86 1) Colorado

3) 4) Bulletin 386

May, 1932

PARSHALL FLUMES OF LARGE SIZE

By R. L. Parshall, Senior Irrigation Engineer

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

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

2)
Colorado Agricultural College
Colorado Experiment Station
Fort Collins

The Colorado Agricultural College
FORT COLLINS, COLORADO

Acknowledgments

The author wishes to acknowledge his sincere appreciation of the assistance furnished by all who have aided in planning and reviewing the material for the manuscript, gathering field data, checking computations, and preparing the illustrations for this bulletin. He feels especially under obligations to Carl Rohwer, Associate Irrigation Engineer, Bureau of Agricultural Engineering, U. S. Department of Agriculture, who contributed a number of current-meter check gagings, together with suggestions and direct aid in preparing the manuscript; Ralph Owens, Colorado State Hydrographer, who furnished current-meter gagings and material aid in designing flumes and setting instruments; Wm. J. Colson, Jr., who prepared the drawings for the manuscript; L. R. Brooks, who prepared the construction drawings for most of the large flumes; S. W. Cressy, Commissioner of Colorado Water District No. 17, who was largely instrumental in making possible the construction of the large flumes; C. W. Beach, Division Engineer of Colorado Water Division No. 2, in which most of the large flumes are located, who aided materially in arranging for the work; M. C. Hinderlider, Colorado State Engineer, who extended the authority of his office to requests for the large installations; A. L. Fellows, Senior Irrigation Engineer, Bureau of Agricultural Engineering, U. S. Department of Agriculture, who edited the manuscript; and also to the several irrigation companies that have cooperated in the construction of the large flumes which have been essential to the study of the hydraulic characteristics of this type of measuring device.

PARSHALL FLUMES OF LARGE SIZE[1]

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

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

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

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

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

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

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

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

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

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

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

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

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

[4]The Venturi Flume, by V. M. Cone (U. S. Dept. Agr. Journal of Agricultural Research, Vol. IX, No. 4, pages 115-129). 1917.

[5]The Venturi Flume, by R. L. Parshall and Carl Rohwer (Colo. Agr. Exp. Sta. Bul. 265), 1921.

[6]The Improved Venturi Flume, by R. L. Parshall (Colo. Agr. Exp. Sta. Bul. 336).

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

THE PARSHALL MEASURING FLUME

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

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

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

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

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

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

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

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

REPRESENTATIVE LARGE FLUME INSTALLATIONS

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

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

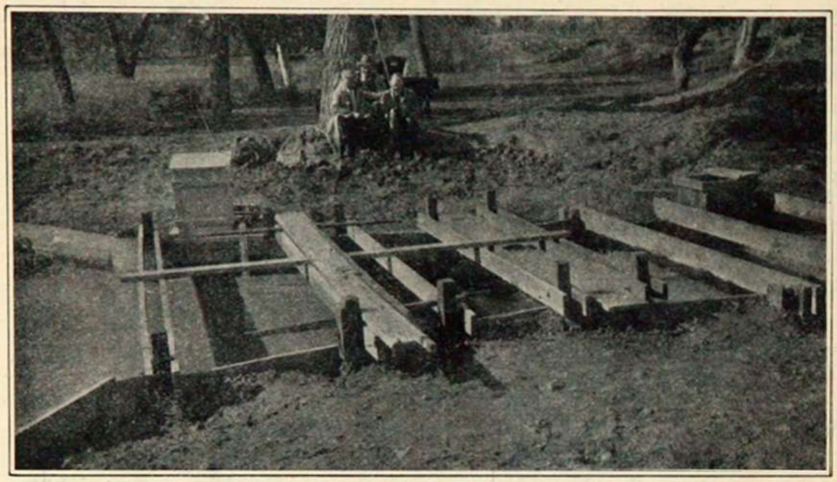


Figure 1.—Ten-foot timber Parshall Measuring Flume, discharge 96 second-feet, Las Animas Consolidated Canal (See Table X).

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

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

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

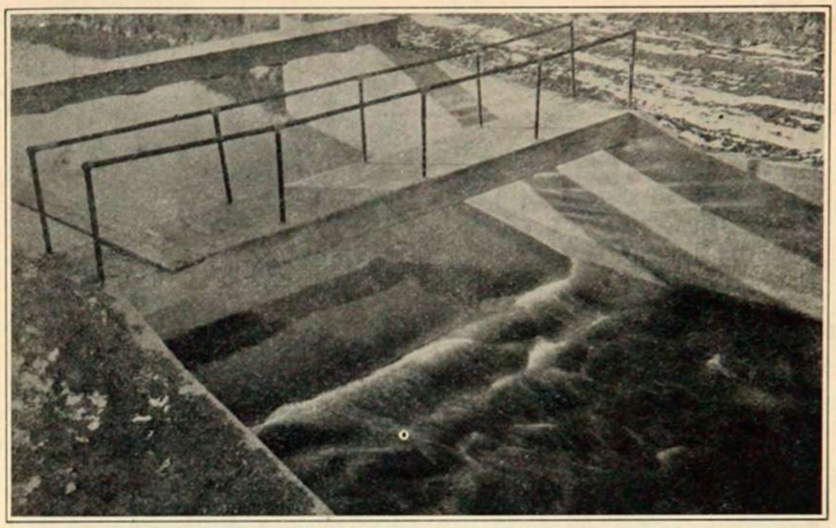


Figure 2.—Twenty-foot Parshall Measuring Flume, Holbrook Canal, discharge 75 second-feet, submergence 82 percent. (See Table X.)

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

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

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

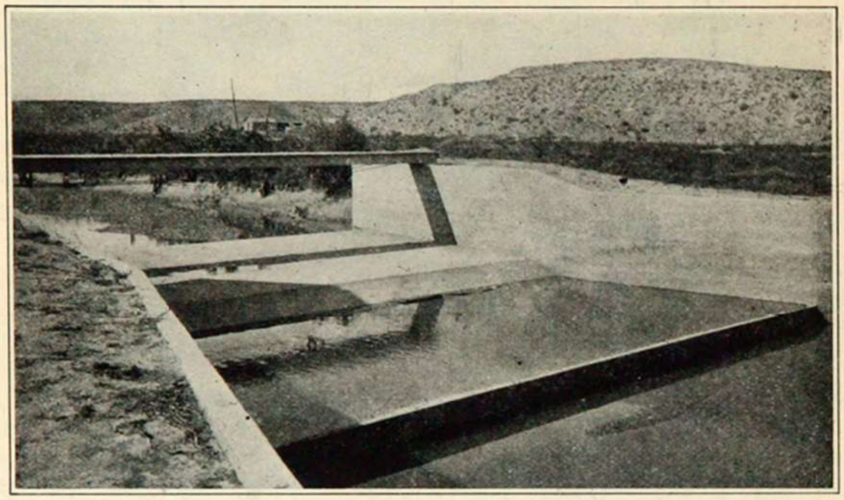


Figure 3.—Forty-foot Parshall Measuring Flume, Fort Lyon Canal.

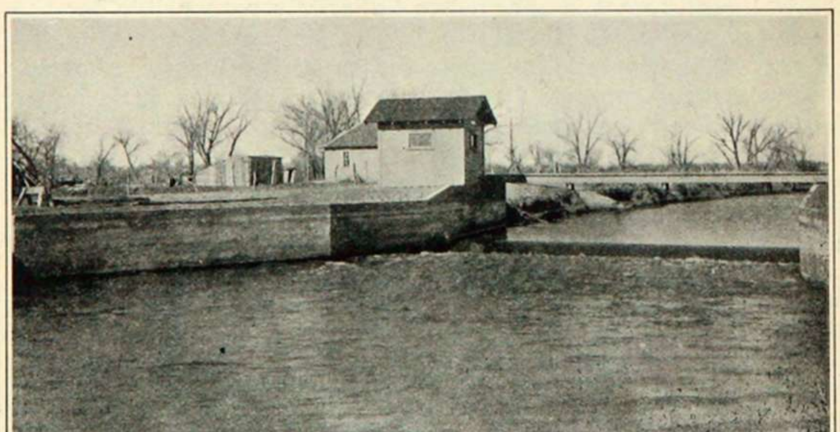


Figure 4.—Forty-foot Parshall Measuring Flume, discharge 177 second-feet, no submergence, Fort Lyon Canal. (See Table X.)

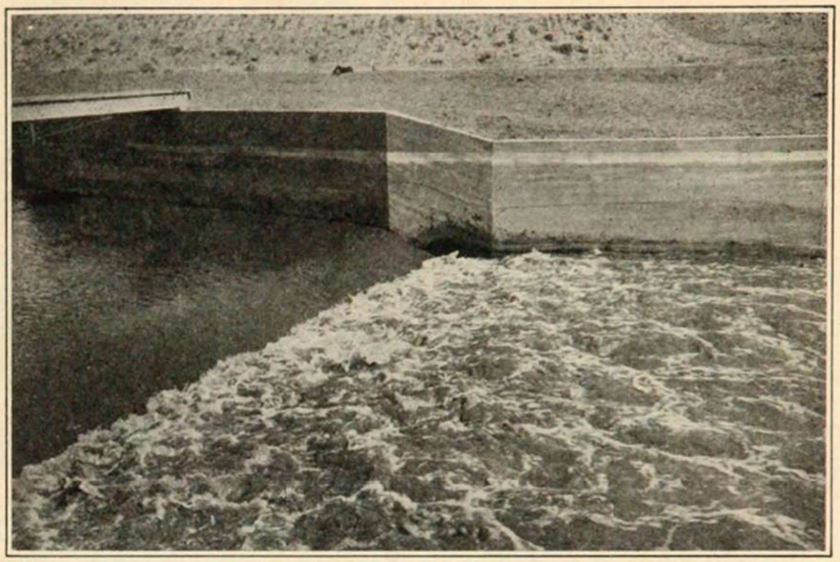


Figure 5.—Smoothness of flow in converging section thru 40-foot Parshall Measuring Flume discharging 177 second-feet, with no submergence. Fort Lyon Canal. (See Table X.)

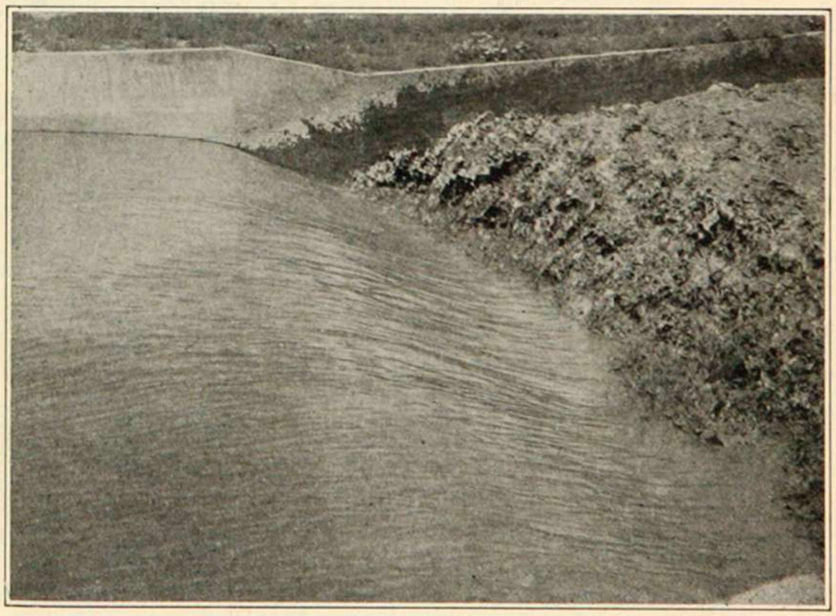


Figure 6.—Forty-foot Parshall Measuring Flume, discharge 1390 second-feet, with submergence not effective, in Fort Lyon Canal. (See Table X.)

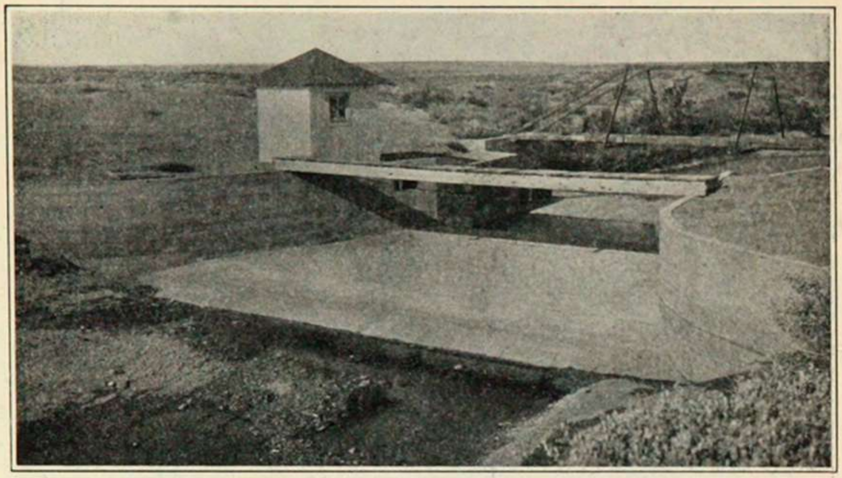


Figure 7.—Thirty-foot Parshall Measuring Flume, in Colorado Canal.

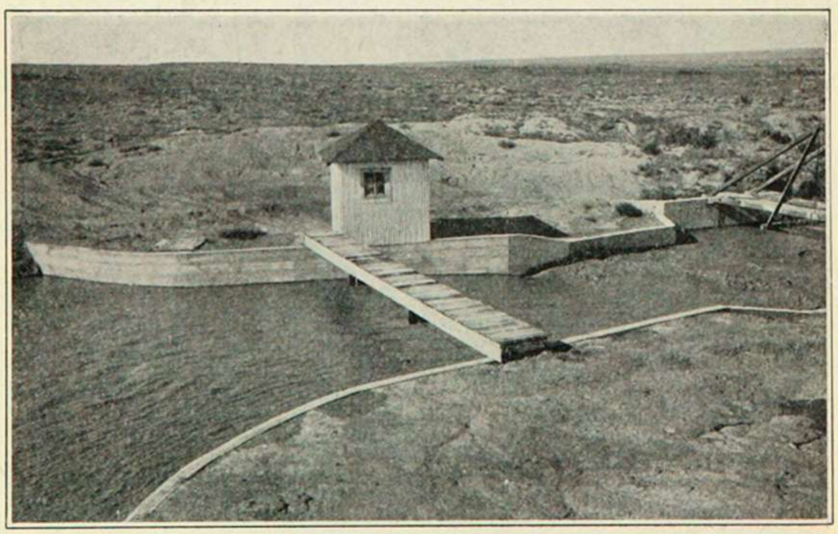


Figure 8.—Thirty-foot Parshall Measuring Flume, discharge 803 second-feet, submergence 89 percent, in Colorado Canal. (See Table X.)

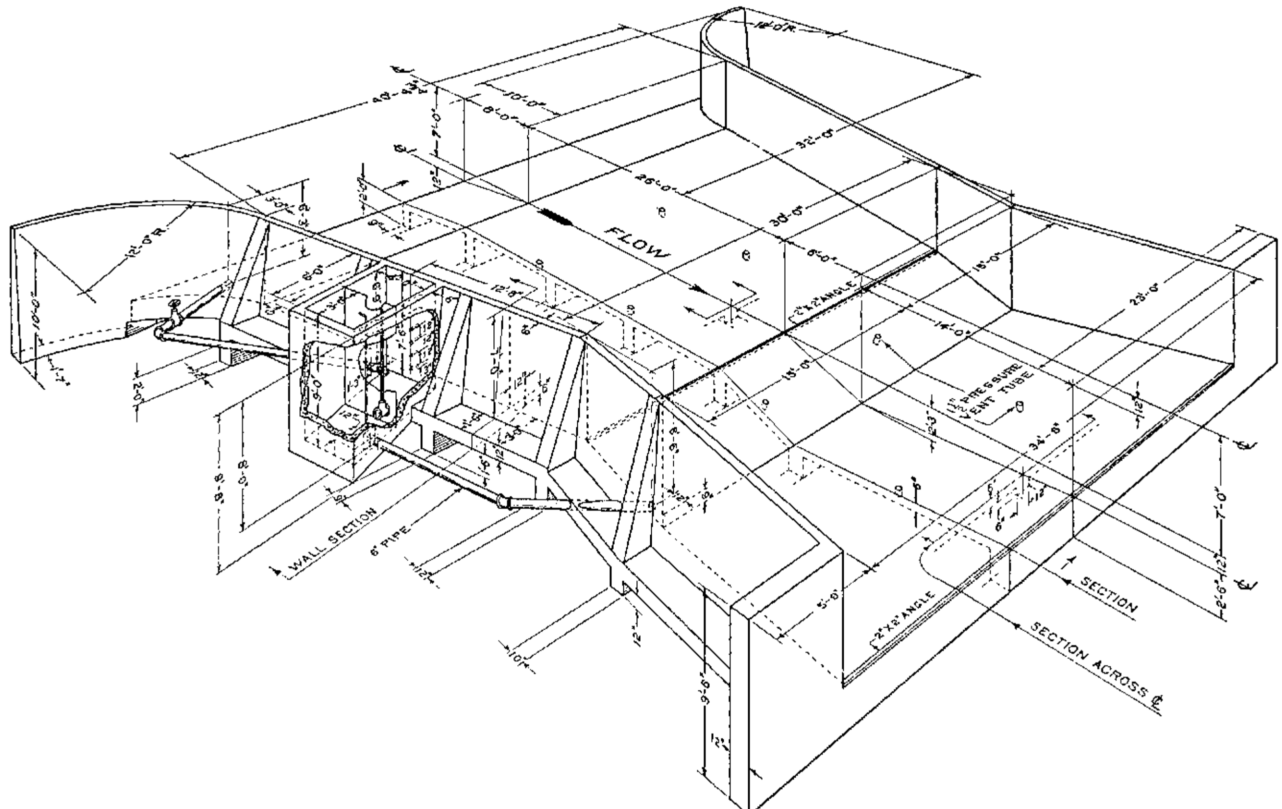


Figure 9.—Large Parshall Measuring Flume of reinforced concrete, with 30-foot throat.

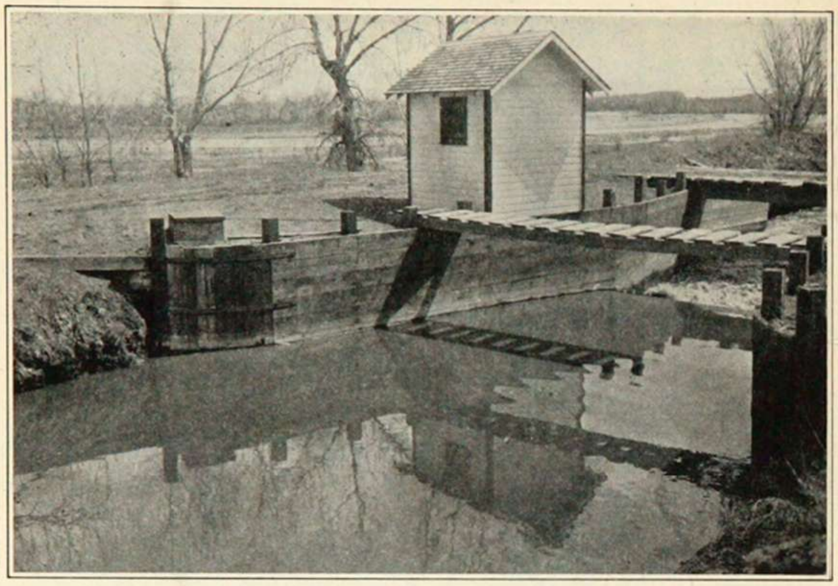


Figure 10.—Fifteen-foot Parshall Measuring Flume, discharge 101 second-feet, submergence 19 percent, Rocky Ford Highline Canal. (See Table X.)

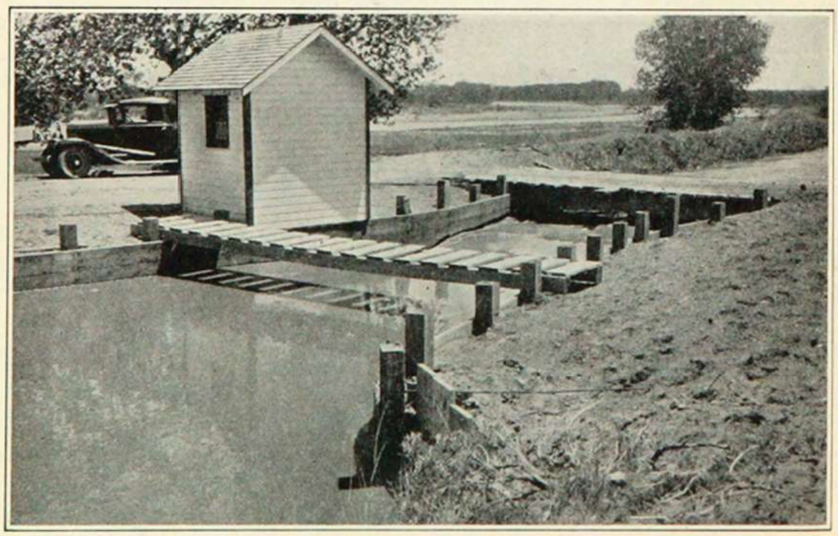


Figure 11.—Fifteen-foot Parshall Measuring Flume, discharge 464 second-feet, submergence 95 percent, Rocky Ford Highline Canal. (See Table X.)

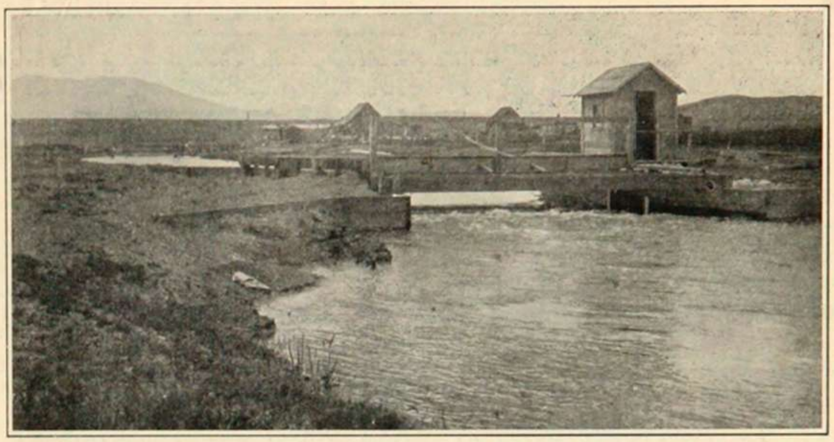
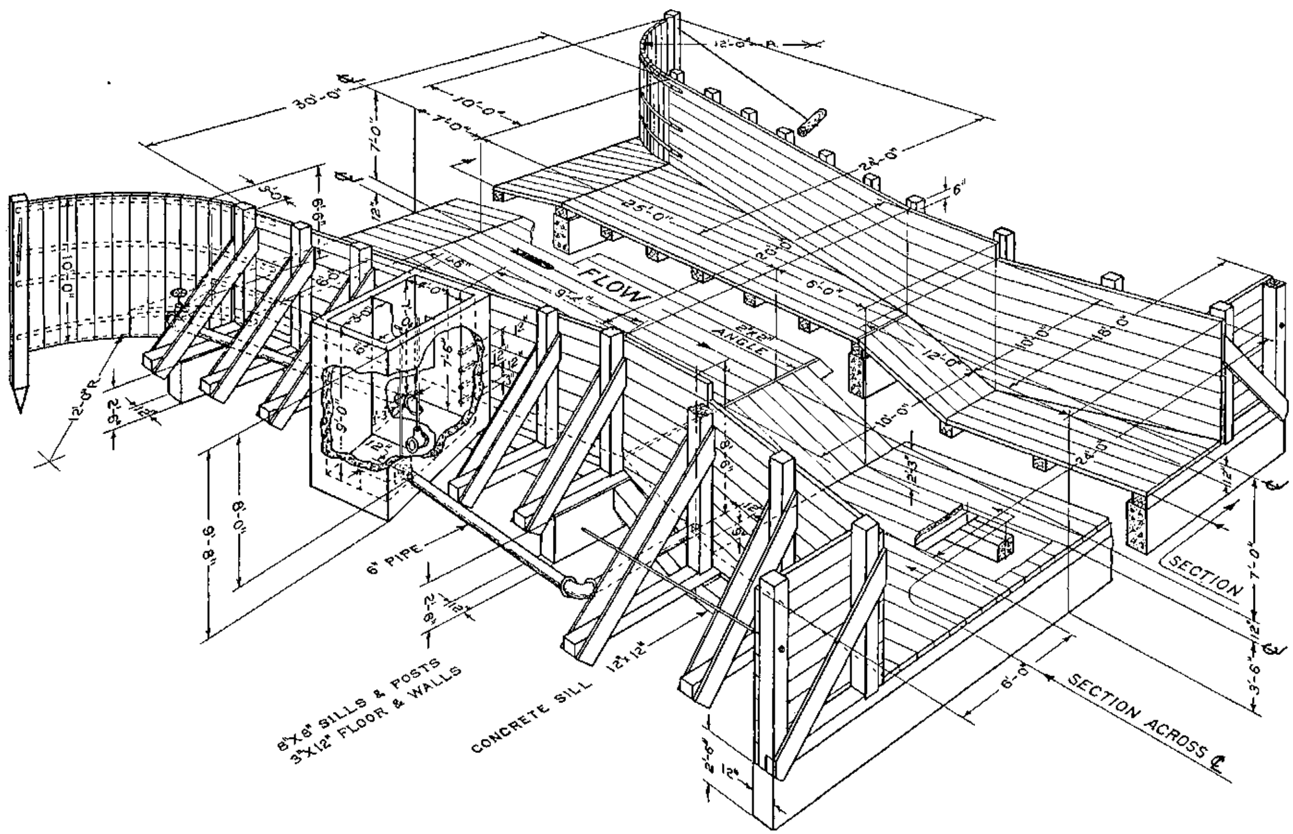


Figure 12.—Twenty-foot Parshall Measuring Flume, discharge 239 second-feet, submergence 69 percent, Antero Reservoir outlet, upper South Platte River. (See Table X.)


FLOW
2"x2" ANGLE
SECTION
SECTION ACROSS ℄
CONCRETE SILL 12"x12"
6" PIPE
8"X8" SILLS & POSTS
3"X12" FLOOR & WALLS
30'-0"
10'-0"
25'-0"
24'-0"

THE SETTING OF LARGE FLUMES

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

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

The first appropriation right of the Holbrook canal to the

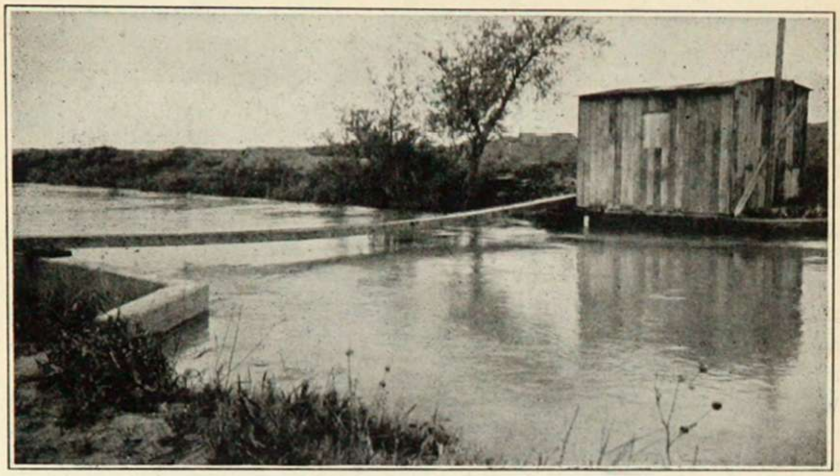


Figure 14.—Old concrete rating flume and gage house on Holbrook Canal, typical of many old structures replaced by Parshall Measuring Flumes.

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

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

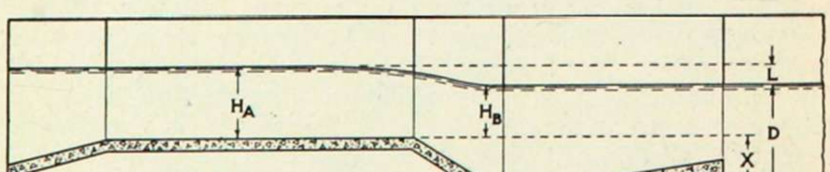


Figure 15.—Section of flume as an aid in the determination of the proper crest elevation.

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

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

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

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

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

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

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

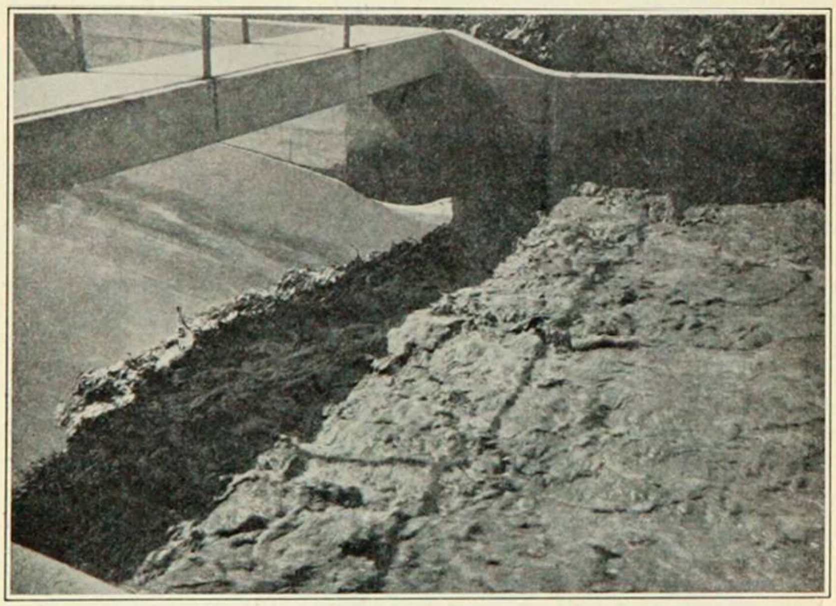


Figure 16.—A discharge of 550 second-feet passing thru the throat section of the 20-foot flume on the Holbrook Canal with 80 percent submergence. (See Table X.)

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

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

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

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

CONSTRUCTION OF LARGE FLUMES

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

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

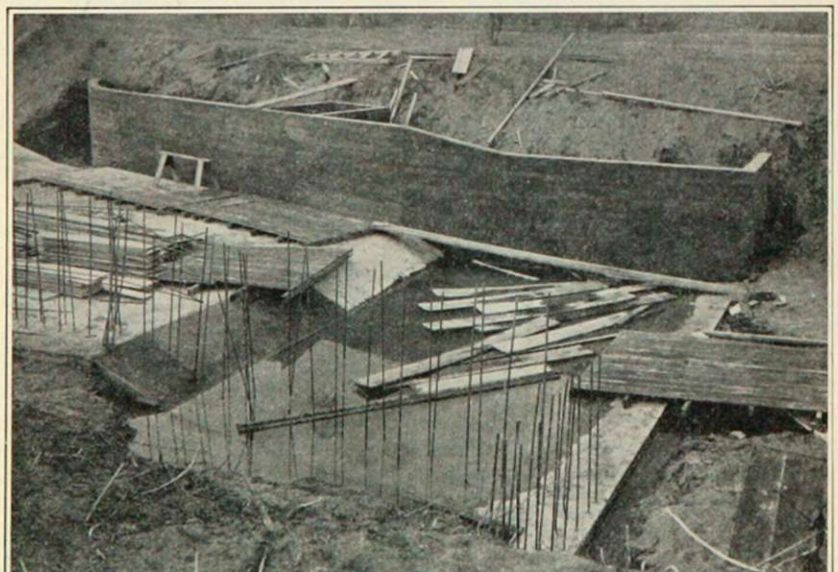


Figure 17.—Partly completed reinforced concrete 20-foot Parshall Measuring Flume on the Bijou Canal, South Platte River, near Greeley, Colo.

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

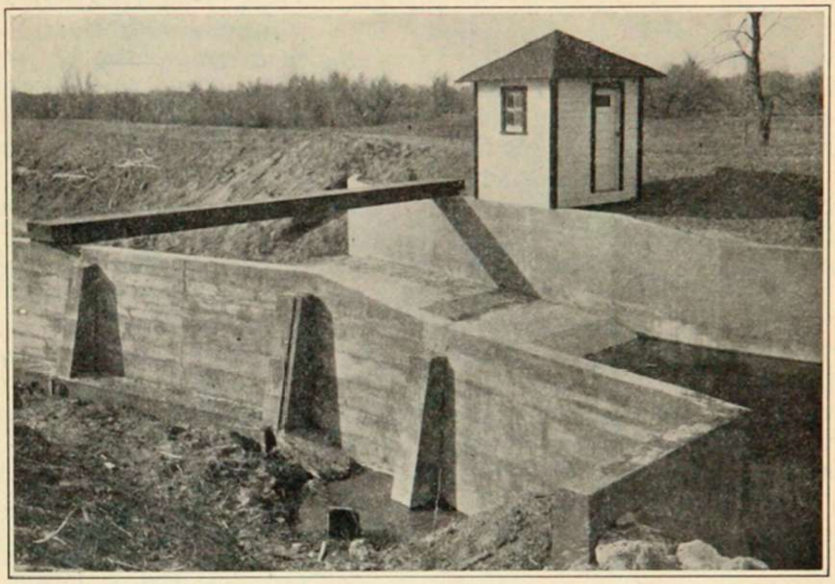


Figure 18.—Flume wall, with counterfort bracing, of the 20-foot flume on Bijou Canal.

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

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

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

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

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

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

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

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

STILLING WELLS

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

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

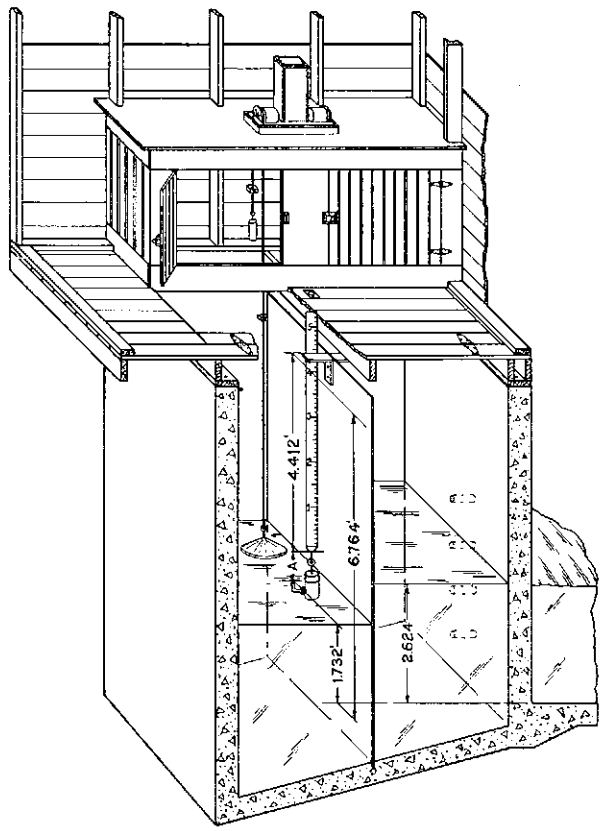


Figure 19.—Method of determining actual values of the H_A and H_B heads in feet, for comparison with indicated values on instrument drums.

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

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

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

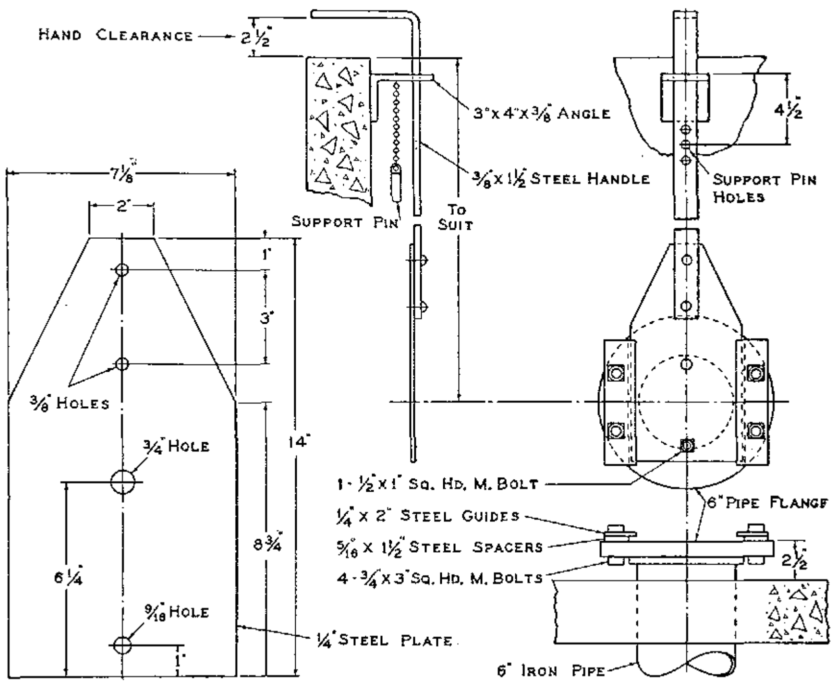


Figure 20.—Slide gate for flushing pipe from the HB stilling well.

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

GAGE HOUSE AND INSTRUMENT

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

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

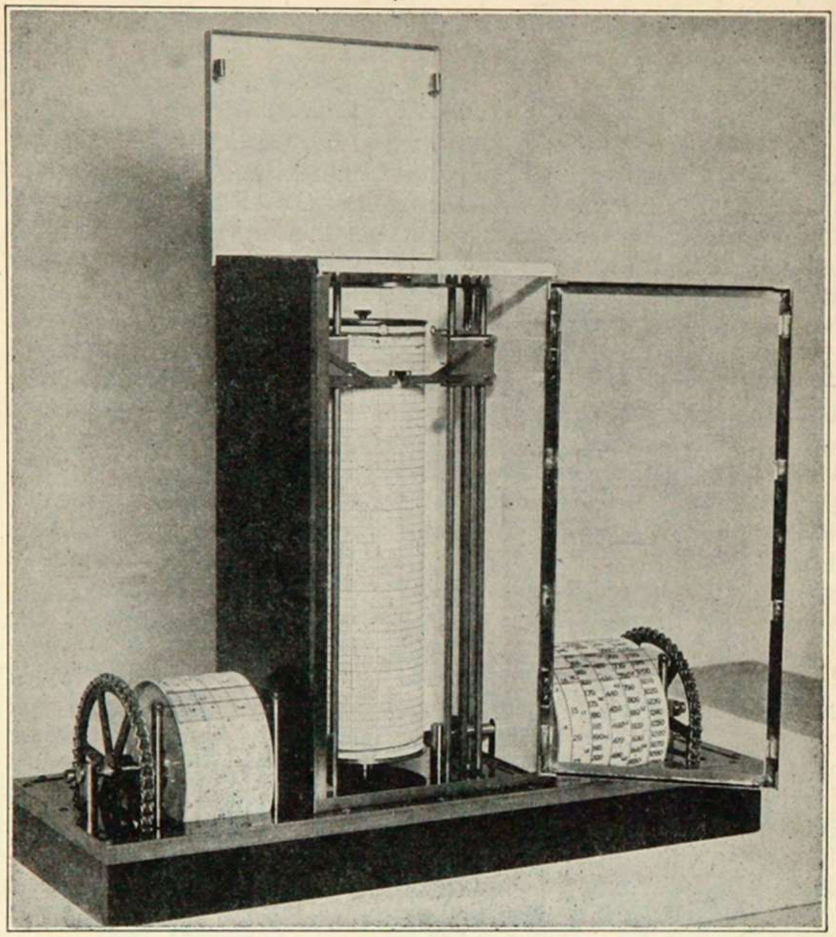


Figure 21.—Double-head recording and indicating instrument designed for use in connection with Parshall Measuring Flumes of large size.

and H_B gage heights. Each of these is moved by a sprocket wheel and chain, the latter being attached to a float in the well, and the system is balanced by a counterweight. The H_A and H_B gage heights are read on continuous spiraled scales, graduated in feet, on the surface of the drums. The scales are of neat, clear-cut marking, printed on white pyralin strips which are afterward formed into cylinders of the proper diameter and provided with heavy pyralin heads, securely fixed to the sprocket wheel shaft. Mounted on a brass support is a strip of clear pyralin with a fine black-etched line spanning across the face of each cylinder. Any change or variation of the water surface in the wells is indicated by the movement of the scale beneath this index line. The drum at the left gives the value of the H_B head, and at the right is a wider-faced drum bearing two sets of graduations, one set giving the H_A readings and the other showing in bold-faced type the rate of free-flow discharge in second-feet. The H_A drum with its discharge graduations is especially designed for any particular size of flume.

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

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

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

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

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

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

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

FREE-FLOW DISCHARGE

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

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

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

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

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

TABLE II

FREE-FLOW DISCHARGE 10-FOOT PARSHALL MEASURING FLUME

FORMULA $Q = 39.38 H_A^{1.6}$

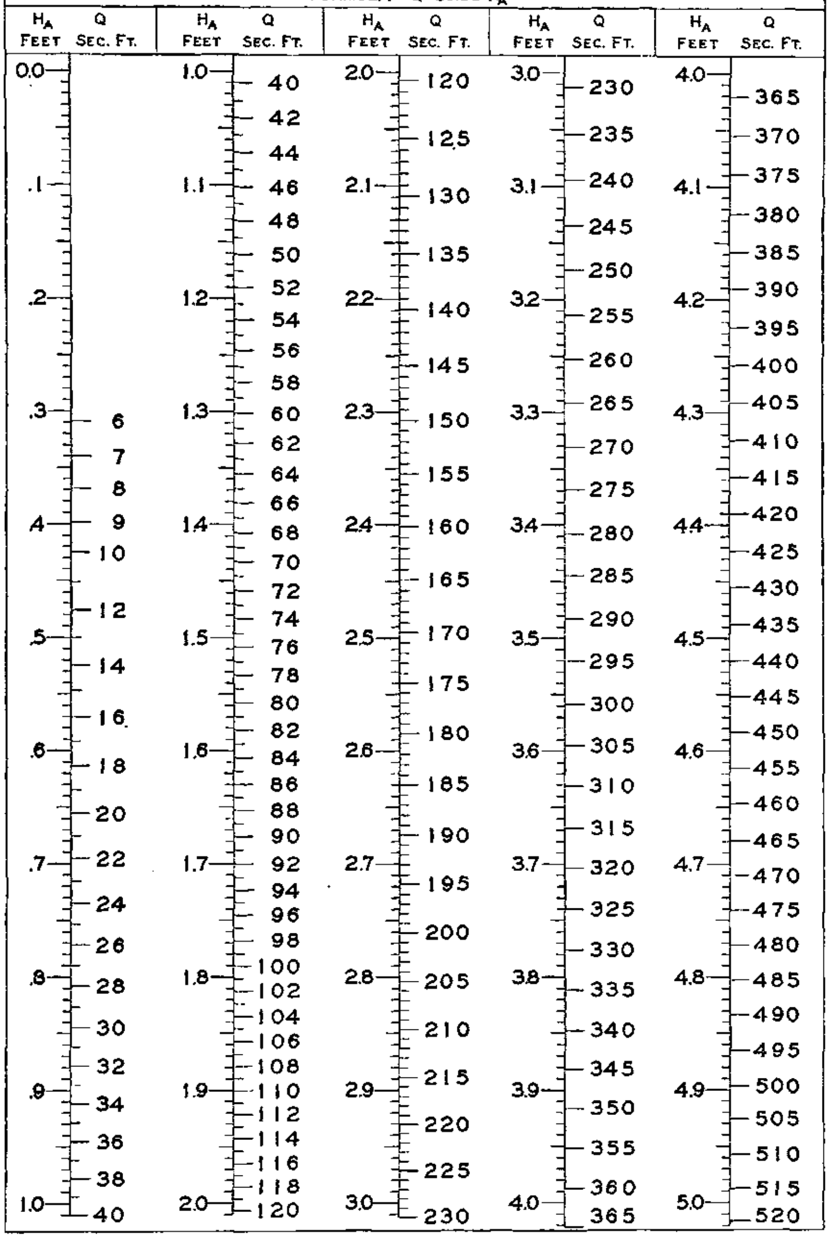


TABLE III

FREE-FLOW DISCHARGE 12-FOOT PARSHALL MEASURING FLUME

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

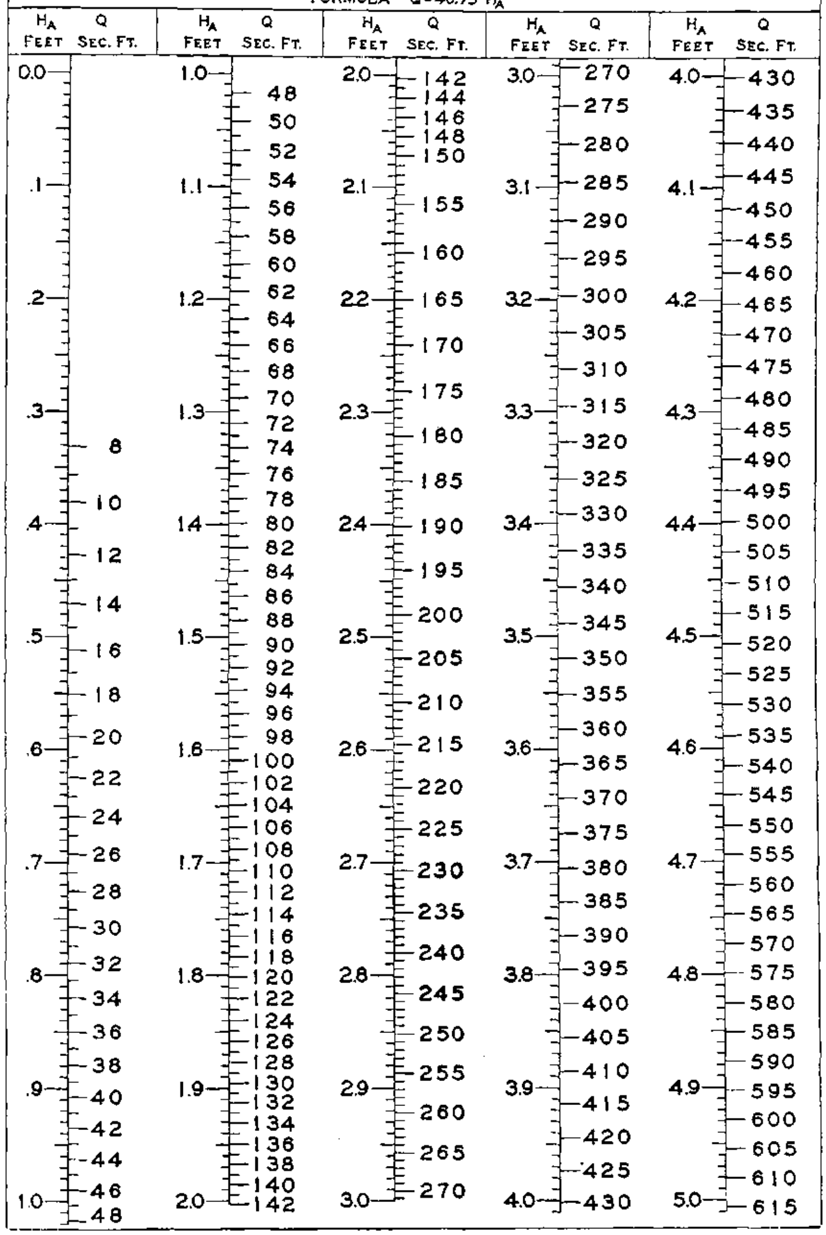


TABLE IV

FREE-FLOW DISCHARGE 15-FOOT PARSHALL MEASURING FLUME

FORMULA $Q = 57.81\ H_A^{1.6}$

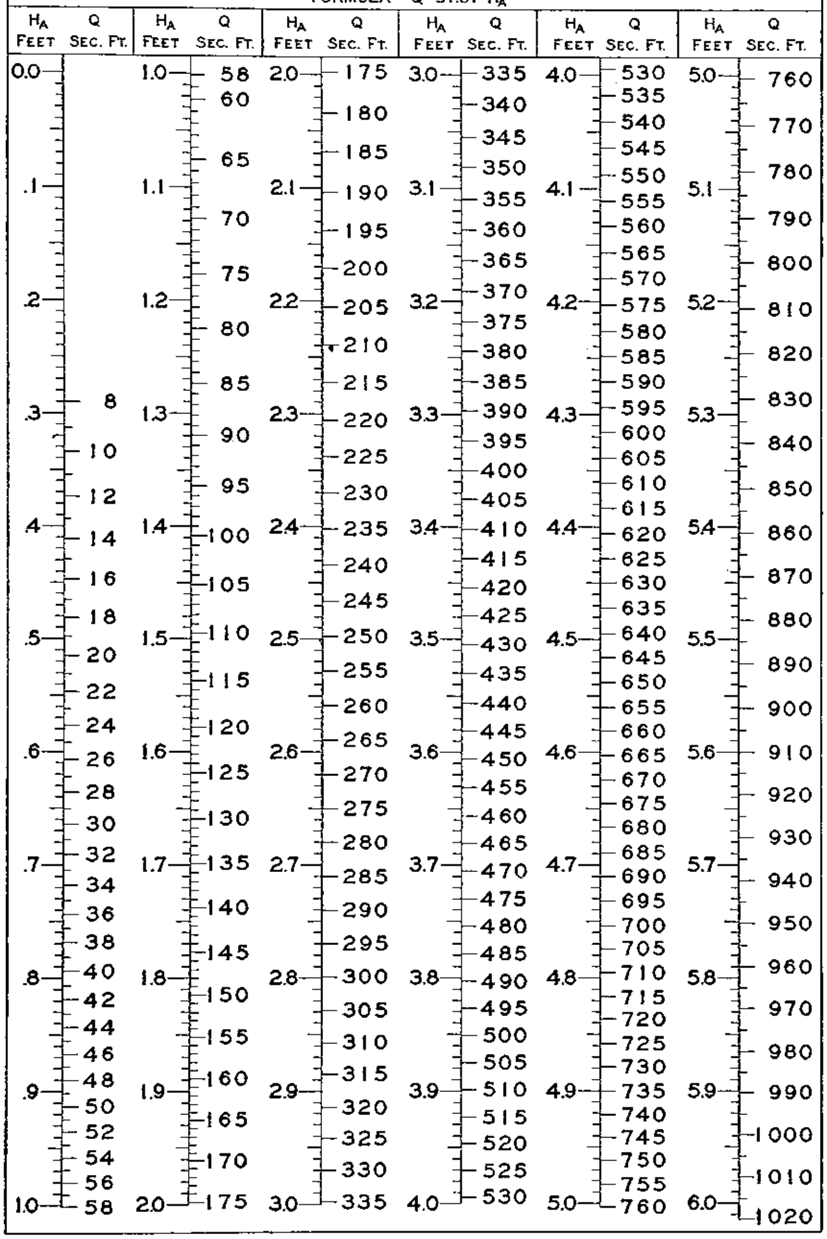


TABLE V

FREE-FLOW DISCHARGE 20-FOOT PARSHALL MEASURING FLUME

FORMULA $Q = 76.25\, H_A^{1.6}$

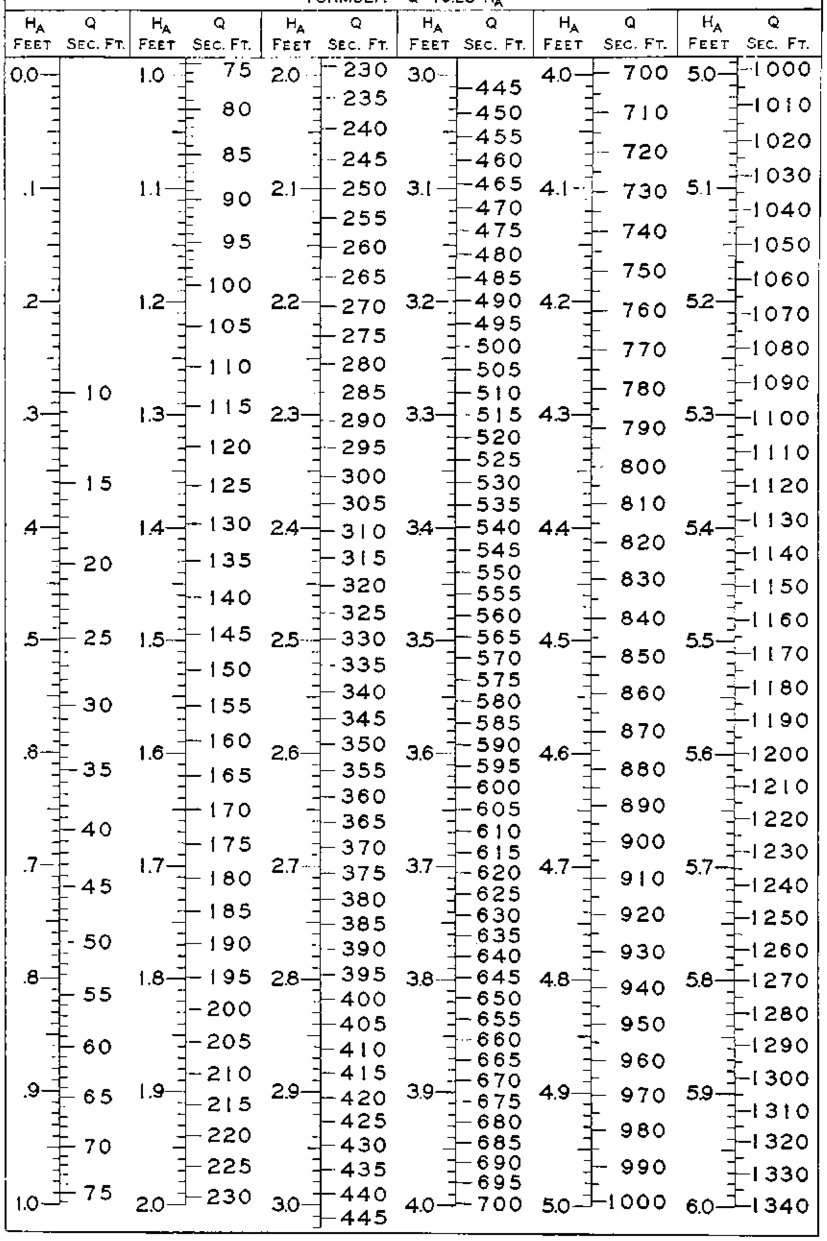


TABLE VI

FREE-FLOW DISCHARGE 25-FOOT PARSHALL MEASURING FLUME

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

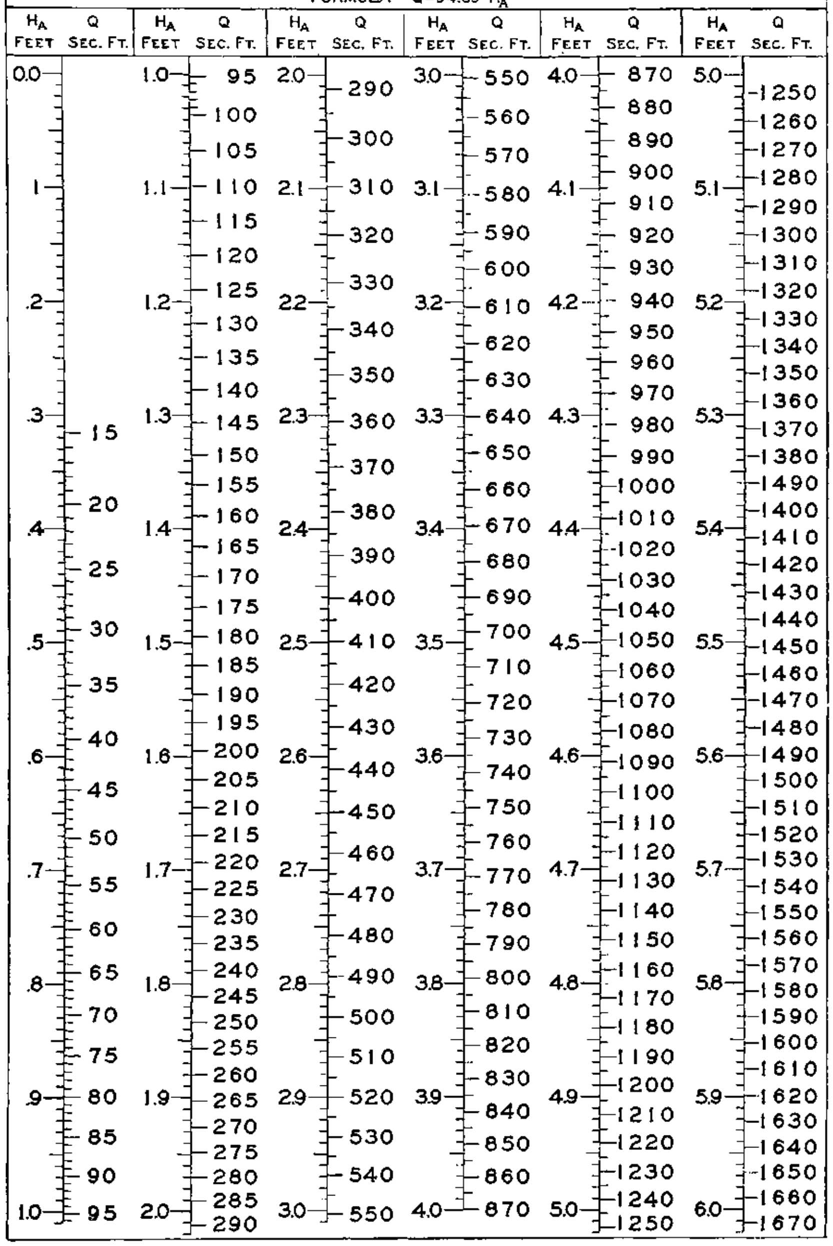


TABLE VII

FREE-FLOW DISCHARGE 30-FOOT PARSHALL MEASURING FLUME

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

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

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

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

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

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

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

TABLE VIII
FREE-FLOW DISCHARGE 40-FOOT PARSHALL MEASURING FLUME

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

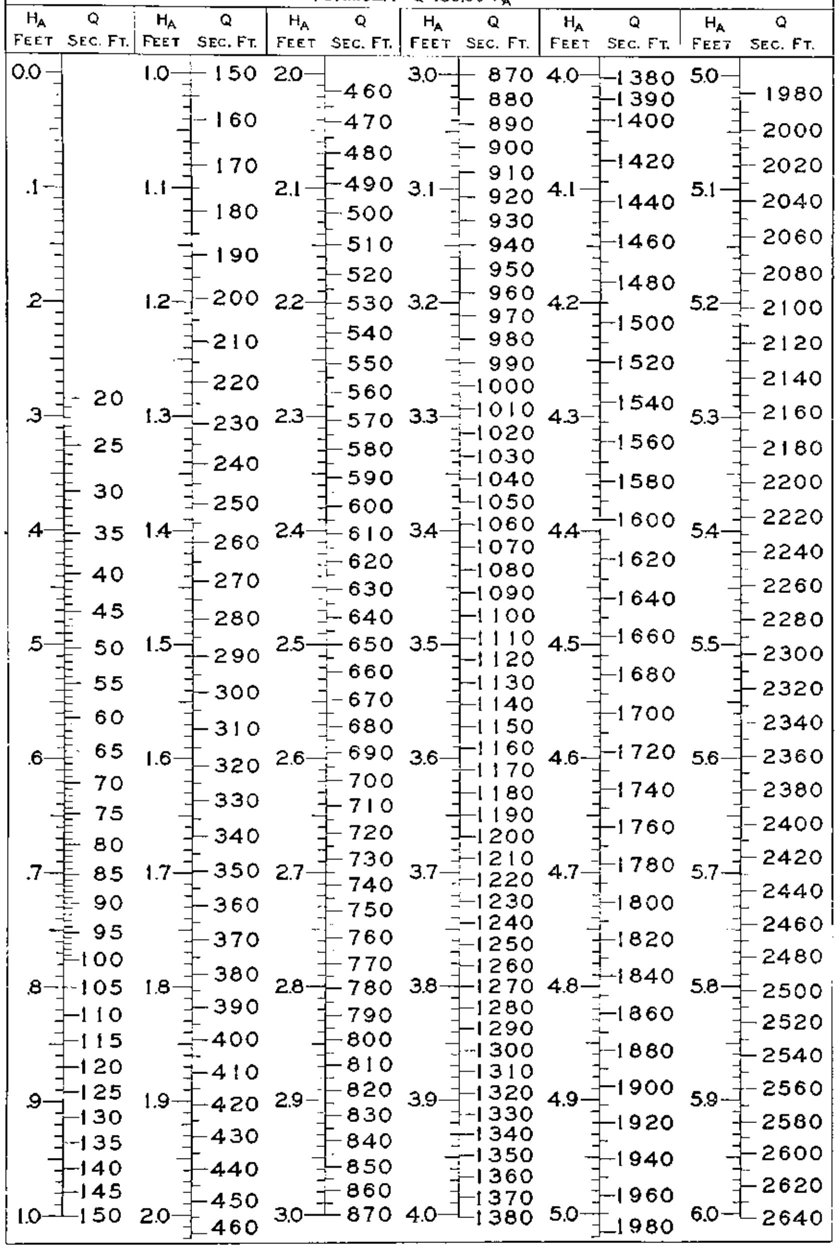


TABLE IX

FREE-FLOW DISCHARGE 50-FOOT PARSHALL MEASURING FLUME

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

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

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

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

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

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

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

SUBMERGED FLOW

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

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

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

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

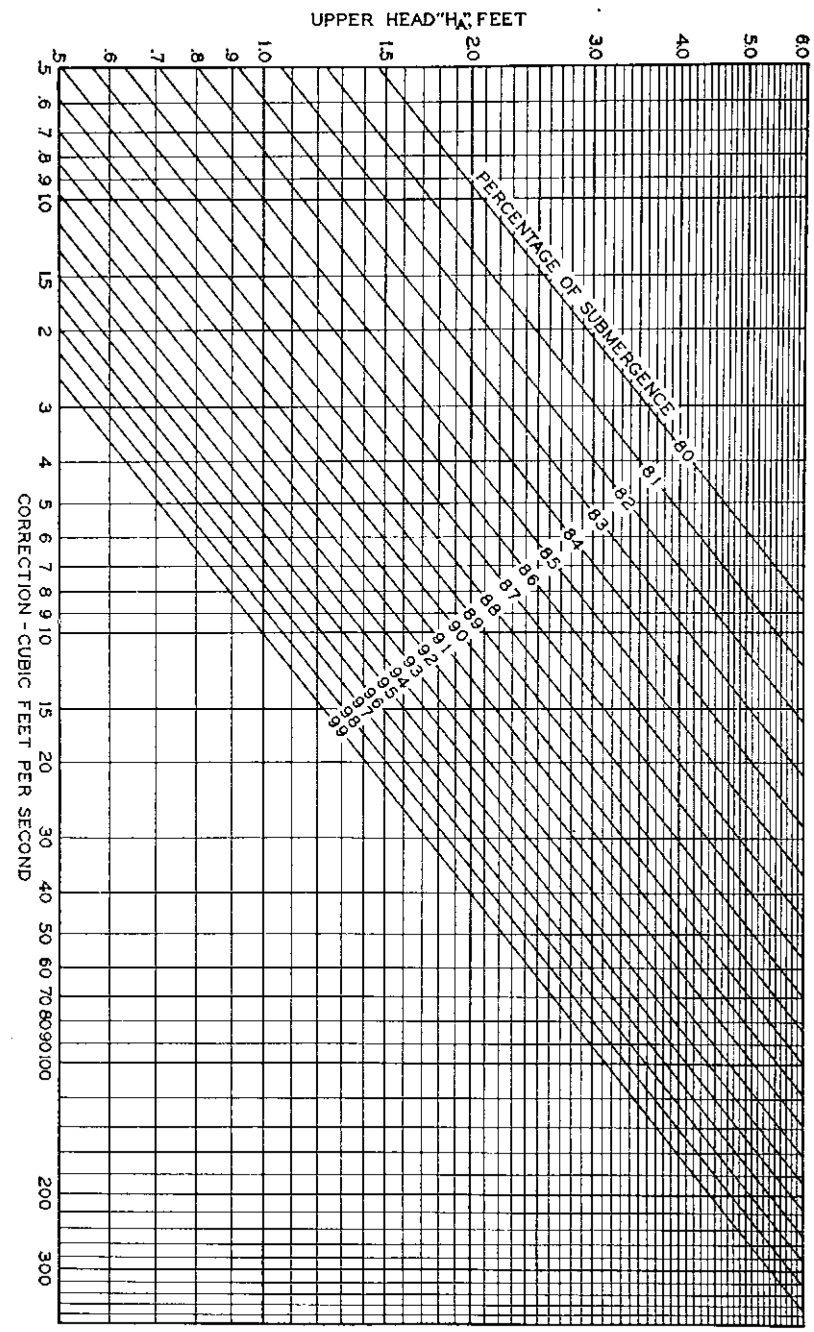


Figure 22.—Diagram for determining the correction in second-feet per 10 feet of crest for submerged-flow discharge. (This diagram, enlarged to a scale of 10.5 by 17.5 inches, printed on heavy stock, is available at 25 cents per copy upon application to the Colorado Agricultural Experiment Station.

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

Loss of Head Thru Flume

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

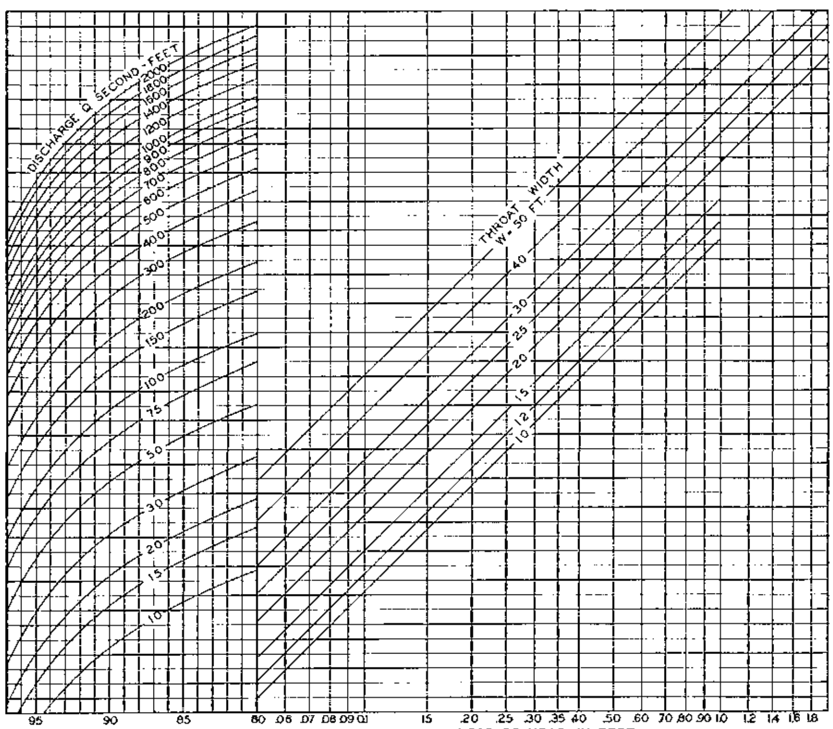


Figure 23.—Diagram for determining the total loss of head thru large Parshall Measuring Flumes.

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

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

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

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

COMPARISON OF OBSERVED TO COMPUTED DISCHARGE

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

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

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

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

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

See footnotes at end of table.

Table X.—Contd.

Heads		Ratio H_B/H_A	Discharge			Deviation
H_A	H_B		Current meter	Computed	Difference	
Feet	Feet	Percent	Sec.-ft.	Sec.-ft.	Sec.-ft.	Percent
HORSE CREEK LATERAL (Torrington, Wyo.) 12-foot flume [1]						
2.07	....	....	148.9	[6]149.7	0.8	—0.5
1.66	....	....	106.6	105.2	1.4	+1.3
1.34	....	....	74.1	74.7	0.6	—0.8
0.78	....	....	31.3	31.4	0.1	—0.3
BOX ELDER CREEK, 12-foot flume [3]						
0.80	....	....	37.6	38.7	1.1	—2.8
0.89	....	....	38.8	38.7	0.1	+0.3
0.95	....	....	42.1	43.1	1.0	—2.3
0.93	....	....	41.9	41.6	0.3	+0.7
0.66	....	....	24.3	24.0	0.3	+1.2
1.19	....	....	60.3	61.8	1.5	—2.4
1.19	....	....	61.0	61.8	0.8	—1.3
1.04	....	....	48.4	49.8	1.4	—2.8
0.86	....	....	38.1	36.7	1.4	+3.8
[7]1.28	....	....	72.7	69.4	3.3	+4.8
[7]1.44	....	....	87.4	83.8	3.6	+4.3
PINE RIVER, 12-foot flume						
1.70	....	....	110.7	109.3	1.4	+1.3
CATLIN CANAL, 12-foot flume [8] [9]						
2.48	1.74	70.0	195.0	200.0	5.0	—2.5
ROCKY FORD CANAL, 12-foot flume [8]						
1.77	....	....	114.1	116.5	2.4	—2.1
1.73	....	....	109.7	112.3	2.6	—2.3
1.71	0.52	30.0	108.2	110.2	2.0	—1.8
1.27	0.86	68.0	68.9	68.4	0.5	+0.7
1.35	1.23	91.1	66.5	68.6	2.1	—3.1
FORT BENT CANAL, 14-foot flume [1]						
0.60	....	....	23.4	23.9	0.5	—2.1
1.16	....	....	70.3	68.6	1.7	+2.5
LAMAR CANAL, 15-foot flume [8]						
1.25	....	....	[10]83.0	82.6	0.4	+0.5
1.50	....	....	111.8	110.6	1.2	+1.1

See footnotes at end of table.

Table X.—Contd.

Heads		Ratio H_B/H_A	Discharge			Deviation
H_A	H_B		Current meter	Computed	Difference	
Feet	Feet	Percent	Sec.-ft.	Sec.-ft.	Sec.-ft.	Percent
ROCKY FORD HIGHLINE CANAL, 15-foot flume [9]						
0.85	....	....	45.5	44.6	0.9	+2.0
4.61	4.37	94.8	[11]463.7	478.5	13.8	—2.9
1.39	0.26	19.0	[12]100.8	97.9	2.9	+3.0
HOLBROOK CANAL, 20-foot flume [13]						
1.00	0.82	82.0	[14]74.5	75.4	0.9	—1.2
2.65	2.58	97.4	248.0	249.5	1.5	—0.6
0.84	....	....	55.8	57.7	1.9	—3.3
1.57	1.31	83.4	155.9	153.8	2.1	+1.4
2.30	1.81	78.8	287.4	289.1	1.7	—0.6
0.93	0.43	46.2	66.8	67.9	1.1	—1.6
0.88	....	....	63.1	62.1	1.0	+1.6
1.08	0.38	35.2	88.3	86.2	2.1	+2.4
1.43	1.10	77.0	139.0	135.2	3.8	+2.8
1.00	0.25	25.0	77.2	76.3	0.9	+1.2
3.40	2.14	63.0	547.5	540.3	7.2	+1.3
3.45	2.79	81.0	[15]546.0	544.8	1.2	+0.2
3.03	2.14	70.7	453.4	449.8	3.6	+0.8
3.31	2.08	62.8	529.9	517.6	12.3	+2.4
2.27	0.74	32.6	272.7	283.1	10.4	—3.7
1.56	0.50	31.8	161.6	155.3	6.3	+4.0
1.57	0.60	38.2	160.2	156.9	3.3	+2.1
1.42	1.15	81.0	130.0	132.2	2.2	—1.7
2.08	1.86	89.4	227.0	225.0	2.0	+0.9
[16]2.07	1.80	87.0	249.5	230.8	18.7	+8.1
1.71	1.24	72.5	178.0	179.9	1.9	—1.1
1.55	1.50	96.8	119.1	118.0	1.1	+0.9
1.94	1.87	96.4	174.1	167.2	6.9	+4.1
4.97	4.68	94.2	757.2	727.0	30.2	+4.1
2.36	2.13	90.3	280.7	269.0	11.7	+4.3
1.80	1.51	83.9	196.1	190.3	5.8	+3.0
3.55	3.16	89.0	504.0	521.0	17.0	—3.3
ANTERO RESERVOIR OUTLET, 20-foot flume [5]						
2.04	1.41	69.0	[17]238.9	238.6	0.3	+0.1
BIJOU CANAL, 20-foot flume [8]						
2.53	2.33	92.1	289.0	288.0	1.0	+0.3
1.00	0.26	26.0	76.8	76.2	0.6	+0.8
1.35	0.66	48.9	[18]125.3	123.2	2.1	+1.7

See footnotes at end of table.

Table X.—Contd.

COLORADO CANAL, 30-foot flume [8]

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

FORT LYON CANAL, 40-foot flume [13]

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

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

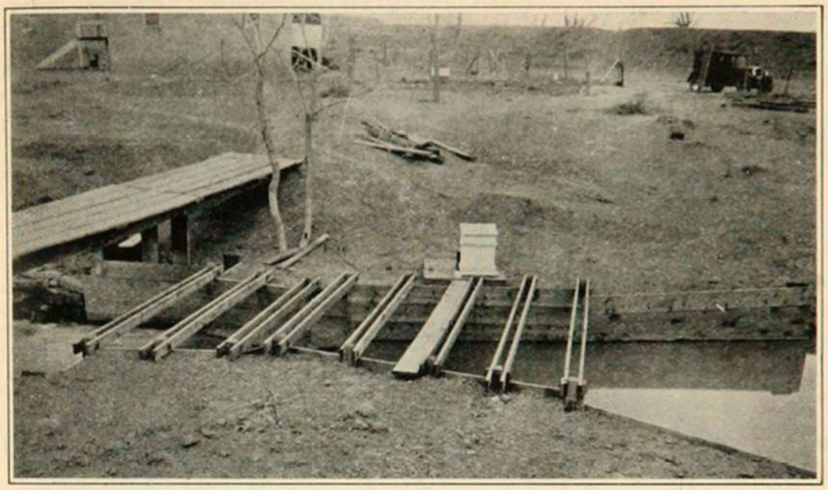


Figure 24.—Ten-foot Parshall Measuring Flume, discharge 27 second-feet, Fort Bent Canal. (See Table X.) In 1930 this was changed to a 14-foot flume.

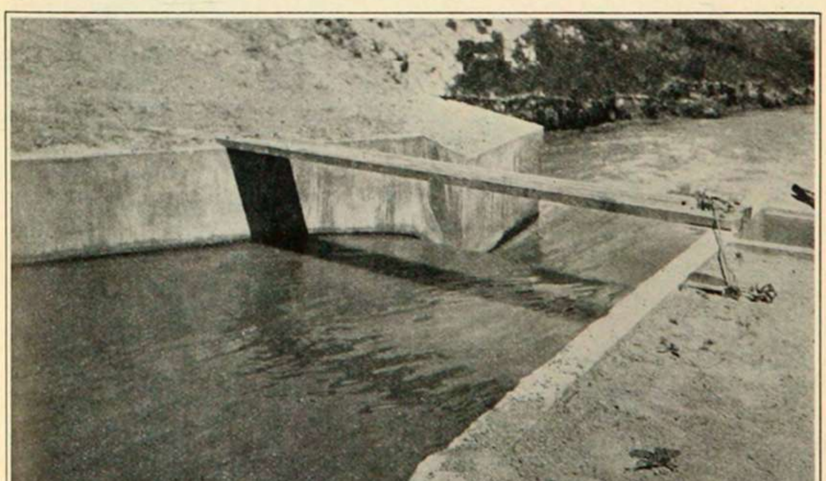


Figure 25.—Twelve-foot Parshall Measuring Flume, discharge 149 second-feet, free flow, Horse Creek Lateral near Torrington, Wyoming. (See Table X.)

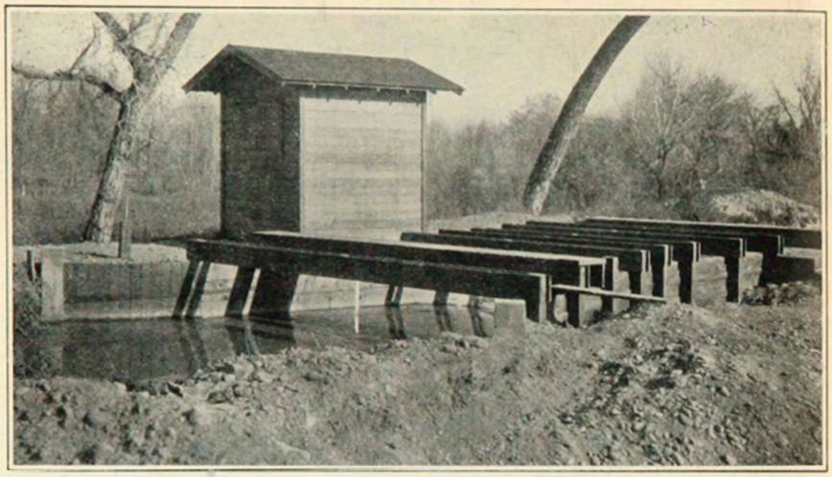


Figure 26.—Twelve-foot Parshall Measuring Flume, discharge about 50 second-feet, no submergence, Catlin Canal. (See Table X.)

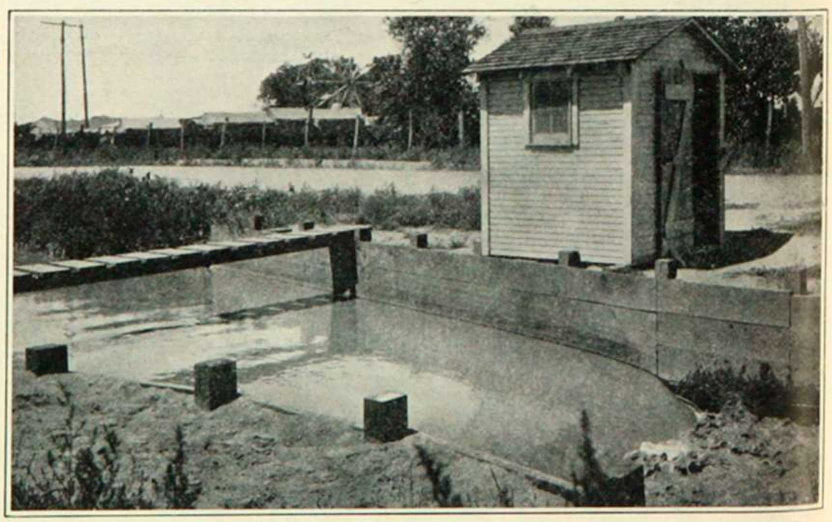


Figure 27.—Fifteen-foot Parshall Measuring Flume, discharge 83 second-feet, no submergence, Lamar Canal. (See Table X.)

SUMMARY

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

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

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

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

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

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

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

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