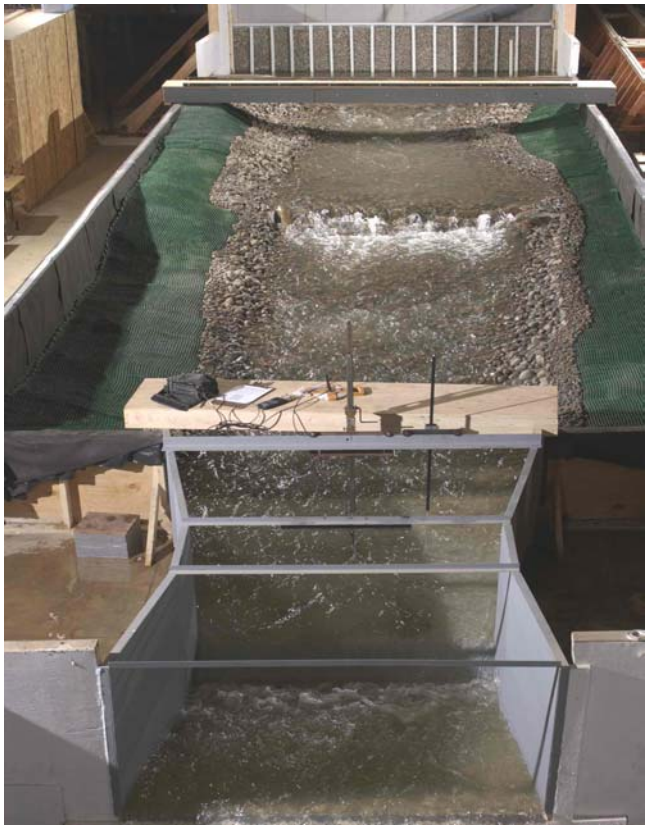
Reese Creek Flume Calibration Study – Phase 3: Parshall Flume Testing

Prepared for:

National Park Service
Water Resources Division
Fort Collins, CO 80525



Prepared by:
Laura G. Girard, Michael D. Robeson,
Christopher I. Thornton (P.I.), Steven R. Abt (Co-P.I.)

February 27, 2004

Colorado State University
Engineering Research Center
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1 INTRODUCTION

Reese Creek, located along the northern boundary of Yellowstone National Park, flows into the Yellowstone River downstream of Gardiner, Montana. Currently, the United States is party to a complex water rights agreement involving the waters of Reese Creek. An agreement was signed in July of 1990 distributing the waters of Reese Creek among four users, including the United States. As part of this agreement, the National Park Service (NPS) is obligated to construct and install flow-measurement structures at appropriate points along Reese Creek.

One currently utilized measurement structure consists of a Parshall flume with a five-foot throat width. NPS hydrologists discovered that the rated discharge for given gage heights within the flume did not agree with the stream gage discharge measurements taken over a range of flows. After a field visit to Reese Creek involving Colorado State University (CSU), Engineering Research Center (ERC) staff, it was hypothesized that the flow entering the flume was in a supercritical state, which the flume was not designed to measure. To aid the NPS with the flow-measurement problems in Reese Creek, CSU proposed a three (3) phase research program.

Phase 1, completed in October of 2001, provided a thorough literature review of flow-measurement structures in supercritical regimes. Phase 2 indicated that calibration equations could be computed for flow-measurement flumes installed in supercritical flow conditions. Additionally, Phase 2 results indicated that a calibration equation would be dependent on the slope and roughness of the approach channel. Objectives for Phase 3 were:

1. to conduct a site visit to quantify the specific conditions at Reese Creek and conduct a field survey to determine the flow conditions, quantify the slope to the flume, conduct a particle-size analysis of the bed, and collect stream-gaging data;

2. to construct a full-scale testing model matching the field conditions found at Reese Creek during the site visit including a Parshall flume with a five-foot throat width; and
3. to generate a rating equation for the modeled condition.

This report provides information and results pertaining to Phase 3 objectives. Additionally, this project was authorized and funded under contract with the National Park Service, Water Resources Division.

2 FIELD SITE VISIT

2.1 INTRODUCTION

One important finding of the Phase 2 research program identified the potential of a Parshall flume to operate in subcritical and supercritical flow regimes. Experimental results showed that separate calibration curves are required to describe the flow for both subcritical and supercritical flow regimes. Additionally, Phase 2 results indicated that a calibration equation would be dependent on the slope and roughness of the channel. A site visit by CSU personnel was conducted in order to quantify the specific conditions at Reese Creek. CSU personnel traveled to Reese Creek and conducted a field survey to determine the flow conditions, quantify the approach slope to the flume, conduct a particle-size analysis of the bed, and collect stream-gaging data. Figure 2.1 presents a photograph of the Upper Reese Creek Parshall flume and surveyed section of the creek, upstream of the flume.

Figure 2.1: Upper Reese Creek Parshall Flume

2.2 FIELD SURVEY

CSU personnel conducted a site visit to Reese Creek on November 8, 2002. During the visit, a forty-eight (48) foot section of Reese Creek, upstream of the Parshall flume, was delineated for data collection. Sixteen (16) channel cross sections were surveyed, Wolman Pebble Counts were obtained at five locations within the reach, and stream gaging was performed at the entrance to the Parshall flume. Figure 2.2 presents a schematic detailing cross-section and pebble count locations.

Topographic survey results showed that the survey reach incorporated a break in bed slope, sixteen (16) feet upstream of the Parshall flume. A natural rock weir, approximately one-half (0.5) foot high, served to segment the approach channel into two (2) distinct approach slopes. The slope above the rock weir was estimated at 0.065 and the slope below the rock weir was estimated at 0.045. Figure 2.3 illustrates the location of the rock weir and the segmented channel bed slope. The average channel width measured during the site visit was eight-and-three fourths (8.75) feet, ranging from 7.7 feet to 10.7 feet.

Results of the Wolman Pebble Count are presented in Table 2.1 and reveal that the average gradation of the bed material ranged from 1.5 (38.1 mm) to 2.9 (78.7 mm) inches in diameter. In accordance with information provided to the project team by NPS staff, Reese Creek was determined to be a cobble bed system. Figure 2.4 presents a photograph of CSU staff conducting the Wolman Pebble Count in section 2.

During the site visit, Reese Creek was stream gaged at the entrance to the Parshall flume. This location was chosen due to the low-flow condition that existed during the visit. At this location, the gaged discharge was approximately 3.36 cubic feet per second (cfs) and the discharge calculated from the staff gage reading utilizing the published rating equation for a

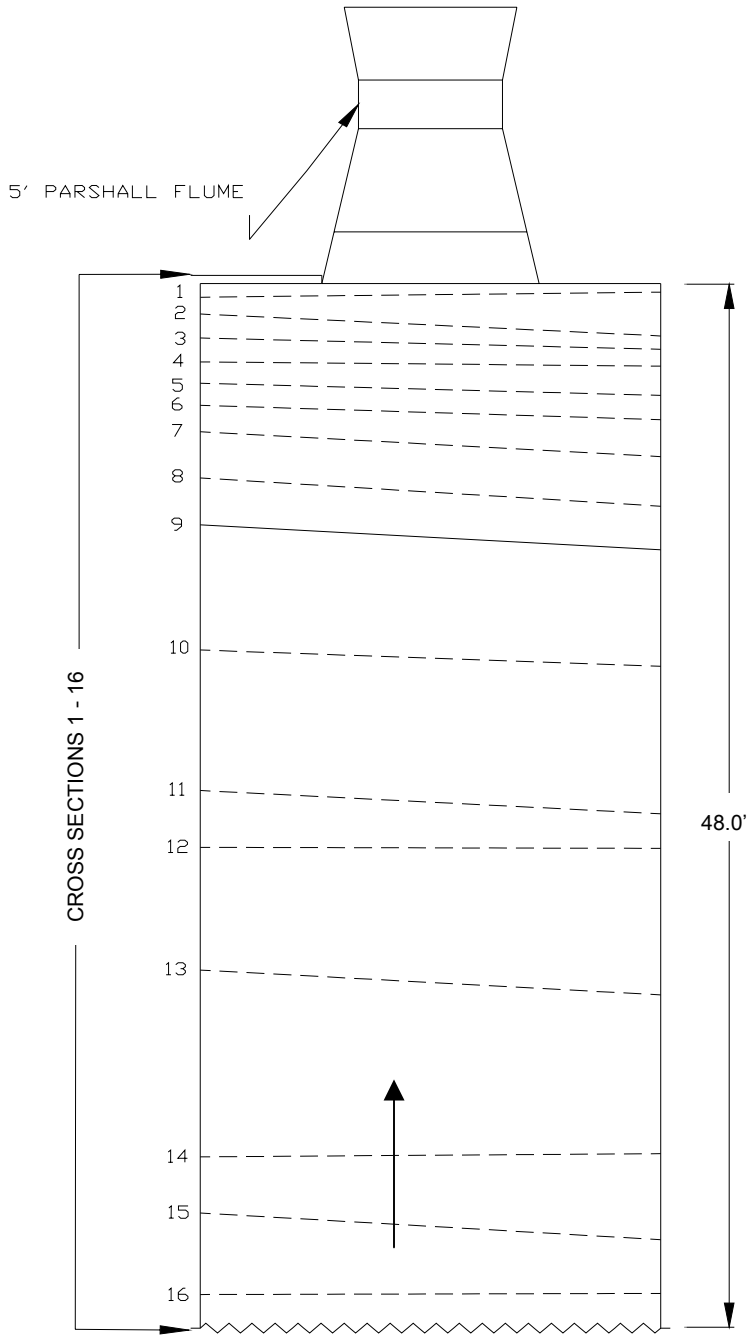

Figure 2.2: Schematic of Cross-section Delineations

Figure 2.3: Illustration of Natural Rock Weir and Channel Bed Slopes

Table 2.1: Results of Wolman Pebble Counts

Pebble Count Section	Cross Sections	Average Diameter (in)
1	1 - 6	1.55
2	7 - 9	2.5
3	10 - 11	2.57
4	12 - 14	1.6
5	15 - 16	2.9

Figure 2.4: CSU Staff Conducting Wolman Pebble Count

five-foot Parshall flume was 2.61 cfs, which is approximately twenty-five (25) percent lower than the gaged value. The reported value from the NPS was thirty-two (32) percent lower, which is consistent with the value calculated during the site visit.

Information collected during the site visit was used to construct a physical model of a portion of Reese Creek in the laboratory at CSU. Channel topography, planform layout and bed material type were formed and duplicated to produce a prototype representation of the channel immediately upstream of the five-foot Parshall flume.

3 TESTING FACILITY

3.1 FACILITY

Laboratory testing was conducted in a sixteen (16) foot wide, fifty-six (56) foot long re-circulating flume. The flume was built in place, with the channel bed shaped to emulate the Reese Creek channel, as determined from field-survey data. Discharge was regulated by two (2) pumps. The first pump was a forty (40) horsepower pump utilizing a sixteen (16) inch diameter pipe capable of regulating discharge up to eleven (11) cfs. The second pump was a seventy-five (75) horsepower pump, with a twenty-four (24) inch diameter pipe capable of regulating discharge up to thirty (30) cfs. Velocity, bed elevations, and water surface elevations were taken with a point gage mounted to a wooden plank that traversed the flume walls.

3.2 FLUME CONSTRUCTION

A flume with the required dimensions was not readily available; therefore, a custom-designed model was constructed for the project. Model construction was divided into three (3) major sections: channel bed and sides, head and tail box, and Parshall flume fabrication.

3.2.1 CHANNEL BED AND SIDES

Initially, two (2) forty-eight (48) foot, parallel walls sixteen (16) feet apart were constructed and secured to the concrete floor of the laboratory. The laboratory model was divided into sixteen (16) cross sections identical to the cross sections delineated in the Reese Creek field survey, as shown in Figure 2.2. Two (2) identical profiles of upstream cross section

16, cut from one-half ($^1/_2$) inch plywood, were installed and filled with sand in order to serve as a physical division between the head box and the channel. Industrial plastic was rolled over the channel walls and floor. The space between the channel walls was filled with silty sand and compacted. Figure 3.1 presents a photograph of the initial soil-installation process. Additionally, Figure 3.1 illustrates the plastic under layer, the channel sidewalls, and the cross section 16 profiles, which can be seen in the background.

Figure 3.1: Initial Soil Installation, Including Channel Sidewalls, Cross Section 16 Profiles, and Industrial Plastic Under Layer

Placed and compacted soil was formed from cross sections 15 through 1 and shaped to fit the cross-section profiles using data obtained from the site visit. A non-woven polypropylene filter fabric was installed on top of the soil to ensure that the channel profile shape was maintained throughout testing by eliminating soil loss. A turf-reinforcement matting (TRM) with a roughness coefficient approximately equivalent to grass, was cut to fit the sides of the

model in an effort to reproduce the characteristics of the Reese Creek channel bank. Once the TRM was in place, rock installation began.

To facilitate an accurate finished bed height, wooden stakes were placed along the cross sections and cut to a height equal to the finished elevation minus the average diameter of the rock in the particular section. This was done to allow the stakes to remain hidden under the finished elevation once rock was placed. Rock size varied among the five (5) sections, which were determined during the Reese Creek Wolman Pebble Count. The particle size within each section was based on the average particle size, which was determined from the pebble count conducted at Reese Creek, as shown in Table 2.1. Average particle size in sections 2 and 3 were similar and, therefore, treated as one (1) combined section. A six (6) inch transition zone of small rocks less than one (1) inch in diameter was installed between the channel rock and the TRM. An additional transition zone was placed at cross section 16 consisting of rock with an approximate diameter of four (4) to five (5) inches. Figure 3.2 is a photograph of the rock-installation process.

Figure 3.2: Rock Installation and Wooden Stakes Marking the Finished Elevation

In order to ensure that the bed would remain immobile during testing, the rock was secured by mortar. A dry mortar mix was spread over the rocks and wetted, thereby setting the mortar in place between the rocks. This process was repeated three (3) times prior to testing to ensure a uniform distribution of mortar within the rock bed. Upon completion of the rock-installation process, the slope of the model was checked and confirmed to represent the slope found during the field survey of Reese Creek.

3.2.2 HEAD AND TAIL BOX

Cement was poured over a convex sand wall adjoining the cross section 16 profile cutouts and the head box area, creating a headwall that would permit a smooth transition from the head box to the channel. Adjacent to the transition area, two (2) eight (8) foot by eight (8) foot walls were erected to serve as sidewalls in the head box. Figure 3.3 depicts the head wall prior to and after the cement pour.

Figure 3.3: Head Box Wall Prior to and Following Cement Installation in the Transition Zone

A six (6) foot high baffle box, intended to diffuse turbulence, was installed spanning the width of the head box. The baffle box was secured to the adjoining head box walls. After installation of the piping system, the head box back wall was installed. A portion of the back wall was custom fit to bring the piping system inside the head box. Finally, head box walls were braced to the concrete floor of the laboratory at one-and-a-half (1 ½) foot intervals to complete the head box.

The installation of two (2) pipes supplying the model was facilitated by a series of pipe modifications, extensions, and diversions fabricated by the ERC Shop staff. The first, a twenty-four (24) inch pipe, was powered by a seventy-five (75) horsepower pump, which was fed directly out of the underground sump. The second, a sixteen (16) inch pipe, was powered by a forty (40) horsepower pump, which was also fed directly out of the underground sump. Figure 3.4 shows the finished pipe system, baffle box, and head box as initial filling of the model commences.

Figure 3.4: Piping System and Baffle Box in Head Box

A sixteen (16) foot by eight (8) foot tail box with a height of four (4) feet was constructed surrounding the grate where the model emptied into the underground sump system. The tail box facilitated capture of overflow and minimized splash and was installed using the same method as the head box, complete with plastic tubing along the base of each section to prevent water leakage. Figure 3.5 is a photograph of the completed tail box.

Figure 3.5: Flume and Tail Box

3.2.3 PARSHALL FLUME

A Parshall flume was constructed of steel sheets by the ERC Shop staff. Steel panels were welded to create a continuous flume and was braced with one-quarter (¼) inch thick, one (1) inch by one (1) inch angle iron in a pattern similar to the bracing of the Parshall flume found in Reese Creek. Design specifications based on the Water Measurement Manual (Bureau of Reclamation, 1984) were compared with the measured field specifications of the Parshall flume

and it was decided that both were similar enough to warrant the use of the Water Measurement Manual specifications. A schematic of the design parameters is presented in Figure 3.6. Figure 3.7 illustrates a plan view drawing of the five-foot Parshall flume installed in the model.

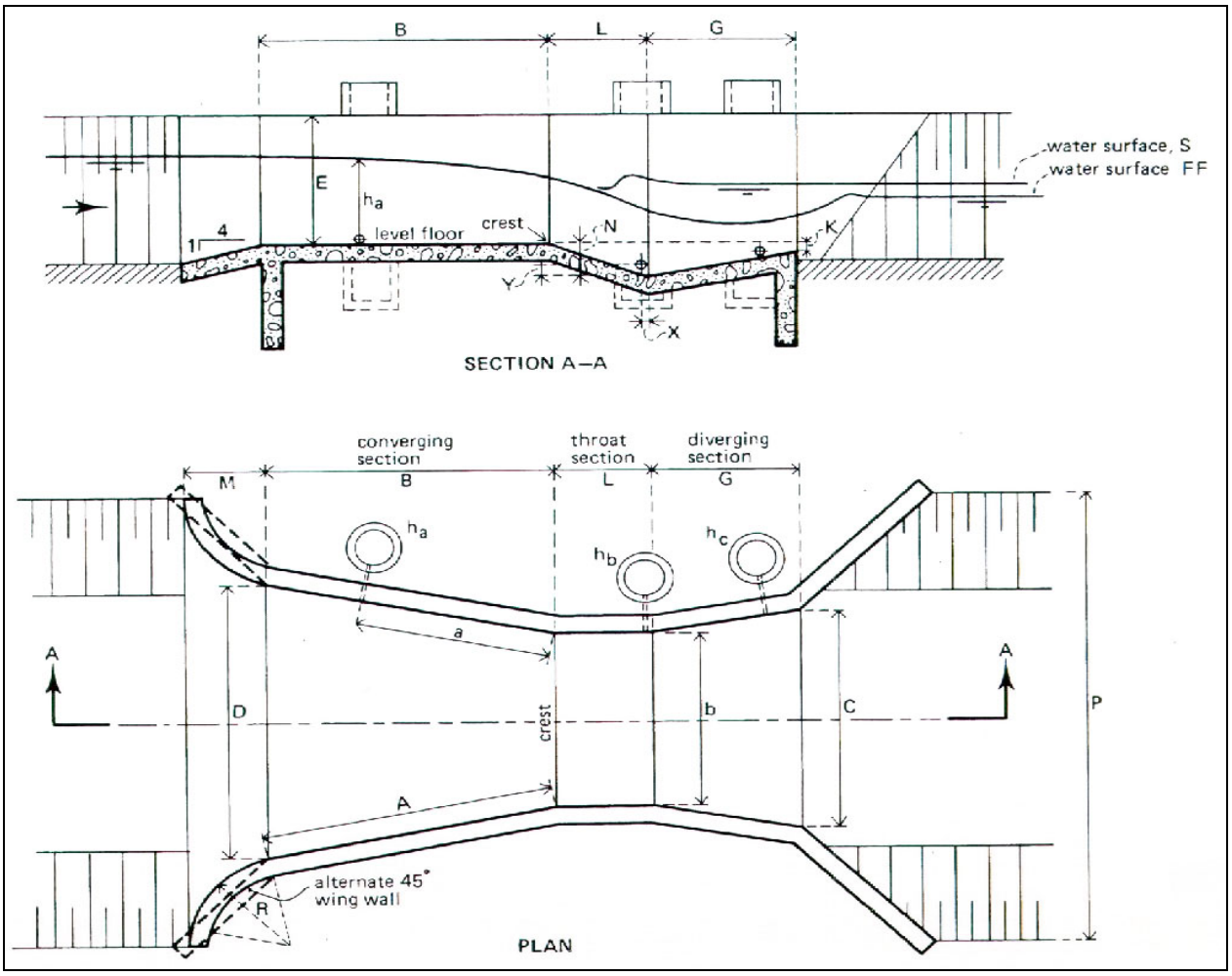

Figure 3.6: Dimensions of Parshall Flume (Bos et al., 1989)

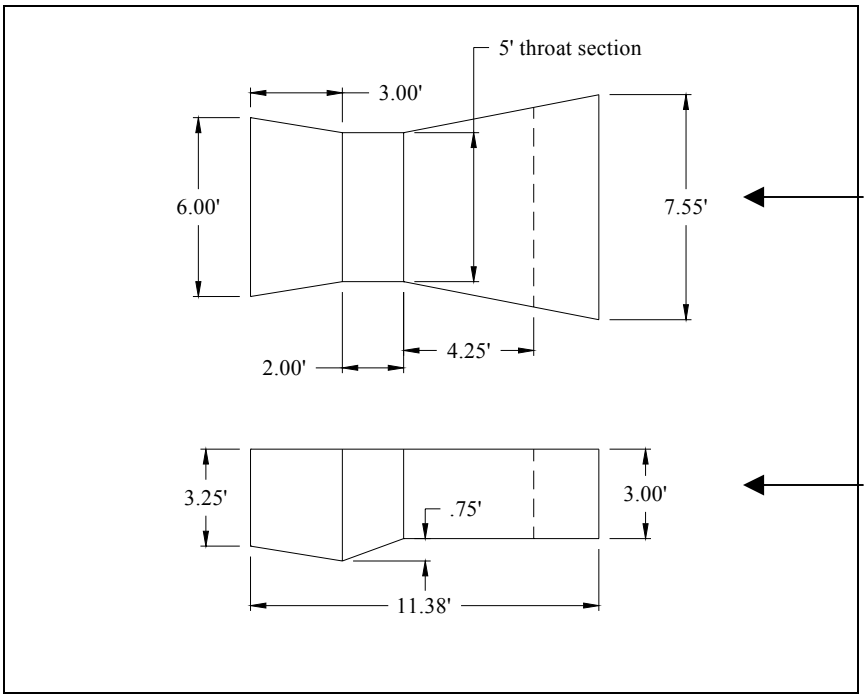

Figure 3.7: Plan View Drawing of the Five-foot Parshall Flume

Two (2) staff gages were installed, one on each side of the flume, at the locations specified by the Water Measurement Manual (Bureau of Reclamation, 1984), yielding two h_a measurement locations at two-thirds (2/3) of the converging section length. Figure 3.8 illustrates one (1) of the two (2) staff gages used for h_a measurement and the point gage utilized to take bed and water surface elevation readings.

Figure 3.8: Staff Gage for h_a Measurement

At the downstream end of the channel bed, two (2) three (3) foot wing walls were erected perpendicular to the flume sidewalls. The wing walls were modeled to emulate the concrete wing walls of the Parshall flume installed in Reese Creek.

In order to set the proper entrance elevation of the Parshall flume, the flume was shimmed using a nine (9) inch high wood frame. Prior to flume installation, an evaluation was made of the Reese Creek field-survey data to determine disparity in flume level. Upon completion of flume installation, the model flume was surveyed. It was determined that the discrepancies in level in the Reese Creek flume were satisfactorily matched in the laboratory. A photograph of the completed five-foot Parshall flume and channel bed is shown in Figure 3.9. A detailed schematic of the entire testing flume after completion is illustrated in Figure 3.10.

Figure 3.9: Completed Installation of Five-foot Parshall Flume

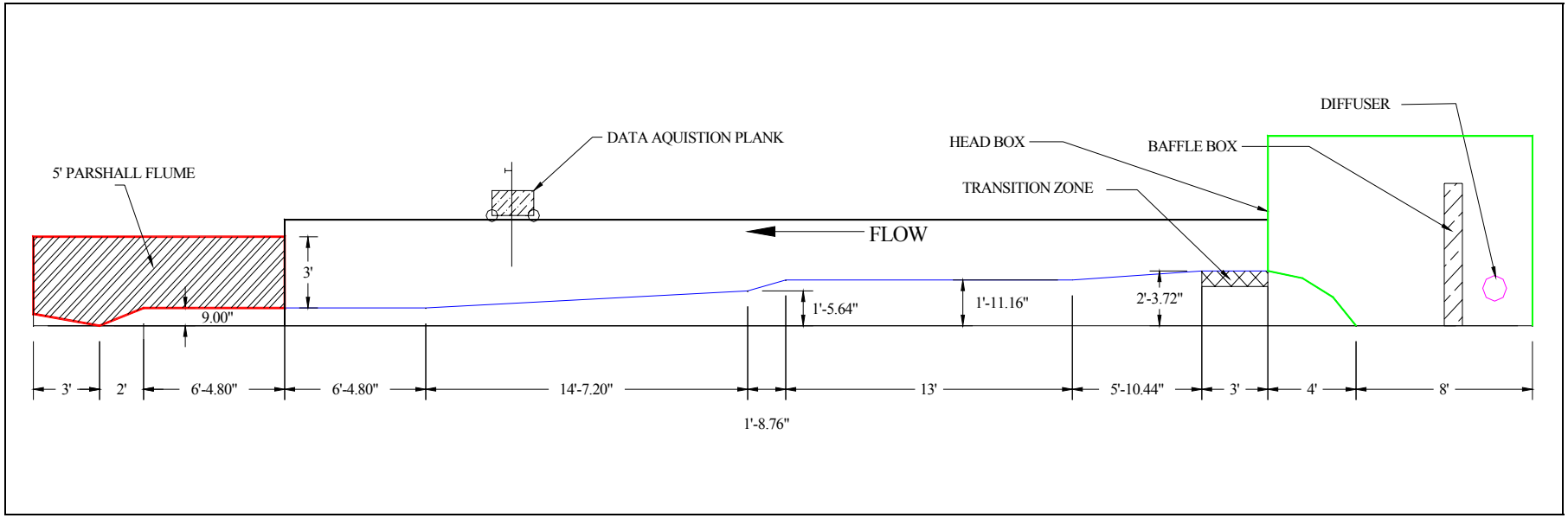

Figure 3.10: Profile View of the Testing Flume

4 TESTING

4.1 INTRODUCTION

Testing for Phase 3 was conducted in a full-scale model constructed on site in the Hydraulics Laboratory. Testing began in the first week of July of 2003 and was completed in the first week of August of 2003. Twelve (12) independent tests comprise the test matrix. Table 4.1 presents the test matrix, which includes projected discharge. Testing was conducted at twelve (12) different discharges ranging from two (2) cfs to thirty (30) cfs. A complete set of data is included in Appendix A.

Table 4.1: Test Matrix

Test Number	Parshall Flume Size (ft)	Approach Bed Slope	Target Discharge (ft^3/s)
1	5	4.38%	2
2	5	4.38%	3
3	5	4.38%	4
4	5	4.38%	5
5	5	4.38%	6
6	5	4.38%	7
7	5	4.38%	8
8	5	4.38%	10
9	5	4.38%	15
10	5	4.38%	20
11	5	4.38%	25
12	5	4.38%	30

4.2 TESTING PROCEDURE

The forty-eight (48) foot test section was broken down into sixteen (16) separate increments based on cross sections laid out during the survey of Reese Creek. Data collection consisted of water surface and bed elevation readings and velocity, taken at twenty (20), sixty (60), and eighty (80) percent of the depth. Velocity and water depth measurements were not collected in the initial four-and-a-half (4.5) feet of the test section as flow was in transition between the head box and the channel. Consequently, data were recorded over an approximately thirty-eight (38) foot test section downstream of the model entrance. Data were collected at each cross section along the flume centerline. Additionally data were collected at the flume entrance, h_a, and the beginning of the throat section. This data-collection system allowed data to be collected at eighteen (18) different cross sections along the model. Velocity readings were taken with a Marsh McBirney velocity meter and depth readings were taken from a point gage mounted on a data-acquisition cart that traversed the model walls. Figure 4.1 displays the locations where data were collected. During testing, the measurement of depth associated with h_a was observed to fluctuate. The range in fluctuation was recorded for analysis.

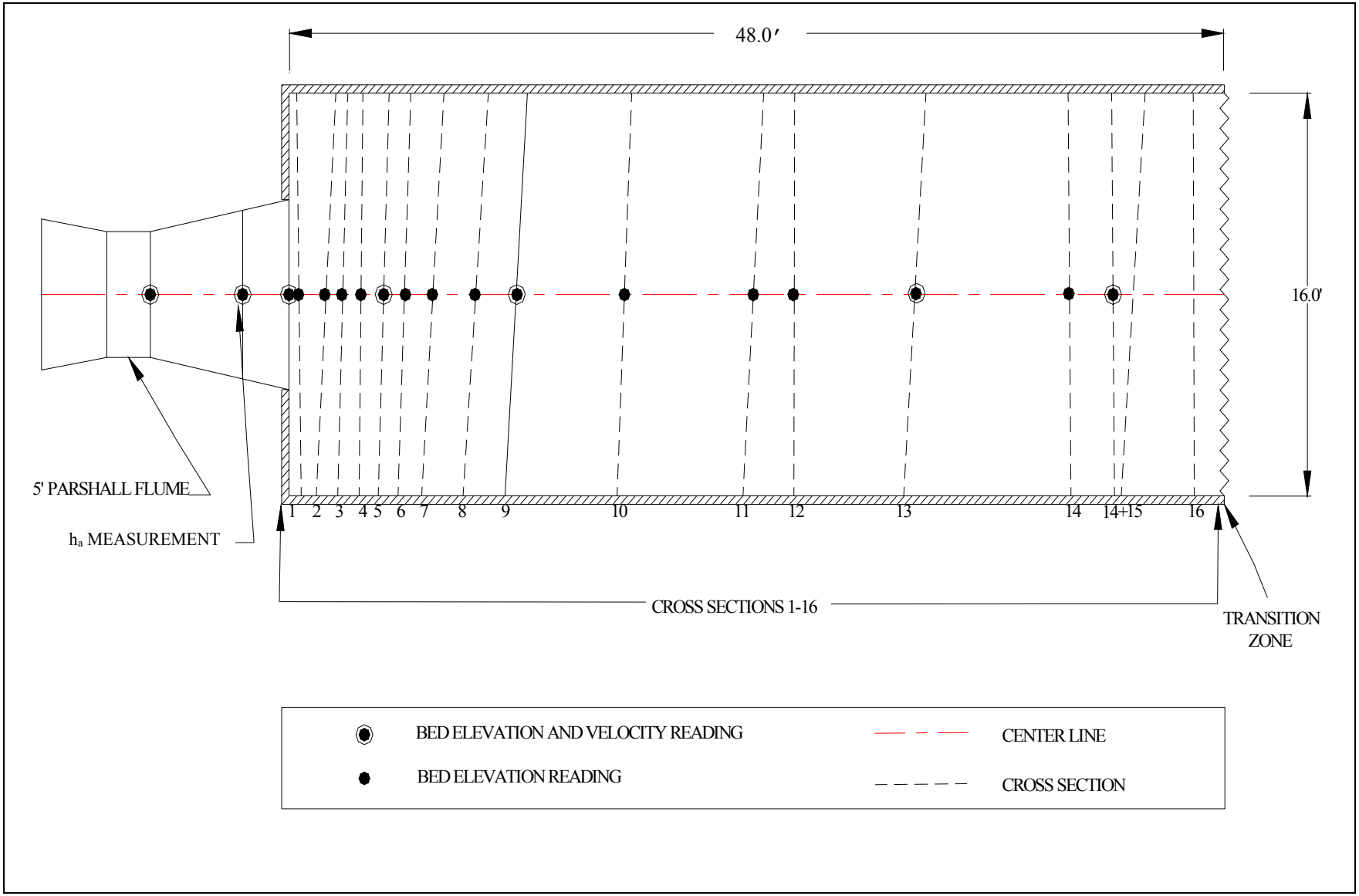

Figure 4.1: Plan View of Data-collection Locations

5 DATA ANALYSIS

5.1 INTRODUCTION

Upon completion of testing, all recorded data were transferred to a database for analysis. Once all data were organized within the database, analysis procedures were initiated. Subsequent sections discuss and present the variables contained within the database, how these variables were utilized for the development of an empirical calibration equation, and finally a discussion of the data analysis results.

5.2 DATABASE

Table 5.1 presents and describes each variable included in the database for analysis. For some conditions, velocity readings were unattainable due to shallow depth. Table 5.2 presents the database used for analysis.

Table 5.1: Database Variable List and Description

Variable	Description
Parshall Flume Size	Throat width of Parshall flumes tested. Designated by dimension "b" in Figure 3.7
h	Flow depth recorded at each cross section in feet
V	Velocity corresponding to the appropriate cross section in ft/s
Q	Flow rate recorded for each individual run in cfs
h_a	Flow depth measured at the specified h_a location in Figure 3.7

Table 5.2: Database

Test Number	Discharge (ft^3/s)	h_a Measurement (ft)	Flow Regime at h_a
1	2.0	0.215	Subcritical
2	3.1	0.275	Subcritical
3	4.0	0.315	Subcritical
4	5.0	0.355	Subcritical
5	6.1	0.4	Supercritical
6	7.0	0.425	Supercritical
7	8.1	0.455	Supercritical
8	10.0	0.505	Supercritical
9	15.0	0.595	Supercritical
10	20.0	0.7	Supercritical
11	25.0	0.805	Supercritical
12	30.1	1	Supercritical

Determination of flow regime was established using the dimensionless Froude number. The Froude number represents a ratio of the relative influence of inertia in the flow to the gravitational force driving the flow. Generally, the Froude number can be defined as:

$$Fr = \frac{V}{\sqrt{gh}} \qquad \textbf{Equation 5.1}$$

where: Fr = Froude number;
V = average cross-sectional velocity (ft/s);
g = gravitational constant (ft/s^2); and
h = flow depth (ft).

Specific energy can be defined as the sum of the flow depth and velocity head at a cross section along the channel. The critical Froude number can be defined for the condition of minimum specific energy and can be seen in Equation 5.2. Critical conditions occur at the location of minimum specific energy and yield a Froude number equal to unity.

$$Fr_c = \frac{V_c}{\sqrt{gh_c}} = 1 \qquad \textbf{Equation 5.2}$$

where: Fr_c = critical Froude number;
V_c = critical average cross-sectional velocity (ft/s);
g = gravitational constant (ft/s^2); and
h_c = critical flow depth (ft).

Froude numbers can also be categorized for flow depths greater than or less than h_c. When a flow depth exceeds the value of h_c for a given discharge, the Froude number will drop below unity and the flow can be classified as subcritical. Correspondingly, when a flow depth drops below the value of h_c for a given discharge, the Froude number will exceed unity and the flow can be classified as supercritical. Table 5.3 presents a summary of specific energy and Froude number concepts.

Table 5.3: Summary of Specific Energy and Froude Number Concepts

Flow Regime	Flow Depth	Specific Energy	Froude Number
Subcritical	$h > h_c$	$E > E_{min}$	$F_r < 1$
Critical	$h = h_c$	$E = E_{min}$	$F_r = 1$
Supercritical	$h < h_c$	$E > E_{min}$	$F_r > 1$

5.3 EMPIRICAL EQUATION DEVELOPMENT

The Parshall flume belongs to a general class of open-channel water measuring devices known generally as Venturi flumes (Bureau of Reclamation, 1984). These devices depend on contraction of the flow either by tapering the sidewalls of the flume, or by changing the elevation of the flume floor, or both (Bureau of Reclamation, 1984). For any given Parshall flume, each

value of discharge (Q) has a corresponding head (h_a) measured from the floor and can be expressed in the following general form:

$$Q = ah_a^{\ b} \qquad \textbf{Equation 5.3}$$

where: Q = discharge (ft^3/s);
a = flume geometry coefficient;
h_a = height of flow measured from flume floor (ft); and
b = flume geometry exponent.

The published rating equation for the five-foot Parshall flume used throughout the testing program is presented in Table 5.4 (Bureau of Reclamation, 1984). Figure 5.1 presents the plot of discharge (Q) versus h_a for the published equation given in Table 5.4. In Figure 5.1, the "Power" equation represents the line fit to the data utilizing a power equation as illustrated in Equation 5.3.

Table 5.4: Published Rating Equation for Five-foot Parshall Flumes

Flume Size	Flow Regime	a	b	Equation
5 foot	Subcritical	20.00	1.59	$Q = 20.00h_a^{1.59}$

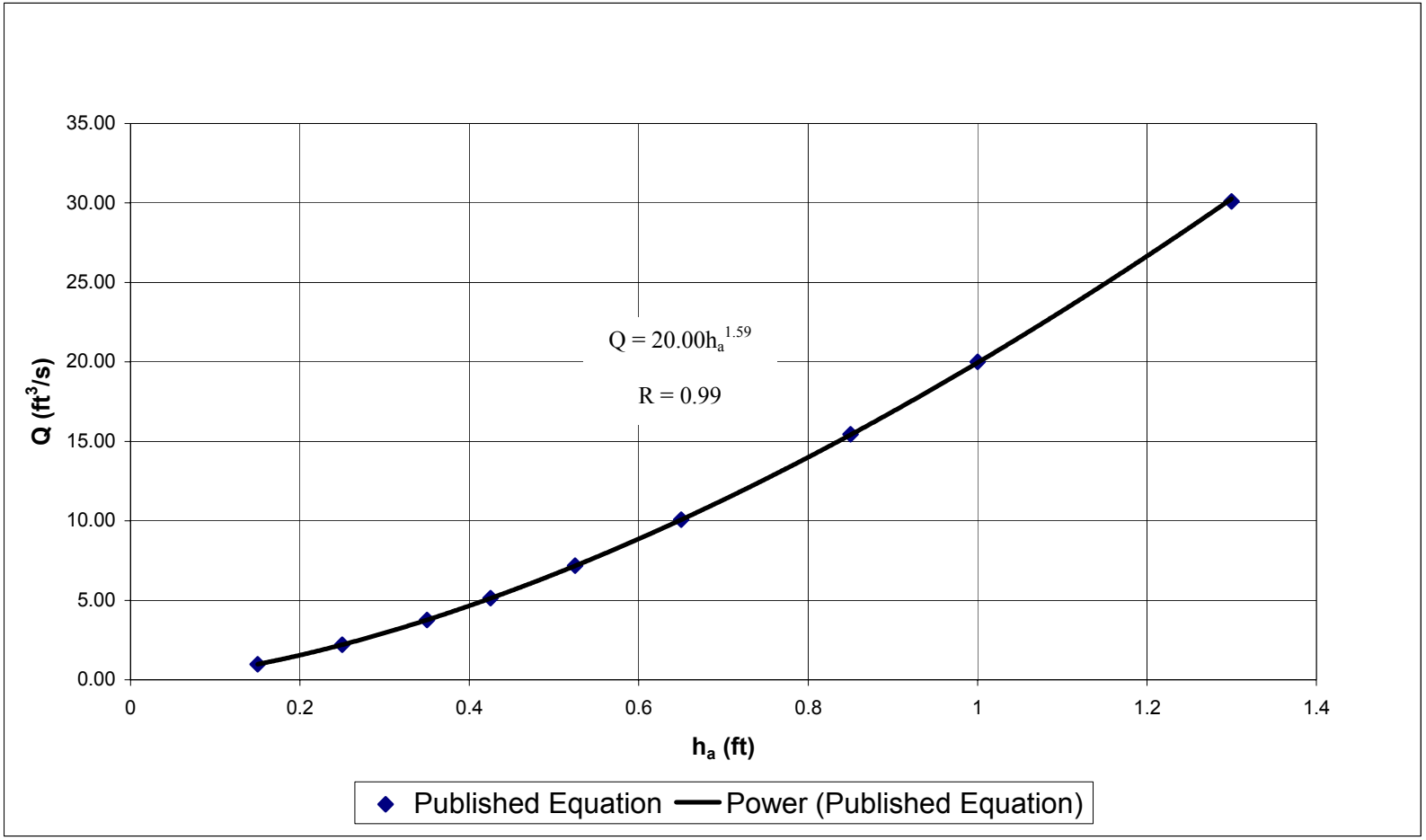

Figure 5.1: Plot of the Published Discharge Rating Curve for the Five-foot Parshall Flume

According to the Bureau of Reclamation (1984), when values of a and b are determined from actual measurements, a flume can be considered calibrated. The measured variables presented in Table 5.1 were used to develop an equation of the general form of Equation 5.3. The new equation is presented in Equation 5.4. Equation 5.4 has a measure of goodness-of-fit (R^2) of 0.998, indicating that at least ninety-nine-and-eight-tenths (99.8) percent of the variability in the data can be explained with the equation. Because the Parshall flume installed in Reese Creek utilizes a direct staff-gage reading for determining h_a, the following equation was computed only from direct staff-gage measurements recorded during testing:

$$Q = 38.22h_a^{1.943} \qquad \textbf{Equation 5.4}$$

Figure 5.2 presents a plot of discharge (Q) versus h_a for the experimental equation, Equation 5.4. In Figure 5.2, the "Power" equation represents the line fit to the data utilizing a power equation. Figure 5.3 displays a plot of both the published and the experimental equations.

For the purposes of examining Equation 5.4, a plot of predicted versus observed discharge is presented in Figure 5.4. Figure 5.4 indicates that Equation 5.4 can be considered a reliable prediction equation, having points both above and below the line of equal prediction. In addition, when the slope of the line plotted through the data points is equal to 1.00, there is perfect agreement between predicted and observed. As shown in Figure 5.4, the slope of the line is 1.01, indicating that there is near perfect agreement between predicted and observed values of discharge.

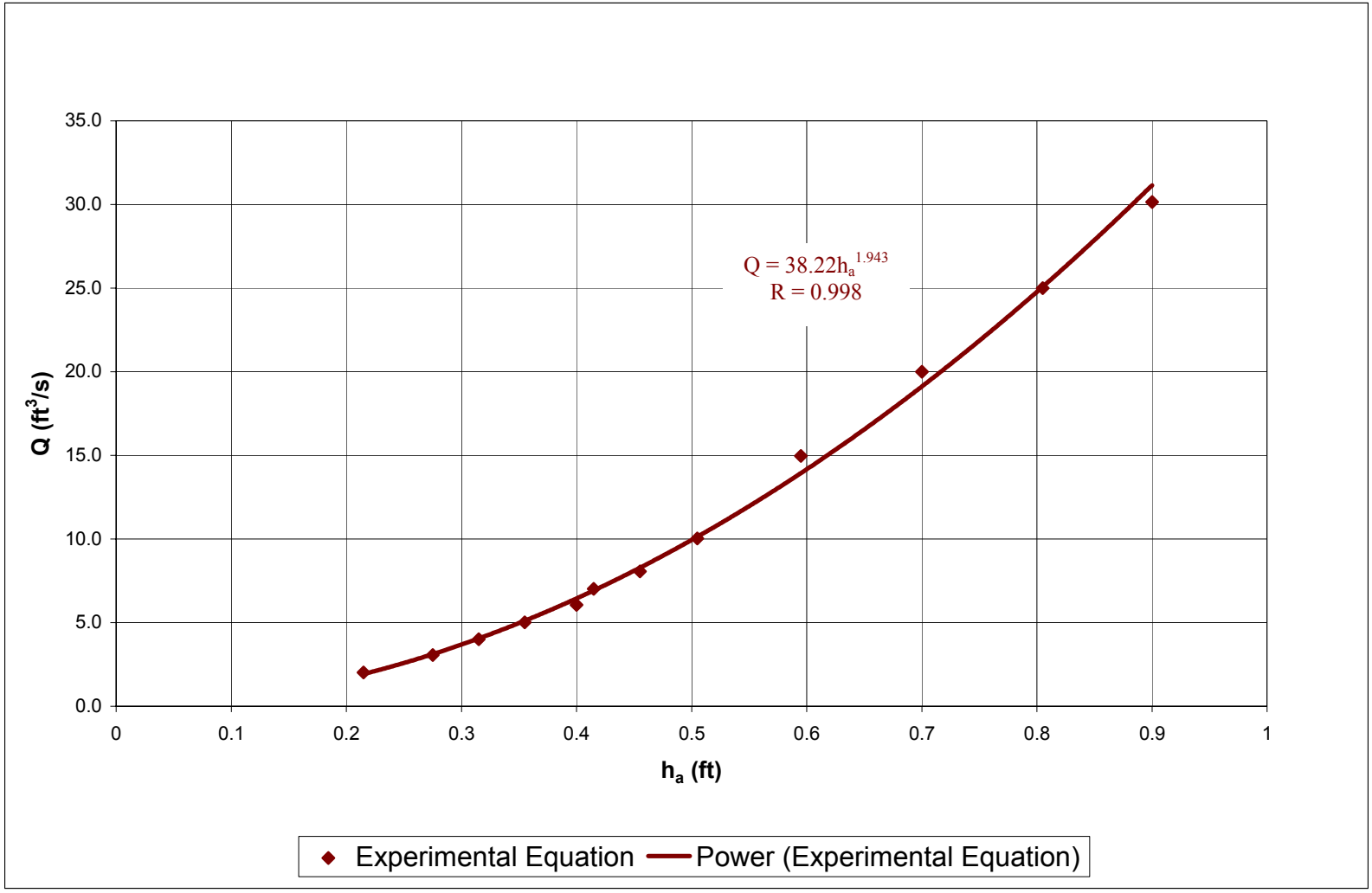

Figure 5.2: Plot of the Experimental Discharge Rating Curve for the Five-foot Parshall Flume

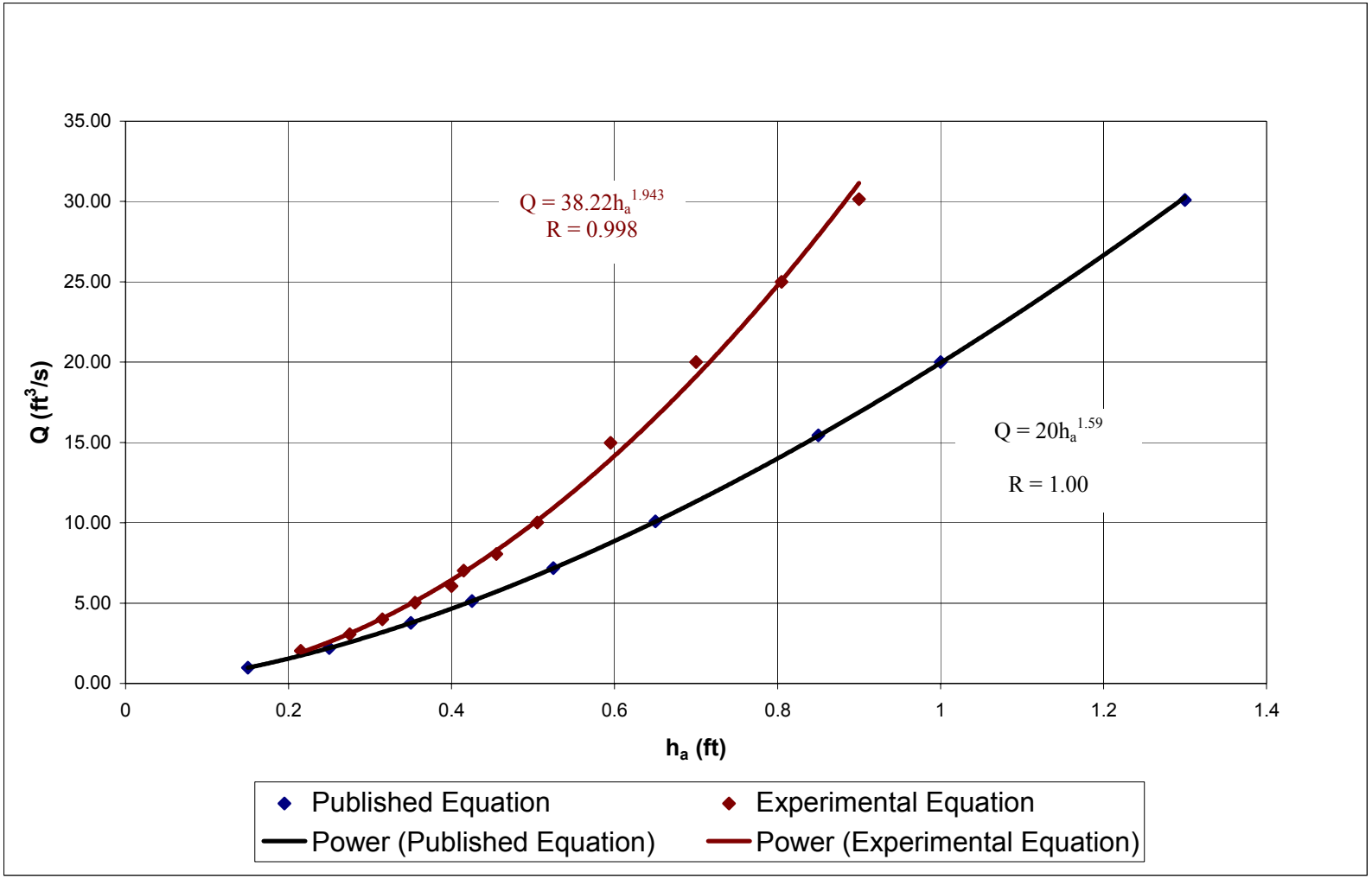

Figure 5.3: Plot of the Experimental and Published Discharge Rating Curves for the Five-foot Parshall Flume

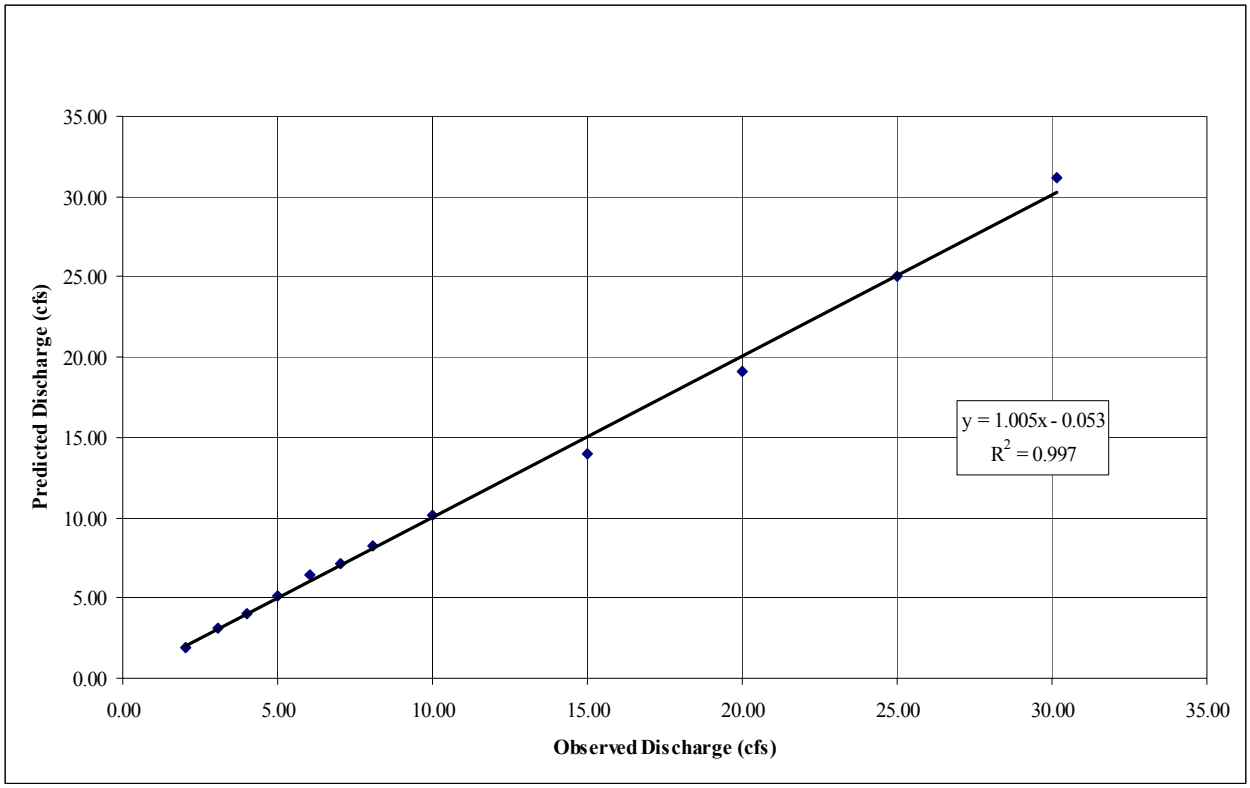

Figure 5.4: Plot of Predicted versus Observed Discharge

5.4 SENSITIVITY ANALYSIS

The empirical relationship presented in Equation 5.4 was analyzed for sensitivity to variations in h_a measurements as observed during testing. The empirical equation presented in Equation 5.4 was utilized to compute discharges for incremental values of h_a. Performing a statistical analysis on the fluctuating h_a measurements determined the sensitivity of the empirically developed equations to variations in h_a measurements.

For comparison purposes, only the average of h_a was utilized for sensitivity analysis. The applicable h_a average was determined from the range of h_a values observed during testing as shown in Tables 5.5, 5.6, and 5.7. Predicted discharges were then computed utilizing the

developed equation and the applicable h_a range. Percent error between the actual values and predicted values was computed by utilizing Equation 5.5.

$$\%_{Error} = \left(\frac{Q_{predicted} - Q_{actual}}{Q_{actual}} \right) * 100 \qquad \textbf{Equation 5.5}$$

Negative percent errors indicated that the predicted value was less than the observed value and positive percent errors indicated that the predicted value was greater than the observed value. Percent error for variations in predicted discharge from the actual discharge was determined and is presented in Tables 5.5, 5.6, and 5.7.

Table 5.5: Calculation of Discharge for Average Recorded Range of h_a

Q (ft^3/s)	Range of h_a (ft)	Average h_a (ft)	Calculated Q (ft^3/s)	Error %
2.03	0.21 - 0.22	0.215	1.93	-4.93
3.07	0.27 - 0.28	0.275	3.11	1.30
4.00	0.3 - 0.33	0.315	4.05	1.25
5.02	0.35 - 0.38	0.355	5.11	1.79
6.07	0.39 - 0.41	0.4	6.45	6.26
7.03	0.41 - 0.44	0.421	7.12	1.28
8.06	0.43 - 0.48	0.455	8.28	2.73
10.03	0.49 - 0.52	0.505	10.14	1.10
14.98	0.58 - 0.61	0.595	13.94	-6.94
20.01	0.68 - 0.72	0.7	19.12	-4.45
25.00	0.78 - 0.83	0.805	25.08	0.32
30.15	0.87 - 0.93	0.9	31.15	3.32
			Average:	**0.25**

Table 5.6: Calculation of Discharge for Lower Recorded Range of h_a

Q (ft^3/s)	Range of h_a (ft)	Lower Range of h_a (ft)	Calculated Q (ft^3/s)	Error %
2.03	0.21 - 0.22	0.21	1.84	-9.14
3.07	0.27 - 0.28	0.27	3.00	-2.28
4.00	0.3 - 0.33	0.3	3.69	-7.75
5.02	0.35 - 0.38	0.35	4.97	-1.00
6.07	0.39 - 0.41	0.39	6.14	1.24
7.03	0.41 - 0.44	0.41	6.76	-3.78
8.06	0.43 - 0.48	0.43	7.42	-7.94
10.03	0.49 - 0.52	0.49	9.56	-4.64
14.98	0.58 - 0.61	0.58	13.27	-11.39
20.01	0.68 - 0.72	0.68	18.07	-9.67
25.00	0.78 - 0.83	0.78	23.59	-5.62
30.15	0.87 - 0.93	0.87	29.16	-3.27
			Average:	**-5.44**

Table 5.7: Calculation of Discharge for Upper Recorded Range of h_a

Q (ft^3/s)	Range of h_a (ft)	Upper Range of h_a (ft)	Calculated Q (ft^3/s)	Error %
2.03	0.21 - 0.22	0.22	2.02	-0.25
3.07	0.27 - 0.28	0.28	3.22	4.89
4.00	0.3 - 0.33	0.33	4.44	11.00
5.02	0.35 - 0.38	0.38	5.83	16.14
6.07	0.39 - 0.41	0.41	6.76	11.46
7.03	0.41 - 0.44	0.44	7.76	10.45
8.06	0.43 - 0.48	0.48	9.19	14.02
10.03	0.49 - 0.52	0.52	10.73	7.03
14.98	0.58 - 0.61	0.61	14.63	-2.30
20.01	0.68 - 0.72	0.72	20.19	0.92
25.00	0.78 - 0.83	0.83	26.61	6.46
30.15	0.87 - 0.93	0.93	33.20	10.13
			Average:	**7.50**

A basic hydraulic analysis was performed for the measured channel conditions for sensitivity to changes in Manning's n values and changes in bed slope. It was found that a ten

(10) percent deviation in Manning's n resulted in an approximate five (5) percent increase or decrease, respectively, in depth. For a ten (10) percent variation in bed slope the depth reflected a less than three (3) percent increase or decrease, respectively, in depth.

5.5 DISCUSSION OF RESULTS

At the completion of testing, the database presented in Table 5.2 was compiled. From the database, an empirical calibration equation was developed. A sensitivity analysis was then conducted on the empirical calibration equation to determine the sensitivity of the developed equation to variations in estimation of a staff-gage reading at two-thirds (2/3) of the converging section length (h_a). The results of this analysis are presented in the following sections.

5.5.1 EMPIRICAL CALIBRATION EQUATION

The measured variables presented in Table 5.2 were used to develop an empirical calibration equation for the upper Parshall flume in Reese Creek. The calibration equation is presented as Equation 5.4. Equation 5.4 has a measure of goodness-of-fit (R^2) of 0.998, indicating that at least ninety-nine-and-eight-tenths (99.8) percent of the variability in the data can be explained with the equation.

Testing was performed on discharges ranging from two (2) cfs to thirty (30) cfs. Reliability of Equation 5.4 outside of this range is unknown.

During the course of testing, both subcritical and supercritical flow regimes were observed. Subcritical was observed at h_a for five (5) cfs and below. Supercritical flow existed

for six (6) cfs and greater. An eddy was observed within the Parshall flume for flow in both the subcritical and supercritical flow regimes.

5.5.2 SENSITIVITY ANALYSIS

A sensitivity analysis was performed for variations in staff-gage measurements at two-thirds (2/3) of the converging section length (h_a). Variations were based on the observed h_a measurement. The average, upper observed, and lower observed boundaries of h_a staff-gage measurements were analyzed for percent error from calculated values of h_a. The average percent errors associated with each of the h_a variations (average, upper observed, and lower observed) were 0.25 %, -5.44 %, and 7.50 %, respectively.

A second sensitivity analysis was performed for variations in Manning's n and changes in bed slope and the resulting depth change. The analysis yielded that a ten (10) percent disparity in Manning's n from the current conditions may result in an approximate five (5) percent variation in depth. Additionally, a ten (10) percent change in bed slope from the current conditions could result in a less than three (3) percent change in depth. The resultant changes in depth computed across variations in Manning's n and bed slope appear to fall within the reported maximum variability of the rating equation presented herein. Therefore, variations in either parameter less than or equal to ten (10) percent would allow for continued use of the empirical equation. Discrepancies in Manning's n or bed slope outside the range of ten (10) percent error would require modification of the empirically calibrated equation. This modification could be performed by CSU with minimal time and effort.

5.6 APPLICATION PROCEDURE

An application procedure was developed to provide users a systematic methodology for utilizing Equation 5.4 for the five-foot Parshall flume located in Reese Creek.

To apply Equation 5.4, the following steps should be completed. Where all measurements are recorded in feet.

1. A flow depth measured upstream from the crest of the Parshall flume at a distance of two-thirds (2/3) of the converging section length (h_a) must be determined from a staff gage placed on the left side of the flume;
2. Fluctuations in height of flow at two-thirds (2/3) of the converging section length (h_a) are to be observed for several minutes and the range of height of flow at two-thirds (2/3) of the converging section length (h_a) recorded;
3. Calculate the average of the range of height of flow at two-thirds (2/3) of the converging section length (h_a); and
4. Use Equation 5.4 to estimate discharge given the average flow depth measured upstream from the crest of the Parshall flume at a distance of two-thirds (2/3) of the converging section length (h_a). The absolute average expected error associated with the use of Equation 5.4 and the above procedure is less than three (3) percent. The maximum expected error associated with the use of Equation 5.4 and the above procedure is ± seven (7) percent.

6 CONCLUSIONS AND RECOMMENDATIONS

Parshall flume testing was conducted in the Hydraulics Laboratory at CSU to determine the empirical calibration equation to accurately predict discharge for a Parshall flume located in Reese Creek. Laboratory testing was conducted in a sixteen (16) foot wide, fifty-six (56) foot long re-circulating flume. Testing yielded a database containing twelve (12) discharge variations, ranging from two (2) cfs to thirty (30) cfs, as presented in Table 5.2. From this database, an empirical calibration equation was developed with an accuracy of ninety-nine-and-eight-tenths (99.8) percent.

In order to meet the first objective of Phase 3 of this study, a field survey of Reese Creek was conducted. During the Reese Creek survey, CSU personnel were able to determine the flow conditions, quantify the approach slope to the flume, conduct a particle size analysis of the bed, and collect stream-gaging data. A forty-eight (48) foot section of Reese Creek upstream of the Parshall flume was divided into sixteen (16) cross sections and surveyed. Within the forty-eight (48) foot section, five (5) Wolman Pebble Counts were conducted. The average diameters found during the Wolman Pebble Counts are presented in Table 2.1.

To meet the second objective of Phase 3, a custom designed flume was constructed for the project. The flume was built in place, with the channel bed shaped to emulate the Reese Creek channel bed. Four (4) sections of rock were placed and secured within the model channel bed. Rock size in each section was determined by the results of the Wolman Pebble Count conducted at Reese Creek. A Parshall flume was constructed of steel sheets and installed with discrepancies in level matching the Parshall flume in Reese Creek.

To meet the third objective of Phase 3, testing was conducted at a range of discharges and staff-gage readings for h_a measurements were recorded. From the recorded data, an empirical calibration equation was developed, Equation 5.4. To determine sensitivity of Equation 5.4 to variations in h_a measurements, a sensitivity analysis was performed. The average error in discharge between the observed discharge and the predicted discharge calculated from the average observed h_a measurement was less than one (1) percent. The maximum error in discharge between the observed discharge and the predicted discharge calculated from the average observed h_a measurement was approximately ± seven (7) percent.

In addition, during the course of testing both subcritical and supercritical flow regimes were observed. Subcritical flow was observed during the lower flows, less than five (5) cfs. Supercritical flow was observed for flows of six (6) cfs and greater.

It is recommended that the application procedure presented in Section 5.6 be utilized to determine discharge at the five-foot Parshall flume installed along Reese Creek. It is also recommended that an analysis of the available data for the Reese Creek system be performed.

7 REFERENCES

Bos, M.G. et al. (1975, Revised 1989). "Discharge Measurement Structures." International Institute for Land Reclamation and Improvement, The Netherlands.

Bureau of Reclamation (1953, Revised 1984). "Water Measurement Manual." U.S. Department of the Interior, Denver, Colorado.

APPENDIX A – EXPANDED DATA TABLES

Table A.1: National Park Service: Five-foot Parshall Flume Calibration – Test 1, 2 cfs Target Discharge

	Elevation (ft)
Staff Gage Reading	.21-.22

Notes

- velocity readings unavailable, too shallow

Date	7/24/2003		
Initials	LG, BH, IM		
Test	1		
Q	2.0-2.05	2	2.05

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.546	1.827	0.281	NA	NA	NA
14	36.05	1.478	1.87	0.392			
13	28.43	1.627	1.857	0.23	NA	NA	NA
12	23.38	1.729	1.784	0.055			
11	21.47	1.008	1.148	0.14			
10	15.56	0.929	1.068	0.139			
9	10.61	0.549	0.868	0.319	NA	NA	NA
8	8.74	0.581	0.719	0.138			
7	6.8	0.378	0.549	0.171			
6	5.47	0.372	0.589	0.217			
5	4.67	0.346	0.55	0.204	NA	NA	NA
4	3.5	0.166	0.577	0.411			
3	2.64	0.396	0.533	0.137			
2	1.88	0.303	0.555	0.252			
1	0.55	0.358	0.527	0.169			

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	1.846	0.379	NA	1.9	NA
2/3 of Converging Section Length	-2.17	1.38	1.539	0.159	NA	1.84	NA
Beginning of Throat Section	-6.37	1.459	1.596	0.137	NA	NA	NA

Table A.2: National Park Service: Five-foot Parshall Flume Calibration – Test 2, 3 cfs Target Discharge

			Elevation (ft)
		Staff Gage Reading	.27-.28
Date	7/28/2003		
Initials	IM, BH, LG		
Test	2		
Q	3.01-3.13	3.01	3.13

Notes

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.541	1.949	0.408	NA	NA	NA
14	36.05	1.39	1.85	0.46			
13	28.43	1.581	1.909	0.328	NA	NA	NA
12	23.38	1.682	1.823	0.141			
11	21.47						
10	15.56	0.915	1.142	0.227			
9	10.61	0.467	0.921	0.454	NA	NA	NA
8	8.74	0.484	0.818	0.334			
7	6.8	0.289	0.582	0.293			
6	5.47	0.387	0.639	0.252			
5	4.67	0.266	0.547	0.281	NA	NA	NA
4	3.5	0.218	0.586	0.368			
3	2.64	0.224	0.585	0.361			
2	1.88	0.27	0.574	0.304			
1	0.55	0.219	0.606	0.387			

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	1.702	0.235	NA	2.11	NA
2/3 of Converging Section Length	-2.17	1.378	1.58	0.202	NA	1.98	NA
Beginning of Throat Section	-6.37	1.462	1.642	0.18	NA	NA	NA

Table A.3: National Park Service: Five-foot Parshall Flume Calibration – Test 3, 4 cfs Target Discharge

	Elevation (ft)
Staff Gage Reading	0.3-0.33

Notes

Date	7/17/2003
Initials	LG, BH, JE
Test	3
Q	4 cfs

3.95 4.05

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.6	1.647	1.972	0.325	4.81	3.43	NA
14	36.5	1.4	1.811	0.411			
13	28.42	1.586	1.922	0.336	4.06	3.27	2.48
12	23.39	1.703	1.837	0.134			
11	21.48	1.05	1.236	0.186			
10	16.57	1.005	1.184	0.179	2.63	2.58	2.43
9	10.61	0.645	0.992	0.347			
8	8.75	0.562	0.863	0.301			
7	6.8	0.221	0.816	0.595			
6	5.48	0.354	0.646	0.292			
5	4.69	0.35	0.628	0.278	4.11	3.91	NA
4	3.48	0.164	0.662	0.498			
3	2.64	0.407	0.63	0.223			
2	1.89	0.289	0.633	0.344			
1	0.55	0.344	0.628	0.284			

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	1.742	0.275	2.97	2.68	NA
2/3 of Converging Section Length	-2.17	1.375	1.672	0.297	2.86	2.79	NA
Beginning of Throat Section	-6.37	1.461	1.671	0.21	3.02	2.98	NA

Table A.4: National Park Service: Five-foot Parshall Flume Calibration – Test 4, 5 cfs Target Discharge

			Elevation (ft)
		Staff Gage Reading	.35-.38
Date	7/25/2003		
Initials	LG, BH, IM		
Test	4		
Q	5.0-5.04	5	5.04

Notes

- roller in throat of flume has disappeared
- continuous flow thru throat
- xs 11 water too turbulent to take surface elev.
- xs14+ water turbulent, velocity reading scattered
- jump inside flume is @ h_a

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.641	2.029	0.388	5.28	4.38	NA
14	36.05	1.41	1.91	0.5			
13	28.43	1.591	1.9	0.309	4.35	3.52	NA
12	23.38	1.552	1.88	0.328			
11	21.47						
10	15.56	0.93	1.198	0.268			
9	10.61	0.648	1.04	0.392	3.11	2.44	NA
8	8.74	0.622	0.877	0.255			
7	6.8	0.386	0.676	0.29			
6	5.47	0.357	0.682	0.325			
5	4.67	0.346	0.676	0.33	4.57	4.13	NA
4	3.5	0.229	0.694	0.465			
3	2.64	0.406	0.692	0.286			
2	1.88	0.29	0.673	0.383			
1	0.55	0.348	0.686	0.338	3.26	3.28	NA

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	1.793	0.326	3.46	3.06	NA
2/3 of Converging Section Length	-2.17	1.37	1.72	0.35	3.05	3.02	NA
Beginning of Throat Section	-6.37	1.458	1.71	0.252	3.507	3.45	NA

Table A.5: National Park Service: Five-foot Parshall Flume Calibration – Test 5, 6 cfs Target Discharge

	Elevation (ft)
Staff Gage Reading	.39-.41

Notes

- jump in flume has moved downstream of h_a

Date	7/25/2003		
Initials	LG, BH, IM		
Test	5	Lower cfs	Upper cfs
Q	6.03-6.10	6.03	6.1

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.586	2.07	0.484	5.135	4.26	NA
14	36.05	1.462	1.897	0.435			
13	28.43	1.565	1.995	0.43	4.875	3.858	NA
12	23.38	1.639	1.904	0.265			
11	21.47						
10	15.56	0.94	1.247	0.307			
9	10.61	0.577	1.033	0.456	3.5	2.44	NA
8	8.74	0.659	0.908	0.249			
7	6.8	0.389	0.705	0.316			
6	5.47	0.312	0.701	0.389			
5	4.67	0.385	0.694	0.309	4.34	3.95	NA
4	3.5	0.133	0.693	0.56			
3	2.64	0.405	0.713	0.308			
2	1.88	0.283	0.693	0.41			
1	0.55	0.342	0.714	0.372			

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	1.808	0.341	3.68	3.35	NA
2/3 of Converging Section Length	-2.17	1.37	1.66	0.29	3.856	4.07	NA
Beginning of Throat Section	-6.37	1.46	1.741	0.281	3.63	3.57	NA

Table A.6: National Park Service: Five-foot Parshall Flume Calibration – Test 6, 7 cfs Target Discharge

			Elevation (ft)
		Staff Gage Reading	.41-.44
Date	7/25/2003		
Initials	BH, LG, IM		
Test	6		
Q	6.998-7.053	6.998	7.053

Notes

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.568	2.089	0.521	5.57	4.56	NA
14	36.05	1.39	1.904	0.514			
13	28.43	1.576	2.011	0.435	5.29	3.99	NA
12	23.38	1.717	1.925	0.208			
11	21.47						
10	15.56	0.957	1.263	0.306			
9	10.61	0.507	1.05	0.543	3.5	2.22	NA
8	8.74	0.426	0.917	0.491			
7	6.8	0.372	0.729	0.357			
6	5.47	0.37	0.718	0.348			
5	4.67	0.348	0.741	0.393	4.19	3.61	NA
4	3.5	0.201	0.709	0.508			
3	2.64	0.394	0.701	0.307			
2	1.88	0.294	0.731	0.437			
1	0.55	0.371	0.763	0.392			

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	1.873	0.406	3.99	3.61	NA
2/3 of Converging Section Length	-2.17	1.368	1.705	0.337	4.32	4.21	NA
Beginning of Throat Section	-6.37	1.46	1.782	0.322	4.04	4.07	NA

Table A.7: National Park Service: Five-foot Parshall Flume Calibration – Test 7, 8 cfs Target Discharge

			Elevation (ft)
		Staff Gage Reading	.43-.48
Date	7/28/2003		
Initials	IM, BH, LG		
Test	7		
Q	7.97-8.15	7.97	8.15

Notes

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.558	2.101	0.543	6.06	5.05	2.28
14	36.05	1.396	1.958	0.562			
13	28.43	1.579	2.027	0.448	5.46	4.32	3.39
12	23.38	1.433	1.951	0.518			
11	21.47						
10	15.56	0.968	1.291	0.323			
9	10.61	0.547	1.094	0.547	3.58	2.26	NA
8	8.74	0.578	0.952	0.374			
7	6.8	0.293	0.727	0.434			
6	5.47	0.27	0.717	0.447			
5	4.67	0.296	0.73	0.434	5.29	4.43	NA
4	3.5	0.327	0.68	0.353			
3	2.64	0.395	0.813	0.418			
2	1.88	0.288	0.775	0.487			
1	0.55	0.377	0.784	0.407			

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	1.9	0.433	4.28	3.94	NA
2/3 of Converging Section Length	-2.17	1.367	1.732	0.365	4.44	4.51	NA
Beginning of Throat Section	-6.37	1.459	1.796	0.337	4.61	4.45	NA

Table A.8: National Park Service: Five-foot Parshall Flume Calibration – Test 8, 10 cfs Target Discharge

			Elevation (ft)
		Staff Gage Reading	0.49-0.52
Date	7/28/2003		
Initials	IM, BH, LG		
Test	8		
Q	9.99-10.06	9.99	10.06

Notes

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.562	2.413	0.851	6.29	5.47	2.62
14	36.05	1.391	2.038	0.647			
13	28.43	1.58	2.13	0.55	5.87	4.87	4.07
12	23.38	1.45	1.99	0.54			
11	21.47						
10	15.56	0.96	1.337	0.377			
9	10.61	0.451	1.174	0.723	4.08	2.11	NA
8	8.74	0.47	0.998	0.528			
7	6.8	0.306	0.781	0.475			
6	5.47	0.298	0.75	0.452			
5	4.67	0.285	0.79	0.505	5.41	3.46	NA
4	3.5	0.303	0.76	0.457			
3	2.64	0.186	0.805	0.619			
2	1.88	0.302	0.866	0.564			
1	0.55	0.358	0.817	0.459			

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	1.932	0.465	4.73	4.33	NA
2/3 of Converging Section Length	-2.17	1.36	1.758	0.398	4.94	4.8	4.62
Beginning of Throat Section	-6.37	1.429	1.825	0.396	4.74	4.81	NA

Table A.9: National Park Service: Five-foot Parshall Flume Calibration – Test 9, 15 cfs Target Discharge

			Elevation (ft)
		Staff Gage Reading	.58-.61
Date	7/30/2003		
Initials	IM, BH, LG		
Test	9		
Q	14.94-15.01	14.94	15.01

Notes

- hard to find a steady velocity reading at 20% and 60% depth inaccuracy between 20 and 60 with 80% at throat section
- (*) indicates velocity in question due to turbulence
- small amount of overflow on left bank

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.536	2.24	0.704	6.72	6.66	2.80*
14	36.05	1.389	2.117	0.728			
13	28.43	1.577	2.123	0.546	6.59	5.32	NA
12	23.38			0			
11	21.47	1.668	2.08	0.412			
10	15.56	0.971	1.467	0.496			
9	10.61	0.559	1.239	0.68	5.55	4.78	3.32
8	8.74	0.425	1.091	0.666			
7	6.8	0.305	0.88	0.575			
6	5.47	0.318	0.867	0.549			
5	4.67	0.273	0.851	0.578	6.68	5.46	3.54*
4	3.5	0.184	0.841	0.657			
3	2.64	0.271	0.841	0.57			
2	1.88	0.268	0.888	0.62			
1	0.55	0.379	0.973	0.594	5.58	4.7	4.15

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	1.997	0.53	5.76	4.64	4.08
2/3 of Converging Section Length	-2.17	1.351	1.794	0.443	6.91	5.75	5.61
Beginning of Throat Section	-6.37	1.458	1.989	0.531	5.18	4.91	5.38

Table A.10: National Park Service: Five-foot Parshall Flume Calibration – Test 10, 20 cfs Target Discharge

			Elevation (ft)
		Staff Gage Reading	.68-.72
Date	7/30/2003		
Initials	BH, LG, IM		
Test	10		
Q	19.99-20.02	19.99	20.02

Notes

- large change in surface elevation at throat (roller)
- (*) indicates velocity in question due to turbulence
- meter often reading negative
- overflow on left bank

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.559	2.307	0.748	7.24	6.68	4.08
14	36.05	1.393	3.191	1.798			
13	28.43	1.582	2.228	0.646	6.95	6.52	4.9
12	23.38	1.414	2.143	0.729			
11	21.47			0			
10	15.56	0.969	1.614	0.645			
9	10.61	0.65	1.227	0.577	6.15*	6.38	4.98
8	8.74	0.47	1.193	0.723			
7	6.8	0.303	0.979	0.676			
6	5.47	0.3	0.93	0.63			
5	4.67	0.264	0.938	0.674	7.12*	6.07	NA
4	3.5	0.206	0.96	0.754			
3	2.64	0.312	0.96	0.648			
2	1.88	0.237	0.973	0.736			
1	0.55	0.32	1.083	0.763			

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	2.236	0.769	NA	5.43	NA
2/3 of Converging Section Length	-2.17	1.336	1.92	0.584	6.88	6.03	5.39
Beginning of Throat Section	-6.37	1.45	2.108	0.658	5.53	6.23	NA

Table A.11: National Park Service: Five-foot Parshall Flume Calibration – Test 11, 25 cfs Target Discharge

			Elevation (ft)
		Staff Gage Reading	.78-.83
Date	7/30/2003		
Initials	LG, BH, IM, AM		
Test	11		
Q	24.98-25.01	24.98	25.01

Notes

- staff gage on east side reading higher than other and has less consistent range 0.8-0.9
- no reading available for 60/80% in throat due to roller
- xs10 has a roller in the water

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.552	2.384	0.832	7.65	6.74	4.22
14	36.05	1.393	2.264	0.871			
13	28.43	1.565	2.269	0.704	7.04	6.65	5.13
12	23.38	1.397	2.168	0.771			
11	21.47			0			
10	15.56	0.971	1.82	0.849			
9	10.61	0.645	1.244	0.599	7.89	7.63	6.67
8	8.74	0.509	1.268	0.759			
7	6.8	0.383	1.04	0.657			
6	5.47	0.401	1.028	0.627			
5	4.67	0.208	1.03	0.822	8.28	6.2	NA
4	3.5	0.217	1.072	0.855			
3	2.64	0.282	1.073	0.791			
2	1.88	0.314	1.133	0.819			
1	0.55	0.36	1.174	0.814			

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	2.309	0.842	6.99	5.56	4.33
2/3 of Converging Section Length	-2.17	1.333	2.083	0.75	6.09	6.15	5.36
Beginning of Throat Section	-6.37	1.88	2.331	0.451	7.67	NA	NA

Table A.12: National Park Service: Five-foot Parshall Flume Calibration – Test 12, 30 cfs Target Discharge

			Elevation (ft)
		Staff Gage Reading	0.95-1.05
Date	7/31/2003		
Initials	LG, AM, BS		
Test	12		
Q	29.98-30.31	29.98	30.31

Notes

- jump in throat reduced
- overflow on left and right banks
- roller at xs 10
- velocity varied at beginning of converging section from 5-12 cfs
- staff gage readings: left .87-0.93 right .95-1.05

APPROACH SECTION

Cross Section No.	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
14+	38.05	1.643	2.46	0.817	7.52	7.76	6.66
14	36.05	1.39	2.3	0.91			
13	28.43	1.491	2.318	0.827	8.21	7.3	5.47
12	23.38	1.469	2.223	0.754			
11	21.47	1.16	1.634	0.474			
10	15.56	0.963	1.876	0.913			
9	10.61	0.569	1.267	0.698	8.34	7.58	NA
8	8.74	0.632	1.31	0.678			
7	6.8	0.329	1.123	0.794			
6	5.47	0.348	1.088	0.74			
5	4.67	0.32	1.097	0.777	9.26	7.32	5.08
4	3.5	0.218	1.158	0.94			
3	2.64	0.353	1.241	0.888			
2	1.88	0.298	1.325	1.027			
1	0.55	0.316	1.349	1.033			

PARSHALL FLUME

Description	CL Distance From Entrance of Flume (ft)	Bed Elevation Reading (ft)	Water Surface Elevation Reading (ft)	Depth (ft)	Velocity 20% (ft/s)	Velocity 60% (ft/s)	Velocity 80% (ft/s)
Beginning of Converging Section	0.00	1.467	2.508	1.036	6.51	6.13	4.77
2/3 of Converging Section Length	-2.17	1.324	2.16	0.836	8.97	6.58	5.96
Beginning of Throat Section	-6.37	1.436	2.349	0.913	NA	7.98	7.66