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Calibration of Parshall Flumes with Non-Standard Entrance Transitions

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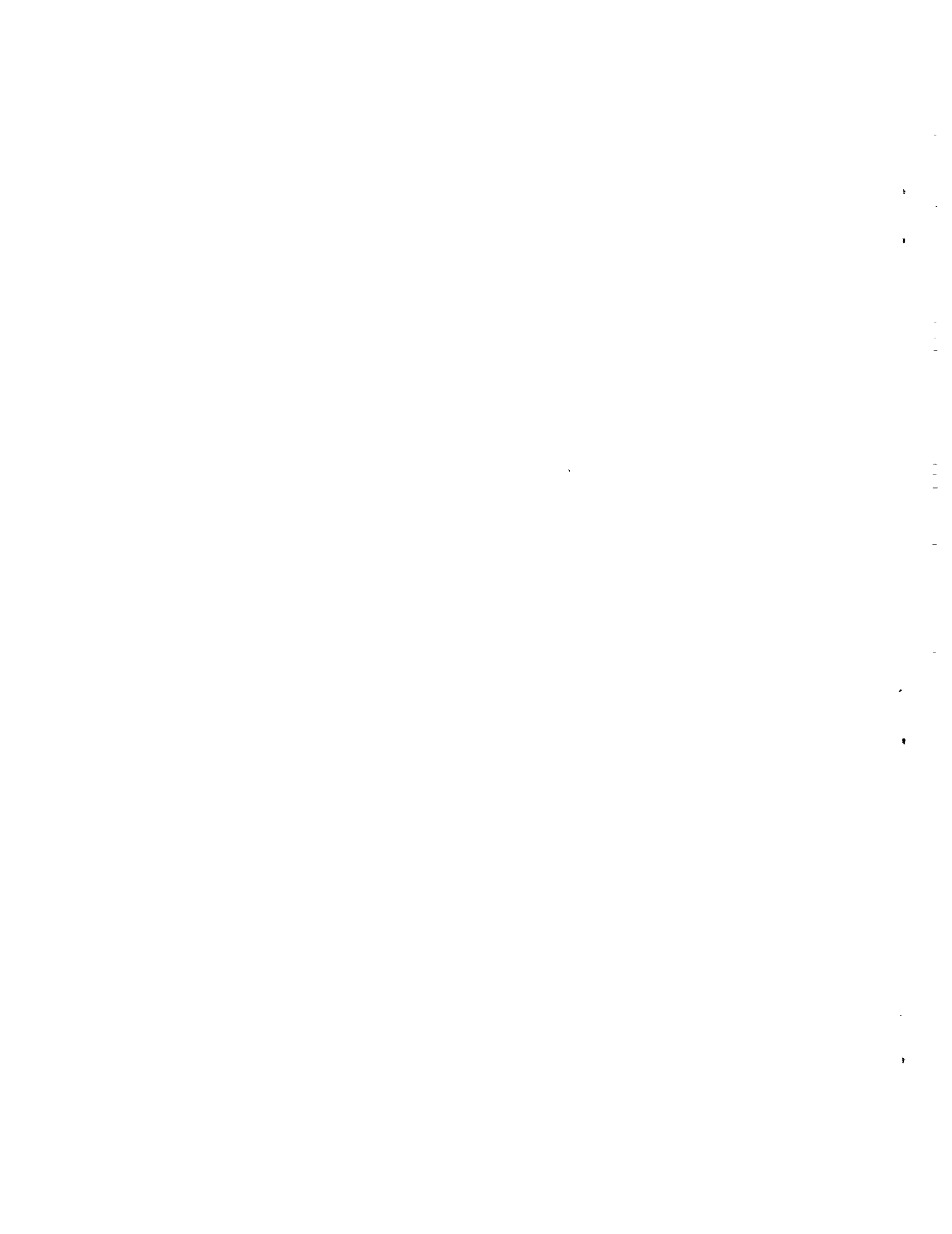
**CALIBRATION OF PARSHALL FLUMES WITH
NON-STANDARD ENTRANCE TRANSITIONS**

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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.

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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:

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.

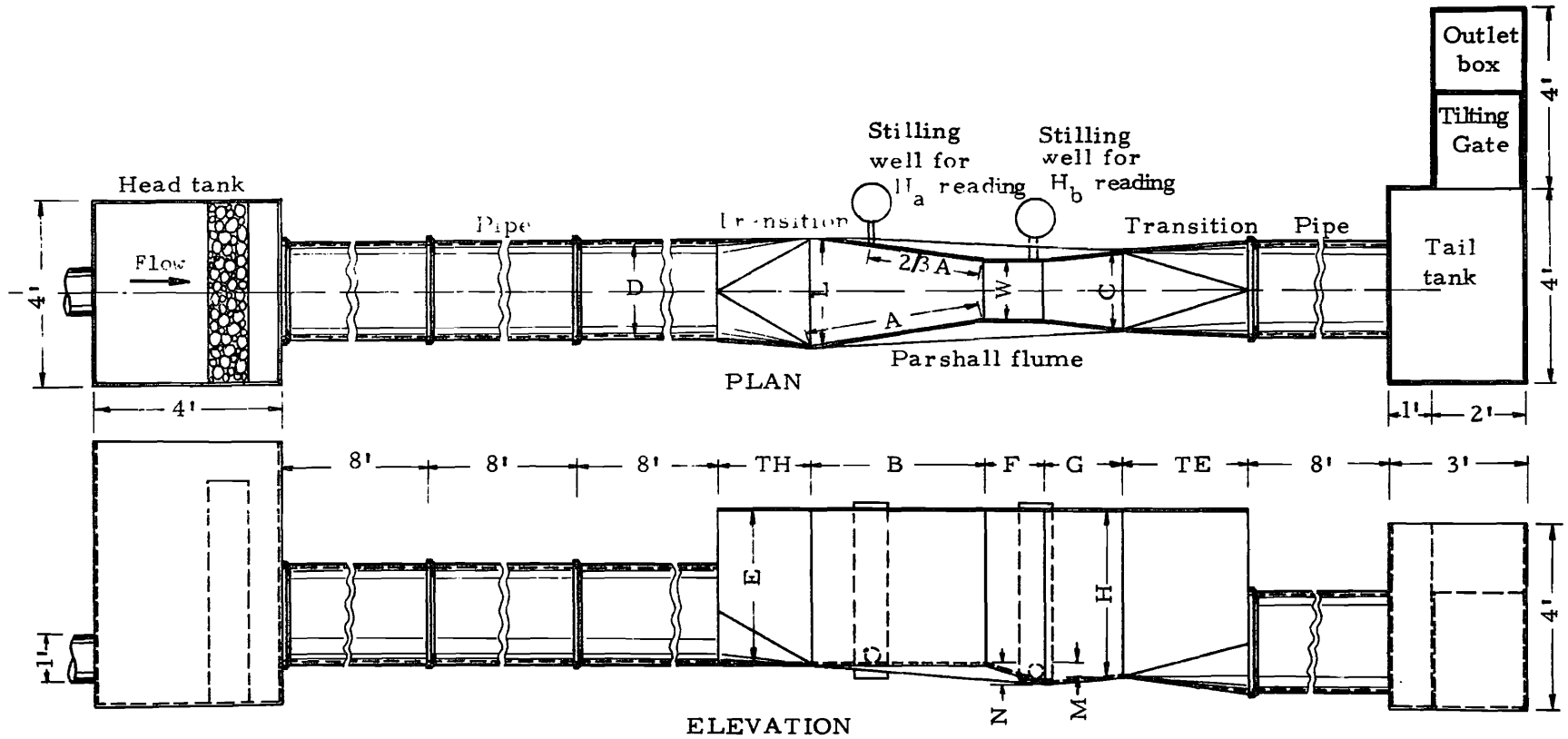
Tests on the 18-inch Parshall flume

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.

*Superscript numerals refer to the corresponding references.



| 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.

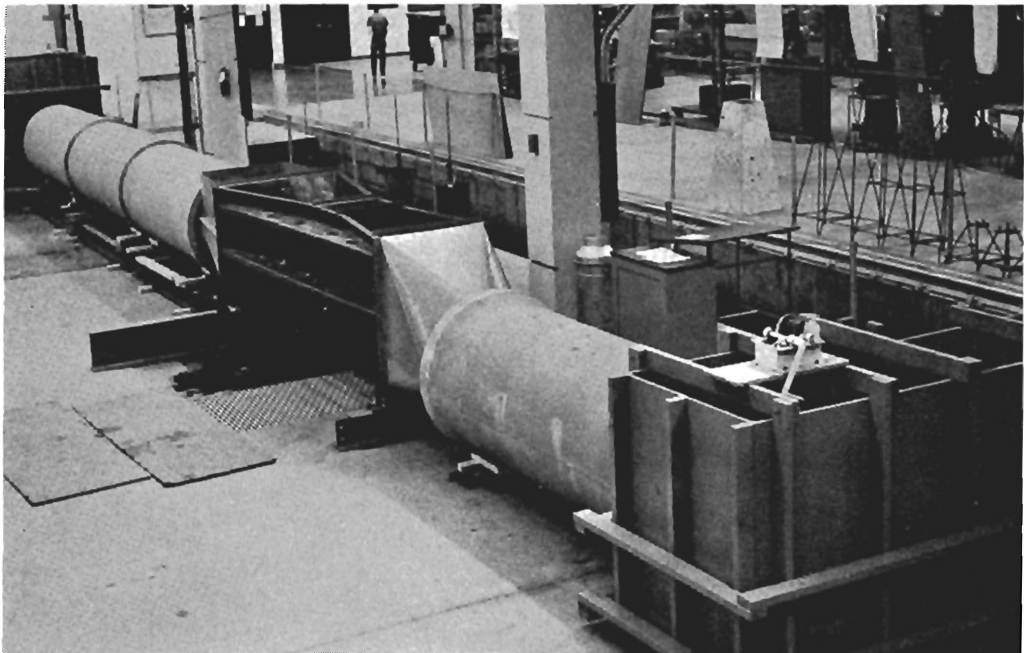


Figure 3. Oblique view of the experimental arrangement for the 18-inch Parshall flume.

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)

$$Q_{st} = 3.07 H_a^{1.53} \dots \dots \dots (1)$$

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

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

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

$$Q_{st} = 6.00 H_a^{1.54} \dots \dots \dots (3)$$

and that for submerged flow is(2)

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

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

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

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

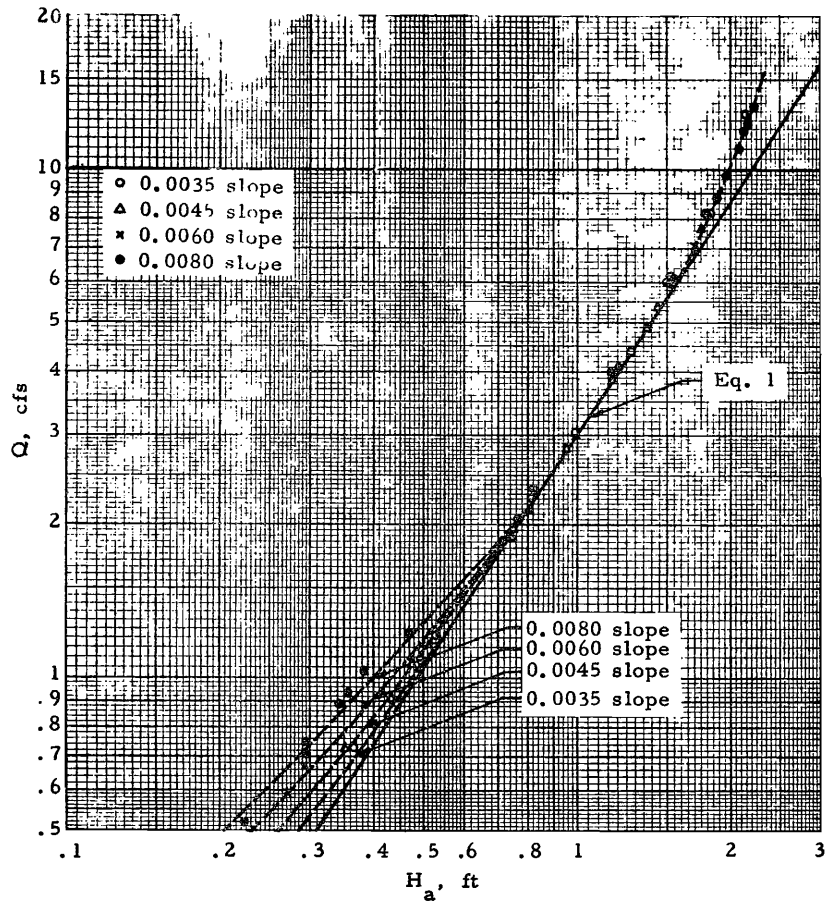


Figure 4. Diagram showing the rate of free flow through the 9-inch Parshall flume.

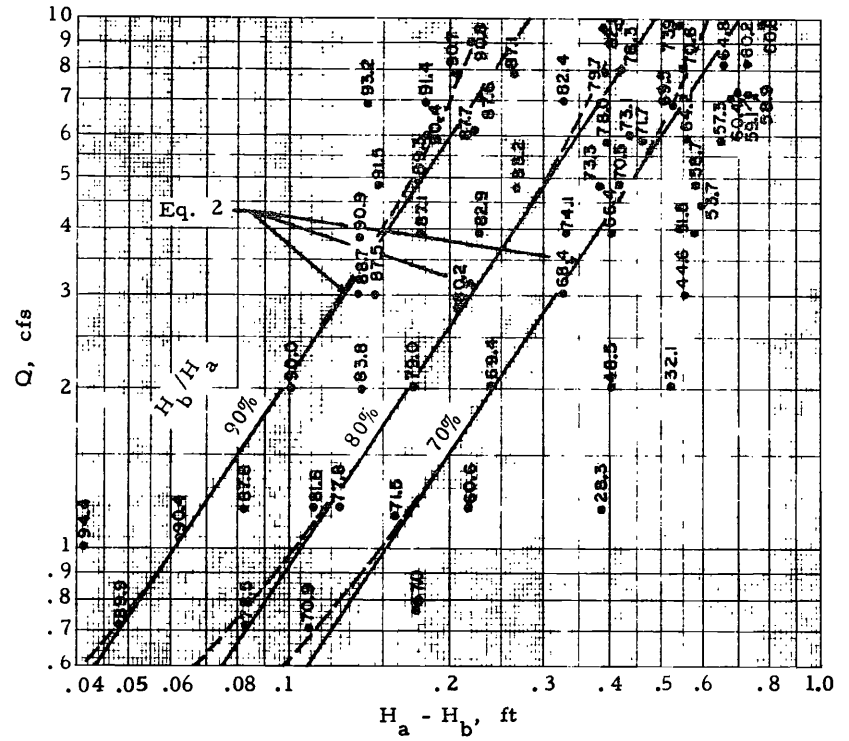


Figure 5. Diagram showing the rate of submerged flow through the 9-inch Parshall flume with 0.0035 slope of the incoming pipe.

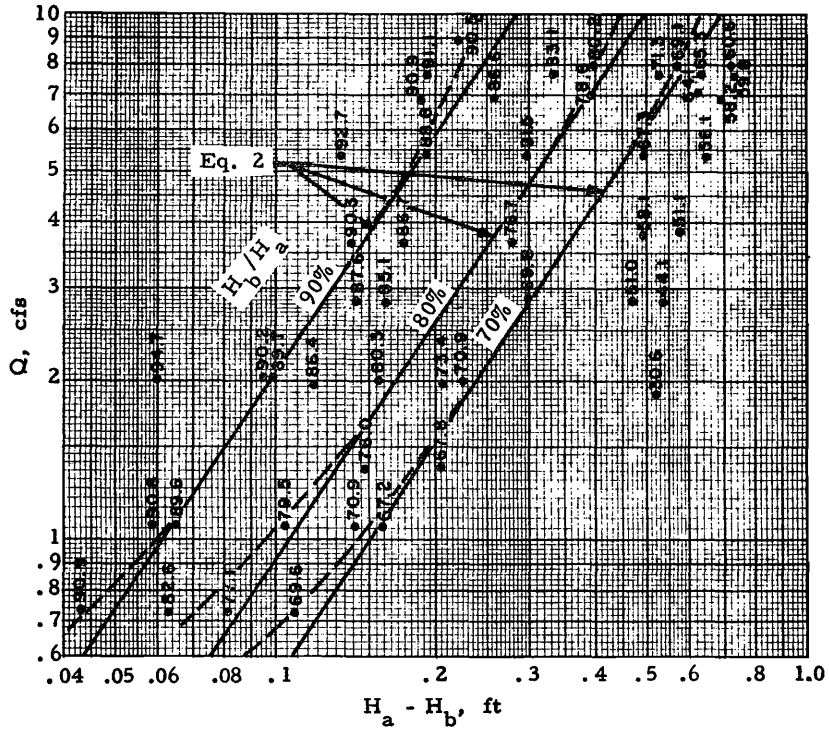


Figure 6. Diagram showing the rate of submerged flow through the 9-inch Parshall flume with 0.0045 slope of the incoming pipe.

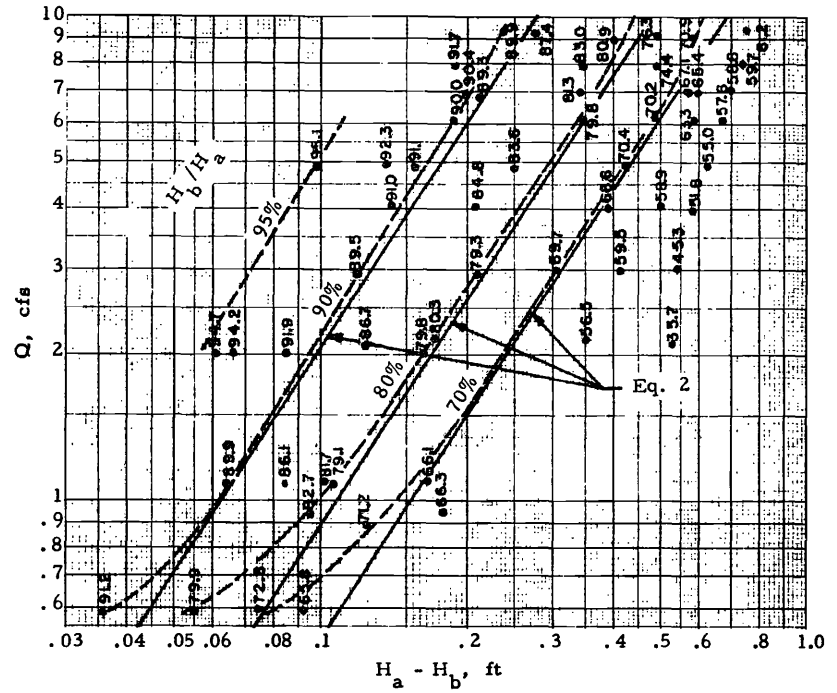


Figure 7. Diagram showing the rate of submerged flow through the 9-inch Parshall flume with 0.0060 slope of the incoming pipe.

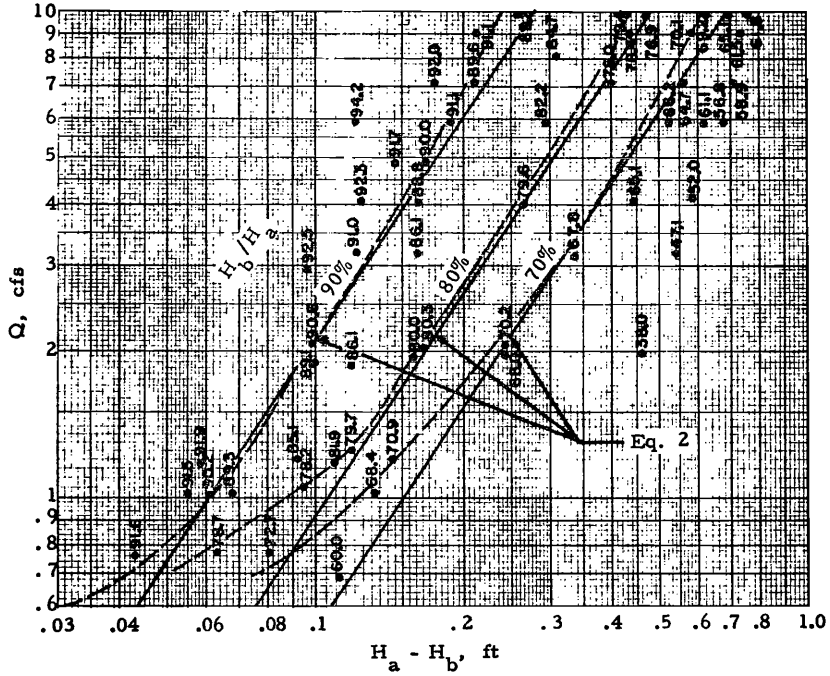


Figure 8. Diagram showing the rate of submerged flow through the 9-inch Parshall flume with 0.0080 slope of the incoming pipe.

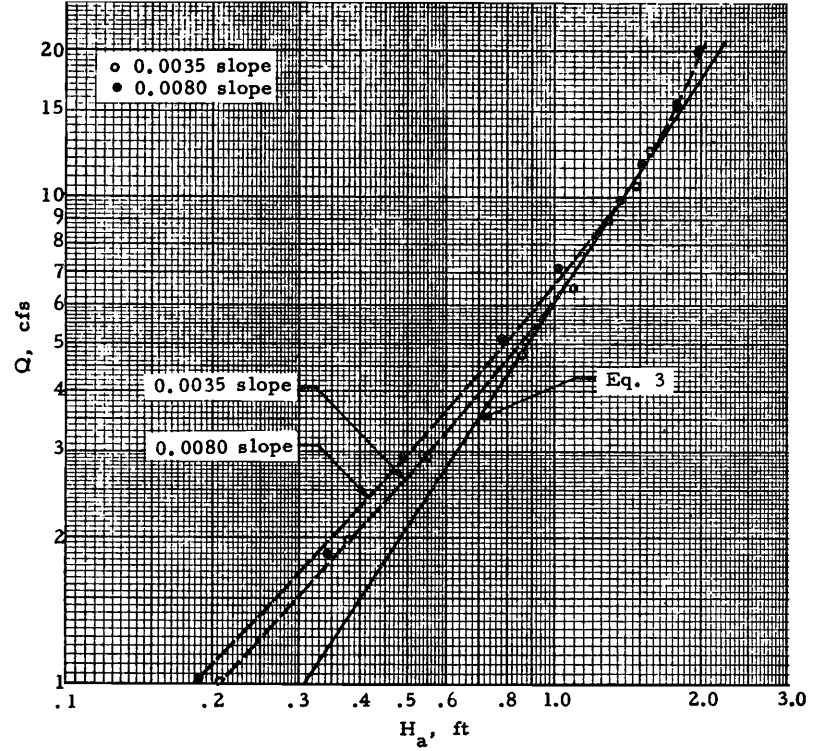


Figure 9. Diagram showing the rate of free flow through the 18-inch Parshall flume.

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., $H_b/H_a \leq (H_b/H_a)_t$]

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

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

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

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

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

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

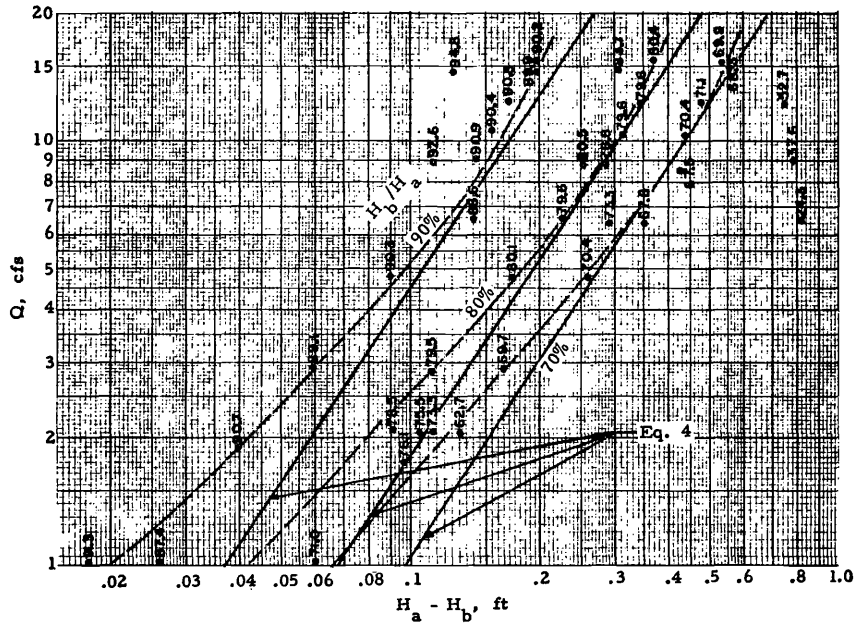


Figure 10. Diagram showing the rate of submerged flow through the 18-inch Parshall flume with 0.0035 slope of the incoming pipe.

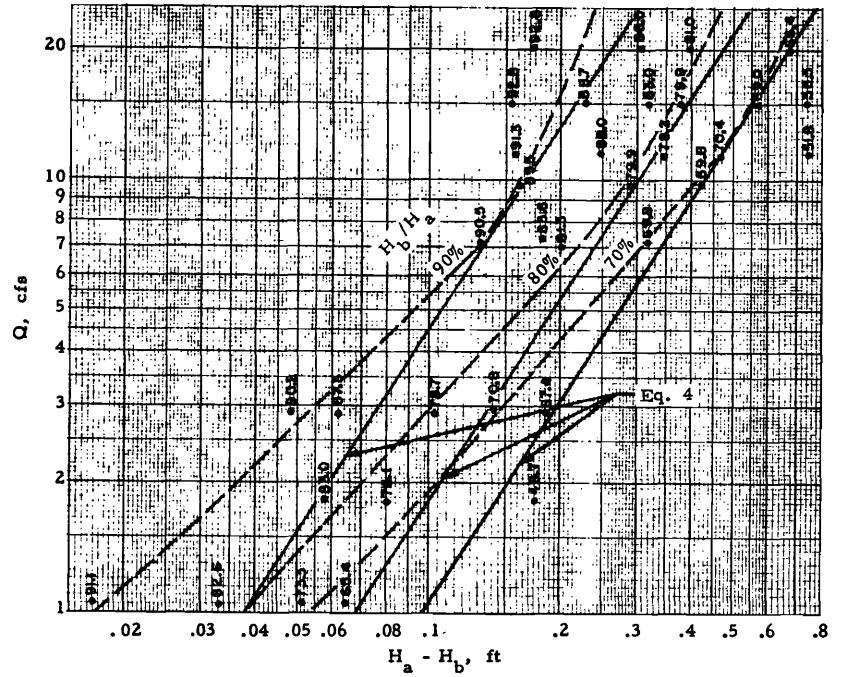


Figure 11. Diagram showing the rate of submerged flow through the 18-inch Parshall flume with 0.0080 slope of the incoming pipe.

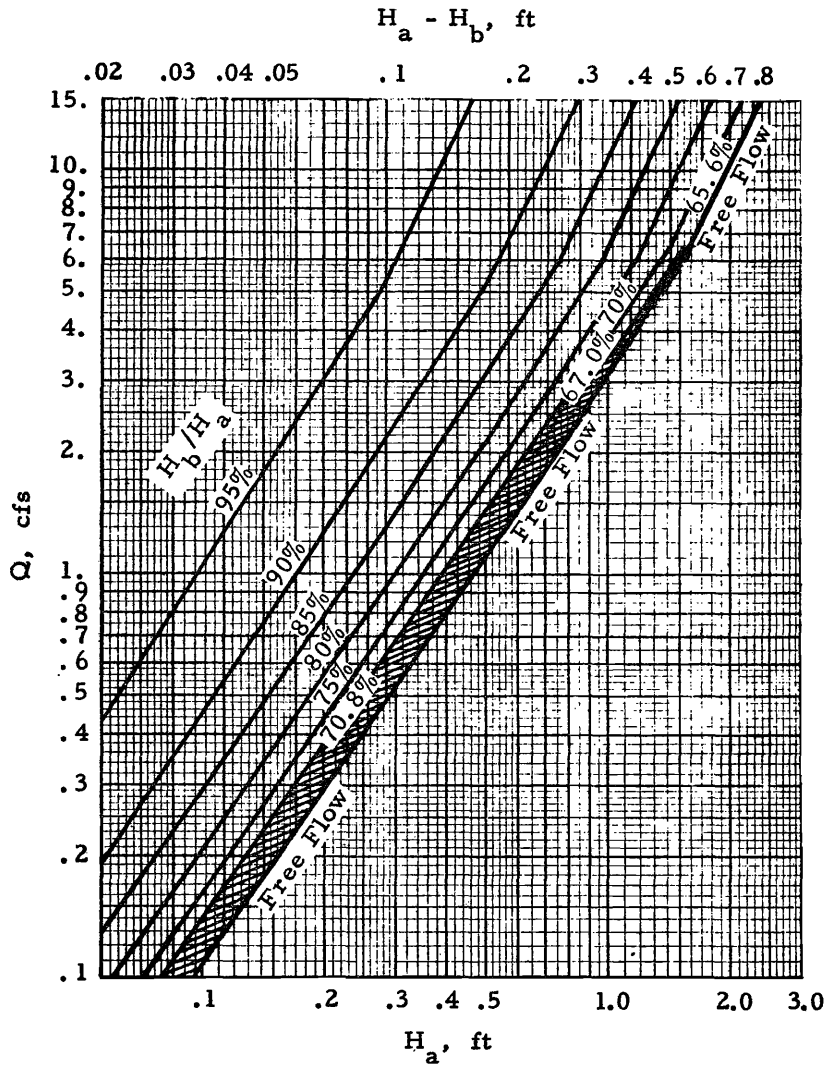


Figure 12. Free and submerged flow calibration curves for 9-inch Parshall flume with 0.0035 slope of the incoming pipe.

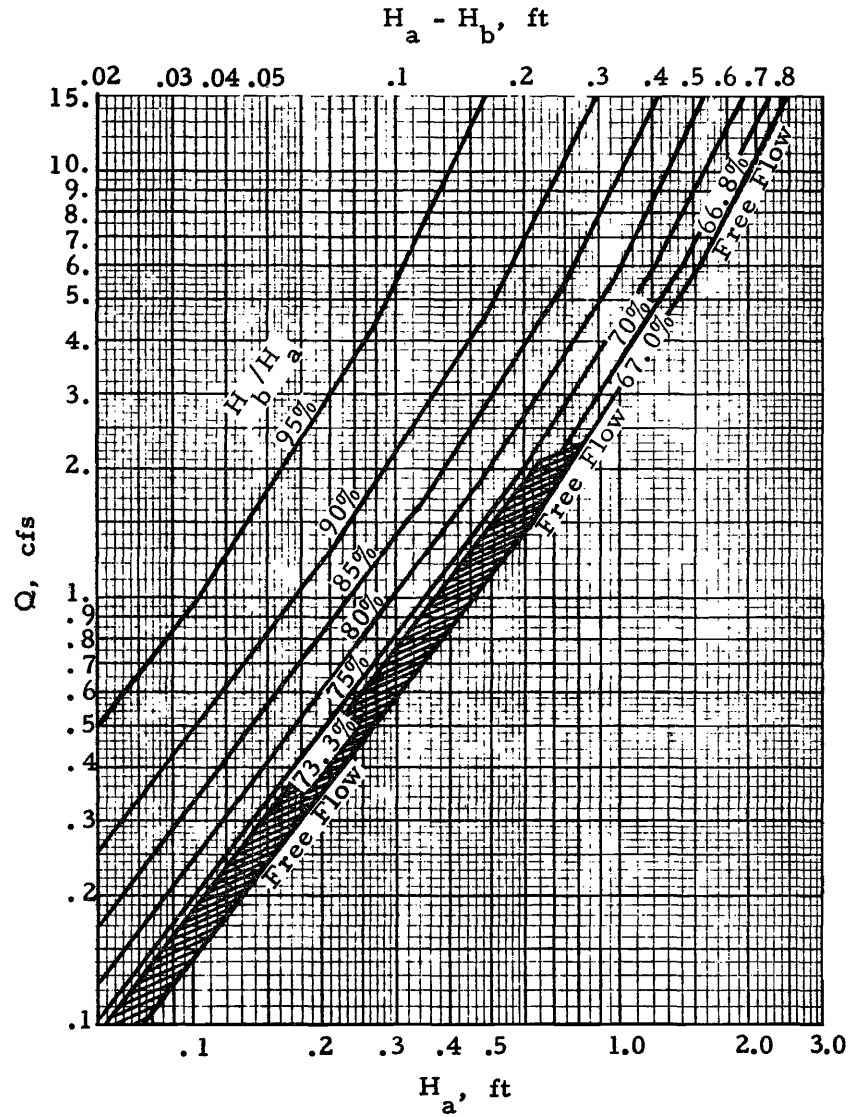


Figure 13. Free and submerged flow calibration curves for 9-inch Parshall flume with 0.0045 slope of the incoming pipe.

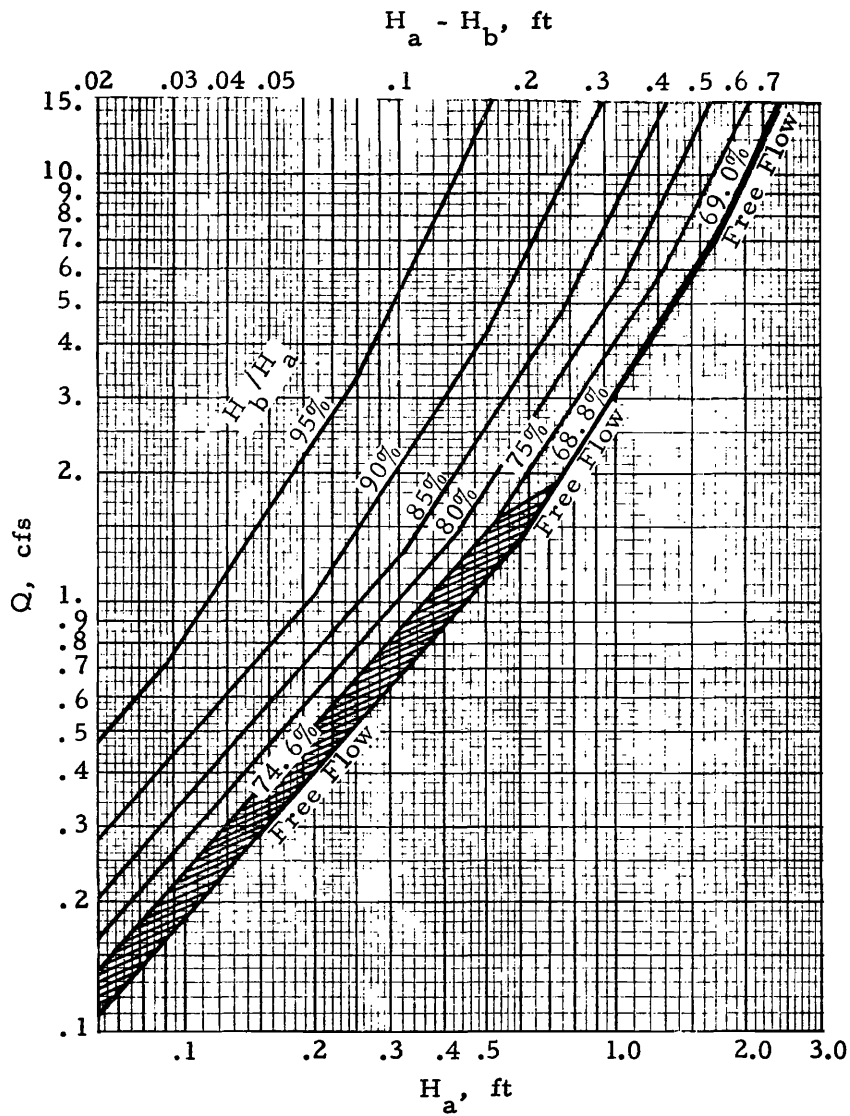


Figure 14. Free and submerged flow calibration curves for 9-inch Parshall flume with 0.0060 slope of the incoming pipe.

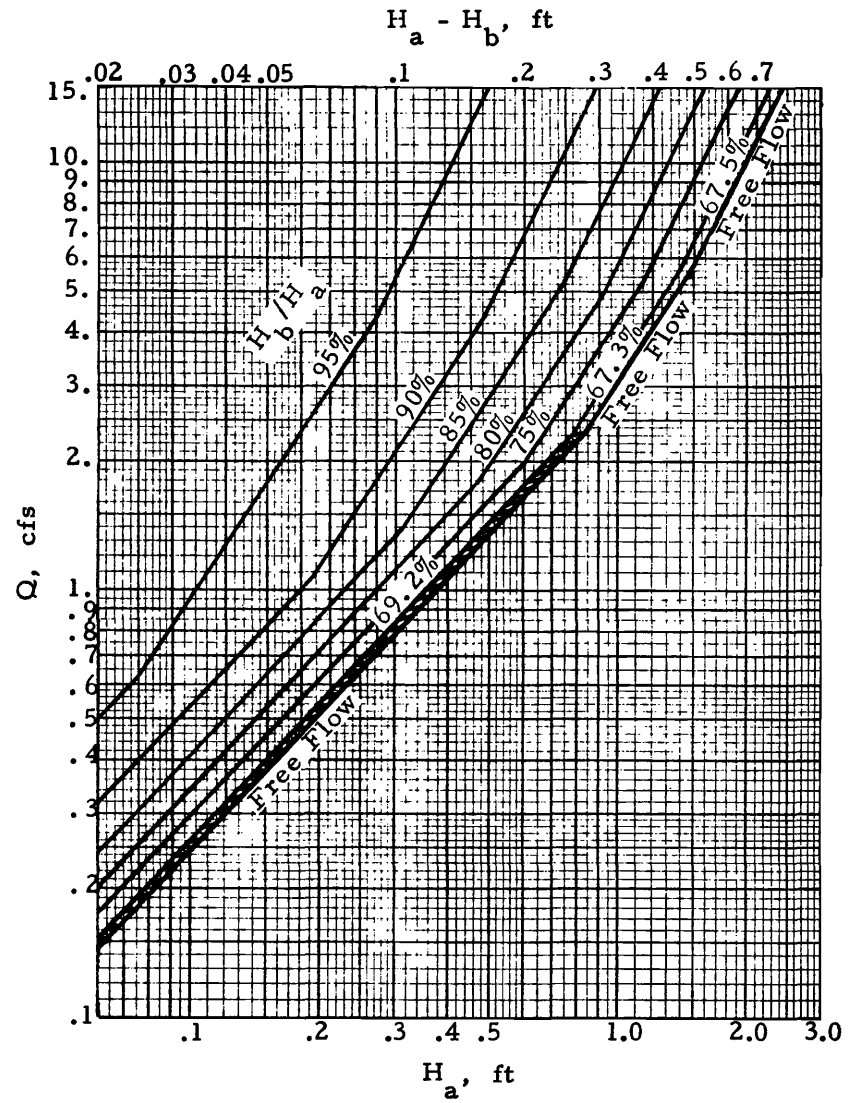


Figure 15. Free and submerged flow calibration curves for 9-inch Parshall flume with 0.0080 slope of the incoming pipe.

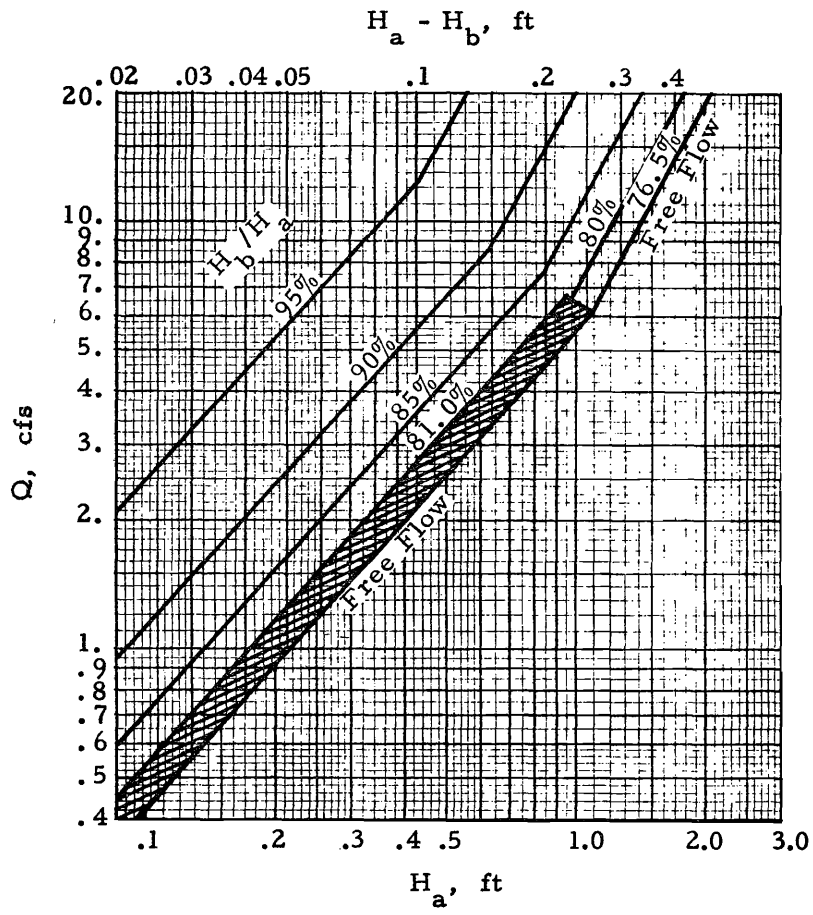


Figure 16. Free and submerged flow calibration curves for 18-inch Parshall flume with 0.0035 slope of the incoming pipe.

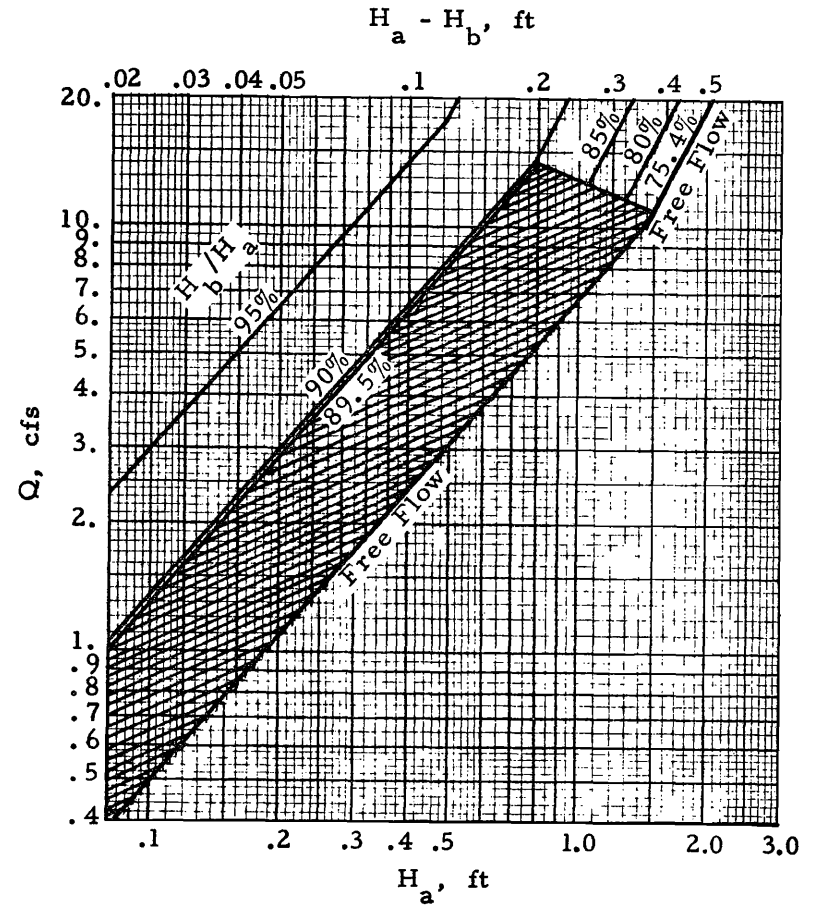


Figure 17. Free and submerged flow calibration curves for 18-inch Parshall flume with 0.0080 slope of the incoming pipe.

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} | | 3.365 | 3.349 | 3.363 | 3.563 |
| | C_2 | | 2.060 | 2.049 | 2.048 | 2.055 |
| | C_3 | | 0.315 | 0.310 | 0.315 | 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} | | 4.115 | 4.248 | 4.454 | 4.130 |
| | C_2 | | 1.559 | 1.538 | 1.537 | 1.522 |
| | C_3 | | 0.277 | 0.297 | 0.329 | 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} | | 4.503 | 4.061 | 4.154 | 4.480 |
| | C_2 | | 1.451 | 1.286 | 1.134 | 1.063 |
| | C_3 | | 0.341 | 0.306 | 0.378 | 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} | | 5.193 | 4.995 |
| | C_2 | | 1.851 | 1.910 |
| H_{at} | | | 1.079 | 1.428 |
| Region II, $H_a \leq H_{at}$ | C_{1f} | | 5.491 | 6.588 |
| | C_2 | | 1.114 | 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

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

for free flow and

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

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

Likewise, the values of H_{at} and $(H_a - H_b)_t$ 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 $(H_a - H_b)_t$ for submerged flow in the 18-inch Parshall flume.

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

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

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

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

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 incom-

ing 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 | H _b | H _b /H _a | H _a -H _b | Q | Q _{st} | Q _n | (Q _{st} -Q)/Q | (Q _n -Q)/Q |
|----------------|----------------|--------------------------------|--------------------------------|------|-----------------|----------------|------------------------|-----------------------|
| ft | ft | % | ft | cfs | cfs | cfs | % | % |
| .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 | -7.39 | 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 | 3.5 | 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 | 2.133 | -.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 |
| 1.100 | 1.015 | 87.50 | .085 | 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 | 3.6 | 6.92 |
| 1.317 | 1.091 | 82.86 | .225 | 3.98 | 3.985 | 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 |
| 1.408 | .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 | H _b | H _b /H _a | H _a -H _b | Q | Q _{st} | Q _n | (Q _{st} -Q)/Q | (Q _n -Q)/Q |
|----------------|----------------|--------------------------------|--------------------------------|-------|-----------------|----------------|------------------------|-----------------------|
| ft | ft | % | ft | cfs | cfs | cfs | % | % |
| 1.640 | 1.465 | 89.33 | .175 | 4.88 | 4.712 | 5.354 | -3.45 | 9.72 |
| 1.639 | 1.400 | 79.32 | .239 | 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 | 6.939 | 7.068 | -2.29 | .98 |
| 1.691 | 1.021 | 60.40 | .670 | 7.00 | 6.858 | 7.094 | -7.03 | 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 | H _b | H _b /H _a | H _a -H _b | Q | Q _{st} | Q _n | (Q _{st} -Q)/Q | (Q _n -Q)/Q |
|----------------|----------------|--------------------------------|--------------------------------|------|-----------------|----------------|------------------------|-----------------------|
| ft | ft | % | ft | cfs | cfs | cfs | % | % |
| .351 | - | - | - | .73 | .619 | .705 | -15.13 | -3.25 |
| .362 | .752 | 69.63 | .110 | .73 | .626 | .733 | -14.10 | .53 |
| .363 | .779 | 77.06 | .083 | .73 | .587 | .702 | -19.45 | -3.66 |
| .366 | .702 | 82.58 | .064 | .73 | .551 | .654 | -24.40 | -10.31 |
| .479 | .435 | 90.92 | .043 | .73 | .684 | .756 | -5.20 | 3.76 |
| .430 | - | - | - | .92 | .844 | .916 | -7.86 | -0.3 |
| .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 | -2.9 |
| .620 | .555 | 89.52 | .065 | 1.06 | 1.058 | 1.101 | -1.8 | 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 | .923 | 10.00 |
| .749 | .729 | 30.57 | .520 | 1.90 | 1.973 | 1.959 | 3.83 | 3.12 |
| .745 | - | - | - | 1.95 | 1.957 | 1.943 | .35 | -3.5 |
| .780 | .573 | 73.42 | .207 | 1.97 | 1.968 | 1.967 | -.08 | -1.6 |
| .844 | .725 | 85.86 | .119 | 1.97 | 1.856 | 1.830 | -5.78 | -7.09 |
| .897 | .779 | 86.85 | .118 | 1.97 | 1.993 | 1.968 | 1.19 | -1.2 |
| .771 | .547 | 70.91 | .224 | 2.02 | 1.977 | 1.942 | -2.11 | -3.86 |
| .798 | .641 | 80.33 | .157 | 2.02 | 1.980 | 1.852 | -5.94 | -8.29 |
| .966 | .866 | 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 | -2.3 |
| 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 | 1.6 | -6.5 |
| 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 | 6.380 | -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 | H _b | H _b /H _a | H _a -H _b | Q | Q _{st} | Q _n | (Q _{st} -Q)/Q | (Q _n -Q)/Q |
|----------------|----------------|--------------------------------|--------------------------------|------|-----------------|----------------|------------------------|-----------------------|
| ft | ft | % | ft | cfs | cfs | cfs | % | % |
| 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 | -6.2 |
| 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 | -1.9 |
| 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 | 1.973 | 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.

| H _a | H _b | H _b /H _a | H _a -H _b | Q | Q _{st} | Q _n | (Q _{st} -Q)/Q | (Q _n -Q)/Q |
|----------------|----------------|--------------------------------|--------------------------------|------|-----------------|----------------|------------------------|-----------------------|
| ft | ft | % | ft | cfs | cfs | cfs | % | % |
| .271 | - | - | - | .59 | .416 | .563 | -29.89 | -5.28 |
| .279 | .177 | 65.80 | .092 | .59 | .408 | .558 | -31.35 | -6.08 |
| .277 | .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 |
| .388 | - | - | - | .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 | 7.39 |
| .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 |
| .917 | .792 | 85.74 | .125 | 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 | .591 | 68.35 | .269 | 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 | -.73 | -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 | -1.19 |
| 1.189 | .516 | 43.41 | .673 | 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 | 68.53 | .385 | 4.01 | 4.095 | 4.166 | 2.12 | 3.89 |
| 1.354 | 1.148 | 84.79 | .206 | 4.01 | 3.913 | 3.871 | -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 |
| 1.966 | 1.870 | 95.02 | .096 | 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 | .997 | 64.35 | .559 | 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 |

Table 9. Continued.

| H _a | H _b | H _b /H _a | H _a -H _b | Q | Q _{st} | Q _n | (Q _{st} -Q)/Q | (Q _n -Q)/Q |
|----------------|----------------|--------------------------------|--------------------------------|------|-----------------|----------------|------------------------|-----------------------|
| ft | ft | % | ft | cfs | cfs | cfs | % | % |
| 1.703 | 1.115 | 65.44 | .588 | 6.97 | 6.881 | 6.975 | -.56 | .07 |
| 1.980 | 1.768 | 89.29 | .212 | 6.97 | 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 |
| 1.691 | .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 | 8.028 | -4.20 | 2.33 |
| 2.009 | 1.668 | 83.03 | .341 | 7.90 | 7.793 | 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 | 9.20 | 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 | H _b | H _b /H _a | H _a -H _b | Q | Q _{st} | Q _n | (Q _{st} -Q)/Q | (Q _n -Q)/Q |
|----------------|----------------|--------------------------------|--------------------------------|------|-----------------|----------------|------------------------|-----------------------|
| ft | ft | % | ft | cfs | cfs | cfs | % | % |
| .279 | .167 | 60.04 | -1.12 | .68 | .435 | .713 | -35.25 | 4.33 |
| .513 | .470 | 91.63 | -0.43 | .76 | .743 | .800 | -2.44 | 4.98 |
| .293 | - | - | - | .76 | .469 | .751 | -38.57 | -1.75 |
| .293 | .713 | 72.70 | -0.80 | .76 | .443 | .714 | -42.02 | -6.49 |
| .295 | .232 | 78.68 | -0.63 | .76 | .421 | .652 | -44.95 | -14.72 |
| .342 | - | - | - | .90 | .595 | .885 | -33.86 | -1.58 |
| .386 | - | - | - | 1.02 | .716 | 1.005 | -29.71 | -1.15 |
| .633 | .565 | 89.29 | -0.68 | 1.02 | 1.099 | 1.105 | 7.51 | 8.10 |
| .621 | .560 | 90.19 | -0.61 | 1.02 | 1.042 | 1.046 | 1.82 | 2.21 |
| .425 | .333 | 78.26 | -0.92 | 1.05 | .737 | .967 | -29.77 | -7.95 |
| .419 | .287 | 68.42 | -1.32 | 1.08 | .791 | 1.098 | -26.76 | 1.66 |
| .600 | .491 | 81.86 | -1.09 | 1.18 | 1.186 | 1.294 | .50 | 9.68 |
| .717 | .659 | 91.91 | -0.58 | 1.18 | 1.227 | 1.225 | 4.00 | 3.80 |
| .617 | .525 | 85.09 | -0.92 | 1.19 | 1.168 | 1.231 | -1.84 | 3.46 |
| .485 | .344 | 70.93 | -1.41 | 1.21 | .972 | 1.253 | -19.68 | 3.51 |
| .562 | .448 | 79.72 | -1.14 | 1.27 | 1.109 | 1.264 | -12.68 | -4.4 |
| .848 | .730 | 86.08 | -1.18 | 1.88 | 1.861 | 1.843 | -1.03 | -1.99 |
| .908 | .809 | 89.10 | -0.99 | 1.88 | 1.919 | 1.909 | 2.08 | 1.53 |
| .733 | .621 | 79.41 | -1.17 | 2.00 | 1.909 | 1.990 | -4.56 | -5.2 |
| .737 | .680 | 77.97 | -0.58 | 2.00 | 1.927 | 2.003 | -3.66 | 1.3 |
| .759 | .616 | 68.01 | -1.43 | 2.00 | 1.970 | 2.066 | -1.48 | 3.31 |
| .784 | .627 | 73.97 | -1.57 | 2.01 | 1.839 | 1.812 | -8.51 | -9.85 |
| .801 | .663 | 70.24 | -1.38 | 2.06 | 2.107 | 2.157 | 2.28 | 4.70 |
| .835 | .670 | 80.28 | -1.65 | 2.06 | 2.016 | 1.986 | -2.12 | -3.60 |
| 1.039 | .941 | 90.58 | -0.98 | 2.06 | 2.260 | 2.249 | 9.69 | 9.17 |
| 1.232 | 1.136 | 92.23 | -0.96 | 2.97 | 2.778 | 2.759 | -6.47 | -7.10 |
| 1.041 | .706 | 67.83 | -3.35 | 3.14 | 3.198 | 3.191 | 1.84 | 1.62 |
| 1.011 | .476 | 47.06 | -5.35 | 3.15 | 3.124 | 3.066 | -4.82 | -2.67 |
| 1.162 | 1.000 | 86.06 | -1.62 | 3.15 | 3.015 | 2.978 | -4.29 | -5.47 |
| 1.341 | 1.221 | 90.99 | -1.21 | 3.15 | 3.297 | 3.275 | 4.67 | 3.98 |
| 1.285 | 1.024 | 79.66 | -2.62 | 3.97 | 3.936 | 3.863 | -8.5 | -2.69 |
| 1.256 | .818 | 65.13 | -4.38 | 4.02 | 4.324 | 4.262 | 7.56 | 6.03 |
| 1.438 | 1.277 | 88.80 | -1.61 | 4.02 | 3.909 | 3.872 | -2.76 | -3.69 |
| 1.595 | 1.472 | 92.32 | -1.23 | 4.07 | 4.113 | 4.076 | 1.05 | .15 |
| 1.203 | .626 | 52.04 | -5.77 | 4.10 | 4.073 | 3.992 | -6.5 | -2.64 |
| 1.349 | .752 | 55.76 | -5.97 | 4.77 | 4.856 | 4.755 | 1.81 | -3.2 |
| 1.413 | 1.026 | 72.61 | -3.87 | 4.77 | 4.922 | 4.851 | 3.18 | 1.71 |
| 1.641 | 1.477 | 90.01 | -1.64 | 4.85 | 4.626 | 4.584 | -4.63 | -5.48 |
| 1.732 | 1.588 | 91.67 | -1.44 | 4.85 | 4.769 | 4.815 | -1.66 | -7.1 |
| 1.864 | 1.698 | 91.09 | -1.56 | 5.85 | 5.437 | 5.726 | -7.06 | -2.13 |
| 2.051 | 1.932 | 94.20 | -1.19 | 5.85 | 5.644 | 6.042 | -3.51 | 3.28 |
| 1.532 | .870 | 56.80 | -6.62 | 5.86 | 5.899 | 5.891 | .67 | .52 |
| 1.545 | .944 | 61.13 | -6.00 | 5.86 | 5.973 | 5.990 | 1.93 | 2.22 |
| 1.556 | 1.030 | 66.18 | -5.26 | 5.86 | 5.968 | 6.078 | 1.84 | 3.72 |
| 1.677 | 1.379 | 82.23 | -2.98 | 5.86 | 5.684 | 5.799 | -3.00 | -1.04 |

Table 10. Continued.

| H _a | H _b | H _b /H _a | H _a -H _b | Q | Q _{st} | Q _n | (Q _{st} -Q)/Q | (Q _n -Q)/Q |
|----------------|----------------|--------------------------------|--------------------------------|-------|-----------------|----------------|------------------------|-----------------------|
| ft | ft | % | ft | cfs | cfs | cfs | % | % |
| 1.685 | .993 | 58.92 | -6.92 | 7.02 | 6.823 | 7.161 | -7.81 | 2.01 |
| 1.709 | 1.105 | 64.71 | -6.03 | 7.03 | 6.934 | 7.361 | -1.36 | 4.71 |
| 2.161 | 1.988 | 91.99 | -1.73 | 7.04 | 6.618 | 7.488 | -5.99 | 6.36 |
| 1.800 | 1.403 | 77.94 | -3.97 | 7.06 | 6.741 | 7.210 | -4.52 | 2.13 |
| 1.991 | 1.783 | 89.55 | -2.08 | 7.06 | 6.299 | 6.914 | -10.77 | -2.07 |
| 2.347 | 2.186 | 93.15 | -1.61 | 7.98 | 7.211 | 8.424 | -9.64 | 5.56 |
| 2.009 | 1.702 | 84.72 | -3.07 | 7.99 | 7.153 | 7.994 | -10.35 | .05 |
| 1.812 | 1.173 | 64.74 | -6.39 | 8.01 | 7.590 | 8.312 | -5.13 | 3.89 |
| 1.791 | 1.089 | 60.79 | -7.13 | 8.02 | 7.491 | 8.119 | -6.59 | 1.24 |
| 1.869 | 1.149 | 61.49 | -7.20 | 8.90 | 7.996 | 8.863 | -10.16 | -4.2 |
| 2.338 | 2.127 | 90.98 | -2.11 | 8.92 | 7.720 | 9.163 | -13.45 | 2.72 |
| 1.920 | 1.345 | 70.05 | -5.75 | 8.96 | 8.031 | 9.112 | -10.37 | 1.70 |
| 1.988 | 1.559 | 78.44 | -4.29 | 9.96 | 7.794 | 8.770 | -13.01 | -2.12 |
| 1.956 | 1.273 | 65.10 | -6.83 | 9.76 | 8.517 | 9.726 | -12.74 | -3.5 |
| 1.980 | 1.370 | 69.19 | -6.10 | 9.80 | 8.470 | 9.799 | -13.58 | -0.1 |
| 2.042 | 1.571 | 76.94 | -4.71 | 9.80 | 8.275 | 9.482 | -15.56 | -3.24 |
| 2.067 | 1.640 | 79.37 | -4.26 | 9.80 | 8.174 | 9.367 | -16.60 | -4.42 |
| 2.336 | 2.084 | 89.19 | -2.52 | 9.80 | 8.128 | 9.715 | -17.06 | -8.7 |
| 1.946 | 1.202 | 61.76 | -7.44 | 9.85 | 8.504 | 9.527 | -13.66 | -2.26 |
| 2.078 | 1.282 | 61.69 | -7.96 | 11.10 | 9.400 | 11.014 | -15.31 | -7.8 |
| 2.145 | 1.317 | 61.40 | -8.28 | 11.90 | 9.858 | 11.756 | -17.08 | -1.21 |
| 2.163 | 1.329 | 61.44 | -8.34 | 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 | H _b | H _b /H _a | H _a -H _b | Q | Q _{st} | Q _n | (Q _{st} -Q)/Q | (Q _n -Q)/Q |
|----------------|----------------|--------------------------------|--------------------------------|-------|-----------------|----------------|------------------------|-----------------------|
| ft | ft | % | ft | cfs | cfs | cfs | % | % |
| .208 | - | - | - | .99 | .53 5 | .9 55 | -46.06 | -3.64 |
| .207 | .147 | 71.01 | .060 | .99 | .50 3 | .9 50 | -49.27 | -4.16 |
| .207 | .181 | 87.44 | .026 | .99 | .41 6 | .9 58 | -59.05 | -3.31 |
| .207 | .189 | 91.30 | .018 | .99 | .38 1 | .9 66 | -61.60 | -2.57 |
| .207 | .198 | 95.65 | .009 | .99 | .34 0 | .9 80 | -65.67 | -1.14 |
| .406 | .309 | 76.11 | .097 | 1.74 | 1.36 7 | 2.0 12 | -21.41 | 15.61 |
| .427 | - | - | - | 1.88 | 1.61 8 | 2.1 28 | -13.93 | 13.19 |
| .431 | .391 | 90.72 | .040 | 1.88 | 1.19 5 | 2.1 83 | -36.43 | 16.11 |
| .427 | .296 | 69.32 | .131 | 2.06 | 1.54 7 | 2.1 28 | -24.88 | 3.30 |
| .430 | .316 | 73.49 | .114 | 2.06 | 1.52 5 | 2.1 45 | -25.96 | 4.10 |
| .433 | .327 | 75.52 | .106 | 2.06 | 1.51 8 | 2.1 61 | -26.33 | 4.91 |
| .428 | .335 | 78.50 | .092 | 2.06 | 1.45 0 | 2.1 33 | -29.63 | 3.56 |
| .542 | .385 | 69.75 | .167 | 2.86 | 2.29 3 | 2.8 33 | -19.83 | -9.6 |
| .552 | .439 | 79.53 | .113 | 2.86 | 2.12 1 | 2.8 33 | -25.83 | -9.6 |
| .555 | .495 | 89.19 | .060 | 2.86 | 1.83 0 | 2.8 84 | -36.03 | .83 |
| .548 | - | - | - | 2.90 | 2.37 6 | 2.8 10 | -18.06 | -3.12 |
| .535 | - | - | - | 2.97 | 2.29 0 | 2.7 36 | -22.90 | -7.90 |
| .873 | .700 | 80.18 | .173 | 4.76 | 4.26 5 | 4.7 20 | -10.39 | -8.4 |
| .871 | .613 | 70.32 | .258 | 4.78 | 4.61 3 | 4.7 08 | -3.50 | -1.51 |
| .854 | - | - | - | 4.79 | 4.70 5 | 4.6 06 | -1.77 | -3.85 |
| .936 | .845 | 90.28 | .091 | 4.79 | 3.98 9 | 5.1 73 | -16.73 | 8.01 |
| 1.118 | .739 | 66.10 | .379 | 6.38 | 6.90 9 | 6.3 88 | 8.30 | .06 |
| 1.143 | .882 | 77.69 | .255 | 6.45 | 6.63 4 | 6.5 48 | 2.86 | 1.52 |
| 1.113 | .264 | 23.72 | .849 | 6.51 | 7.07 5 | 6.3 31 | 8.69 | -2.75 |
| 1.279 | 1.110 | 86.79 | .169 | 6.55 | 6.95 5 | 7.2 78 | 6.19 | -11.17 |
| 1.122 | .803 | 71.57 | .319 | 6.70 | 6.76 6 | 6.4 25 | .98 | -4.09 |
| 1.292 | .872 | 67.49 | .420 | 8.56 | 8.58 6 | 8.3 44 | .31 | -2.53 |
| 1.323 | 1.042 | 78.76 | .281 | 8.69 | 8.22 0 | 8.4 56 | -5.41 | -2.69 |
| 1.554 | 1.422 | 90.92 | .132 | 8.85 | 8.65 4 | 9.1 79 | -2.21 | 3.71 |
| 1.298 | .477 | 36.75 | .821 | 8.86 | 8.96 6 | 8.4 16 | 1.20 | -5.01 |
| 1.474 | .658 | 47.35 | .816 | 10.30 | 10.90 5 | 10.6 49 | 5.88 | 3.39 |
| 1.490 | 1.052 | 70.60 | .438 | 10.35 | 10.53 1 | 10.8 64 | 1.75 | 4.97 |
| 1.525 | 1.213 | 79.57 | .311 | 10.35 | 10.13 8 | 10.8 67 | -2.05 | 5.00 |
| 1.630 | 1.474 | 90.43 | .156 | 10.35 | 9.33 7 | 9.7 65 | -9.79 | -5.65 |
| 1.585 | .836 | 52.74 | .749 | 12.19 | 12.19 5 | 12.1 81 | .04 | -0.8 |
| 1.618 | 1.150 | 71.08 | .468 | 12.19 | 11.92 4 | 12.6 54 | -2.18 | 3.81 |
| 1.658 | 1.319 | 79.55 | .339 | 12.19 | 11.53 7 | 12.6 94 | -5.36 | 4.13 |
| 1.785 | 1.616 | 90.53 | .169 | 12.19 | 10.71 2 | 11.5 15 | -12.13 | -5.54 |
| 1.732 | .990 | 57.16 | .742 | 14.26 | 13.98 0 | 14.3 54 | -1.96 | .66 |
| 2.428 | 2.301 | 94.77 | .127 | 14.26 | 15.35 3 | 16.9 92 | 7.67 | 19.16 |
| 1.848 | 1.547 | 83.71 | .301 | 14.50 | 12.91 4 | 14.4 81 | -10.94 | -1.3 |
| 1.943 | 1.747 | 89.91 | .196 | 14.50 | 12.39 1 | 13.7 35 | -14.54 | -5.28 |
| 1.756 | 1.200 | 68.34 | .556 | 14.67 | 13.72 1 | 14.7 24 | -6.47 | .37 |
| 1.783 | - | - | - | 15.10 | 14.62 6 | 15.1 54 | -3.14 | .36 |
| 2.020 | 1.823 | 90.23 | .197 | 15.30 | 13.06 2 | 14.6 25 | -14.63 | -4.41 |
| 1.806 | 1.262 | 69.88 | .544 | 15.40 | 14.21 9 | 15.5 10 | -7.67 | .71 |
| 1.861 | 1.496 | 80.39 | .365 | 15.40 | 13.65 0 | 15.5 22 | -11.36 | .79 |
| 2.014 | - | - | - | 20.00 | 17.63 6 | 18.9 77 | -11.82 | -5.11 |

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

| H _a | H _b | H _b /H _a | H _a -H _b | Q | Q _{st} | Q _n | (Q _{st} -Q)/Q | (Q _n -Q)/Q |
|----------------|----------------|--------------------------------|--------------------------------|-------|-----------------|----------------|------------------------|-----------------------|
| ft | ft | % | ft | cfs | cfs | cfs | % | % |
| .191 | - | - | - | 1.04 | .46 9 | 1.0 10 | -55.14 | -3.38 |
| .183 | .123 | 65.43 | .065 | 1.04 | .44 5 | .9 92 | -57.44 | -5.10 |
| .191 | .140 | 73.30 | .051 | 1.04 | .43 8 | 1.0 10 | -58.12 | -3.38 |
| .190 | .157 | 82.63 | .033 | 1.04 | .39 5 | 1.0 04 | -62.21 | -3.96 |
| .191 | .174 | 91.10 | .017 | 1.04 | .33 8 | 1.0 08 | -67.66 | -3.51 |
| .330 | .251 | 76.06 | .079 | 1.80 | .99 4 | 1.8 76 | -44.77 | 4.22 |
| .337 | .164 | 48.66 | .173 | 1.81 | 1.12 4 | 1.9 21 | -37.91 | 6.14 |
| .323 | .313 | 96.90 | .010 | 1.81 | .68 0 | 1.8 13 | -62.41 | .18 |
| .335 | .278 | 82.99 | .057 | 1.82 | .94 1 | 1.9 08 | -48.30 | 4.85 |
| .341 | - | - | - | 1.84 | 1.14 4 | 1.9 47 | -37.80 | 5.81 |
| .484 | .381 | 78.72 | .103 | 2.84 | 1.74 8 | 2.8 95 | -38.45 | 1.94 |
| .480 | .404 | 84.17 | .076 | 2.84 | 1.60 8 | 2.8 68 | -43.36 | .99 |
| .490 | .428 | 87.35 | .062 | 2.86 | 1.57 0 | 2.9 36 | -45.10 | 2.65 |
| .487 | .328 | 67.35 | .159 | 2.90 | 1.91 2 | 2.9 16 | -34.07 | .54 |
| .488 | .440 | 90.16 | .048 | 2.90 | 1.46 7 | 2.9 21 | -49.42 | .72 |
| .479 | .339 | 70.77 | .140 | 2.94 | 1.83 3 | 2.8 61 | -37.66 | -2.67 |
| .788 | .033 | 4.19 | .755 | 5.05 | 4.15 7 | 5.0 29 | -17.68 | -4.1 |
| 1.072 | .871 | 81.25 | .201 | 6.96 | 5.77 6 | 7.1 28 | -17.01 | 2.41 |
| 1.026 | .294 | 28.65 | .732 | 7.03 | 6.24 2 | 6.7 82 | -11.21 | -3.52 |
| 1.369 | 1.239 | 90.50 | .130 | 7.11 | 7.12 4 | 9.3 96 | .19 | 32.16 |
| 1.045 | .729 | 69.76 | .316 | 7.16 | 6.12 7 | 6.9 25 | -14.43 | -3.28 |
| 1.105 | .924 | 83.62 | .181 | 7.31 | 5.85 8 | 7.3 77 | -19.87 | .92 |
| 1.369 | - | - | - | 9.70 | 9.73 2 | 9.4 04 | .32 | -3.06 |
| 1.402 | .978 | 69.76 | .424 | 9.70 | 9.63 3 | 9.6 61 | -.70 | -4.1 |
| 1.435 | 1.147 | 79.93 | .288 | 9.70 | 9.19 6 | 9.9 19 | -5.20 | 2.25 |
| 1.531 | 1.371 | 89.55 | .160 | 9.70 | 8.65 8 | 10.6 74 | -10.75 | 10.03 |
| 1.569 | 1.105 | 70.43 | .464 | 11.24 | 11.41 5 | 11.8 08 | 1.56 | 5.05 |
| 1.576 | 1.233 | 78.24 | .343 | 11.29 | 10.82 1 | 11.5 33 | -4.15 | 2.15 |
| 1.815 | 1.657 | 91.29 | .158 | 11.38 | 10.77 9 | 12.9 25 | -5.28 | 13.57 |
| 1.653 | 1.405 | 85.00 | .248 | 11.47 | 10.65 7 | 11.6 43 | -7.09 | 1.51 |
| 1.525 | .790 | 51.80 | .735 | 11.51 | 11.49 2 | 11.1 84 | -.16 | -2.84 |
| 1.818 | 1.252 | 68.87 | .566 | 15.00 | 14.43 8 | 15.6 44 | -3.74 | 4.30 |
| 1.867 | 1.491 | 79.86 | .376 | 15.00 | 13.80 3 | 15.6 18 | -7.98 | 4.12 |
| 1.881 | 1.568 | 83.36 | .313 | 15.00 | 13.74 1 | 15.0 67 | -11.06 | .45 |
| 1.948 | 1.771 | 88.64 | .277 | 15.00 | 13.31 5 | 15.2 23 | -11.23 | 1.95 |
| 2.183 | 2.030 | 92.99 | .153 | 15.00 | 13.67 9 | 15.9 50 | -8.81 | 6.34 |
| 1.780 | 1.041 | 58.48 | .739 | 15.10 | 14.58 1 | 15.0 26 | -3.43 | -4.9 |
| 2.013 | 1.335 | 66.32 | .678 | 20.00 | 17.07 7 | 19.0 05 | -14.62 | -4.97 |
| 2.102 | 1.706 | 81.16 | .396 | 20.00 | 16.31 1 | 19.2 46 | -18.44 | -3.77 |
| 2.163 | 1.862 | 86.08 | .301 | 20.00 | 15.82 5 | 18.7 71 | -20.87 | -6.15 |
| 2.443 | 2.271 | 92.96 | .172 | 20.00 | 16.28 2 | 19.7 98 | -18.59 | -1.01 |

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

| H _a feet | 9 inches Throat Width Slope | | | | 18 inches Throat Width Slope | |
|------------------------|-----------------------------------|--------|--------|--------|------------------------------------|--------|
| | 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 feet | 9 inches Throat Width Slope | | | | 18 inches Throat Width Slope | |
|------------------------|-----------------------------------|--------|--------|--------|------------------------------------|--------|
| | 0.0035 | 0.0045 | 0.0060 | 0.0080 | 0.0035 | 0.0080 |
| | Q in cfs | | | | Q in cfs | |
| .58 | 1.347 | 1.347 | 1.333 | 1.551 | 2.994 | 3.554 |
| .59 | 1.377 | 1.375 | 1.359 | 1.581 | 3.051 | 3.624 |
| .60 | 1.411 | 1.405 | 1.386 | 1.611 | 3.108 | 3.693 |
| .61 | 1.445 | 1.436 | 1.421 | 1.641 | 3.166 | 3.763 |
| .62 | 1.479 | 1.466 | 1.457 | 1.671 | 3.224 | 3.833 |
| .63 | 1.514 | 1.502 | 1.493 | 1.701 | 3.282 | 3.903 |
| .64 | 1.549 | 1.535 | 1.529 | 1.731 | 3.340 | 3.973 |
| .65 | 1.584 | 1.575 | 1.566 | 1.761 | 3.398 | 4.044 |
| .66 | 1.620 | 1.613 | 1.604 | 1.791 | 3.456 | 4.114 |
| .67 | 1.655 | 1.651 | 1.641 | 1.821 | 3.515 | 4.185 |
| .68 | 1.691 | 1.689 | 1.679 | 1.851 | 3.573 | 4.255 |
| .69 | 1.727 | 1.727 | 1.717 | 1.881 | 3.632 | 4.327 |
| .70 | 1.764 | 1.766 | 1.755 | 1.911 | 3.691 | 4.398 |
| .71 | 1.801 | 1.805 | 1.794 | 1.941 | 3.749 | 4.469 |
| .72 | 1.838 | 1.844 | 1.833 | 1.971 | 3.808 | 4.541 |
| .73 | 1.875 | 1.883 | 1.872 | 1.981 | 3.867 | 4.612 |
| .74 | 1.912 | 1.923 | 1.912 | 2.011 | 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 | 2.169 | 2.155 | 2.183 | 4.282 | 5.116 |
| .81 | 2.180 | 2.210 | 2.197 | 2.213 | 4.342 | 5.187 |
| .82 | 2.227 | 2.252 | 2.239 | 2.242 | 4.402 | 5.259 |
| .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 | 2.436 | 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 | 2.647 | 2.627 | 2.611 | 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 | 5.185 | 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 | 2.991 | 2.967 | 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 | 3.199 | 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 | | | | 18 inches Throat Width Slope | |
|------------------------|-----------------------------------|--------|--------|--------|------------------------------------|--------|
| | 0.0035 | 0.0045 | 0.0060 | 0.0080 | 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 | 6.051 | 7.264 |
| 1.10 | 3.513 | 3.538 | 3.515 | 3.483 | 6.115 | 7.339 |
| 1.11 | 3.563 | 3.588 | 3.565 | 3.532 | 6.180 | 7.415 |
| 1.12 | 3.613 | 3.638 | 3.615 | 3.580 | 6.245 | 7.491 |
| 1.13 | 3.664 | 3.688 | 3.665 | 3.629 | 6.311 | 7.566 |
| 1.14 | 3.714 | 3.738 | 3.715 | 3.678 | 6.378 | 7.642 |
| 1.15 | 3.765 | 3.789 | 3.765 | 3.727 | 6.445 | 7.718 |
| 1.16 | 3.816 | 3.840 | 3.815 | 3.777 | 6.513 | 7.794 |
| 1.17 | 3.868 | 3.891 | 3.866 | 3.826 | 6.582 | 7.871 |
| 1.18 | 3.919 | 3.942 | 3.917 | 3.876 | 6.652 | 7.947 |
| 1.19 | 3.971 | 3.993 | 3.968 | 3.926 | 6.723 | 8.023 |
| 1.20 | 4.023 | 4.045 | 4.019 | 3.977 | 6.795 | 8.100 |
| 1.21 | 4.076 | 4.097 | 4.071 | 4.027 | 6.868 | 8.176 |
| 1.22 | 4.128 | 4.149 | 4.123 | 4.078 | 6.942 | 8.253 |
| 1.23 | 4.181 | 4.202 | 4.175 | 4.129 | 7.017 | 8.329 |
| 1.24 | 4.234 | 4.254 | 4.227 | 4.180 | 7.093 | 8.406 |
| 1.25 | 4.288 | 4.307 | 4.280 | 4.232 | 7.170 | 8.483 |
| 1.26 | 4.341 | 4.360 | 4.332 | 4.283 | 7.248 | 8.560 |
| 1.27 | 4.395 | 4.414 | 4.385 | 4.335 | 7.327 | 8.637 |
| 1.28 | 4.448 | 4.467 | 4.438 | 4.387 | 7.407 | 8.714 |
| 1.29 | 4.504 | 4.521 | 4.492 | 4.439 | 7.488 | 8.791 |
| 1.30 | 4.558 | 4.575 | 4.545 | 4.492 | 7.570 | 8.869 |
| 1.31 | 4.613 | 4.629 | 4.599 | 4.544 | 7.653 | 8.946 |
| 1.32 | 4.668 | 4.684 | 4.653 | 4.597 | 7.737 | 9.023 |
| 1.33 | 4.723 | 4.738 | 4.708 | 4.651 | 7.822 | 9.101 |
| 1.34 | 4.779 | 4.793 | 4.762 | 4.704 | 7.908 | 9.178 |
| 1.35 | 4.834 | 4.848 | 4.817 | 4.757 | 7.995 | 9.256 |
| 1.36 | 4.890 | 4.904 | 4.872 | 4.811 | 8.083 | 9.334 |
| 1.37 | 4.947 | 4.959 | 4.927 | 4.865 | 8.172 | 9.411 |
| 1.38 | 5.003 | 5.015 | 4.982 | 4.919 | 8.262 | 9.489 |
| 1.39 | 5.060 | 5.071 | 5.038 | 4.974 | 8.353 | 9.567 |
| 1.40 | 5.116 | 5.127 | 5.094 | 5.028 | 8.445 | 9.645 |
| 1.41 | 5.174 | 5.184 | 5.150 | 5.083 | 8.538 | 9.723 |
| 1.42 | 5.231 | 5.240 | 5.206 | 5.138 | 8.632 | 9.802 |
| 1.43 | 5.288 | 5.297 | 5.263 | 5.193 | 8.727 | 9.881 |
| 1.44 | 5.346 | 5.354 | 5.319 | 5.248 | 8.823 | 9.960 |
| 1.45 | 5.404 | 5.412 | 5.376 | 5.304 | 8.920 | 10.040 |
| 1.46 | 5.462 | 5.469 | 5.433 | 5.360 | 9.018 | 10.120 |
| 1.47 | 5.521 | 5.527 | 5.490 | 5.416 | 9.117 | 10.200 |
| 1.48 | 5.579 | 5.585 | 5.548 | 5.483 | 9.217 | 10.280 |
| 1.49 | 5.638 | 5.643 | 5.606 | 5.560 | 9.318 | 10.360 |
| 1.50 | 5.697 | 5.701 | 5.664 | 5.637 | 9.420 | 10.440 |
| 1.51 | 5.757 | 5.760 | 5.722 | 5.714 | 9.523 | 10.520 |
| 1.52 | 5.816 | 5.819 | 5.780 | 5.792 | 9.627 | 10.600 |
| 1.53 | 5.876 | 5.878 | 5.839 | 5.871 | 9.732 | 10.680 |

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Table 13. Continued.

| H _a feet | 9 inches Throat Width Slope | | | | 18 inches Throat Width Slope | |
|------------------------|-----------------------------------|--------|--------|--------|------------------------------------|--------|
| | 0.0035 | 0.0045 | 0.0060 | 0.0080 | 0.0035 | 0.0080 |
| | Q in cfs | | | | Q in cfs | |
| 1.54 | 5.936 | 5.937 | 5.897 | 5.851 | 11.548 | 11.795 |
| 1.55 | 5.996 | 5.995 | 5.956 | 5.910 | 11.608 | 11.856 |
| 1.56 | 6.057 | 6.056 | 6.016 | 6.010 | 11.667 | 11.919 |
| 1.57 | 6.117 | 6.116 | 6.075 | 6.191 | 11.726 | 11.982 |
| 1.58 | 6.178 | 6.176 | 6.135 | 6.272 | 11.785 | 12.045 |
| 1.58 | 6.249 | 6.236 | 6.194 | 6.354 | 11.844 | 12.107 |
| 1.60 | 6.330 | 6.296 | 6.254 | 6.436 | 11.903 | 12.170 |
| 1.61 | 6.412 | 6.357 | 6.314 | 6.519 | 11.962 | 12.232 |
| 1.62 | 6.494 | 6.418 | 6.375 | 6.603 | 12.021 | 12.295 |
| 1.63 | 6.577 | 6.479 | 6.435 | 6.687 | 12.080 | 12.357 |
| 1.64 | 6.661 | 6.558 | 6.496 | 6.771 | 12.139 | 12.420 |
| 1.65 | 6.745 | 6.601 | 6.557 | 6.856 | 12.198 | 12.482 |
| 1.66 | 6.829 | 6.723 | 6.618 | 6.940 | 12.257 | 12.545 |
| 1.67 | 6.914 | 6.806 | 6.680 | 7.024 | 12.316 | 12.607 |
| 1.68 | 7.000 | 6.889 | 6.741 | 7.108 | 12.375 | 12.670 |
| 1.69 | 7.086 | 6.975 | 6.803 | 7.192 | 12.434 | 12.732 |
| 1.70 | 7.172 | 7.059 | 6.866 | 7.276 | 12.493 | 12.795 |
| 1.71 | 7.259 | 7.145 | 6.929 | 7.360 | 12.552 | 12.857 |
| 1.72 | 7.347 | 7.231 | 7.003 | 7.444 | 12.611 | 12.920 |
| 1.73 | 7.435 | 7.317 | 7.067 | 7.528 | 12.670 | 12.982 |
| 1.74 | 7.524 | 7.404 | 7.132 | 7.612 | 12.729 | 13.045 |
| 1.75 | 7.614 | 7.491 | 7.197 | 7.696 | 12.788 | 13.107 |
| 1.76 | 7.704 | 7.579 | 7.263 | 7.780 | 12.847 | 13.170 |
| 1.77 | 7.794 | 7.668 | 7.328 | 7.864 | 12.906 | 13.232 |
| 1.78 | 7.885 | 7.757 | 7.393 | 7.948 | 12.965 | 13.295 |
| 1.79 | 7.976 | 7.846 | 7.458 | 8.032 | 13.024 | 13.357 |
| 1.80 | 8.069 | 7.937 | 7.523 | 8.116 | 13.083 | 13.420 |
| 1.81 | 8.161 | 8.027 | 7.588 | 8.200 | 13.142 | 13.482 |
| 1.82 | 8.254 | 8.119 | 7.653 | 8.284 | 13.201 | 13.545 |
| 1.83 | 8.348 | 8.210 | 7.718 | 8.368 | 13.260 | 13.607 |
| 1.84 | 8.442 | 8.302 | 7.783 | 8.452 | 13.319 | 13.670 |
| 1.85 | 8.537 | 8.395 | 7.848 | 8.536 | 13.378 | 13.732 |
| 1.86 | 8.632 | 8.488 | 7.913 | 8.620 | 13.437 | 13.795 |
| 1.87 | 8.728 | 8.582 | 7.978 | 8.704 | 13.496 | 13.857 |
| 1.88 | 8.825 | 8.676 | 8.043 | 8.788 | 13.555 | 13.920 |
| 1.89 | 8.922 | 8.771 | 8.108 | 8.872 | 13.614 | 13.982 |
| 1.90 | 9.019 | 8.866 | 8.173 | 8.956 | 13.673 | 14.045 |
| 1.91 | 9.117 | 8.962 | 8.238 | 9.040 | 13.732 | 14.107 |
| 1.92 | 9.216 | 9.059 | 8.303 | 9.124 | 13.791 | 14.170 |
| 1.93 | 9.315 | 9.156 | 8.368 | 9.208 | 13.850 | 14.232 |
| 1.94 | 9.415 | 9.253 | 8.433 | 9.292 | 13.909 | 14.295 |
| 1.95 | 9.515 | 9.351 | 8.498 | 9.376 | 13.968 | 14.357 |
| 1.96 | 9.616 | 9.449 | 8.563 | 9.460 | 14.027 | 14.420 |
| 1.97 | 9.717 | 9.548 | 8.628 | 9.544 | 14.086 | 14.482 |
| 1.98 | 9.818 | 9.646 | 8.693 | 9.628 | 14.145 | 14.545 |
| 1.99 | 9.921 | 9.745 | 8.758 | 9.712 | 14.204 | 14.607 |
| 2.00 | 10.024 | 9.844 | 8.823 | 9.796 | 14.263 | 14.670 |

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

| H _a -H _b feet | Submergence | | | | | | |
|--|-------------|-------|-------|--------|--------|--------|--------|
| | 65.6% | 70% | 75% | 80% | 85% | 90% | 95% |
| .02 | - | .059 | .072 | .092 | .127 | .199 | .429 |
| .03 | - | .106 | .129 | .156 | .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 | 1.209 | 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 | - | 3.583 | 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 feet | Submergence | | | | | | |
|--|-------------|--------|--------|--------|-----|-----|-----|
| | 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 | 10.151 | 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 feet | Submergence | | | | | | |
|--|-------------|--------|--------|---------|---------|---------|---------|
| | 68.8% | 70% | 75% | 80% | 85% | 90% | 95% |
| .02 | - | .12 2 | .14 0 | .16 6 | .20 6 | .28 0 | .47 4 |
| .03 | - | .19 4 | .22 2 | .26 3 | .32 7 | .44 4 | .75 8 |
| .04 | - | .26 8 | .30 8 | .36 4 | .45 3 | .61 5 | 1.18 0 |
| .05 | - | .34 5 | .39 7 | .46 9 | .58 3 | .79 3 | 1.66 2 |
| .06 | - | .42 5 | .48 8 | .57 7 | .71 7 | .97 5 | 2.20 0 |
| .07 | - | .50 6 | .58 1 | .68 7 | .85 4 | 1.20 7 | 2.78 8 |
| .08 | - | .58 9 | .67 6 | .80 0 | .99 4 | 1.48 2 | 3.47 3 |
| .09 | - | .67 3 | .77 2 | .91 4 | 1.13 6 | 1.77 6 | 4.36 2 |
| .10 | - | .75 8 | .87 0 | 1.03 0 | 1.28 0 | 2.08 8 | 5.41 3 |
| .11 | - | .84 5 | .97 0 | 1.14 8 | 1.48 1 | 2.41 8 | 6.57 9 |
| .12 | - | .93 2 | 1.07 0 | 1.26 7 | 1.69 3 | 2.76 3 | 7.86 3 |
| .13 | - | 1.02 1 | 1.17 2 | 1.38 7 | 1.91 5 | 3.12 5 | 9.26 3 |
| .14 | - | 1.11 0 | 1.27 4 | 1.51 6 | 2.14 6 | 3.50 2 | 10.78 2 |
| .15 | - | 1.20 1 | 1.37 8 | 1.68 6 | 2.38 6 | 3.89 4 | 12.41 8 |
| .16 | - | 1.29 2 | 1.48 3 | 1.86 1 | 2.63 5 | 4.30 0 | 14.17 3 |
| .17 | - | 1.38 4 | 1.58 8 | 2.04 3 | 2.89 2 | 4.82 7 | - |
| .18 | - | 1.47 7 | 1.70 4 | 2.23 1 | 3.15 8 | 5.42 7 | - |
| .19 | - | 1.57 0 | 1.85 1 | 2.42 4 | 3.43 1 | 6.06 2 | - |
| .20 | - | 1.66 4 | 2.00 3 | 2.62 3 | 3.71 3 | 6.73 3 | - |
| .21 | - | 1.75 9 | 2.15 9 | 2.82 7 | 4.00 2 | 7.44 1 | - |
| .22 | - | 1.86 1 | 2.31 9 | 3.03 7 | 4.29 9 | 8.18 5 | - |
| .23 | 1.9 00 | 1.99 2 | 2.48 3 | 3.25 1 | 4.60 3 | 8.96 5 | - |
| .24 | 2.0 29 | 2.12 7 | 2.65 1 | 3.47 1 | 4.91 4 | 9.78 1 | - |
| .25 | 2.1 60 | 2.26 5 | 2.82 3 | 3.69 6 | 5.26 7 | 10.63 4 | - |
| .26 | 2.2 94 | 2.40 5 | 2.99 8 | 3.92 6 | 5.70 7 | 11.52 4 | - |
| .27 | 2.4 31 | 2.54 9 | 3.17 7 | 4.16 0 | 6.16 6 | 12.45 0 | - |
| .28 | 2.5 71 | 2.69 6 | 3.36 0 | 4.39 9 | 6.64 3 | 13.41 2 | - |
| .29 | 2.7 13 | 2.84 5 | 3.54 6 | 4.64 3 | 7.13 8 | 14.41 2 | - |
| .30 | 2.8 59 | 2.99 7 | 3.73 6 | 4.89 1 | 7.65 1 | - | - |
| .31 | 3.0 06 | 3.15 2 | 3.92 9 | 5.14 4 | 8.18 2 | - | - |
| .32 | 3.1 57 | 3.31 0 | 4.12 5 | 5.40 2 | 8.73 2 | - | - |
| .33 | 3.3 10 | 3.47 0 | 4.32 5 | 5.66 3 | 9.30 0 | - | - |
| .34 | 3.4 65 | 3.63 3 | 4.52 8 | 6.00 5 | 9.88 6 | - | - |
| .35 | 3.6 23 | 3.79 9 | 4.73 4 | 6.37 2 | 10.49 1 | - | - |
| .36 | 3.7 83 | 3.96 7 | 4.94 4 | 6.75 1 | 11.11 4 | - | - |
| .37 | 3.9 46 | 4.13 7 | 5.15 7 | 7.14 0 | 11.75 9 | - | - |
| .38 | 4.1 11 | 4.31 0 | 5.37 2 | 7.54 1 | 12.41 5 | - | - |
| .39 | 4.2 78 | 4.48 6 | 5.59 1 | 7.95 3 | 13.09 4 | - | - |
| .40 | 4.4 48 | 4.66 4 | 5.81 3 | 8.37 6 | 13.79 0 | - | - |
| .41 | 4.6 20 | 4.84 4 | 6.03 8 | 8.81 1 | 14.50 6 | - | - |
| .42 | 4.7 95 | 5.02 7 | 6.28 8 | 9.25 7 | - | - | - |
| .43 | 4.9 71 | 5.21 2 | 6.59 8 | 9.71 4 | - | - | - |
| .44 | 5.1 50 | 5.40 0 | 6.91 7 | 10.18 2 | - | - | - |
| .45 | 5.3 31 | 5.59 0 | 7.24 2 | 10.66 2 | - | - | - |
| .46 | 5.5 14 | 5.78 2 | 7.57 6 | 11.15 2 | - | - | - |
| .47 | 5.6 99 | 5.97 6 | 7.91 7 | 11.65 5 | - | - | - |

Table 16. Continued.

| H _a -H _b feet | Submergence | | | | | | |
|--|-------------|----------|---------|---------|-----|-----|-----|
| | 68.8% | 70% | 75% | 80% | 85% | 90% | 95% |
| .48 | 5.8 87 | 6.1 7 2 | 8.26 6 | 12.16 8 | - | - | - |
| .49 | 6.0 76 | 6.3 7 1 | 8.62 2 | 12.69 3 | - | - | - |
| .50 | 6.2 68 | 6.5 7 2 | 8.98 6 | 13.22 9 | - | - | - |
| .51 | 6.4 62 | 6.8 2 3 | 9.35 8 | 13.77 7 | - | - | - |
| .52 | 6.6 57 | 7.1 0 0 | 9.73 8 | 14.33 6 | - | - | - |
| .53 | - | 7.3 8 2 | 10.12 5 | 14.90 6 | - | - | - |
| .54 | - | 7.6 7 0 | 10.52 1 | - | - | - | - |
| .55 | - | 7.9 6 4 | 10.92 3 | - | - | - | - |
| .56 | - | 8.2 6 4 | 11.33 4 | - | - | - | - |
| .57 | - | 8.5 6 9 | 11.75 2 | - | - | - | - |
| .58 | - | 8.8 7 9 | 12.17 9 | - | - | - | - |
| .59 | - | 9.1 9 6 | 12.61 3 | - | - | - | - |
| .60 | - | 9.5 1 8 | 13.05 4 | - | - | - | - |
| .61 | - | 9.8 4 5 | 13.50 4 | - | - | - | - |
| .62 | - | 10.1 7 9 | 13.96 1 | - | - | - | - |
| .63 | - | 10.5 1 8 | 14.42 6 | - | - | - | - |
| .64 | - | 10.8 6 3 | 14.89 9 | - | - | - | - |
| .65 | - | 11.2 1 3 | - | - | - | - | - |
| .66 | - | 11.5 6 9 | - | - | - | - | - |
| .67 | - | 11.9 3 1 | - | - | - | - | - |
| .68 | - | 12.2 9 9 | - | - | - | - | - |
| .69 | - | 12.6 7 2 | - | - | - | - | - |
| .70 | - | 13.0 5 1 | - | - | - | - | - |
| .71 | - | 13.4 3 5 | - | - | - | - | - |
| .72 | - | 13.8 2 6 | - | - | - | - | - |
| .73 | - | 14.2 2 2 | - | - | - | - | - |
| .74 | - | 14.6 2 4 | - | - | - | - | - |
| .75 | - | - | - | - | - | - | - |

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

| H _a -H _b feet | Submergence | | | | | | |
|--|-------------|-------|-------|--------|--------|--------|--------|
| | 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 | 2.955 | 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 | - | - | - |

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Table 17. Continued.

| H _a -H _b feet | Submergence | | | | | | |
|--|-------------|--------|--------|--------|-----|-----|-----|
| | 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 feet | Submergence | | | | |
|--|-------------|----------|----------|----------|----------|
| | 76.5% | 80% | 85% | 90% | 95% |
| .02 | - | .4 22 | .5 85 | .9 27 | 2 .0 35 |
| .03 | - | .6 63 | .9 19 | 1 .4 55 | 3 .1 97 |
| .04 | - | .9 13 | 1 .2 66 | 2 .0 05 | 4 .4 04 |
| .05 | - | 1 .1 71 | 1 .6 23 | 2 .5 71 | 5 .6 47 |
| .06 | - | 1 .4 35 | 1 .9 88 | 3 .1 51 | 6 .9 19 |
| .07 | - | 1 .7 03 | 2 .3 61 | 3 .7 41 | 8 .2 15 |
| .08 | - | 1 .9 75 | 2 .7 40 | 4 .3 41 | 9 .5 33 |
| .09 | - | 2 .2 54 | 3 .1 24 | 4 .9 49 | 10 .8 70 |
| .10 | - | 2 .5 34 | 3 .5 13 | 5 .5 66 | 12 .2 23 |
| .11 | - | 2 .8 18 | 3 .9 06 | 6 .1 89 | 13 .9 64 |
| .12 | - | 3 .1 05 | 4 .3 04 | 6 .8 19 | 16 .4 05 |
| .13 | - | 3 .3 95 | 4 .7 05 | 7 .4 55 | 19 .0 25 |
| .14 | - | 3 .6 87 | 5 .1 10 | 8 .0 97 | - |
| .15 | - | 3 .9 81 | 5 .5 19 | 8 .7 44 | - |
| .16 | - | 4 .2 78 | 5 .9 30 | 9 .5 62 | - |
| .17 | - | 4 .5 77 | 6 .3 44 | 10 .6 97 | - |
| .18 | - | 4 .8 78 | 6 .7 61 | 11 .8 91 | - |
| .19 | - | 5 .1 81 | 7 .1 81 | 13 .1 43 | - |
| .20 | - | 5 .4 85 | 7 .7 18 | 14 .4 52 | - |
| .21 | - | 5 .7 92 | 8 .4 47 | 15 .8 18 | - |
| .22 | - | 6 .1 00 | 9 .2 07 | 17 .2 40 | - |
| .23 | - | 6 .4 09 | 9 .9 97 | 18 .7 18 | - |
| .24 | - | 6 .9 31 | 10 .8 16 | - | - |
| .25 | - | 7 .4 75 | 11 .6 65 | - | - |
| .26 | 6 .2 63 | 8 .0 38 | 12 .5 43 | - | - |
| .27 | 6 .7 16 | 8 .6 19 | 13 .4 51 | - | - |
| .28 | 7 .1 84 | 9 .2 20 | 14 .3 88 | - | - |
| .29 | 7 .6 66 | 9 .8 38 | 15 .3 53 | - | - |
| .30 | 8 .1 62 | 10 .4 75 | 16 .3 47 | - | - |
| .31 | 8 .6 73 | 11 .1 31 | 17 .3 70 | - | - |
| .32 | 9 .1 98 | 11 .8 05 | 18 .4 22 | - | - |
| .33 | 9 .7 37 | 12 .4 96 | 19 .5 02 | - | - |
| .34 | 10 .2 91 | 13 .2 06 | - | - | - |
| .35 | 10 .8 58 | 13 .9 34 | - | - | - |
| .36 | 11 .4 39 | 14 .6 80 | - | - | - |
| .37 | 12 .0 34 | 15 .4 44 | - | - | - |
| .38 | 12 .6 43 | 16 .2 25 | - | - | - |
| .39 | 13 .2 66 | 17 .0 25 | - | - | - |
| .40 | 13 .9 02 | 17 .8 42 | - | - | - |
| .41 | 14 .5 52 | 18 .6 76 | - | - | - |
| .42 | 15 .2 16 | 19 .5 28 | - | - | - |
| .43 | 15 .8 94 | - | - | - | - |
| .44 | 16 .5 84 | - | - | - | - |
| .45 | 17 .2 89 | - | - | - | - |
| .46 | 18 .0 07 | - | - | - | - |
| .47 | 18 .7 38 | - | - | - | - |
| .48 | 19 .4 83 | - | - | - | - |
| .49 | - | - | - | - | - |

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

| H _a -H _b feet | Submergence | | | | |
|--|-------------|----------|----------|----------|----------|
| | 75.4% | 80% | 85% | 90% | 95% |
| .02 | - | .4 88 | .6 74 | 1 .0 63 | 2 .3 19 |
| .03 | - | .7 72 | 1 .0 67 | 1 .6 83 | 3 .6 71 |
| .04 | - | 1 .0 69 | 1 .4 78 | 2 .3 32 | 5 .0 86 |
| .05 | - | 1 .3 77 | 1 .9 03 | 3 .0 03 | 6 .5 49 |
| .06 | - | 1 .6 93 | 2 .3 40 | 3 .6 92 | 8 .0 52 |
| .07 | - | 2 .0 16 | 2 .7 86 | 4 .3 96 | 9 .5 88 |
| .08 | - | 2 .3 45 | 3 .2 41 | 5 .1 14 | 11 .1 55 |
| .09 | - | 2 .6 80 | 3 .7 04 | 5 .8 45 | 12 .7 47 |
| .10 | - | 3 .0 19 | 4 .1 73 | 6 .5 86 | 14 .3 63 |
| .11 | - | 3 .3 64 | 4 .6 49 | 7 .3 37 | 16 .0 01 |
| .12 | - | 3 .7 12 | 5 .1 31 | 8 .0 97 | 17 .6 59 |
| .13 | - | 4 .0 65 | 5 .6 18 | 8 .8 65 | - |
| .14 | - | 4 .4 21 | 6 .1 10 | 9 .6 42 | - |
| .15 | - | 4 .7 80 | 6 .6 07 | 10 .4 26 | - |
| .16 | - | 5 .1 43 | 7 .1 08 | 11 .2 17 | - |
| .17 | - | 5 .5 08 | 7 .6 14 | 12 .0 14 | - |
| .18 | - | 5 .8 77 | 8 .1 23 | 12 .8 18 | - |
| .19 | - | 6 .2 48 | 8 .6 36 | 13 .6 28 | - |
| .20 | - | 6 .6 22 | 9 .1 53 | 14 .4 16 | - |
| .21 | - | 6 .9 99 | 9 .6 73 | 15 .2 64 | - |
| .22 | - | 7 .3 77 | 10 .1 97 | 16 .0 75 | - |
| .23 | - | 7 .7 58 | 10 .7 23 | 16 .8 50 | - |
| .24 | - | 8 .1 42 | 11 .2 53 | - | - |
| .25 | - | 8 .5 27 | 11 .7 86 | - | - |
| .26 | - | 8 .9 15 | 12 .3 22 | - | - |
| .27 | - | 9 .3 04 | 12 .8 59 | - | - |
| .28 | - | 9 .6 95 | 13 .4 00 | - | - |
| .29 | - | 10 .0 89 | 13 .9 45 | - | - |
| .30 | - | 10 .4 84 | 14 .4 94 | - | - |
| .31 | - | 10 .9 27 | 15 .0 46 | - | - |
| .32 | - | 11 .3 70 | 15 .6 01 | - | - |
| .33 | - | 11 .8 12 | 16 .1 58 | - | - |
| .34 | - | 12 .2 53 | 16 .7 17 | - | - |
| .35 | - | 12 .7 77 | 17 .2 78 | - | - |
| .36 | 10 .3 38 | 14 .5 38 | - | - | - |
| .37 | 10 .8 94 | 15 .1 20 | - | - | - |
| .38 | 11 .4 63 | 15 .7 04 | - | - | - |
| .39 | 12 .0 46 | 16 .2 90 | - | - | - |
| .40 | 12 .6 43 | 16 .8 79 | - | - | - |
| .41 | 13 .2 53 | 17 .4 79 | - | - | - |
| .42 | 13 .8 78 | 18 .0 81 | - | - | - |
| .43 | 14 .5 16 | 18 .6 84 | - | - | - |
| .44 | 15 .1 67 | 19 .2 88 | - | - | - |
| .45 | 15 .8 32 | - | - | - | - |
| .46 | 16 .5 11 | - | - | - | - |
| .47 | 17 .2 03 | - | - | - | - |
| .48 | 17 .9 09 | - | - | - | - |
| .49 | 18 .6 29 | - | - | - | - |
| .50 | 19 .3 62 | - | - | - | - |
| .51 | - | - | - | - | - |

