|
| 5.0 | 1250 |
| | 1260 |
| | 1270 |
| | 1280 |
| 5.1 | |
| | 1290 |
| | 1300 |
| | 1310 |
| 5.2 | 1320 |
| | 1330 |
| | 1340 |
| | 1350 |
| | 1360 |
| 5.3 | |
| | 1370 |
| | 1380 |
| | 1490 |
| | 1400 |
| 5.4 | 1410 |
| | 1420 |
| | 1430 |
| | 1440 |
| 5.5 | 1450 |
| | 1460 |
| | 1470 |
| | 1480 |
| 5.6 | 1490 |
| | 1500 |
| | 1510 |
| | 1520 |
| 5.7 | 1530 |
| | 1540 |
| | 1550 |
| | 1560 |
| | 1570 |
| 5.8 | 1580 |
| | 1590 |
| | 1600 |
| | 1610 |
| 5.9 | 1620 |
| | 1630 |
| | 1640 |
| | 1650 |
| 6.0 | 1660 |
| | 1670 |

## TABLE VII
## FREE-FLOW DISCHARGE 30-FOOT PARSHALL MEASURING FLUME

FORMULA $Q = 113.13\ H_A^{1.6}$

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 0.0 | |
| .1 | |
| .2 | |
| | 15 |
| .3 | |
| | 20 |
| | 25 |
| .4 | |
| | 30 |
| | 35 |
| .5 | |
| | 40 |
| | 45 |
| .6 | 50 |
| | 55 |
| | 60 |
| .7 | 65 |
| | 70 |
| | 75 |
| .8 | 80 |
| | 85 |
| | 90 |
| .9 | 95 |
| | 100 |
| | 105 |
| | 110 |
| 1.0 | 115 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 1.0 | 115 |
| | 120 |
| | 125 |
| 1.1 | 130 |
| | 135 |
| | 140 |
| | 145 |
| 1.2 | 150 |
| | 155 |
| | 160 |
| | 165 |
| 1.3 | 170 |
| | 175 |
| | 180 |
| | 185 |
| | 190 |
| 1.4 | 195 |
| | 200 |
| | 205 |
| | 210 |
| 1.5 | 215 |
| | 220 |
| | 225 |
| | 230 |
| | 235 |
| 1.6 | 240 |
| | 245 |
| | 250 |
| | 255 |
| | 260 |
| 1.7 | 265 |
| | 270 |
| | 275 |
| | 280 |
| | 285 |
| 1.8 | 290 |
| | 295 |
| | 300 |
| | 305 |
| | 310 |
| 1.9 | 315 |
| | 320 |
| | 325 |
| | 330 |
| | 335 |
| | 340 |
| 2.0 | 345 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 2.0 | 345 |
| | 350 |
| | 360 |
| 2.1 | 370 |
| | 380 |
| | 390 |
| 2.2 | 400 |
| | 410 |
| | 420 |
| 2.3 | 430 |
| | 440 |
| | 450 |
| 2.4 | 460 |
| | 470 |
| | 480 |
| 2.5 | 490 |
| | 500 |
| | 510 |
| 2.6 | 520 |
| | 530 |
| | 540 |
| | 550 |
| 2.7 | |
| | 560 |
| | 570 |
| | 580 |
| 2.8 | 590 |
| | 600 |
| | 610 |
| 2.9 | 620 |
| | 630 |
| | 640 |
| | 650 |
| 3.0 | 660 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 3.0 | 660 |
| | 670 |
| | 680 |
| 3.1 | 690 |
| | 700 |
| | 710 |
| | 720 |
| 3.2 | 730 |
| | 740 |
| | 750 |
| | 760 |
| 3.3 | |
| | 770 |
| | 780 |
| | 790 |
| 3.4 | 800 |
| | 810 |
| | 820 |
| | 830 |
| 3.5 | 840 |
| | 850 |
| | 860 |
| | 870 |
| 3.6 | 880 |
| | 890 |
| | 900 |
| | 910 |
| 3.7 | 920 |
| | 930 |
| | 940 |
| | 950 |
| 3.8 | 960 |
| | 970 |
| | 980 |
| | 990 |
| 3.9 | 1000 |
| | 1010 |
| | 1020 |
| | 1030 |
| 4.0 | 1040 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 4.0 | 1040 |
| | 1050 |
| | 1060 |
| | 1070 |
| 4.1 | 1080 |
| | 1090 |
| | 1100 |
| | 1110 |
| 4.2 | 1120 |
| | 1130 |
| | 1140 |
| | 1150 |
| | 1160 |
| 4.3 | 1170 |
| | 1180 |
| | 1190 |
| | 1200 |
| 4.4 | 1210 |
| | 1220 |
| | 1230 |
| | 1240 |
| | 1250 |
| 4.5 | |
| | 1260 |
| | 1270 |
| | 1280 |
| | 1290 |
| 4.6 | 1300 |
| | 1310 |
| | 1320 |
| | 1330 |
| | 1340 |
| 4.7 | 1350 |
| | 1360 |
| | 1370 |
| | 1380 |
| 4.8 | 1390 |
| | 1400 |
| | 1410 |
| | 1420 |
| | 1430 |
| 4.9 | 1440 |
| | 1450 |
| | 1460 |
| | 1470 |
| | 1480 |
| 5.0 | 1490 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 5.0 | |
| | 1490 |
| | 1500 |
| | 1510 |
| | 1520 |
| | 1530 |
| 5.1 | |
| | 1540 |
| | 1550 |
| | 1560 |
| | 1570 |
| 5.2 | 1580 |
| | 1590 |
| | 1600 |
| | 1610 |
| | 1620 |
| 5.3 | 1630 |
| | 1640 |
| | 1650 |
| | 1660 |
| | 1670 |
| 5.4 | 1680 |
| | 1690 |
| | 1700 |
| | 1710 |
| | 1720 |
| 5.5 | 1730 |
| | 1740 |
| | 1750 |
| | 1760 |
| | 1770 |
| 5.6 | 1780 |
| | 1790 |
| | 1800 |
| | 1810 |
| | 1820 |
| 5.7 | 1830 |
| | 1840 |
| | 1850 |
| | 1860 |
| | 1870 |
| 5.8 | 1880 |
| | 1890 |
| | 1900 |
| | 1910 |
| | 1920 |
| | 1930 |
| 5.9 | |
| | 1940 |
| | 1950 |
| | 1960 |
| | 1970 |
| | 1980 |
| 6.0 | 1990 |

TABLE VIII

FREE-FLOW DISCHARGE 40-FOOT PARSHALL MEASURING FLUME

FORMULA $Q=150.00\ H_A^{1.6}$

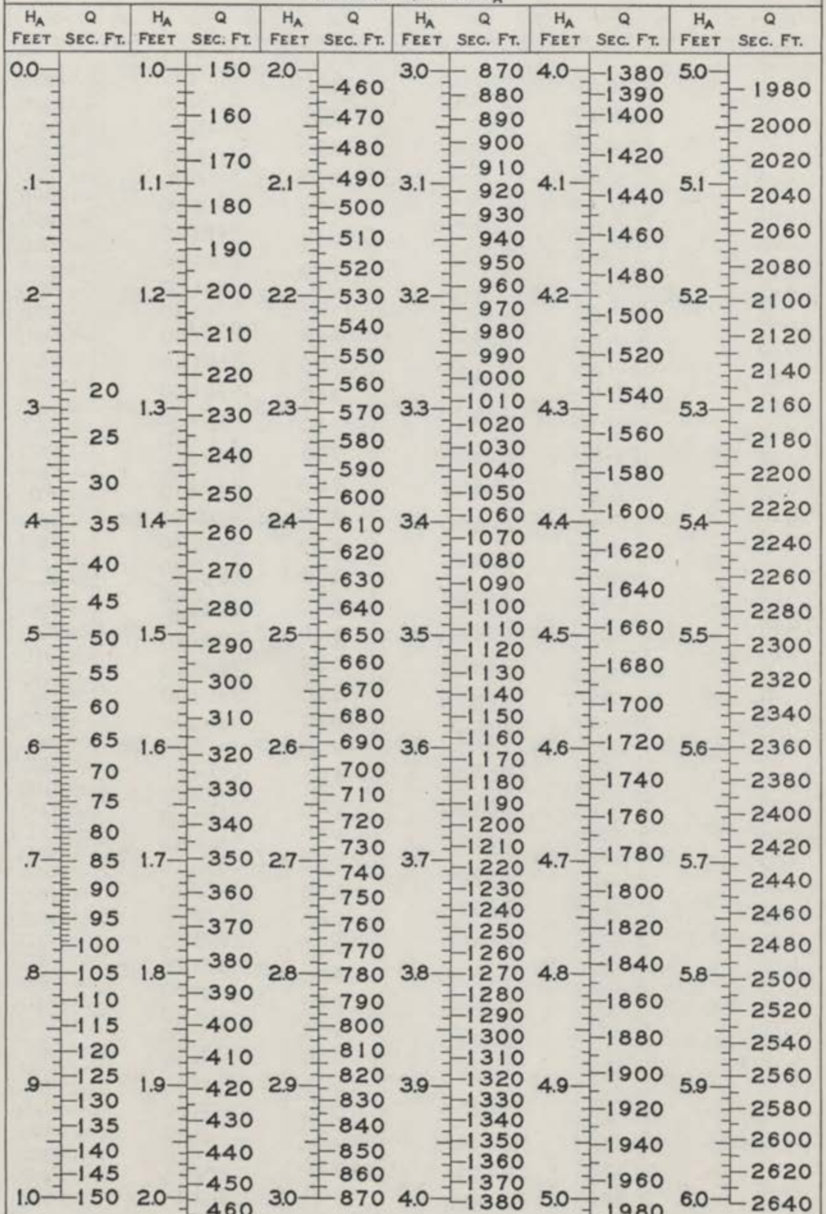

TABLE IX

FREE-FLOW DISCHARGE 50-FOOT PARSHALL MEASURING FLUME

FORMULA $Q = 186.88\, H_A^{1.6}$

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 0.0 | |
| .1 | |
| .2 | |
| .3 | 25 |
| | 30 |
| | 35 |
| | 40 |
| .4 | 45 |
| | 50 |
| | 55 |
| .5 | 60 |
| | 65 |
| | 70 |
| | 75 |
| .6 | 80 |
| | 85 |
| | 90 |
| | 95 |
| | 100 |
| .7 | 105 |
| | 110 |
| | 115 |
| | 120 |
| | 125 |
| .8 | 130 |
| | 135 |
| | 140 |
| | 145 |
| | 150 |
| | 155 |
| .9 | 160 |
| | 165 |
| | 170 |
| | 175 |
| | 180 |
| 1.0 | 185 |
| | 190 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 1.0 | 190 |
| | 195 |
| | 200 |
| | 210 |
| 1.1 | 220 |
| | 230 |
| | 240 |
| 1.2 | 250 |
| | 260 |
| | 270 |
| 1.3 | 280 |
| | 290 |
| | 300 |
| | 310 |
| 1.4 | 320 |
| | 330 |
| | 340 |
| | 350 |
| 1.5 | 360 |
| | 370 |
| | 380 |
| | 390 |
| 1.6 | 400 |
| | 410 |
| | 420 |
| | 430 |
| 1.7 | 440 |
| | 450 |
| | 460 |
| | 470 |
| 1.8 | 480 |
| | 490 |
| | 500 |
| | 510 |
| 1.9 | 520 |
| | 530 |
| | 540 |
| | 550 |
| | 560 |
| 2.0 | 570 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 2.0 | 570 |
| | 580 |
| | 590 |
| | 600 |
| 2.1 | 610 |
| | 620 |
| | 630 |
| | 640 |
| | 650 |
| 2.2 | 660 |
| | 670 |
| | 680 |
| | 690 |
| | 700 |
| 2.3 | 710 |
| | 720 |
| | 730 |
| | 740 |
| | 750 |
| 2.4 | 765 |
| | 780 |
| | 795 |
| 2.5 | 810 |
| | 825 |
| | 840 |
| 2.6 | 855 |
| | 870 |
| | 885 |
| | 900 |
| 2.7 | 915 |
| | 930 |
| | 945 |
| | 960 |
| 2.8 | 975 |
| | 990 |
| | 1005 |
| 2.9 | 1020 |
| | 1035 |
| | 1050 |
| | 1065 |
| 3.0 | 1080 |
| | 1095 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 3.0 | 1095 |
| | 1110 |
| | 1125 |
| 3.1 | 1140 |
| | 1155 |
| | 1170 |
| | 1185 |
| 3.2 | 1200 |
| | 1215 |
| | 1230 |
| | 1245 |
| 3.3 | 1260 |
| | 1275 |
| | 1290 |
| | 1305 |
| 3.4 | 1320 |
| | 1335 |
| | 1350 |
| | 1365 |
| | 1380 |
| 3.5 | 1395 |
| | 1410 |
| | 1425 |
| | 1440 |
| 3.6 | 1455 |
| | 1470 |
| | 1485 |
| | 1500 |
| 3.7 | 1515 |
| | 1530 |
| | 1545 |
| | 1560 |
| | 1575 |
| 3.8 | 1590 |
| | 1605 |
| | 1620 |
| | 1635 |
| 3.9 | 1650 |
| | 1665 |
| | 1680 |
| | 1695 |
| 4.0 | 1710 |
| | 1725 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 4.0 | 1725 |
| | 1740 |
| | 1760 |
| 4.1 | 1780 |
| | 1800 |
| | 1820 |
| | 1840 |
| 4.2 | 1860 |
| | 1880 |
| | 1900 |
| 4.3 | 1920 |
| | 1940 |
| | 1960 |
| | 1980 |
| 4.4 | 2000 |
| | 2020 |
| | 2040 |
| | 2060 |
| 4.5 | 2080 |
| | 2100 |
| | 2120 |
| 4.6 | 2140 |
| | 2160 |
| | 2180 |
| | 2200 |
| 4.7 | 2220 |
| | 2240 |
| | 2260 |
| | 2280 |
| 4.8 | 2300 |
| | 2320 |
| | 2340 |
| | 2360 |
| 4.9 | 2380 |
| | 2400 |
| | 2420 |
| | 2440 |
| 5.0 | 2460 |

| $H_A$ Feet | Q Sec. Ft. |
|---|---|
| 5.0 | 2460 |
| | 2480 |
| | 2500 |
| | 2520 |
| 5.1 | 2540 |
| | 2560 |
| | 2580 |
| | 2600 |
| 5.2 | 2620 |
| | 2640 |
| | 2660 |
| | 2680 |
| 5.3 | 2700 |
| | 2720 |
| | 2740 |
| | 2760 |
| 5.4 | 2780 |
| | 2800 |
| | 2820 |
| | 2840 |
| 5.5 | 2860 |
| | 2880 |
| | 2900 |
| | 2920 |
| 5.6 | 2940 |
| | 2960 |
| | 2980 |
| | 3000 |
| 5.7 | 3020 |
| | 3040 |
| | 3060 |
| | 3080 |
| | 3100 |
| 5.8 | 3120 |
| | 3140 |
| | 3160 |
| | 3180 |
| 5.9 | 3200 |
| | 3220 |
| | 3240 |
| | 3260 |
| 6.0 | 3280 |
| | 3300 |

## SUBMERGED FLOW

For the small-sized flumes, the free-flow condition of discharge is very desirable, because only one gage height or depth is involved in determining the rate of flow. Here the exit velocities are relatively high, but as the amount of water is not great, the resulting effect of erosion is easily controlled and of small moment. For the large flumes, where 500 or 1,000 second-feet are being discharged under a condition of free flow, as illustrated in Figure 6 (page 13), the matter of erosion due to the higher velocities, particularly in soft materials, presents a problem. In general, where the banks and bottom of the downstream section of the channel would be subject to considerable cutting, it is the better practice to set the larger structures so that a submerged condition of flow will result for the higher discharges. For submerged flow, where there is no hydraulic jump, both the upper gage and the throat gage heights must be considered in the determination of the rate of flow.

To determine the rate of submerged flow, the ratio $H_B$ to $H_A$ is expressed ordinarily as the percentage or degree of submergence. Figure 22 is a correction diagram showing the amount in second-feet to be deducted for each 10 feet of crest from the free-flow discharge for that particular value of $H_A$. At the left, vertically, are given the values of the upper head, $H_A$, in feet. Crossing the diagram diagonally are straight lines indicating the ratio $H_B/H_A$, the degree of submergence, and along the base of the diagram is the correction in second-feet. The following tabulation gives the multiplying factor for correcting the indicated value from the diagram for the various sizes of flumes:

| Size of flume | Multiplying factor | Size of flume | Multiplying factor |
|---|---|---|---|
| W in feet | | W in feet | |
| 10 | 1.0 | 25 | 2.5 |
| 12 | 1.2 | 30 | 3.0 |
| 15 | 1.5 | 40 | 4.0 |
| 20 | 2.0 | 50 | 5.0 |

To illustrate the use of the correction diagram, let it be required to determine the discharge thru a 20-foot Parshall measuring flume, where the upper head, $H_A$, is 3.25 feet and the $H_B$, or lower head, is 3.06 feet. The ratio 3.06/3.25 is 0.941. From the diagram find the value of $H_A$ at 3.25 feet, vertically, along the left-hand side. Next move horizontally to the right to the diagonal line 94; then, by estimation, advance one-tenth of the

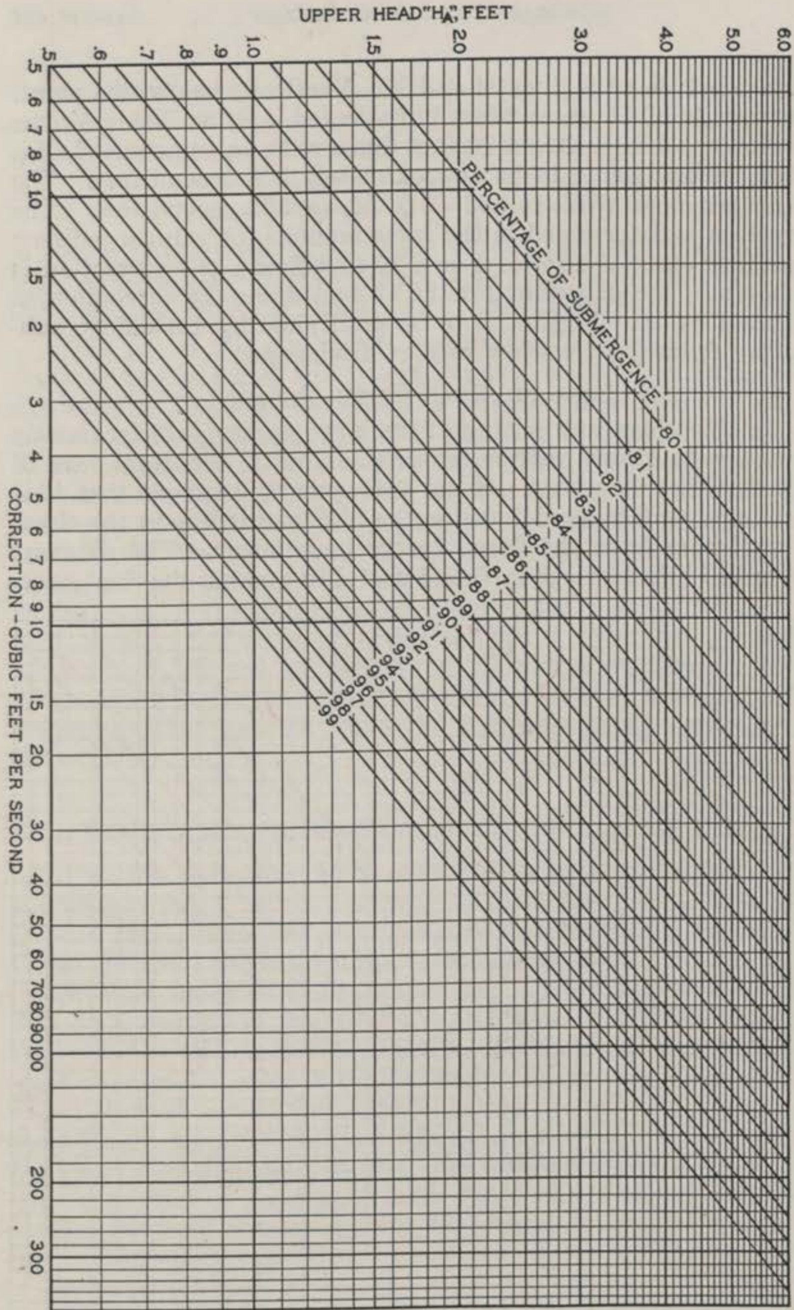


Figure 22.—Diagram for determining the correction in second-feet per 10 feet of crest for submerged-flow discharge. (This diagram, enlarged to a scale of 10.5 by 17.5 inches, printed on heavy stock, is available at 25 cents per copy upon application to the Colorado Agricultural Experiment Station.)

distance between the lines 94 and 95. Vertically below this point, a correction of 56 second-feet is indicated. From Table V, the free-flow discharge thru a 20-foot flume with an upper head, $H_A$, of 3.25 feet is found to be approximately 503 second-feet. The submerged flow, then, is $503-2 \times 56$, or 391 second-feet. The correction is determined in the same manner for submerged flow thru other sizes of flumes. For a 10-foot flume, the correction is as shown by the diagram; for the 12-foot flume the correction as indicated by the diagram is to be multiplied by 1.2 before subtracting from the free-flow rate of discharge.

## LOSS OF HEAD THRU FLUME

In the design and setting of the large flumes, it is frequently necessary to know, within reasonable limits, the total loss of head thru the structure. It not infrequently happens that it is quite important to predetermine the high-water line in the channel upstream from the flume before installation. The diagram shown in Figure 23 will be found useful in making the final selec-

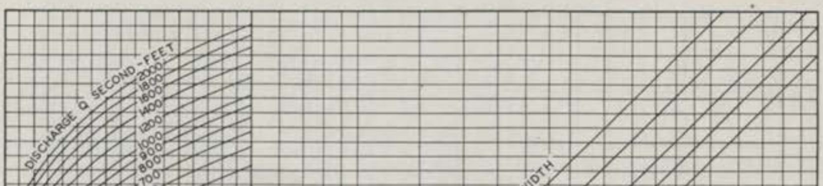


Figure 23.—Diagram for determining the total loss of head thru large Parshall Measuring Flumes.

tion of the size of flume which is to meet the requirements as to capacity, loss of head, degree of submergence, and channel freeboard. This diagram is based on the formula

$$L = \frac{1}{(W + 15)^{1.46}} \left(\frac{100 - S}{5}\right)^{0.72} Q^{0.67}$$

where L is the total loss of head in feet thru the structure, W the size of flume (width of throat) in feet, S the percentage of submergence (ratio $H_B/H_A$), and Q the discharge in second-feet.

The use of this diagram is best shown by example. Let it be required to determine the loss of head thru a 30-foot flume when discharging 1,000 second-feet at a submergence where the ratio of the gage heights, $H_B/H_A$, is 95 percent. At the left-hand side of the diagram will be found vertical lines, equally spaced, representing the ratio $H_B/H_A$. On the line 95, move vertically until the discharge curve 1,000 is reached. At this point, move horizontally to the right until an intersection is made with the straight line marked $W = 30$. Now move vertically downward to the base of the diagram, where the loss of head is found to be 0.39 foot. Likewise, let it be required to determine the loss of head where 100 second-feet are to be measured thru a 10-foot flume at a submergence of 80 percent. Making use of the diagram, as in the previous case, the total loss of head is found to be 0.54 foot.

## COMPARISON OF OBSERVED TO COMPUTED DISCHARGE

Table X gives comparative discharge data for both free and submerged flows for flumes ranging in size from 10 to 40 feet. In this table, data are given on the Las Animas Consolidated Canal 10-foot flume and the Box Elder Creek 12-foot flume, which were reported upon in Colorado Agricultural Experiment Station Bulletin 336, previously referred to. Furthermore, since this bulletin was published there have become available the results of special studies in the determination of velocities with the use of current meters for shallow depths by the various standard methods of gaging. In this table, for depths of 1 foot or less at the gaging station, the result of the discharge measurement has been corrected in accordance with the findings of current-meter studies made in the laboratory with shallow water depths and moderate-to-slow velocities.

The current-meter gagings here reported have, in every instance, been made near the upper end of the converging section of the flume. The accelerating velocity of the water in this part of the flume tends to eliminate the eddies and cross currents. This results more or less in a state of streamline flow and gives very good gaging conditions.

The mean deviation between the measured and computed discharges, as determined from 118 observations made by various hydrographers using different current meters and methods of gaging, with the head $H_A$ observed both by the use of staff gage on wall of flume and in stilling well, is about + 0.5 percent. This result, however, is not to be interpreted as showing that the formula is inaccurate, for the probable error of individual current-meter measurements, even when made by experienced operators, is from 2 to 3 percent.

Table X.—Comparison of discharges obtained from current-meter measurements with amounts computed by formula, for Parshall measuring flumes of various throat widths.

| Heads | | Ratio $H_B/H_A$ | Discharge | | | Deviation |
|---|---|---|---|---|---|---|
| $H_A$ | $H_B$ | | Current meter | Computed | Difference | |
| Feet | Feet | Percent | Sec.-ft. | Sec.-ft. | Sec.-ft. | Percent |
| FORT BENT CANAL, 10-foot flume [1] | | | | | | |
| 0.78 | ............ | ............ | [2]27.1 | 26.5 | 0.6 | +2.3 |
| .79 | ............ | ............ | 27.8 | 27.0 | 0.8 | +3.0 |
| .79 | ............ | ............ | 27.7 | 27.0 | 0.7 | +2.6 |
| .83 | ............ | ............ | 29.6 | 29.2 | 0.4 | +1.4 |
| .83 | ............ | ............ | 28.7 | 29.2 | 0.5 | —1.7 |
| .82 | ............ | ............ | 28.7 | 28.7 | 0.0 | 0.0 |
| LAS ANIMAS CONSOLIDATED CANAL, 10-foot flume [3] | | | | | | |
| 1.15 | ............ | ............ | 49.5 | 49.3 | 0.2 | +0.4 |
| 1.71 | ............ | ............ | [4]96.1 | 92.9 | 3.2 | +3.4 |
| 1.99 | ............ | ............ | 120.4 | 118.4 | 2.0 | +1.7 |
| 1.16 | ............ | ............ | 50.2 | 49.9 | 0.3 | +0.6 |
| 0.48 | ............ | ............ | 13.0 | 12.2 | 0.8 | +6.6 |
| 0.51 | ............ | ............ | 14.3 | 13.4 | 0.9 | +6.7 |
| 0.43 | ............ | ............ | 10.5 | 10.2 | 0.3 | +2.9 |
| 2.05 | ............ | ............ | 127.6 | 124.2 | 3.4 | +2.7 |
| 1.18 | ............ | ............ | 51.4 | 51.3 | 0.1 | +0.2 |
| 1.22 | ............ | ............ | 54.2 | 54.1 | 0.1 | +0.2 |
| 1.09 | ............ | ............ | 42.9 | 45.3 | 2.4 | —5.3 |
| PINE RIVER CANAL, 10-foot flume | | | | | | |
| 0.78 | ............ | ............ | 25.8 | 26.5 | 0.7 | —2.6 |
| 1.65 | ............ | ............ | 92.4 | 87.8 | 4.6 | +5.2 |
| HOLBROOK RESERVOIR OUTLET, 10-foot flume [1] | | | | | | |
| 2.21 | 2.02 | 91.4 | 123.5 | 123.0 | 0.5 | +0.4 |
| 2.21 | 2.08 | 94.1 | 118.1 | 114.5 | 3.6 | +3.1 |
| 1.96 | 1.79 | 91.3 | 105.8 | 102.6 | 3.2 | +3.1 |
| 1.91 | 1.67 | 87.4 | 101.2 | 104.9 | 3.7 | —3.5 |
| OTERO CANAL, 12-foot flume [3] | | | | | | |
| 0.66 | ............ | ............ | 24.4 | 24.1 | 0.3 | +1.2 |
| 1.57 | ............ | ............ | 97.0 | 96.2 | 0.8 | +0.8 |
| 0.92 | ............ | ............ | 39.4 | 40.9 | 1.5 | —3.7 |
| 1.28 | ............ | ............ | 71.7 | 69.4 | 2.3 | +3.3 |
| 1.03 | ............ | ............ | 50.0 | 49.0 | 1.0 | +2.0 |
| 1.01 | ............ | ............ | 48.4 | 47.5 | 0.9 | +1.9 |
| 1.04 | ............ | ............ | 45.8 | 49.8 | 4.0 | [5]—8.0 |
| 1.00 | ............ | ............ | 46.3 | 46.8 | 0.5 | —1.1 |
| 1.21 | ............ | ............ | 61.6 | 63.4 | 1.8 | —2.8 |

See footnotes at end of table.

Table X.—Contd.

| Heads | | Ratio | Discharge | | | Deviation |
|---|---|---|---|---|---|---|
| $H_A$ | $H_B$ | $H_B/H_A$ | Current meter | Computed | Difference | |
| Feet | Feet | Percent | Sec.-ft. | Sec.-ft. | Sec.-ft. | Percent |
| **HORSE CREEK LATERAL (Torrington, Wyo.) 12-foot flume [1]** | | | | | | |
| 2.07 | ............ | ............ | 148.9 | [6]149.7 | 0.8 | —0.5 |
| 1.66 | ............ | ............ | 106.6 | 105.2 | 1.4 | +1.3 |
| 1.34 | ............ | ............ | 74.1 | 74.7 | 0.6 | —0.8 |
| 0.78 | ............ | ............ | 31.3 | 31.4 | 0.1 | —0.3 |
| **BOX ELDER CREEK, 12-foot flume [3]** | | | | | | |
| 0.89 | ............ | ............ | 37.6 | 38.7 | 1.1 | —2.8 |
| 0.89 | ............ | ............ | 38.8 | 38.7 | 0.1 | +0.3 |
| 0.95 | ............ | ............ | 42.1 | 43.1 | 1.0 | —2.3 |
| 0.93 | ............ | ............ | 41.9 | 41.6 | 0.3 | +0.7 |
| 0.66 | ............ | ............ | 24.3 | 24.0 | 0.3 | +1.2 |
| 1.19 | ............ | ............ | 60.3 | 61.8 | 1.5 | —2.4 |
| 1.19 | ............ | ............ | 61.0 | 61.8 | 0.8 | —1.3 |
| 1.04 | ............ | ............ | 48.4 | 49.8 | 1.4 | —2.8 |
| 0.86 | ............ | ............ | 38.1 | 36.7 | 1.4 | +3.8 |
| [7]1.28 | ............ | ............ | 72.7 | 69.4 | 3.3 | +4.8 |
| [7]1.44 | ............ | ............ | 87.4 | 83.8 | 3.6 | +4.3 |
| **PINE RIVER, 12-foot flume** | | | | | | |
| 1.70 | ............ | ............ | 110.7 | 109.3 | 1.4 | +1.3 |
| **CATLIN CANAL, 12-foot flume [8, 9]** | | | | | | |
| 2.48 | 1.74 | 70.0 | 195.0 | 200.0 | 5.0 | —2.5 |
| **ROCKY FORD CANAL, 12-foot flume [8]** | | | | | | |
| 1.77 | ............ | ............ | 114.1 | 116.5 | 2.4 | —2.1 |
| 1.73 | ............ | ............ | 109.7 | 112.3 | 2.6 | —2.3 |
| 1.71 | 0.52 | 30.0 | 108.2 | 110.2 | 2.0 | —1.8 |
| 1.27 | 0.86 | 68.0 | 68.9 | 68.4 | 0.5 | +0.7 |
| 1.35 | 1.23 | 91.1 | 66.5 | 68.6 | 2.1 | —3.1 |
| **FORT BENT CANAL, 14-foot flume [1]** | | | | | | |
| 0.60 | ............ | ............ | 23.4 | 23.9 | 0.5 | —2.1 |
| 1.16 | ............ | ............ | 70.3 | 68.6 | 1.7 | +2.5 |
| **LAMAR CANAL, 15-foot flume [8]** | | | | | | |
| 1.25 | ............ | ............ | [10]83.0 | 82.6 | 0.4 | +0.5 |
| 1.50 | ............ | ............ | 111.8 | 110.6 | 1.2 | +1.1 |

See footnotes at end of table.

Table X.—Contd.

ROCKY FORD HIGHLINE CANAL, 15-foot flume [5]

| Heads | | Ratio $H_B/H_A$ | Discharge | | | Deviation |
|---|---|---|---|---|---|---|
| $H_A$ | $H_B$ | | Current meter | Computed | Difference | |
| Feet | Feet | Percent | Sec.-ft. | Sec.-ft. | Sec.-ft. | Percent |
| 0.85 | ............ | ............ | 45.5 | 44.6 | 0.9 | +2.0 |
| 4.61 | 4.37 | 94.8 | [11]463.7 | 478.5 | 13.8 | —2.9 |
| 1.39 | 0.26 | 19.0 | [12]100.8 | 97.9 | 2.9 | +3.0 |

HOLBROOK CANAL, 20-foot flume [13]

| | | | | | | |
|---|---|---|---|---|---|---|
| 1.00 | 0.82 | 82.0 | [14]74.5 | 75.4 | 0.9 | —1.2 |
| 2.65 | 2.58 | 97.4 | 248.0 | 249.5 | 1.5 | —0.6 |
| 0.84 | ............ | ............ | 55.8 | 57.7 | 1.9 | —3.3 |
| 1.57 | 1.31 | 83.4 | 155.9 | 153.8 | 2.1 | +1.4 |
| 2.30 | 1.81 | 78.8 | 287.4 | 289.1 | 1.7 | —0.6 |
| 0.93 | 0.43 | 46.2 | 66.8 | 67.9 | 1.1 | —1.6 |
| 0.88 | ............ | ............ | 63.1 | 62.1 | 1.0 | +1.6 |
| 1.08 | 0.38 | 35.2 | 88.3 | 86.2 | 2.1 | +2.4 |
| 1.43 | 1.10 | 77.0 | 139.0 | 135.2 | 3.8 | +2.8 |
| 1.00 | 0.25 | 25.0 | 77.2 | 76.3 | 0.9 | +1.2 |
| 3.40 | 2.14 | 63.0 | 547.5 | 540.3 | 7.2 | +1.3 |
| 3.45 | 2.79 | 81.0 | [15]546.0 | 544.8 | 1.2 | +0.2 |
| 3.03 | 2.14 | 70.7 | 453.4 | 449.8 | 3.6 | +0.8 |
| 3.31 | 2.08 | 62.8 | 529.9 | 517.6 | 12.3 | +2.4 |
| 2.27 | 0.74 | 32.6 | 272.7 | 283.1 | 10.4 | —3.7 |
| 1.56 | 0.50 | 31.8 | 161.6 | 155.3 | 6.3 | +4.0 |
| 1.57 | 0.60 | 38.2 | 160.2 | 156.9 | 3.3 | +2.1 |
| 1.42 | 1.15 | 81.0 | 130.0 | 132.2 | 2.2 | —1.7 |
| 2.08 | 1.86 | 89.4 | 227.0 | 225.0 | 2.0 | +0.9 |
| [16]2.07 | 1.80 | 87.0 | 249.5 | 230.8 | 18.7 | +8.1 |
| 1.71 | 1.24 | 72.5 | 178.0 | 179.9 | 1.9 | —1.1 |
| 1.55 | 1.50 | 96.8 | 119.1 | 118.0 | 1.1 | +0.9 |
| 1.94 | 1.87 | 96.4 | 174.1 | 167.2 | 6.9 | +4.1 |
| 4.97 | 4.68 | 94.2 | 757.2 | 727.0 | 30.2 | +4.1 |
| 2.36 | 2.13 | 90.3 | 280.7 | 269.0 | 11.7 | +4.3 |
| 1.80 | 1.51 | 83.9 | 196.1 | 190.3 | 5.8 | +3.0 |
| 3.55 | 3.16 | 89.0 | 504.0 | 521.0 | 17.0 | —3.3 |

ANTERO RESERVOIR OUTLET, 20-foot flume [5]

| | | | | | | |
|---|---|---|---|---|---|---|
| 2.04 | 1.41 | 69.0 | [17]238.9 | 238.6 | 0.3 | +0.1 |

BIJOU CANAL, 20-foot flume [8]

| | | | | | | |
|---|---|---|---|---|---|---|
| 2.53 | 2.33 | 92.1 | 289.0 | 288.0 | 1.0 | +0.3 |
| 1.00 | 0.26 | 26.0 | 76.8 | 76.2 | 0.6 | +0.8 |
| 1.35 | 0.66 | 48.9 | [15]125.3 | 123.2 | 2.1 | +1.7 |

See footnotes at end of table.

Table X.—Contd.

COLORADO CANAL, 30-foot flume [8]

| Heads $H_A$ | Heads $H_B$ | Ratio $H_B/H_A$ | Discharge Current meter | Discharge Computed | Discharge Difference | Deviation |
|---|---|---|---|---|---|---|
| Feet | Feet | Percent | Sec.-ft. | Sec.-ft. | Sec.-ft. | Percent |
| 2.29 | 1.57 | 68.6 | 426.4 | 425.9 | 0.5 | +0.1 |
| 3.66 | 3.27 | 89.4 | [19]802.6 | 803.0 | 0.4 | —0.1 |
| 1.93 | 0.67 | 34.8 | 325.3 | 324.0 | 1.3 | +0.4 |

FORT LYON CANAL, 40-foot flume [13]

| $H_A$ | $H_B$ | $H_B/H_A$ | Current meter | Computed | Difference | Deviation |
|---|---|---|---|---|---|---|
| 1.29 | ............ | ............ | 222.7 | 225.4 | 2.7 | —1.2 |
| 0.92 | ............ | ............ | 129.6 | 131.3 | 1.7 | —1.3 |
| 1.45 | ............ | ............ | 276.0 | 271.8 | 4.2 | +1.5 |
| 1.46 | ............ | ............ | 278.9 | 274.8 | 4.1 | +1.5 |
| 1.60 | ............ | ............ | 324.9 | 318.2 | 6.7 | +2.1 |
| 1.14 | ............ | ............ | 184.9 | 185.0 | 0.1 | —0.5 |
| 1.85 | 0.12 | 6.5 | 410.2 | 401.4 | 8.8 | +2.2 |
| 2.37 | 0.74 | 31.2 | 595.4 | 596.6 | 1.2 | —0.2 |
| 1.11 | ............ | ............ | [20]176.5 | 177.3 | 0.8 | —0.5 |
| 2.80 | 1.30 | 46.5 | 774.1 | 779.0 | 4.9 | —0.6 |
| 2.77 | 0.95 | 34.3 | 751.8 | 765.7 | 13.9 | —1.8 |
| 4.21 | ............ | ............ | 1464.0 | 1496.0 | 32.0 | —2.1 |
| 3.43 | 2.00 | 58.3 | 1054.0 | 1077.8 | 23.8 | —2.2 |
| 1.39 | ............ | ............ | 260.3 | 254.1 | 6.2 | +2.4 |
| 1.25 | ............ | ............ | 214.5 | 214.4 | 0.1 | +0.5 |
| 1.08 | ............ | ............ | 165.9 | 169.5 | 3.6 | —2.1 |
| 2.91 | ............ | ............ | 829.6 | 828.5 | 1.1 | +0.1 |
| 3.08 | ............ | ............ | 916.5 | 907.3 | 9.2 | +1.0 |
| 3.49 | ............ | ............ | 1107.1 | 1108.2 | 1.1 | —0.1 |
| 3.85 | 1.17 | 30.4 | 1305.4 | 1296.7 | 8.7 | +0.7 |
| 4.00 | 1.31 | 32.8 | [21]1390.3 | 1378.5 | 11.8 | +0.9 |
| 3.19 | ............ | ............ | 974.0 | 959.7 | 14.3 | +1.5 |
| 1.78 | ............ | ............ | 386.7 | 377.4 | 9.3 | +2.5 |

[1] Staff gage in stilling well.
[2] Figure 24.
[3] Staff gage on flume wall.
[4] Figure 1.
[5] Poor gaging conditions.
[6] Figure 25.
[7] $H_A$ gage checked July, 1931, and found to be 0.06 high.
[8] Heads indicated by instrument illustrated in Figure 21.
[9] Figure 26.
[10] Figure 27.
[11] Figure 11.
[12] Figure 10.
[13] Heads observed by using special indicating tapes.
[14] Figure 2.
[15] Figure 16. View taken Aug. 6, 1930; $H_A$ = 3.44 ft.; $H_B$ = 2.75 ft., submergence = 80 percent; discharge=550 sec. ft.
[16] Value doubtful.
[17] Figure 12.
[18] Frontispiece.
[19] Figure 8.
[20] Figures 4 and 5.
[21] Figure 6.

Figure 24.—Ten-foot Parshall Measuring Flume, discharge 27 second-feet, Fort Bent Canal. (See Table X.) In 1930 this was changed to a 14-foot flume.

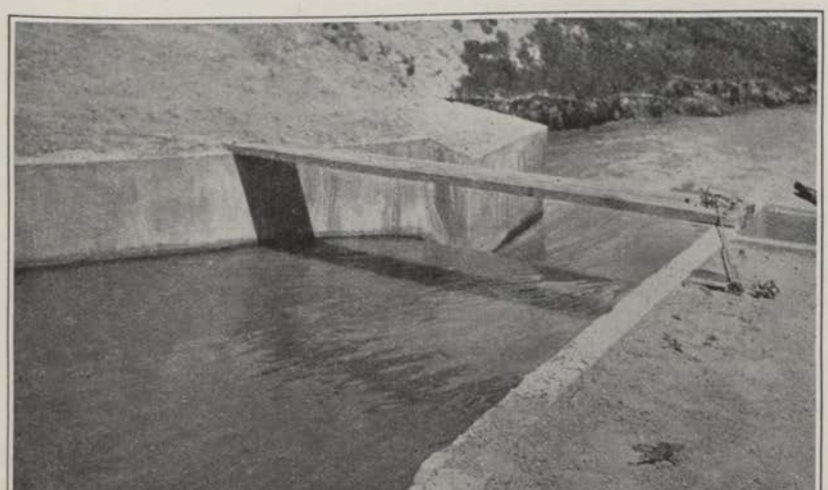

Figure 25.—Twelve-foot Parshall Measuring Flume, discharge 149 second-feet, free flow. Horse Creek Lateral near Torrington, Wyoming. (See Table X.)

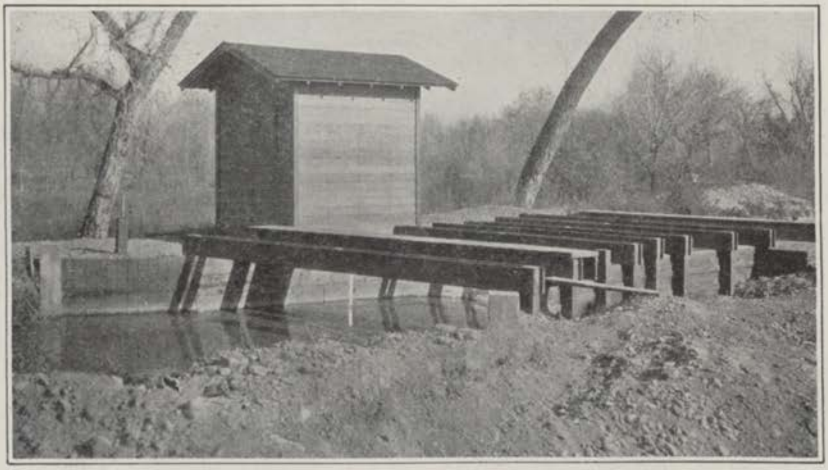

Figure 26.—Twelve-foot Parshall Measuring Flume, discharge about 50 second-feet, no submergence, Catlin Canal. (See Table X.)

Figure 27.—Fifteen-foot Parshall Measuring Flume, discharge 83 second-feet, no submergence, Lamar Canal. (See Table X.)

## SUMMARY

The Parshall measuring flume has been found accurate enough to meet practical irrigation requirements under conditions where sand and silt had given trouble in the old type of rating flume.

The range of capacity of the measuring flume extends from less than 0.1 second-foot for the 3-inch flume to more than 2,000 second-feet for the 40-foot flume.

The successful operation of the flume depends largely upon the correct setting of the elevation of the crest above the grade of the channel, and on precise construction to correct dimensions. It is recommended that these flumes be built in straight canal sections.

The cost of the large flumes varies with the size and material used. Ordinarily, for reinforced concrete construction, this cost may be approximated at about $100 per linear foot of crest length. The frame structures generally cost less than the concrete. The 20-foot timber flume is the largest frame structure thus far constructed.

The problem of economically selecting the proper size and setting of flume to meet the requirements of measurement, is best determined by the use of the loss-of-head diagram. (Fig. 23.)

A practical and efficient flushing system has been provided for cleaning the $H_A$ and $H_B$ gage wells for flumes operating under severe sand and silt conditions.

A special recording and indicating instrument has been designed for operation in connection with the large Parshall measuring flume.

This type of flume will measure irrigation water supplies efficiently and accurately. It is rapidly replacing the ordinary rating flume, especially where the deposition of sand and silt has been a serious problem.