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PARSHALL FLUMES OF LARGE SIZE

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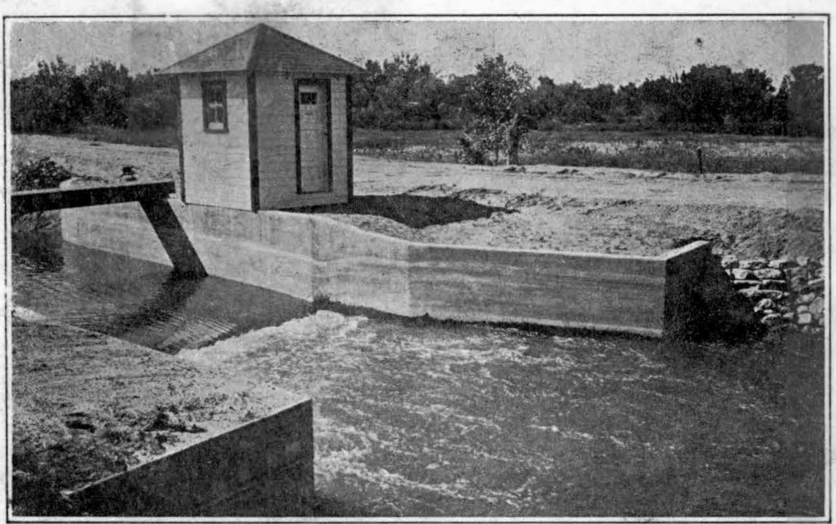

Twenty-foot Parshall Measuring Flume for Bijou Canal, South Platte Valley, near Greeley, Colorado.

United States Department of Agriculture
Soil Conservation Service
Division of Irrigation Engineering and Water Conservation
in cooperation with
Colorado Agricultural Experiment Station
Colorado Agricultural and Mechanical College

COLORADO AGRICULTURAL EXPERIMENT STATION
COLORADO AGRICULTURAL AND MECHANICAL COLLEGE
FORT COLLINS

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PARSHALL FLUMES OF LARGE SIZE[1]

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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 1 are given the main dimensions for sizes ranging from 10 to 50 feet in throat widths and having maximum capacities from 200 to 3,000 second-feet under conditions of free-flow discharge.[2] The flumes may successfully measure greater flows than those indicated as the maximum in Table 1, but under

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. Revised edition prepared by Carl Rohwer under the direction of George D. Clyde, Chief, Division of Irrigation Engineering and Water Conservation, Soil Conservation Service.

2/ See pages 34 to 39 for discussion of free flow and submerged flow.

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

Size (throat width)	Free-flow capacity		Axial length			Width		Wall depth converg-ing section	Vertical distance below crest		H_A gage distance (not axial)**
	Max.*	Min.	Converg-ing	Throat	Diverg-ing	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.

* For special conditions these maximums may be exceeded if the depth of the flume is increased, without impairing the accuracy of the device. However, if large increases in capacity are necessary, the axial dimensions should also be modified. Information regarding these changes may be obtained by writing to the Division of Irrigation, Soil Conservation Service, Colorado A and M College, Fort Collins, Colorado.

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

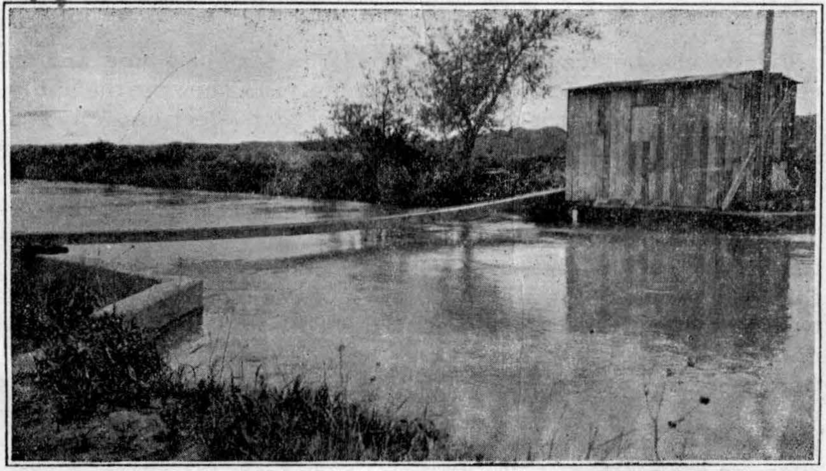

Figure 1.—Old concrete rating flume and gage house on Holbrook Canal, typical of many old structures replaced by Parshall Measuring Flumes.

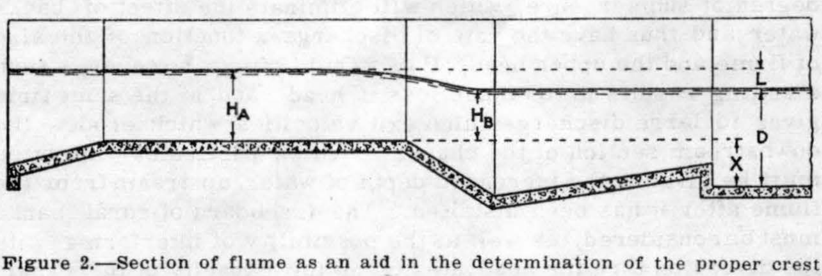

Figure 2.—Section of flume as an aid in the determination of the proper crest elevation.

ordinary channel-capacity conditions the size of flume and the related maximum flow are approximately as shown in the 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 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 W/2 + 4 in order to obtain a smoother flow as the water passed thru this part of the structure. The location of the gage point, H_A, however, is maintained at 2/3(W/2 + 4) back from the crest. The lower gage, H_B, is located near the downstream end of the throat section (see Table 1 and Figures 4 and 5), 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 fhe 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.

THE SETTING OF LARGE FLUMES

For the successful operation of the large 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 have 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 1, 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 use of water from the Arkansas River is for 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, p20), should have been about 1 foot for the limiting submerged flow of about 80 percent.

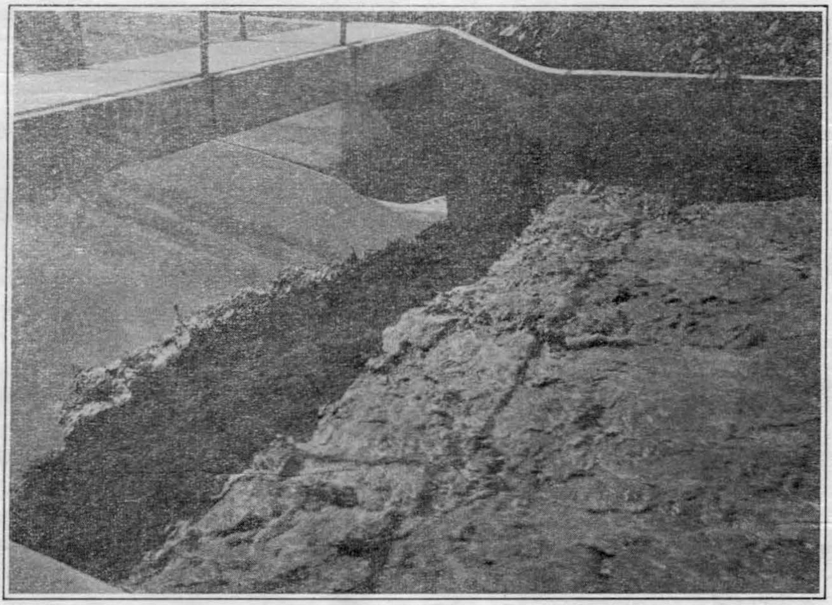

Figure 3.—A discharge of 550 second-feet passing through the throat section of 20-foot flume in the Holbrook Canal with 80 percent submergence.

To arrive at the elevation of 1 foot, refer to Figure 2. It will be observed from the discharge given in Table V for a 20-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. 2) 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 reach 3.25 feet, and for such a limiting stage the crest of the new structure should be 2 feet (3.25 - 1.25) 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. About 3 years before this 20-foot Parshall 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. 13, p. 35) 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. (See pages 8 and 9 for details of method.) 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 by considering various sizes of flumes, 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.
0.5	18	3.5	398
1.0	45	4.0	500
1.5	86	4.5	607
2.0	145	5.0	718
2.5	218	5.5	892
3.0	303	6.0	949

First, consider a 20-foot flume. For a free-flow discharge of 500 second-feet the H_A gage will be 3.24 feet (see Table V) and the H_B gage 2.59 feet at 80 percent submergence. This percentage of submergence is illustrated in Figure 3. 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. 2) is 4.00 - 2.59 = 1.41 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, first assume the submergence to be 90 percent. Since the canal gage is 6.0 for 949 c.f.s., the H_B gage reading will be approximately 6.0 - 1.4, or 4.6 feet. For 90 percent submergence H_A will be 4.6/0.90 or 5.11 feet, and the corresponding free-flow discharge 1,037 second-feet. (See discussion of submerged flow, pages 36 to 39) From the correction diagram (Fig. 13) it is found that the correction for submergence is about 145 second-feet, giving computed discharge of 1,037 - 145, or 892-

second-feet. Since this discharge is too small the submergence must be less. 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. The actual submergence is therefore between 88 and 89 percent. For a 20-foot flume set 1.4 feet above the bottom of the channel and discharging 950 second-feet, with a submergence of 89 percent, the loss of head (Fig. 14) is about 1 foot. In this case, therefore, the increase in depth upstream from the proposed structure would be 1 foot more than the amount the flume was set above the rating flume grade, which might seriously reduce the freeboard of the canal banks and also interfere with the diversion or entrance conditions at the headworks of the canal.

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 14, page 38, 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 increased 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. After the flume was built, 550 second-feet was measured thru it with submergence of 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. For this condition the depth upstream from the Parshall flume is 5.8 feet (2.00 + 3.50 + .33). Prior to the construction of this flume a gage height of 6.0 feet was noted in the old rating flume for approximately the same discharge when sand was filling the

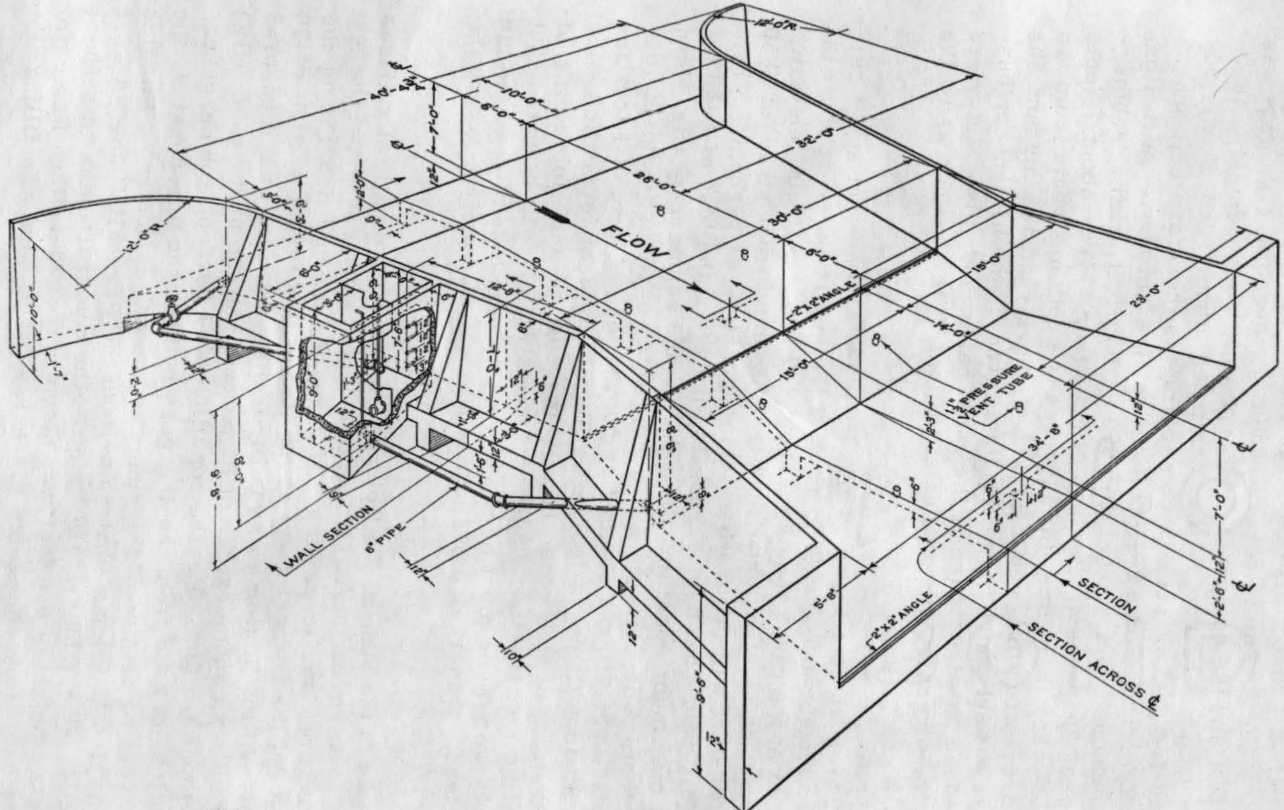

Figure 4.—Large Parshall Measuring Flume of reinforced concrete, with 30-foot threat.

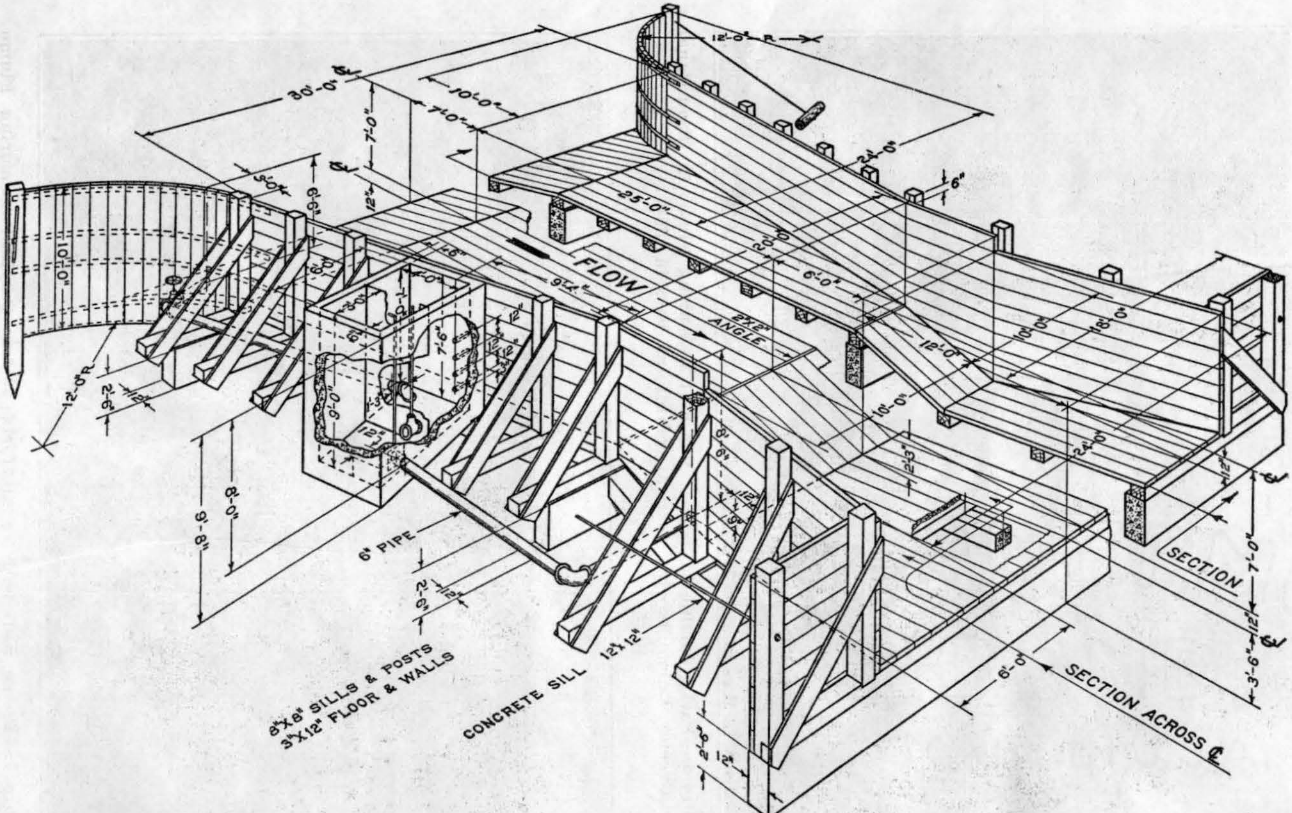

Figure 5.—Large Parshall Measuring Flume of timber construction, with 20-foot throat.

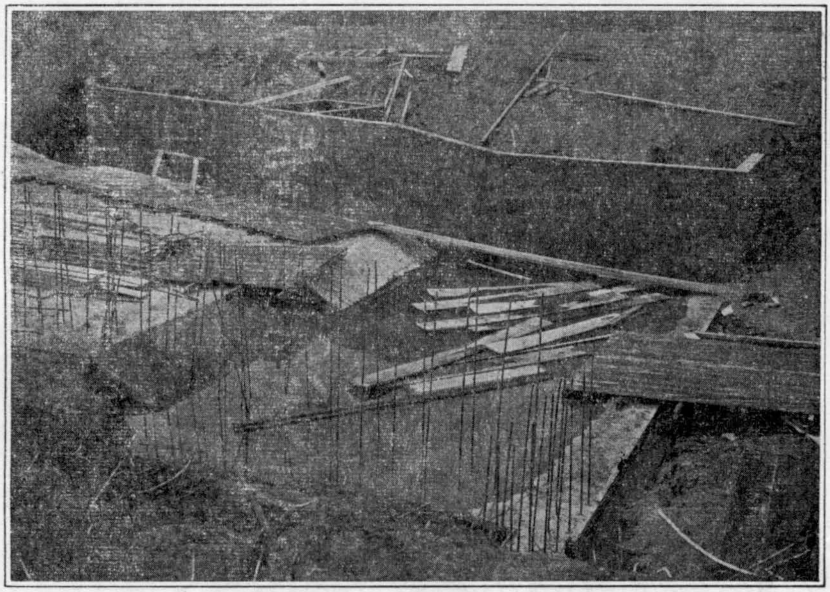

Figure 6.—Partly completed 20-foot Parshall Measuring Flume in Bijou Canal near Greeley, Colo., showing vertical reinforcing bars in place.

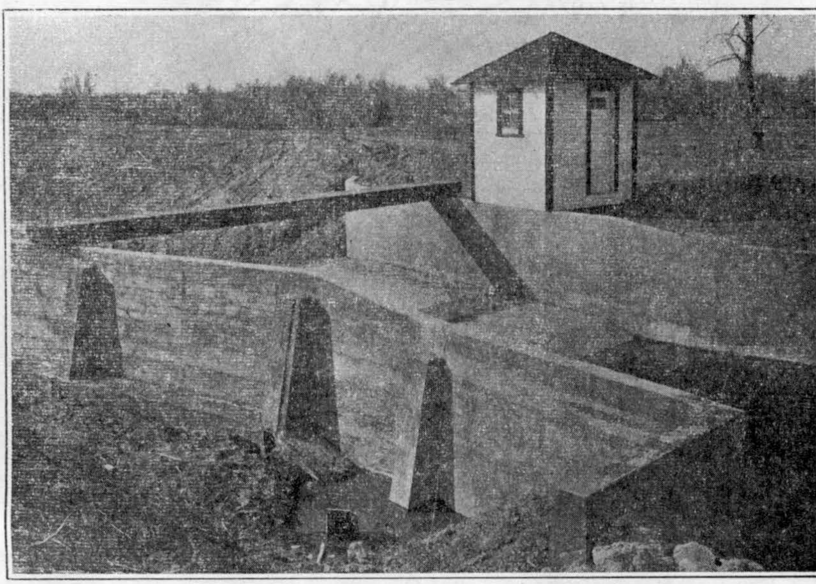

Figure 7.—Flume wall with counterforts, 20-foot Parshall Measuring Flume in Bijou Canal.

channel. This comparison shows that the filling in of sand in the channel caused the gage height to increase more than reducing the channel to a 20-foot throat and raising the flume floor 2 feet above the grade of the old rating flume. This condition is cited merely to indicate that under 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, but wood may also be used. Figure 4 gives a design showing the principal dimensions for a concrete 30-foot flume, and Figure 5 gives a design for a frame structure having a throat width of 20 feet.

The concrete structures are of monolithic construction, with steel reinforcing bars cast into the walls and floor, (Fig. 6). Because of the wide span, it is not feasible to provide cross bracing or struts between the tops of walls, and counterforts 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. 7). It will be noted in Figure 4 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 pieces of reinforcing bars 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. High grade concrete should be used in the construction of the flumes. Clean sand and gravel are essential and a minimum of water should be used in mixing the concrete.

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

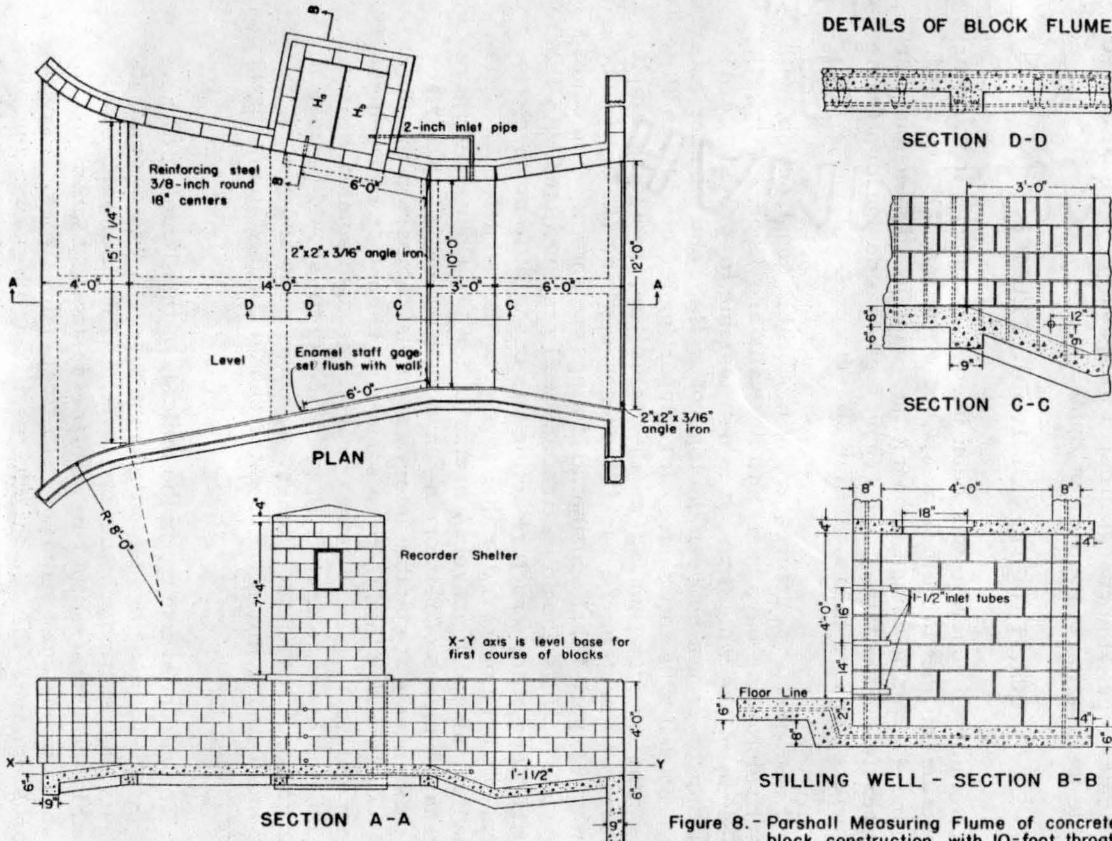

Figure 8.- Parshall Measuring Flume of concrete block construction, with 10-foot throat

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 with the ends of the angle iron extending 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 4. 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 distances to these points be carefully determined. Table 1 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 4 and 5 show inlet tubes leading from the inside face of the wall into the H_A gage well, which 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 1). 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.

Concrete blocks may be used in the construction of large Parshall flumes. When this type of construction is used the floor of the flume is made of monolithic concrete and only the walls are made of blocks. This eliminates the expensive form work for the walls and has proved to be an economical method of construction. The design of a Parshall flume with a 10-foot throat, and side walls of concrete blocks is shown in Figure 8.

Careful planning is required when building a flume by this method. The walls must be reinforced by horizontal steel rods laid in the mortar between the courses of blocks and by vertical rods set in the floor and extending up through the holes in the blocks. These vertical rods should be set by means of a template so that the spacing of the rods will coincide with the holes in the blocks. The template should be made to fit the particular type of block being used. After the walls are completed the holes in the blocks are carefully filled with concrete to bond the walls with the floor.

Since the floor of the flume slopes downward in the throat and upward in the diverging section, the walls in this part of the flume up to the floor line of the converging section should be made of concrete as shown in the figure. When this plan is followed all the courses can be laid without cutting the blocks to fit the sloping floor.

The large concrete blocks can not be used to build the curving walls at the upper end of the flume. Half blocks should be used for this purpose. A smooth wall can be obtained if the blocks are laid without breaking joints as shown in the figure. If the walls of the flume are not more than three feet high they are strong enough to support the backfill of earth. Higher walls should be strengthened by tie-rods anchored to deadmen buried in the ground. The tie-rods should be attached to the vertical reinforcing rods in the walls to distribute the load.

The best grade of concrete blocks should be used for the walls. Cinder or pumice blocks are not suitable for this type of construction. A dense concrete is important. This reduces the absorption of water by the walls and consequent deterioration due to frost action. After the walls are laid they should be given a wash coat of white portland cement or other suitable sealing compound.

Flumes built by this method have been in successful operation for several years. They have shown no signs of cracking or disintegration. Because of the low cost of these flumes this

TABLE II

FREE-FLOW DISCHARGE 10-FOOT PARSHALL MEASURING FLUME

FORMULA $Q = 39.38\ H_A^{1.6}$

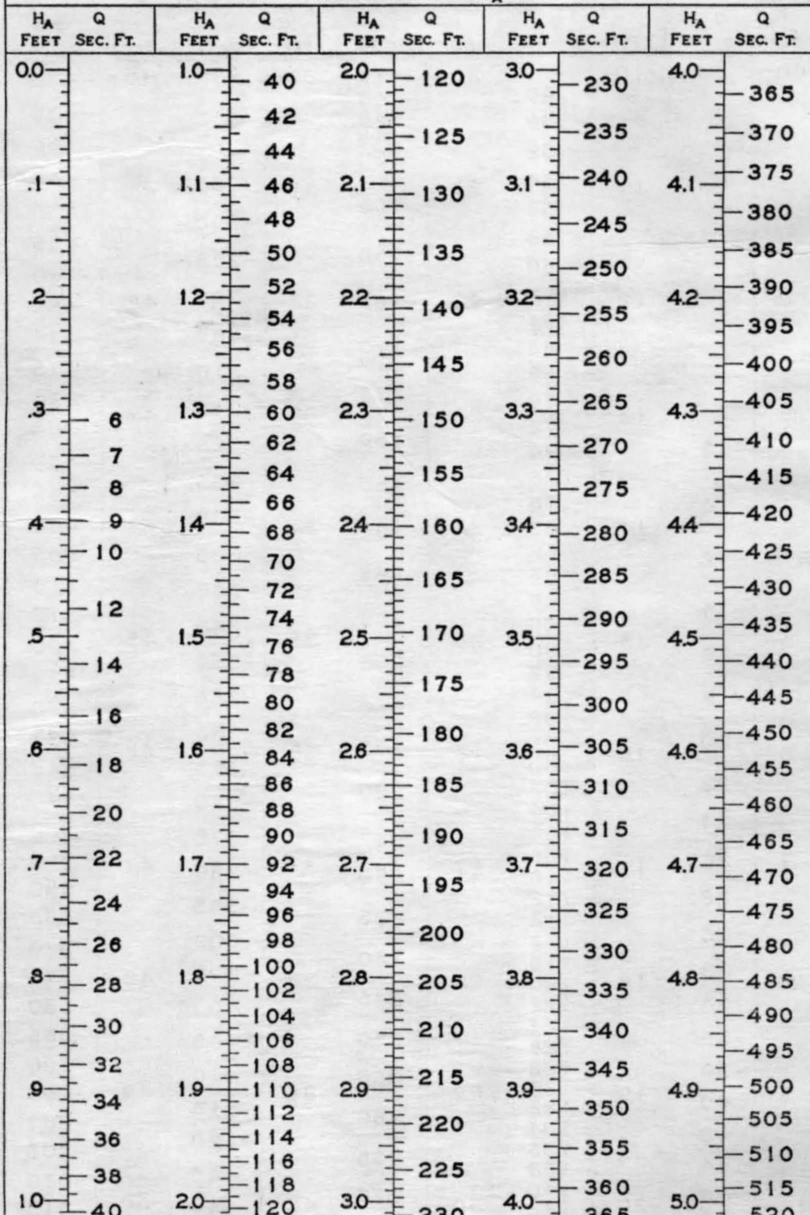

TABLE III

FREE-FLOW DISCHARGE 12-FOOT PARSHALL MEASURING FLUME

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

H_A Feet	Q Sec. Ft.
0.0	
.1	
.2	
.3	
	8
	10
.4	
	12
	14
.5	16
	18
.6	20
	22
	24
.7	26
	28
	30
.8	32
	34
	36
	38
.9	40
	42
	44
1.0	46
	48

H_A Feet	Q Sec. Ft.
1.0	
	48
	50
	52
1.1	54
	56
	58
	60
1.2	62
	64
	66
	68
1.3	70
	72
	74
	76
	78
1.4	80
	82
	84
	86
	88
1.5	90
	92
	94
	96
	98
1.6	100
	102
	104
	106
1.7	108
	110
	112
	114
	116
	118
1.8	120
	122
	124
	126
	128
1.9	130
	132
	134
	136
	138
	140
2.0	142

H_A Feet	Q Sec. Ft.
2.0	142
	144
	146
	148
	150
2.1	
	155
	160
2.2	165
	170
	175
2.3	
	180
	185
2.4	190
	195
	200
2.5	
	205
	210
2.6	215
	220
	225
2.7	230
	235
	240
2.8	
	245
	250
	255
2.9	
	260
	265
3.0	270

H_A Feet	Q Sec. Ft.
3.0	270
	275
	280
3.1	285
	290
	295
3.2	300
	305
	310
3.3	315
	320
	325
3.4	330
	335
	340
	345
3.5	
	350
	355
	360
3.6	365
	370
	375
3.7	380
	385
	390
3.8	395
	400
	405
	410
3.9	415
	420
	425
4.0	430

H_A Feet	Q Sec. Ft.
4.0	430
	435
	440
4.1	445
	450
	455
	460
4.2	465
	470
	475
4.3	480
	485
	490
	495
4.4	500
	505
	510
	515
4.5	520
	525
	530
4.6	535
	540
	545
	550
4.7	555
	560
	565
	570
4.8	575
	580
	585
	590
4.9	595
	600
	605
	610
5.0	615

TABLE IV

FREE-FLOW DISCHARGE 15-FOOT PARSHALL MEASURING FLUME

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

H_A FEET	Q SEC. FT.	H_A FEET	Q SEC. FT.	H_A FEET	Q SEC. FT.	H_A FEET	Q SEC. FT.	H_A FEET	Q SEC. FT.	H_A FEET	Q SEC. FT.

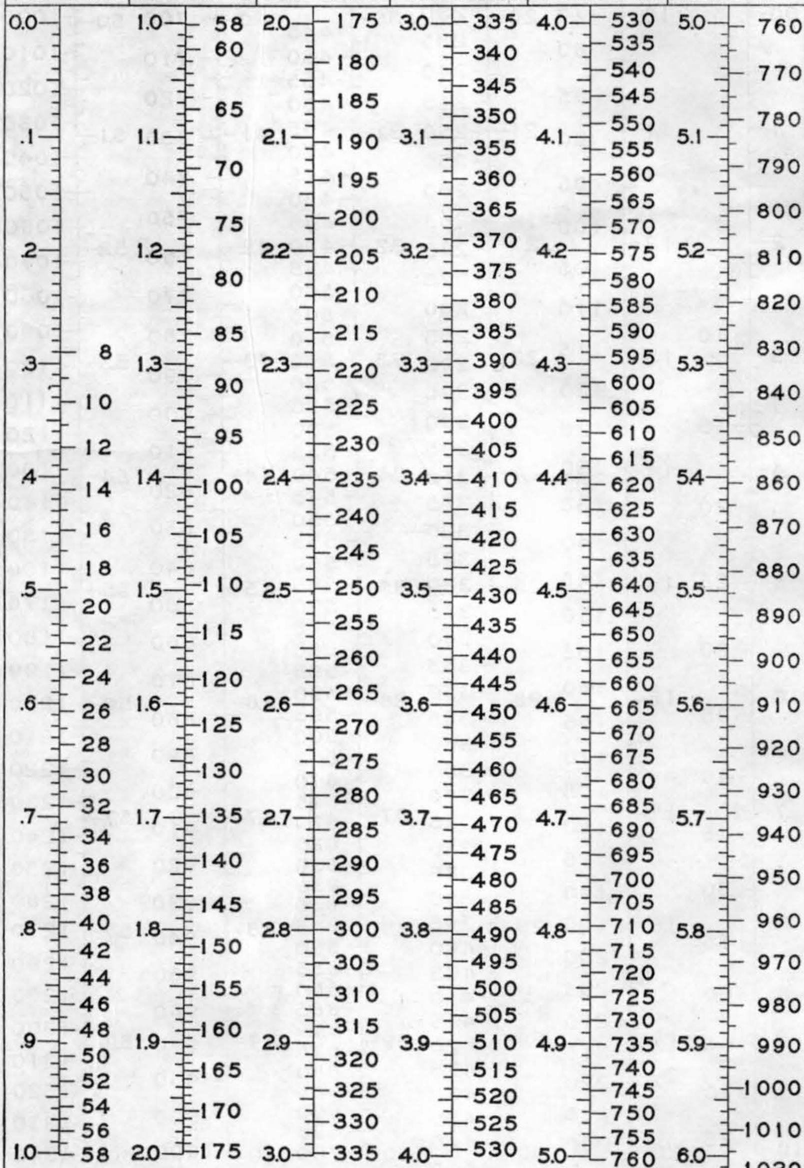

TABLE V
FREE-FLOW DISCHARGE 20-FOOT PARSHALL MEASURING FLUME

FORMULA $Q = 76.25 H_A^{1.6}$

H_A Feet	Q Sec. Ft.
0.0	
.1	
.2	
	10
.3	
	15
.4	
	20
.5	25
	30
.6	35
	40
.7	45
	50
.8	55
	60
.9	65
	70
1.0	75

H_A Feet	Q Sec. Ft.
1.0	75
	80
	85
1.1	90
	95
	100
1.2	
	105
	110
1.3	115
	120
	125
1.4	130
	135
	140
1.5	145
	150
	155
1.6	160
	165
	170
	175
1.7	180
	185
	190
1.8	195
	200
	205
	210
1.9	215
	220
	225
2.0	230

H_A Feet	Q Sec. Ft.
2.0	230
	235
	240
	245
2.1	250
	255
	260
	265
2.2	270
	275
	280
	285
2.3	290
	295
	300
	305
2.4	310
	315
	320
	325
2.5	330
	335
	340
	345
2.6	350
	355
	360
	365
	370
2.7	375
	380
	385
	390
2.8	395
	400
	405
	410
	415
2.9	420
	425
	430
	435
3.0	440
	445

H_A Feet	Q Sec. Ft.
3.0	
	445
	450
	455
	460
3.1	465
	470
	475
	480
	485
3.2	490
	495
	500
	505
	510
3.3	515
	520
	525
	530
	535
3.4	540
	545
	550
	555
	560
3.5	565
	570
	575
	580
	585
3.6	590
	595
	600
	605
	610
	615
3.7	620
	625
	630
	635
	640
3.8	645
	650
	655
	660
	665
	670
3.9	675
	680
	685
	690
	695
4.0	700

H_A Feet	Q Sec. Ft.
4.0	700
	710
	720
4.1	730
	740
	750
4.2	760
	770
	780
4.3	790
	800
	810
4.4	820
	830
	840
4.5	850
	860
	870
4.6	880
	890
	900
4.7	910
	920
	930
4.8	940
	950
	960
4.9	970
	980
	990
5.0	1000

H_A Feet	Q Sec. Ft.
5.0	1000
	1010
	1020
5.1	1030
	1040
	1050
	1060
5.2	1070
	1080
	1090
5.3	1100
	1110
	1120
5.4	1130
	1140
	1150
	1160
5.5	1170
	1180
	1190
5.6	1200
	1210
	1220
	1230
5.7	1240
	1250
	1260
5.8	1270
	1280
	1290
	1300
5.9	1310
	1320
	1330
6.0	1340

TABLE VI
FREE-FLOW DISCHARGE 25-FOOT PARSHALL MEASURING FLUME
FORMULA $Q = 94.69\ H_A^{1.6}$

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

H_A Feet	Q Sec. Ft.
1.0	95
	100
	105
1.1	110
	115
	120
1.2	125
	130
	135
	140
1.3	145
	150
	155
	160
1.4	
	165
	170
	175
1.5	180
	185
	190
	195
1.6	200
	205
	210
	215
1.7	220
	225
	230
	235
1.8	240
	245
	250
	255
	260
1.9	265
	270
	275
	280
2.0	285
	290

H_A Feet	Q Sec. Ft.
2.0	
	290
	300
2.1	310
	320
	330
2.2	
	340
	350
2.3	360
	370
	380
2.4	
	390
	400
2.5	410
	420
	430
2.6	440
	450
	460
2.7	
	470
	480
2.8	490
	500
	510
2.9	520
	530
	540
3.0	550

H_A Feet	Q Sec. Ft.
3.0	550
	560
	570
3.1	580
	590
	600
3.2	610
	620
	630
3.3	640
	650
	660
3.4	670
	680
	690
3.5	700
	710
	720
	730
3.6	740
	750
	760
3.7	770
	780
	790
3.8	800
	810
	820
	830
3.9	840
	850
	860
4.0	870

H_A Feet	Q Sec. Ft.
4.0	870
	880
	890
	900
4.1	
	910
	920
	930
4.2	940
	950
	960
	970
4.3	980
	990
	1000
4.4	1010
	1020
	1030
	1040
4.5	1050
	1060
	1070
	1080
4.6	1090
	1100
	1110
	1120
4.7	1130
	1140
	1150
	1160
4.8	
	1170
	1180
	1190
	1200
4.9	
	1210
	1220
	1230
	1240
5.0	
	1250

H_A Feet	Q Sec. Ft.
5.0	
	1250
	1260
	1270
	1280
5.1	
	1290
	1300
	1310
	1320
5.2	
	1330
	1340
	1350
	1360
5.3	
	1370
	1380
	1490
	1400
5.4	1410
	1420
	1430
	1440
5.5	1450
	1460
	1470
	1480
5.6	1490
	1500
	1510
	1520
	1530
5.7	
	1540
	1550
	1560
	1570
5.8	1580
	1590
	1600
	1610
5.9	1620
	1630
	1640
	1650
	1660
6.0	
	1670

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
	170
1.3	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
2.7	550
	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
4.5	1250
	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 $Q=150.00\ H_A^{1.6}$

H_A Feet	Q Sec. Ft.
0.0, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1.0	20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120, 125, 130, 135, 140, 145, 150
1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0	150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300, 310, 320, 330, 340, 350, 360, 370, 380, 390, 400, 410, 420, 430, 440, 450, 460
2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0	460, 470, 480, 490, 500, 510, 520, 530, 540, 550, 560, 570, 580, 590, 600, 610, 620, 630, 640, 650, 660, 670, 680, 690, 700, 710, 720, 730, 740, 750, 760, 770, 780, 790, 800, 810, 820, 830, 840, 850, 860, 870
3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0	870, 880, 890, 900, 910, 920, 930, 940, 950, 960, 970, 980, 990, 1000, 1010, 1020, 1030, 1040, 1050, 1060, 1070, 1080, 1090, 1100, 1110, 1120, 1130, 1140, 1150, 1160, 1170, 1180, 1190, 1200, 1210, 1220, 1230, 1240, 1250, 1260, 1270, 1280, 1290, 1300, 1310, 1320, 1330, 1340, 1350, 1360, 1370, 1380
4.0, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0	1380, 1390, 1400, 1420, 1440, 1460, 1480, 1500, 1520, 1540, 1560, 1580, 1600, 1620, 1640, 1660, 1680, 1700, 1720, 1740, 1760, 1780, 1800, 1820, 1840, 1860, 1880, 1900, 1920, 1940, 1960, 1980
5.0, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6.0	1980, 2000, 2020, 2040, 2060, 2080, 2100, 2120, 2140, 2160, 2180, 2200, 2220, 2240, 2260, 2280, 2300, 2320, 2340, 2360, 2380, 2400, 2420, 2440, 2460, 2480, 2500, 2520, 2540, 2560, 2580, 2600, 2620, 2640

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
.5	60
	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
1.0	185
	190

H_A FEET	Q SEC. FT.
1.0	190
	195
	200
	210
1.1	220
	230
	240
1.2	250
	260
	270
1.3	280
	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
3.5	1380
	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
4.0	1710
	1725

H_A FEET	Q SEC. FT.
4.0	1725
	1740
	1760
4.1	1780
	1800
	1820
	1840
4.2	1860
	1880
	1900
4.3	1920
	1940
	1960
	1980
4.4	2000
	2020
	2040
	2060
4.5	2080
	2100
	2120
4.6	2140
	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
5.8	3100
	3120
	3140
	3160
	3180
5.9	3200
	3220
	3240
	3260
6.0	3280
	3300

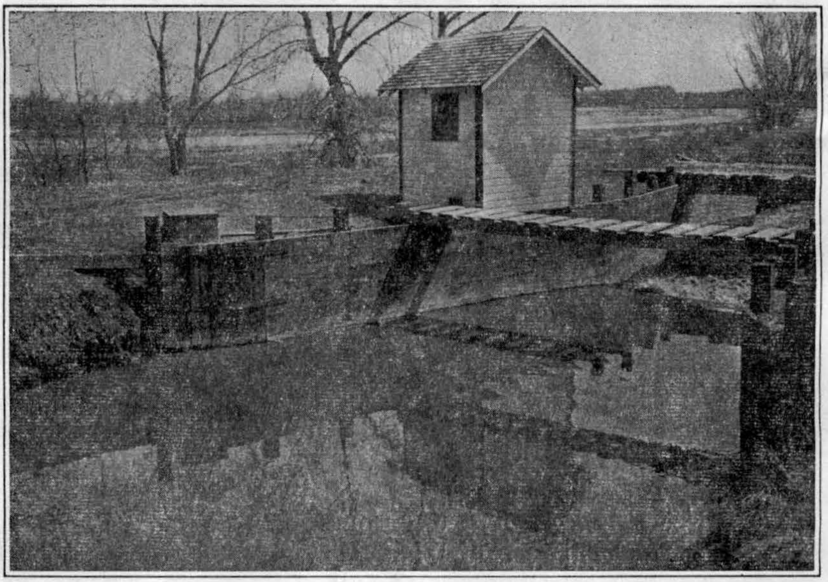

Figure 9.—Large Parshall Measuring Flume of timber construction in Rocky Ford Highline Canal, with 15-foot throat, discharge 101 second-feet, submergence 19 percent.

method of construction should always be investigated when planning to build a Parshall flume.

Large Parshall flumes may also be successfully constructed of wood where the cost of concrete is excessive or the soil is unsuitable for concrete. The design of a wooden flume with a 20-foot throat is shown in Figure 5.

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 stops between the planks 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. 9) the curved transition at the entrance is formed of 3- by 6-inch pieces set on end and held in place by 1/4 x 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 which 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

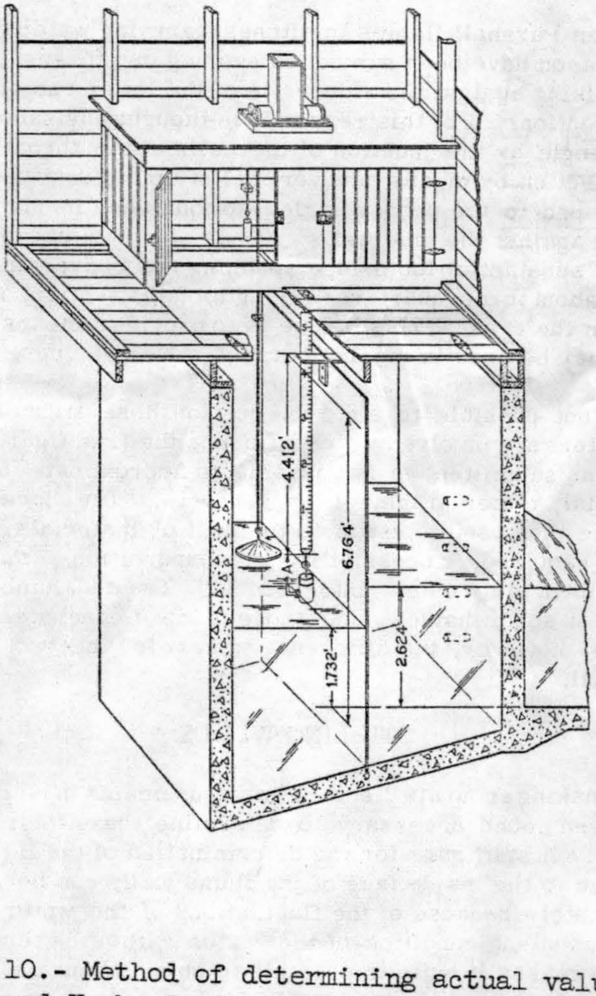

Figure 10.- Method of determining actual values of the H_a and H_b heads in feet, for comparison with indicated values on recorder chart.

other preservative is fully warranted.

Wooden Parshall 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 the effective heads carefully. 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. 10) 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. 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 4 and 5. 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 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 operations, 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. 11) by using a standard 6-inch cast-iron flange screwed on the projecting end of the pipe. A 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 RECORDING 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 handwheel 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

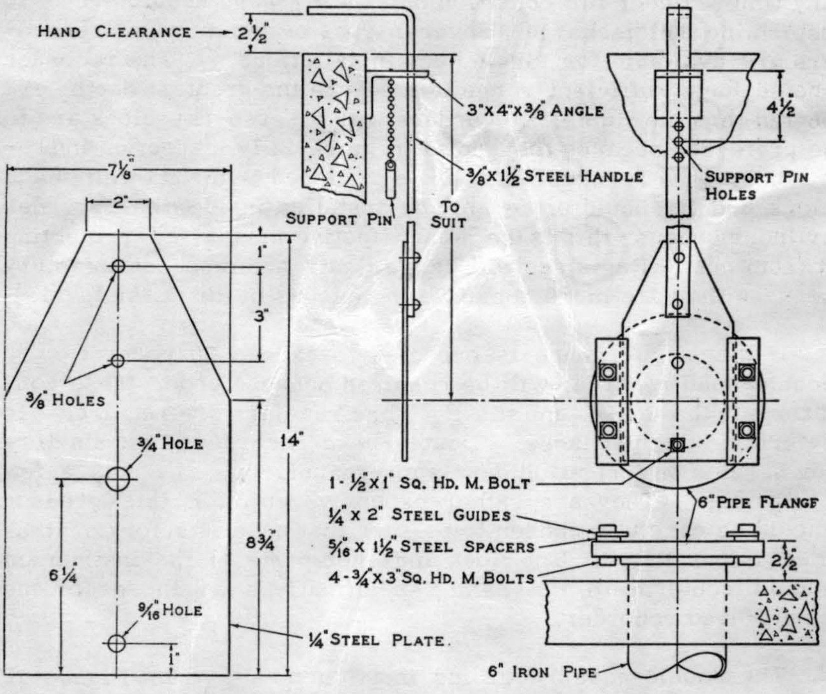

Figure 11.—Slide valve for flushing pipe from the Hb stilling well.

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.

A single-head recording instrument is satisfactory for all installations where the submergence will not exceed 80 percent at any time. Under this condition only the H_A gage need be read to determine the discharge. Several types of commercial recorders are available for single head installations. The recorder should have sufficient range to measure the greatest depth expected thru the flume. Recorders with a seven-day clock are to be preferred because they do not require daily inspection and rewinding. The recorder should be equipped with a well-made clock and it should preferably be installed inside the recorder cylinder because this is the most effective means for protecting it from dust. Registers with large floats are most satisfactory because they are more sensitive to changes in the water level.

If the submergence is expected to exceed 80 percent, a double-head recorder will be required because under these conditions both the H_A and the H_B gage readings are required to determine the discharge. Double-head recorders satisfactory for service on irrigation canals are manufactured by only a few companies. They are rather expensive and for this reason should be carefully chosen to be sure that a satisfactory instrument is purchased. The clock and other parts of the instrument should conform to the same specifications as those for the single-head recorder.

The double-head recording instrument shown in Figure 12 was designed for use in connection with Parshall flumes of large size. This instrument included gage-height indicators for the H_A and H_B heads in addition to the recorder cylinder. A dozen or more of these instruments have been installed and they have given long and satisfactory service. It was hoped that the manufacture and distribution of this instrument would be taken over by one of the instrument companies specializing in this field but to date no company has been willing to manufacture it.

The mounting and setting of the recording instrument require no expert mechanical skill. By carefully determining the mean crest elevation, using an engineer's level and rod, a

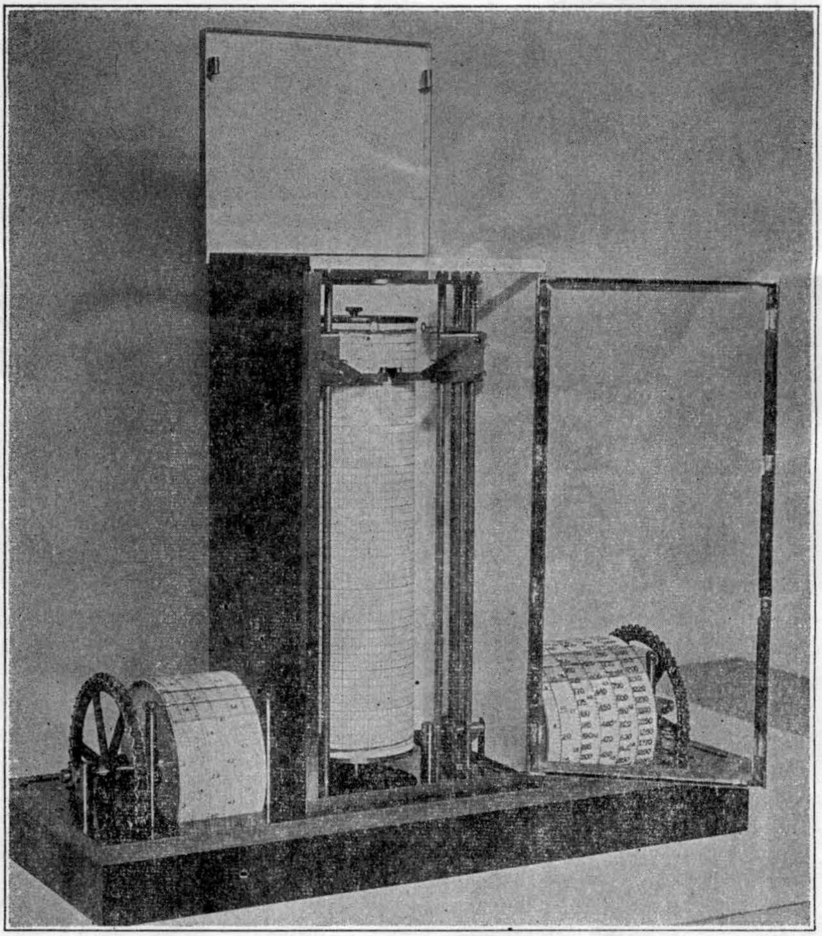

Figure 12.—Double-head recording and indicating instrument for use in connection with Parshall Flumes of large size.

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 points, (Fig. 10). 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 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 recording instrument for the first time, a material error may be expected. By moving the chain or tape on the drive wheel, large corrections may be made until a fair agreement is attained. Several hook-gage and instrument 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 accuracy with which the instrument is recording the depths should be checked from time to time by means of the hook-gage plumb bob.

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 degree of submergence becomes greater, the standing wave moves upstream in the throat until it becomes "drowned" and the rate of flow is

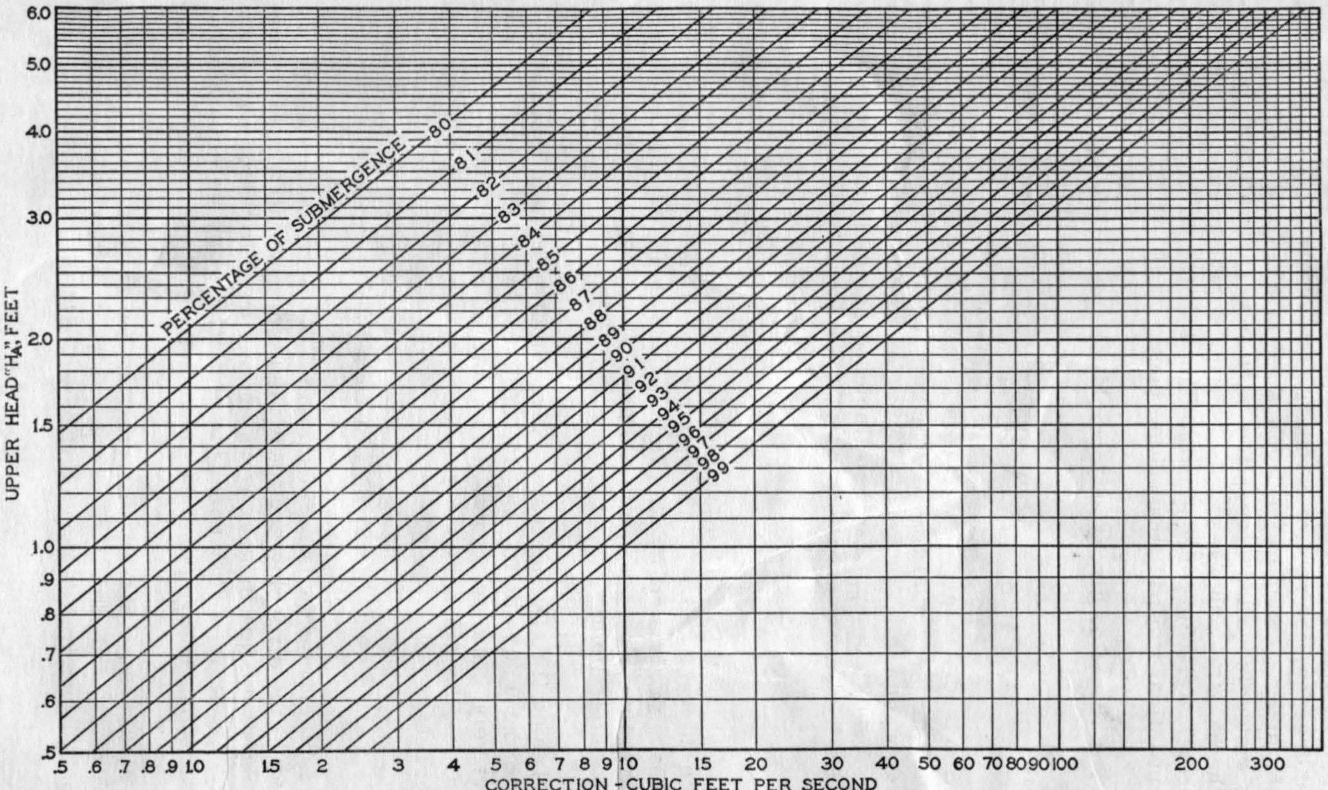

Figure 13.—Diagram for determining the correction in second-feet per 10 feet of crest for submerged-flow discharge.

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)[3],

$$Q = 4WH_A^{1.522W^{0.026}},$$

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.

SUBMERGED FLOW

Submerged flow is defined as that condition of flow where the water in the diverging section of the flume rises to a level where it retards the flow in the converging section. 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

3/ "Measuring Water in Irrigation Channels with Parshall Flumes and Small Weirs", by R. L. Parshall, USDA, Soil Conservation Service Cir. No. 843.

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, the matter of erosion due to the higher velocities, particularly in soft materials, presents a problem. In general, where the banks and bottoms 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 as the percentage or degree of submergence. Figure 13 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 W in feet	Multiplying factor	Size of flume W in feet	Multiplying factor
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 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

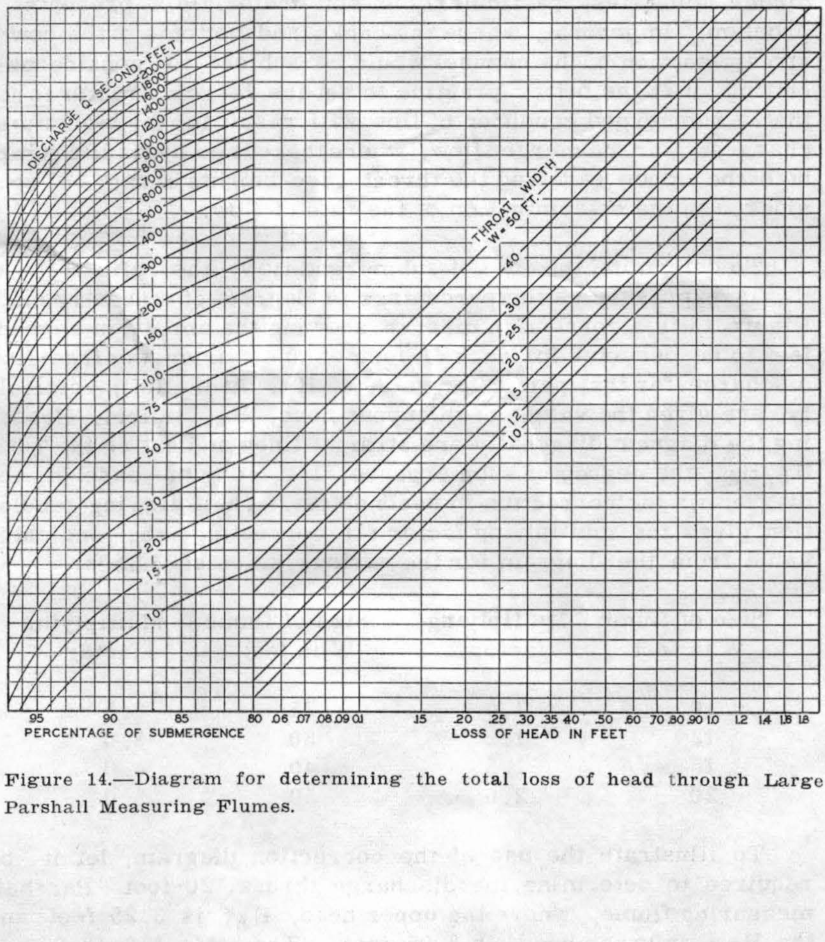

Figure 14.—Diagram for determining the total loss of head through Large Parshall Measuring Flumes.

an upper head, H_A, of 3.25 feet is found to be approximately 503 second-feet. The submerged flow, then, is 503 - 2 X 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 14 will be found useful in making the final selection of the size of flume which is to meet the requirements as to capacity, loss of head, degree of submergence, and channel freeboard.

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 1000 is reached. At this point move horizontally to the right until an intersection is made with the diagonal 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 is 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

Current meter discharge measurements have been made in flumes ranging in size from 10 to 40 feet for both free-flow and submerged conditions to determine how closely the measured and the computed discharges agree. The current-meter gagings referred to 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.

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.

Large flows can be measured with the Parshall flume with a relatively small loss of head.

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.

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