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ABSTRACT

CALIBRATION OF PARSHALL FLUMES WITH NON-STANDARD ENTRANCE TRANSITIONS

The 9-inch and 18-inch Parshall flumes with the throat section installed level with the bottom of an incoming pipe were tested. The measured discharges for given flow depths (free flow) or differences in flow depths (submerged flow) were found to deviate quite significantly from the computed standard Parshall flume discharges at both low and high flow rates. New empirical formulas have been developed to take such deviations into account. It is noted that the values of the coefficients and exponents contained in the new formulas depend on the throat size of the flume and the slope of the incoming pipe. Calibration curves and tables were prepared for convenient application of the new formulas.

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KEYWORDS—calibration, flow measurements, hydraulics, hydraulic structures, Parshall flumes, sewer

ACKNOWLEDGMENTS

This investigation originated in 1971 under a contract entitled "Prototype Parshall Flume Tests," Detroit Metro Water Department Contract No. PC-239A, through Joseph C. Wolf, Inc., 26490 West Eight Mile Road, Southfield, Michigan 48075. The technical completion report was prepared in July 1971 and supplemented in December 1971. Newly-developed empirical formulas for submerged flow in the 9-inch and 18-inch Parshall flumes with non-standard entrance transitions originally did not contain a submergence factor. Therefore, in application there was an apparent difficulty in computer interpolation or extrapolation of the formulas for flow at submergences other than the specified 70, 80, and 90 percents. This difficulty was circumvented by using a submergence factor explicitly in the new formulas. Although the results were given in the supplementary report to Joseph C. Wolf, Inc., further improvements on the final forms of the new formulas were achieved by means of some adjustments in the values of the coefficients and exponents in the formulas. This laboratory report presents the final results of the investigation.

The cooperation and financial support of the Utah Water Research Laboratory made possible the publication of this report. Thanks are due Mr. Avigdor Berlant for his assistance on taking experimental data and Mr. Chin-Kuang Chang for his assistance with data computation and drawing. The writers also wish to thank Mrs. Donna Falkenborg for editorial assistance.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (CONTINUED)

Figure **Page**

LIST OF TABLES

LIST OF TABLES (CONTINUED)

EXPERIMENTATION

The waterway dimensions of the 9-inch and 18-inch Parshall flumes shipped to the laboratory were checked and found to conform with those in the latest revision of the U.S. Department of Agriculture Soil Conservation Circular No. 843.(6)* The material used for the flume liner is fabricated in one piece from polyester resin reinforced with fiberglass. The thickness of the flume walls is a minimum of 1/4 inch.

The entrance and outlet transitions of the 9-inch and 18-inch Parshall flumes were made of steel sheet in conformity to the dimensions specified in the contract, as shown in Figure 1. The transitions were thinly coated with cement mortar to provide the same roughness as smooth concrete pipe. Specific attention was called to the arrangement of the entrance transitions. For example, the bottom of the entrance transition of the 9-inch Parshall flume changes uniformly from an 18-inch semi-circular section to a bottom corner point on a 22-5/8 inch rectangular section in a length of 16-1/2 inches. The bottom (invert) of the entrance transition is level. The transition has vertical flat walls above the center line of 18 inch approach pipe. The flat side walls of the transition bend outward 8 degrees from the spring line of the 18-inch pipe.

Data taken during the experiments are the discharge Q, and the flow depths, H_a and H_b, in stilling wells (Figure 1) at the specified locations in the entrance section and the throat of the Parshall flume, respectively.

The fluid used for the test was Logan River water from the reservoir which supplies the laboratory.

Tests on the 9-inch Parshall flume

The incoming 18-inch diameter concrete pipe for the 9-inch Parshall flume is 24 feet in length and the outgoing pipe is 8 feet in length. The testing arrangement for the 9-inch Parshall flume is schematically depicted in Figure 1 and photographed as shown in Figure 2. The incoming pipes were set at varying slopes of 0.35, 0.45, 0.60, and 0.80 feet in 100 feet. At each slope setting, tests were conducted over the full range of flow capacities and conditions stated as follows:

*Superscript numerals refer to the corresponding references.

The tests were supposed to be conducted by using increments of flow of 1 cubic foot per second (cfs) between the range of 1 cfs and the specified full-flow capacity of the incoming pipe (approximately 9 cfs). However, during the test, it was discovered that the depth-discharge relationships for this type of entrance transition arrangement deviated quite significantly at lower and higher flow rates from those for the standard. Therefore, measurements on the flow rates less than 1 cfs and higher than 9 cfs were also carried out. Each increment of flow was tested under both free flow and submerged conditions with submergence being varied approximately in 10 percent increments.

In the first series of tests (i.e., at a slope of 0.0035 of the incoming pipe), each increment of flow was determined at the beginning and the end of each increment of testing by using weighing tanks. At the same time an elbow meter installed between the control valve and the head tank was calibrated and read. To facilitate flow measurements after the first series of tests, only the elbow meter was used, but its calibration was checked often using the weighing tanks.

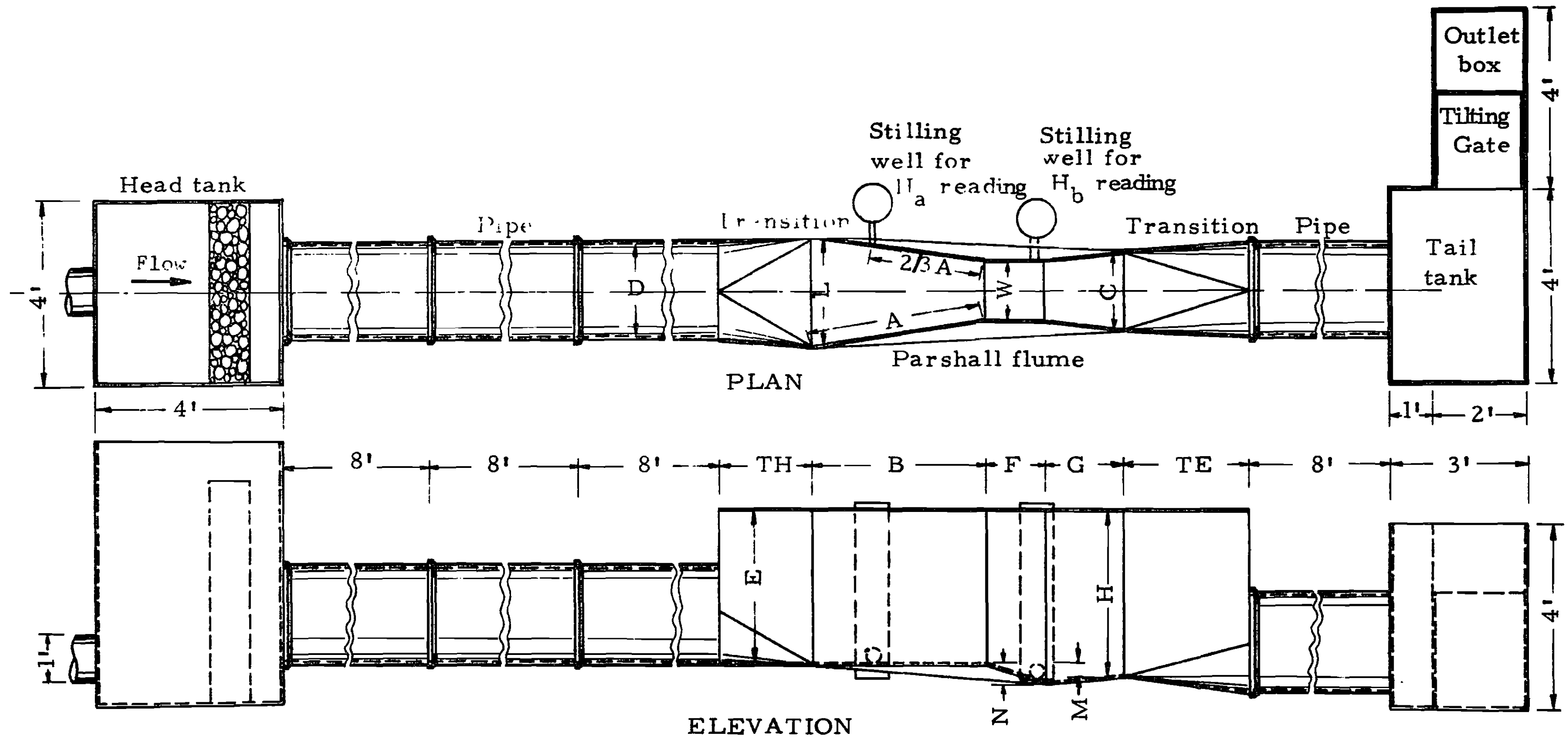
The measured and computed data for each series of tests on the 9-inch Parshall flume are shown in Appendix Tables 7 through 10.

Tests on the 18-inch Parshall flume

The testing arrangement for the 18-inch flume is similar to the one for the 9-inch flume (see Figures 1 and 3). The incoming and outgoing concrete pipes were 30 inches in diameter and 24 feet and 8 feet in length, respectively.

Since the testing of the 18-inch flume was not required to be as complete as that of the 9-inch flume, only two series of tests (i.e., at slopes of 0.0035 and 0.0080 of the incoming pipe) were performed. To check a similar trend in the measured depth-discharge relationships for the 18-inch flume, the range of flow rates tested is approximately from 1 cfs to 20 cfs.

The measured and computed data for each series of tests on the 18-inch Parshall flume are shown in Appendix Tables 11 and 12.



Size W	A	B	C	D	E	F	G	H	L	M	N	TE	TH
9"	34 5/8"	34"	15"	18"	30"	12"	18"	33"	22 5/8"	3"	4 1/2"	38"	16 1/2"
18"	57"	55 7/8"	30"	30"	36"	24"	36"	39"	40 3/8"	3"	9"	27"	37"

Figure 1. Schematic diagram of the experimental arrangement for 9-inch and 18-inch Parshall flume tests.

Figure 2. Oblique view of the experimental arrangement for the 9-inch Parshall flume.

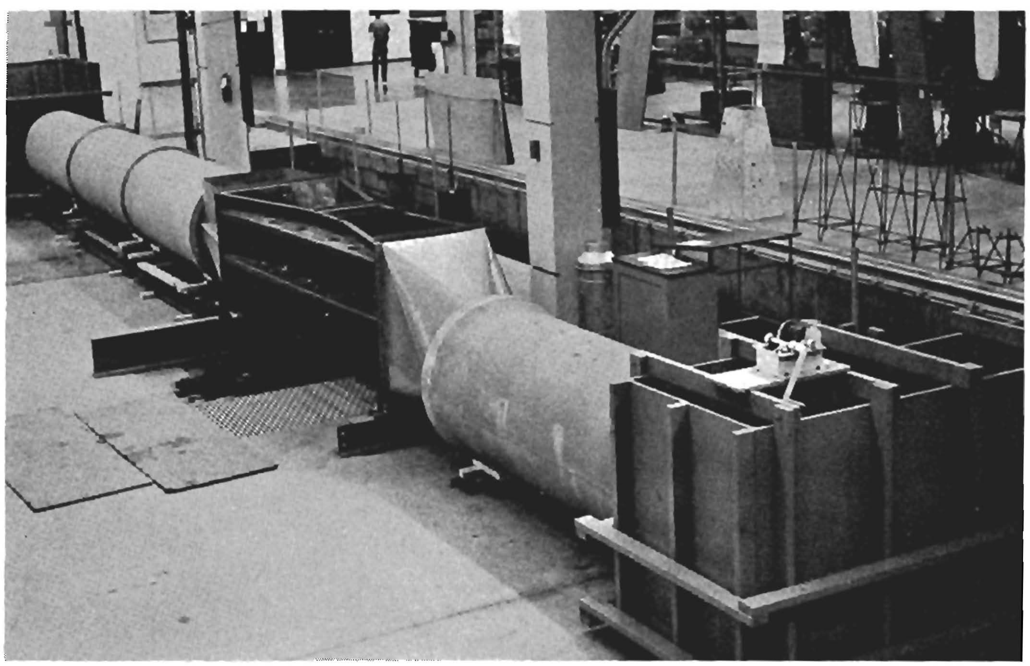


Figure 3. Oblique view of the experimental arrangement for the 18-inch Parshall flume.

ANALYSIS

Comparisons of test results with the standard Parshall flume formulas

The standard 9-inch Parshall flume formula for free flow is[1,2,3,4,5]

$$Q_{st} = 3.07\, H_a^{1.53} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

and the empirical (standard) formula for submerged flow formulated by Skogerboe et al.[2] is

$$Q_{st} = \frac{2.51\,(H_a - H_b)^{1.53}}{[-\log(H_b/H_a) - 0.0044]^{1.060}} \quad \ldots\ldots \quad (2)$$

in which Q_{st} = the flow rate or discharge calculated from the standard formulas; H_a = the flow depth at the specified location in the entrance section of the Parshall flume; and H_b = the flow depth above the flume crest at the specified location in the throat of the Parshall flume.

The standard 18-inch Parshall flume formula for free flow is

$$Q_{st} = 6.00\, H_a^{1.54} \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

and that for submerged flow is[2]

$$Q_{st} = \frac{4.42\,(H_a - H_b)^{1.54}}{[-\log(H_b/H_a) - 0.0044]^{1.115}} \quad \ldots\ldots \quad (4)$$

The transition submergence,[2] often called the critical or incipient submergence, is the boundary value of H_b/H_2, below which a free flow formula applies and above which a submerged flow formula applies. The theoretical values of the transition submergence were found to be 0.63 for the 9-inch flume and 0.64 for the 18-inch flume.[2] These theoretical values are obtained by equating Eq. 1 to Eq. 2 and Eq. 3 to Eq. 4, respectively. If the entrance transition for the Parshall flume were arranged differently from the standard one, the situations would be complicated and determining the values of the transition submergence would become difficult.

Measured depth and discharge as tabulated in the Appendix were plotted on log-log paper. The measured depth-discharge relationships for free flow in the 9-inch Parshall flume were plotted in broken lines, as shown in Figure 4, for different slopes of the incoming pipe. In the same figure, the standard formula (Eq. 1) was drawn in a solid line for comparison. There are apparent deviations of the measured values from the computed standard values at low and high flow rates. The lower or the higher the flow rates are, the greater the differences between the measured values and the computed standard values. Furthermore the deviations depend on the slope of the incoming pipe at low flow rates whereas they are independent of slope at high flow rates. The percents of error between the measured and computed standard values, defined as

$$\text{Error }(\%) = \frac{Q_{st} - Q}{Q} \times 100 \quad \ldots\ldots\ldots \quad (5)$$

in which Q = the measured flow rate, are also tabulated in Tables 7 through 12 in the Appendix.

The measured depth-discharge relationships for submerged flow were similarly plotted for 0.0035, 0.0045, 0.0060, and 0.0080 slopes of the incoming pipe in Figures 5, 6, 7, and 8, respectively. In each of these figures, three broken lines were drawn by interpolation to express the measured depth-discharge relationships at 70 percent, 80 percent, and 90 percent submergence. The standard formulas at the corresponding submergence (Eq. 2) were shown in solid lines for comparison. There are similar trends of deviation in the measured values at low and high flow rates from the computed standard values. The trends for larger slopes of the incoming pipe were more significant.

The measured depth-discharge relationships for free flow in the 18-inch Parshall flume were compared with the computed standard formula (Eq. 3), Figure 9. Similarly the measured and computed (Eq. 4) depth-discharge relationships were compared for submerged flow

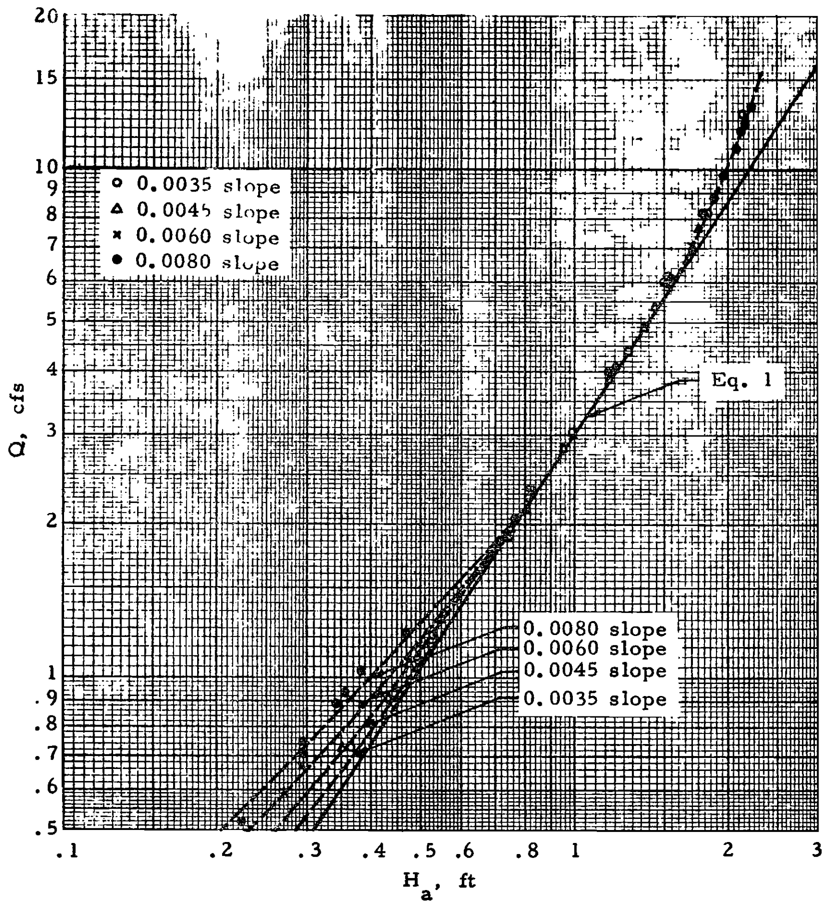


Figure 4. Diagram showing the rate of free flow through the 9-inch Parshall flume.

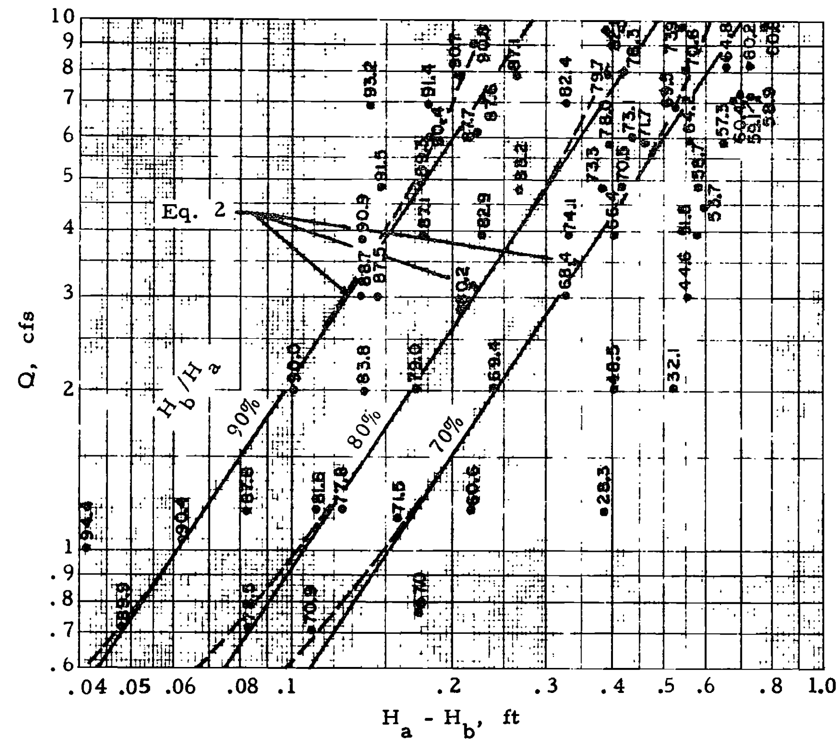


Figure 5. Diagram showing the rate of submerged flow through the 9-inch Parshall flume with 0.0035 slope of the incoming pipe.

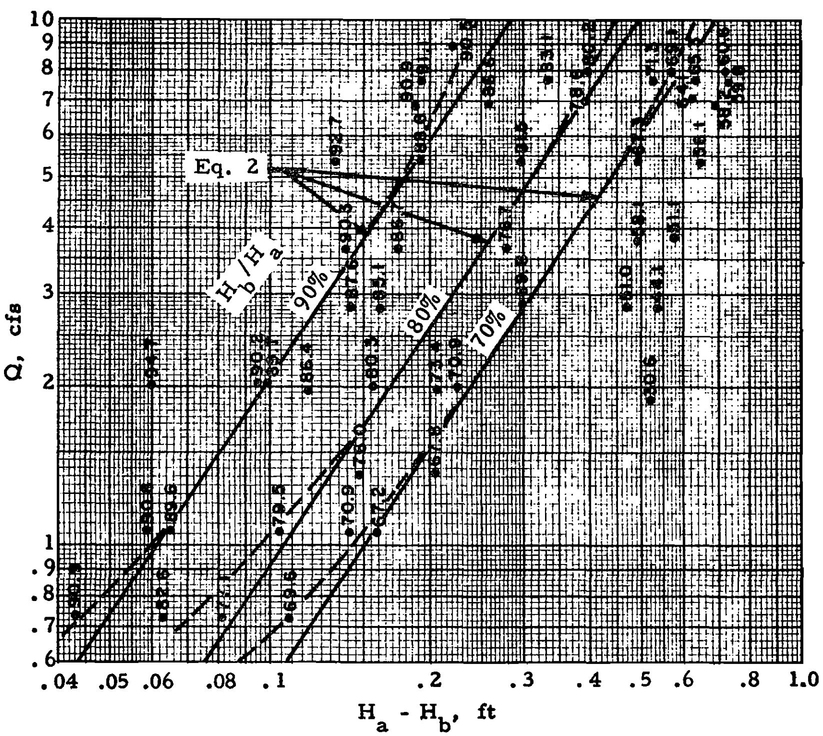


Figure 6. Diagram showing the rate of submerged flow through the 9-inch Parshall flume with 0.0045 slope of the incoming pipe.

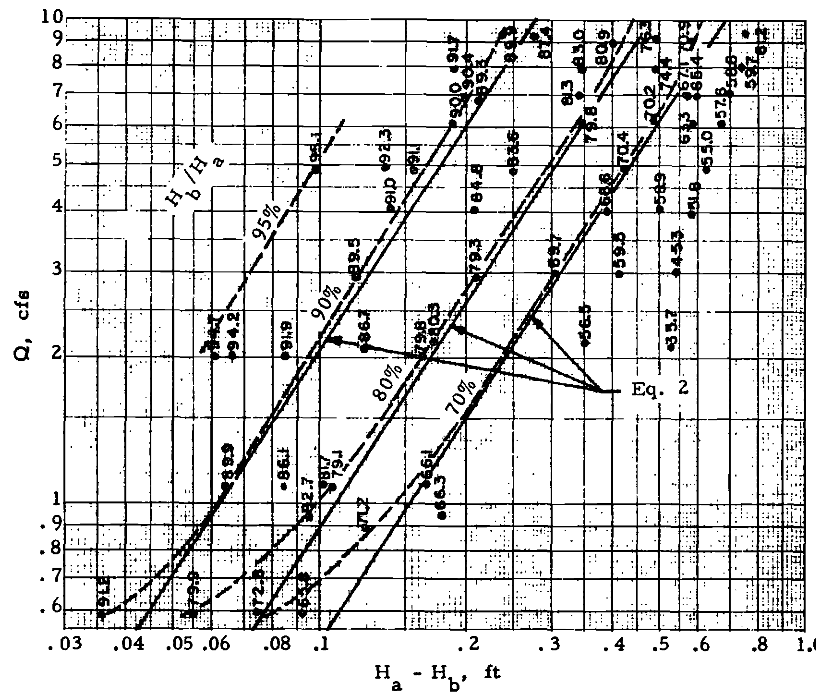


Figure 7. Diagram showing the rate of submerged flow through the 9-inch Parshall flume with 0.0060 slope of the incoming pipe.

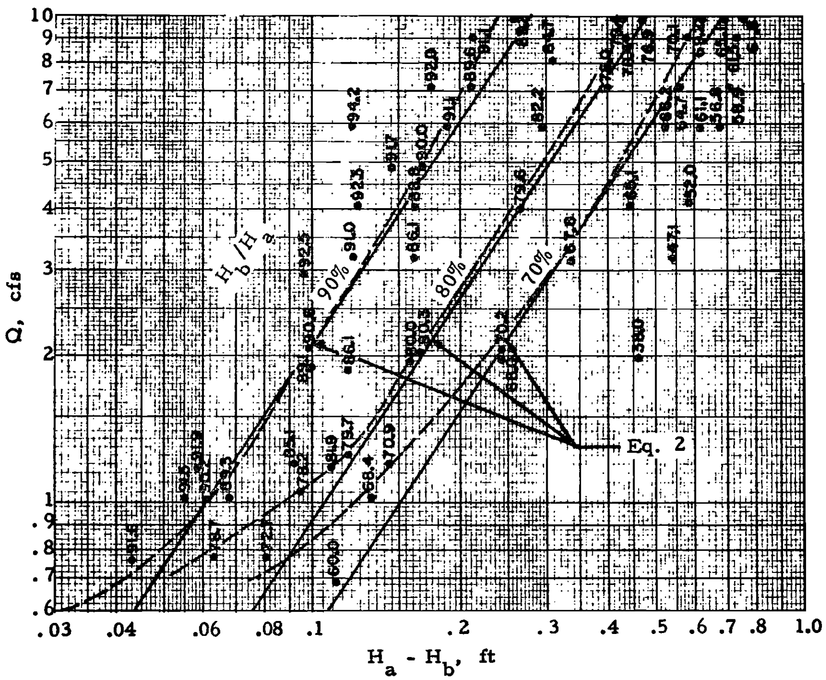


Figure 8. Diagram showing the rate of submerged flow through the 9-inch Parshall flume with 0.0080 slope of the incoming pipe.

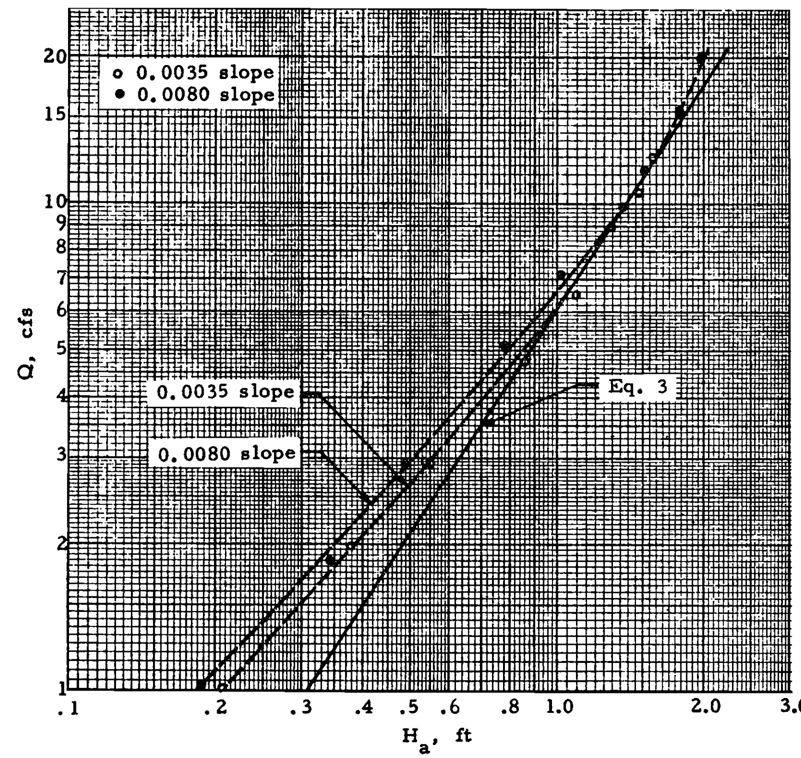


Figure 9. Diagram showing the rate of free flow through the 18-inch Parshall flume.

in the 18-inch Parshall flume with 0.0035 slope, Figure 10, and 0.0080 slope, Figure 11, of the incoming pipe, respectively. Note that the deviations of the measured values for the 18-inch flume from the computed standard values were more significant at low flow rates and less significant at high flow rates than those of the corresponding curves for the 9-inch flume over the ranges tested.

Formulation of new empirical formulas

For the development of new empirical formulas, many curves representing simple mathematical functions, or a combination thereof, were tried to fit the measured points such as along the broken lines shown in Figures 4 through 11. Use of a single all inclusive curve in fitting all the measured points and with the same value of a flow parameter was extremely difficult. A simple method was therefore developed to fit data points in segments with a number of short-range curves (or lines on a log-log scale). For convenience in expressing such a family of short-range curves or segments in a form similar to the standard formulas for both free and submerged flow, significant factors which most affect the discharge had to be known. A dimensional analysis was conducted for that purpose and data points were then plotted against the significant factors. New depth-discharge relationships or empirical formulas so developed were generalized as follows:

For free flow [i.e., $H_b/H_a \leq (H_b/H_a)_t$]

$$Q_n = C_{1f} H_a^{C_2} \quad \dots\dots\dots\dots\dots \quad (6)$$

and for submerged flow [i.e., $H_b/H_a \geq (H_b/H_a)_t$]

$$Q_n = C_{1s} H_a^{C_2} \left(1 - \frac{H_b}{H_a}\right)^{C_3} \quad \dots\dots\dots \quad (7)$$

in which Q_n = discharge computed by new empirical formulas; $(H_b/H_a)_t$ = transition submergence; C_{1f} and C_{1s} = coefficients; and C_2 and C_3 = exponents. The values of $(H_b/H_a)_t$, C_{1f}, C_{1s}, C_2, and C_3 were found to depend on the slope of the incoming pipe, S_o, and the throat size of the Parshall flume. Note that the values of $(H_b/H_a)_t$ were obtained by equating Eq. 6 to Eq. 7; namely

$$\left(\frac{H_b}{H_a}\right)_t (\%) = \left[1 - \left(\frac{C_{1f}}{C_{1s}}\right)^{1/C_3}\right] \times 100 \quad \dots \quad (8)$$

As mentioned previously, because of the difficulty in fitting data points with one all inclusive curve, data points for flow with the same value of submergence and free flow in the 9-inch Parshall flume were fitted by three short straight segments on a log-log scale as shown in Figures 12 through 15. Data for the 18-inch Parshall flume were fitted by two short straight segments as shown in Figures 16 and 17. The values of C_{1f}, C_{1s}, C_2, and C_3, for each segment were determined by using the least-squares method and are tabulated in Table 1 for free flow in the 9-inch Parshall flume, Table 2 for submerged flow in the 9-inch Parshall flume, Table 3 for free flow in the 18-inch Parshall flume, and Table 4 for submerged flow in the 18-inch Parshall flume. Included in the tables are also the values or expressions of H_a for free flow or $(H_a - H_b)$ for submerged flow at a breaking point between two

Table 1. Values of C_{1f}, C_2, and H_{at} for free flow in the 9-inch Parshall flume.

Regions	S_o	0.0035	0.0045	0.0060	0.0080
Region I, $H_a \geq H_{at1}$	C_{1f} C_2	2.404 2.060	2.380 2.049	2.326 2.048	2.450 2.055
H_{at1}		1.585	1.631	1.685	1.474
Region II, $H_{at1} \leq H_a \leq H_{at2}$	C_{1f} C_2	3.028 1.559	3.056 1.538	3.037 1.537	3.013 1.522
H_{at2}		0.810	0.622	0.601	0.831
Region III, $H_a \leq H_{at2}$	C_{1f} C_2	2.960 1.451	2.711 1.286	2.473 1.134	2.768 1.063

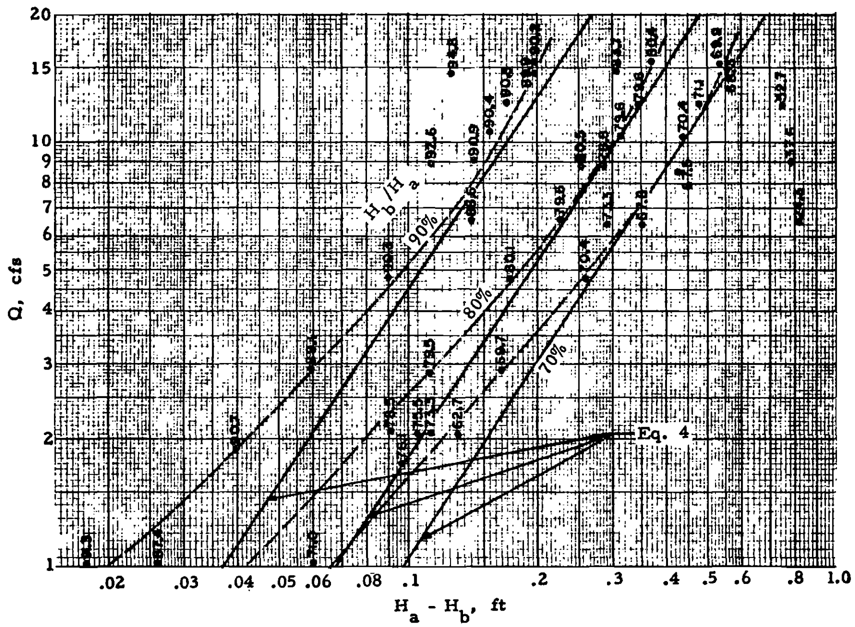


Figure 10.Diagram showing the rate of submerged flow through the 18-inch Parshall flume with 0.0035 slope of the incoming pipe.

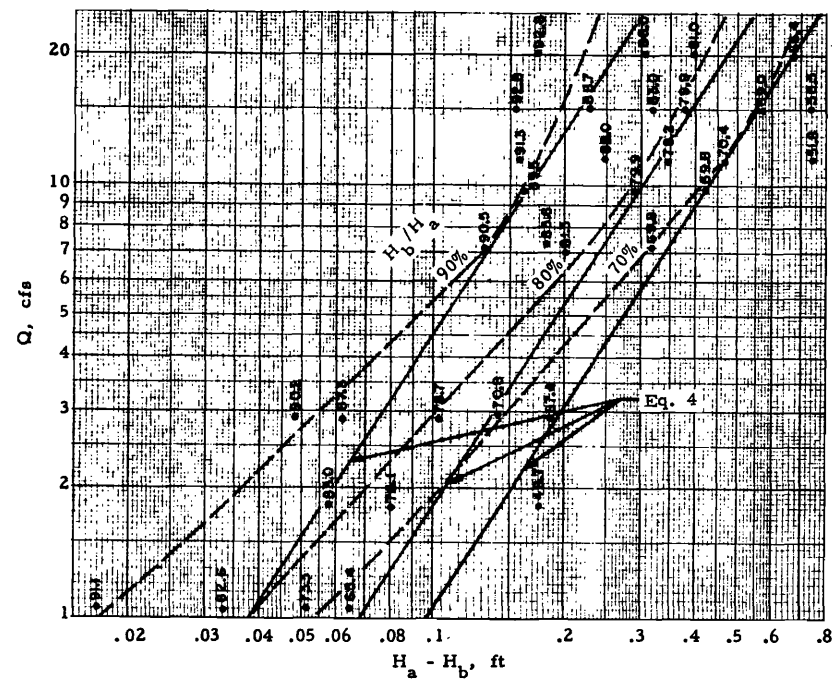


Figure 11.Diagram showing the rate of submerged flow through the 18-inch Parshall flume with 0.0080 slope of the incoming pipe.

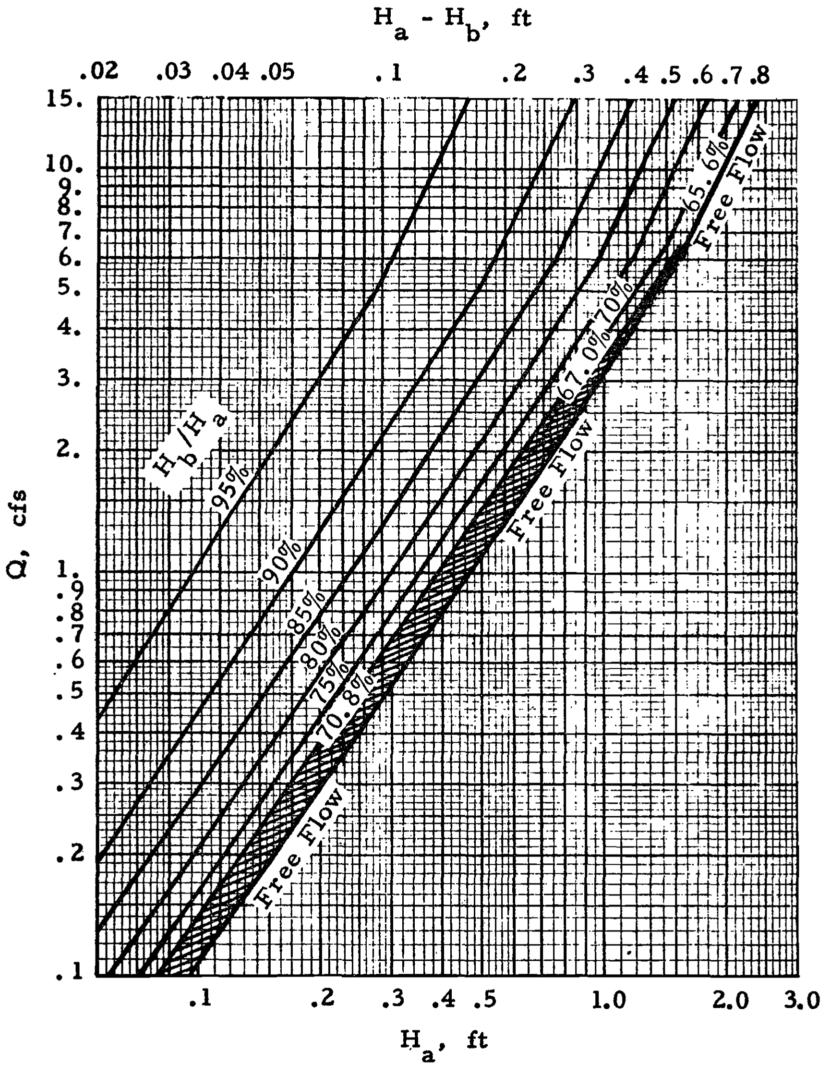


Figure 12. Free and submerged flow calibration curves for 9-inch Parshall flume with 0.0035 slope of the incoming pipe.

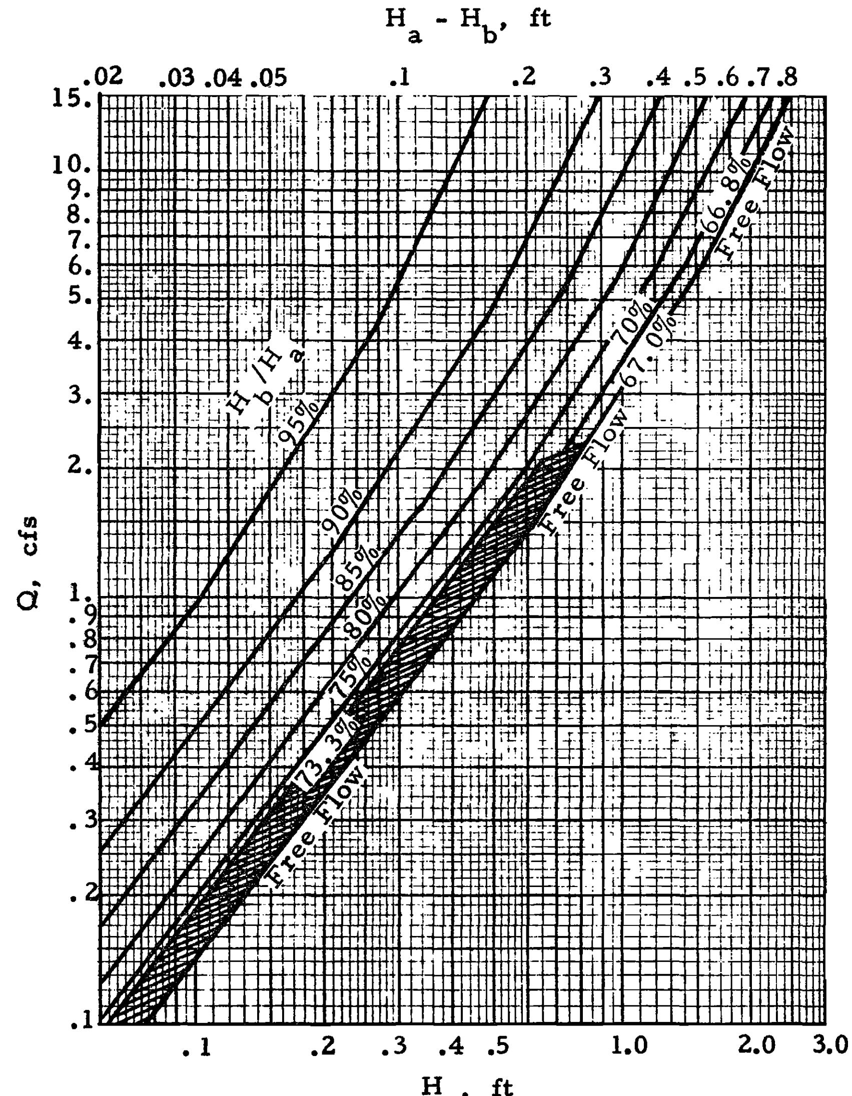


Figure 13. Free and submerged flow calibration curves for 9-inch Parshall flume with 0.0045 slope of the incoming pipe.

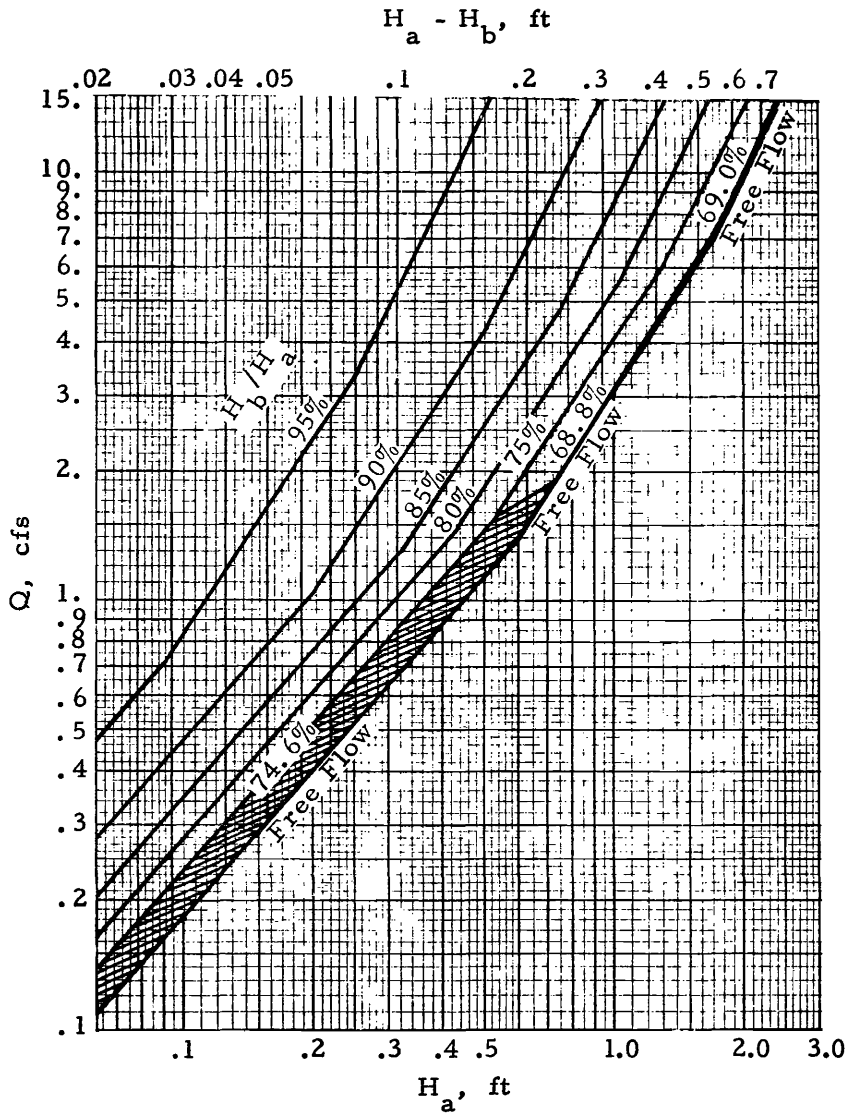


Figure 14.Free and submerged flow calibration curves for 9-inch Parshall flume with 0.0060 slope of the incoming pipe.

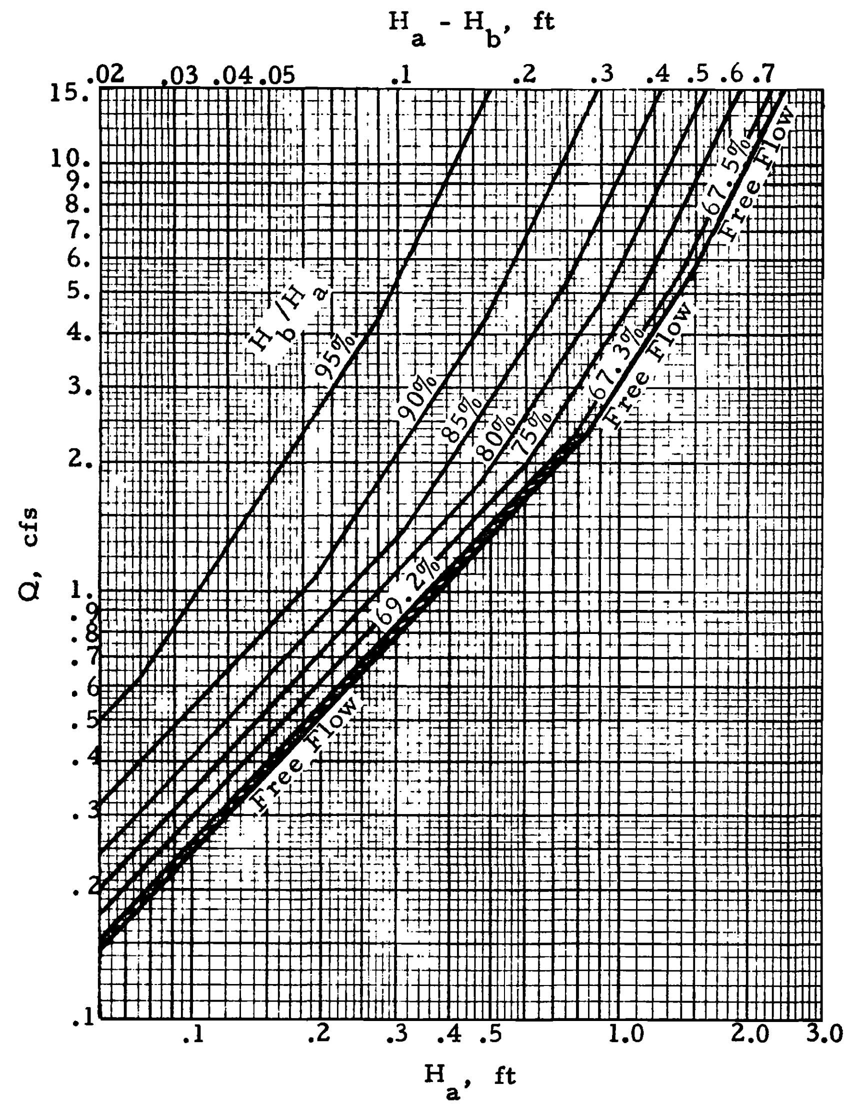


Figure 15.Free and submerged flow calibration curves for 9-inch Parshall flume with 0.0080 slope of the incoming pipe.

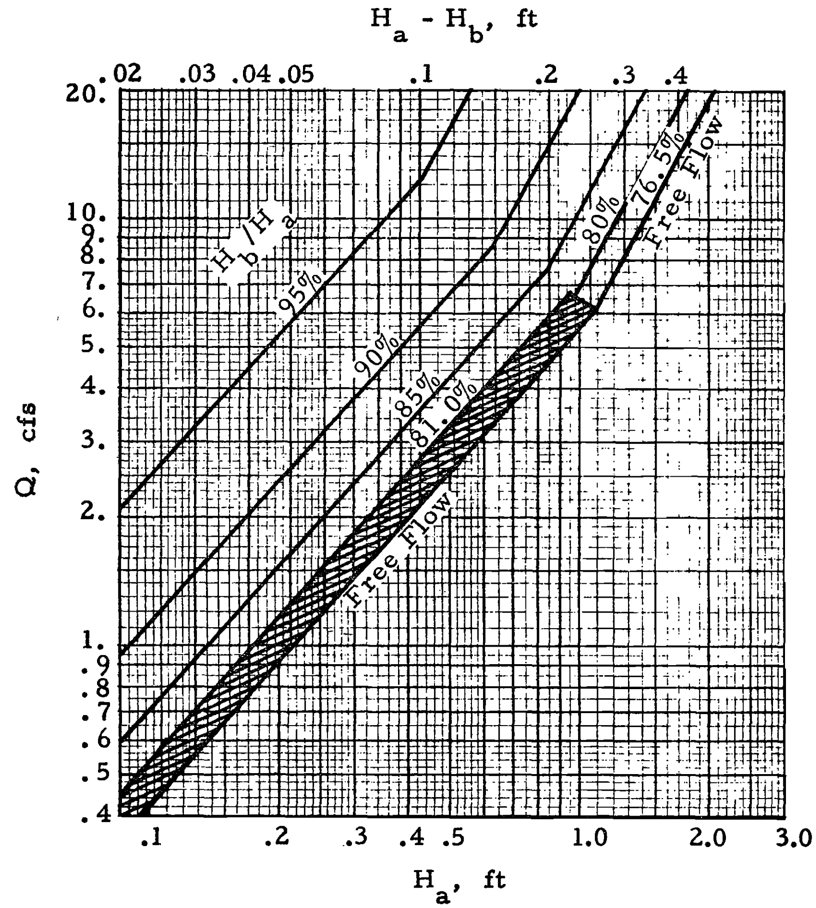


Figure 16.Free and submerged flow calibration curves for 18-inch Parshall flume with 0.0035 slope of the incoming pipe.

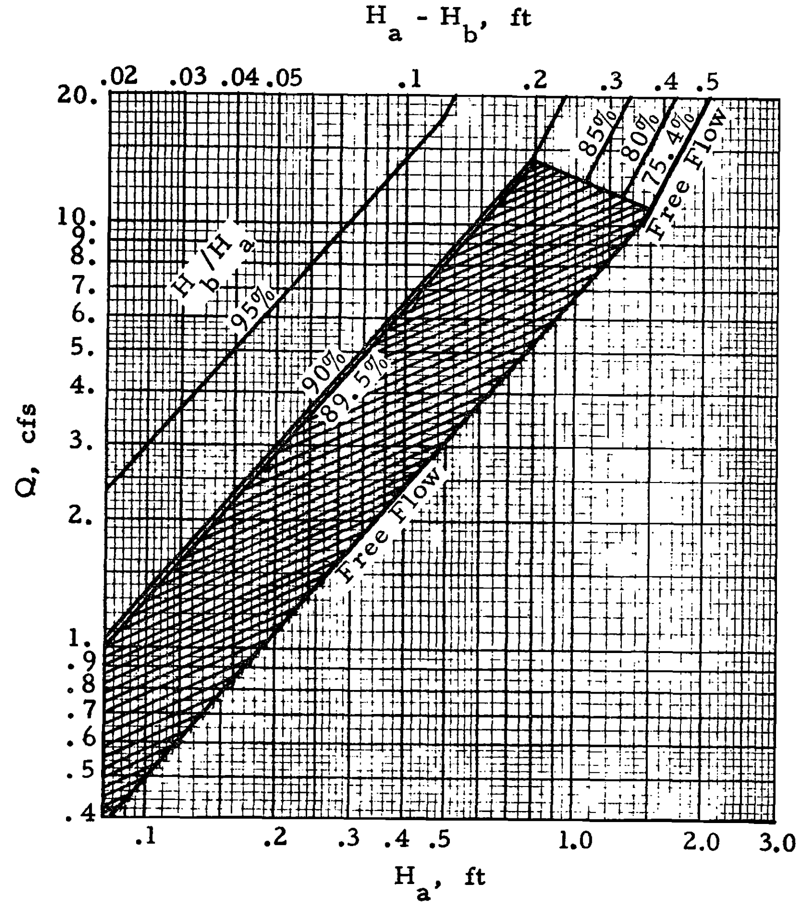


Figure 17.Free and submerged flow calibration curves for 18-inch Parshall flume with 0.0080 slope of the incoming pipe.

Table 2. Values of C_{1s}, C_2, C_3, and $(H_a-H_b)_t$ for submerged flow in the 9-inch Parshall flume.

Regions	S_o	0.0035	0.0045	0.0060	0.0080
Region I, $(H_a-H_b) \geq (H_a-H_b)_{t1}$	C_{1s} C_2 C_3	3.365 2.060 0.315	3.349 2.049 0.310	3.363 2.048 0.315	3.563 2.055 0.333
$(H_a-H_b)_{t1}$		$1.494\left(1-\frac{H_b}{H_a}\right)^{0.824}$	$1.593\left(1-\frac{H_b}{H_a}\right)^{0.975}$	$1.733\left(1-\frac{H_b}{H_a}\right)^{1.027}$	$1.319\left(1-\frac{H_b}{H_a}\right)^{0.904}$
Region II, $(H_a-H_b)_{t1} \leq (H_a-H_b) \leq (H_a-H_b)_{t2}$	C_{1s} C_2 C_3	4.115 1.559 0.277	4.248 1.538 0.297	4.454 1.537 0.329	4.130 1.522 0.282
$(H_a-H_b)_{t2}$		$2.303\left(1-\frac{H_b}{H_a}\right)^{2.056}$	$0.836\left(1-\frac{H_b}{H_a}\right)^{1.036}$	$0.841\left(1-\frac{H_b}{H_a}\right)^{1.122}$	$1.194\left(1-\frac{H_b}{H_a}\right)^{1.277}$
Region III, $(H_a-H_b) \leq (H_a-H_b)_{t2}$	C_{1s} C_2 C_3	4.503 1.451 0.341	4.061 1.286 0.306	4.154 1.134 0.378	4.480 1.063 0.409

Table 3. Values of C_{1f}, C_2, and H_{at} for free flow in the 18-inch Parshall flume.

Regions	S_o	0.0035	0.0080
Region I, $H_a \geq H_{at}$	C_{1f} C_2	5.193 1.851	4.995 1.910
H_{at}		1.079	1.428
Region II, $H_a \leq H_{at}$	C_{1f} C_2	5.491 1.114	6.588 1.133

segments or regions. These are denoted by H_{at} and $(H_a-H_b)_t$, respectively, for free flow and submerged flow. It follows from the experimental results that there are two breaking points in the 9-inch Parshall flume (Figures 12 through 15), but only one in the 18-inch Parshall flume (Figures 16 and 17). In order to distinguish between two breaking points, subscripts 1 and 2 are further attached to the preceding notations. Therefore, H_{at1} and H_{at2} are used to denote those for free flow and $(H_a-H_b)_{t1}$ and $(H_a-H_b)_{t2}$, for submerged flow in the 9-inch Parshall flume (see Tables 1 and 2). Specifically, in terms of coefficients and exponents in region I (denoted by superscript I) and region II (denoted by superscript II), it can readily be shown that

$$H_{at1} = \left(\frac{C_{1f}^{II}}{C_{1f}^{I}}\right)^{1/(C_2^I - C_2^{II})} \quad \text{. . . . . (9)}$$

for free flow and

$$(H_a - H_b)_{t1} = \left(\frac{C_{1s}^{II}}{C_{1s}^{I}}\right)^{1/(C_2^{I} - C_2^{II})} \left(1 - \frac{H_b}{H_a}\right)^{1 + (C_3^{II} - C_3^{I})/(C_2^{I} - C_2^{II})} \quad \ldots\ldots\ldots (10)$$

for submerged flow. The H_{at2} and $(H_a\text{-}H_b)_{t2}$ between region II and region III can be expressed accordingly.

Likewise, the values of H_{at} and $(H_a\text{-}H_b)_t$ for free flow and submerged flow in the 18-inch Parshall flume were calculated in accordance with Eqs. 9 and 10, respectively. These values along with the values of C_{1f}, C_{1s}, C_2, and C_3 for different slopes of the incoming pipe were tabulated in Tables 3 and 4.

For each slope of the incoming pipe, the values of C_{1f}, C_{1s}, and C_3 in one region are different from those in the other region. Thus, the transition submergence, as calculated by Eq. 8, has different values for different regions (see Tables 5 and 6).

Table 4. Values of C_{1s}, C_2, C_3, and $(H_a\text{-}H_b)_t$ for submerged flow in the 18-inch Parshall flume.

Regions \ S_o		0.0035	0.0080
Region I, $(H_a\text{-}H_b) \geq (H_a\text{-}H_b)_t$	C_{1s}	8.067	7.224
	C_2	1.851	1.910
	C_3	0.304	0.263
$(H_a\text{-}H_b)_t$		$0.566\left(1 - \frac{H_b}{H_a}\right)^{0.559}$	$0.909\left(1 - \frac{H_b}{H_a}\right)^{0.672}$
Region II, $(H_a\text{-}H_b) \leq (H_a\text{-}H_b)_t$	C_{1s}	5.303	6.708
	C_2	1.114	1.133
	C_3	-0.021	0.008

New empirical formulas, Eqs. 6 and 7, with the values of C_{1f}, C_{1s}, C_2, C_3, and $(H_b/H_a)_t$ so determined were used to compute the discharge (Q_n) by inserting the measured values of H_a and H_b/H_a into the equations. The error involved in using the new empirical formulas for the estimation of the discharge (Q_n) in comparison with the measured discharge (Q) was calculated by

$$\text{Error (\%)} = \left(\frac{Q_n - Q}{Q}\right) \times 100 \quad \ldots\ldots (11)$$

Table 5. Transition submergence $(H_b/H_a)_t$ in percent for 9-inch Parshall flume.

Regions \ S_o	0.0035	0.0045	0.0060	0.0080
I	65.6	66.8	69.0	67.5
II	67.0	67.0	68.8	67.3
III	70.8	73.3	74.6	69.2

Table 6. Transition submergence $(H_b/H_a)_t$ in percent for 18-inch Parshall flume.

Regions \ S_o	0.0035	0.0080
I	76.5	75.4
II	81.0	89.5

For comparison, calculated values by using the new empirical formulas were all tabulated in Tables 7 through 12 in the Appendix.

Development of new calibration curves and tables

As shown in Figures 12 through 17, new calibration curves for free flow and submerged flow were prepared for each Parshall flume. For convenience, the calibration curves for both free flow and submerged flow were plotted in the same figure on log-log paper: Q as the ordinate, H_a-H_b as the upper abscissa for submerged flow, H_a as the lower abscissa for free flow, and submergence (H_b/H_a) as the varying parameter.

Theoretically speaking, the transition submergence line should coincide with the calibration line for free flow, as was successfully accomplished by Skogerboe et al.[2] for the standard formulas. It could not be done in such a way, however, in the case of the new empirical formulas. Because the calibration line for the new formulas is composed of either three portions for 9-inch Parshall flume or two portions for 18-inch Parshall flume, there are three (or two) different values of the transition submergence for each slope of the incoming pipe (see Tables 5 and 6). Therefore, the calibration line for free flow could not be made to match all of the three or two transition submergence lines having different values. Instead, the major portion of a transition submergence line in the smallest value was adjusted to overlap approximately the calibration line for free flow. The areas between the other transition submergence lines and the calibration line for free flow were then crosshatched, as shown in Figures 12 through 17, with the understanding that any measured point falling within the shaded areas would be considered as free flow and the calibration line for free flow should be used.

For convenience for practical application of the new formulas, calibration tables for free flow (Table 13) and submerged flow (Tables 14 through 19) were constructed in the Appendix. Note that in the submerged flow calibration tables, only those flow rates with the smallest value of the transition submergence were tabulated.

DISCUSSION

As demonstrated, a short Parshall flume entrance transition of non-standard arrangement (Figure 1) causes higher readings in discharge for given H_a or (H_a-H_b) at low and high flow rates than the computed discharge with the standard transition. The effect of such a non-standard entrance transition with different slopes of the incoming pipe on the measured Q, H_a, and H_b is quite significant at such low and high flow rates. This may be due mainly to the high approaching flow velocity in the incoming pipe which cannot adjust fast enough in such a short transition section to yield the usual standard flow pattern at the specified locations of measurement for H_a and H_b in the Parshall flume. A typical example of low flow and that of high flow is shown in Figures 18 and 19, respectively.

For the 9-inch Parshall flume, the specified arrangement that the flat side walls of the transition bend outward at 8 degrees from the spring line of the 18-inch pipe may not prevent separation of the flow from the boundaries, specifically at low flow rates (see Figure 18). Generally, a wall deflection of somewhat less than 4 degrees can insure freedom from separation. However, an overall expansion rate of such magnitude would result in an excessively long transition which may not be justified. If the flow in the system is debris- and sediment-free, the use of intermediate guide walls with angles of approximately 7 degrees would control the flow locally and yet would greatly reduce the length of the transition structure as a whole. Unfortunately, this kind of arrangement may not be satisfactory for a storm or sanitary sewer in which a great amount of debris and sediment is transported with water.

It is true that the standard formulas can be more conveniently adapted to recording equipment for Parshall flumes than a set of new empirical formulas. However, an application of the standard formulas to Parshall flumes with such non-standard entrance transitions is not justified because use of the standard formulas tends to underestimate both low and high flow rates. It appears that with the larger throat size of the Parshall flume and steeper slope of the incoming pipe, the more significant is the underestimation of discharge at low and high flow. The convenience in the adaption of the standard formulas for recording equipment evidently cannot offset the loss in revenue resulting from the underestimation of discharge, especially at high flow. If one insists on using the standard formulas for recording equipment, it is advisable to install between the first transition and the Parshall flume another uniform transition in rectangular cross-section with the same size as the Parshall flume specified. This also is a problem, however, because not all the field situations will permit such an installation. Further experiments will be required to determine the least length of the second transition for different slopes of the incoming pipe and for Parshall flumes of various throat width.

New empirical formulas or depth-discharge relationships for a Parshall flume of any throat size with a non-standard entrance transition, such as shown in Figure 1, have been developed as shown in a general form in Eqs. 6 and 7 for free flow and submerged flow, respectively. As mentioned previously, data points in broken lines (Figures 4 through 11) have been fitted to the accuracy of least squares with three or two calibration line segments of a type of Eqs. 6 and 7 (Figures 12 through 17). The values of the coefficients and exponents in Eqs. 6 and 7 (see Tables 1 through 4) depend on the throat size of the Parshall flume and the slope of the incoming pipe. Specifically, for a 9-inch Parshall flume, note that the values of C_{1f} and C_2 in region II are very close to the respective standard formula values, 3.07 and 1.53 (see Eq. 1). The result is not surprising when one considers that in region II are moderate flow rates on which the effect of the slope of the incoming pipe is a minimum. This is not true, however, for the 18-inch Parshall flume (see Table 3).

The general form of Eq. 7 for submerged flow may be misleading because the true expression for discharge based on a dimensional analysis is

$$Q_n = C_{1s}(H_a - H_b)^{C_2}\left(1 - \frac{H_b}{H_a}\right)^{C_3 - C_2} \quad . . . . (12)$$

which can be transformed into Eq. 7. Calibration curves in Figures 12 through 17 for submerged flow were actually based on Eq. 12, in which H_a-H_b has been plotted in the figures as the abscissa and H_b/H_a as the controlling parameter. An extensive study of data points reveals that the validity of Eq. 12 starts breaking down for submergence greater than 90 percent.

Analysis was made of errors involved in the computation of discharge by using the standard formulas, Eqs. 1 through 4, and those by using the new empirical formulas, Eqs. 6 and 7. Errors (differences) between the measured and computed values were calculated by using Eqs. 5 and 11, respectively, for the standard formulas and the new empirical formulas. An electronic digital computer was used to calculate Q_s, Q_n, and hence the errors on those data points for 9-inch and 18-inch Parshall flumes with different slopes of the incoming pipe. These are tabulated in Tables 7 through 12 in the Appendix. A comparison between the errors computed by Eqs. 5 and 11 reveals that except for few data points the error involved in the prediction of discharge by using the new empirical formulas is in general smaller than that by using the standard formulas.

Figure 18. Typical view of low flow in the entrance section of the 18-inch Parshall flume. (Free flow, Q = 1 cfs, H_a = 0.191 ft, the slope of the incoming concrete pipe = 0.0080, facing upstream.)

Figure 19. Typical view of high flow in the entrance section of the 18-inch Parshall flume. (Submerged flow, Q = 15 cfs, H_a = 2.02 ft, H_b = 1.82 ft, 90% submergence, the slope of the incoming concrete pipe = 0.0035, facing upstream.)

SUMMARY AND CONCLUSIONS

The 9-inch and 18-inch Parshall flumes with the specified non-standard entrance transitions were tested and the results of the experiments have been presented in this report. The measured depth-discharge relationships for free flow and submerged flow were plotted on log-log paper and then compared with the standard formulas. The measured discharge for given H_a in free flow or H_a-H_b in submerged flow has been found to deviate quite significantly from the computed discharge by using the standard formulas, especially at both low and high flow rates. New empirical formulas have been developed for the mathematical expression of the measured depth-discharge relationships for 9-inch and 18-inch Parshall flumes with non-standard entrance transitions. The values of the coefficients and exponents in the new empirical formulas have been found to depend on the throat size of the flume and the slope of the incoming pipe. For the purpose of practical application, calibration curves of the flumes tested were constructed on log-log paper and are tabulated in the Appendix.

This investigation has shown that the larger the flume throat size and the steeper the slope of the incoming pipe, the greater is the difference between the actual flume flow and the flow predicted by the standard formulas.

Use of a Parshall flume with such non-standard entrance conditions without further calibration of the flume is to be avoided.

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APPENDIX

For compilation of measured and computed data, an electronic digital computer (UNIVAC 1108) was used. Tables 7 through 10 are measured and computed data on the 9-inch Parshall flume and Tables 11 and 12 on the 18-inch Parshall flume. Note that in these tables, the values of H_b, H_b/H_a, and H_a-H_b for some data points are omitted. These are the free flow data for which H_b was not measured during the experiments. The errors computed in these tables confirm the fact that the new empirical formulas tend to give poor results for submergence greater than 90 percent but are good otherwise.

Calibration tables for free flow in the 9-inch and 18-inch Parshall flumes with various slopes of the incoming pipe are constructed, as shown in Table 13, for the range of H_a from 0.10 to 2.00 ft in 0.01 ft increments. The table approximately covers the computation range of discharge from 0.1 to 10 cfs for 9-inch Parshall flume and from 0.5 to 20 cfs for 18-inch flume. Calibration tables for submerged flow in the 9-inch Parshall flume are shown in Tables 14 through 17 for computed discharge up to 15 cfs, and those for 18-inch flume in Tables 18 and 19 for computed discharge up to 20 cfs. Although the computed discharges at 95 percent submergence are also given in the tables, these values are only shown for the purpose of understanding the characteristics of Eq. 7 and therefore are not recommended for use in any event.

Table 7. Test and computed data on the 9-inch Parshall flume with 0.0035 slope of the incoming pipe.

H_a ft	H_b ft	H_b/H_a %	H_a-H_b ft	Q cfs	Q_{st} cfs	Q_n cfs	$(Q_{st}-Q)/Q$ %	$(Q_n-Q)/Q$ %
.365	-	-	-	.72	.657	.686	-9.15	-5.15
.373	.264	70.91	.109	.72	.650	.707	-10.04	-2.27
.385	.303	78.55	.083	.72	.633	.668	-12.47	-7.59
.479	.430	89.87	.049	.72	.706	.777	-2.39	7.42
.405	.231	57.04	.174	.77	.770	.797	.27	3.84
.400	-	-	-	.78	.756	.783	-3.13	.41
.646	.584	90.40	.062	1.02	1.098	1.223	7.64	19.91
.728	.687	94.37	.041	1.02	1.150	1.306	12.73	28.01
.532	-	-	-	1.15	1.169	1.185	1.64	3.01
.550	.393	71.48	.157	1.16	1.175	1.235	1.26	6.44
.540	.327	60.59	.213	1.20	1.195	1.210	-.76	.47
.605	.494	81.60	.111	1.20	1.208	1.281	.35	6.43
.670	.588	87.76	.082	1.20	1.247	1.367	3.51	13.47
.533	.151	28.33	.382	1.21	1.172	1.188	-3.12	-1.83
.560	.435	77.77	.124	1.21	1.132	1.185	-6.48	-2.10
.554	-	-	-	1.25	1.244	1.256	-.51	.51
.773	.249	32.16	.524	2.02	2.070	2.037	2.44	.80
.777	.377	48.52	.400	2.03	2.087	2.053	2.65	.96
.822	.651	79.20	.171	2.02	1.998	2.123	-1.26	4.87
.798	.558	69.92	.240	2.02	2.098	2.204	3.60	8.82
.783	.543	69.37	.240	2.03	2.048	2.150	1.08	6.14
.809	.639	78.99	.170	2.03	1.957	2.076	-3.61	2.28
.838	.702	83.77	.136	2.03	1.914	2.067	-5.80	1.75
.994	.894	89.97	.100	2.03	2.150	2.419	5.82	19.03
.813	-	-	-	2.25	2.237	2.193	-.60	-2.54
.821	-	-	-	2.34	2.270	2.226	-2.98	-4.85
1.039	.834	80.25	.205	2.88	2.819	3.024	-2.10	5.00
.988	-	-	-	3.00	3.014	2.972	.46	-.95
1.160	1.015	87.50	.145	3.01	2.909	3.235	-3.39	7.44
1.182	1.048	88.66	.134	3.01	2.907	3.258	-3.53	8.13
1.026	.702	68.42	.324	3.01	3.114	3.297	3.30	9.39
.998	.455	45.59	.543	3.03	3.061	3.019	1.04	-.34
1.372	1.195	87.10	.177	3.93	3.797	4.233	-3.39	7.70
1.488	1.353	90.91	.135	3.93	3.876	4.439	-1.36	12.95
1.218	.808	66.38	.409	3.95	4.097	4.115	3.71	4.21
1.188	.612	51.52	.576	3.97	3.996	3.961	.65	-.23
1.195	.661	55.31	.534	3.97	4.032	3.997	1.56	.69
1.244	.921	74.08	.322	3.98	3.994	4.255	.36	6.92
1.317	1.091	82.86	.225	3.98	3.885	4.235	-2.40	6.40
1.284	-	-	-	4.43	4.500	4.471	1.59	.93
1.426	1.046	73.35	.380	4.79	4.958	5.300	3.51	10.65
1.497	1.231	82.22	.266	4.85	4.781	5.218	-1.41	7.59
1.406	.991	70.49	.415	4.86	4.971	5.307	2.28	9.20
1.739	1.592	91.52	.147	4.86	4.825	5.571	-.73	14.63
1.363	.799	58.65	.564	4.87	4.931	4.907	1.25	.76

Table 7. Continued.

H_a ft	H_b ft	H_b/H_a %	H_a-H_b ft	Q cfs	Q_{st} cfs	Q_n cfs	$(Q_{st}-Q)/Q$ %	$(Q_n-Q)/Q$ %
1.640	1.465	89.33	.175	4.88	4.712	5.354	-3.45	9.72
1.639	1.300	79.32	.339	5.83	5.735	6.216	-1.56	6.70
1.520	.871	57.30	.649	5.85	5.826	5.816	-.45	-.61
1.541	.989	64.18	.552	5.88	5.939	5.942	.99	1.04
1.571	1.126	71.67	.445	5.89	5.834	6.250	-.90	6.16
1.520	-	-	-	5.89	5.826	5.816	-1.09	-1.25
1.889	1.708	90.43	.181	6.02	5.665	6.512	-5.89	8.17
1.541	-	-	-	6.10	5.949	5.942	-2.47	-2.59
1.797	1.577	87.75	.220	6.13	5.649	6.372	-7.85	3.94
1.789	1.395	77.98	.394	6.77	6.673	7.228	-1.43	6.77
2.211	2.071	93.65	.141	6.82	6.465	7.586	-5.21	11.23
1.722	1.196	69.45	.526	6.87	6.827	7.334	-.62	6.76
2.090	1.911	91.44	.179	6.93	6.407	7.434	-7.55	7.27
1.688	.996	59.00	.692	7.00	6.839	7.068	-2.29	.98
1.691	1.021	60.40	.670	7.00	6.858	7.094	-2.03	1.35
1.832	1.510	82.44	.322	7.00	6.485	7.125	-7.36	1.78
1.916	1.679	87.63	.237	7.00	6.249	7.056	-10.73	.81
1.766	1.347	76.30	.418	7.05	6.673	7.203	-5.34	2.16
1.695	1.002	59.12	.693	7.13	6.883	7.129	-3.51	-.06
1.726	1.016	58.86	.710	7.15	7.076	7.400	-1.06	3.47
2.041	1.778	87.11	.263	7.81	6.969	7.860	-10.83	.57
2.195	1.990	90.66	.205	7.84	7.078	8.183	-9.72	4.38
2.220	2.018	90.90	.202	7.84	7.148	8.280	-8.83	5.61
1.913	1.525	79.72	.388	7.85	7.225	7.875	-7.96	.33
1.901	1.488	78.27	.413	7.96	7.295	7.921	-8.41	-.55
1.862	1.314	70.57	.548	7.98	7.633	8.238	-4.41	3.17
1.825	1.178	64.55	.647	8.11	7.680	8.301	-5.30	2.36
1.817	-	-	-	8.12	7.655	8.226	-5.73	1.31
1.817	1.094	60.21	.723	8.12	7.655	8.226	-5.73	1.31
1.810	-	-	-	8.22	7.610	8.161	-7.42	-.72
1.828	-	-	-	8.22	7.726	8.329	-6.01	1.33
2.355	2.139	90.83	.216	8.93	7.841	9.257	-12.19	3.66
2.142	1.758	82.07	.384	9.55	8.288	9.404	-13.24	-1.56
2.040	1.507	73.87	.533	9.56	8.533	9.577	-10.72	.19
1.964	1.195	60.85	.769	9.60	8.623	9.656	-10.19	.57
2.163	-	-	-	13.06	9.995	11.780	-23.47	-9.80

Table 8. Test and computed data on the 9-inch Parshall flume with 0.0045 slope of the incoming pipe.

H_a ft	H_b ft	H_b/H_a %	H_a-H_b ft	Q cfs	Q_{st} cfs	Q_n cfs	$(Q_{st}-Q)/Q$ %	$(Q_n-Q)/Q$ %
.351	-	-	-	.73	.619	.705	-15.13	-3.25
.362	.252	69.63	.110	.73	.626	.773	-14.10	.53
.363	.279	77.06	.083	.73	.587	.702	-19.45	-3.66
.366	.302	82.58	.064	.73	.551	.654	-24.40	-10.31
.479	.435	90.92	.043	.73	.684	.756	-6.20	3.76
.430	-	-	-	.92	.844	.916	-7.86	-.03
.473	-	-	-	1.06	.977	1.035	-7.89	-2.34
.484	.325	67.15	.159	1.06	.994	1.066	-5.21	.59
.485	.344	70.92	.141	1.06	.974	1.070	-8.16	.99
.497	.388	78.01	.109	1.06	.940	1.040	-11.33	-1.92
.512	.407	79.48	.105	1.06	.964	1.057	-9.04	-.29
.620	.555	89.52	.065	1.06	1.058	1.101	-.18	3.90
.643	.584	90.82	.059	1.06	1.076	1.108	1.52	4.53
.615	.467	75.95	.148	1.37	1.334	1.405	-2.63	2.57
.637	.432	67.82	.205	1.38	1.507	1.518	9.23	10.00
.749	.229	30.57	.520	1.90	1.973	1.959	3.83	3.12
.745	-	-	-	1.95	1.957	1.943	.35	-.35
.780	.573	73.42	.207	1.97	1.968	1.967	-.08	-.16
.844	.725	85.86	.119	1.97	1.656	1.830	-5.78	-7.09
.897	.779	86.85	.118	1.97	1.993	1.968	1.19	-.12
.771	.547	70.91	.224	2.02	1.977	1.942	-2.11	-3.86
.798	.641	80.33	.157	2.02	1.880	1.852	-6.94	-8.29
.966	.966	89.68	.100	2.02	2.076	2.052	2.76	1.58
1.147	1.087	94.73	.060	2.02	2.275	2.188	12.62	8.33
.977	.881	90.18	.096	2.04	2.083	2.058	2.09	.91
1.080	.919	85.07	.161	2.82	2.753	2.719	-2.37	-3.57
.955	.487	50.96	.468	2.83	2.861	2.847	1.10	.60
.952	.420	44.12	.532	2.84	2.847	2.833	.26	-.23
1.146	1.004	87.51	.142	2.85	2.848	2.817	-.08	-1.14
.986	.688	69.79	.298	2.85	2.905	2.915	1.85	2.22
1.426	1.287	90.26	.139	3.63	3.703	3.671	2.02	1.14
1.306	1.133	86.71	.174	3.65	3.554	3.518	-2.63	-3.61
1.197	.918	76.66	.279	3.66	3.666	3.636	.16	-.65
1.165	.677	58.11	.488	3.83	3.878	3.865	1.26	.92
1.157	.591	51.04	.567	3.88	3.839	3.826	-1.06	-1.39
1.920	1.784	92.94	.135	5.37	5.343	5.604	-.50	4.35
1.449	.912	56.05	.637	5.40	5.413	5.404	.24	.08
1.483	.999	67.35	.484	5.40	5.509	5.587	2.02	3.46
1.585	1.291	81.45	.294	5.40	5.280	5.230	-2.21	-3.14
1.688	1.496	88.63	.192	5.40	5.021	4.993	-7.02	-7.54
1.638	.954	58.24	.684	6.80	6.532	6.542	-3.94	-3.80
2.055	1.867	90.85	.188	6.85	6.361	6.980	-7.14	1.90
1.688	.992	58.80	.696	6.95	6.839	6.958	-1.59	.11
1.803	1.417	78.59	.386	6.99	6.701	6.949	-4.14	-.58
1.912	1.655	86.56	.257	6.99	6.388	6.784	-8.62	-2.94

Table 8. Continued.

H_a ft	H_b ft	H_b/H_a %	H_a-H_b ft	Q cfs	Q_{st} cfs	Q_n cfs	$(Q_{st}-Q)/Q$ %	$(Q_n-Q)/Q$ %
1.712	1.097	64.08	.615	7.10	6.980	7.162	-1.69	.87
1.951	1.621	83.09	.330	7.64	7.061	7.593	-7.57	-.62
2.169	1.977	91.15	.192	7.64	6.844	7.718	-10.41	1.02
1.772	1.059	59.76	.713	7.70	7.357	7.686	-4.33	-.19
1.783	1.111	62.31	.672	7.70	7.437	7.784	-3.42	1.09
1.795	1.172	65.29	.623	7.70	7.461	7.891	-3.11	2.49
1.841	1.323	71.86	.518	7.70	7.425	7.894	-3.57	2.52
2.119	1.873	88.42	.245	7.95	7.145	7.995	-10.13	.56
1.959	1.571	80.19	.388	8.00	7.442	8.041	-6.97	.51
1.840	1.272	69.13	.568	8.01	7.574	8.115	-5.44	1.31
1.805	1.094	60.61	.711	8.05	7.578	7.982	-5.86	-.85
2.292	2.073	90.46	.219	8.90	7.607	8.841	-14.53	-.66

Table 9. Test and computed data on the 9-inch Parshall flume with 0.0060 slope of the incoming pipe.

Table 9. Continued.

H_a ft	H_b ft	H_b/H_a %	H_a-H_b ft	Q cfs	Q_{st} cfs	Q_n cfs	$(Q_{st}-Q)/Q$ %	$(Q_n-Q)/Q$ %
.271	-	-	-	.59	.416	.563	-29.89	-5.28
.269	.177	65.80	.092	.59	.408	.558	-31.35	-6.08
.272	.198	72.79	.074	.59	.395	.565	-33.51	-4.89
.273	.218	79.85	.055	.59	.357	.520	-38.26	-12.45
.409	.373	91.20	.036	.59	.532	.601	-10.40	1.26
.386	-	-	-	.87	.721	.845	-16.91	-2.63
.428	.305	71.24	.123	.88	.800	.944	-9.11	7.26
.549	.454	82.74	.095	.94	1.020	1.083	8.51	15.17
.525	.348	66.29	.177	.95	1.131	1.191	19.09	25.36
.597	.514	86.05	.083	1.07	1.089	1.100	1.41	2.39
.641	.576	89.91	.065	1.08	1.101	1.057	2.23	-1.82
.553	.452	81.66	.101	1.08	1.052	1.119	-2.38	3.77
.487	.322	66.05	.166	1.08	1.011	1.095	-6.35	1.38
.506	.400	79.05	.106	1.08	.953	1.063	-11.75	-1.61
.507	-	-	-	1.17	1.088	1.146	-6.73	-1.71
.788	.561	71.26	.226	2.00	2.037	2.049	2.00	2.61
.799	.638	79.80	.161	2.00	1.899	1.866	-5.03	-6.71
1.032	.948	91.86	.084	2.00	2.146	2.048	7.30	2.41
1.121	1.056	94.16	.065	2.01	2.245	2.087	11.67	3.81
.908	.777	85.57	.131	2.01	2.088	2.030	3.66	.80
1.158	1.097	94.73	.061	2.02	2.307	2.118	14.23	4.86
.817	.292	35.74	.525	2.11	2.253	2.226	6.80	5.50
.929	.805	86.66	.124	2.11	2.114	2.052	.19	-2.76
.809	.457	56.49	.352	2.13	2.220	2.193	4.21	2.94
.860	.691	80.35	.169	2.15	2.107	2.068	-2.00	-3.80
1.224	1.096	89.54	.128	2.89	2.993	2.891	3.58	.04
.995	.592	59.54	.403	2.95	3.047	3.014	3.27	2.16
1.060	.841	79.34	.219	2.95	2.943	2.900	-.23	-1.71
.985	.446	45.28	.539	2.99	3.000	2.968	.34	-.74
1.185	.614	51.84	.571	3.95	3.980	3.942	.77	-.19
1.189	.616	51.81	.573	4.01	4.001	3.963	-.22	-1.18
1.202	.708	58.90	.494	4.01	4.068	4.030	1.45	.49
1.228	.843	68.63	.385	4.01	4.095	4.165	2.12	3.89
1.354	1.148	84.79	.206	4.01	3.913	3.821	-2.43	-4.72
1.543	1.404	90.99	.139	4.01	4.086	3.931	1.90	-1.98
1.353	.744	55.00	.609	4.88	4.874	4.832	-.12	-.99
1.405	.989	70.39	.416	4.88	4.968	5.033	1.80	3.13
1.515	1.267	83.63	.248	4.88	4.749	4.650	-2.69	-4.71
1.968	1.870	95.02	.098	4.88	5.143	5.230	5.39	7.17
1.757	1.622	92.32	.135	4.90	4.769	4.753	-2.67	-3.00
1.556	.897	57.65	.659	6.02	6.038	5.992	.30	-.47
1.574	.996	63.28	.578	6.05	6.159	6.099	1.81	.81
1.872	1.685	90.04	.186	6.05	5.653	5.873	-6.56	-2.92
1.689	1.348	79.81	.341	6.07	5.964	5.943	-1.75	-2.09
1.603	1.125	70.18	.478	6.08	6.088	6.178	.12	1.61
1.703	1.115	65.44	.589	6.92	6.881	6.925	-.56	.07
1.980	1.768	89.29	.212	6.92	6.292	6.740	-9.08	-2.60
2.031	1.836	90.40	.195	6.92	6.335	6.860	-8.45	-.86
1.708	1.154	67.56	.554	6.98	6.827	6.962	-2.19	-.26
1.813	1.474	81.30	.339	6.98	6.501	6.707	-6.86	-3.91
1.681	.988	58.77	.693	7.00	6.796	6.747	-2.91	-3.61
1.811	1.082	59.75	.729	7.90	7.616	7.849	-3.59	-.64
1.892	1.407	74.37	.485	7.90	7.558	8.084	-4.20	2.33
2.009	1.668	83.03	.341	7.90	7.393	8.028	-5.42	1.62
2.256	2.068	91.66	.188	7.90	7.144	8.132	-9.57	2.94
1.982	1.405	70.90	.577	8.80	8.381	9.259	-4.77	5.22
2.070	1.676	80.95	.394	8.92	8.010	8.856	-10.20	-.72
2.040	1.557	76.32	.483	9.10	8.319	9.199	-8.58	1.09
2.232	1.956	87.62	.276	9.15	7.897	9.020	-13.70	-1.42
1.918	1.175	61.24	.744	9.70	8.318	8.831	-9.59	-4.01
2.328	2.090	89.79	.238	9.20	7.947	9.249	-13.62	.53

Table 10. Test and computed data on the 9-inch Parshall flume with 0.0080 slope of the incoming pipe.

H_a ft	H_b ft	H_b/H_a %	H_a-H_b ft	Q cfs	Q_{st} cfs	Q_n cfs	$(Q_{st}-Q)/Q$ %	$(Q_n-Q)/Q$ %
.279	.167	60.04	.112	.68	.435	.713	-35.25	4.33
.513	.470	91.63	.043	.76	.743	.800	-2.44	4.98
.293	-	-	-	.76	.469	.751	-38.57	-1.75
.293	.213	72.70	.080	.76	.443	.714	-42.02	-6.49
.295	.232	78.68	.063	.76	.421	.652	-44.95	-14.72
.342	-	-	-	.90	.595	.885	-33.86	-1.58
.386	-	-	-	1.02	.716	1.006	-29.71	-1.15
.633	.565	89.29	.068	1.02	1.099	1.105	7.51	8.10
.621	.560	90.19	.061	1.02	1.042	1.046	1.82	2.21
.425	.333	78.26	.092	1.05	.737	.967	-29.77	-7.95
.419	.287	68.42	.132	1.08	.791	1.098	-26.76	1.66
.600	.491	81.86	.109	1.18	1.186	1.294	.50	9.68
.717	.659	91.91	.058	1.18	1.227	1.225	4.00	3.80
.617	.525	85.09	.092	1.19	1.168	1.231	-1.84	3.46
.485	.344	70.93	.141	1.21	.972	1.253	-19.68	3.51
.562	.448	79.72	.114	1.27	1.109	1.264	-12.68	-.44
.848	.730	86.08	.118	1.88	1.861	1.843	-1.03	-1.99
.908	.809	89.10	.099	1.88	1.919	1.909	2.08	1.53
.733	.216	29.41	.517	2.00	1.909	1.990	-4.56	-.52
.737	.280	37.97	.458	2.00	1.927	2.003	-3.66	.13
.759	.516	68.01	.243	2.00	1.970	2.065	-1.48	3.31
.784	.627	79.97	.157	2.01	1.839	1.812	-8.51	-9.85
.801	.563	70.24	.238	2.06	2.107	2.157	2.28	4.70
.835	.670	80.28	.165	2.06	2.016	1.986	-2.12	-3.60
1.039	.941	90.58	.098	2.06	2.260	2.249	9.69	9.17
1.232	1.136	92.23	.096	2.97	2.778	2.759	-6.47	-7.10
1.041	.706	67.83	.335	3.14	3.198	3.191	1.84	1.62
1.011	.476	47.06	.535	3.15	3.124	3.065	-.82	-2.67
1.162	1.000	86.06	.162	3.15	3.015	2.978	-4.29	-5.47
1.341	1.221	90.99	.121	3.15	3.297	3.275	4.67	3.98
1.285	1.024	79.66	.262	3.97	3.936	3.863	-.85	-2.69
1.256	.818	65.13	.438	4.02	4.324	4.262	7.56	6.03
1.438	1.277	88.80	.161	4.02	3.909	3.872	-2.76	-3.69
1.595	1.472	92.32	.123	4.07	4.113	4.076	1.05	.15
1.203	.626	52.04	.577	4.10	4.073	3.992	-.65	-2.64
1.349	.752	55.76	.597	4.77	4.856	4.755	1.81	-.32
1.413	1.026	72.61	.387	4.77	4.922	4.851	3.18	1.71
1.641	1.477	90.01	.164	4.85	4.626	4.584	-4.63	-5.48
1.732	1.588	91.67	.144	4.85	4.769	4.815	-1.66	-.71
1.864	1.698	91.09	.166	5.85	5.437	5.726	-7.06	-2.13
2.051	1.932	94.20	.119	5.85	5.644	6.042	-3.51	3.28
1.532	.870	56.80	.662	5.86	5.899	5.891	.67	.52
1.545	.944	61.13	.600	5.86	5.973	5.990	1.93	2.22
1.556	1.030	66.18	.526	5.86	5.968	6.078	1.84	3.72
1.677	1.379	82.23	.298	5.86	5.684	5.799	-3.00	-1.04

Table 10. Continued.

H_a ft	H_b ft	H_b/H_a %	H_a-H_b ft	Q cfs	Q_{st} cfs	Q_n cfs	$(Q_{st}-Q)/Q$ %	$(Q_n-Q)/Q$ %
1.685	.993	58.92	.692	7.02	5.823	7.161	-2.81	2.01
1.708	1.105	64.71	.603	7.03	6.934	7.361	-1.36	4.71
2.161	1.988	91.99	.173	7.04	6.618	7.488	-5.99	5.36
1.800	1.403	77.94	.397	7.06	6.741	7.210	-4.52	2.13
1.991	1.783	89.55	.208	7.06	6.299	6.914	-10.77	-2.07
2.347	2.186	93.15	.161	7.98	7.211	8.424	-9.64	5.56
2.009	1.702	84.72	.307	7.99	7.163	7.994	-10.35	.05
1.812	1.173	64.74	.639	8.00	7.590	8.312	-5.13	3.89
1.791	1.089	60.79	.703	8.02	7.491	8.119	-6.59	1.24
1.869	1.149	61.49	.720	8.90	7.996	8.863	-10.16	-.42
2.338	2.127	90.98	.211	8.92	7.720	9.163	-13.45	2.72
1.920	1.345	70.05	.575	8.96	8.031	9.112	-10.37	1.70
1.988	1.559	78.44	.429	8.96	7.794	8.770	-13.01	-2.12
1.956	1.273	65.10	.683	9.76	8.517	9.726	-12.74	-.35
1.980	1.370	69.19	.610	9.80	8.470	9.799	-13.58	-.01
2.042	1.571	76.94	.471	9.80	8.275	9.487	-15.56	-3.24
2.067	1.640	79.37	.426	9.80	8.174	9.367	-16.60	-4.42
2.336	2.084	89.19	.252	9.80	8.128	9.715	-17.06	-.87
1.946	1.202	61.76	.744	9.85	8.504	9.627	-13.66	-2.26
2.078	1.282	61.69	.796	11.10	9.400	11.014	-15.31	-.78
2.145	1.317	61.40	.828	11.90	9.858	11.756	-17.08	-1.21
2.163	1.329	61.44	.834	12.30	9.995	11.959	-18.74	-2.77
2.232	-	-	-	13.40	10.487	12.757	-21.74	-4.80

Table 11. Test and computed data on the 18-inch Parshall flume with 0.0035 slope of the incoming pipe.

H_a ft	H_b ft	H_b/H_a %	H_a-H_b ft	Q cfs	Q_{st} cfs	Q_n cfs	$(Q_{st}-Q)/Q$ %	$(Q_n-Q)/Q$ %
.208	-	-	-	.99	.535	.955	-46.06	-3.64
.207	.147	71.01	.060	.99	.503	.950	-49.27	-4.16
.207	.181	87.44	.026	.99	.416	.958	-58.05	-3.31
.207	.189	91.30	.018	.99	.381	.966	-61.60	-2.57
.207	.198	95.65	.009	.99	.340	.980	-65.67	-1.14
.406	.309	76.11	.097	1.74	1.367	2.012	-21.41	15.61
.427	-	-	-	1.88	1.618	2.128	-13.93	13.19
.431	.391	90.72	.040	1.88	1.195	2.183	-36.43	16.11
.427	.296	69.32	.131	2.06	1.547	2.128	-24.88	3.30
.430	.316	73.49	.114	2.06	1.525	2.145	-25.96	4.10
.433	.327	75.52	.106	2.06	1.518	2.161	-26.33	4.91
.428	.336	78.50	.092	2.06	1.450	2.133	-29.63	3.56
.552	.385	69.75	.167	2.86	2.293	2.833	-19.83	-.96
.552	.439	79.53	.113	2.86	2.121	2.833	-25.83	-.96
.555	.495	89.19	.060	2.86	1.830	2.884	-36.03	.83
.548	-	-	-	2.90	2.376	2.810	-18.06	-3.12
.535	-	-	-	2.97	2.290	2.736	-22.90	-7.90
.873	.700	80.18	.173	4.76	4.265	4.720	-10.39	-.84
.871	.613	70.38	.258	4.78	4.613	4.708	-3.50	-1.51
.854	-	-	-	4.79	4.705	4.606	-1.77	-3.85
.936	.845	90.28	.091	4.79	3.989	5.173	-15.73	8.01
1.118	.739	66.10	.379	6.38	6.909	6.384	8.30	.06
1.143	.888	77.69	.255	6.45	6.634	6.548	2.86	1.52
1.113	.264	23.72	.849	6.51	7.075	6.331	8.69	-2.75
1.279	1.110	86.79	.169	6.55	6.955	7.278	6.19	11.12
1.122	.803	71.57	.319	6.70	6.766	6.425	.98	-4.09
1.292	.872	67.49	.420	8.56	8.586	8.344	.31	-2.53
1.323	1.042	78.76	.281	8.69	8.220	8.456	-5.41	-2.69
1.564	1.422	90.92	.142	8.85	8.654	9.179	-2.21	3.71
1.298	.477	36.75	.821	8.86	8.966	8.416	1.20	-5.01
1.474	.698	47.35	.776	10.30	10.905	10.649	5.88	3.39
1.490	1.052	70.60	.438	10.35	10.531	10.864	1.75	4.97
1.525	1.213	79.57	.311	10.35	10.138	10.867	-2.05	5.00
1.630	1.474	90.43	.155	10.35	9.337	9.765	-9.79	-5.65
1.585	.836	52.74	.749	12.19	12.195	12.181	.04	-.08
1.618	1.150	71.08	.468	12.19	11.924	12.654	-2.18	3.81
1.658	1.319	79.55	.339	12.19	11.537	12.694	-5.36	4.13
1.785	1.616	90.53	.169	12.19	10.712	11.515	-12.13	-5.54
1.732	.990	57.16	.742	14.26	13.980	14.354	-1.96	.66
2.428	2.301	94.77	.127	14.26	15.353	16.992	7.67	19.16
1.848	1.547	83.71	.301	14.50	12.914	14.481	-10.94	-.13
1.943	1.747	89.91	.196	14.50	12.391	13.735	-14.54	-5.28
1.756	1.200	68.34	.556	14.67	13.721	14.724	-6.47	.37
1.783	-	-	-	15.10	14.626	15.154	-3.14	.36
2.020	1.823	90.23	.197	15.30	13.062	14.625	-14.63	-4.41
1.806	1.262	69.88	.544	15.40	14.219	15.510	-7.67	.71
1.861	1.496	80.39	.365	15.40	13.650	15.522	-11.36	.79
2.014	-	-	-	20.00	17.636	18.977	-11.82	-5.11

Table 12. Test and computed data on the 18-inch Parshall flume with 0.0080 slope of the incoming pipe.

H_a ft	H_b ft	H_b/H_a %	H_a-H_b ft	Q cfs	Q_{st} cfs	Q_n cfs	$(Q_{st}-Q)/Q$ %	$(Q_n-Q)/Q$ %
.191	-	-	-	1.04	.469	1.010	-55.14	-3.38
.188	.123	65.43	.065	1.04	.445	.932	-57.44	-5.10
.191	.140	73.30	.051	1.04	.438	1.010	-58.12	-3.38
.190	.157	82.63	.033	1.04	.395	1.004	-62.21	-3.96
.191	.174	91.10	.017	1.04	.338	1.008	-67.66	-3.51
.330	.251	76.06	.079	1.80	.994	1.876	-44.77	4.22
.337	.164	48.66	.173	1.81	1.124	1.921	-37.91	6.14
.323	.313	96.90	.010	1.81	.680	1.813	-62.41	.18
.335	.278	82.99	.057	1.82	.941	1.908	-48.30	4.85
.341	-	-	-	1.84	1.144	1.947	-37.80	5.81
.484	.381	78.72	.103	2.84	1.748	2.895	-38.45	1.94
.480	.404	84.17	.076	2.84	1.608	2.868	-43.36	.99
.490	.428	87.35	.062	2.86	1.570	2.936	-45.10	2.65
.487	.328	67.35	.159	2.90	1.912	2.916	-34.07	.54
.488	.440	90.16	.048	2.90	1.467	2.921	-49.42	.72
.479	.339	70.77	.140	2.94	1.833	2.861	-37.66	-2.67
.788	.033	4.19	.755	5.05	4.157	5.029	-17.68	-.41
1.072	.871	81.25	.201	6.96	5.776	7.128	-17.01	2.41
1.026	.294	28.65	.732	7.03	6.242	6.782	-11.21	-3.52
1.369	1.239	90.50	.130	7.11	7.124	9.396	.19	32.16
1.045	.729	69.76	.316	7.16	6.127	6.925	-14.43	-3.28
1.105	.924	83.62	.181	7.31	5.858	7.377	-19.87	.92
1.369	-	-	-	9.70	9.732	9.404	.32	-3.06
1.402	.978	69.76	.424	9.70	9.633	9.661	-.70	-.41
1.435	1.147	79.93	.288	9.70	9.196	9.919	-5.20	2.25
1.531	1.371	89.55	.160	9.70	8.658	10.674	-10.75	10.03
1.569	1.105	70.43	.464	11.24	11.415	11.808	1.56	5.05
1.576	1.233	78.24	.343	11.29	10.821	11.533	-4.15	2.15
1.815	1.657	91.29	.158	11.38	10.779	12.925	-5.28	13.57
1.653	1.405	85.00	.248	11.47	10.657	11.643	-7.09	1.51
1.525	.790	51.80	.735	11.51	11.492	11.184	-.16	-2.84
1.818	1.252	68.87	.566	15.00	14.438	15.644	-3.74	4.30
1.867	1.491	79.86	.376	15.00	13.803	15.618	-7.98	4.12
1.881	1.568	83.36	.313	15.00	13.341	15.067	-11.06	.45
1.998	1.771	88.64	.227	15.00	13.315	15.293	-11.23	1.95
2.183	2.030	92.99	.153	15.00	13.679	15.950	-8.81	6.34
1.780	1.041	58.48	.739	15.10	14.581	15.026	-3.43	-.49
2.013	1.335	66.32	.678	20.00	17.077	19.005	-14.62	-4.97
2.102	1.706	81.16	.396	20.00	16.311	19.246	-18.44	-3.77
2.163	1.862	86.08	.301	20.00	15.825	18.771	-20.87	-6.15
2.443	2.271	92.96	.172	20.00	16.282	19.798	-18.59	-1.01

Table 13. Free flow calibration tables for 9-inch and 18-inch Parshall flumes.

H_a	9 inches Throat Width				18 inches Throat Width	
	Slope				Slope	
feet	0.0035	0.0045	0.0060	0.0080	0.0035	0.0080
	Q in cfs				Q in cfs	
.10	.105	.140	.182	.239	.422	.485
.11	.120	.159	.202	.265	.470	.540
.12	.137	.177	.223	.291	.517	.596
.13	.153	.197	.245	.316	.566	.653
.14	.171	.216	.266	.342	.614	.710
.15	.189	.236	.288	.368	.663	.768
.16	.207	.257	.310	.395	.713	.826
.17	.226	.278	.332	.421	.763	.885
.18	.246	.299	.354	.447	.813	.944
.19	.266	.320	.376	.474	.863	1.004
.20	.286	.342	.399	.500	.914	1.064
.21	.307	.364	.421	.527	.965	1.124
.22	.329	.387	.444	.554	1.017	1.185
.23	.351	.410	.467	.580	1.068	1.246
.24	.373	.433	.490	.607	1.120	1.308
.25	.396	.456	.513	.634	1.172	1.370
.26	.419	.479	.537	.661	1.224	1.432
.27	.443	.503	.560	.688	1.277	1.494
.28	.467	.527	.584	.715	1.330	1.557
.29	.491	.552	.608	.742	1.383	1.621
.30	.516	.576	.631	.770	1.436	1.684
.31	.541	.601	.655	.797	1.489	1.748
.32	.567	.626	.679	.824	1.543	1.812
.33	.592	.652	.703	.852	1.597	1.876
.34	.619	.677	.728	.879	1.651	1.941
.35	.645	.703	.752	.907	1.705	2.005
.36	.672	.729	.776	.934	1.759	2.070
.37	.699	.755	.801	.962	1.814	2.136
.38	.727	.781	.825	.990	1.869	2.201
.39	.755	.808	.850	1.017	1.924	2.267
.40	.783	.834	.875	1.045	1.979	2.333
.41	.812	.861	.900	1.073	2.034	2.399
.42	.841	.888	.925	1.101	2.089	2.465
.43	.870	.916	.950	1.129	2.145	2.532
.44	.899	.943	.975	1.157	2.200	2.599
.45	.929	.971	1.000	1.184	2.256	2.666
.46	.959	.999	1.025	1.212	2.312	2.733
.47	.990	1.027	1.050	1.241	2.368	2.801
.48	1.020	1.055	1.076	1.269	2.424	2.868
.49	1.051	1.083	1.101	1.297	2.480	2.936
.50	1.083	1.112	1.127	1.325	2.537	3.004
.51	1.114	1.140	1.152	1.353	2.593	3.072
.52	1.146	1.169	1.178	1.381	2.650	3.140
.53	1.178	1.198	1.204	1.410	2.707	3.209
.54	1.211	1.227	1.230	1.438	2.764	3.278
.55	1.243	1.257	1.255	1.466	2.821	3.346
.56	1.276	1.286	1.281	1.494	2.878	3.415
.57	1.309	1.316	1.307	1.523	2.936	3.485

Table 13. Continued.

H_a	9 inches Throat Width				18 inches Throat Width	
	Slope				Slope	
feet	0.0035	0.0045	0.0060	0.0080	0.0035	0.0080
	Q in cfs				Q in cfs	
.58	1.347	1.346	1.333	1.551	2.993	3.554
.59	1.377	1.375	1.359	1.580	3.051	3.624
.60	1.411	1.405	1.386	1.608	3.108	3.693
.61	1.445	1.436	1.421	1.637	3.166	3.763
.62	1.479	1.466	1.457	1.665	3.224	3.833
.63	1.514	1.502	1.493	1.694	3.282	3.903
.64	1.549	1.538	1.529	1.722	3.340	3.973
.65	1.584	1.575	1.566	1.751	3.398	4.044
.66	1.620	1.613	1.604	1.780	3.456	4.114
.67	1.655	1.651	1.641	1.808	3.515	4.185
.68	1.691	1.689	1.679	1.837	3.573	4.255
.69	1.728	1.727	1.717	1.866	3.632	4.327
.70	1.764	1.766	1.755	1.895	3.691	4.398
.71	1.801	1.805	1.794	1.923	3.749	4.469
.72	1.838	1.844	1.833	1.952	3.808	4.541
.73	1.875	1.883	1.872	1.981	3.867	4.612
.74	1.912	1.923	1.912	2.010	3.926	4.684
.75	1.950	1.963	1.952	2.039	3.985	4.756
.76	1.988	2.004	1.992	2.068	4.045	4.827
.77	2.026	2.044	2.032	2.097	4.104	4.899
.78	2.064	2.085	2.073	2.126	4.163	4.972
.79	2.103	2.127	2.114	2.154	4.223	5.044
.80	2.141	2.168	2.155	2.183	4.282	5.116
.81	2.180	2.210	2.197	2.213	4.342	5.189
.82	2.222	2.252	2.239	2.242	4.402	5.261
.83	2.265	2.295	2.281	2.271	4.462	5.334
.84	2.307	2.337	2.323	2.311	4.522	5.407
.85	2.350	2.380	2.366	2.353	4.582	5.480
.86	2.394	2.423	2.409	2.395	4.642	5.553
.87	2.437	2.467	2.452	2.438	4.702	5.626
.88	2.481	2.511	2.495	2.480	4.762	5.700
.89	2.525	2.555	2.539	2.523	4.822	5.773
.90	2.569	2.599	2.583	2.567	4.883	5.847
.91	2.614	2.643	2.627	2.610	4.943	5.920
.92	2.659	2.688	2.672	2.654	5.004	5.994
.93	2.704	2.733	2.716	2.698	5.065	6.068
.94	2.750	2.779	2.761	2.742	5.125	6.142
.95	2.795	2.824	2.807	2.787	5.186	6.216
.96	2.841	2.870	2.852	2.831	5.247	6.290
.97	2.888	2.915	2.898	2.877	5.308	6.365
.98	2.934	2.963	2.944	2.922	5.369	6.439
.99	2.981	3.009	2.990	2.957	5.430	6.513
1.00	3.028	3.056	3.037	3.013	5.491	6.588
1.01	3.075	3.103	3.084	3.059	5.552	6.663
1.02	3.123	3.151	3.131	3.105	5.613	6.737
1.03	3.171	3.198	3.178	3.152	5.675	6.812
1.04	3.219	3.246	3.226	3.198	5.736	6.887
1.05	3.267	3.294	3.274	3.245	5.798	6.962

Table 13. Continued.

H_a feet	9 inches Throat Width, Slope 0.0035	0.0045	0.0060	0.0080	18 inches Throat Width, Slope 0.0035	0.0080
	Q in cfs				Q in cfs	
1.06	3.316	3.343	3.322	3.292	5.859	7.038
1.07	3.365	3.391	3.370	3.340	5.921	7.113
1.08	3.414	3.440	3.418	3.387	5.988	7.188
1.09	3.463	3.489	3.467	3.435	6.091	7.264
1.10	3.513	3.538	3.516	3.483	6.195	7.339
1.11	3.563	3.588	3.565	3.532	6.300	7.415
1.12	3.613	3.638	3.615	3.580	6.405	7.491
1.13	3.664	3.688	3.665	3.629	6.511	7.566
1.14	3.714	3.738	3.715	3.678	6.618	7.642
1.15	3.765	3.789	3.765	3.727	6.726	7.718
1.16	3.816	3.840	3.815	3.777	6.835	7.794
1.17	3.868	3.891	3.866	3.826	6.944	7.871
1.18	3.919	3.942	3.917	3.876	7.055	7.947
1.19	3.971	3.993	3.968	3.926	7.166	8.023
1.20	4.023	4.045	4.019	3.977	7.278	8.100
1.21	4.076	4.097	4.071	4.027	7.390	8.176
1.22	4.128	4.149	4.123	4.078	7.504	8.253
1.23	4.181	4.202	4.175	4.129	7.618	8.329
1.24	4.234	4.254	4.227	4.180	7.733	8.406
1.25	4.288	4.307	4.280	4.232	7.849	8.483
1.26	4.341	4.360	4.332	4.283	7.965	8.560
1.27	4.395	4.414	4.385	4.335	8.083	8.637
1.28	4.449	4.467	4.438	4.387	8.201	8.714
1.29	4.504	4.521	4.492	4.439	8.320	8.791
1.30	4.558	4.575	4.545	4.492	8.440	8.869
1.31	4.613	4.629	4.599	4.544	8.560	8.946
1.32	4.668	4.684	4.653	4.597	8.682	9.023
1.33	4.723	4.738	4.708	4.651	8.804	9.101
1.34	4.779	4.793	4.762	4.704	8.927	9.178
1.35	4.834	4.848	4.817	4.757	9.050	9.256
1.36	4.890	4.904	4.872	4.811	9.175	9.334
1.37	4.947	4.959	4.927	4.865	9.300	9.411
1.38	5.003	5.015	4.982	4.919	9.426	9.489
1.39	5.060	5.071	5.038	4.974	9.553	9.567
1.40	5.116	5.127	5.094	5.028	9.681	9.645
1.41	5.174	5.184	5.150	5.083	9.809	9.723
1.42	5.231	5.240	5.206	5.138	9.938	9.802
1.43	5.288	5.297	5.263	5.193	10.068	9.881
1.44	5.346	5.354	5.319	5.248	10.199	10.023
1.45	5.404	5.412	5.376	5.304	10.330	10.157
1.46	5.462	5.469	5.433	5.360	10.462	10.291
1.47	5.521	5.527	5.490	5.416	10.596	10.426
1.48	5.579	5.585	5.548	5.483	10.729	10.562
1.49	5.638	5.643	5.606	5.560	10.864	10.698
1.50	5.697	5.701	5.664	5.637	10.999	10.836
1.51	5.757	5.760	5.722	5.714	11.135	10.974
1.52	5.816	5.819	5.780	5.792	11.272	11.114
1.53	5.876	5.878	5.839	5.871	11.410	11.254

Table 13. Continued.

H_a feet	9 inches Throat Width, Slope 0.0035	0.0045	0.0060	0.0080	18 inches Throat Width, Slope 0.0035	0.0080
	Q in cfs				Q in cfs	
1.54	5.936	5.937	5.897	5.956	11.548	11.395
1.55	5.996	5.996	5.956	6.036	11.688	11.536
1.56	6.057	6.056	6.016	6.116	11.827	11.679
1.57	6.117	6.116	6.075	6.191	11.968	11.822
1.58	6.178	6.176	6.135	6.272	12.110	11.967
1.58	6.249	6.236	6.194	6.354	12.252	12.112
1.60	6.330	6.296	6.254	6.436	12.395	12.258
1.61	6.412	6.357	6.314	6.519	12.539	12.404
1.62	6.494	6.418	6.375	6.603	12.683	12.552
1.63	6.577	6.479	6.435	6.687	12.829	12.700
1.64	6.661	6.558	6.496	6.771	12.975	12.850
1.65	6.745	6.641	6.557	6.856	13.121	13.000
1.66	6.829	6.723	6.618	6.942	13.269	13.150
1.67	6.914	6.806	6.680	7.028	13.417	13.302
1.68	7.000	6.890	6.741	7.115	13.565	13.455
1.69	7.086	6.975	6.813	7.202	13.716	13.608
1.70	7.172	7.059	6.896	7.290	13.867	13.762
1.71	7.259	7.145	6.979	7.379	14.018	13.917
1.72	7.347	7.231	7.063	7.468	14.170	14.073
1.73	7.435	7.317	7.147	7.557	14.323	14.230
1.74	7.524	7.404	7.232	7.647	14.477	14.387
1.75	7.614	7.491	7.317	7.738	14.631	14.546
1.76	7.704	7.579	7.403	7.829	14.786	14.705
1.77	7.794	7.668	7.490	7.920	14.942	14.865
1.78	7.885	7.757	7.577	8.013	15.099	15.026
1.79	7.976	7.846	7.664	8.105	15.256	15.167
1.80	8.069	7.937	7.752	8.199	15.414	15.350
1.81	8.161	8.027	7.840	8.293	15.573	15.513
1.82	8.254	8.118	7.929	8.387	15.733	15.677
1.83	8.348	8.210	8.019	8.482	15.893	15.842
1.84	8.442	8.302	8.109	8.578	16.054	16.008
1.85	8.537	8.395	8.193	8.674	16.215	16.175
1.86	8.632	8.488	8.290	8.770	16.379	16.342
1.87	8.729	8.582	8.382	8.867	16.542	16.510
1.88	8.825	8.676	8.474	8.965	16.705	16.679
1.89	8.922	8.771	8.566	9.063	16.871	16.849
1.90	9.019	8.866	8.660	9.152	17.037	17.020
1.91	9.117	8.962	8.753	9.262	17.203	17.191
1.92	9.216	9.059	8.847	9.362	17.370	17.364
1.93	9.315	9.156	8.942	9.462	17.538	17.537
1.94	9.415	9.253	9.037	9.563	17.707	17.711
1.95	9.515	9.351	9.133	9.665	17.876	17.886
1.96	9.616	9.450	9.229	9.767	18.045	18.061
1.97	9.717	9.549	9.326	9.869	18.217	18.238
1.98	9.819	9.648	9.423	9.973	18.388	18.415
1.99	9.921	9.748	9.521	10.076	18.561	18.593
2.00	10.024	9.849	9.619	10.181	18.734	18.772

Table 14. Submerged flow calibration tables for 9-inch Parshall flume with 0.0035 slope of the incoming pipe.

H_a-H_b	Submergence						
feet	65.6%	70%	75%	80%	85%	90%	95%
.02	-	.059	.072	.092	.127	.199	.429
.03	-	.106	.129	.166	.228	.358	.809
.04	-	.161	.197	.252	.346	.543	1.267
.05	-	.222	.272	.348	.479	.751	1.795
.06	-	.289	.354	.453	.624	.981	2.385
.07	-	.362	.443	.567	.780	1.247	3.032
.08	-	.439	.537	.688	.947	1.536	3.734
.09	-	.521	.637	.817	1.124	1.845	4.487
.10	-	.607	.743	.951	1.309	2.175	5.461
.11	-	.697	.853	1.092	1.503	2.523	6.646
.12	-	.790	.968	1.240	1.718	2.889	7.951
.13	-	.888	1.087	1.392	1.947	3.273	9.376
.14	-	.988	1.210	1.550	2.185	3.674	10.922
.15	-	1.092	1.338	1.713	2.433	4.092	12.590
.16	-	1.200	1.469	1.882	2.691	4.525	14.380
.17	-	1.310	1.604	2.055	2.957	4.973	-
.18	-	1.423	1.743	2.236	3.233	5.468	-
.19	-	1.539	1.885	2.432	3.517	6.112	-
.20	-	1.658	2.030	2.635	3.810	6.794	-
.21	-	1.780	2.179	2.843	4.111	7.512	-
.22	-	1.904	2.332	3.057	4.420	8.268	-
.23	-	2.031	2.487	3.276	4.738	9.060	-
.24	-	2.161	2.645	3.501	5.063	9.891	-
.25	-	2.292	2.807	3.731	5.395	10.758	-
.26	-	2.427	2.980	3.966	5.748	11.664	-
.27	-	2.563	3.160	4.207	6.213	12.606	-
.28	-	2.702	3.344	4.452	6.697	13.587	-
.29	-	2.843	3.533	4.702	7.199	14.606	-
.30	-	2.987	3.724	4.958	7.719	-	-
.31	-	3.132	3.920	5.218	8.259	-	-
.32	-	3.280	4.119	5.482	8.817	-	-
.33	-	3.430	4.321	5.752	9.394	-	-
.34	-	3.563	4.527	6.047	9.990	-	-
.35	-	3.749	4.736	6.419	10.604	-	-
.36	-	3.917	4.949	6.803	11.238	-	-
.37	-	4.088	5.165	7.198	11.891	-	-
.38	-	4.262	5.384	7.604	12.562	-	-
.39	-	4.438	5.606	8.022	13.253	-	-
.40	-	4.616	5.832	8.451	13.962	-	-
.41	-	4.798	6.061	8.892	14.691	-	-
.42	-	4.981	6.331	9.345	-	-	-
.43	-	5.167	6.645	9.809	-	-	-
.44	-	5.356	6.968	10.285	-	-	-
.45	-	5.547	7.298	10.772	-	-	-
.46	-	5.740	7.636	11.271	-	-	-
.47	-	5.936	7.982	11.782	-	-	-

Table 14. Continued.

H_a-H_b	Submergence						
feet	65.6%	70%	75%	80%	85%	90%	95%
.48	-	6.134	8.336	12.304	-	-	-
.49	-	6.335	8.697	12.838	-	-	-
.50	-	6.596	9.067	13.383	-	-	-
.51	-	6.871	9.444	13.941	-	-	-
.52	-	7.151	9.830	14.510	-	-	-
.53	-	7.437	10.223	-	-	-	-
.54	-	7.729	10.625	-	-	-	-
.55	-	8.027	11.034	-	-	-	-
.56	6.561	8.331	11.451	-	-	-	-
.57	6.804	8.640	11.876	-	-	-	-
.58	7.053	8.955	12.310	-	-	-	-
.59	7.305	9.276	12.751	-	-	-	-
.60	7.563	9.603	13.200	-	-	-	-
.61	7.825	9.935	13.657	-	-	-	-
.62	8.091	10.274	14.122	-	-	-	-
.63	8.362	10.618	14.596	-	-	-	-
.64	8.638	10.968	-	-	-	-	-
.65	8.919	11.324	-	-	-	-	-
.66	9.203	11.686	-	-	-	-	-
.67	9.493	12.054	-	-	-	-	-
.68	9.787	12.427	-	-	-	-	-
.69	10.086	12.807	-	-	-	-	-
.70	10.389	13.192	-	-	-	-	-
.71	10.698	13.583	-	-	-	-	-
.72	11.010	13.980	-	-	-	-	-
.73	11.328	14.383	-	-	-	-	-
.74	11.650	14.792	-	-	-	-	-
.75	11.976	-	-	-	-	-	-
.76	12.307	-	-	-	-	-	-
.77	12.643	-	-	-	-	-	-
.78	12.984	-	-	-	-	-	-
.79	13.329	-	-	-	-	-	-
.80	13.679	-	-	-	-	-	-
.81	14.034	-	-	-	-	-	-
.82	14.393	-	-	-	-	-	-
.83	14.757	-	-	-	-	-	-
.84	-	-	-	-	-	-	-

Table 15. Submerged flow calibration tables for 9-inch Parshall flume with 0.0045 slope of the incoming pipe.

H_a-H_b feet	Submergence 66.8%	70%	75%	80%	85%	90%	95%
.02	-	.086	.103	.128	.170	.253	.500
.03	-	.145	.174	.216	.287	.427	.842
.04	-	.211	.252	.313	.415	.618	1.238
.05	-	.280	.335	.417	.553	.823	1.745
.06	-	.355	.424	.528	.699	1.041	2.310
.07	-	.432	.517	.643	.853	1.269	2.928
.08	-	.513	.614	.764	1.013	1.521	3.595
.09	-	.597	.714	.889	1.178	1.823	4.412
.10	-	.684	.818	1.018	1.349	2.144	5.475
.11	-	.773	.924	1.150	1.525	2.482	6.656
.12	-	.865	1.034	1.287	1.716	2.838	7.955
.13	-	.958	1.146	1.426	1.940	3.209	9.373
.14	-	1.054	1.261	1.569	2.175	3.597	10.910
.15	-	1.152	1.378	1.714	2.418	4.000	12.567
.16	-	1.252	1.497	1.869	2.670	4.417	14.343
.17	-	1.353	1.618	2.051	2.931	4.865	-
.18	-	1.457	1.742	2.240	3.201	5.470	-
.19	-	1.561	1.867	2.434	3.478	6.111	-
.20	-	1.668	1.997	2.634	3.764	6.788	-
.21	-	1.776	2.152	2.839	4.057	7.501	-
.22	-	1.885	2.312	3.050	4.358	8.252	-
.23	-	1.996	2.476	3.265	4.667	9.038	-
.24	-	2.109	2.643	3.486	4.982	9.862	-
.25	-	2.244	2.814	3.712	5.305	10.722	-
.26	-	2.384	2.989	3.943	5.741	11.620	-
.27	-	2.526	3.168	4.179	6.202	12.554	-
.28	-	2.672	3.350	4.419	6.682	13.525	-
.29	-	2.820	3.536	4.664	7.180	14.533	-
.30	-	2.971	3.725	4.914	7.697	-	-
.31	-	3.125	3.918	5.168	8.232	-	-
.32	-	3.281	4.114	5.427	8.785	-	-
.33	-	3.440	4.313	5.690	9.357	-	-
.34	-	3.602	4.516	6.031	9.947	-	-
.35	-	3.766	4.722	6.401	10.556	-	-
.36	-	3.933	4.931	6.781	11.183	-	-
.37	-	4.102	5.143	7.172	11.829	-	-
.38	-	4.274	5.359	7.575	12.493	-	-
.39	-	4.448	5.577	7.989	13.176	-	-
.40	-	4.624	5.798	8.415	13.878	-	-
.41	-	4.803	6.023	8.852	14.598	-	-
.42	-	4.985	6.309	9.300	-	-	-
.43	-	5.168	6.620	9.759	-	-	-
.44	-	5.354	6.940	10.230	-	-	-
.45	-	5.543	7.267	10.712	-	-	-
.46	-	5.733	7.601	11.205	-	-	-
.47	-	5.926	7.944	11.710	-	-	-

Table 15. Continued.

H_a-H_b feet	Submergence 66.8%	70%	75%	80%	85%	90%	95%
.48	-	6.121	8.294	12.226	-	-	-
.49	-	6.318	8.652	12.754	-	-	-
.50	-	6.567	9.018	13.293	-	-	-
.51	-	6.839	9.391	13.843	-	-	-
.52	-	7.117	9.772	14.405	-	-	-
.53	-	7.400	10.161	14.978	-	-	-
.54	-	7.689	10.558	-	-	-	-
.55	6.694	7.984	10.962	-	-	-	-
.56	6.945	8.284	11.375	-	-	-	-
.57	7.202	8.590	11.795	-	-	-	-
.58	7.463	8.902	12.223	-	-	-	-
.59	7.729	9.219	12.658	-	-	-	-
.60	8.000	9.542	13.102	-	-	-	-
.61	8.276	9.871	13.553	-	-	-	-
.62	8.556	10.205	14.012	-	-	-	-
.63	8.841	10.545	14.479	-	-	-	-
.64	9.131	10.891	14.954	-	-	-	-
.65	9.426	11.242	-	-	-	-	-
.66	9.725	11.600	-	-	-	-	-
.67	10.030	11.963	-	-	-	-	-
.68	10.339	12.331	-	-	-	-	-
.69	10.653	12.706	-	-	-	-	-
.70	10.971	13.086	-	-	-	-	-
.71	11.295	13.472	-	-	-	-	-
.72	11.623	13.864	-	-	-	-	-
.73	11.957	14.261	-	-	-	-	-
.74	12.295	14.664	-	-	-	-	-
.75	12.637	-	-	-	-	-	-
.76	12.985	-	-	-	-	-	-
.77	13.338	-	-	-	-	-	-
.78	13.695	-	-	-	-	-	-
.79	14.057	-	-	-	-	-	-
.80	14.424	-	-	-	-	-	-
.81	14.796	-	-	-	-	-	-
.82	-	-	-	-	-	-	-

Table 16. Submerged flow calibration tables for 9-inch Parshall flume with 0.0060 slope of the incoming pipe.

H_a-H_b	Submergence						
feet	68.8%	70%	75%	80%	85%	90%	95%
.02	-	.122	.140	.166	.206	.280	.474
.03	-	.194	.222	.263	.327	.444	.758
.04	-	.268	.308	.364	.453	.615	1.180
.05	-	.345	.397	.469	.583	.793	1.662
.06	-	.425	.488	.577	.717	.975	2.200
.07	-	.506	.581	.687	.854	1.207	2.788
.08	-	.589	.676	.800	.994	1.482	3.423
.09	-	.673	.772	.914	1.136	1.776	4.352
.10	-	.758	.870	1.030	1.280	2.088	5.413
.11	-	.845	.970	1.148	1.481	2.418	6.579
.12	-	.932	1.070	1.267	1.693	2.763	7.863
.13	-	1.021	1.172	1.387	1.915	3.125	9.263
.14	-	1.110	1.274	1.516	2.146	3.502	10.782
.15	-	1.201	1.378	1.686	2.386	3.894	12.418
.16	-	1.292	1.483	1.861	2.635	4.300	14.173
.17	-	1.384	1.588	2.043	2.892	4.827	-
.18	-	1.477	1.704	2.231	3.158	5.427	-
.19	-	1.570	1.851	2.424	3.431	6.062	-
.20	-	1.664	2.003	2.623	3.713	6.733	-
.21	-	1.759	2.159	2.827	4.002	7.441	-
.22	-	1.861	2.319	3.037	4.299	8.185	-
.23	1.900	1.992	2.483	3.251	4.603	8.965	-
.24	2.029	2.127	2.651	3.471	4.914	9.781	-
.25	2.160	2.265	2.823	3.696	5.267	10.634	-
.26	2.294	2.405	2.998	3.926	5.707	11.524	-
.27	2.431	2.549	3.177	4.160	6.166	12.450	-
.28	2.571	2.696	3.360	4.399	6.643	13.412	-
.29	2.713	2.845	3.546	4.643	7.138	14.412	-
.30	2.859	2.997	3.736	4.891	7.651	-	-
.31	3.006	3.152	3.929	5.144	8.182	-	-
.32	3.157	3.310	4.125	5.402	8.732	-	-
.33	3.310	3.470	4.325	5.663	9.300	-	-
.34	3.465	3.633	4.528	6.005	9.886	-	-
.35	3.623	3.799	4.734	6.372	10.491	-	-
.36	3.783	3.967	4.944	6.751	11.114	-	-
.37	3.946	4.137	5.157	7.140	11.755	-	-
.38	4.111	4.310	5.372	7.541	12.415	-	-
.39	4.278	4.486	5.591	7.953	13.094	-	-
.40	4.448	4.664	5.813	8.376	13.790	-	-
.41	4.620	4.844	6.038	8.811	14.506	-	-
.42	4.795	5.027	6.288	9.257	-	-	-
.43	4.971	5.212	6.598	9.714	-	-	-
.44	5.150	5.400	6.917	10.182	-	-	-
.45	5.331	5.590	7.242	10.662	-	-	-
.46	5.514	5.782	7.576	11.152	-	-	-
.47	5.699	5.976	7.917	11.655	-	-	-

Table 16. Continued.

H_a-H_b	Submergence						
feet	68.8%	70%	75%	80%	85%	90%	95%
.48	5.887	6.172	8.266	12.168	-	-	-
.49	6.076	6.371	8.622	12.693	-	-	-
.50	6.268	6.572	8.986	13.229	-	-	-
.51	6.462	6.823	9.358	13.777	-	-	-
.52	6.657	7.100	9.738	14.336	-	-	-
.53	-	7.382	10.125	14.906	-	-	-
.54	-	7.670	10.521	-	-	-	-
.55	-	7.964	10.923	-	-	-	-
.56	-	8.264	11.334	-	-	-	-
.57	-	8.569	11.752	-	-	-	-
.58	-	8.879	12.179	-	-	-	-
.59	-	9.196	12.613	-	-	-	-
.60	-	9.518	13.054	-	-	-	-
.61	-	9.845	13.504	-	-	-	-
.62	-	10.179	13.961	-	-	-	-
.63	-	10.518	14.426	-	-	-	-
.64	-	10.863	14.899	-	-	-	-
.65	-	11.213	-	-	-	-	-
.66	-	11.569	-	-	-	-	-
.67	-	11.931	-	-	-	-	-
.68	-	12.299	-	-	-	-	-
.69	-	12.672	-	-	-	-	-
.70	-	13.051	-	-	-	-	-
.71	-	13.435	-	-	-	-	-
.72	-	13.826	-	-	-	-	-
.73	-	14.222	-	-	-	-	-
.74	-	14.624	-	-	-	-	-
.75	-	-	-	-	-	-	-

Table 17. Submerged flow calibration tables for 9-inch Parshall flume with 0.0080 slope of the incoming pipe.

H_a-H_b	Submergence						
feet	67.3%	70%	75%	80%	85%	90%	95%
.02	-	.154	.173	.201	.242	.316	.497
.03	-	.237	.267	.309	.373	.486	.815
.04	-	.322	.362	.419	.506	.660	1.263
.05	-	.408	.459	.531	.641	.836	1.774
.06	-	.495	.557	.645	.779	1.015	2.342
.07	-	.583	.657	.760	.917	1.254	2.961
.08	-	.672	.757	.876	1.057	1.536	3.629
.09	-	.761	.858	.993	1.198	1.838	4.397
.10	-	.852	.959	1.110	1.340	2.157	5.460
.11	-	.942	1.062	1.229	1.509	2.494	6.641
.12	-	1.034	1.165	1.348	1.722	2.848	7.942
.13	-	1.126	1.268	1.467	1.945	3.216	9.361
.14	-	1.218	1.372	1.588	2.178	3.600	10.901
.15	-	1.310	1.476	1.708	2.419	3.999	12.562
.16	-	1.404	1.581	1.868	2.669	4.412	14.344
.17	-	1.497	1.687	2.048	2.926	4.925	-
.18	-	1.591	1.792	2.235	3.192	5.539	-
.19	-	1.685	1.898	2.426	3.466	6.189	-
.20	-	1.779	2.005	2.623	3.748	6.878	-
.21	-	1.874	2.143	2.825	4.037	7.603	-
.22	-	1.969	2.300	3.033	4.333	8.366	-
.23	-	2.064	2.461	3.245	4.636	9.166	-
.24	-	2.160	2.625	3.462	4.976	10.003	-
.25	-	2.256	2.794	3.684	5.412	10.879	-
.26	-	2.365	2.965	3.911	5.866	11.792	-
.27	-	2.505	3.141	4.142	6.339	12.743	-
.28	-	2.648	3.320	4.378	6.831	13.732	-
.29	2.510	2.793	3.502	4.618	7.342	14.759	-
.30	2.643	2.941	3.687	4.862	7.872	-	-
.31	2.778	3.092	3.876	5.131	8.420	-	-
.32	2.916	3.245	4.068	5.477	8.988	-	-
.33	3.056	3.400	4.263	5.834	9.575	-	-
.34	3.198	3.558	4.461	6.203	10.181	-	-
.35	3.342	3.719	4.662	6.584	10.806	-	-
.36	3.488	3.882	4.866	6.977	11.450	-	-
.37	3.637	4.047	5.073	7.381	12.113	-	-
.38	3.787	4.215	5.309	7.796	12.795	-	-
.39	3.940	4.384	5.600	8.224	13.497	-	-
.40	4.095	4.557	5.899	8.663	14.217	-	-
.41	4.252	4.731	6.206	9.114	14.957	-	-
.42	4.411	4.908	6.521	9.577	-	-	-
.43	4.571	5.087	6.844	10.051	-	-	-
.44	4.734	5.268	7.176	10.537	-	-	-
.45	4.899	5.490	7.515	11.036	-	-	-
.46	5.066	5.744	7.862	11.545	-	-	-
.47	5.234	6.003	8.217	12.067	-	-	-

Table 17. Continued.

H_a-H_b	Submergence						
feet	67.3%	70%	75%	80%	85%	90%	95%
.48	5.405	6.268	8.581	12.601	-	-	-
.49	-	6.540	8.952	13.146	-	-	-
.50	-	6.817	9.331	13.703	-	-	-
.51	-	7.100	9.719	14.272	-	-	-
.52	-	7.389	10.115	14.854	-	-	-
.53	-	7.684	10.518	-	-	-	-
.54	-	7.985	10.930	-	-	-	-
.55	-	8.292	11.350	-	-	-	-
.56	-	8.605	11.778	-	-	-	-
.57	-	8.924	12.215	-	-	-	-
.58	-	9.248	12.659	-	-	-	-
.59	-	9.579	13.112	-	-	-	-
.60	-	9.915	13.573	-	-	-	-
.61	-	10.258	14.042	-	-	-	-
.62	-	10.607	14.519	-	-	-	-
.63	-	10.961	-	-	-	-	-
.64	-	11.322	-	-	-	-	-
.65	-	11.688	-	-	-	-	-
.66	-	12.061	-	-	-	-	-
.67	-	12.439	-	-	-	-	-
.68	-	12.824	-	-	-	-	-
.69	-	13.214	-	-	-	-	-
.70	-	13.611	-	-	-	-	-
.71	-	14.014	-	-	-	-	-
.72	-	14.422	-	-	-	-	-
.73	-	14.837	-	-	-	-	-
.74	-	-	-	-	-	-	-

Table 18. Submerged flow calibration tables for 18-inch Parshall flume with 0.0035 slope of the incoming pipe.

H_a-H_b	Submergence				
feet	76.5%	80%	85%	90%	95%
.02	-	.422	.585	.927	2.035
.03	-	.663	.919	1.455	3.197
.04	-	.913	1.266	2.005	4.404
.05	-	1.171	1.623	2.571	5.647
.06	-	1.435	1.988	3.151	6.919
.07	-	1.703	2.361	3.741	8.215
.08	-	1.975	2.740	4.341	9.533
.09	-	2.254	3.124	4.949	10.870
.10	-	2.534	3.513	5.566	12.223
.11	-	2.818	3.906	6.189	13.964
.12	-	3.105	4.304	6.819	16.405
.13	-	3.395	4.705	7.455	19.025
.14	-	3.687	5.110	8.097	-
.15	-	3.981	5.519	8.744	-
.16	-	4.278	5.930	9.562	-
.17	-	4.577	6.344	10.697	-
.18	-	4.878	6.761	11.891	-
.19	-	5.181	7.181	13.143	-
.20	-	5.485	7.718	14.452	-
.21	-	5.792	8.447	15.818	-
.22	-	6.100	9.207	17.240	-
.23	-	6.409	9.997	18.718	-
.24	-	6.931	10.816	-	-
.25	-	7.475	11.665	-	-
.26	6.263	8.038	12.543	-	-
.27	6.716	8.619	13.451	-	-
.28	7.184	9.220	14.388	-	-
.29	7.666	9.838	15.353	-	-
.30	8.162	10.475	16.347	-	-
.31	8.673	11.131	17.370	-	-
.32	9.198	11.805	18.422	-	-
.33	9.737	12.496	19.502	-	-
.34	10.291	13.206	-	-	-
.35	10.858	13.934	-	-	-
.36	11.439	14.680	-	-	-
.37	12.034	15.444	-	-	-
.38	12.643	16.225	-	-	-
.39	13.266	17.025	-	-	-
.40	13.902	17.842	-	-	-
.41	14.552	18.676	-	-	-
.42	15.216	19.528	-	-	-
.43	15.894	-	-	-	-
.44	16.584	-	-	-	-
.45	17.289	-	-	-	-
.46	18.007	-	-	-	-
.47	18.738	-	-	-	-
.48	19.483	-	-	-	-
.49	-	-	-	-	-

Table 19. Submerged flow calibration tables for 18-inch Parshall flume with 0.0080 slope of the incoming pipe.

H_a-H_b	Submergence				
feet	75.4%	80%	85%	90%	95%
.02	-	.488	.674	1.063	2.319
.03	-	.772	1.067	1.683	3.671
.04	-	1.069	1.478	2.332	5.086
.05	-	1.377	1.903	3.003	6.549
.06	-	1.693	2.340	3.692	8.052
.07	-	2.016	2.786	4.396	9.588
.08	-	2.345	3.241	5.114	11.155
.09	-	2.680	3.704	5.845	12.747
.10	-	3.019	4.173	6.586	14.363
.11	-	3.364	4.649	7.337	16.001
.12	-	3.712	5.131	8.097	17.659
.13	-	4.065	5.618	8.865	-
.14	-	4.421	6.110	9.642	-
.15	-	4.780	6.607	10.426	-
.16	-	5.143	7.108	11.217	-
.17	-	5.508	7.614	12.014	-
.18	-	5.877	8.123	12.818	-
.19	-	6.248	8.636	13.628	-
.20	-	6.622	9.153	14.816	-
.21	-	6.999	9.673	16.264	-
.22	-	7.377	10.197	17.775	-
.23	-	7.758	10.723	19.350	-
.24	-	8.142	11.253	-	-
.25	-	8.527	11.786	-	-
.26	-	8.915	12.542	-	-
.27	-	9.304	13.479	-	-
.28	-	9.695	14.449	-	-
.29	-	10.089	15.450	-	-
.30	-	10.484	16.484	-	-
.31	-	10.927	17.549	-	-
.32	-	11.610	18.646	-	-
.33	-	12.312	19.775	-	-
.34	-	13.035	-	-	-
.35	-	13.777	-	-	-
.36	10.338	14.538	-	-	-
.37	10.894	15.320	-	-	-
.38	11.463	16.120	-	-	-
.39	12.046	16.940	-	-	-
.40	12.643	17.779	-	-	-
.41	13.253	18.638	-	-	-
.42	13.878	19.516	-	-	-
.43	14.516	-	-	-	-
.44	15.167	-	-	-	-
.45	15.832	-	-	-	-
.46	16.511	-	-	-	-
.47	17.203	-	-	-	-
.48	17.909	-	-	-	-
.49	18.629	-	-	-	-
.50	19.362	-	-	-	-
.51	-	-	-	-	-