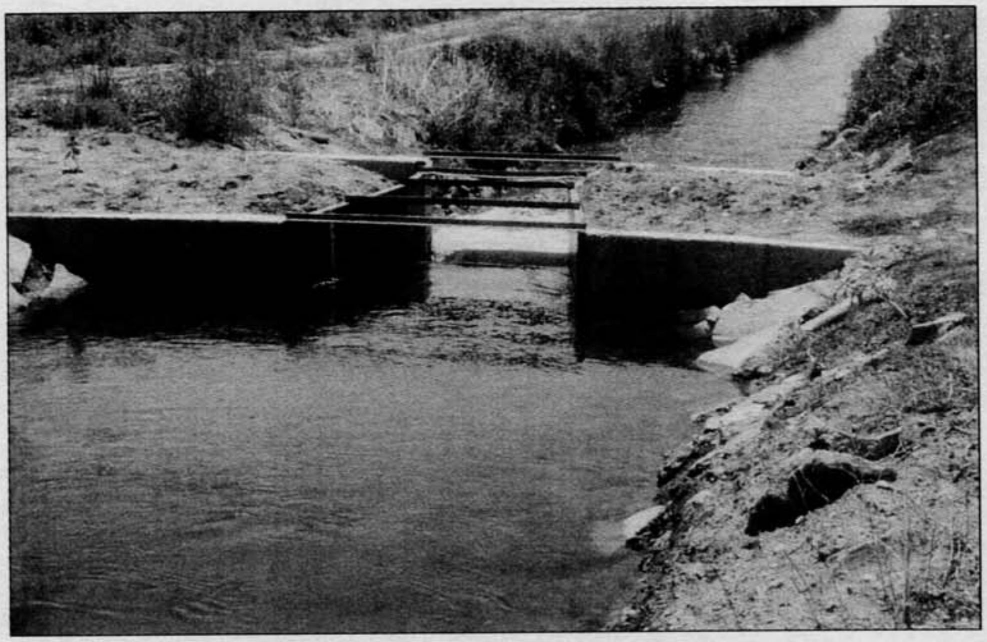
WATER OPERATION AND MAINTENANCE BULLETIN

No. 180 June 1997



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UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Reclamation personnel and water user groups in operating and maintaining project facilities.

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Cover photograph: *Parshall flume in irrigation canal.*

UNITED STATES DEPARTMENT OF THE INTERIOR Bureau of Reclamation

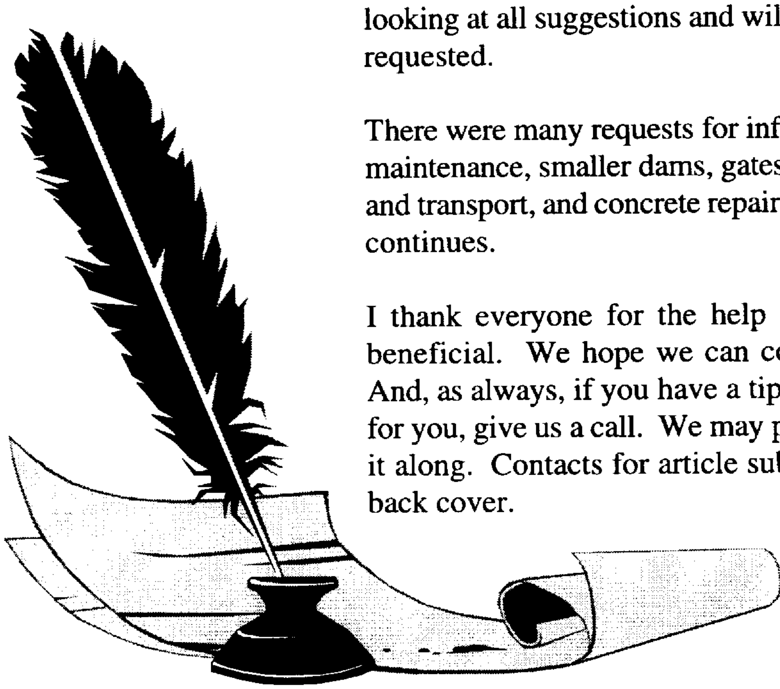
THANK YOU FOR YOUR RESPONSE ! !

To Our Readers:

The survey forms sent out with the December 1996 issue, No. 178, of the *Water Operation and Maintenance Bulletin* are coming back and are loaded with ideas for future articles. I am looking at all suggestions and will pursue the articles that were requested.

There were many requests for information on canal repair and maintenance, smaller dams, gates, valves, water measurement and transport, and concrete repair and maintenance, and the list continues.

I thank everyone for the help and input—it has been very beneficial. We hope we can continue to serve your needs. And, as always, if you have a tip or technique that is working for you, give us a call. We may print it in the bulletin and pass it along. Contacts for article submission are listed inside the back cover.



Jerry L. Fischer

Jerry L. Fischer
Managing Editor

WATER OPERATION AND MAINTENANCE BULLETIN
No. 180—June 1997

CONTENTS

CONDITION ASSESSMENT OF PARSHALL FLUMES IN COLORADO

Part 2

by Steven R. Abt, Bryan C. Ruth, Cara M. Mitchell, and Chad M. Lipscomb

Acknowledgments

The study presented herein was supported by the Colorado Agricultural Experiment Station, Project No. 1-57151, based at Colorado State University, Fort Collins, Colorado. The authors extend their appreciation to the flume owners for allowing the staff access to perform the field assessments. Most important, the authors wish to acknowledge and thank those individuals that located the flumes and coordinated access with the flume owners for the Colorado State University staff. Without their efforts, this study would not have been possible. The primary field contacts were:

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Key Words With Definitions

Corrected Discharge:	The actual amount of water flowing through the Parshall flume with given flume size, settlement, and submergence conditions.
U.S. Customary Units:	A system of units expressed in the English terms, usually feet, cubic feet per second, etc., based upon the inch and pound.
S.I. Units:	The international system of units established as a world wide standard of measurement. In this case, the meter and cubic meters per second will be used.
Lateral Slope:	The side-to-side tilt of the Parshall flume expressed as a percentage.
Longitudinal Slope:	The end-to-end tilt of the Parshall flume expressed as a percentage.
Throat Width:	The width of the Parshall flume (between the side walls) at the location of the crest.
Submergence:	The ration of the downstream depth of flow (H_b) to the upstream depth of flow (H_a). H_a must be greater than or equal to H_b.

Conversions

Length

1 inch	=	0.0254 meters
1 foot	=	0.3048 meters
1 meter	=	100 centimeters

Discharge

1 cubic foot per second	=	0.028 cubic meters per second

Introduction

The increasing demand for water resources has forced water suppliers, ditch and irrigation companies, and water districts to improve the accounting for the appropriate allocation and distribution of water shares to users. Accurate water measurement through the water conveyance and distribution system is a vital component of water resource management throughout the arid and semi-arid western United States, and particularly in Colorado.

Instruments that accurately measure discharge (i.e., weirs and flumes) in open channel water distribution systems have been routinely used for more than 70 years. The allocations and monitoring of flow have become dependent upon flume measurements. One of the most critical flow measurement locations is where water is diverted to individual users, particularly for agricultural applications. Thousands of flumes throughout the west serve as the basis to volumetrically monitor water resource distribution. Abt et al. (1995b) observed that many flumes have been in place for several decades and have become severely damaged, are poorly maintained, and/or are subjected to field practices that may result in questionable discharge measurements.

The Parshall flume was developed at Colorado State University (CSU) to measure open channel discharge (Cone, 1917; Parshall and Rowher, 1921; Parshall, 1926; Parshall, 1950) as presented in Figure 1, and is the most common instrument used in the agricultural community of Colorado. When the Parshall flume is properly installed, the flume is accurate to ± 3%, which has become the industry standard for acceptable flow measurement. Generally, the flume is constructed of concrete or metal for durability. However, because of the material weight, long-term consolidation of the foundation soil leads to the potential settlement of the flume. Low gradient channels or improper flume installations often create submerged flow conditions, where submergence is the ratio of the downstream depth of flow to the upstream depth of flow exceeding 0.7. In addition, the flume is routinely subjected to many cycles of wetting and drying, freezing and thawing, and heating and

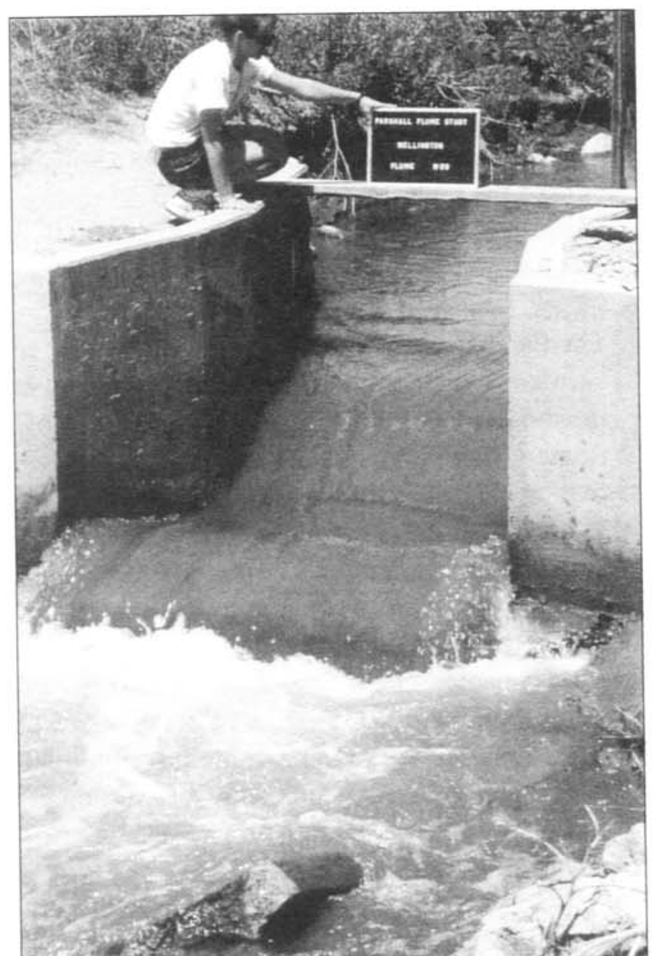

Figure 1.—Typical Parshall flume in operation.

cooling. Vibrations from agricultural equipment also affect the flume stability. The flume measurement accuracy may be affected because of the adverse influences.

A two-year pilot study was conducted by the CSU Agricultural Experiment Station to assess the condition of Parshall flumes used for flow measurement throughout the Colorado agricultural community (Abt et al., 1995b). The study objective was to provide agricultural water users (e.g., water supply and irrigation districts, ditch companies, and regional water managers) a snapshot of the current conditions of the water measurement and monitoring system infrastructure.

The study included a survey of the literature, a field-assessment and measurement program, and data analysis. A representative sample of Parshall flumes located throughout the State of Colorado was assessed for physical integrity, settlement, and submergence conditions. Based upon the study findings, recommendations are presented, where appropriate, to summarize the state of water measurement at the user level.

Background

Procedures and methods for accurate flow measurement and to improve water management are continually sought to enhance the allocation and use of water resources. Flumes are among the most-widely accepted of all devices and structures developed for flow measurement. The Parshall flume is the most-widely used flow measurement instrument in Colorado agriculture.

The Parshall flume, or venturi flume as first reported by Cone (1917), was developed for agricultural applications (Parshall and Rohwer, 1921; Parshall, 1926, 1928, 1959) as a simple, inexpensive, and relatively accurate means of measuring flow in open channels. The Parshall flume provided potential users the flexibility of determining flow discharge under a variety of free-outfall and submerged conditions. Since the flume was developed, its use has expanded to the industrial and municipal areas. In addition, the flume has been adapted throughout the international agricultural community.

Since the original development of the flume, numerous investigators have focused on one or more aspects of the flume attempting to simplify, refine, improve, or discount its operation. Robinson (1957, 1965) worked to simplify some flow-correction factors for submerged conditions as well as expand the information base for the use of small Parshall flumes. Robinson emphasized that flow measurements with the Parshall flume under submerged conditions are subject to a wider variation in accuracy because of problems in measuring the exact submergence.

Skogerboe et al. (1967) developed calibration curves describing submergence in Parshall flumes through the application of the momentum theory and dimensional analysis. Peck (1988) collected data from a submerged Parshall flume and observed a discontinuity in the discharge-submergence relationship for a high degree of submergence. The discontinuity is believed to be due to the flow regime changing from a state in which critical depth occurs on the horizontal section to a state in which the flow is subcritical throughout the flume. The data indicated that supercritical flow occurs on the crest at a higher submergence than previously assumed. Equations were developed that correct the discharge measurement for submergence effects, one for each side of the discontinuity.

Wu (1971) studied the effect of settlement of cutthroat flume ratings for free- and submerged-flow conditions. When comparing the measured discharges in sloped flumes with those having no slope, measurement errors were observed as high as 66% for submerged-flow conditions. Skogerboe et al. (1971) conducted studies to evaluate the effects of a floor slope on the discharge rating of cutthroat flumes under submerged flows. The most significant finding was that the free- and submerged-flow exponent have a unique value for each flume length. Genovez et al. (1993) conducted a study to evaluate the effects of settlement in Parshall flumes of 30.5 cm and 61.0 cm (1 ft. and 2 ft.) for free-outfall conditions. The flumes were tested for lateral, longitudinal, and combined lateral-longitudinal slope settlements, with slopes varying up to 7%. Genovez et al. (1993) presented a rating equation determining the measured discharge for free-outfall conditions as

$$Q_m = Q_a \times C_{lat} \times C_{long} \times C_{TW} \tag{1}$$

where

$$Q_a = a\, H_a^b \qquad (m^3/s) \tag{2}$$

and

C_{lat} = Coefficient for lateral settlement
C_{long} = Coefficient for longitudinal settlement
C_{TW} = (Throat Width)^f

as H_a = the depth of flow near the flume inlet in m, C_{TW} is expressed in cm, f is a value dependent upon the throat length, and the coefficients a and b are dependent upon the flume geometry (Water Measurement Manual, 1983). Genovez et al. (1993) developed correction coefficients for both lateral and longitudinal settlement for adjusting discharge measurements and are expressed as

$$C_{long} = 0.056\ S_{long} + 1.00 \tag{3}$$

and

$$C_{lat} = -0.020\ S_{lat} + 1.00 \tag{4}$$

where S_{long} = the flume longitudinal slope in % and S_{lat} = the lateral slope in %. The coefficients 0.056 and -0.020 are specific to the flume sizes tested.

Wright et al. (1994) performed a study that focused on the Parshall flume rating in the lower portion of the flume. A numerical model was developed to predict the effect of fluid viscosity on the depth-discharge relation. The experimental investigation indicated that the original rating equations and data over predict the discharge at flow rates that are less than about 15% of the maximum rated discharge for the flume. The discrepancy can be as much as 25% for the range of flows for which the flume is recommended for use.

Blaisdell (1994) re-analyzed the Parshall data set and indicated that the rating equations presented by Parshall predict the discharge to within 5%. Parshall's rating equations represent 78% of the observations within ±2% and 96% of the observations within ±5%. Blaisdell concluded that Parshall flumes of various sizes are not geometrically similar, and the application of generalized equations to all sizes of flumes are, therefore, questionable.

Abt et al. (1994) conducted a series of tests analyzing the accuracy of the Parshall flume when subjected to lateral-slope, or cross-slope settlement, up to 3% for submerged outfall conditions. The results indicated that flume ratings were in error 3, 5, and 11% for 70, 80, and 90% submergence, respectively, at a lateral settlement of ±2%. The rating equation recommended for determining the discharge in the Parshall flume under submerged flow conditions was

$$Q_m = C_{lat}\ (Q_a - C_k) \tag{5}$$

where

$$C_k = (H_a/A)^n + B \tag{6}$$

as C_k is a correction factor for submergence, the coefficients a and b are dependent upon the flume geometry, the coefficients A and B depend on the degree of submergence K, C_{lat}, and Q_a are as described in Equations 1 and 2, and n is an exponent dependent on K for fixed geometry. The degree of submergence, K, is the ratio of H_b to H_a where H_b is the downstream depth of flow. Specific values for A, B, and n are derived from Parshall (1928). The correction for longitudinal settlement was not presented.

Abt et al. (1995) conducted a laboratory study in which commercially available Parshall flumes were subjected to an array of lateral, longitudinal, and submergence conditions and the flow measurement errors were recorded. The results indicated that although there exists a significant difference between apparent and measured discharges, the apparent discharge can be corrected. Based upon the findings of the laboratory program, a comprehensive procedure was formulated to correct the discharge measurement, for settlement, using a Parshall flume for free-flow and submergence-flow conditions. The true or measured discharge, Q_m, may be determined using Equation 1. The apparent discharge, Q_a, for submergence is obtained from Parshall (1928) as

$$Q_a = (a\ H_a^b) - C_k \tag{7}$$

where

$$C_k = \left((H_a/A)^a + B\right) * D \tag{8}$$

and

$$D = (\text{Throat Width})^{0.815} \tag{9}$$

Since the coefficients for lateral and longitudinal settlement previously presented were flume crest width specific, coefficients had to be derived that have a broader application. The general expression for determining the coefficient for lateral settlement is

$$C_{lat} = C_{dlat} * S_{lat} + 1.0 \tag{10}$$

and the expression determining the coefficient for longitudinal settlement is

$$C_{long} = C_{dlong} * S_{long} + 1.0 \tag{11}$$

where for free-flow conditions

$$C_{dlat} = -0.0003 * TW - 0.006 \tag{12}$$

and

$$C_{dlong} = 0.011 * \ln(TW) + 0.015 \tag{13}$$

and for submergence conditions

$$C_{dlat} = (-0.003 * TW -0.006) + \left((0.0003 * TW -0.006) * (28-97 * K + 103 * K^2 -31 * K^3)\right) \quad \textbf{(14)}$$

and

$$C_{dlong} = (0.011 * \ln(TW) + 0.015) + \left((0.011 * \ln(TW) + 0.015) * (-24 + 105 * K -152 * K^2 + 74K^3)\right) \quad \textbf{(15)}$$

Abt et al. (1995) determined that for a submergence of less than 90%, the flow can be corrected to within ±3% of the true discharge. However, flow conditions with submergence of 90% or greater can only be corrected to within ±5% of the true discharge. Abt and Florentin (1994) consolidated Equations 1 through 15 into a comprehensive program that corrects Parshall flume flow measurements by accounting for lateral, longitudinal, and submergence conditions. Abt et al. (1996) updated and enhanced the program package in 1996.

Approach

Since the Parshall flume assessment program was voluntary, the Colorado State University Extension Service placed a request for voluntary assistance in a periodic newsletter. Seven (7) responses were received in which water resource managers agreed to align volunteers and allow access to field sites in which Parshall flumes were actively used for monitoring flow measurement in agricultural settings.

Field Site Locations

Seven field sites were identified in the northeast, southeast, south-central, north-central, western portions of Colorado as presented in Figure 2. A series of 8 to 83 flume sites was identified in each of the seven regions. The sites provide a representative sample of flumes that span the diverse climatic, geographic, and agricultural land use conditions of the state. It is recognized that assessment sites do not provide complete coverage of the state. However, the dispersal of sites provide a relatively random glimpse of the use and field conditions of existing Parshall flumes.

Field Assessment

The field assessment focused on three criteria pertinent to flume use and operation: flume physical integrity, flume settlement, and flume submergence. The physical integrity

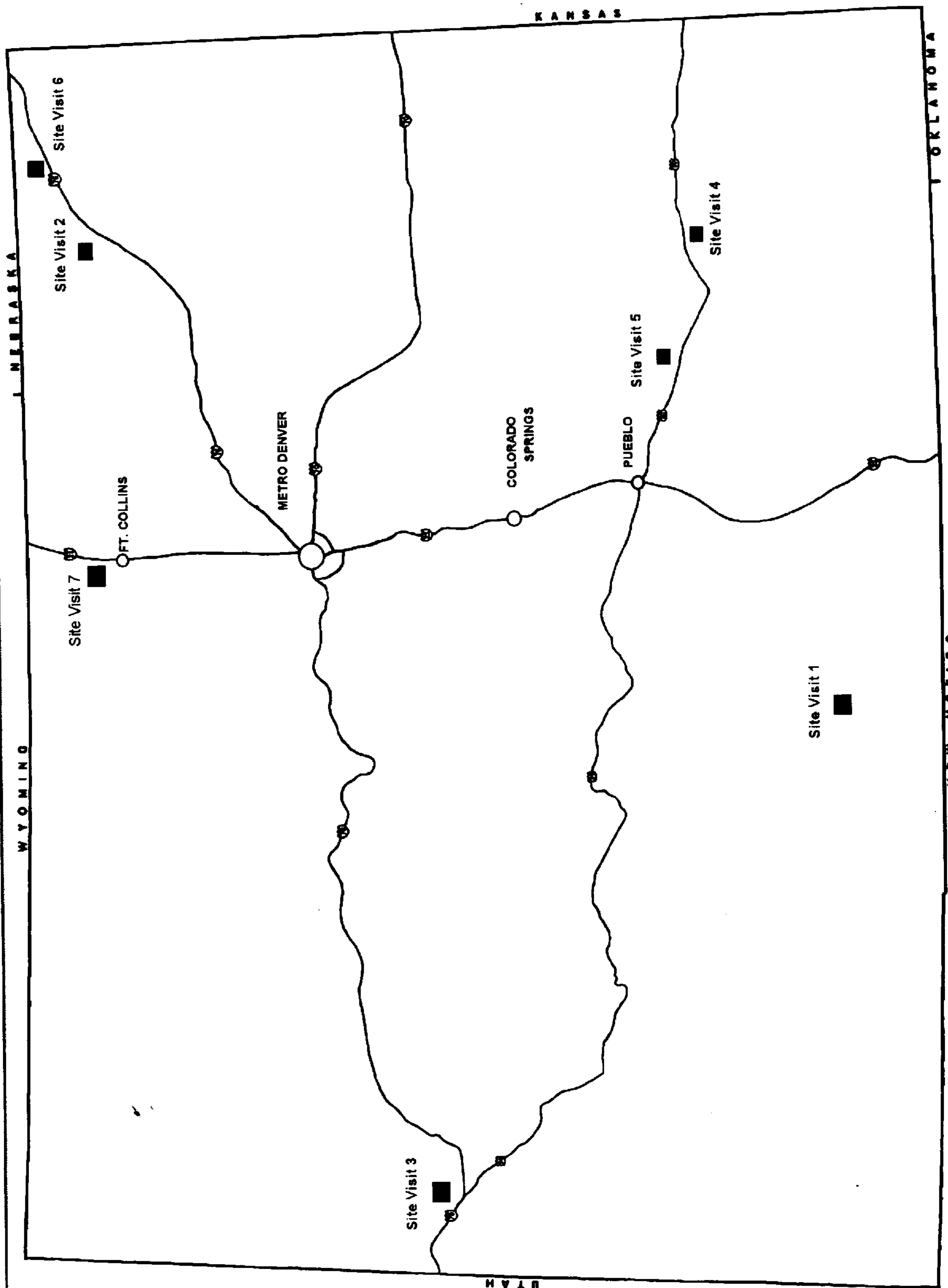

Figure 2.—Study assessment locations.

assessment was a visual inspection (with photographs) documenting items such as damage, channel and flume alignment, and site specific aspects. Flumes observed to have bypassing flows, sediment deposition, vegetation overgrowth, extensive corrosion, and/or flume blockage were documented. Supplemental information pertaining to the flume age and construction material was also obtained.

A survey (theodolite and rod) was performed to determine the dimensions of each flume and its settlement. When installed, the tops of the flume walls are leveled to the same elevation. Settlement occurs when the top wall elevations are no longer constant in lateral, longitudinal, or combined lateral-longitudinal directions. A minimum of five (5) points were marked on the top of each flume as shown in Figure 3. The throat width was measured and the marked points were surveyed to identify potential elevation changes. If the flume was operational at the time of the assessment, the discharge and submergence were also determined. The survey data, inspection findings, and photographs served as the base documentation of each assessment.

In the instances where the flow was conveyed through the flumes, H_a (upstream flow depth) and H_b (downstream flow depth) values were recorded. If the staff gages were not available in the flume, the CSU staff used survey equipment to determine the depth of flow. Based upon the measured flow depths, the discharge was determined. The data were transported to the CSU Engineering Research Center and placed into a comprehensive data base for evaluation and analysis.

Data Acquisition Procedure

The CSU data acquisition team consisted of a supervisor/instrument operator and an assistant/rod person. The team met with the regional water manager and then proceeded to each field site. The assessment process was as follows:

1. The CSU team arrived at the flume site and inspected the flume. The flume condition was generally assessed.

2. A theodolite was set up approximately 3 m from the flume by the team supervisor.

3. The assistant checked the flume for debris, material deposition, or any other conditions that would affect the survey. All conditions an/or observations were recorded.

4. The assistant marked five locations on the top of the flume. Marks were placed inside the flume walls on the entrance brace or the flume walls. Marks were also placed on the mid-wall brace or flume wall. One mark was placed on the midpoint of the brace above the throat. If the flume did not have a throat brace, the throat wall was measured.

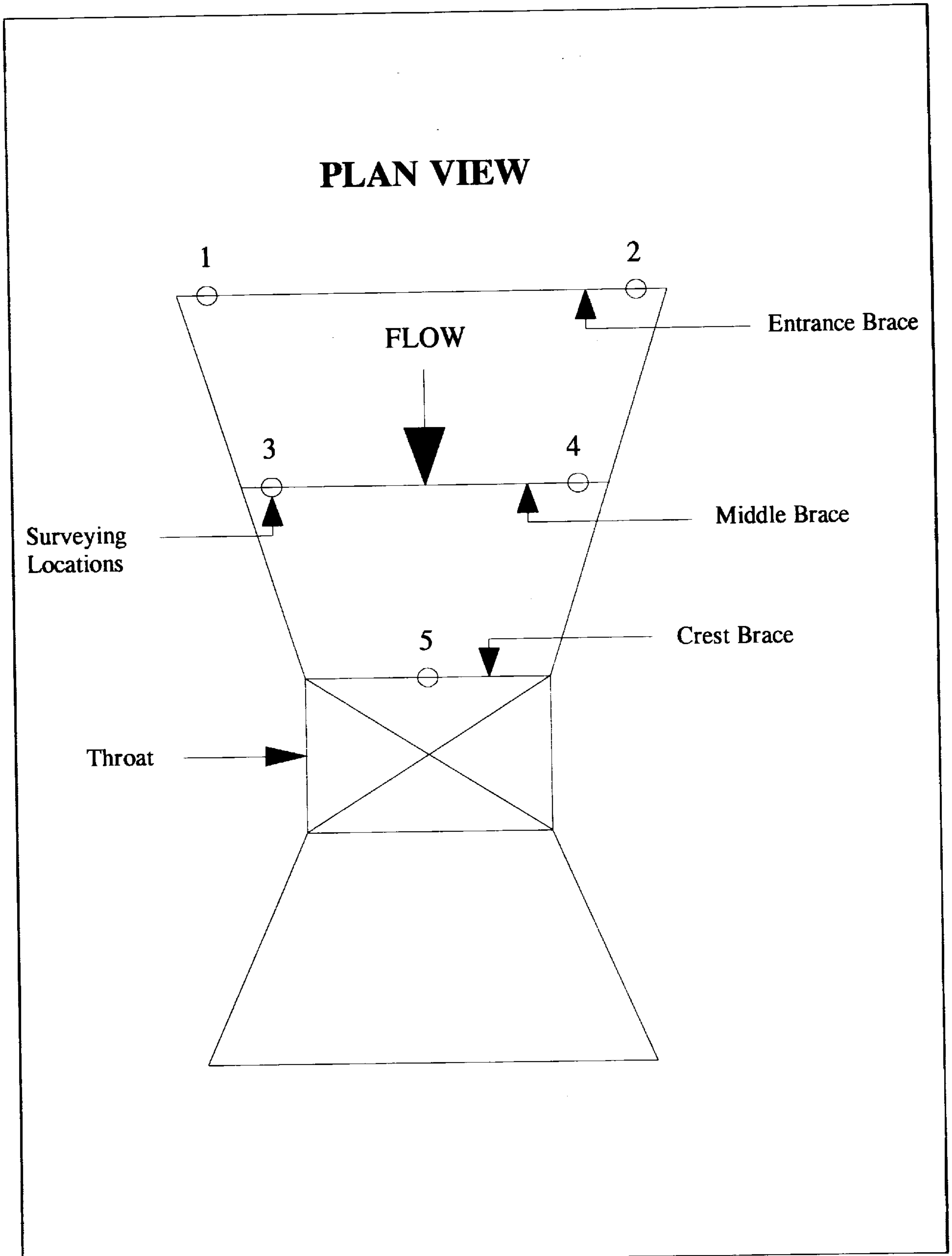

Figure 3.—Typical flume measurement locations to determine lateral and longitudinal slopes.

5. The assistant measured the horizontal distances between each of the five points.

6. The supervisor thoroughly inspected the flume and recorded the findings.

7. The flume was surveyed. The rod was placed adjacent to the marked points and allowed to rest on the floor of the flume. A hand level was used to assure that the rod was vertical. If submergence conditions existed during the survey, an additional point was shot to determine H_b. H_a was determined with the flume staff gage. If a staff gage was not mounted at the entrance, H_a was determined by survey. Figure 4 illustrates the approximate locations where staff gage measurements were obtained.

8. Photographs were take either before or after completion of the data acquisition.

9. The team checked to insure all data were obtained and departed the site.

Data and Findings

A series of 149 field sites was visited during the summers of 1995 and 1996. A summary of flume sites and flume assessments at each locale is presented in Table 1. Flume throat widths ranged from 0.75 ft. (22.86 cm) to 12 ft. (366 cm). Sixty-six (66) of the flumes were operational at the time of the assessment. Six (6) flumes could not be measured, therefore neither settlement nor submergence could be determined.

Table 1.—Field site locales

Location	No. of flumes
Las Animas (LA)	13
Rocky Ford (RF)	10
Sedwick (SD)	8
Alamosa (A)	15
Sterling (S)	12
Grand Junction (GJ)	8
Wellington (W)	83
Total	149

Summary of Data

A summary of the data collected at each flume site including flume geometry, flume settlement, and discharge information is presented in Table 2. Submergence can only be determined during flume operation. Therefore, the term "unknown" observed in Table 2 indicates the flumes that were not operational at the time of assessment. Also, NA, "not

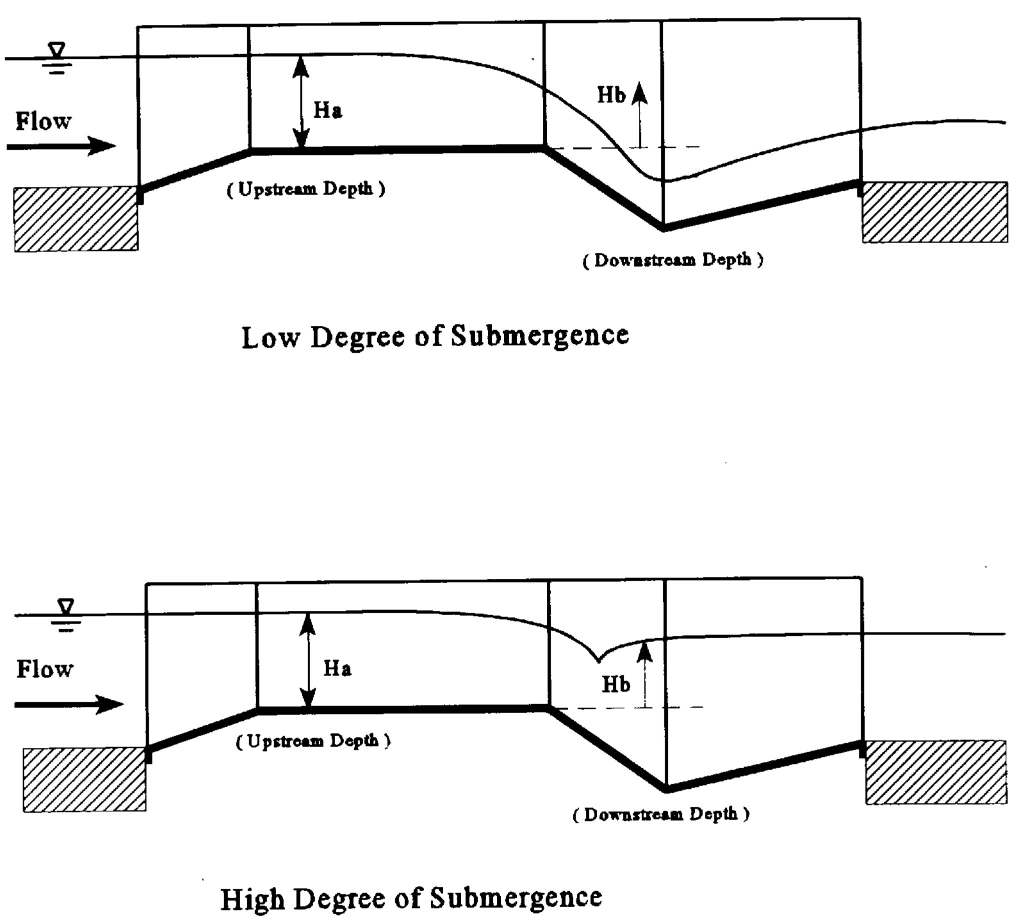

Figure 4.—Schematic of low and high submergence conditions.

Table 2.--Summary of field data

Flume #	Throat width (ft)	Throat width (cm)	Lateral slope (%)	Longitudinal slope (%)	Ha (ft)	Ha (cm)	Hb (ft)	Hb (cm)	Submergence (%)	Measured discharge (cfs)	Total error (%)	Corrected discharge (cfs)	Settlement error (%)
A1	4.0	121.92	-0.295	-0.522	1.19	36.27	0.65	*****	54.6	21.06	-1.52	20.74	-1.52
A2	1.0	30.48	4.504	1.296	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	-0.59
A3	6.0	182.88	-0.070	0.955	0.90	27.43	0.00	0.00	0.0	20.29	5.24	21.41	5.24
A4	5.0	152.40	0.977	0.079	1.19	36.27	0.65	*****	54.6	26.36	-5.11	25.08	-5.11
A5	5.0	152.40	-0.015	-0.555	0.07	2.07	0.00	0.00	0.0	0.29	-0.01	0.29	-2.95
A6	5.0	152.40	2.722	-3.857	1.42	43.28	1.42	*****	100.0	N/A	N/A	N/A	-47.27
A7	4.0	121.92	-0.060	1.396	1.50	45.72	0.00	0.00	0.0	30.34	7.13	32.67	7.13
A8	2.0	60.96	0.116	0.698	0.58	17.68	0.00	0.00	0.0	3.44	3.28	3.56	3.28
A9	3.0	91.44	0.580	0.385	0.49	14.94	0.17	5.18	34.7	3.93	-0.01	3.93	-0.01
A10	2.0	60.96	-0.582	0.276	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	2.86
A11	6.0	182.88	0.388	-1.643	0.44	13.41	0.00	0.00	0.0	6.48	-12.3	5.77	-12.3
A12	1.5	45.72	1.389	-0.630	0.36	10.97	0.00	0.00	0.0	1.25	-6.45	1.17	-6.45
A13	3.0	91.44	0.616	2.216	1.18	35.97	0.00	0.00	0.0	15.56	8.55	17.01	8.55
A14	2.0	60.96	1.292	1.002	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	1.86
A15	2.5	76.20	0.121	1.923	0.95	28.96	0.66	*****	69.5	9.23	6.26	9.85	8.92
S1	2.0	60.96	-0.156	1.833	0.78	23.77	0.00	0.00	0.0	5.45	9.21	6.00	9.21
S2	3.0	91.44	0.418	0.397	0.65	19.81	0.00	0.00	0.0	6.11	0.62	6.15	0.62
S3	3.0	91.44	0.461	0.732	0.49	14.94	0.00	0.00	0.0	3.92	2.17	4.01	2.17
S4	3.0	91.44	-0.105	0.303	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	1.94
S5	3.0	91.44	-1.074	0.324	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	5.22
S6	2.0	60.96	2.651	3.956	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	11.44
S7	2.0	60.96	-0.992	1.106	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	7.83
S8	2.0	60.96	-1.152	-0.244	0.57	17.37	0.00	0.00	0.0	3.35	1.53	3.40	1.53
S9	3.0	91.44	-1.050	0.960	0.17	5.18	0.00	0.00	0.0	0.74	8.18	0.81	8.18
S10	3.0	91.44	0.036	1.878	0.90	27.43	0.90	*****	100.0	N/A	N/A	N/A	8.93
S11	2.0	60.96	0.124	-0.138	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	-1.05
S12	3.0	91.44	0.029	0.002	1.68	51.21	1.68	*****	100.0	N/A	N/A	N/A	-0.9
GJ1	3.0	91.44	0.405	-0.407	1.30	39.62	0.00	0.00	0.0	18.10	-3.66	17.46	-3.66
GJ2	3.0	91.44	-0.298	0.302	1.50	45.72	0.00	0.00	0.0	22.64	2.58	23.24	2.58
GJ3	2.5	76.20	1.778	-0.568	1.30	39.62	0.00	0.00	0.0	15.05	-8.88	13.82	-8.88
GJ4	3.0	91.44	0.225	-3.598	1.03	31.39	0.00	0.00	0.0	12.56	-24.52	10.09	-24.52
GJ5	2.5	76.20	-1.791	-0.649	0.53	16.15	0.00	0.00	0.0	3.72	1.70	3.78	1.70
GJ6	2.0	60.96	0.730	-0.308	1.26	38.40	0.00	0.00	0.0	11.44	-3.55	11.05	-3.55
GJ7	1.5	45.72	-0.538	-0.755	1.34	40.84	0.83	*****	61.9	9.27	-3.04	9.00	-3.04
GJ8	1.5	45.72	0.131	-0.275	0.43	13.11	0.08	2.44	18.6	1.64	-1.75	1.61	-1.75

Table 2.--Summary of field data (continued)

Flume #	Throat width (ft)	Throat width (cm)	Lateral slope (%)	Longitudinal slope (%)	Ha (ft)	Ha (cm)	Hb (ft)	Hb (cm)	Submergence (%)	Measured discharge (cfs)	Total error (%)	Corrected discharge (cfs)	Settlement error (%)
LA1	3.0	0.00	-0.338	0.434	0.39	11.89	0.00	0.00	0.0	2.74	3.38	2.84	3.38
LA2	0.75	22.86	-0.200	-0.003	0.67	20.42	0.00	0.00	0.0	1.64	0.25	1.64	0.25
LA3	0.75	22.86	0.129	1.277	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	6.18
LA4	2.0	0.00	0.118	1.781	0.31	9.45	0.07	2.13	22.6	1.30	8.35	1.42	8.35
*LA5	0.83	25.30	N/A	N/A	1.22	37.19	0.00	0.00	100.0	N/A	N/A	N/A	N/A
LA6	0.75	22.86	-0.477	0.710	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	4.22
LA7	2.0	60.96	-0.940	1.346	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	8.8
LA8	2.0	60.96	0.637	2.587	0.65	19.81	0.00	0.00	0.0	4.10	10.62	4.59	10.62
LA9	2.0	60.96	-0.037	-0.108	0.89	27.13	0.00	0.00	0.0	6.68	-0.48	6.65	-0.48
LA10	2.0	60.96	0.792	0.569	1.04	31.70	0.00	0.00	0.0	8.50	0.96	8.58	0.96
LA11	4.0	121.92	-0.085	0.083	0.00	0.00	0.00	0.00	Unknown	0.00	N/A	N/A	0.81
LA12	3.0	91.44	0.500	-2.244	1.00	30.48	0.00	0.00	0.0	12.00	-15.49	10.39	-15.49
LA13	1.0	30.48	3.240	3.973	0.50	15.24	0.00	0.00	0.0	1.39	13.02	1.6	13.02
RF1	3.00	91.44	0.688	1.006	1.95	59.44	1.95	*****	100.0	N/A	N/A	N/A	2.74
RF2	0.75	22.86	0.295	0.135	0.59	17.98	0.00	0.00	0.0	1.36	0.33	1.36	0.33
RF3	0.75	22.86	0.991	0.039	0.59	17.98	0.00	0.00	0.0	1.35	-1.10	1.34	-1.10
RF4	12.00	365.76	-0.112	-0.546	1.63	49.68	0.00	0.00	0.0	106.11	-1.64	104.40	-1.64
RF5	1.00	30.48	-0.704	0.009	0.69	21.03	0.00	0.00	0.0	2.27	1.13	2.30	1.13
RF6	2.00	60.96	0.248	0.598	0.66	20.12	0.00	0.00	0.0	4.20	2.46	4.31	2.46
RF7	1.50	45.72	-0.959	-2.943	0.54	16.46	0.00	0.00	0.0	2.32	-16.21	2.00	-16.21
RF8	1.50	45.72	-4.140	0.588	0.55	16.76	0.00	0.00	0.0	2.39	10.53	2.67	10.53
RF9	1.50	45.72	1.534	-2.083	0.55	16.76	0.00	0.00	0.0	2.39	-16.01	2.06	-16.01
RF10	1.00	30.48	-0.169	-0.032	0.70	21.34	0.00	0.00	0.0	2.33	0.09	2.33	0.09
SD1	2.5	76.20	-0.248	-0.194	0.55	16.76	0.17	5.18	30.9	3.94	-0.30	3.93	-0.30
SD2	6.0	182.88	-0.116	-0.370	1.19	36.27	0.00	0.00	0.0	31.67	-1.25	31.28	-1.25
SD3	6.0	182.88	-0.016	-0.064	1.19	36.27	0.00	0.00	0.0	31.68	-0.24	31.60	-0.24
SD4	2.5	76.20	-0.494	1.405	0.36	10.97	0.36	*****	100.0	N/A	N/A	N/A	8.28
SD5	1.5	45.72	2.122	0.933	0.26	7.92	0.26	7.92	100.0	N/A	N/A	N/A	0.43
SD6	1.5	45.72	1.511	0.631	0.62	18.90	0.16	4.88	25.8	2.87	0.18	2.88	0.18
SD7	1.5	45.72	1.728	-0.803	0.76	23.16	0.00	0.00	0.0	3.93	-8.23	3.63	-8.23
SD8	1.5	45.72	2.262	-0.645	0.60	18.29	0.60	*****	100.0	N/A	N/A	N/A	-8.51
W1	6.0	182.88	-0.036	-0.348	0.89	27.13	0.40	*****	44.9	19.93	-1.65	19.61	-1.65
W2	1.0	30.48	0.339	1.106	0.00	0.00	0.00	0.00	0.0	0.00	4.72	0.00	4.72
W3	2.0	60.96	0.339	1.106	0.00	0.00	0.00	0.00	0.0	0.00	4.72	0.00	4.72
W4	1.0	30.48	0.658	0.531	0.46	14.02	0.46	*****	100.0	N/A	N/A	N/A	1.73
W5	1.0	30.48	2.483	-1.480	0.79	24.08	0.73	*****	100.0	N/A	N/A	N/A	-12.84

Table 2.--Summary of field data (continued)

Flume #	Throat width (ft)	Throat width (cm)	Lateral slope (%)	Longitudinal slope (%)	Ha (ft)	Ha (cm)	Hb (ft)	Hb (cm)	Submergence (%)	Measured discharge (cfs)	Total error (%)	Corrected discharge (cfs)	Settlement error (%)
W6	1.0	30.48	-1.145	0.173	0.00	0.00	0.00	0.00	0.0	0.00	2.63	0.00	2.63
W7	1.0	30.48	-0.553	-0.341	0.00	0.00	0.00	0.00	0.0	0.00	-0.98	0.00	-0.98
W8	1.0	30.48	0.120	0.405	0.00	0.00	0.00	0.00	0.0	0.00	1.92	0.00	1.92
W9*	1.0	30.48	N/A	N/A	0.00	0.00	0.00	0.00	Unknown	N/A	N/A	N/A	N/A
W10*	1.0	30.48	N/A	N/A	0.00	0.00	0.00	0.00	Unknown	N/A	N/A	N/A	N/A
W11	1.0	30.48	0.010	0.658	0.00	0.00	0.00	0.00	Unknown	0.00	3.35	0.00	3.35
W12	1.0	30.48	1.458	0.524	0.00	0.00	0.00	0.00	Unknown	0.00	0.45	0.00	0.45
W13	1.0	30.48	0.402	-0.103	0.65	19.81	0.65	*****	100.0	N/A	N/A	N/A	-1.18
W14	1.0	30.48	-0.215	-0.262	0.70	21.34	0.00	0.00	0.0	2.32	-1.07	2.30	-1.07
W15	1.0	30.48	0.076	0.012	0.00	0.00	0.00	0.00	Unknown	0.00	-0.05	0.00	-0.05
W16	1.0	30.48	-0.424	-0.060	0.00	0.00	0.00	0.00	Unknown	0.00	0.34	0.00	0.34
W17	1.0	30.48	-0.515	0.213	0.00	0.00	0.00	0.00	Unknown	0.00	1.90	0.00	1.90
W18	2.0	60.96	-0.444	-0.093	0.00	0.00	0.00	0.00	Unknown	0.00	0.61	0.00	0.61
W19	1.0	30.48	-0.527	-0.926	0.00	0.00	0.00	0.00	Unknown	0.00	-4.31	0.00	-4.31
W20	1.0	30.48	-1.227	-0.600	0.00	0.00	0.00	0.00	Unknown	0.00	-1.36	0.00	-1.36
W21	1.0	30.48	1.179	0.179	0.00	0.00	0.00	0.00	Unknown	0.00	-0.90	0.00	-0.90
W22	1.0	30.48	N/A	N/A	0.00	0.00	0.00	0.00	Unknown	N/A	N/A	N/A	N/A
W23	2.05	62.48	1.053	1.777	0.23	7.01	0.00	0.00	0.0	0.84	6.08	0.89	6.08
W24	1.0	30.48	1.026	2.450	0.00	0.00	0.00	0.00	Unknown	0.00	10.06	0.00	10.06
W25	1.0	30.48	0.133	0.186	0.36	10.97	0.00	0.00	0.0	0.84	0.77	0.85	0.77
W26	1.0	30.48	0.456	-0.815	0.00	0.00	0.00	0.00	Unknown	0.00	-5.25	0.00	-5.25
W27	1.0	30.48	0.656	0.485	0.00	0.00	0.00	0.00	Unknown	0.00	1.50	0.00	1.50
W28	4.0	121.92	0.553	-0.008	0.89	27.13	0.00	0.00	0.0	13.31	-2.55	12.98	-2.55
W29	1.0	30.48	0.357	0.560	0.32	9.75	0.00	0.00	0.0	0.70	2.34	0.72	2.34
W30	1.0	30.48	0.514	0.998	0.00	0.00	0.00	0.00	Unknown	0.00	4.26	0.00	4.26
W31	1.0	30.48	-1.185	6.112	0.00	0.00	0.00	0.00	Unknown	0.00	25.82	0.00	25.82
W32	1.0	30.48	-0.802	-2.774	0.00	0.00	0.00	0.00	Unknown	0.00	-15.79	0.00	-15.79
W33	1.0	30.48	-0.432	-1.573	0.00	0.00	0.00	0.00	Unknown	0.00	-8.36	0.00	-8.36
W34	1.0	30.48	1.397	1.288	0.00	0.00	0.00	0.00	Unknown	0.00	4.32	0.00	4.32
W35	1.0	30.48	-1.552	2.567	0.00	0.00	0.00	0.00	Unknown	0.00	14.03	0.00	14.03
W36	1.0	30.48	1.343	0.312	0.00	0.00	0.00	0.00	Unknown	0.00	-0.46	0.00	-0.46
W37*	1.0	30.48	N/A	N/A	0.00	0.00	0.00	0.00	Unknown	N/A	N/A	N/A	N/A
W38	2.0	60.96	-0.100	0.808	0.00	0.00	0.00	0.00	Unknown	0.00	4.34	0.00	4.34
W39	1.0	30.48	-1.050	0.400	0.00	0.00	0.00	0.00	Unknown	0.00	3.64	0.00	3.64
W40	1.0	30.48	0.009	-2.064	0.00	0.00	0.00	0.00	Unknown	0.00	-12.29	0.00	-12.29
W41	1.0	30.48	0.195	0.138	0.00	0.00	0.00	0.00	Unknown	0.00	0.43	0.00	0.43

Table 2.--Summary of field data (continued)

Flume #	Throat width (ft)	Throat width (cm)	Lateral slope (%)	Longitudinal slope (%)	Ha (ft)	Ha (cm)	Hb (ft)	Hb (cm)	Submergence (%)	Measured discharge (cfs)	Total error (%)	Corrected discharge (cfs)	Settlement error (%)
W42	1.0	30.48	1.640	0.950	0.00	0.00	0.00	0.00	Unknown	0.00	2.31	0.00	2.31
W43	1.0	30.48	-1.093	0.238	0.00	0.00	0.00	0.00	Unknown	0.00	2.89	0.00	2.89
W44	2.0	60.96	0.115	-0.103	0.00	0.00	0.00	0.00	Unknown	0.00	-0.84	0.00	-0.84
W45	1.0	30.48	-0.083	0.460	0.00	0.00	0.00	0.00	Unknown	0.00	2.50	0.00	2.50
W46	1.0	30.48	-0.832	0.425	0.00	0.00	0.00	0.00	Unknown	0.00	3.45	0.00	3.45
W47	1.0	30.48	-1.284	-1.250	0.00	0.00	0.00	0.00	Unknown	0.00	-5.00	0.00	-5.00
W48	1.0	30.48	1.351	-0.112	0.00	0.00	0.00	0.00	Unknown	0.00	-2.75	0.00	-2.75
W49	2.0	60.96	-0.261	0.500	0.00	0.00	0.00	0.00	Unknown	0.00	3.21	0.00	3.21
W50*	1.0	30.48	N/A	N/A	0.00	0.00	0.00	0.00	Unknown	N/A	N/A	N/A	N/A
W51	1.0	30.48	-0.322	-0.025	0.74	22.56	0.00	0.00	0.0	2.53	0.36	2.54	0.36
W52	1.0	30.48	1.997	0.190	0.70	21.34	0.00	0.00	0.0	2.33	-2.16	2.28	-2.16
W53	4.0	121.92	0.463	1.310	0.00	0.00	0.00	0.00	Unknown	0.00	4.53	0.00	4.53
W54	4.0	121.92	-0.755	-1.802	0.97	29.57	0.00	0.00	0.0	15.24	-6.98	14.25	-6.98
W55	1.0	30.48	-1.198	0.398	0.00	0.00	0.00	0.00	Unknown	0.00	3.85	0.00	3.85
W56	2.0	60.96	-0.939	-0.036	0.00	0.00	0.00	0.00	Unknown	0.00	2.11	0.00	2.11
W57	1.0	30.48	1.505	0.353	0.00	0.00	0.00	0.00	Unknown	0.00	-0.51	0.00	-0.51
W58	2.0	60.96	-1.424	0.181	0.61	18.59	0.00	0.00	0.0	3.71	2.51	3.81	2.51
W59	1.0	30.48	1.068	-0.824	0.00	0.00	0.00	0.00	Unknown	0.00	-6.32	0.00	-6.32
W60	2.0	60.96	0.790	-0.516	0.00	0.00	0.00	0.00	Unknown	0.00	-4.89	0.00	-4.89
W61	1.0	30.48	-3.938	-0.852	0.00	0.00	0.00	0.00	Unknown	0.00	1.29	0.00	1.29
W62	1.0	30.48	-0.299	0.837	0.00	0.00	0.00	0.00	Unknown	0.00	4.69	0.00	4.69
W63	1.0	30.48	0.688	-0.063	0.00	0.00	0.00	0.00	Unknown	0.00	-1.41	0.00	-1.41
W64	2.0	60.96	0.060	-0.333	0.00	0.00	0.00	0.00	Unknown	0.00	-1.95	0.00	-1.95
W65	1.0	30.48	-1.143	-0.250	0.00	0.00	0.00	0.00	Unknown	0.00	0.42	0.00	0.42
W66	1.0	30.48	0.146	-0.013	0.00	0.00	0.00	0.00	Unknown	0.00	-0.30	0.00	-0.30
W67	1.0	30.48	0.396	-0.275	0.08	2.44	0.00	0.00	0.0	0.08	-2.10	0.08	-2.10
W68	1.0	30.48	0.313	-0.662	0.10	3.05	0.00	0.00	0.0	0.12	-4.14	0.12	-4.14
W69	2.0	60.96	0.451	0.634	0.45	13.72	0.00	0.00	0.0	2.32	2.14	2.37	2.14
W70	1.0	30.48	0.781	-0.135	0.00	0.00	0.00	0.00	Unknown	0.00	-1.95	0.00	-1.95
W71	3.5	106.68	1.375	2.745	0.58	17.68	0.00	0.00	0.0	5.95	7.68	6.44	7.68
W72	1.0	30.48	0.313	0.450	0.00	0.00	0.00	0.00	Unknown	0.00	1.85	0.00	1.85
W73	1.0	30.48	4.651	-0.753	0.00	0.00	0.00	0.00	Unknown	0.00	-12.23	0.00	-12.23
W74	2.0	60.96	-0.735	0.825	0.00	0.00	0.00	0.00	Unknown	0.00	5.92	0.00	5.92
W75	1.0	30.48	1.746	-0.212	0.00	0.00	0.00	0.00	Unknown	0.00	-3.94	0.00	-3.94
W76	2.0	60.96	0.224	-0.125	0.35	10.67	0.00	0.00	0.0	1.57	-1.24	1.55	-1.24
W77*	1.0	30.48	N/A	N/A	0.00	0.00	0.00	0.00	Unknown	N/A	N/A	N/A	N/A

Table 2.--Summary of field data (continued)

Flume #	Throat width (ft)	Throat width (cm)	Lateral slope (%)	Longitudinal slope (%)	Ha (ft)	Ha (cm)	Hb (ft)	Hb (cm)	Submergence (%)	Measured discharge (cfs)	Total error (%)	Corrected discharge (cfs)	Settlement error (%)
W78	1.85	56.39	-0.332	0.213	1.25	38.10	0.00	0.00	0.0	10.45	1.89	10.65	1.89
W79	0.75	22.86	-0.544	0.074	0.00	0.00	0.00	0.00	Unknown	0.00	1.09	0.00	1.09
W80	0.75	22.86	-1.843	-0.866	0.00	0.00	0.00	0.00	Unknown	0.00	-2.34	0.00	-2.34
W81	1.0	30.48	2.158	0.362	0.00	0.00	0.00	0.00	Unknown	0.00	-1.51	0.00	-1.51
W82	1.0	30.48	0.776	0.712	0.00	0.00	0.00	0.00	Unknown	0.00	2.46	0.00	2.46
W83	1.0	30.48	0.919	1.132	0.85	25.91	0.00	0.00	0.0	0.00	2.46	0.00	2.46

* Flume noted for condition sheet, could not be surveyed due to the condition.

All errors were calculated using the Parshall Flume Discharge Correction Program V1.1.

applicable," is entered for the measured discharge and corrected discharge if flow was not observed. A submergence less than 70% is considered a free-fall condition and, therefore, does not impact the flow measurement accuracy.

It is observed in Table 2 that lateral slopes ranged form -4.14% to 4.65% and longitudinal slopes ranged from -3.86% to 6.11%. These data indicate that lateral and longitudinal slopes are both positive and negative in nature. For longitudinal slopes, a negative slope is where the flume entrance is lowered in relation to the flume toe and the measured flow is greater than the true flow. In the case where the flume is situated with a positive longitudinal slope, the flume entrance is raised in relation to the flume toe and the measured discharge is lower than the true flow. For lateral slopes, a negative lateral slope is when the right side (looking downstream) is lower that the flume floor centerline. When the left side of the flume crest is lower than the flume floor centerline, the flume is considered to have a positive slope.

Findings

The field data presented in Table 2 and the field notes/observations were analyzed to indicate the condition status and trends of the Parshall flumes assessed in the study. The aspects of flume age, physical condition, and measurement errors will be presented.

Flume Age

The age of 141 of the 149 flumes was estimated (owner interviews) during the field assessment based upon the time since installation. The average age of the 141 flumes was in excess of 25 years ± 2 years as depicted in Figure 5. The flume age could not be determined at 8 sites. In several cases, the flume was older than the owner and record of purchase or installation were not available. Figure 5 presents a histogram of the flume ages in 10-year groupings. It is observed that 38 of the flumes (27%) were 40 years old or older while 52% of the flumes were 30 years old or older.

Physical Integrity

The physical integrity of each flume was documented during the field assessment. The flumes were comprised of either metal (49%) or concrete (51%). A summary of the flume conditions is presented in Table 3. More than one condition may exist for each flume. Therefore, the sum of observations exceeds the number of flumes assessed. A total of 392 defects was observed at the 149 flume sites. The sample flumes were comprised of metal (49%) and of concrete (51%). Examples of commonly observed conditions include: nine flumes (6%) were found to have bent components (i.e., sidewall, brace, etc.); 50 flumes (33.6%) have blockage at the entrance; ten flumes had grass/vegetation at the entrance

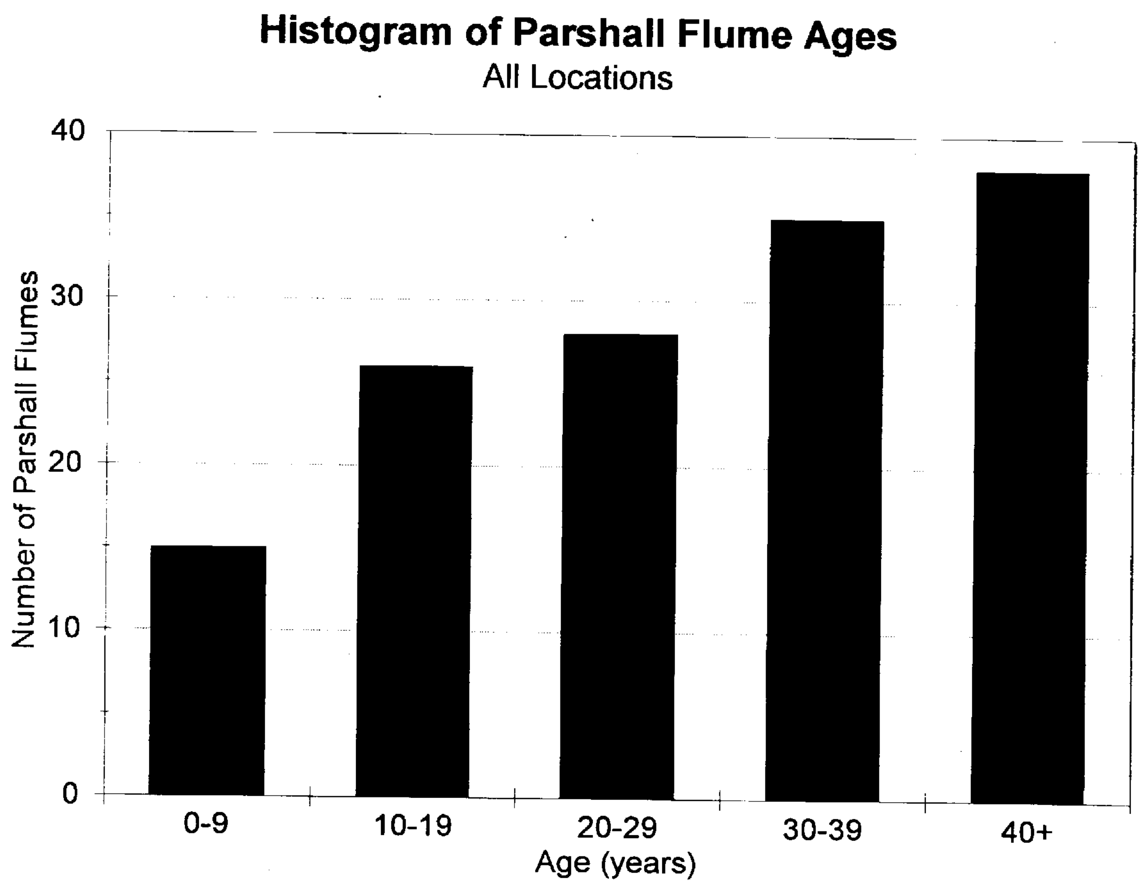

Figure 5.—Histogram of Parshall flume ages.

Table 3.—Condition of Parshall flumes assessed

General condition	Number of observations[1]	% of total flumes
Bent	9	6.0
Blockage in entrance	50	33.6
Corrosion	24	16.1
Erosion around flume	14	9.4
Grass/vegetation in entrance	10	6.7
Holes in flume	10	6.7
No. H_a staff gage	41	27.5
No. H_b staff gage	149	100.0
Rust	49	32.9
Sand/debris in throat	25	16.8
Worn concrete materials	11	7.4
Good/excellent condition	39	26.2

[1] More than one condition may exist for each flume.

(Figure 6); and 25 flumes (16.8%) were observed to have sand and/or debris in the throat (Figure 7). Flume settlement resulted in the collapse of a portion of the flume structure as observed in Figures 8 through 10.

One of the more interesting observations was that 41 (27.5%) of the flumes did not have a staff gage (H_a) mounted in the flume entrance. A staff gage (H_b) was not observed at any of the 149 flumes indicating that submergence measurements (or adjustments) are not monitored. However, 13 of the 66 operational flumes were observed to operate with a submergence condition ($\geq$ 70%) at the time of assessment.

Thirty-nine (26.2%) of the flumes were judged to be in good to excellent condition. The flumes judged to be in good to excellent condition are relatively new (< 10 years old). It appears that care was taken by the owners to install the majority of the flumes properly. However, many of the flumes have not been adequately maintained. Flow measurement accuracy is questionable, particularly when the flumes age exceeds 20 years.

Figure 6.—Vegetation at flume entrance.

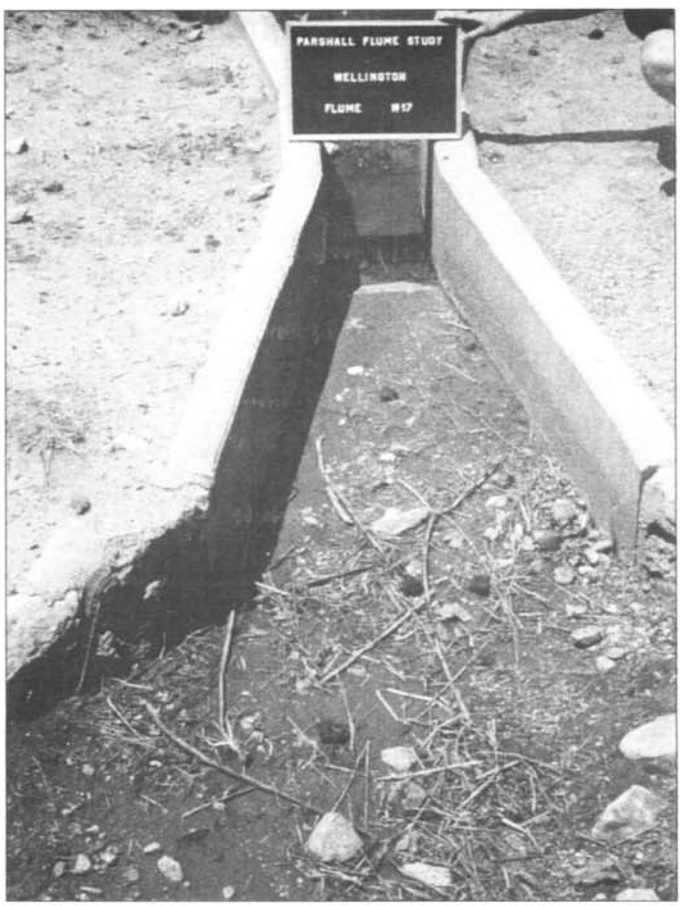

Figure 7.—Siltation in flume throat.

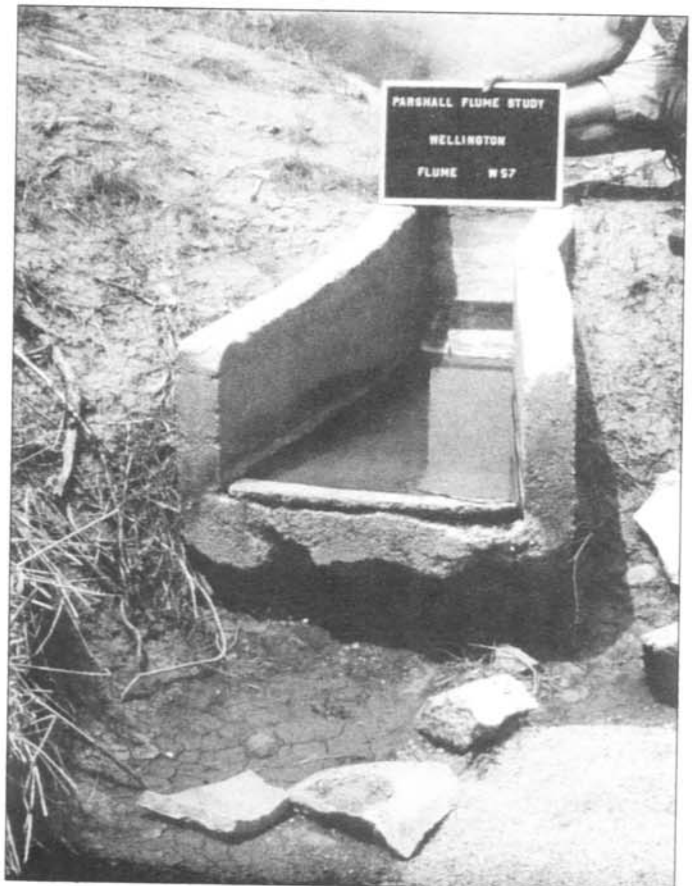

Figure 8.—Erosion and undermining at flume outlet.

Figure 9.—Erosion and undermining at flume outlet.

Figure 10.—Settlement at flume outlet.

Potential Measurement Errors

Abt et al. (1994, 1995a) reported the results of an extensive laboratory study in which the flow measurement accuracy of Parshall flumes ranging in throat widths of 10 to 61 cm was determined as a function of submergence, lateral settlement, longitudinal settlement, and combined lateral-longitudinal settlement conditions. A series of equations was developed to adjust the measured discharge (staff gage) to reflect the actual volumetric flow rate. Adjustment, or correction, procedures were presented in the "Background" section.

Utilizing Abt et al. (1994, 1995a), each flume in the field study was assessed for potential flow measurement errors based upon submergence, lateral settlement, and/or longitudinal settlement. Settlement error is the composite of lateral and longitudinal settlements as indicated by the slope information presented in Table 2. The total error is the combination of submergence error and settlement error. The estimated flow measurement errors are presented in Table 2. It is observed that the total measurement errors ranged from approximately -24.52% to 25.82%. It is noted that a negative error indicates that the measured flow is greater than the true flow value. Positive error indicates that the measured flow in the flume is less than the true flow value. The true value is the computed (adjusted) flow rate determined by Abt et al. (1995a). Eighty of the 149 flumes (53.7%) had a positive settlement error thereby indicating that the majority of the flumes measure less than the true or actual discharge.

An analysis was performed relating the approximate flume age to the settlement error (%) as presented in Figure 11. An envelope curve (one outlier) was fit to the data indicating the

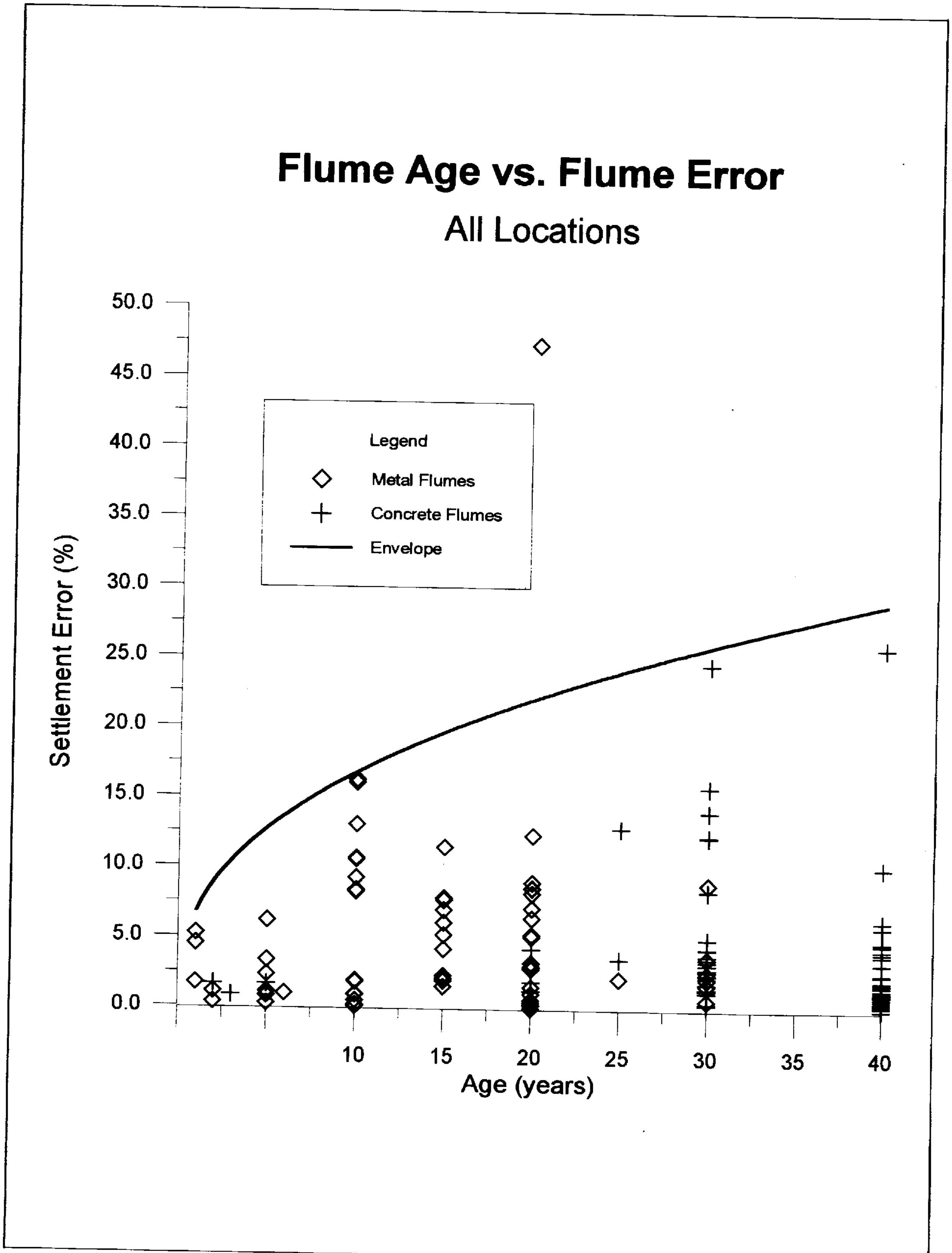

Figure 11.—Flume age vs. flume error.

trend of the potential flume water measurement error (worst case) as a function of age. Although the data base is biased toward flumes less than or equal to 30 years of age, it is evident that potential measurement error increases with the age of the flume.

Based upon the total errors reported in Table 2, 59% of the flumes underestimate the true quantity of water conveyed through canal, ditch and/or lateral systems as indicated in Table 4. Therefore, many water users receive more water than their appropriate allocation. Further, approximately 55 of the flumes meet measurement standards with an accuracy of 3% or less error and approximately 72.5% of the flumes meet measurement standards with an accuracy of 5% or less error. Nearly 27.5% of the flumes in operation do not measure water within ± 5% due to settlement and/or submergence. Approximately 45% of the flumes observed do not meet the ± 3% error standard. It was not possible to assess the potential measurement error from bypassing flows, blockage, or flume damage.

Table 4.—Summary of measurement errors

Condition	% observed
Discharge overestimated	41
Discharge underestimated	59
Total error less than 3%	55
Total error less than 5%	72.5

Conclusions and Recommendations

The results of the condition assessment reported herein are derived from a small sample of Parshall flumes surveyed in seven regions of the state, but are indicative of the status of the flow measurement and monitoring systems throughout Colorado. All of the data presented were specific to the agricultural infrastructure. These results can be extrapolated to similar systems throughout the arid and semi-arid western United States. It is apparent that the water measurement infrastructure is aging. The deterioration of the infrastructure demonstrates the need to focus attention toward maintenance and/or replacement of the flow measurement instruments. The potential flow measurement discrepancies of nearly 27.5% of the flumes assessed portray a false sense of water accounting accuracy to water users and water resource managers. These results also indicate that many water users receive more than their allotted appropriation. Since water has a significant economic value in arid and semi-arid regions, it is advantageous to water owners to insure an accurate accounting of their assets.

It is recommended that water users and managers perform a condition assessment of the comprehensive water distribution and measurement system(s). The assessment may provide a data base that will identify common discrepancies. Strategies can then be developed for upgrading the infrastructure and restoring confidence in the water measurement, monitoring, and management system. The flow measurement infrastructure must be upgraded if a relatively accurate accounting of water delivery and use is desired.

References

Abt, S. R. and Florentin, C. B. (1994) "Correction for Settlement in Submerged Parshall Flumes." J. of Irrigation and Drainage Engineering, ASCE, 120(3), pp. 676-682.

Abt, S. R., Florentin, C. B., Genovez, A., and Ruth, B.C. (1995a) "Settlement and Submergence Adjustments for the Parshall Flume." J. of Irrigation and Drainage Engineering, ASCE, 121(5).

Abt, S. R., Ruth, B. C., Brisendine, T. L., Mitchell, C. M., and Lipscomb, C. M. (1995b) "Condition Assessment of Parshall Flumes in Colorado." Colorado Agriculture Experiment Station Report, Colorado State University, Project No. COLO715, Fort Collins, CO, pp. 25, November.

Blaisdell, F. W. (1994) "Results of Parshall Flume Tests." J. of Irrigation and Drainage Engineering, ASCE, 120(2), pp. 278-291.

Cone, V. M. (1917) "The Venturi Flume." J. of Agricultural Research, 9(4), pp. 115-123.

Genovez, A., Abt, S. R., Florentin, B., and Garton, A. (1993) "Correction for Settlement in a Parshall Flume." J. of Irrigation and Drainage Engineering, ASCE, 119(6), pp. 1081-1091.

Parshall, R. L., and Rohwer, C. (1921) "The Venturi Flume." Report of the Agricultural Experiment Station, Colorado Agricultural College, Fort Collins, CO.

Parshall, R. L. (1926) "The Improved Venturi Flume." Transactions, ASCE, 89, pp. 841-851.

Parshall, R. L. (1928) "The Improved Venturi Flume." Bulletin No. 336, Agricultural Experiment Station, Colorado Agricultural College, Fort Collins, CO.

Parshall, R. L. (1950) "Parshall Flumes of Large Size." Bulletin 426-A, Colorado Agricultural Experiment Station, Colorado Agricultural College, Fort Collins, CO.

Peck, H. (1988) "Submerged Flow in Parshall Flumes." Proceedings, National Conference on Hydraulic Engineering, ASCE, New York, NY.

Robinson, A. R. (1957) "Parshall Measuring Flumes of Small Sizes." Bulletin No. 61, Agricultural Experiment Station, Colorado State University, Fort Collins, CO.

Robinson, A. R. (1965) "Simplified Flow Corrections for Parshall Flumes Under Submerged Conditions." Civil Engineering, ASCE 25(9), p. 75.

Skogerboe, G. V., Hyatt, M. L., England, J. D., and Johnson, J. L. (1967) "Design and Calibration of Submerged Open Channel Flow Measurement Structures. Part 2: Parshall Flumes." Report WG31-2, Utah Water Research Laboratory, Utah State University, Logan, UT.

Skogerboe, G. V., Walker, W. R., Wu, T. Y., and Bennett, R. S. (1971) "Slope-Discharge Ratings for Cutthroat Flumes." Agriculture Engineering Department, Colorado State University, Fort Collins, CO.

Water Measurement Manual, 2nd Ed. (1984) U.S. Bureau of Reclamation, U.S. Department of the Interior, Denver, CO.

Wright, S. J., Tullis, B. P., and Long T. M. (1994) "Recalibration of Parshall Flumes at Low Discharges." J. of Irrigation and Drainage Engineering, ASCE, 129(2), pp. 348-362.

Wu, T. Y., (1971) "Effects of Settlement of Flume Ratings." Water Management Technical Report No. 12, AET-71-72-TYWIV, Colorado State University, Fort Collins, CO.

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Steven R. Abt (Professor, Director, Hydraulics Laboratory; phone (970) 491-8203), Condition Assessment of Parshall Flumes in Colorado, Part 2 (December 1996). Colorado Agriculture Experiment Station, Colorado State University, Fort Collins, Colorado 80523.

REPAIRING GEOMEMBRANES IN THE FIELD

by Alice I. Comer[1]

Background

Beginning in 1969, the Bureau of Reclamation (Reclamation) has used several different types of geomembranes (plastic liners) for seepage control in canals and reservoirs. Traditionally, these liners have been placed on 2.5:1 slopes (or flatter) and then covered with 12 to 18 inches of soil to protect from ultraviolet (UV) degradation, vandalism, and mechanical damage. As the need to reduce right-of-way has increased (steeper side slopes) and better UV stabilized resins have been developed, Reclamation has experimented with several types of exposed geomembranes. The problem now arises in how to repair exposed geomembranes which have been damaged by the forces of nature and man.

Current Repair Techniques

Several types of geomembranes can be stabliized for UV resistance and used in an exposed condition. These geomembranes can be classified into three types based on their repair technique.

Exposed geomembranes that can be repaired by chemical bonding include Chlorosulfonated Polyethylene (CSPE), with trade name hypalon; Chloronated Polyethylene (CPE); Ethylene Interpolymer Alloy (EIA); and specially formulated Polyvinyl Chloride (PVC). Hypalon continues to cure as it ages and will require proper surface treatment before attempting to solvent weld on a patch.

Geomembranes that must be repaired by thermal welding include spread-coated reinforced EIA (trade name XR-5) and members of the Polyolefin family. Polyolefins include High Density Polyethylene (HDPE), Very Low Density Polyethylene[2] (VLDPE), and Polypropylene[3] (PP). Thermally welded patches may require grinding and are usually extrusion welded.

The third type of repair technique uses an acetylene torch and is used for polymer modified bituminous liners.

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[2] VLDPE is no longer recommended for exposed applications.

[3] PP is difficult to stabilize for UV and should only be used if specifically formulated for protection from UV light by using Hindered Light Amine Stabilizers (HALS).

For all the various repair techniques, patches should have rounded edges and extend at least 6 inches beyond the affected areas. Recommended repair procedures are detailed in the EPA Technical Guidance Document, "Inspection Techniques for the Fabrication of Geomembrane Field Seams" (EPA/530/SW-91/051).

Possible New Repair Technique

The most difficult type of repair is the thermal welded repair because water districts and area offices generally do not have the required extrusion welding equipment. Extrusion welding equipment typically costs between $10,000 and $20,000 and requires specialized training. Therefore, the Technical Service Center, Materials Engineering and Research Laboratories (MERL) in Denver, with support from the Bureau of Reclamation Pacific Northwest Region Water Conservation Center, has acquired a hand-held welding device to perform temporary repairs on exposed geomembranes.

The original cost of the Novaweld GT-100 welder in 1995 was about $2,000. The welder (pictured in figure 1) was originally designed to seam together geotextile (filter fabric) materials but can also be used on geomembranes. John Schaffer (D-8180) experimented with the hand-held welder both inside and outside the Denver labs. Table 1 records preliminary laboratory test data using the GT-100 welder.

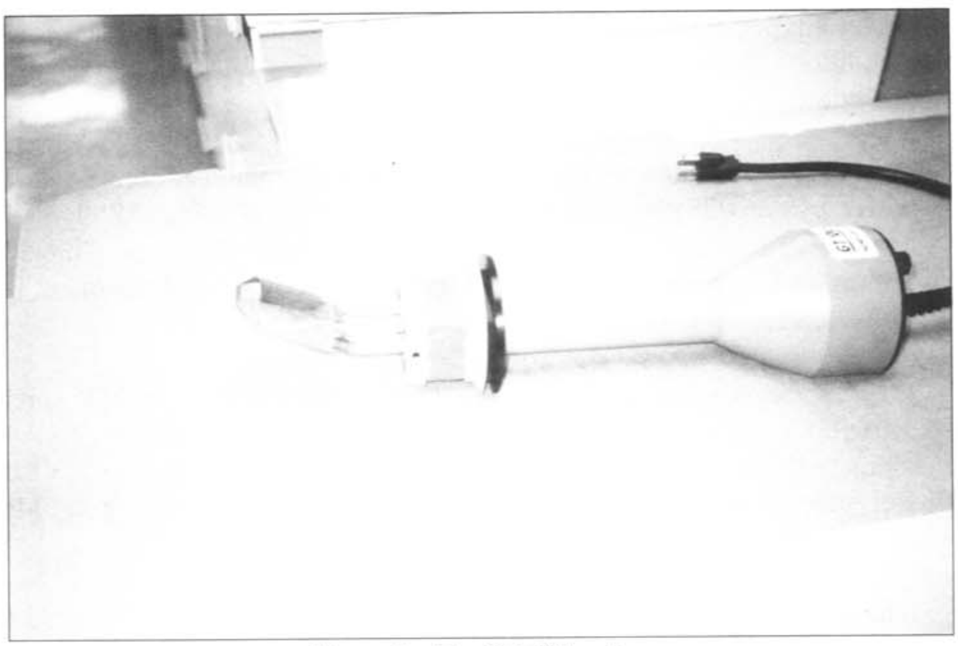


Figure 1.—The GT-100 welder.

The GT-100 welder is capable of yielding seams with good shear strength and peel strength; however, seam quality is highly dependent on operator skill and temperature setting. Figure 2 shows Mr. Schaffer demonstrating the seaming technique. Good peel strength was not attained until the welding temperatures and pressures used were high enough. When the temperatures are high enough to produce a good weld, the material smokes and gives off a noxious odor, requiring the need for good ventilation or the use of a respirator. The values for 60-mil smooth HDPE in the table show extremely low peel strength when the temperature setting of the welder was 3.5 but excellent values when the

Table 1.—GT-100 seam strengths for geomembranes

Material	Thickness (mils)	Heat setting	Shear lbs (avg)	Peel lbs (avg)	Comments
PVC	40	3	73	14	Good
Hypalon	36	4	48	5	Poor
HDPE smooth	60	3.5 5	164 159	1 55	Poor Good
HDPE textured	60	4.5	152	2	Poor
HDPE smooth-textured	60	4	134	4	Poor
VLDPE smooth	60	4	53	3	Poor
VLDPE textured	60	4	85	25	Good
VLDPE smooth-textured	60	4	88	15	Good

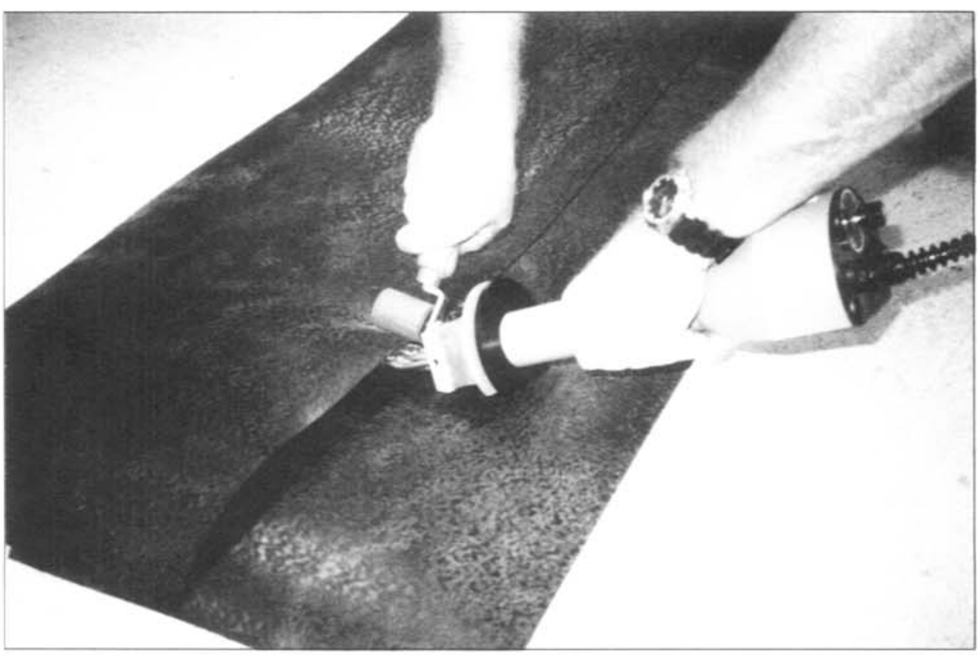


Figure 2.—John Schaffer demonstrates seaming technique.

temperature of the welder was increased to 5.0. The last column in the table gives comments on peel strength values only. If the temperature setting on the other polyolefin types was increased, the values would probably improve just as the smooth HDPE values did. The poor values for Hypalon were probably due to the fact that the material was aged and the surface cure was not removed before seaming.

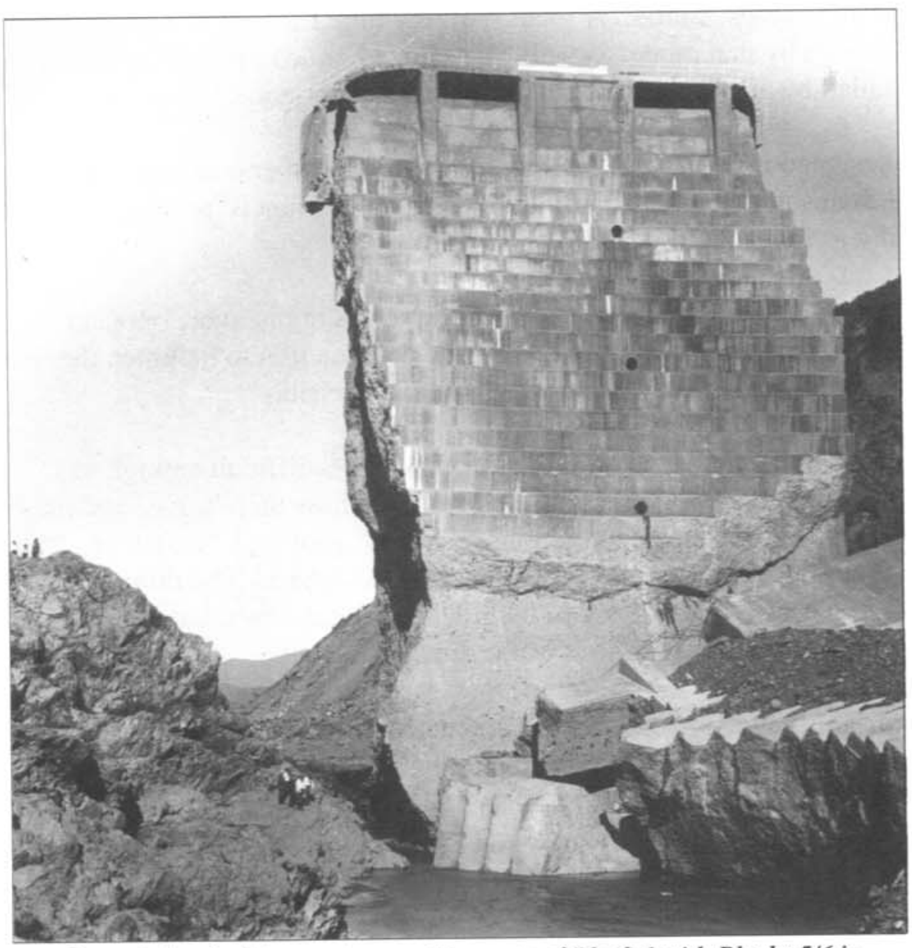
As the laboratory tests show, initial testing of this welder is promising. MERL is currently seeking field test sites to examine the long-term effectiveness of this type of repair for exposed geomembranes. Please contact the author if you are interested in participating in the field study of this welder.

CAUSE OF DAM FAILURE DISCOVERED . . . ALMOST 70 YEARS LATER

by Ann Lucius

Persistence pays off. Nobody knows that better than J. David Rogers, Ph.D., president of Rogers/Pacific, Pleasant Hill, California, who began researching the 1928 St. Francis Dam failure in 1977. Now, 20 years after he started, Rogers has found the answers to the questions engineers had been asking for almost 70 years.

The dam's failure upon its first full filling near midnight on March 12-13, 1928, resulted in the death of more than 500 people in Ventura County, northwest of Los Angeles. It is considered by many to be the worst civil engineering disaster of the 20th century. The dam's demise has been shrouded in mystery for the past 68 years, and it was a mystery Rogers wanted to solve.



Ground view looking upstream at the mass of Block 1 with Blocks 5/6 in right foreground. Note level of schist detritus atop Block 5, well above the channel bed, which is still flowing when this photo was taken four days after the failure. Huber Collection, University of California Water Resources Center Archives.

Rogers first studied about the failure of the 205-foot-high, curved concrete gravity St. Francis Dam while in graduate school analyzing the 1976 failure of the Teton Dam. In 1977, he began collecting information about the St. Francis Dam's history in earnest. After the dam's failure, 13 boards of inquiry were set up by various government entities to write reports assessing the tragedy. "There's a plethora of literature out there dating from that era," Rogers said, "so the first few years [of my investigation] was really just gathering as much data as I could."

From there, he started looking at the dam's design. This phase of his work became more serious in the late '80s, Rogers said, when he started using more sophisticated forensic methodology. He then began "reassembling" the displaced dam pieces with computerized, three-dimensional drafting software and terrestrial photogrammetry techniques using 300 or so historic photos.

The process, he laughed, was "kind of like Picasso going through different stages of his life." His assessment, said Rogers, also went through stages, changing over the years.

"By 1989, I thought that I had figured it out; that it was a keyblock uplift failure underneath the left abutment, similar to the Malpasset Dam failure in France in 1959," he said. "I was really convinced that that's what it was because I hadn't looked at anything else except that particular failure mode" because that's where the failure was thought to have been.

Curiosity got the best of him, however, and Rogers began exploring other areas: the concrete, the structural design, arching loads, cantilever loads. "Every time I looked at something new, the analysis predicted failure by that mode, as well," he said. "I ended up looking at it seven different ways, and it failed by all seven, which is a humbling experience."

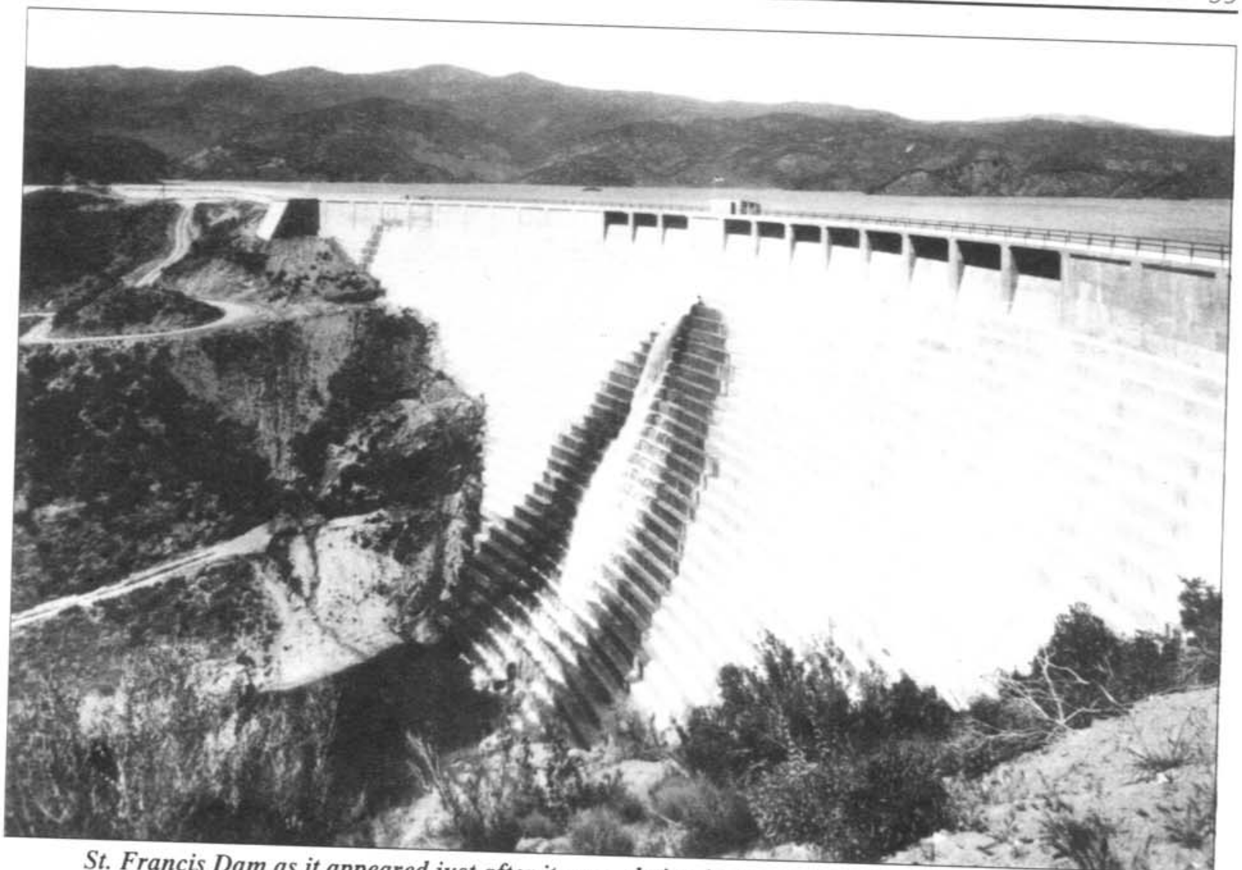
The St. Francis Dam, designed in 1922, was no different from any other concrete gravity dam designed in the United States in that era, according to Rogers. St. Francis' problem, he said, was not in its design, it was in its geology.

"It was a geologically complex site. That's what tipped the scales in disfavor," Rogers explained. "There was also a design decision made during construction to heighten the dam 20 feet without increasing the basal width. That was a critical decision."

The dam was unknowingly built against a bedrock paleo landslide, difficult enough to recognize today, let alone in the 1920s, Rogers said. "We know now there's over 100 major dams in the United States that have also been built against [such geology]," he added. "They haven't failed yet, but that information is of critical import to designers. The thing keeping those dams in place is the inherent redundancy of their design, not the fact that their designers adequately recognized the geological conditions of the site."

Dams built against landslides have a much greater chance of failing. "When the ground or the rock has slid in a landslide, it dilates or increases in volume," Rogers explained. "That increase in volume sets up a whole bunch of cracks, and water can go through those cracks quite easily."

What was interesting about the St. Francis Dam was that it failed within days of the water getting at the crest, meaning water moved through the abutment rapidly. This action was similar to the Teton Dam failure in Idaho in 1976, the last major dam built in the U.S., according to Rogers.



St. Francis Dam as it appeared just after its completion in May 1926. It was a curved concrete gravity section, standing approximately 200-feet high and was comprised of 130,000 cubic yards of concrete without benefit of any contraction joints, drainage galleries, cut-off walls, or grout curtain. The Pelona Schist made up the east abutment, on the right side of the photo, while the Sespe formation red beds comprised the upper two-thirds of the west abutment (shown at left). Photo from Huber Collection, University of California Water Resources Center Archives, Berkeley.

"Usually, you'd hope that it takes a couple years for water to start seeping around an abutment," Rogers said of the St. Francis' rapid movement. "You don't want it to move in hours or days; that's much too fast." When that happens, high water pressures develop.

Today's methodology and computerized analytical techniques enabled Rogers to "re-build" the dam, allowing him to see where each of its pieces came from and explain how they moved so far downstream.

Some of the blocks that weighed up to 10,000 tons were over a mile downstream, Rogers said. "It is very hard, even today, to explain how something that big moves that far downstream. We've been able to do that by showing that it was a landslide."

Conclusions from the original inquiry boards, said Rogers, "lack a lot from a modern perspective. You can't have both abutments fail simultaneously if there are dramatically different geological [bedrock] materials (schist and conglomerate). That doesn't make any sense." Although it may have looked that way then, it turns out that's not what happened.

"It was left abutment failure completely," Rogers said. "The right abutment subsequently failed late in the failure sequence. They did not go simultaneously.

"[Because of the landslide], the left abutment slid down, and then the lake had to remove the landslide debris, which was over half a million cubic yards of rock," Rogers continued. "In doing that, the outflow [became dirty.] The dirtier the water, the more it will defreight large pieces of concrete. That's how the huge pieces of concrete got moved so far downstream."

Rogers' research will be used to help analyze and assess present dams, especially those built against landslides, and look at the effects of aging.

"The thing that has failed dams of late," Rogers said, "has been high runoff events. You have a high precipitation event like a hurricane, and then you have a high runoff event, and the dams aren't able to handle [it]. That was the situation St. Francis was in when it failed. The water was right at the spillway, and it was completely full."

To prevent future dam failures, Rogers said the geology of the dam site must be properly characterized. "That's usually the one thing that's unique to every single dam site," he said. "The geology at every dam site, the geologic history of that site, are all unique. The designs aren't. They pretty much all follow the same principles."

Rogers was recently honored with the 1996 R.H. Jahns Distinguished Lectureship Award of the Association of Engineering Geologists and Geological Society of America for his research.

His book, *The St. Francis Dam Disaster Revisited,* was published by the Historical Society of Southern California and Ventura County Museum Association. In addition, three new television productions profiling the disaster and Rogers' findings are in the works. Rogers began a lecture tour in October, speaking at universities and professional society meetings around the country, and will continue touring through March.

"I've been flattered by all the interest that's stirred," he said.

Photos courtesy of J. David Rogers, Ph.D., president of Rogers/Pacific, Pleasant Hill, California.

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