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EVALUATION OF FLOW MEASUREMENT INSTALLATIONS IN WASTEWATER TREATMENT FACILITIES

TRAINING MANUAL

U. S. ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF WATER PROGRAM OPERATIONS

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U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Water Program Operations
National Training and Operational Technology Center

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MEASUREMENT OF WASTEWATER FLOWS: SHARP-CRESTED WEIRS

I General Considerations

A A weir is an overflow structure built across an open channel, usually to measure the rate of flow of the liquid being carried in the channel. There are two broad categories of weirs.

1 Sharp-crested weirs, made of a thin plate having a sharp upstream corner or edge so formed that the overflowing liquid springs clear of the weir crest. These are quite commonly used to measure wastewater flow in treatment plants.

2 Weirs not sharp-crested. Also referred to as broad-crested weirs. The overflowing liquid does not spring clear of the crest of these weirs. Although flow rates can be measured accurately by means of a broad-crested weir, they have not been used in this country as extensively as thin plate weirs and Parshall flumes for flow measurement, and will rarely, if ever, be found in a wastewater flow measurement application.

This outline deals only with the sharp-crested weir as a primary flow measurment device. When the term "weir" is used herein, a sharp-crested weir is meant.

B A weir is one of the oldest, simplest and most reliable structures that can be used to measure flows in canals, ditches, flumes, and other open channels. Weirs have several advantages in comparison with other measuring devices, among which are:

1 They are relatively simple to construct and install. This does not imply that lack of care and precision in their construction and installation is tolerable.

2 A considerable data base exists for these devices.

C Main disadvantages of sharp-crested weirs are:

1 Solids will collect behind the weir plate and can seriously affect the accuracy of the measurement.

2 Their use involves an appreciable head loss. Usually a fall of at least 0.5 feet must be available in the channel in which the weir is installed.

3 They are relatively difficult to maintain if used for long periods. The crest, for example, is likely to become dulled, rusted, or damaged, with loss of accuracy resulting.

II Definitions and Terminology

A A section through a weir installation is shown in Figure 1. Pertinent definitions are given below:

Weir Crest - The edge of the weir over which the the liquid flows.

Nappe - The overflowing sheet of water.

Head - The depth of water over the crest of the weir. For a specific weir operating under steady-state free-flow conditions and a proper weir-to-pool relationship, only one depth of water (H) can exist in the upstream pool for a given discharge.

Channel of Approach - The channel leading up to the weir.

Velocity of Approach - The mean velocity in the channel of approach.

Free Flow (Free discharge) - A condition of flow existing when the nappe discharges into the air.

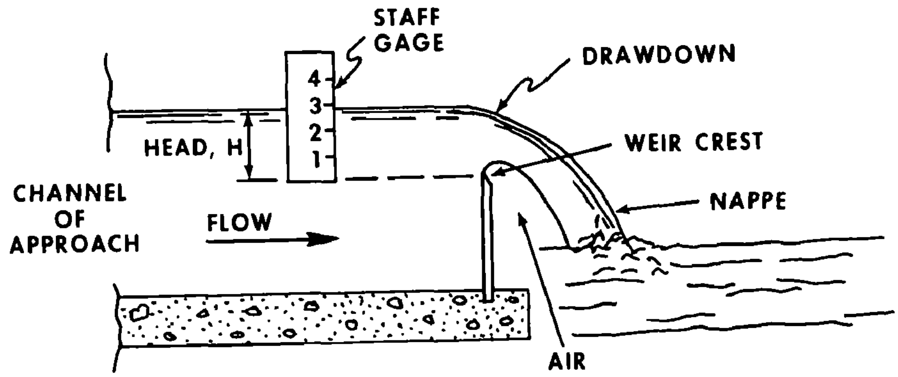

FIG. 1
SHARP-CRESTED WEIR INSTALLATION

Submerged Flow (Submerged discharge) - A condition of flow existing when the nappe discharges partially under water (Figure 2), due to the liquid level downstream of the weir being at the same elevation, or higher than, the weir crest. Accurate measurements cannot be made of submerged weir discharges because of lack of extensive, accurate experiments for determining the discharge coefficients (1).

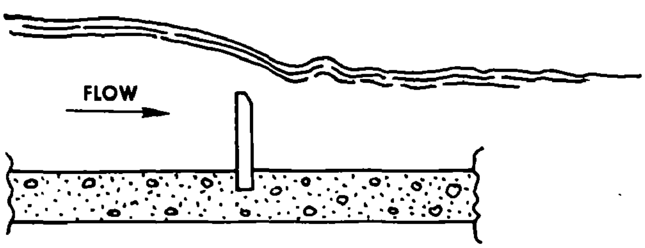

FIG. 2
SUBMERGED DISCHARGE

Drawdown - The drop in the elevation of the liquid surface as it approaches the weir.

Staff Gage - A measuring device, used for determining the head on weir.

Nappe Contraction - Formation of the nappe into a jet narrower than the weir opening as the liquid passes over the weir crest. It results from the liquid having to assume a curved flow path as it approaches the crest. When approach conditions allow complete contractions, the weir is called a contracted weir.

III Weir Configurations

A A weir can be made in any shape desired, however, those most commonly used to measure flow (so-called "standard" weirs) are shown in Figure 3.

These are:

1 The rectangular weir: either with end contractions, or suppressed.

2 The V-notch weir, most often having a 90° notch angle.

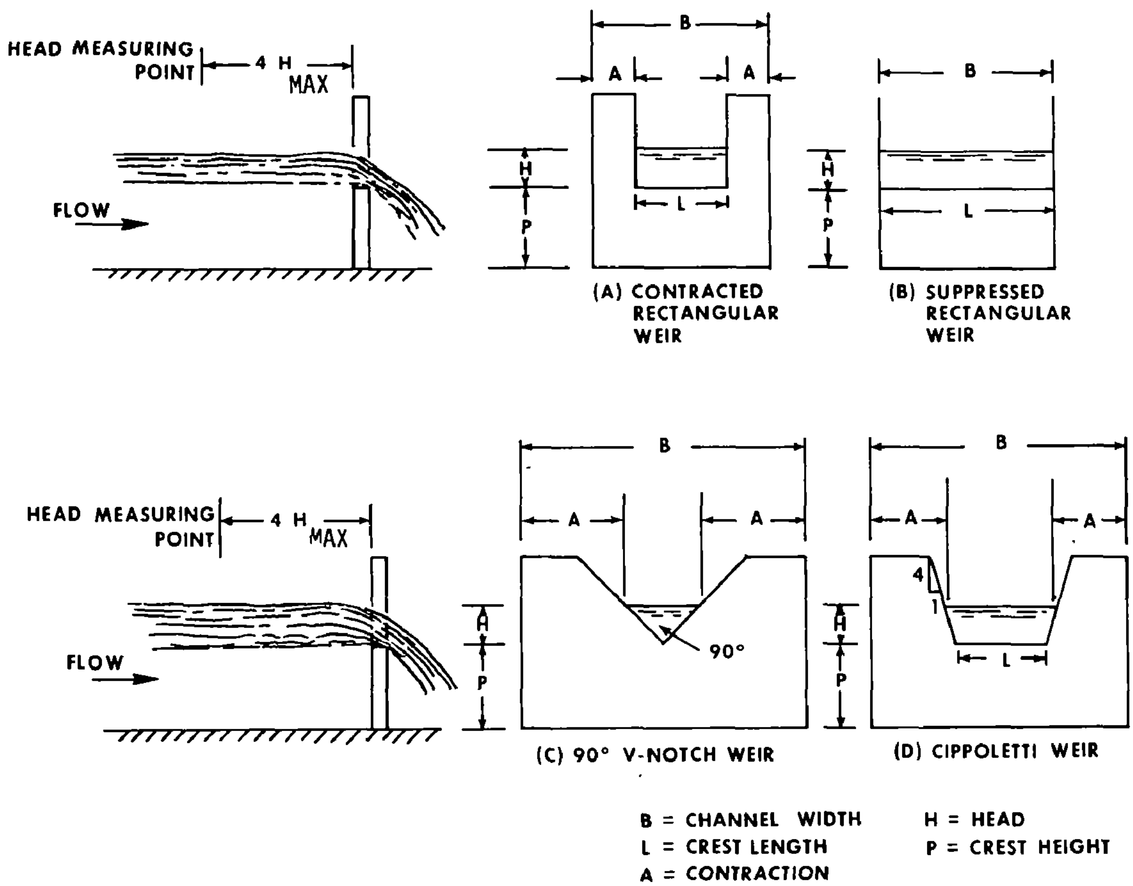

FIG. 3 - WEIR CONFIGURATIONS

3 The Cippoletti or trapezoidal weir.

In wastewater applications, the rectangular and V-notch weirs are most frequently used, the Cippoletti weir may occasionally be found.

B The weir itself should be made of a hard, durable material, most often metal of an appropriate type. A plate can be cut to any of the forms shown in Figure 3, or in some cases a bulkhead can be built to the proper shape and used as a support for a narrow metal strip constituting the weir proper. (Figure 4)

However the weir itself is constructed, the weir crest should be from 0.03-0.08 inch thick (about 1-2 mm) and have a sharp upstream edge, as shown in Figure 5.

The crest should not be formed by cutting it as a knife edge, this being unnecessary in the first place, and secondly being considerably more difficult to maintain in satisfactory condition than the edge formed as shown in Figure 5.

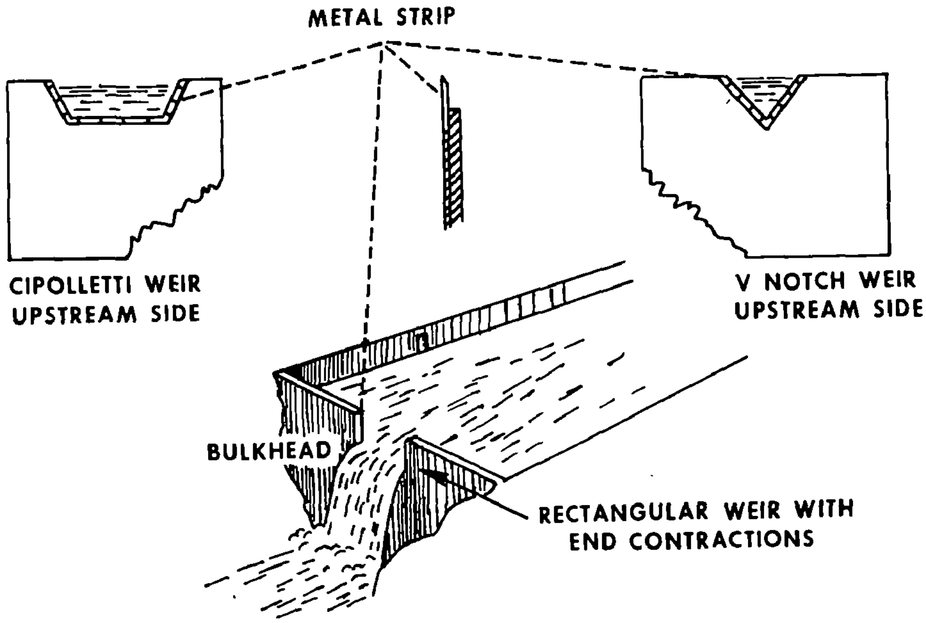

FIGURE. 4
TYPICAL SHARP CRESTED WEIRS

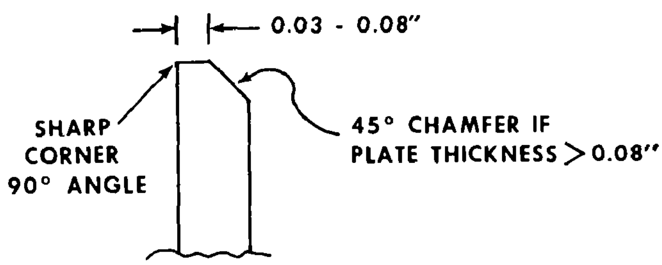

FIG. 5
WEIR CREST DETAIL

C These weir configurations are so frequently used because of the extensive data base that is available in terms of their head-discharge relationships, and conditions of operation. Equations and tables are readily available which can be used with confidence, provided that the weir is installed and maintained in conformity with the conditions prevailing when the data base was developed. These conditions are discussed further below.

IV Rectangular Weirs

A The rectangular weir with two end contractions (Figure 3a), and the rectangular suppressed weir (Figure 3b) are in common use. A number of equations for the head-discharge relation for these weirs have been proposed by different investigators. Comparative discussions of the various formulations will be found in the literature (2).

B The Francis formulas are frequently used:

For the suppressed weir: $Q = 3.33\ LH^{3/2}$ ...(a)

For the contracted weir:

$Q = 3.33\ (L-0.2H)H^{3/2}$ ..(b)

where Q = discharge, $ft^3/sec.$
L = crest length, ft.
H = measured head, ft.

Tables of discharge are available (1, 2, 3) which provide the solution for these equations for various combinations of L and H. A portion of a table for a contracted weir is shown in Table I, and for a suppressed weir in Table II.

C The Francis equations should not be used for weirs which are not fully contracted. To ensure full contraction of the nappe, the dimensions A and P in Figure 3a must be at least 2H, and in no case less than 1 foot. The same applies to dimension P in Figure 3b.

D The Francis equations should not be used for heads greater than one-third of the crest length, even if such results appear in published tables. Significant errors can result. Similarly, heads less than 0.2 feet should not be used.

E Significant errors can also be introduced by neglecting to take velocity of approach into consideration. (The velocity of approach is the average velocity of the liquid in the approach channel just upstream of the weir.) Examples of the magnitude of these errors are shown in Table III(4).

Table III

Velocity of Approach ft./sec.	Measured Head-ft. 0.2	0.6	1.0
	error in Q, %		
0.5	2.7	0.9	0.6
1.0	9.8	3.4	2.2
1.5	20.8	7.5	4.7

In developing this Table the Francis equation was used, and velocity of approach was ignored. The data shows that approach velocities have to be well below 0.5 ft./sec. before the error becomes negligible at low heads. In general, moderate velocities of approach with low heads on the weir produce large errors, whereas comparatively high velocities of approach with large heads on the weir produce small errors.

F If velocity of approach is included in the Francis equations, they become:

For the suppressed weir:
$Q' = 3.33\ L[(H+h)^{3/2}-h^{3/2}]$............(c)

For the contracted weir:
$Q' = 3.33\ (L-0.2H)\ [(H+h)^{3/2}-h^{3/2}]$ ...(d)

Where Q' = discharge, $ft.^3sec.$, considering velocity of approach;

L = crest length, ft.

H = measured head, ft.

h = head on the weir in feet due to the velocity of approach

$= \frac{v^2}{2g}$ where v is the velocity of approach.

G When using the Francis equations, correction for velocity of approach is usually made by trial, as follows:

1 Measure H. Determine Q, using formula (a) or (b) without velocity of approach considered.

TABLE 1

FLOW THROUGH RECTANGULAR WEIRS WITH END CONTRACTIONS

Formula CFS = $3.33(L-0.2H)H^{3/2}$ MGD = CFS X .646317

Head	LENGTH OF WEIR CREST IN FEET											
	1		1½		2		3		4		5	
Ft	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD
.01	.003	.002	.005	.003	.007	.005	.010	.006	.013	008	017	.011
.02	.009	.006	014	.009	019	.012	.028	.018	038	.025	.047	.030
.03	.017	011	.026	.017	035	.023	.052	.034	.069	.045	.086	.056
.04	.026	.017	.040	.026	.053	.034	080	.052	.106	.069	.133	.086
.05	.037	024	.055	036	.074	048	111	.072	.149	.096	.186	.120
.06	048	.031	073	.047	.097	.063	.146	.094	.195	.126	.244	.158
.07	.061	.039	.092	.059	122	.079	184	.119	.246	.159	.307	198
.08	.074	.048	.112	.072	.149	.096	.225	.145	.300	.194	.376	.243
.09	.088	.057	.133	086	.178	.115	.268	.173	.358	.231	.448	290
.10	.103	.067	156	.101	.209	.135	.314	.203	.419	.271	.524	.339
.11	.119	.077	.180	.116	.240	.155	.362	.234	.483	.312	.605	391
12	.135	.087	.204	.132	.274	.177	.412	.266	.550	.355	.689	.445
.13	.152	.098	.230	.149	.308	199	.464	.300	.620	.401	.776	.502
.14	.170	.110	.257	.166	344	222	.518	.335	.693	.448	.867	.560
.15	.188	.122	.284	.184	.381	.246	.575	.372	.768	.496	.961	.621
.16	.206	.133	.313	202	.419	.271	.633	.409	.846	547	1.059	.684
17	225	.145	342	.221	.459	.297	692	.447	926	.598	1.159	.749
.18	245	.158	372	.240	.499	.323	754	487	1.008	.651	1.262	.816
.19	.265	.171	.404	260	.541	.350	.817	.528	1.093	.706	1.368	.884
.20	.286	.185	.435	.281	.584	.377	.882	.570	1.179	762	1.477	.955
.21	.307	.198	.468	302	627	405	.948	.613	1.268	.820	1.589	1.027
.22	.329	.213	.501	323	.672	434	1 016	.657	1 359	878	1.703	1.101
.23	.350	.226	.534	.345	.718	.464	1 085	.701	1 452	.938	1.820	1.176
.24	.373	.241	.568	.367	.764	494	1.156	.747	1.547	1.000	1.939	1.253
.25	.395	.255	.604	.390	.812	.525	1.228	.794	1.644	1.063	2.060	1.331
.26	.419	.271	639	413	.860	.556	1 301	.841	1.743	1.127	2.184	1.412
.27	.442	.286	.676	437	.909	588	1.376	.889	1.844	1.192	2.311	1.494
.28	.466	.301	.712	460	.959	.620	1.453	.939	1.946	1.258	2.439	1.576
.29	490	.317	750	.485	1 010	653	1.530	.989	2.050	1.325	2.570	1 661
.30	.514	.332	788	.509	1.062	.686	1.609	1.040	2.156	1.393	2.703	1.747
.31	.539	.348	.827	.535	1.114	720	1.689	1.092	2.263	1.463	2.838	1.834
.32	564	.365	.866	.560	1 167	.754	1.770	1.144	2.373	1.534	2.975	1.923
.33	.590	.381	.905	.585	1.221	.789	1.852	1.197	2.483	1.605	3.115	2.013
.34	.615	.397	.945	.611	1.275	824	1.936	1.251	2.596	1.678	3.256	2 104
.35	641	.414	.986	.637	1.331	.860	2.020	1.306	2.710	1.752	3.399	2.197

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TABLE 2

FLOW PER FOOT OF LENGTH THROUGH RECTANGULAR WEIRS WITHOUT END CONTRACTIONS

Formula CFS = $3.33 L H^{3/2}$ MGD = CFS x .646317

Head	.00		01		.02		03		04		.05		.06		07		08		.09	
Ft.	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD
0.0	.00	00	.00	00	.01	.01	.02	01	.03	.02	04	.03	.05	.03	.06	04	08	.05	.09	06
1	.11	07	.12	08	.14	.09	.16	.10	17	11	.19	.12	.21	.14	.23	.15	.25	.16	.28	.18
.2	.30	.19	.32	.21	.34	22	.37	24	.39	25	.42	27	.44	.28	47	.30	.49	.32	.52	.34
.3	55	.36	.57	37	.60	39	.63	.41	.66	43	.69	.45	.72	.47	75	.48	.78	.50	.81	.52
4	.84	54	.87	56	.91	.59	94	.61	97	.63	1.01	.65	1.04	67	1.07	.69	1 11	.72	1.14	74
5	1.18	76	1.21	.78	1.25	.81	1.28	83	1.32	.85	1.36	88	1 40	90	1 43	92	1.47	95	1.51	98
.6	1 55	1.00	1 59	1 03	1.63	1.05	1.67	1.08	1 70	1 10	1.75	1.13	1.79	1.16	1.83	1.18	1.87	1.21	1.91	1.23
.7	1.95	1.26	1.99	1.29	2.03	1.31	2.08	1.34	2.12	1.37	2.16	1 40	2 21	1.43	2 25	1.45	2.29	1.48	2.34	1.51
.8	2 38	1 54	2.43	1.57	2.47	1 60	2 52	1 63	2 56	1.65	2 61	1.69	2.66	1.72	2.70	1.75	2.75	1.78	2.80	1.81
.9	2.84	1.84	2.89	1.87	2.94	1 90	2 99	1 93	3.03	1.96	3.08	1.99	3.13	2.02	3.18	2.06	3.23	2.09	3.28	2.12
1.0	3.33	2.15	3.38	2.18	3 43	2.22	3 48	2 25	3.53	2.28	3 58	2 31	3.63	2.35	3 69	2.38	3.74	2.42	3.79	2 45
1.1	3.84	2 48	3 89	2 51	3 95	2 55	4 00	2 59	4.05	2 62	4.11	2.66	4.16	2.69	4.21	2 72	4.27	2.76	4.32	2.79
1.2	4.38	2.83	4.43	2.86	4 49	2 90	4 54	2.94	4 60	2.97	4.65	3.01	4 71	3.04	4.77	3.08	4.82	3.12	4.88	3.15
1 3	4.94	3.19	4.99	3.23	5.05	3.26	5 11	3.30	5 17	3.34	5 22	3.37	5.28	3.41	5.34	3.45	5.40	3.49	5.46	3.53
1.4	5 52	3 57	5.58	3.61	5.63	3.64	5.69	3.68	5 75	3 72	5.81	3 76	5.87	3.79	5.93	3.84	6.00	3.88	6.06	3.92
1.5	6.12	3 96	6 18	3 99	6 24	4 03	6.30	4 07	6 36	4 11	6 43	4 16	6 49	4.19	6.55	4.23	6.61	4.27	6.68	4.32

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2 Compute velocity of approach, $v = \frac{Q}{A}$, "A" being the cross-sectional area of the approach channel in square feet.

3 Compute velocity of approach head, h

$$h = \frac{v^2}{2g} = 0.0156\ v^2$$

4 Compute effective head on weir, D

$$D = [(H + h)^{3/2} - h^{3/2}]^{2/3}$$

5 Substitute "D" for "H" in formula used and calculate Q'.

6 The second approximation to the true value of Q, as obtained in step 5 above, is always sufficiently close for practical purposes.

H Using the above method of correcting for velocity of approach it will be seen that;

$$\frac{Q'}{Q} = \frac{D^{3/2}}{H^{3/2}} = C, \text{ or } Q' = CQ \ \ldots\ldots\ldots\ldots \text{(e)}$$

where Q' = discharge considering velocity of approach

Q = discharge neglecting velocity of approach

D = effective head on weir crest considering velocity of approach

H = measured head on weir crest

C = a coefficient

Values of C appear in Table IV for velocities of approach from 0.4 to 3.0 ft./sec. The table is used as follows:

1 Compute velocity of approach as described in G1 and G2 above.

2 Determine "C" from table for the applicable combination of v and H values.

3 Use formula (e) to obtain Q'.

I An improved formula for computing discharges for rectangular weirs has been developed by Kindsvater and Carter. This equation is coming into more frequent use and is considered by some to be more accurate than the Francis formulations. Direct, accurate, simple computations quickly yield the rate of flow with correction factors for approach velocity and approach channel width and depth included.

The basic equation is:

$$Q = C_e\ L_e\ H_e^{3/2} \ \ldots\ldots\ldots\ldots\ldots\ldots \text{(f)}$$

Table IV—Discharge correction coefficient, C, for determining effect of velocity of approach to weirs. Computed from the formula $C = \frac{Q'}{Q} = \frac{D^{3/2}}{H^{3/2}}$.

v	h	$h^{3/2}$	H											
			0.2	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
0.4	0.0025	0.0002	1.014	1.007	1.004	1.004	1.004	1.002	1.002	1.002	1.001	1.001	1.001	1.001
.5	.0039	.0003	1.027	1.013	1.009	1.006	1.006	1.004	1.003	1.002	1.002	1.002	1.001	1.001
.6	.0056	.0005	1.037	1.019	1.013	1.009	1.008	1.005	1.004	1.003	1.003	1.002	1.002	1.002
.7	.0076	.0007	1.050	1.026	1.017	1.013	1.011	1.007	1.006	1.004	1.004	1.003	1.003	1.002
.8	.0099	.0010	1.064	1.033	1.022	1.016	1.014	1.009	1.007	1.006	1.005	1.004	1.003	1.003
.9	.0126	.0014	1.082	1.042	1.029	1.021	1.018	1.012	1.009	1.007	1.006	1.005	1.005	1.004
1.0	.0155	.0019	1.098	1.051	1.034	1.027	1.022	1.015	1.011	1.009	1.007	1.006	1.005	1.005
1.1	.0188	.0025	1.122	1.062	1.041	1.031	1.026	1.017	1.013	1.011	1.009	1.008	1.007	1.006
1.2	.0224	.0033	1.141	1.072	1.049	1.037	1.031	1.021	1.016	1.013	1.011	1.009	1.008	1.007
1.3	.0263	.0041	1.163	1.084	1.057	1.043	1.036	1.024	1.018	1.015	1.012	1.011	1.009	1.008
1.4	.0305	.0051	1.186	1.096	1.056	1.050	1.041	1.028	1.021	1.017	1.014	1.012	1.011	1.010
1.5	.0350	.0064	1.208	1.109	1.075	1.057	1.047	1.032	1.024	1.019	1.016	1.014	1.012	1.011
1.6	.0398	.0079	1.225	1.122	1.084	1.065	1.052	1.035	1.027	1.022	1.018	1.016	1.014	1.012
1.7	.0449	.0095	1.254	1.135	1.093	1.071	1.059	1.040	1.031	1.025	1.021	1.018	1.016	1.014
1.8	.0504	.0111	1.277	1.149	1.104	1.080	1.065	1.045	1.034	1.027	1.023	1.020	1.017	1.016
1.9	.0561	.0132	1.308	1.165	1.115	1.089	1.072	1.049	1.038	1.030	1.026	1.022	1.019	1.017
2.0	.0622	.0154	1.335	1.181	1.126	1.097	1.079	1.055	1.042	1.034	1.028	1.025	1.021	1.019
2.1	.0686	.0179	1.363	1.197	1.137	1.106	1.087	1.060	1.046	1.037	1.031	1.027	1.024	1.021
2.2	.0752	.0206	1.391	1.213	1.149	1.118	1.094	1.065	1.050	1.039	1.034	1.029	1.026	1.023
2.3	.0822	.0235	1.420	1.231	1.161	1.124	1.102	1.071	1.054	1.044	1.037	1.032	1.028	1.025
2.4	.0895	.0268	1.449	1.248	1.176	1.134	1.110	1.077	1.059	1.047	1.040	1.034	1.030	1.027
2.5	.0972	.0303	1.480	1.266	1.187	1.145	1.119	1.083	1.063	1.051	1.043	1.037	1.033	1.029
2.6	.1051	.0340	1.511	1.285	1.200	1.155	1.128	1.088	1.069	1.055	1.046	1.040	1.035	1.032
2.7	.1133	.0381	1.542	1.303	1.213	1.166	1.137	1.095	1.073	1.059	1.050	1.043	1.038	1.034
2.8	.1219	.0426	1.573	1.322	1.228	1.178	1.146	1.100	1.078	1.063	1.053	1.046	1.041	1.036
2.9	.1307	.0472	1.606	1.341	1.242	1.189	1.155	1.108	1.083	1.067	1.057	1.049	1.043	1.039
3.0	.1399	.0524	1.637	1.361	1.256	1.199	1.165	1.115	1.088	1.072	1.061	1.053	1.046	1.041

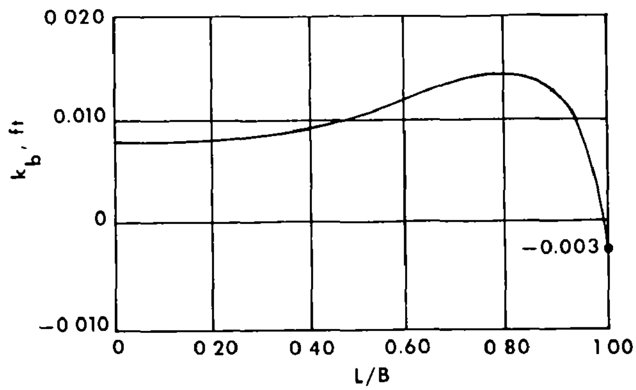

FIGURE 6.

VALUES OF K_b FOR KINDSVATER-CARTER EQUATION

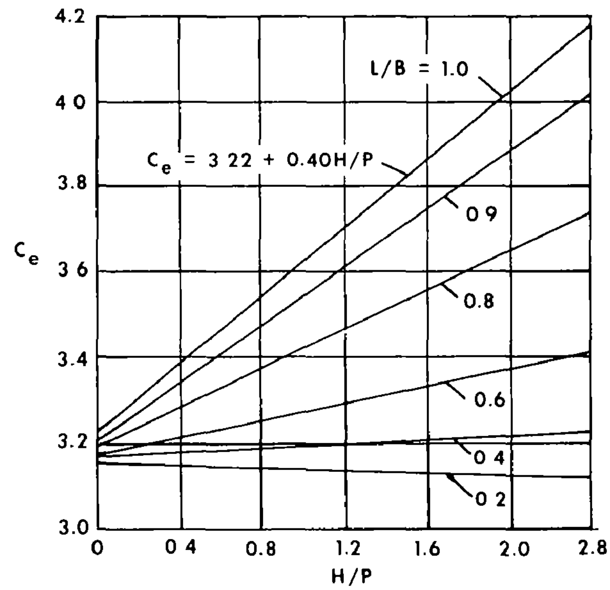

FIGURE 7.

VALUES OF C_e FOR KINDSVATER-CARTER EQUATION where C_e = a discharge coefficient, obtained from Figure 7

$L_e = L + k_b$, and

$H_e = H + k_h = H + 0.003$

In these relationships

Q = discharge, ft.^{3}/sec.

H = head above weir crest, ft.

L = length of weir crest, ft.

B = width of approach channel, ft.

k_b = a correction factor to obtain the effective weir length L_e (Figure 6)

k_h = a correction factor to obtain the effective head H_e

This method is particularly useful for installations where full crest contractions or full end contractions are difficult to achieve, and should be used for determining the discharge of rectangular weirs not fully contracted, or when H is greater than 1/3 of the crest length. In these cases, large errors can be involved if the Francis formula is used. The Kindsvater-Carter formula is not applicable to V-notch or Cippoletti weirs.

V V-Notch Weir

A These are particularly useful for low flows. Standard contraction requirements are the same as for rectangular weirs. Probably the most commonly-used weir of this type is the 90° V-notch weir, for which the Cone formula - $Q = 2.49\ H^{2.48}$ - is usually employed. Table V shows the head-discharge relationship for a 90° fully contracted V-notch weir using this formula.

Weirs notched at angles other than 90° will sometimes be encountered. Tables are available (3) for weirs having angles of 60°, 45°, and 22-1/2°.

B The Kindsvater-Sten equation (5) valid for any notch angle is

$$Q = (8/15)(2g)^{1/2}\ C_e \tan(\theta/2) H_e^{3/2} \ldots\ldots (g)$$

Q = discharge, ft.^{3}/ sec.

g = gravity constant

C_e = a coefficient (Figs. 8 & 9)

(Note that values of C_e shown on Figure 9 are for 90°, V-notch weirs only, incompletely contracted. Corrections for other notch angles are not available.)

θ = notch angle

H_e = measured head plus K_h (Figure 10)

C Ordinarily, V-notch weirs are not appreciably affected by velocity of approach. If the weir is installed with complete contractions, the velocity of approach will be low.

D The Kindsvater-Sten and Cone formulas give results within about 0.5% of each other for fully contracted 90° V-notch weirs. If contractions are incomplete, the Kindsvater-Sten equation should be used with the correction as shown above.

WATER MEASUREMENT MANUAL

Table V —Discharge of 90° V-notch weirs in second-feet. Computed from the formula $Q=2.49\ H^{2.48}$

Head in feet	Discharge in second-feet	Head in feet	Discharge in second-feet	Head in feet	Discharge in second-feet
0 20	0 046	0 55	0 564	0 90	1.92
21	052	56	590	91	1 97
22	058	57	617	92	2 02
.23	065	58	.644	93	2 08
24	072	.59	.672	.94	2 13
25	080	.60	.700	95	2 19
26	088	.61	730	96	2 25
.27	096	62	760	97	2 31
28	106	.63	.790	98	2.37
29	115	64	.822	99	2.43
30	.125	65	.854	1.00	2 49
.31	.136	66	887	1.01	2 55
32	147	.67	921	1 02	2 61
.33	.159	68	955	1 03	2 68
.34	.171	.69	991	1 04	2 74
35	.184	.70	1 03	1 05	2 81
36	.197	71	1 06	1 06	2 87
37	211	72	1.10	1 07	2 94
.38	.226	73	1.14	1 08	3 01
.39	.240	.74	1 18	1 09	3.08
40	.256	.75	1.22	1 10	3.15
41	272	.76	1 26	1 11	3 22
42	289	77	1 30	1.12	3 30
43	306	.78	1 34	1 13	3.37
.44	324	79	1.39	1 14	3 44
.45	.343	80	1 43	1 15	3.52
.46	.362	.81	1.48	1.16	3 59
.47	.382	82	1 52	1 17	3 67
.48	.403	83	1 57	1 18	3 75
.49	.424	84	1 61	1.19	3 83
.50	.445	.85	1 66	1 20	3 91
.51	.468	.86	1.71	1 21	3 99
52	491	.87	1 76	1 22	4 07
.53	515	.88	1 81	1 23	4 16
.54	.539	.89	1.86	1.24	4 24
....	....	....	....	1 25	4 33

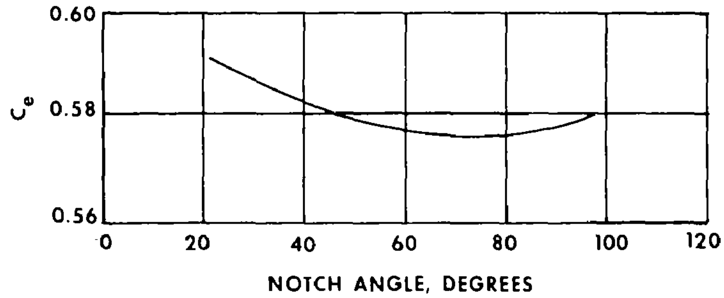

FIGURE 8.

VALUES OF C_e FOR KINDSVATER-SHEN EQUATION, FULLY CONTRACTED V-NOTCH WEIRS

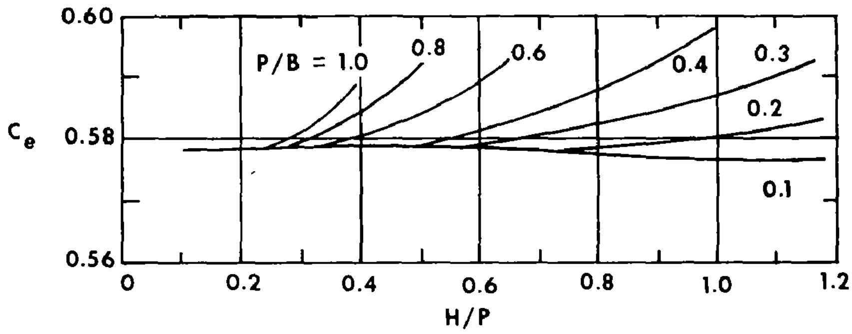

FIGURE 9.

VALUES OF C_e FOR KINDSVATER-SHEN EQUATION, 90° V-NOTCH WEIRS WITH INCOMPLETE CONTRACTIONS

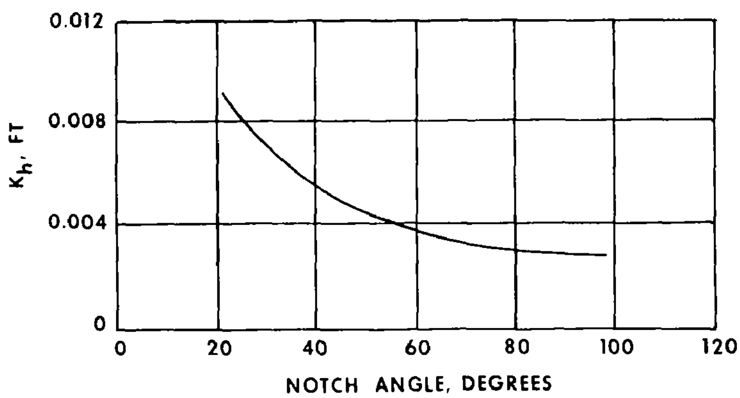

FIGURE 10.

VALUES OF K_h FOR KINDERSVATER-SHEN EQUATION

E The angle at which the notch is cut should be measured accurately. A change of only 1° for a nominal 90° notch would introduce an error of almost 2% in measured flow rate.

VI Cippoletti Weir

A This must also be installed as a fully contracted weir if reasonably correct and consistent discharge measurements are to be obtained. The accuracy of measurements with this weir, however, is less than that obtainable with rectangular and V-notch weirs but is acceptable when no great precision is required (1, 2).

B The formula for this weir, neglecting velocity of approach is

$$Q = 3.367\ LH^{3/2} \ldots\ldots\ldots\ldots\ldots\ldots (h)$$

where Q, L, and H have the same meanings as for rectangular weirs.

C With velocity of approach included, discharge can be obtained from the formula.

$$Q' = 3.367\ L\ (H + 1.5h)^{3/2} \ldots\ldots\ldots (i)$$

where the symbols have the same meanings as for rectangular weirs. The velocity-of-approach correction can be applied, as in the Francis formula, with fair results.

VII Setting Standard Weirs (1)

A Rectangular, V-notch, and Cippoletti weirs are sometimes referred to as "standard" weirs when set so that the nappe is fully contracted. Extensive experiments on weirs and long experience with their use dictate that the following conditions are necessary for accurate measurement of flow with standard contracted weirs.

1 The upstream face of the bulkhead should be smooth and in a vertical plane perpendicular to the axis of the channel.

2 The upstream face of the weir plate should be smooth, straight, and flush with the upstream face of the bulkhead.

3 The entire crest should be a level, plane surface which forms a sharp, right-angled edge where it intersects the upstream face. The thickness of the crest, measured in the direction of flow, should be between 0.03 and 0.08 inch (about 1 to 2 mm). Both side edges of rectangular weirs should be truly vertical and of the same thickness as the crest.

4 The upstream corners of the notch must be sharp. They should be machined or filed perpendicular to the upstream face, free of burrs or scratches, and not smoothed off with abrasive cloth or paper. Knife edges should be avoided because they are difficult to maintain.

5 The downstream edges of the notch should be relieved by chamfering if the plate is thicker than the prescribed crest width. This chamfer should be at an angle of 45° or more to the surface of the crest.

6 The distance of the crest from the bottom of the approach channel (weir pool) should preferably be not less than twice the depth of water above the crest and in no case less than 1 foot.

7 The distance from the sides of the weir to the sides of the approach channel should preferably be no less than twice the depth of water above the crest and never less than 1 foot.

8 The overflow sheet (nappe) should touch only the upstream edges of the crest and sides.

9 Air should circulate freely both under and on the sides of the nappe.

10 The measurement of head on the weir should be taken as the difference in elevation between the crest and the water surface at a point upstream from the weir a distance of four times the maximum head on the crest.

11 The cross-sectional area of the approach channel should be at least 8 times that of the overflow sheet at the crest for a distance upstream from 15 to 20 times the depth of the sheet.

12 If the weir pool is smaller than defined by the above criteria, the velocity of approach may be too high and the staff gage reading too low. The head should be corrected by increasing it as explained earlier.

B In addition, for the suppressed weir

1 The sides of the approach channel should be coincident with the sides of the weir, and should extend downstream beyond the crest to prevent lateral expansion of the nappe.

2 Special care must be taken to secure proper aeration beneath the nappe at the crest.

VIII Selection of Weirs (1)

A In general, for best accuracy, a rectangular suppressed weir or a 90° V-notch weir should be used. Cippoletti weirs and contracted rectangular weirs, although useful in many applications, have not been investigated experimentally as thoroughly as the suppressed rectangular and V-notch weirs.

B Usually, the range of flows to be measured can be fairly well estimated in advance, and the following points considered:

1 The minimum head should be at least 0.2 foot to prevent the nappe from clinging to the crest, and because at smaller depth it is difficult to get sufficiently accurate gage readings to calculate reliable discharges.

2 The length of rectangular and Cippoletti weirs should be at least three times the head.

3 The 90° V-notch weir is the best type for measuring discharges less than 1 ft.^{3}/sec. It is as accurate as other types for flows from 1-10 ft.^{3}/sec.

4 If possible, the crests should be placed high enough so the liquid will fall freely, leaving an air space under and around the nappe. If submergence is permitted, special computations and reduced flow measurement accuracy may be expected.

C Capacities of standard weirs are shown in Table VI.

Table VI—Capacities of standard weirs in second-feet.

Length in feet	Contracted rectangular		Suppressed rectangular		Cipolletti	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1 0	0 590	0 286	0 631	0 298	0.638	0 303
1 5	1 65	435	1.77	447	1.79	452
2 0	3 34	584	3 65	.596	3 69	.602
2 5	5 87	.732	6 30	744	6.37	753
3 0	9 32	881	10 0	893	10 1	903
3 5	13 8	1 03	14.8	1.04	15 0	1 05
4 0	19 1	1 18	20.4	1 19	20 6	1 20
4 5	25 7	1 33	27 5	1 34	27 8	1 35
5 0	33 5	1.48	36 0	1 49	36 4	1 51
5 5	42 3	1.63	45 3	1.64	45 8	1 66
6 0	52 7	1 78	56 6	1 79	57 2	1.81
7 0	77.4	2 07	82 9	2 08	83 8	2 11
8.0	108 5	2 37	116.2	2 38	117.5	2 41
9.0	145.3	2 67	155.9	2 68	157 6	2 71
10 0	188 9	2 97	202 4	2.98	204.6	3.01
12 0	298 4	3.56	320 0	3.57	323.6	3 61
14 0	439 1	4 16	470 4	4 17	475 6	4.21
16.0	612 0	4 75	656 5	4 76	663 8	4.82
18 0	822 4	5.35	882.0	5.36	891.8	5.42

NOTE—Limits follow the prescribed practice of $h>0.2$ foot and $h<\frac{1}{3}L$.

IX Care of Weirs

A A weir installation requires some maintenance and care to ensure continued accuracy of the measurement being made.

1 The weir and the channel upstream of the weir should be kept free of trash, debris, & excessive sediment build-ups.

2 Sediment should be removed from the channel upstream of the weir as it accumulates.

3 The crest should be checked periodically to be sure it is absolutely level.

4 A periodic check should be made to ensure that the zero of the gage is at the same elevation as the crest.

5 Any leakage which may occur around the weir should be immediately eliminated.

6 Great care must be taken to avoid damage to the weir notch itself, as even small nicks or dents can reduce the accuracy of an otherwise good installation. Dress any nicks and dents that do occur with a fine-cut file or stone, but only to remove any metal that may protrude above the normal surfaces. Under no circumstances should the upstream corners of the notch be rounded or chamfered, nor should an attempt be

made to completely remove an imperfection if the shape of the weir opening is thereby changed. Erosion, rusting, and wear can produce rounding of the weir crest, or unacceptable changes in the shape of the notch. Badly eroded weirs should be replaced.

This outline was prepared by C. E. Sponagle, Sanitary Engineer, National Training & Operational Technology Center, MOTD, OWPO, USEPA, Cincinnati, Ohio 45268

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MEASUREMENT OF WASTEWATER FLOW: PARSHALL FLUME

I Background and Description

A The Parshall Flume is a specific type of venturi flume, named for its principal developer, the late Mr. Ralph L. Parshall. It was developed in the late 1920's, primarily to measure irrigation water, but is also now frequently used to measure wastewater flows.

B Configuration of the Flume is shown in Figure 1, standard sizes and dimensions appear in Table 1. It is essential that these dimensions be strictly adhered to, when using standard H-Q relationships. For the smallest flume sizes, tolerances of 1/64 inch for the throat and 1/32 inch elsewhere have been suggested (1). In a 1-inch flume a throat width difference of even 1/64 inch will result in a 1.5% error, unless corrected as explained in V-C below.

C Referring to Figure 1 it can be seen that the flume proper consists of three sections:

1 A converging section in which the entering flow is accelerated.

2 A constricted throat, producing a differential head that can be related to discharge

3 A diverging section in which liquid is carried away from the throat.

D Wing walls are provided (a) at entrance, (b) at exit, or (c) at both entrance and exit from the flume when the channel width exceeds dimension C or D in Figure 1. These can be either straight or curved as shown, and provide a gradual smooth transition of the flowing liquid into and away from the flume.

E The crest of the flume is the floor of the converging section. It must be level in all directions if accurate measurements are to be made.

F Flume sizes are designated by the throat width W, Figure 1.

G Flumes can be built of wood, concrete, galvanized sheet metal, or other suitable materials. They can be constructed as an integral part of the channel in which they are situated, or purchased as pre-fabricated structures to be installed in one piece.

II Measuring Flow

A Discharge through the flume can occur for two conditions of flow

1 Free flow, which occurs when there is insufficient backwater depth to reduce the discharge rate.

2 Submerged flow, which occurs when the water surface downstream of the flume is far enough above the elevation of the flume crest to reduce the discharge.

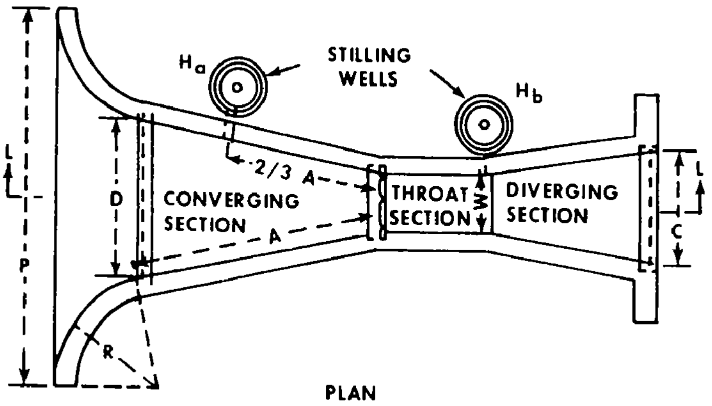
B For free flow only the head at the upstream gage location (H_a, Figure 1) is needed to determine the discharge from a standard table.

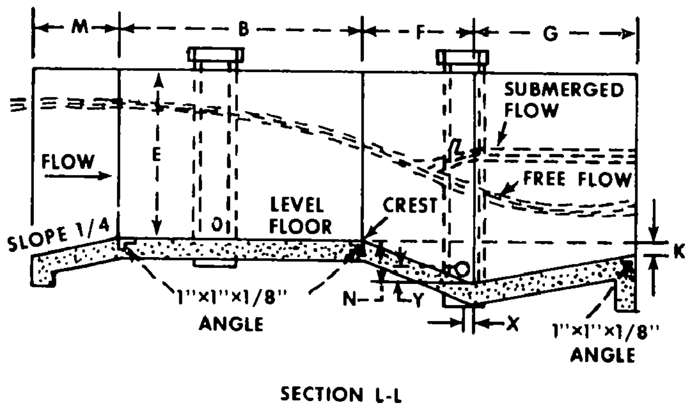
C For submerged flows both the upstream and downstream heads (H_a and H_b, Figure 1) are needed to determine the discharge.

III Free-flow Measurements

A In free flow the discharge depends solely on the throat width and the depth of the liquid at the gaging point in the converging section (H_a, Figure 1). This depth must be measured at the point shown in the plan view of the flume, Figure 1, which is upstream of the throat at a distance equal to 2/3 the length of the converging section.

B Once H_a is known, the discharge for the size flume being used can be obtained from a table. See Table II.





LEGEND·

W Size of flume, in inches or feet.
A Length of side wall of converging section.
2/3A Distance back from end of crest to gage point.
B Axial length of converging section.
C Width of downstream end of flume.
D Width of upstream end of flume.
E Depth of flume.
F Length of throat.
G Length of diverging section.
K Difference in elevation between lower end of flume and crest.
N Depth of depression in throat below crest.
R Radius of curved wing wall.
M Length of approach floor.
P Width between ends of curved wing walls.
X Horizontal distance to H_b gage point from low point in throat.
Y Vertical distance to H_b gage point from low point in throat.

FIGURE 1. Configuration and Standard Nomenclature of Parshall Flumes

TABLE I. STANDARD PARSHALL FLUME DIMENSIONS AND CAPACITIES

Widths			Axial Lengths			Wall Depth in Con-verging Section	Vertical Distance Below Crest		Con-verging Wall Length	Gage Points			Free Flow Capacities	
Size; Throat Width W	Up-stream End D	Down-stream End C	Con-verging Section B	Throat Section F	Diverging Section G	E	Dip at Throat N	Lower End of Flume K	A*	Ha, Dist Upstream of Crest**	Hb x	Hb y	Min	Max
Inches	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	cfs	cfs
1	0.549	0.305	1.17	0.250	0.67	0.5-0.75	0.094	0.062	1.19	0.79	0.026	0.042	0.005	0.15
2	.700	.443	1.33	.375	.83	0.50-0.83	.141	.073	1.36	.91	.052	.083	.01	.30
3	.849	.583	1.50	.500	1.00	1.00-2.00	.188	.083	1.53	1.02	.083	.125	.03	1.90
6	1.30	1.29	2.00	1.00	2.00	2.0	.375	.25	2.36	1.36	.167	.25	.05	3.90
9	1.88	1.25	2.83	1.00	1.50	2.5	.375	.25	2.88	1.93	.167	.25	.09	8.90
Feet														
1.0	2.77	2.00	4.41	2.0	3.0	3.0	.75	.25	4.50	3.00	.167	.25	.11	16.1
1.5	3.36	2.50	4.66	2.0	3.0	3.0	.75	.25	4.75	3.17	.167	.25	.15	24.6
2.0	3.96	3.00	4.91	2.0	3.0	3.0	.75	.25	5.00	3.33	.167	.25	.42	33.1
3.0	5.16	4.00	5.40	2.0	3.0	3.0	.75	.25	5.50	3.67	.167	.25	.61	50.4
4.0	6.35	5.00	5.88	2.0	3.0	3.0	.75	.25	6.00	4.00	.167	.25	1.30	67.9
5.0	7.55	6.00	6.38	2.0	3.0	3.0	.75	.25	6.50	4.33	.167	.25	1.60	85.6
6.0	8.75	7.00	6.86	2.0	3.0	3.0	.75	.25	7.0	4.67	.167	.25	2.60	103.5
7.0	9.95	8.00	7.35	2.0	3.0	3.0	.75	.25	7.5	5.0	.167	.25	3.00	121.4
8.0	11.15	9.00	7.84	2.0	3.0	3.0	.75	.25	8.0	5.33	.167	.25	3.50	139.5
10	15.60	12.00	14.0	3.0	6.0	4.0	1.12	.50	9.0	6.00			6	300
12	18.40	14.67	16.0	3.0	8.0	5.0	1.12	.50	10.0	6.67			8	520
15	25.0	18.33	25.0	4.0	10.0	6.0	1.50	.75	11.5	7.67			8	900
20	30.0	24.00	25.0	6.0	12.0	7.0	2.25	1.00	14.0	9.33			10	1340
25	35.0	29.33	25.0	6.0	13.0	7.0	2.25	1.00	16.5	11.00			15	1660
30	40.4	34.67	26.0	6.0	14.0	7.0	2.25	1.00	19.0	12.67			15	1990
40	50.8	45.33	27.0	6.0	16.0	7.0	2.25	1.00	24.0	16.00			20	2640
50	60.8	56.67	27.0	6.0	20.0	7.0	2.25	1.00	29.0	19.33			25	3280

* For sizes 1' to 8', A = W/2 + 4.

** Ha located 2/3 A distance from crest for all sizes; distance is wall length, not axial.

Notes:

1. Flume sizes 3 inches through 8 feet have approach aprons rising at a 1:4 slope and the following entrance roundings: 3 through 9 inches, radius = 1.33 feet; 1 through 3 feet, radius = 1.67 feet; 4 through 8 feet, radius = 2.00 feet.
2. To maximize clarity, equivalent SI units are not given.
3. Table prepared by Kilpatrick.

TABLE II

G.C.H. N.W.N.

FREE FLOW DISCHARGE TABLE FOR PARSHALL MEASURING FLUME

SEC-FT X .646317 = M.G.D.
M.G.D. X 1.54723 = SEC-FT.

SEC-FT X 448.831 = G.P.M.
G.P.M. X .002228 = SEC-FT.

THROAT WIDTH

HEAD		6"			9"			12"			18"			24"		
FT.	IN.	SEC-FT	G.P.M.	M.G.D.	SEC-FT	G.P.M.	M.G.D.	SEC-FT	G.P.M.	M.G.D.	SEC-FT	G.P.M.	M.G.D.	SEC-FT	G.P.M.	M.G.D.
0.10	1 3/16	0.05	22.4	0.032	0.09	40.4	.0580									
0.11	1 5/16	0.06	26.9	0.039	0.10	44.9	.0650									
0.12	1 7/16	0.07	31.4	0.045	0.12	53.8	.0775									
0.13	1 9/16	0.08	35.9	0.052	0.14	62.8	.0905									
0.14	1 11/16	0.09	40.4	0.058	0.15	67.3	.0970									
0.15	1 13/16	0.10	44.9	0.065	0.17	76.3	.1100									
0.16	1 15/16	0.11	49.4	0.071	0.19	85.2	.1230									
0.17	2 1/16	0.12	53.8	0.077	0.20	89.8	.1290									
0.18	2 3/16	0.14	62.8	0.090	0.22	98.7	.1420									
0.19	2 1/4	0.15	67.3	0.097	0.24	107.7	.1550									
0.20	2 3/8	0.16	71.6	0.103	0.26	116.9	.1680	0.35	157.1	0.226	0.51	229.0	0.330	0.66	296.3	0.426
0.21	2 1/2	0.18	80.7	0.116	0.28	125.7	.1810	0.37	166.1	0.239	0.55	247.0	0.355	0.71	318.7	0.458
0.22	2 5/8	0.19	85.2	0.123	0.30	134.6	.1940	0.40	179.5	0.259	0.59	265.0	0.381	0.77	345.6	0.498
0.23	2 3/4	0.20	89.8	0.129	0.32	143.6	.2070	0.43	193.0	0.278	0.63	283.0	0.407	0.82	368.0	0.530
0.24	2 7/8	0.22	98.7	0.142	0.35	157.1	.2260	0.46	206.5	0.297	0.67	301.0	0.433	0.88	395.0	0.569
0.25	3	0.23	103.3	0.149	0.37	166.1	.2390	0.49	219.9	0.316	0.71	318.7	0.458	0.93	417.5	0.601
0.26	3 1/8	0.25	112.2	0.162	0.39	175.	.2520	0.51	229.0	0.330	0.76	341.1	0.491	0.99	444.3	0.640
0.27	3 1/4	0.26	116.9	0.168	0.41	184.0	.2650	0.54	242.3	0.349	0.80	359.0	0.517	1.05	471.3	0.679
0.28	3 3/8	0.28	125.7	0.181	0.44	197.5	.2840	0.58	260.3	0.374	0.85	381.5	0.549	1.11	498.2	0.717
0.29	3 1/2	0.29	130.2	0.187	0.46	206.5	.2970	0.61	274.0	0.394	0.90	404.0	0.582	1.18	530.0	0.763
0.30	3 5/8	0.31	139.2	0.203	0.49	219.9	.3160	0.64	287.3	0.414	0.94	422.0	0.607	1.24	556.6	0.801
0.31	3 3/4	0.32	143.6	0.207	0.51	229.0	.3300	0.68	305.2	0.439	0.99	444.3	0.640	1.30	583.4	0.840
0.32	3 13/16	0.34	152.6	0.220	0.54	242.3	.3490	0.71	318.7	0.458	1.04	466.8	0.672	1.37	615.0	0.886
0.33	3 15/16	0.36	161.5	0.233	0.56	251.3	.3620	0.74	332.0	0.478	1.09	489.0	0.704	1.44	646.0	0.930
0.34	4 1/16	0.38	170.5	0.246	0.59	265.0	.3810	0.77	345.6	0.498	1.14	512.0	0.737	1.50	673.2	0.969
0.35	4 3/16	0.39	175.1	0.252	0.62	278.0	.4010	0.80	359.0	0.517	1.19	534.0	0.769	1.57	705.0	1.015
0.36	4 5/16	0.41	184.0	0.265	0.64	287.3	.4140	0.84	377.0	0.543	1.25	561.0	0.808	1.64	736.0	1.060
0.37	4 7/16	0.43	193.0	0.278	0.67	301.0	.4330	0.88	395.0	0.569	1.30	583.4	0.840	1.72	772.0	1.111
0.38	4 9/16	0.45	201.9	0.291	0.70	314.0	.4520	0.92	412.9	0.594	1.36	610.0	0.879	1.79	803.4	1.156
0.39	4 11/16	0.47	210.9	0.304	0.73	327.6	.4720	0.95	426.0	0.614	1.41	633.0	0.911	1.86	835.0	1.202
0.40	4 13/16	0.48	215.5	0.310	0.76	341.1	.4912	0.99	444.3	0.640	1.47	659.0	0.950	1.93	866.0	1.247
0.41	4 15/16	0.50	224.4	0.323	0.78	350.0	.5040	1.03	462.0	0.666	1.53	686.0	0.989	2.01	902.0	1.299
0.42	5 1/16	0.52	233.3	0.336	0.81	363.5	.5240	1.07	480.0	0.692	1.58	709.0	1.021	2.09	938.0	1.350
0.43	5 3/16	0.54	242.3	0.349	0.84	377.0	.5430	1.11	498.1	0.717	1.64	736.0	1.060	2.16	969.0	1.396
0.44	5 1/4	0.56	251.3	0.362	0.87	390.4	.5620	1.15	516.0	0.743	1.70	763.0	1.098	2.24	1005	1.447
0.45	5 3/8	0.58	260.3	0.375	0.90	404.0	.5820	1.19	534.0	0.769	1.76	790.0	1.137	2.32	1041	1.499
0.46	5 1/2	0.61	274.0	0.394	0.94	422.0	.6075	1.23	552.0	0.795	1.82	816.0	1.176	2.40	1077	1.551
0.47	5 5/8	0.63	283.0	0.407	0.97	435.0	.6270	1.27	570.0	0.821	1.88	843.0	1.215	2.48	1113	1.602
0.48	5 3/4	0.65	292.0	0.420	1.00	448.8	.6460	1.31	588.0	0.847	1.94	870.0	1.254	2.57	1153	1.661
0.49	5 7/8	0.67	301.0	0.433	1.03	462.0	.6660	1.35	606.0	0.872	2.00	898.0	1.293	2.65	1189	1.712
0.50	6	0.69	310.0	0.446	1.06	475.7	.6850	1.39	624.0	0.898	2.06	925.0	1.331	2.73	1225	1.764
0.51	6 1/8	0.71	318.7	0.459	1.10	493.7	.7109	1.44	646.0	0.930	2.13	956.0	1.376	2.82	1266	1.872
0.52	6 1/4	0.73	327.6	0.472	1.13	507.0	.7300	1.48	664.0	0.956	2.19	983.0	1.415	2.90	1301	1.875
0.53	6 3/8	0.76	341.1	0.491	1.16	521.0	.7500	1.52	682.0	0.982	2.25	1010	1.454	2.99	1342	1.932
0.54	6 1/2	0.78	350.0	0.504	1.20	538.0	.7760	1.57	705.0	1.015	2.32	1041	1.499	3.08	1382	1.990
0.55	6 5/8	0.80	359.0	0.517	1.23	552.0	.7950	1.62	727.0	1.047	2.39	1073	1.545	3.17	1422	2.049
0.56	6 3/4	0.82	368.0	0.530	1.26	565.5	.8140	1.66	745.0	1.073	2.45	1099	1.583	3.26	1463	2.107
0.57	6 13/16	0.85	381.5	0.549	1.30	583.4	.8400	1.70	763.0	1.098	2.52	1131	1.628	3.35	1504	2.165
0.58	6 15/16	0.87	390.4	0.562	1.33	597.0	.8600	1.75	786.0	1.131	2.59	1163	1.674	3.44	1544	2.224
0.59	7 1/16	0.89	399.5	0.575	1.37	615.0	.8860	1.80	808.0	1.163	2.66	1194	1.719	3.53	1585	2.282
0.60	7 3/16	0.92	412.9	0.595	1.40	628.0	.9050	1.84	826.0	1.189	2.73	1225	1.764	3.62	1625	2.340
0.61	7 5/16	0.94	422.0	0.608	1.44	646.0	.9300	1.88	843.0	1.215	2.80	1257	1.809	3.72	1670	2.404
0.62	7 7/16	0.97	435.0	0.627	1.48	664.0	.9560	1.93	866.0	1.247	2.87	1290	1.855	3.81	1710	2.463
0.63	7 9/16	0.99	444.3	0.640	1.51	678.0	.9760	1.98	889.0	1.280	2.95	1324	1.907	3.91	1755	2.527
0.64	7 11/16	1.02	457.8	0.659	1.55	696.0	1.002	2.03	911.0	1.312	3.02	1355	1.952	4.01	1800	2.592
0.65	7 13/16	1.04	466.8	0.672	1.59	714.0	1.028	2.08	934.0	1.345	3.09	1387	1.997	4.11	1845	2.656
0.66	7 15/16	1.07	480.0	0.692	1.63	732.0	1.054	2.13	956.0	1.376	3.17	[illegible]	2.049	4.20	1885	2.714
0.67	8 1/16	[illegible]	493.7	0.711	1.66	745.0	1.073	2.18	978.0	1.409	3.24	[illegible]	2.094	4.30	1930	2.780
0.68	8 3/16	1.12	503.0	0.724	1.70	763.0	1.098	2.23	[illegible]	[illegible]	3.31	1486	2.140	4.40	1975	2.844
0.69	8 1/4	1.15	516.0	0.743	1.74	781.0	1.125	2.28	1024	1.474	3.39	1522	2.191	4.50	2020	2.908
0.70	8 3/8	[illegible]	525.[illegible]	0.756	1.78	799.0	1.151	2.33	1046	1.506	3.46	1553	2.236	4.60	2065	2.973
0.71	8 1/2	1.20	538	0.776	1.87	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.54	1590	2.288	4.70	2111	3.038
0.72	8 5/8	1.23	552	0.795	1.86	835	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1625	2.340	4.81	2159	3.110
0.73	8 3/4	1.26	566	0.814	1.90	853	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1656	2.385	4.91	2204	3.174
0.74	8 7/8	1.28	575	0.827	1.94	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1692	2.437	5.02	2253	3.245
0.75	9	1.31	588	0.847	1.98	889	1.280	[illegible]	[illegible]	[illegible]	3.85	1728	2.488	5.12	2300	3.310
0.76	9 1/8	1.34	601	0.866	2.02	907	[illegible]	2.63	1182	1.700	3.93	1764	2.540	5.23	2347	3.380
0.77	9 1/4	1.36	610	0.879	2.06	925	1.331	2.68	1203	1.732	4.01	1800	2.592	5.34	2397	3.451
0.78	9 3/8	1.39	624	0.898	2.10	943	1.357	2.74	1230	[illegible]	4.09	1836	2.643	5.44	2442	3.516
0.79	9 1/2	1.42	637	0.918	2.14	960	1.383	2.80	1257	1.809	[illegible]	1872	2.695	5.55	2491	3.587
0.80	9 5/8	1.45	651	0.937	2.18	978	1.409	2.85	1280	1.842	4.26	1912	2.753	5.66	2540	3.658
0.81	9 3/4	1.48	664	0.957	2.22	996	1.435	2.90	1301	1.875	4.34	1948	2.805	5.77	2597	3.730
0.82	9 13/16	1.50	673	0.970	2.27	1019	1.467	2.96	1329	1.913	4.42	1984	2.857	5.88	2639	3.800
0.83	9 15/16	1.53	686	0.989	2.31	1036	1.493	3.02	1355	1.952	4.50	2020	2.908	6.00	2692	3.878
0.84	10 1/16	1.56	700	1.008	2.35	1054	1.518	3.07	1377	1.984	4.59	2060	2.967	6.11	2742	3.950
0.85	10 3/16	1.59	714	1.028	2.39	1073	1.545	3.12	1400	2.017	4.67	2096	3.018	6.22	2791	4.020
0.86	10 5/16	1.62	727	1.047	2.44	1095	1.577	3.18	1427	2.055	4.76	2136	3.076	6.33	2841	4.091
0.87	10 7/16	1.65	741	1.066	2.48	1113	1.602	3.24	1454	2.094	4.84	[illegible]	3.128	6.44	2891	4.162
0.88	10 9/16	1.68	754	1.085	2.52	1131	1.628	3.29	1476	2.126	4.93	2212	3.186	6.56	2944	4.240
0.89	10 11/16	1.71	768	1.105	2.57	1153	1.661	3.35	1504	2.165	5.01	2248	3.238	6.68	2998	4.318
0.90	10 13/16	1.74	781	1.125	2.61	1171	1.686	3.41	1530	2.203	5.10	2289	3.296	6.80	3052	4.394
0.91	10 15/16	1.77	794	1.144	2.66	1194	1.720	3.46	1553	2.236	5.19	2329	3.354	6.92	3105	4.473
0.92	11 1/16	1.81	812	1.169	2.70	1212	1.745	3.52	1580	2.275	5.28	2370	3.413	7.03	3155	4.543
0.93	11 3/16	1.84	826	1.189	2.75	1234	1.777	3.58	1606	2.313	5.37	2410	3.470	7.15	3209	4.621
0.94	11 1/4	1.87	839	1.208	2.79	1252	1.803	3.64	1633	2.352	5.46	2450	3.529	7.27	3263	4.698
0.95	11 3/8	1.90	853	1.228	2.84	1274	1.835	3.70	1661	2.391	5.55	2491	3.587	7.39	3316	4.777
0.96	11 1/2	1.93	866	1.247	2.88	1292	1.862	3.76	1687	2.430	5.64	2531	3.645	7.51	3370	4.853
0.97	11 5/8	1.97	884	1.273	2.93	1315	1.894	3.82	1714	2.469	5.73	2572	3.703	7.63	3425	4.930
0.98	11 3/4	2.00	898	1.293	2.98	1337	1.926	3.88	1741	2.510	5.82	2612	3.762	7.75	3478	5.009
0.99	11 7/8	2.03	911	1.312	3.02	1355	1.952	3.94	1768	2.547	5.91	2653	3.820	7.88	3537	5.093
1.00	12	2.06	925	1.331	3.07	1377	1.984	4.00	1795	2.585	6.00	2692	3.878	8.00	3590	5.170
1.01	12 1/8	2.09	938	1.350	3.12	1400	2.017	4.06	1822	2.624	6.09	2733	3.936	8.12	3645	5.248
1.02	12 1/4	2.12	952	1.370	3.17	1422	2.049	4.12	1849	2.662	6.19	2778	4.000	8.25	3703	5.332
1.03	12 3/8	2.16	969	1.396	3.21	1440	2.074	4.18	1876	2.701	6.28	2818	4.059	8.38	3761	5.416
1.04	12 1/2	2.19	983	1.415	3.26	1463	2.107	4.25	1908	2.747	6.37	2859	4.117	8.50	3815	5.494
1.05	12 5/8	2.22	996	1.435	3.31	1486	2.140	4.31	1934	2.786	6.47	2904	4.182	8.63	3873	5.578
1.06	12 3/4	2.26	1014	1.460	3.36	1508	2.172	4.37	1961	2.824	6.56	2944	4.240	8.76	3932	5.662
1.07	12 13/16	2.29	1027	1.480	3.40	1526	2.197	4.43	1988	2.863	6.66	2989	4.304	8.88	3986	5.740
1.08	12 15/16	2.32	1041	1.500	3.45	1548	2.230	4.50	2020	2.908	6.75	3030	4.362	9.01	4044	5.823
1.09	13 1/16	2.36	1060	1.525	3.50	1571	2.262	4.56	2047	2.947	6.85	3075	4.427	9.14	4102	5.907
1.10	13 3/16	2.40	1077	1.551	3.55	1594	2.295	4.62	2074	2.986	6.95	3119	4.492	9.27	4161	5.991
1.11	13 5/16	2.43	1091	1.571	3.60	1616	2.327	4.68	2101	3.025	7.04	3160	4.550	9.40	4220	6.075
1.12	13 7/16	2.46	1104	1.590	3.65	1638	2.360	4.75	2132	3.070	7.14	3205	4.614	9.54	4282	6.165
1.13	13 9/16	2.50	1122	1.616	3.70	1661	2.391	4.82	2164	3.115	7.24	3250	4.680	9.67	4340	6.250
1.14	13 11/16	2.53	1136	1.635	3.75	1683	2.424	4.88	2190	3.154	7.34	3294	4.744	9.80	4399	6.334
1.15	13 13/16	2.57	1153	1.661	3.80	1706	2.458	4.94	2217	3.193	7.44	3339	4.810	9.94	4461	6.424
1.16	13 15/16	2.60	1167	1.681	3.85	1728	2.490	5.01	2248	3.238	7.54	3384	4.873	10.1	4578	6.528
1.17	14 1/16	2.64	1185	1.706	3.90	1750	2.521	5.08	2280	3.283	7.64	3429	4.940	10.2	4581	6.593
1.18	14 3/16	2.68	1203	1.732	3.95	1773	2.553	5.15	2311	3.329	7.74	3474	5.003	10.3	4623	6.657
1.19	14 1/4	2.71	1217	1.752	4.01	1800	2.592	5.21	2338	3.367	7.84	3519	5.067	10.5	4713	6.786
1.20	14 3/8	2.75	1234	1.777	4.06	1822	2.624	5.28	2370	3.413	7.94	3564	5.132	10.6	4760	6.851
1.21	14 1/2	2.78	1248	1.797	4.11	1845	2.656	5.34	2397	3.451	8.05	3613	5.203	10.8	4850	6.980
1.22	14 5/8	2.82	1266	1.823	4.16	1867	2.689	5.41	2428	3.497	8.15	3658	5.267	10.9	4892	7.045
1.23	14 3/4	2.86	1284	1.848	[illegible]	1894	2.728	5.48	2460	3.542	8.25	3703	5.332	11.0	4940	7.110
1.24	14 7/8	2.89	1297	1.867	4.27	1917	2.760	5.55	2491	3.587	8.36	3752	5.403	11.2	5027	7.240
1.25	15	2.93	1315	1.894	4.32	1939	2.793	5.62	2522	3.632	8.46	3800	5.468	11.3	5072	7.304
1.26	15 1/8	2.97	1333	1.920	4.37	1961	2.824	5.69	2554	3.678	8.56	3842	5.533	11.5	5162	7.433
1.27	15 1/4	3.01	1350	1.945	4.43	1988	2.863	5.76	2585	3.723	8.67	3892	5.603	11.6	5210	7.497
1.28	15 3/8	3.04	1364	1.965	4.48	2011	2.896	5.82	2612	3.762	8.77	3936	5.668	11.7	5251	7.562
1.29	15 1/2	3.08	1382	1.991	4.53	2033	2.928	5.89	2644	3.807	8.88	3986	5.740	11.9	5341	7.691
1.30	15 5/8	3.12	1400	2.017	4.59	2060	2.967	5.96	2675	3.852	8.99	4035	5.810	12.0	5386	7.756
1.31	15 3/4	3.16	1418	2.042	4.64	2083	3.000	6.03	2710	3.900	9.09	4080	5.875	12.2	5476	7.885

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C The basic head-discharge equation for the Parshall Flume is:

$$Q = CH_a^n$$

Where

Q = discharge, ft^3/sec

H_a = upstream head, ft.

C and n are constants, which vary with the size of flume. Values of these constants are given in Table III.

Table III

Free Flow Values of C and n for Parshall Flumes

Flume Throat, W	C	n
1 in	0.338	1.55
2 in	0.676	1.55
3 in	0.992	1.55
6 in	2.06	1.58
9 in	3.07	1.53
1 ft	4W (*)	$1.522W^{0.026}$
1.5 ft	"	"
2 ft	"	"
3 ft	"	"
4 ft	"	"
5 ft	"	"
6 ft	"	"
7 ft	"	"
8 ft	"	"
10 ft	39.38	1.6
12 ft	46.75	1.6
15 ft	57.81	1.6
20 ft	76.25	1.6
25 ft	94.69	1.6
30 ft	113.13	1.6
40 ft	150.00	1.6
50 ft	186.88	1.6

* W in feet

D To determine if the flume is operating in the free-flow condition the submergence can be calculated. Submergence (S) is defined as

$$S = \frac{H_b}{H_a} \times 100$$

Where S = % submergence

H_a = upstream head, ft.

H_b = downstream head, ft.

Free-flow discharge is not reduced until the submergence exceeds the values shown in Table IV.

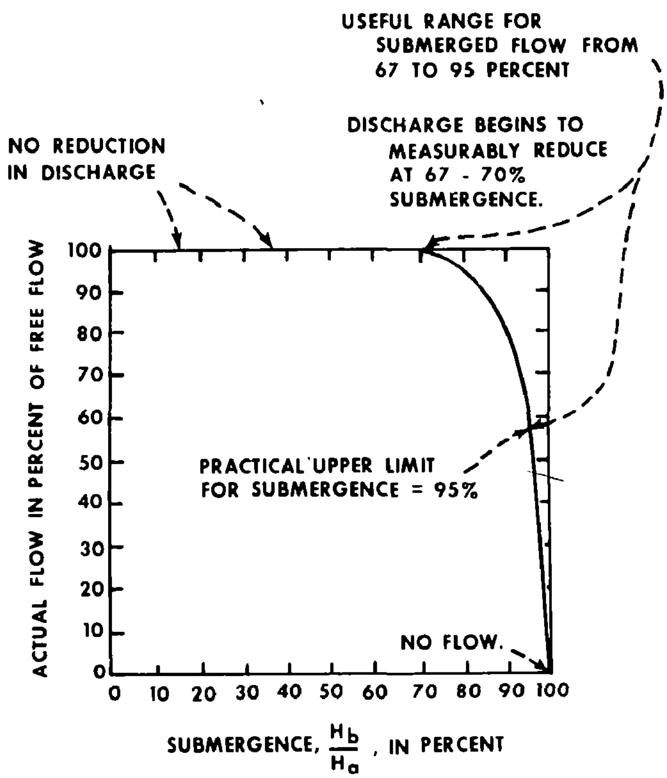
Table IV

Critical Submergence for Parshall Flumes

(Data from Ref. 4)

Flume Size	Critical Submergence	Flume Size	Critical Submergence
1 in	0.56	3 ft	0.68
2 in	0.61	4 ft	0.70
3 in	0.64	5 ft	0.72
6 in	0.55	6 ft	0.74
9 in	0.63	7 ft	0.76
1.5 ft	0.64	10 to 50 ft	0.80
2 ft	0.66		

The effect of submergence on discharge is shown in Figure 2. It can be seen that



Typical Discharge Reduction caused by Submergence in 1-to-8 foot Parshall Flumes

FIGURE 2

for 1 to 8 foot flumes the reduction in discharge does not become significant below 70% submergence, then increases rapidly above this value. The 95% submergence point on the curve is of practical interest. This is considered to be the point when the Parshall Flume ceases to be an effective measuring device because the head differential between H_a and H_b becomes so small that any slight inaccuracy in either head reading results in a large error in flow measurement.

E In many cases a determination as to whether or not the free-flow condition exists can be more simply made. Under free-flow conditions a hydraulic jump or "standing wave" will be observed downstream of the flume, or in the converging section, or even in the throat section. The formation of this jump is a certain indication of free-flow conditions.

IV Submerged-flow Measurements

A When submergence exceeds the percentages shown in Table IV, it is necessary to measure both H_a and H_b in order to determine the discharge, and also to make a correction to the free-flow discharges appearing in standard tables. These procedures are discussed below for 6-inch to 8-foot flumes.

B When 6-inch and 9-inch flumes are operating with a submergence greater than shown in Table IV, the flow can be obtained by using Figure 3 (for a 6-inch flume) or Figure 4 (for a 9-inch flume). First H_a and H_b are determined and the submergence calculated. The intersection of the horizontal line corresponding to this value of submergence with with the appropriate "upstream Head" line is found. A vertical line dropped from this point intersects the "Discharge" axis at the discharge value.

C For 1-foot flumes, Figure 5 can be used to estimate the flow when submergence exceeds the values of Table IV.

1 Measure H_a and H_b, calculate submergence.

2 Using measured value of H_a, go horizontally to right to intersect the appropriate "Percentage of Submergence" curve.

3 Drop vertically from this point to "correction" scale. Read correction.

4 From Table I, obtain free-flow corresponding to measured H_a.

5 Subtract the correction determined in step 3 from the free-flow discharge. This gives the submerged flow discharge.

D For 1 1/2-foot to 8-foot flumes follow the above procedure, except that the correction has to be multiplied by the factor "M" for the size flume being used. This multiplying factor appears in the box on the right-hand side of Figure 5.

E Flumes larger than 8 feet will rarely be encountered in wastewater flow applications. Corrections for larger flumes are discussed in Reference 1.

V Sources of Error in Flume Use

A Head-discharge relation

1 Published tables are apparently all based on the original experiments of Parshall. There might be uncertainties of up to 5% in these values. It is therefore necessary that flumes be calibrated in place if greater accuracy is desired.

B Errors in Head Measurement

1 The percentage error in head measurement is multiplied by about 1.5 to determine its contribution to the percentage error in flow rate.

C Departures from Standard Geometry

1 Width

a For slight differences in throat width from the standard dimension it has been recommended (1) that the standard flow

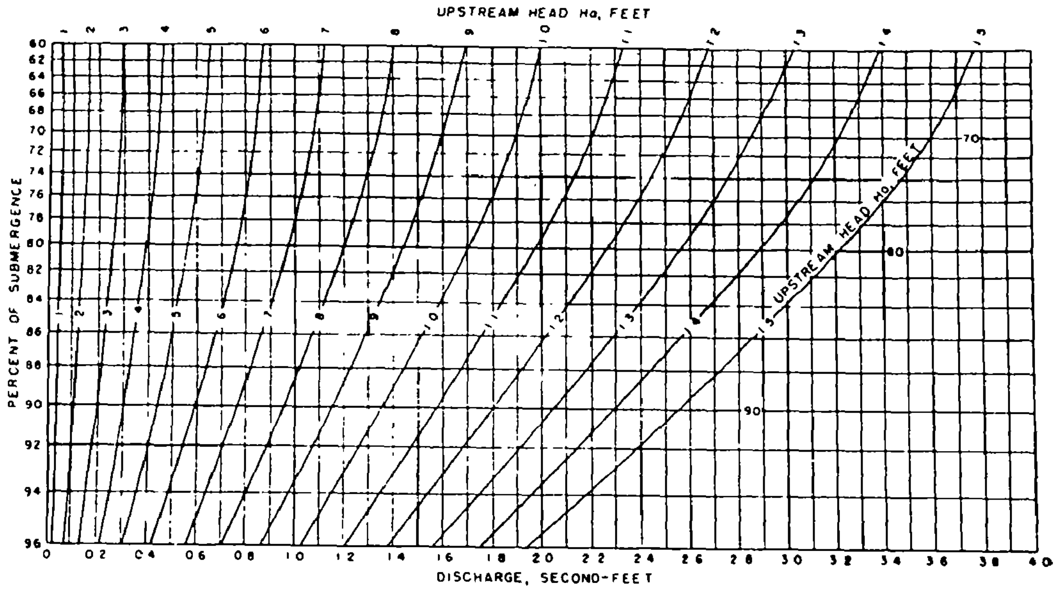


FIG. 3 —Diagram for determining rate of submerged flow for a 6-inch Parshall flume. 103-D-897. (Courtesy U.S. Soil Conservation Service.)

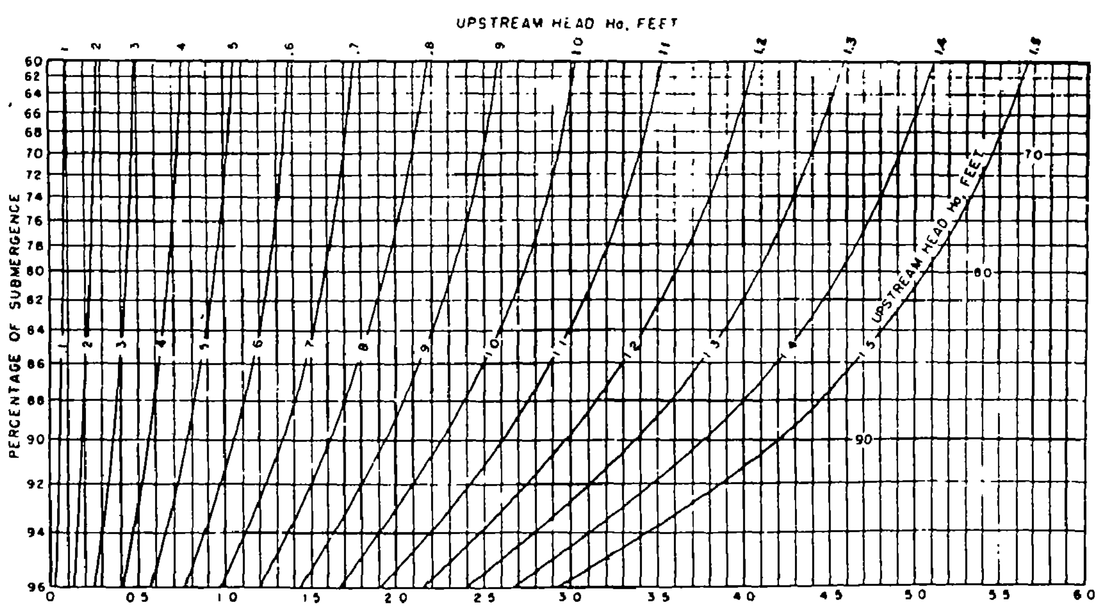
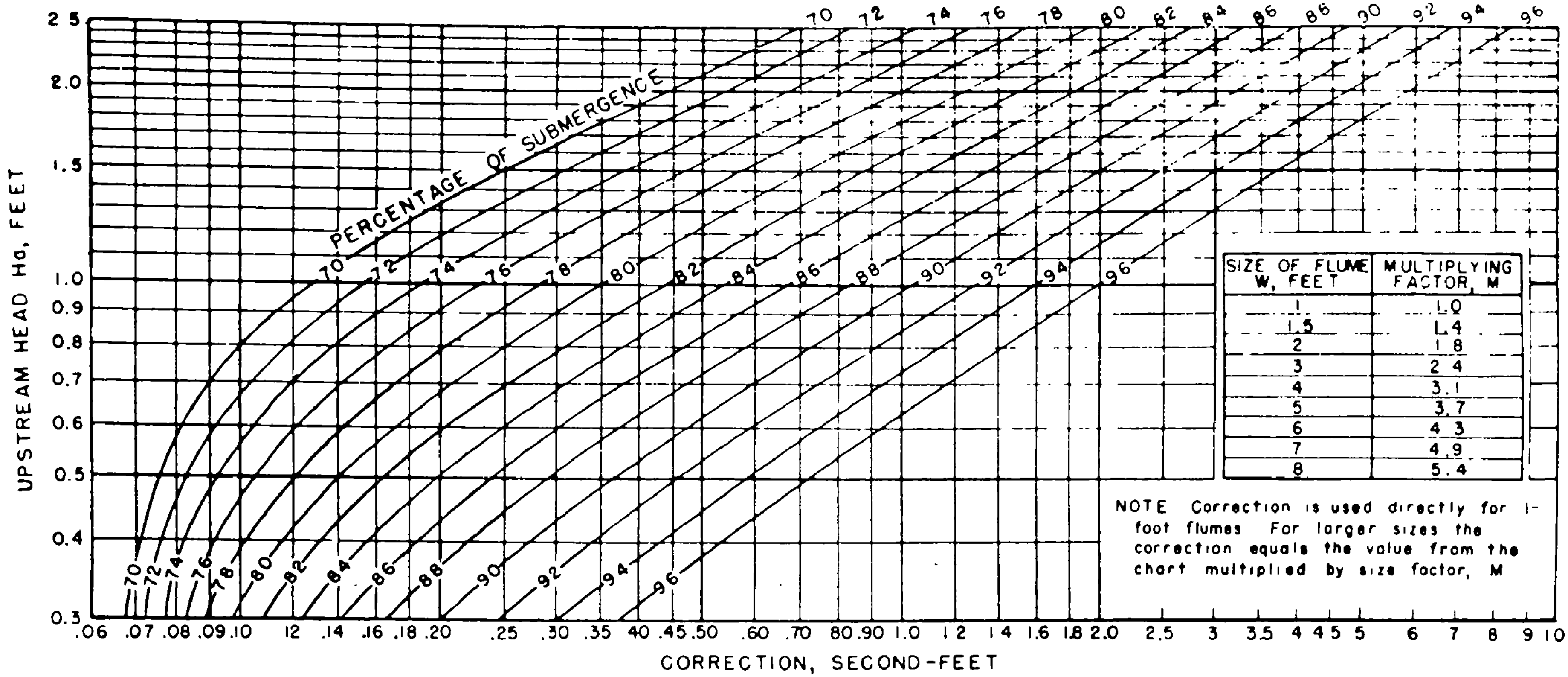


FIG. 4—Diagram for determining rate of submerged flow for a 9-inch Parshall flume 103-D-898. (Courtesy U.S. Soil Conservation Service.)



SIZE OF FLUME W, FEET	MULTIPLYING FACTOR, M
1	1.0
1.5	1.4
2	1.8
3	2.4
4	3.1
5	3.7
6	4.3
7	4.9
8	5.4

FIG. 5—Diagram for determining correction to be subtracted from free-discharge flow to obtain rate of submerged flow through Parshall flumes 1 to 8 feet wide. 103–D–875. (Courtesy U.S. Soil Conservation Service.)

rate be changed proportionately. Use of this correction should be restricted to throat change widths of a few percent only.

b For flumes which are not of standard dimensions but which have the correct sidewall convergence angle, and for flumes in which only the location of the depth measurement is incorrect, corrections can be made by the method of Davis (2), which is summarized in the Appendix of this outline.

2 Level

a There are no guidelines for adjusting the standard flow rate for flumes which are not level longitudinally.

b If flume is slightly out of level transversely use the standard H-Q curves only if an average H is used.

3 Length

a Shortening the converging section of the flume will affect the performance.

b Lengthening the converging section produces no discernible effect, but the head should be measured at the standard point in the converging section (2/3 A, Figure 1).

c There is reportedly no difference in performance between straight and curved entrance wingwalls (Figure 1) although the curved wall appears to ensure smooth flow at the head measuring point.

D Velocity Distribution

1 Situations which distort the entering flow should be avoided, eg

a Placement of flume immediately downstream of a bend without allowing sufficient straightening length.

b Discharging from a narrower conduit into a wider flume without providing enough entrance length for the flow to become evenly distributed across the section. A transition section is helpful here if available length is restricted.

2 It is best to provide a long and regular entrance channel to the flume where possible, as experimental evidence regarding the flume's ability to flatten non-uniform velocity distributions is lacking. Where conditions are such that distorted velocity distributions are expected in the approach flow, only in-place calibration can inspire confidence in use of the standard H-Q curves.

E Other Entrance Effects

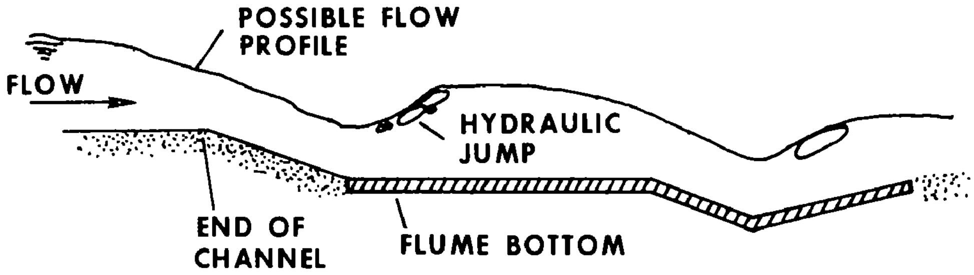
1 The flume should not be placed at a lower elevation than that of the channel being measured because of the danger of inducing a hydraulic jump within the flume (Figure 6). Large errors in measurement can result.

2 If a hydraulic jump occurs in the approach channel, a check should be made to insure that the jump is sufficiently far upstream to permit adequate smoothing of the flow at entrance. A minimum distance of 20 channel widths upstream of the flume has been suggested (3).

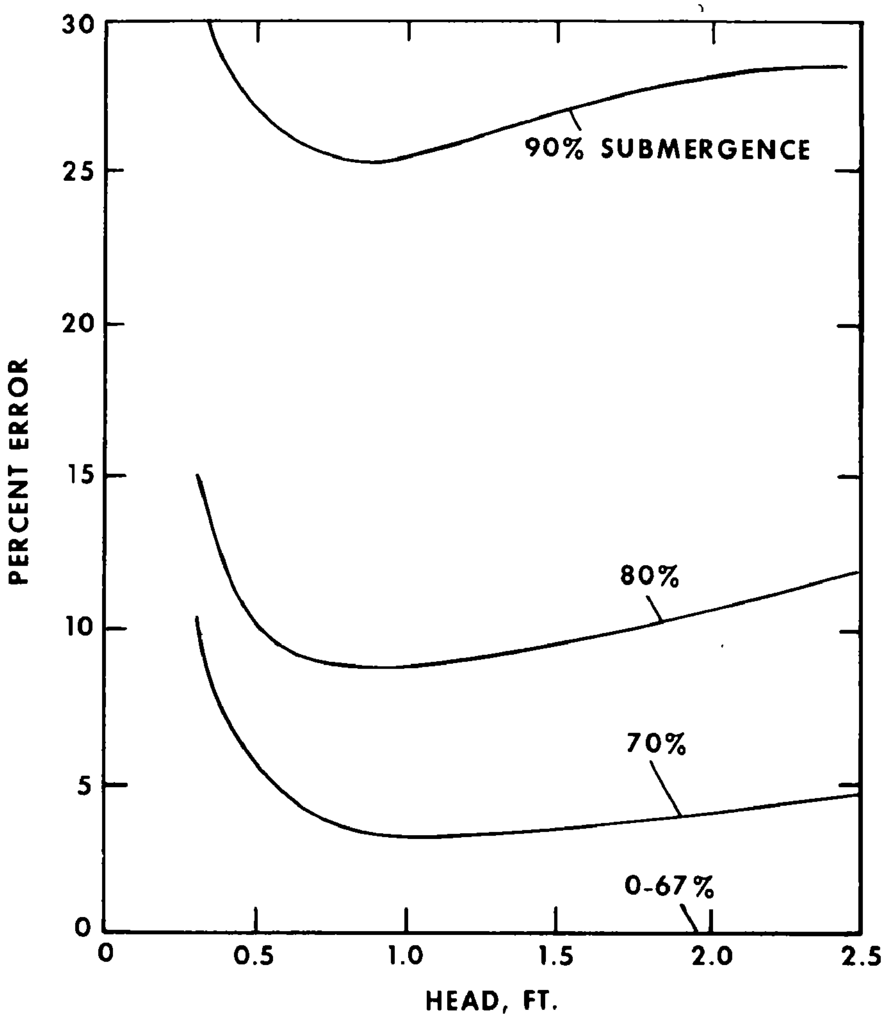
3 Weak hydraulic jumps upstream of the flume, characterized by long-lasting standing waves downstream, should in particular be avoided. These will lead to erroneous measurements.

F Submerged Flow

1 In wastewater measurement applications, flumes should operate in free-flow. Significant errors can be introduced if submergence ratios even slightly in excess of the values shown in Table IV are not taken into account. Figure 7 illustrates the magnitude of such errors for a 1-foot flume. Here, an error as large as 10% can occur at low heads for uncorrected submergence of 70% while at higher submergences the error becomes intolerable under all conditions.



Potential Hydraulic Jump Development in a Parshall Flume.
Figure 6



Errors in 1-ft. Parshall Flume Measurements if uncorrected for Submergence. Figure 7

2 Even when the submergence correction is properly made, errors in flows can be introduced if the depth measurements are in error. For example, in a 1-foot flume operating at 85% submergence (H_a = 1 foot, H_b = 0.85 foot), an error of $\pm$ 1% in the depth measurements could introduce an error as large as 5% in the discharge. This illustrates the desirability of having flume installations operate in the free-flow condition.

VI Maintenance

A Although the Parshall flume was originally designed to pass moderate sediment loads, heavy debris will settle out and affect performance. Periodic cleaning may be necessary in wastewater applications.

B Periodic calibrations of float gages, recorders and checks on flume level, are also necessary to maintain accuracy of measurement.

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This outline was prepared by C. E. Sponagle, Sanitary Engineer, National Training & Operational Technology Center, MOTD, OWPO, USEPA, Cincinnati, Ohio 45268.

Unification of Parshall Flume Data

In his paper by this title (2) Davis states ". . . dimensional methods have been used to develop a semi-theoretical equation relating flow and depth for all flumes from 1 inch to 50 feet. Excellent agreement between this equation and all published data is found. This will permit using flumes of non-standard sizes and will broaden the field of application for this type of measuring device."

He derived the following equation, which he states closely fits all data published on Parshall flumes and can be used for calculating the flow for flumes of any size. It can also be used for correcting the calibration curves of standard size flumes that do not conform with the specified dimensions of throat width or upstream measuring distance.

$$y_o + \frac{Q_o^2}{2y_o^2(1 + 0.4\,x_o)^2} = 1.351\,Q_o^{0.645}$$

where y_o = non-dimensional depth $\frac{y_1}{b}$

y_1 = depth at measuring section (see Figure A-1)

b = throat width (see Figure A-1)

Q_o = non-dimensional discharge $\frac{Q}{g^{1/2}b^{5/2}}$

g = acc^n due to gravity

Q = discharge

x_o = non-dimensional distance, $\frac{x_1}{b}$

x_1 = distance from throat crest to measuring section (see Figure A-1)

Figure A-1 shows the important dimensions referred to in the above equation.

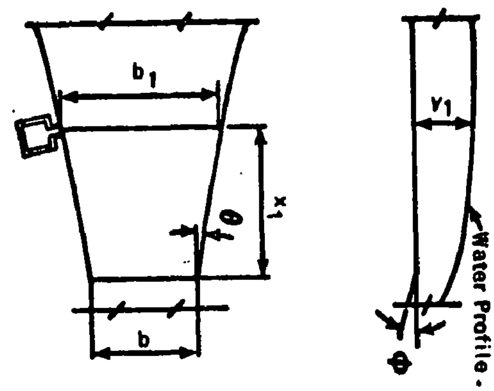


Figure A-1

The Davis equation can be used only with flumes having a side angle $\theta = \tan^{-1} 0.2 = 11°\,19'$, and a drop down angle $\phi = \tan^{-1} 0.375 = 20°\,33'$. The effects of varying these angles have not been investigated. All standard Parshall flumes, with dimensions as shown in Table I, have these angles.

The non-dimensional factors in the equation can be eliminated by substituting dimensional factors, and the equation then will be

$$\frac{y_1}{b} + \frac{Q^2}{2g\,b y_1^2\,(b + 0.4\,x_1)^2} = \frac{0.4409\,Q^{0.645}}{b^{1.613}} \quad \ldots\ldots$$

For a particular flume installation, all variables in the above equation, except Q, will be known. Substituting the known values (y_1, b, g, x_1), the equation becomes

$$A + BQ^2 = CQ^{0.645}$$

Where A, B, and C would be constants for the particular installation. This equation can then be written

$$A + BQ^2 - C\,Q^{0.645} = F$$

Several values of Q can be assumed, and the corresponding values of F obtained. The values of Q vs F can be plotted, and the plotted line extended to intersect the F - Axis (F=O). The corresponding value of Q would be the flow.

I Measurement of Head

A When primary flow measurement devices such as weirs and flumes are used to measure open channel flow, discharge (Q) is related to a head (H), or depth of flowing liquid, measured at a specific point upstream of the crest.

B Since there is a definite H-Q relationship in these cases, varying with the primary device used, changes in Q can be obtained by observing changes in H.

C Several methods of measuring and recording changes in H are considered in this outline.

II Staff gage; Float gage

A Frequently a staff gage (Figure 1) is used to measure H. This is a graduated scale, usually installed vertically at the point where the depth of the liquid is to be measured.

FIG. 1 - STAFF GAGE SECTION

B Commercially-available gages are made of 18-gage metal coated with a substantial thickness of porcelain enamel. Face of the gage is white, numerals and graduations are black. Gages are available in several styles, in widths from 2 1/2 to 4 inches, in lengths from 1 to 5 feet. A metric gage is also available in 1 meter sections, graduated in centimeters and decimeters.

C The gage is usually installed so that the bottom of the gage is at the same level as the crest of the primary measuring device. The head can then be read directly, being the gage division at which the liquid surface intersects the gage. From time-to-time the installation should be checked to be sure that the gage bottom is at crest level.

D When surges with flow or oscillations in the water surface are such as to make the accuracy of a head reading questionable from a gage installed in the flowing liquid, use of a stilling well will substantially reduce or eliminate this difficulty.

1 A stilling well (sometimes called a float well) is a chamber that has a small inlet connecting it to the channel in which the liquid to be measured is flowing. Sudden waves or surges in the flow will not appear in the well. The quiet water in the well will nevertheless follow all the steady fluctuations of the flow. Such conditions are very necessary to obtain good records of water levels, particularly for float-operated devices.

2 Stilling wells can be made of wood or reinforced concrete, rectangular or square; of round metal pipe, cement or vitrified sewer pipe. The well must have a bottom and be practically water tight except for the liquid inlet.

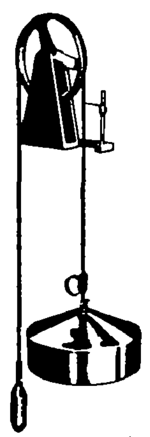
3 Size of the well depends on the equipment to be installed, although in installations where considerable suspended materials are carried in the flow it is advisable to make the well large enough for cleaning.

4 In order to effectively eliminate wave action and surges, the area of the liquid inlet should be about 1/1000 the area of the well. Where a pipe connects the well with the liquid, it can be somewhat larger than where connection is by a mere hole in the wall. If the inlet is placed at considerable depth, it can be considerably larger than if near the surface. Some suggested relationships are shown below. (1)

Diameter of Float Well	Diameter of Inlet Hole	Diameter of Inlet Pipe 20-30 Ft. Long
16 inches	1/2 inch	3/4 inch
24 inches	3/4 inch	1 inch
36 inches	1 1/4 inch	2 inches
3' x 3'	1 1/4 inch	2 inches
3' x 4'	1 1/2 inch	3 inches

5 In wastewater applications, provisions must be made for frequent cleaning of stilling wells or levels in them will not be representative. Another problem is that the inlet to the well can be quickly clogged with sediment or grease. Routine maintenance is necessary to prevent erroneous flow records from being obtained as a result of these conditions.

E Another simple device used to indicate water levels is the float gage (Figure 2).



(Fig. 2)

This can usefully be employed in stilling wells, when it would be difficult or impossible to accurately read a staff gage.

1 A float gage consists of:

a A graduated stainless steel tape attached to a copper float.

b A guide pulley mounted on a standard having an adjustable index, and

c A couterpoise attached to the other end of the tape.

The tape is graduated to read in feet, tenths and hundredths, or meters, decimeters and centimeters.

2 As for the staff gage, tape readings on the float gage must be referenced to the crest of the weir or flume.

III Instantaneous vs. Continuous Discharge Measurements

A A staff gage or float gage installation can be used, in conjunction with a primary flow measuring device, to read instantaneous flows, or, by means of frequent readings, to estimate average flows over a desired period of time.

B In many cases, however, a continuous record of flow is desired. More sophisticated sensing and recording instrumentation is then required, although a staff or float gage should ideally be a part of any such installation, so that operation of the automatic equipment can readily be checked.

IV Secondary Devices

A A number of automatic flow sensing and recording devices are commercially available. These may be called flowmeters by their manufacturers, but in actuality they are secondary devices for measuring liquid depth. They must be used with some sort of primary device, such as a weir or flume, before true flow measurement can be made. A brief discussion of these devices is given below along generic lines.

1 As is the case with all secondary devices, there are three basic types of information that can be provided, either separately or in combination. These are an indication of flow rate (typical units are cfs, gph, mgd, etc.; such devices are sometimes referred to as indicators); a running total of flow to the observed moment (typical units are cu. ft., gal., m.g., etc.; such devices are sometimes called totalizers); and a record, ranging from a curve drawn in ink with a pen to a magnetic tape recording, of the rate of flow with time over some suitable period (hour, day, week, etc.; such devices are termed recorders). Additional features may include the ability to transmit the flow data to a remote site (transmitters, the corresponding instruments at the other end being termed receivers), the ability to operate in digital versus analog form, etc.

B Float-in-Well. This is probably the oldest type of secondary device in existence. It is applied in a stilling well connected to the gage point of the primary device (weir, flume, etc.). The float-in-well essentially consists of a float of some suitable shape (sized for compatibility with the dimensions of the well) connected via a cable to a wheel and counterbalanced in some fashion so that the cable remains taut. As the float rises or falls with changes in water level, the cable rotates the wheel, which is connected either mechanically or electronically to the readout, recorde or whatever. Discharge is determined by the use of cams, electronic circuits, etc., that are characterized for the primary device involved.

C Float-in-Flow. In this type of secondary device, the float rides on the actual surface of the flow, directly sensing its level rather than indirectly sensing it as with a stilling well. Float shapes range from spherical, to scow or ski shaped, the latter being designed to minimize disturbances of the liquid surface, fouling by trash or debris, oscillations in the instrument, etc. The float is attached to a hinged arm that is directly or indirectly (e.g., by cable) connected to the main body of the instrument. Directly-connected designs should be immersion proof if they are to be used in storm or combined sewers with any history of surcharging. In indirectly-connected designs, where the main body of the instrument can be located above the high water level, it need not necessarily be immersion proof, but this feature never hurts.

Advantages of float-in-flow devices include: freedom from the requirement for a stilling well and purge system; direct (rather than indirect) sensing of the liquid level; and avoidance (in some designs) of cables, counterweights, etc., typical of float-in-well devices. Disadvantages include: possible fouling by trash or debris (which can result in erroneous readings or even physical damage); broad chart records in some instances due to the lack of damping of water surface oscillations that some stilling wells provide; and a more limited range due to the restrictions on arm length necessary at some installations.

D Bubbler. In this type secondary device, a pressure transducer senses the back-pressure experienced by a gas which is bubbled at a constant flow rate through a tube anchored at an appropriate point with respect to the primary device. This back-pressure can be translated into water depth and subsequently related to discharge. Advantages include a lack of moving parts or mechanisms, a sort of self-cleaning action arising from the gas flow, and virtually no obstruction to the flow. One of its main disadvantages is that if the exit end base of the bubble tube becomes appreciably reduced due to build-up of contaminants from the flow, erroneous readings will result even though the instrument may appear to be functioning normally. Aspiration effects due to the velocity of the flow may also present problems.

E Electrical. These secondary devices make use of some sort of change in electric circuit characteristics in order to indicate the liquid level. Most designs utilize a probe or some similar sensor which is immersed in the flow at the gage point. This sensor is a part of an electrical circuit, and its behavior in the circuit is a function of its degree of immersion. For example, the sensor could basically be an admittance-to-current transducer, providing a measure of depth based on the small current flowing from the sensor to the grounded stream. Changes in any electrical property (capacitance, resistance, etc.) can be used to sense liquid depth. Advantages are the absence of any moving parts, floats, cables, stilling wells, gas supplies, purge requirements and the fact that they cannot plug and are usually unaffected by build-up of sludge, algae, slime, mud, etc. The major disadvantage is the requirement for the sensing element to physically be in the flow. The presence of appreciable foam or floating oil and grease can cause errors in most designs.

In a somewhat different design belonging to this class, the probe is not actually in the stream but is periodically lowered, via a motor-pulley-cable arrangement, until it makes contact with the water surface, which completes a microampere circuit through the liquid to a ground return.

This signal reverses the motor, raising the probe above the surface of the liquid. As in the case with a float, the amount of cable paid out is the measure of stage. Although this design does not require immersion of the sensor in the flow, it does involve mechanical complexities and moving parts not characteristic of the other electrical secondary devices.

F Acoustic. This type of secondary device is growing in popularity as prices decrease. Requiring no physical contact with the liquid, they enjoy all of the advantages listed for electronic designs. They were covered in the discussion of acoustic primary devices and will not be redescribed here. However, a few precautionary words will be given. For applications where space is restricted as in some manholes and small meter vaults, problems due to false echos may be encountered. This problem may be overcome at some sites by shielding the transducer, but accurate readings (at low flows at least) should not be expected for flows in round pipes or deep, narrow channels from most designs. Also, good results should not be expected if the surface of the flow is highly turbulent or foam covered as the reduced return signal may not be properly detected.

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This outline was prepared by C. E. Sponagle, Sanitary Engineer, National Training & Operational Technology Center, MOTD, OWPO, USEPA, Cincinnati, Ohio 45268

EVALUATION OF FLOW INSTALLATIONS

I EVALUATION OF EXISTING FLOW MEASUREMENT INSTALLATIONS INVOLVES THE EVALUATION OF

A The primary measuring device

1 Is it installed in conformance with the requirements for the particular device?

2 Is it accurately measuring the flow?

B The secondary devices (if any) for sensing and recording the flow

1 Are these functioning properly and recording the correct values of flow?

II PRIMARY MEASURING DEVICE

A A check list should be prepared listing all pertinent features of the installation which require examination and documentation

1 Example check lists for weirs and the Parshall flume are included in this outline.

B Channel conditions upstream and downstream of the device should be observed for obstructions, turbulence, etc. Any condition which might influence performance should be noted.

1 Such conditions should be eliminated to the extent possible, prior to calibration of the device.

C Measure flow by an independent means, and compare results with these obtained from existing installation.

1 The most appropriate independent method of measuring flow will depend on the characteristics of the installation. Three methods commonly used are·

a Current meter traverse

b Dilution methods

c Thin-plate weir

III SECONDARY DEVICES

A Compare value of recorded flow obtained by independent means.

1 Comparison may be made based on one or several instantaneous measurements.

2 A separate recording device can be set up, and comparable results compared over a longer period of time.

This outline was prepared by C. E. Sponagle, Sanitary Engineer, National Training & Operational Technology Center, MOTD, OWPO, USEPA, Cincinnati, Ohio 45268.

CHECKLIST FOR EXISTING FLOW MEASUREMENT DEVICES

Name of Industry or Municipality ____________________

Name of Contact ____________________

Date: ____________________

Permit Discharge Number: ____________________

Type of Wastes: ____________________

Type of Discharge: Batch ________, ________ Hrs/Batch, ________ Number/Day

Continuous ________, ________ Hrs/Day

Type of Measurement Device: ____________________

Dimensions (e.g., Length of Weir) ____________________

____

____

Capacity of Device ____________________ (max-min mgd)

Range of Flows ____________________

Is Device Properly Installed ________ Yes ________ No

If no, specify reasons installation is not correct: ____________________

____

____

When was device last calibrated by permittee: ____________________

Type of Stage Recording Device (Manufacturer, model, etc.) ____________________

Relation Between Recording Device and Measuring Device ____________________

____

Is Recorder Device Properly Installed: ________ Yes ________ No

If no, specify reasons installation is not correct: ____________________

____

____

Is Recording Device Functioning Properly: ________ Yes ________ No

If no, specify reasons for malfunctions: ____________________

____

Remarks ____________________

____

____

Date ____________________ By ____________________ (Signature)

CHECK LIST

Suppressed Rectangular Weir

	YES	NO	REMARKS
1. Bulkhead (or weir Plate)			
a. Upstream face smooth			
b. Upstream face vertical			
c. Upstream face perpendicular to axis of channel			
d. Is weir plate smooth, straight, flush with upstream face of bulkhead			
e. Any leakage around bulkhead			
2. Weir Crest			
a. Level			
b. Upstream edge forms a sharp right angle at intersection with upstream face			
c. Thickness 0.03-0.08 inches (1-2 mm.)			
d. Downstream edge properly chamfered			
e. Crest minimum of 1 foot or 2 $H_{max.}$ above bottom of channel			
f. Any nicks, dents, rust, or deformation of weir shape			
3. Nappe			
a. Touches only upstream edge of crest			
b. Free discharge into atmosphere			
c. Proper ventilation provided			
d. Sides of channel extend downstream of weir			
4. Head			
a. Measured at proper location			
b. Measuring device zeroed to crest level			
c. Head remains between 0.2 ft and 1/3 L ft.			
5. Approach Conditions			
a. Excessive solids deposits in weir pool			
b. Weir pool dimensions satisfactory*			
c. Velocity-of-approach correction indicated			

*Area of flow at least 8 times that of overflow sheet at crest for a distance upstream from 15-20 times depth of overflow sheet.

<u>Other remarks or pertinent observations</u>: (Use back of sheet)

CHECK LIST
Rectangular Weir with End Contractions

	YES	NO	REMARKS
1. Bulkhead (or weir plate)			
a. Upstream face smooth			
b. Upstream face vertical			
c. Upstream face perpendicular to axis of channel			
d. Is weir plate smooth, straight, flush with upstream face of bulkhead			
e. Any leakage around bulkhead			
2. Weir Notch			
a. Crest level			
b. Sides vertical			
c. Upstream edge forms a sharp right angle at intersection with upstream face			
d. Thickness 0.03-0.08 inches (1-2 mm.)			
e. Downstream edge properly chamfered			
f. Crest minimum of 1 foot or 2 $H_{max.}$ above bottom of channel			
g. Sides minimum of 1 foot or 2 $H_{max.}$ from sides of channel			
3. Nappe			
a. Touches only upstream edge of crest and sides of notch			
b. Free discharge into atmosphere			
4. Head			
a. Measured at proper location			
b. Measuring device zeroed to crest level			
c. Head remains between 0.2 ft and L/3 ft			
5. Approach Conditions			
a. Excessive solids deposits in weir pool			
b. Weir pool dimensions satisfactory*			
c. Velocity-of-approach correction indicated			

*Area of flow at least 8 times that of overflow sheet at crest for a distance upstream from 15-20 times depth of overflow sheet.

Other remarks or pertinent observations: (Use back of sheet)

CHECK LIST

V-Notch Weir

	YES	NO	REMARKS
1. Bulkhead (or weir plate)			
a. Upstream face smooth			
b. Upstream face vertical			
c. Upstream face perpendicular to axis of channel			
d. Is weir plate smooth, straight, flush with upstream face of bulhead			
e. Any leakage around bulkhead			
2. Weir Notch			
a. Is top of weir level			
b. Notch angle cut accurately			
c. Vertical through bottom of notch bisects notch angle			
d. Upstream edge forms a sharp right angle at intersection with upstream face			
e. Thickness 0.03-0.08 inches (1-2 ml)			
f. Downstream edge properly chamfered			
g. Bottom of notch minimum of 1 foot or 2 $H_{max.}$ above bottom of channel			
h. At $H_{max.}$, intersection of liquid surface with notch a minimum of 1 foot or 2 $H_{max.}$ from sides of channel			
i. Any nicks, dents, rust, or deformation of weir shape			
3. Nappe			
a. Touches only upstream edge of notch			
b. Free discharge into atmosphere			
4. Head			
a. Measured at proper location			
b. Measuring device zeroed to bottom of notch			
c. Minimum head no less than 0.2 ft			
5. Approach Conditions			
a. Excessive solids deposits in weir pool			
b. Weir pool dimensions satisfactory*			
c. Velocity-of-approach correction indicated			

*Area of flow at least 8 times that of overflow sheet at crest for a distance upstream from 15-20 times depth of overflow sheet.

Other remarks or pertinent observations: (Use back of sheet)

CHECK LIST
Parshall Flumes

	YES	NO	REMARKS
1. Is channel upstream of flume free of debris or deposit.			
2. Does flow entering flume appear reasonably well distributed across the channel and free of turbulence, boils, or other distortions			
3. Are cross-sectional velocities at entrance relatively uniform			
4. Is flume clean and free of debris or deposits			
5. Is crest level in all directions			
6. Are all dimensions accurate			
7. Are side walls vertical and smooth			
8. Are sides of throat vertical and parallel			
9. Is head being measured at proper location			
10. Is head measurement zeroed to flume crest			
11. Is flume of proper size to measure range of flows existing			
12. Is flume operating under free-flow conditions over existing range of flows			
13. Is channel downstream of flume free of debris or deposits			

PARSHALL FLUME DIMENSIONS AND CAPACITIES

Widths			Axial Lengtns			Wall Depth in Con-verging Section	Vertical Distance Below Crest		Con-verging Wall Length	Gage Points			Free Flow Capacities	
Size; Throat Width W	Up-stream End D	Down-stream End C	Con-verging Section B	Throat Section F	Diverging Section G	E	Dip at Throat N	Lower End of Flume K	A*	Ha, Dist Upstream of Crest**	Hb x	Hb y	Min	Max
Inches	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	cfs	cfs

APPENDIX A

SECTION VI

WASTEWATER FLOW MEASUREMENT

A. Introduction

The measurement of flow in conjunction with wastewater sampling is essential to almost all water pollution control activities. All activities such as NPDES permit compliance monitoring, municipal operation and maintenance, planning and research rely on accurate flow measurement data. The importance of obtaining accurate flow data cannot be overemphasized, particularly with respect to NPDES compliance monitoring inspections, since these data should be usable for enforcement purposes. NPDES permits limit the quantity (mass loading) of a particular pollutant that may be discharged. The error involved in determining these mass loadings is the sum of errors from flow measurement, sample collection, and laboratory analyses. It should be obvious that measurement of wastewater flow should be given as much attention and care in the design of a sampling program as the collection of samples and their subsequent laboratory analyses.

The basic objectives of this chapter are:

(1) To discuss basic wastewater flow measurement systems;

(2) To outline what is expected of field personnel with respect to wastewater flow measurement during NPDES compliance monitoring activities; and

(3) To present acceptable wastewater flow measurement techniques commonly used.

A complete discussion of all available flow measurement techniques and the theory behind them is beyond the scope of this manual. Most of the common techniques in current use are covered, however, in rather general terms. A comprehensive list of references is included at the end of this chapter for those who desire a more detailed discussion.

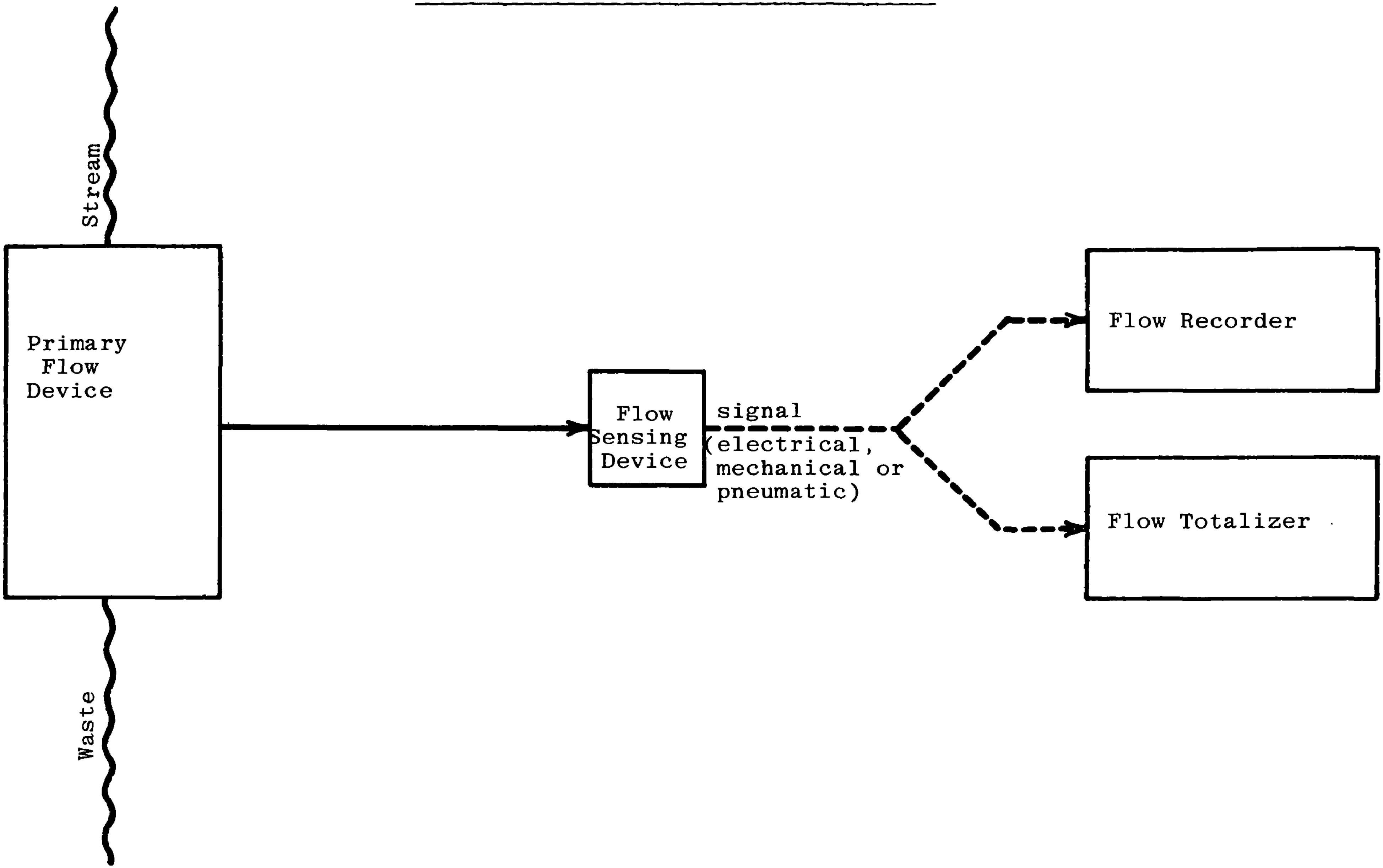
B. <u>Wasterwater Flow Measurements Systems</u>

Flow data may be collected on an instantaneous or a continuous basis. A flow measurement system is required for the collection of continuous data. A typical continuous system consists of a primary flow device, a flow sensor, transmitting equipment, a recorder, and possibly, a totalizer. Instantaneous flow data can be obtained without using such a system.

The heart of a typical continuous flow measurement system, as shown in Figure VI-1, is the primary flow device. This device is constructed such that it has predictable hydraulic responses which are related to the flowrate of water or wastewater through it. Examples of such devices include weirs and flumes which relate water depth (head) to flow, Venturi and orifice type meters which relate differential pressure to flow, and magnetic flow meters which relate induced electric voltage to flow. A standard primary flow device has undergone detailed testing and experimentation and its accuracy has been verified.

FIGURE VI-1

COMPONENTS OF FLOW MEASURING SYSTEMS



A flow sensor is required to measure the particular hydraulic responses of the primary flow device and transmit them to the recording system. Typically, sensors include floats, pressure transducers, capacitance probes, differential pressure cells, electromagnetic cells, etc.

The sensor signal is generally conditioned by using mechanical, electromechanical, or electronic systems. These systems convert the signal into units of flow which are recorded on a chart or put into a data system. Those systems which utilize a recorder are generally equipped with a flow totalizer which displays the total flow on a real time basis.

NPDES permits that necessitate continuous flow measurement require a complete system. Permits that require instantaneous flow measurement do not necessarily dictate the use of any portion of such a system. Techniques are available (described later in this chapter) for measuring instantaneous flow with portable equipment.

An important consideration during sampling inspections for NPDES compliance purposes is that the investigator may want to obtain continuous flow data at a facility where only instantaneous flow data is required by permit monitoring conditions. If an open channel primary flow device is utilized for making instantaneous measurements, only the installation of a portable field sensor and recorder is necessary. If, on the other hand, the facility being investigated does not utilize a primary flow device, and a continuous flow record is desired, the investigator's job becomes more difficult. A portable primary flow device will have to be installed. Generally, the investigator is limited to the installation of open channel equipment, since the installation of closed-conduit flowmeters is more complex and time-consuming. This chapter does not cover in detail the installation of primary flow devices, but many of the references cited treat this area quite adequately. The _USDI Water Measurement Manual_ (1) is an excellent reference for details on checking the installation of primary flow devices.

The accuracy of wastewater measurement systems varies widely, depending principally upon the primary flow device used. The total error inherent in a flow measuring system is, of course, the sum of each component part of the system. However, any system that can not measure the wastewater flow within ± 10% is considered unacceptable for NPDES compliance purposes.

C. Field Verification Of Flow Measurement Systems

The responsibility of the investigator during NPDES compliance sampling inspections includes the collection of accurate flow data during the inspection, as well as the validation of such data collected by the permittee for self-monitoring purposes.

The investigator must insure that the flow measurement system or technique being used measures the entire wastewater discharge as described by the NPDES permit. A careful inspection should be made to determine if recycled wastewaters or wastewater diversions are present upstream of the system. The investigator should note any anomalies on the inspection report form or in a bound field notebook.

The investigator's second task is to verify that the system being used is accurate. In cases where the discharger is making instantaneous flow measurements to satisfy permit requirements, the specific method used should be evaluated. If a primary flow device is used, the device should be checked for conformity with recognized construction and installation standards. Any deviation from standard conditions should be well documented. Where there are significant deviations, accuracy of the primary flow device should be checked by making an independent flow measurement.

All components of continuous flow measuring systems should be verified. The primary flow device should be checked for conformity with recognized construction and installation standards (where possible). The flow sensing and recording devices are usually checked simultaneously. The procedure most often used is to make an independent flow measurement utilizing the primary flow device, obtaining the flow rate from an appropriate hydraulic handbook and comparing this flow rate with the recorded value. Since most primary flow devices do not have linear responses, several checks should be made over as wide a flow range as is possible. The accuracy of the recorder timing mechanism may be checked by marking the position of the recorder indicator and checking this position after an known elapsed time interval. Flow totalizers are easily checked by integrating the area under the curve. If the investigator has the proper equipment and knowledge, electronic recorders and totalizers may be checked by inducing known electric current to simulate flow. The accuracy of closed conduit flow measurement systems can be verified by making independent flow measurements at several different flowrates or by electrically, mechanically or hydraulically inducing known flowrates. Specific techniques for making independent flow measurements are given later in this section.

If the discharger's flow measurement system is accurate within ± 10 percent, the investigator is encouraged to use the installed system. If the flow sensor or recorder is found to be inaccurate, determine if it can be corrected in time for use during the inspection. If the equipment cannot be repaired in a timely manner, the investigator should install a portable flow sensor and recorder for the duration of the investigation. The installation and use of such equipment is preferred over attempts to correct erroneous flow measurement systems. The inspector should note the action taken in the inspection report and inform the permittee that the equipment should be repaired as soon as possible. If non-standard primary flow devices are being used, it is the responsibility of the discharger to supply data supporting the accuracy and precision of the method being employed.

The inspector should evaluate and review calibration and maintenance programs for the discharger's flow measurement system. The permit normally requires that the calibration of such systems be checked by the permittee on a regular basis. The lack of such a program should be noted in the inspection report.

The compliance inspection report should contain an evaluation of the discharge flow measurement system. Inadequacies may be discussed with the permittee during the inspection and deficiencies noted in the report so that follow-up activity can be conducted. Any recommendations to the permittee should be made in such a manner that any subsequent enforcement will not be jepordized.

D. Wasterwater Flow Measurement Methods

This section outlines and familiarizes the field investigator with the most commonly used methods of wastewater flow measurement and the primary devices that will be encountered during NPDES compliance sampling inspections. Volumetric and dilution techniques are presented at the beginning of this chapter, since they are applicable to both open-channel and closed-conduit flow situations. The remaining methods are grouped under categories dealing with open channels and closed-conduits. The general method of checking individual primary flow devices is given, where applicable. Several estimation techniques are presented. However, it should be recognized that flow estimates do not satisfy NPDES permit monitoring requirements unless the permit specifically states that this is permissible.

1. Volumetric Techniques

Volumetric flow techniques are among the simplest and most accurate methods for measuring flow. These techniques basically involve the measurement of volume and/or the measurement of time required to fill a container of known size.

(a) Vessel Volumes

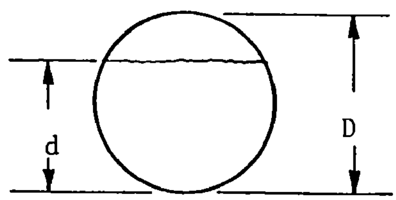
The measurement of vessel volumes to obtain flow data is particularly applicable to batch wastewater discharges. An accurate measurement of the vessel volume(s) and the frequency that they are dumped is all that is required. An accurate engineering tape measure to verify vessel dimensions and a stop watch are the only required field equipment. The equations for calculating the volumes of various containers is given in Figure VI-2.

(b) Pump Sumps

Pump sumps may be used to make volumetric wastewater flow measurements. This measurement is made by observing the sump levels at which the pump(s) cut on and off and calculating the volume contained between these levels. This volume, along with the number of pump cycles, will give a good estimate of the daily wastewater flow. One source of error in this measurement is the quantity of wastewater that flows into the sump during the pumping cycle. This error may be particularly significant if the

FIGURE VI-2
EQUATIONS FOR CONTAINER VOLUMES

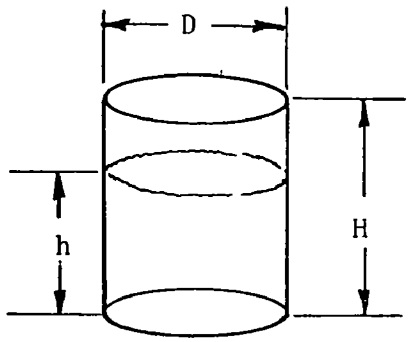
SPHERE



Total Volume
$V = 1/6\ \pi D^3 = 0.523598D^3$

Partial Volume
$V = 1/3\ \pi d^2\ (3/2\ D-d)$

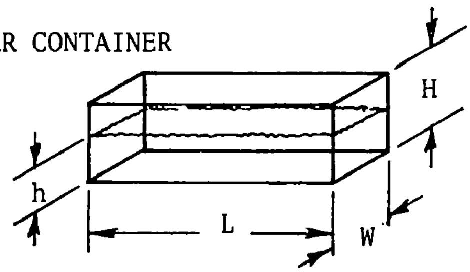
RIGHT CYLINDER



Total Volume
$V = 1/4\ \pi D^2 H$

Partial Volume
$V = 1/4\ \pi D^2 h$

ANY RECTANGULAR CONTAINER

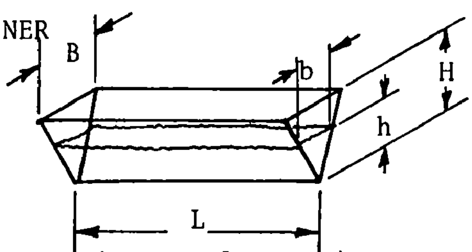


Total Volume
$V = HLW$

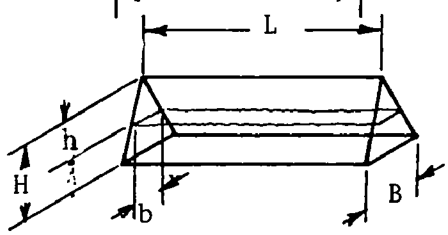
Partial Volume
$V = hLW$

TRIANGULAR CONTAINER

Case 1



Case 2

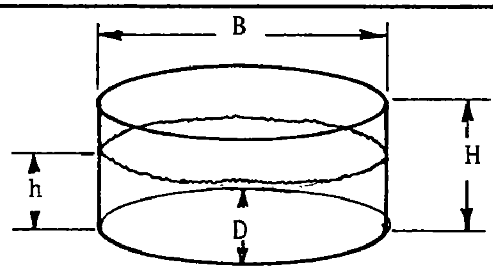


Partial Volume (case 1)
$V = 1/2\ hbL$

Total Volume
$V = 1/2\ HBL$

Partial Volume (case 2)
$V = 1/2\ L\ (HB - hb)$

ELLIPTICAL CONTAINER

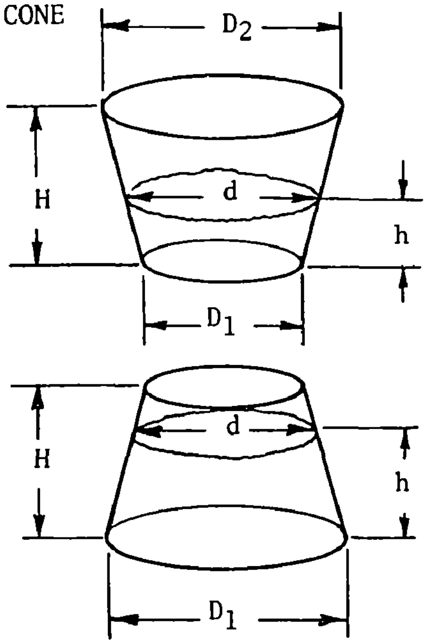


Total Volume
$V = \pi BDH$

Partial Volume
$V = \pi BDh$

FIGURE VI-2 (CONTINUED).

FRUSTUM OF A CONE



Case 1

Case 2

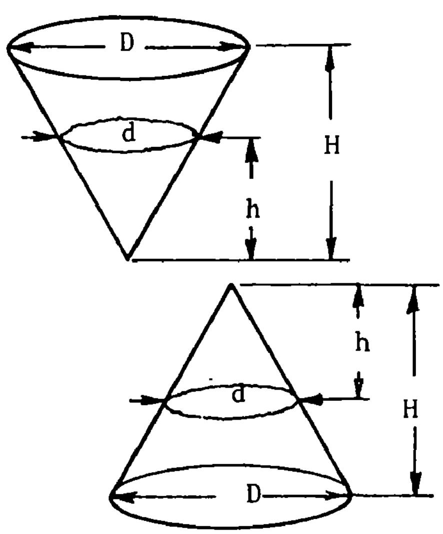
Total Volume

$V = \pi/12\ H\ (D_1^2 + D_1 D_2 + D_2^2)$

Partial Volume

$V = \pi/12\ h\ (D_1^2 + D_1 d + d^2)$

CONE



Case 1

Case 2

Partial Volume (case 1)

$V = 1/12\ \pi\ d^2 h$

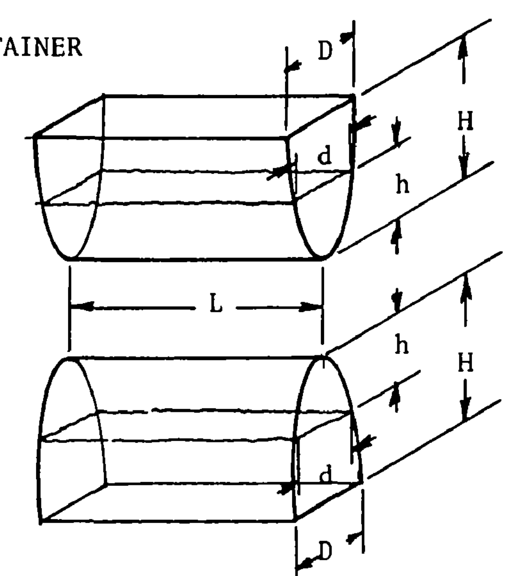
Total Volume

$V = 1/12\ \pi\ D^2 H$

Partial Volume (case 2)

$V = 1/12\ \pi (D^2 H - d^2 h)$

PARABOLIC CONTAINER



Case 1

Case 2

Partial Volume

$V = 2/3\ hdL$

Total Volume

$V = 2/3\ HDL$

Partial Volume

$V = 2/3\ (HD - hd)\ L$

sump is large, the rate of inflow is high, and/or the pumping cycle is long. This error may be accounted for if the inflow is fairly constant, by measuring the time required to fill the sump and adding this additional flow for each pump cycle. The number of times that the pump cycles during a measurement period may be obtained by using a counter on the pump or using a stage recorder to indicate the number of pump cycles.

(c) Bucket and Stopwatch

The bucket and stopwatch technique is particularly suited to the measurement of small wastewater flows. It is accurate and easy to perform. The only equipment required to make this measurement are a calibrated container (bucket, drum, tank, etc.) and a stop watch. The container should be calibrated carefully, using primary standards, or other containers which have been calibrated using such equipment. Ordinarily, this measurement is made at the end of a pipe; however, using some ingenuity, a bucket and stopwatch flow measurement may be made in ditches and other open channel locations. Short sections of pipe may be used to channel or split flows into measurable portions. A shovel is often needed to dig a hole under a pipe or in an open channel to get the container under the wastewater stream that is to be measured. As with all flow measurement techniques, it is important to insure that all of the wastewater stream is measured. This method is limited by the amount of flow that can practically be measured in a reasonably sized container. A five gallon bucket filled to capacity, for example, would weigh 42 pounds. Also, the filling time of the container should be sufficiently long so that the calibrated container can be moved in and out of the wastestream without spilling the contents or overflowing the bucket. A minimum filling time of 10 seconds is recommended. If the container is hand-held, the practical limit of container size is what can be comfortably handled, about five gallons. Therefore, with a 5-gallon container, the maximum flow that could practically be measured would be 30 gpm. At least three consecutive measurements should be made, and the results averaged.

(d) Orifice Bucket

The orifice bucket permits the investigator to measure higher wastewater flows than is possible by using a bucket and stopwatch. An orifice bucket is a metal container (bucket) that has been modified by cutting holes (orifices) in the bottom. The bucket is calibrated by plugging the orifices with rubber stoppers and using bucket and stopwatch measurements to calibrate the bucket. The calibration curve relates the depth of the water in the bucket, for various combinations of orifices, to the flowrate. This method is usable over a flow range of 7 to 100 gpm. Construction of the orifice bucket and directions for its use is given by Smoot (3).

2. Dilution Methods

Dilution methods for water and wastewater flow are based on the color, conductivity, fluorescence, or other quantifiable property of an injected tracer. The dilution methods require specialized equipment, extreme attention to detail by the investigator, and are time consuming. However, these techniques offer the investigator:

- A method for making instantaneous flow measurements where other methods are inappropriate or impossible to use;
- A reference procedure of high accuracy to check in situ those primary flow devices and flow measurement systems that are nonstandard or are improperly installed; and
- A procedure to verify the accuracy of closed conduit flow measuring systems.

The tracer may be introduced as a slug (instantaneously) or on a continuous flow basis. The constant rate dilution method is performed by injecting a tracer at a constant rate into a wastewater stream at an upstream location and measuring the resulting tracer concentration at a downstream location. The method is based on the following continuity equation:

$$Q = q(C_1-C_2)/(C_2-C_0) \quad (1)$$

Where: Q = Flowrate of the stream to be measured

q = Constant flowrate of injected tracer

C_1 = Concentration of injected tracer

C_2 = Concentration of tracer in the stream at downstream sampling location

C_0 = Background tracer concentration upstream from the tracer injection site.

If the flowrate and background concentration of the injected tracer are negligible when compared to the total stream characteristics, this equation reduces to:

$$Q = qC_1/C_2 \qquad (2)$$

Where Q, q, C_1 and C_2 are as previously defined for equation (1).

The use of this method requires that the following conditions be attained:

- The injection rate of the tracer (q) must be precisely controlled and must remain constant over the measurement period;
- The tracer used must not degrade, sorb, or be changed in basic characteristics by environmental factors or the wastestream to which it is added;
- The location of injection and sampling sites must be judiciously selected and located such that the dye is well mixed across the cross-section, so that a concentration plateau is reached during the measurement period; and

The tracer used must be capable of being analyzed precisely.

In practice, many tracers have been used for dilution flow measurements including sodium chloride, lithium chloride, and fluorescent dyes. Fluorescent dyes and fluorometric analyses have been widely employed in dilution measurements and are particularly convenient. The tracer is normally injected into the wastestream by using a piston type chemical metering pump. The use of this type of pump is almost mandatory to maintain a constant injection rate. Automatic samplers are widely used to collect samples during the period of measurement. If fluorescent dyes are used, a submersible pump may be used in conjunction with a flow-through fluorometer and recorder to provide a continuous record of the dye concentration at the sampling point.

The flowrate may also be determined by making a slug (instantaneous) injection of tracer and measuring the resultant concentration at the downstream location during the entire time of passage of the tracer. The principle of the slug injection method is expressed in the following equation:

$$Q = C_1 \times V / {}_0\int^{\infty}(C_2-C_0)\,dt \qquad (3)$$

Where: V = Volume of tracer injected

t = time

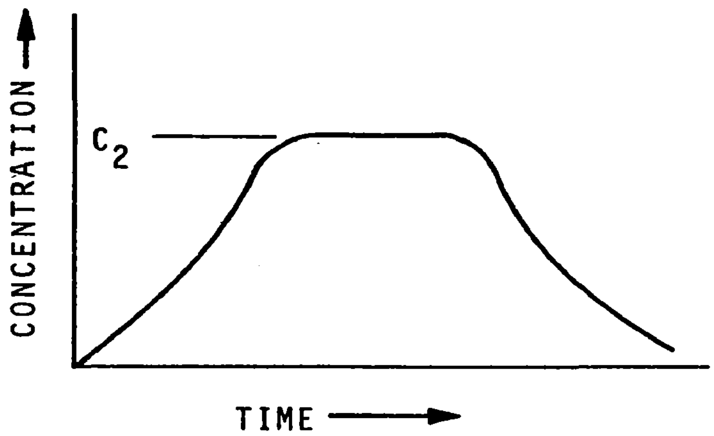
Q, q, C_0, C_1, C_2 are as previously defined for equation (1).

The principal advantage of this method is that sophisticated equipment is not required to inject the tracer. The disadvantages of the method are that it may not be used for unsteady flow situations and the entire tracer pulse must be sampled. The latter problem is easily solved by using fluorescent dyes and a flow-through fluorometer and recorder. The denominator of equation (3) may then be obtained by simply integrating the fluorometer recorder chart (after allowing for the background concentration, C_0) for the measurement period.

A graphical comparison of the constant rate and slug injection methods is given in Figure VI-3. The use of dilution techniques is covered in detail in the references (1, 3, 4). The monograph available from the Turner Design Company (4) is a particularly valuable reference for the use of fluorescent dyes and fluorometers in dilution flow measurement work. Experience indicates that accuracies of ± 3 percent are achievable utilizing the dilution method under field conditions.

3. Open Channel Flow Measurements

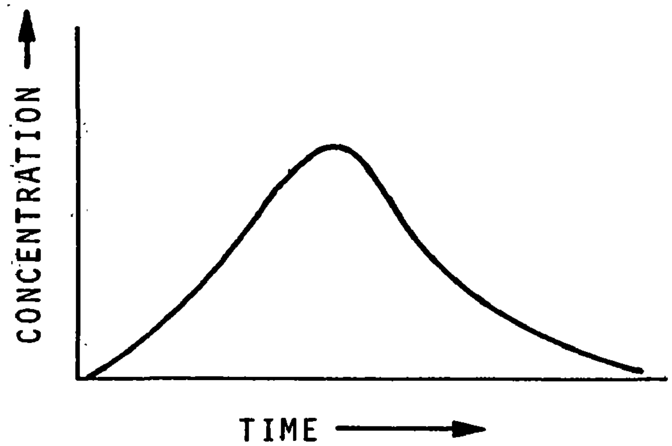
The measurement of wastewater flow in open channels is the most frequently encountered situation in field investigations. An open channel is defined as any open conduit such as a ditch or flume or any closed conduit such as a pipe, which is not flowing full. The most commonly encountered methods and primary flow devices used in measuring open channel wastewater flow are described in this section. Several flow estimation techniques are also presented.



a. CONCENTRATION-TIME CURVE FOR CONSTANT-RATE INJECTION METHOD.

$$Q = \left(\frac{C_1 - C_2}{C_2 - C_o}\right) q$$

- Q IS FLOW RATE OF STREAM
- q IS FLOW RATE OF CHEMICAL
- C_o IS BACKGROUND CONCENTRATION OF STREAM
- C_1 IS CONCENTRATION OF CHEMICAL INJECTED
- C_2 IS CONCENTRATION OF STREAM PLATEAU



b. CONCENTRATION-TIME CURVE FOR SLUG-INJECTION METHOD.

$$Q = \frac{v\ C_1}{\int_0^\infty (C - C_o)\,dt}$$

- Q IS FLOW RATE OF STREAM
- v IS VOLUME OF CHEMICAL INJECTED
- C_o IS BACKGROUND CONCENTRATION OF STREAM
- C_1 IS CONCENTRATION OF CHEMICAL INJECTED
- C IS INSTANTANEOUS STREAM CONCENTRATION

FIGURE VI-3
CONSTANT RATE AND SLUG INJECTION METHODS (10)

The measurement accuracies quoted in this section apply only to the specific method or to the primary flow device being discussed. The total error involved in a continuous flow measurement system, which is the sum of the errors of each component, is beyond the scope of this discussion. The reader is referred to the list of references at the end of this chapter for such a discussion.

(a) Velocity-Area Method

(i) Introduction

The velocity-area method is the established method of making instantaneous flow measurements in open channels. This method is particularly useful where the flow is too large to permit the installation of a primary flow device. It is also useful for checking the accuracy of an installed primary flow device or other flow measurement method. The basic principle of this method is that the flow (Q) in a channel is equal to the average velocity (V) times the cross-sectional area of the channel (A) at the point where the average velocity was measured, i.e., $Q = V \times A$. The velocity of water or wastewater is determined with a current meter; the area of the channel is calculated by using an approximation technique in conjunction with a series of velocity measurements.

While the velocity-area method is an instantaneous flow measurement method, it can be used to develop a continuous flow measurement system. This is accomplished by making a number of individual measurements at different flow rates and developing a curve or curves that relate water depth (head) to discharge (generally referred to as a rating curve). This curve can then be utilized along with a stage recorder to provide a continuous flow record.

This method requires some experience and good judgement in practice. A complete description of the equipment needed and the basic measurement methods are given in the references (1, 3, 5). Before attampting to use current meters or the velocity-area method, the neophyte investigator should accompany an experienced field professional during the conduct of several such measurements.

The accuracy of this method is directly dependent on the experience of the investigator, the strict adherence to procedures outlined in the references, and the care and maintenance of the equipment used. An experienced field investigator can make flow measurements using current meters that are accurate within a ± 10 percent.

(ii) Current Meters

There are two types of current meters, rotating element and electromagnetic. Conventional rotating element current meters are of two general types--the propeller type with the horizontal axis as in the Neyrpic, Ott, Hoff, and Haskell meters (Figure VI-4), and the cup-type instrument with the vertical axis as in the Price A-A and Pygmy meters (Figure VI-5).

In comparison with horizontal-axis (propeller) meters, the vertical axis (cup type) meters have the following advantages:

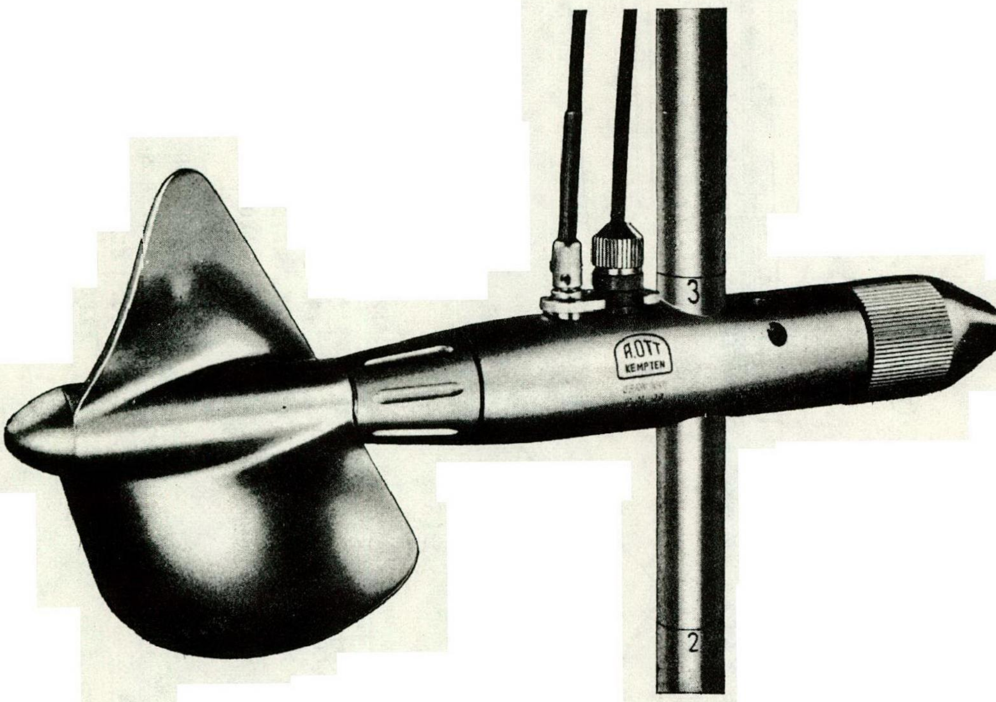
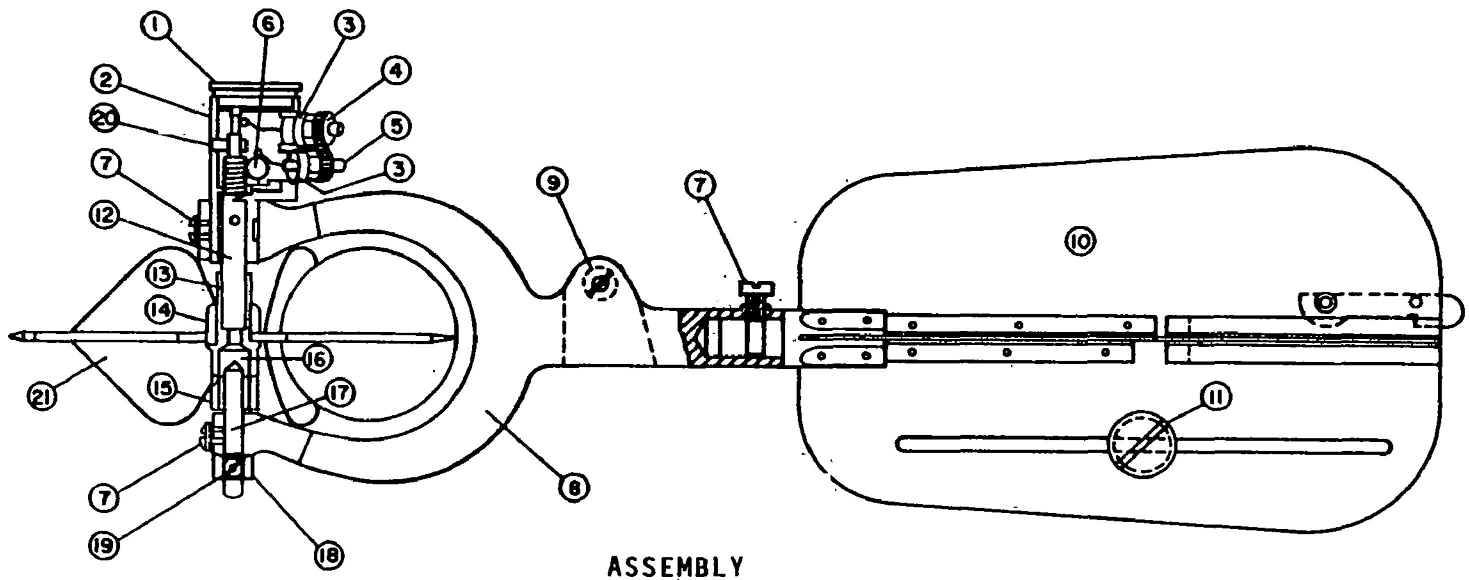


FIGURE VI—4

OTT TYPE HORIZONTAL AXIS CURRENT METER



ASSEMBLY

LIST OF PARTS

1. CAP FOR CONTACT CHAMBER
2. CONTACT CHAMBER
3. INSULATING BUSHING FOR CONTACT BINDING POST
4. SINGLE-CONTACT BINDING POST
5. PENTA-CONTACT BINDING POST
6. PENTA GEAR
7. SET SCREWS
8. YOKE
9. HOLE FOR HANGER SCREW
10. TAILPIECE
11. BALANCE WEIGHT
12. SHAFT
13. BUCKET-WHEEL HUB
14. BUCKET-WHEEL HUB NUT
15. RAISING NUT
16. PIVOT BEARING
17. PIVOT
18. PIVOT ADJUSTING NUT
19. KEEPER SCREW FOR PIVOT ADJUSTING NUT
20. BEARING LUG
21. BUCKET WHEEL

FIGURE VI-5

ASSEMBLY DRAWING OF PRYCE TYPE AA CURRENT METER (10)

(1) Their threshold velocities are usually lower;

(2) The lower pivot bearing operates in an air pocket, so the likelihood of silt intrusion is reduced;

(3) The meter, in particular the Price type, has earned a reputation for sturdiness and reliability under field use.

On the other hand, the propeller and ducted meters have the advantages of being less sensitive than Price meters to velocity components not parallel to the meter axis, being smaller in size, and being more suited for mounting in multiple units.

Current meters are provided with either a direct readout or a method for counting meter revolutions and a rating curve or table that relates meter vane rotation to velocity. Regardless of type, all current meters must receive the best of care during transportation and use to insure accurate velocity measurements. If the cups or blades on a conventional current meter become bent or damaged, the results obtained from the rating curve for the meter will be unreliable. Meter damage may occur because of improper packing and careless handling in transportation. Meters should be transported in substantial wooden or other rigid cases with properly fitted interior supports to prevent movement and damage to the delicate parts. Although all current meters are provided with a rating curve or table, they should be recalibrated periodically. If there is any sign of damage to any of the moving parts of the meter, it should be reconditioned and recalibrated.

(iii) Field Practice

The two principal methods for determining mean velocities in a vertical section with a current meter are the two-point method and the six-tenths-depth method. The two-point method consists of measuring the velocity at 0.2 and then at 0.8 of the depth from the water surface, and using the average of the two measurements. The accuracy obtainable with this method is high and its use is recommended. The method should not be used where the depth is less than two feet and should always be used at depths greater than two and one-half feet.

The six-tenths-depth method consists of measuring the velocity at 0.6 of the depth from the water surface, and is generally used for shallow depths where the two-point method is not applicable.

Current meters should be carefully checked before each measurement. It is good field practice to periodically check each current meter against one known to be in calibration. When making a measurement, the cross-section of the stream or channel should be divided into vertical sections, such that there will be no more than 10 percent, and preferably not more than 5 percent, of the discharge between any two adjacent vertical segments. This, of course, is possible only in open conduits. When making measurements through a manhole, it is rarely possible to obtain more than one section (at the center of the channel, normally).

This particular situation can be a significant source of error. Appropriate velocity measurements are made and the depth is measured at each vertical in the cross-section by using a current meter and wading rod or special sounding line and current meter assembly. Depths and velocities are recorded for each section.

(iv) Area and Flow Calculations

The midsection method and Simpson's parabolic rule are two methods for computing flow from current meter measurements. Both are based on the summation of discharges from each section measured.

If the two-point method of determining mean velocities is used, the formula for computing the discharge of an elementary area by the midsection method is:

$$q = \frac{V_1 + V_2}{2}\left[\frac{(L_2 - L_1) + (L_3 - L_2)}{2}\right] d_2 \qquad (4)$$

Where

L_1, L_2, and L_3 = distance in feet from the initial point, for any three consecutive verticals,

d_2 = water depth in feet at vertical L_2,

V_1 and V_2 = velocities in feet per second at 0.2 and 0.8 of the water depth, respectively, at vertical L_2, and

q = discharge in cubic feet per second through section of average depth d_2.

The formula for computing the discharge for each pair of elementary areas by Simpson's parabolic rule is:

Where

$$q' = \left[\frac{V_a+4V_b+V_c}{3}\right]\left[\frac{a+4b+c}{3}\right]L \qquad (5)$$

a,b,and c = The water depths in feet at three consecutive verticals,

V_a, V_b, and V_c = The respective mean velocities in feet per second at these verticals,

L = The distance in feet between the consecutive verticals (note-this distance is not measured from the initial point as in equation (4)),

q'= The discharge in cubic feet per second for the pair of elementary areas.

Typical current meter notes and computations for the midsection method are shown in Figure VI-6.

(b) Weirs

A weir is an obstruction built across an open channel or in a pipe flowing partially full over which water flows. The water usually flows through an opening or notch, but may flow over the entire weir crest. The theory of flow measurement utilizing weirs involves the release of potential (static) energy to kinetic energy. Equations can be derived for weirs of specific geometry which relate static head to water flow (discharge). Weirs are generally classified into two general categories: broad crested and sharp crested.

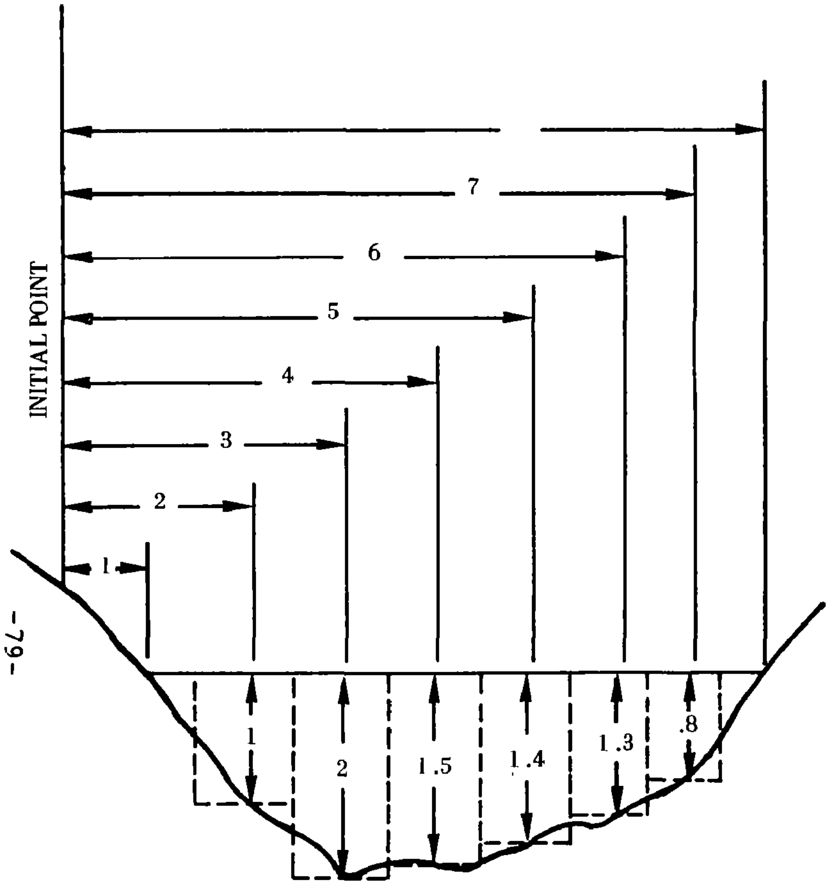


FIGURE VI-6

FIELD NOTES FOR THE MID-SECTION METHOD

River at—

Angle coefficient	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	VELOCITY At point	VELOCITY Mean in vertical	Adjusted for hor. angle or	Area	Discharge
		0.5	0		-	-	-	-		-	-
	2	1.0	1	.6	30	47	1.4	1.4		1.0	1.40
	3	1.0	2	.2	40	62	1.41	1.34		2.0	2.68
				.8	30	52	1.26				
	4	1.0	1.5	.2	50	55	1.98	1.75		1.5	2.63
				.8	30	43	1.52				
	5	1.0	1.4	.6	30	40	1.63	1.63		1.4	2.28
	6	1.0	1.3	.6	20	60	.742	.742		1.3	0.96
	7	1.0	0.8	.6	15	47	.712	.712		0.8	0.57
	8	0.5	0		-	-	-	-		-	-
		7.0									10.32 cfs

(i) Broad Crested Weirs

Broad crested weirs are normally incorporated into hydraulic projects as overflow structures. However, they can be used to measure flow. Typical broad crested weir profiles are shown in Figure VI-7. The equation for a broad crested weir takes the following form:

$$Q = C\ L\ H^{3/2} \qquad (6)$$

Where

Q = discharge

L = length of weir crest

H = head on weir crest, and

C = coefficient dependent on the shape of the crest and the head.

Values of the coefficient for various shapes of broad crested weirs are given in hydraulic handbooks (6,7). When these structures are used to measure wastewater flow, they should be calibrated using independent flow measurements (refer to techniques later in chapter). A discharge table based on these measurements should be prepared for each installation.

(ii) Sharp Crested Weirs

A sharp crested weir is one whose top edge (crest) is thin or beveled and presents a sharp upstream corner to the water flow. The water flowing over the weir (the weir nappe) does not contact any portion of the downstream edge of the weir, but springs past it. Sharp crested weirs may be constructed in a wide variety of shapes (Figure VI-8). A great deal of work has

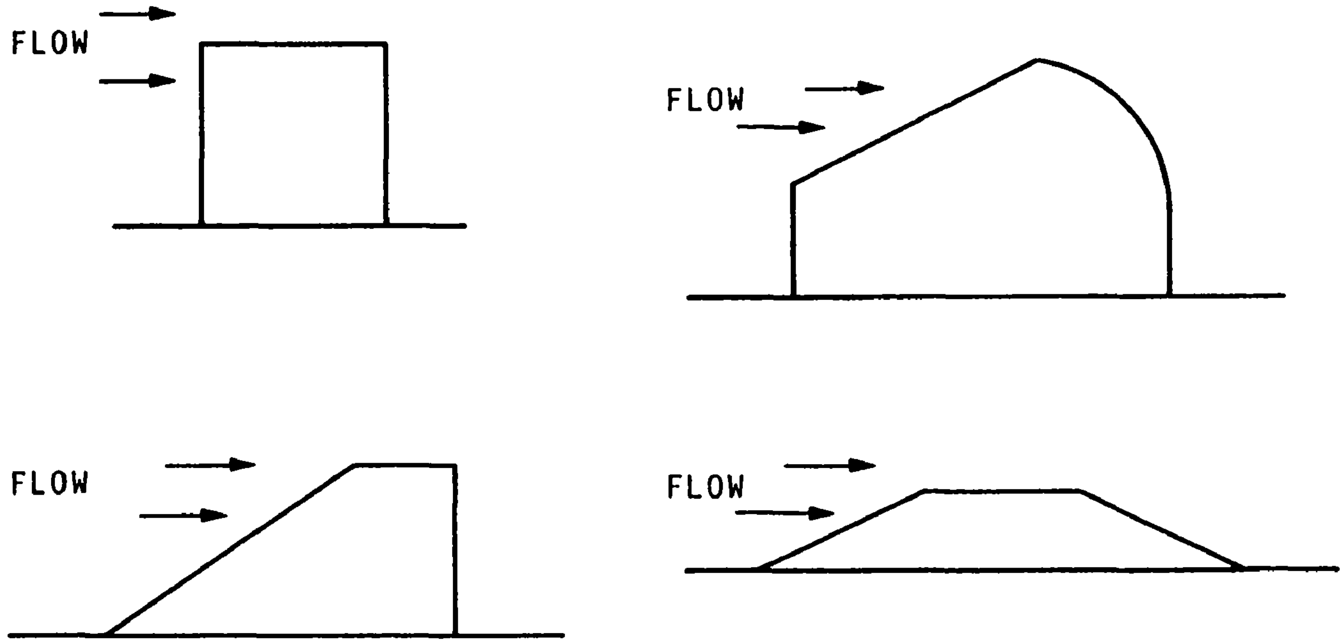


FIGURE VI-7
BROAD-CRESTED WEIR PROFILES (10)

been performed with sharp crested weirs and certain of these weirs are recognized as primary flow devices. If such weirs are constructed and installed in accordance with standard criteria, they can be used in the field without calibration.

The advantages of sharp crested weirs are accuracy and relatively low cost of fabrication and installation. The principal disadvantages are maintenance problems if the wastewater contains corrosive materials, trash or floating solids. These weirs can also cause undesirable settling of solids behind the weirs in the quiescent waters of the weir pool. The nominal accuracy of a standard, properly installed, sharp crested weirs in good condition, is approximately ± five percent (3,8,9,10).

(1) Standard Sharp Crested Weir Shapes

The most commonly encountered sharp crested weirs are the V-notch, rectangular, and Cippoletti. Typically, V-notch weirs are limited to measuring lower flows, while rectangular weirs are used to measure higher flows. When a rectangular weir is constructed with sharp crested sides, it is said to be contracted; when such a weir extends from one side of the channel to the other, and the smooth sides of the channel form the weir sides, the weir is said to be suppressed. Cippoletti weirs combine the features of both the contracted rectangular and V-notch weirs and are used to measure highly variable flows. These weirs and their equations are shown in Figure VI-9.

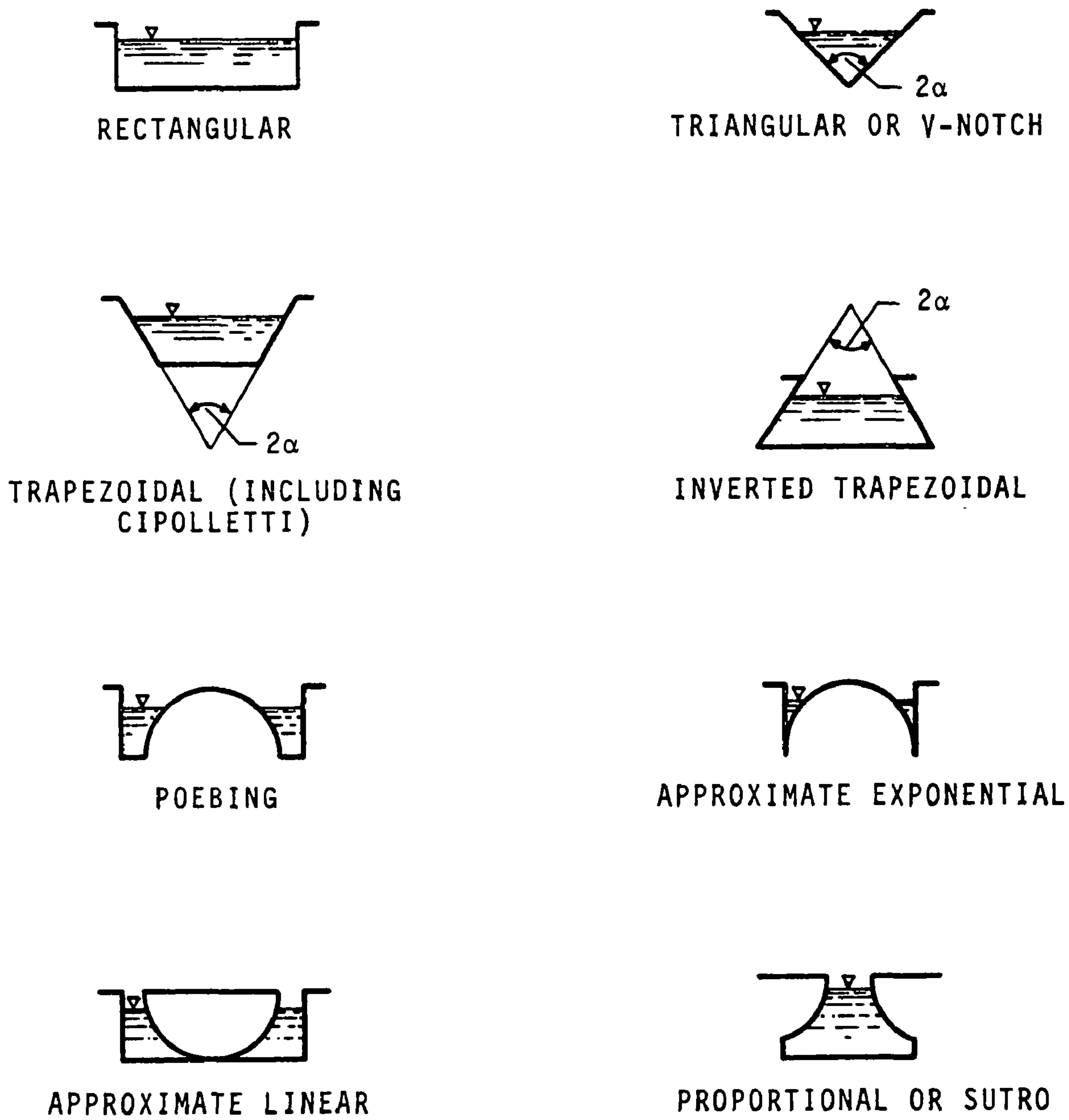


FIGURE VI-8

SHARP CRESTED WEIR PROFILES (10)

$Q = 3.33 (L-0.2H)H^{3/2}$ (CONT.)

$Q = 3.33 LH^{3/2}$ (SUP.)

$Q = 3.367 LH^{3/2}$

90 - $Q = 2.50 H^{2.50}$

$Q = 2.49 H^{2.48}$

60 - $Q = 1.443 H^{2.50}$

45 - $Q = 1.035 H^{2.50}$

22.5 - $Q = 0.497 H^{2.50}$

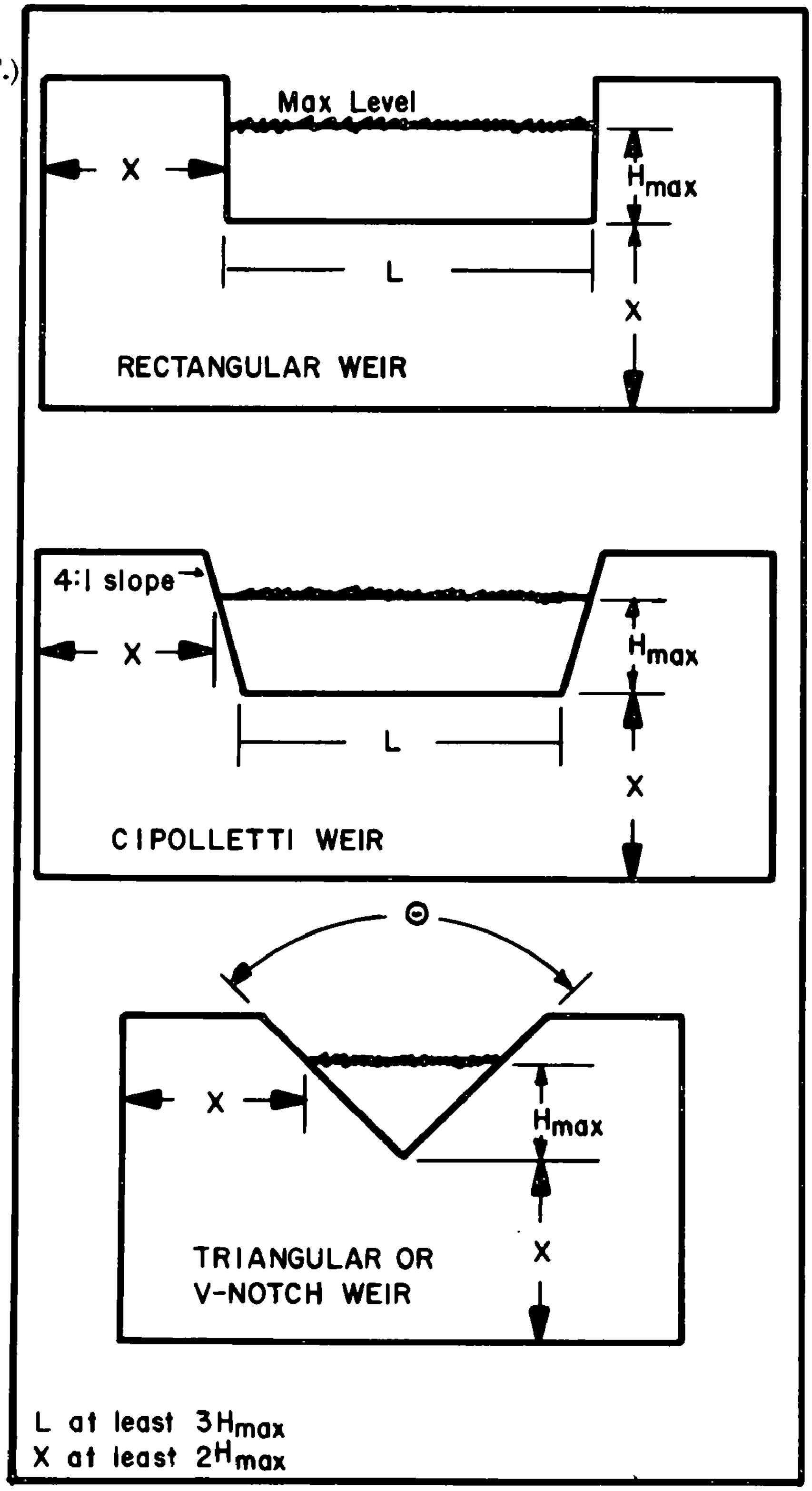


FIGURE VI - 9

THREE COMMON TYPES OF SHARP CRESTED WEIRS AND THEIR EQUATIONS (15)

Occasionally a proportional or "Sutro" weir is encountered in field installations. These weirs are generally used as velocity control devices for municipal sewage treatment plant grit chambers. Flow through these weirs is directly proportional to the head, and the use of sophisticated flow recording equipment is not required. This type of weir is not generally considered to be a primary flow device. The design and construction of these weirs is given in most standard hydraulic handbooks. The remaining sharp crested shapes shown in Figure VI-8 are rarely encountered.

(2) Standard Conditions

The profile of a sharp crested weir is shown on Figure VI-10, along with the standard sharp crested weir nomenclature. Table VI-1 summarizes the standard conditions used for the construction and installation of these weirs.

(3) Field Inspection

All weirs installed by the investigatory agency or those installed by the facility being investigated should be checked for conformance with the standard conditions given in Table VI-1. It should be noted that the dimensions for placement of the weir in the flow channel and the point at which the head is measured are in terms of the maximum head that can be measured for a particular weir. In actual practice, the maximum head expected

TABLE VI-I
STANDARD CONDITIONS FOR SHARP-CRESTED WEIRS
(See Figure VI-10)

1. The weir should be installed so that it is perpendicular to the axis of flow. The weir plate should be level. The sides of rectangular contracted weirs should be truly vertical. V-notch weir angles must be cut precisely.

2. The thickness of the weir crest should be less than 0.1 inch. The downstream edges of the crest or notch should be relieved by chamfering at a 45° angle (or greater) if the weir plate is thicker.

3. The distance from the weir crest to the bottom of the approach channel should not be less than twice the maximum weir head and never less than one foot. The distance from the sides of the weir to the sides of the approach channel should be no less than twice the maximum head and never less than one foot (except for the suppressed rectangular weir).

4. The nappe (overflow sheet) should touch only the upstream edges of the weir crest or notch.

5. Air should circulate freely under, and on both sides of, the nappe.

6. The measurement of head on the weir should be made at a point at least four (4) times the maximum head upstream from the weir crest.

7. The cross-sectional area of the approach channel should be at least eight times that of the nappe at the weir crest for a distance of 15-20 times the maximum head upstream from the weir. The approach channel should be straight and uniform upstream from the weir for the same distance.

8. If the criteria in Items 3 and 7 are not met, the velocity of approach corrections will have to be made.

9. Heads less than 0.2 feet (2.4 inches) should not be used under ordinary field conditions, because the nappe may not spring free of the crest.

10. All of the flow must pass through the weir and no leakage at the weir plate edges or bottom should be present.

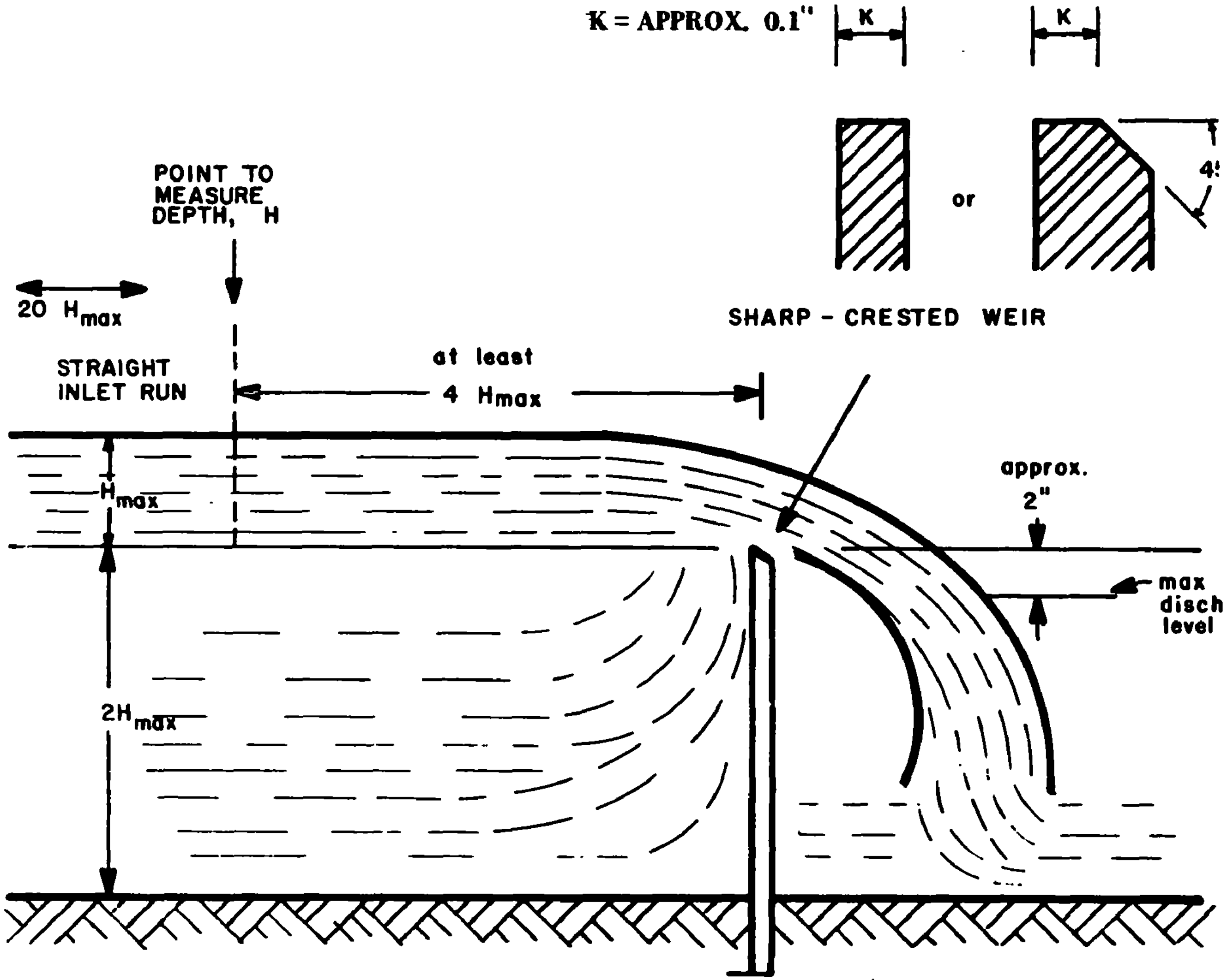


FIGURE VI-10
SHARP CRESTED WEIR NOMENCLATURE (15)

during the measurement period should be used. Any deviation from standard conditions should be noted on the field sheet.

Any trash, slime, or debris should be removed from the weir crest before proceeding with a flow measurement. The head on a sharp crested weir can be measured by knowing the depth of the weir notch from the top of the weir and measuring the head approximately four times the maximum head upstream using the top of the weir as a reference. The head is the difference in these two measurements. A carpenter's level, straight edge and framing square are invaluable for making this measurement. An engineering level and level rod can also be used. The carpenter's level can also be used to plumb the weir. A measuring tape is necessary to check the dimensions of weirs.

A problem frequently encountered when using suppressed rectangular weirs is the lack of ventilation of the weir nappe. When the weir nappe is not ventilated it will stutter or jump erratically. In permanent installations, provisions should be made for a vent to maintain atmospheric pressure behind the nappe. In field installations, flexible plastic tubing can be used for this purpose.

The pool upstream of the weir should be quiescent with approach velocities much less than one foot per second. Generally, excessive approach velocities are not a problem with V-notch weirs. However, if all the standard conditions outlined in Table VI-1 are not met or some other condition is encountered, it is possible to encounter excessive approach velocities when using rectangular weirs. When approach velocities exceed one foot per second, a correction should be applied to the observed measurements. One method of making such a correction is given in Table VI-2.

(4) Use of Weir Tables

The most convenient method for translating weir head measurements to flow is a set of weir tables. The use of weir formulas and curves in the field is not recommended, since this is a cumbersome procedure and leads to numerous computational errors. Excellent weir tables are included in the USDI Water Measurement Manual (1) and the Stevens Water Resources Data Book (11). The explanatory material accompanying these tables should be read thoroughly before they are used. In some cases, flow data are tabulated which are outside the useful range for a particular weir.

(c) Flumes

Flumes are widely used to measure wastewater flow in open channels. They are particularly useful for measuring large flowrates.

(i) Parshall Flumes

The Parshall flume is the most widely used open channel, primary flow device for wastewater flow measurement. Parshall flumes are available in a wide range of sizes and flow capacities, and are available to fit almost any open-channel, flow measuring application. These flumes operate with relatively low head loss, are insensitive to the velocity of approach, and

TABLE VI-2

SHARP CRESTED RECTANGULAR WEIRS
VELOCITY OF APPROACH CORRECTION

1. Compute the Velocity of Approach from: V = Q/A

   Where: V = Velocity of Approach in feet per second
   Q = Discharge in cfs (from weir formula)
   A = Cross-sectional area of approach channel

2. Enter the following table with the velocity of approach (V) and head (H) and obtain the coefficient (C) from the table:

v	h	$h^{3/2}$	H											
			0.2	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
0.4	0.0025	0.0002	1.014	1.007	1.004	1.004	1.004	1.002	1.002	1.002	1.001	1.001	1.001	1.001
.5	.0039	.0003	1.027	1.013	1.009	1.006	1.006	1.004	1.003	1.002	1.002	1.002	1.001	1.001
.6	.0056	.0005	1.037	1.019	1.013	1.009	1.008	1.005	1.004	1.003	1.003	1.002	1.002	1.002
.7	.0076	.0007	1.050	1.026	1.017	1.013	1.011	1.007	1.006	1.004	1.004	1.003	1.003	1.002
.8	.0099	.0010	1.064	1.033	1.022	1.016	1.014	1.009	1.007	1.006	1.005	1.004	1.003	1.003
.9	.0126	.0014	1.082	1.042	1.029	1.021	1.018	1.012	1.009	1.007	1.006	1.005	1.005	1.004
1.0	.0155	.0019	1.098	1.051	1.034	1.027	1.022	1.015	1.011	1.009	1.007	1.006	1.005	1.005
1.1	.0188	.0025	1.122	1.062	1.041	1.031	1.026	1.017	1.013	1.011	1.009	1.008	1.007	1.006
1.2	.0224	.0033	1.141	1.072	1.049	1.037	1.031	1.021	1.016	1.013	1.011	1.009	1.008	1.007
1.3	.0263	.0041	1.163	1.084	1.057	1.043	1.036	1.024	1.018	1.015	1.012	1.011	1.009	1.008
1.4	.0305	.0051	1.186	1.096	1.036	1.050	1.041	1.028	1.021	1.017	1.014	1.012	1.011	1.010
1.5	.0350	.0064	1.208	1.109	1.075	1.057	1.047	1.032	1.024	1.019	1.016	1.014	1.012	1.011
1.6	.0398	.0079	1.225	1.122	1.084	1.065	1.052	1.035	1.027	1.022	1.018	1.016	1.014	1.012
1.7	.0449	.0095	1.254	1.135	1.093	1.071	1.059	1.040	1.031	1.025	1.021	1.018	1.016	1.014
1.8	.0504	.0111	1.277	1.149	1.104	1.080	1.065	1.045	1.034	1.027	1.023	1.020	1.017	1.016
1.9	.0561	.0132	1.308	1.165	1.115	1.089	1.072	1.049	1.038	1.030	1.026	1.022	1.019	1.017
2.0	.0622	.0154	1.335	1.181	1.126	1.097	1.079	1.055	1.042	1.034	1.028	1.025	1.021	1.019
2.1	.0686	.0179	1.363	1.197	1.137	1.106	1.087	1.060	1.046	1.037	1.031	1.027	1.024	1.021
2.2	0752	.0206	1.391	1.213	1.149	1.118	1.094	1.065	1.050	1.039	1.034	1.029	1.026	1.023
2.3	.0822	.0235	1.420	1.231	1.161	1.124	1.102	1.071	1.054	1.044	1.037	1.032	1.028	1.025
2.4	.0895	.0268	1.449	1.248	1.176	1.134	1.110	1.077	1.059	1.047	1.040	1.034	1.030	1.027
2.5	.0972	.0303	1.480	1.266	1.187	1.145	1.119	1.083	1.063	1.051	1.043	1.037	1.033	1.029
2.6	.1051	.0340	1.511	1.285	1.200	1.155	1.128	1.088	1.068	1.055	1.046	1.040	1.035	1.032
2.7	.1133	.0381	1.542	1.303	1.213	1.166	1.137	1.095	1.073	1.059	1.050	1.043	1.038	1.034
2.8	.1219	.0426	1.573	1.322	1.228	1.178	1.146	1.100	1.078	1.063	1.053	1.046	1.041	1.036
2.9	.1307	.0472	1.606	1.341	1.242	1.189	1.155	1.108	1.083	1.067	1.057	1.049	1.043	1.039
3.0	.1399	.0524	1.637	1.361	1.256	1.199	1.165	1.115	1.088	1.072	1.061	1.053	1.046	1.041

3. The correct flow then = CxQ

   For example: V = 1 fps, Q = 6.31 cfs, H = 1 ft, then C = 1.022 and corrected Q = 1.022 x 6.31 = 6.45 cfs.

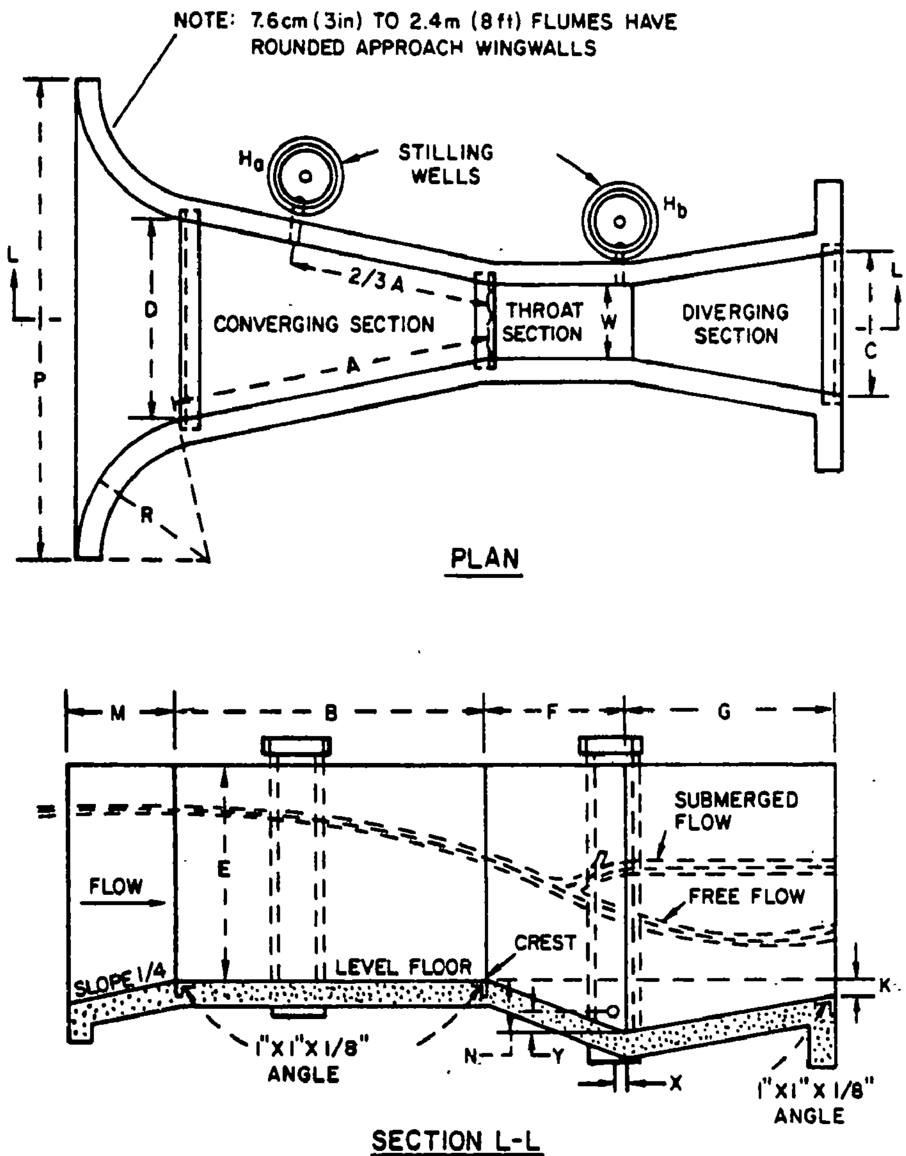
Note: Method and Table from Water Measurement Manual (1).

are self-cleaning in most applications. The accuracy of a Parshall flume in a good field installation is recognized to be approximately ± 5 percent (3,8,9,10).

(1) Parshall Flume Structure and Nomenclature

A Parshall flume consists of a converging section, throat section, and diverging section, as shown in Figure VI-11. The size of the flume is determined by the width of the throat section. All dimensions for various Parshall flume sizes are given in the USDI Water Measurement Manual (1). Tolerances for Parshall flume dimensions, as given by this manual, are ± 1/64 inch for the throat width and ± 1/32 for the remaining sections.

The head (Ha) is measured at the point 2/3 of the length of the converging section (wingwall), upstream from the throat section. During conditions of free-flow, this is the only measurement required to determine flow. Occasionally, back water exists which causes some flooding of the diverging section of the flume. In those cases, it is necessary to check the head at an additional location (Hb) between the throat and diverging sections as shown in Figure VI-11. The ratio of the measured heads (Hb/Ha) is known as the submergence. Flumes can be used to accurately measure flow without correction until the following limits are reached for each indicated size of flume:



LEGEND:

W	Size of flume, in inches or feet.
A	Length of side wall of converging section.
2/3A	Distance back from end of crest to gage point.
B	Axial length of converging section.
C	Width of downstream end of flume.
D	Width of upstream end of flume.
E	Depth of flume.
F	Length of throat.
G	Length of diverging section.
K	Difference in elevation between lower end of flume and crest.
N	Depth of depression in throat below crest.
R	Radius of curved wing wall.
M	Length of approach floor.
P	Width between ends of curved wing walls.
X	Horizontal distance to H_b gage point from low point in throat.
Y	Vertical distance to H_b gage point from low point in throat.

FIGURE VI-11

CONFIGURATION AND STANDARD NOMENCLATURE FOR PARSHALL FLUME (10)

Hb/Ha (%)	Flume Size
50	1, 2, 3 inches
60	6, 9 inches
70	1-8 feet
80	8-50 feet

When the submergence exceeds 95%, the flume is not usable for flow measurement purposes. A detailed description of submergence corrections is given in the USDI Water Measurement Manual (1).

Although the Parshall flume is relatively insensitive to approach velocities, influent flow should be evenly distributed across the channel as it enters the converging section. These flumes should not be installed immediately downstream from transition sections in order to assure such an even distribution. As a practical matter, a uniform channel should be provided upstream from the flume as far as is practical. A minimum distance of 15-20 channel widths or pipe diameters is recommended.

(2) Field Inspection and Flow Measurement

During compliance sampling inspections, flumes should be inspected to determine if entrance conditions provide a uniform influent flow distribution, the flume dimensions conform to those given in the USDI Water Measurement Manual (1), the flume converging throat section flow is level, and the throat section walls are vertical. Useful tools for checking Parshall flumes include a carpenter's level, framing square and tape. The flume should be closely examined to determine if it is discharging freely. If there is any question about free discharge, the downstream head (Hb) should be measured. A staff gage is useful for making head measurements. Any problems observed during the inspection should be noted on the field sheet.

A set of flume tables is necessary for calculating flows. Both the USDI Water Measurement Manual (1) and the Stevens Water Resources Data Book (11) contain a complete set of tables. The explanatory material accompanying these tables should be read and understood before they are used. In many cases, tabulated flow values are given for measured heads that are not within the usable measurement range.

The most frequently encountered problems with facility installed flumes include:

- Poor entrance and exit hydraulics that cause poor flow distribution or submergence,
- Improper installation, out of level, throat sidewalls not vertical, improper throat dimensions, or
- Improper location of head measuring points.

(ii) Palmer-Bowlus Flumes

Palmer-Bowlus flumes depend upon existing conduit slopes and a channel contraction (provided by the flume) to produce supercritical flow. Several different shapes of this flume are in use and are shown in Figure VI-12. These flumes are being increasingly used as primary flow devices for measuring flow in circular conduits. Their principal advantage lies in simplicity

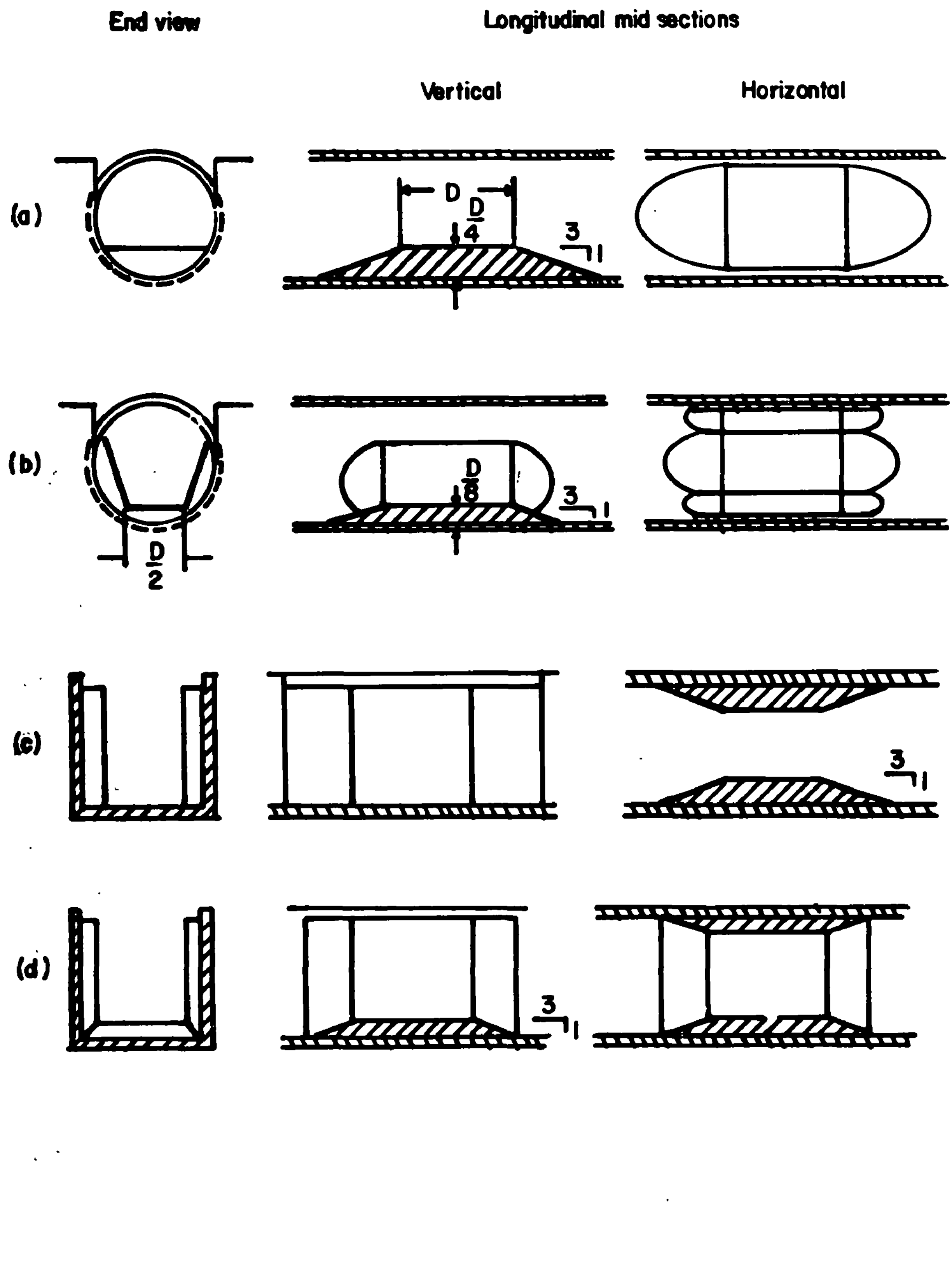


FIGURE VI - 12
VARIOUS CROSS - SECTIONAL SHAPES OF PALMER-BOWLUS FLUMES (15)

of construction and ease of installation through manholes. There is a paucity of data on the accuracy of this flume, although one reference reports that the performance of these flumes can be theoretically predicted to within 3 percent when used in U-shaped channels, so long as the upstream depth does not exceed 0.9D (where D is the diameter of the circular conduit leading into the flume) (3). A complete description of the theory of these flumes and their use is given in the references (3,10,12).

(iii) Other Flumes

A number of other flumes have been developed to solve specific flow measurement problems, including cutthroat, trapezoidal with bottom slope, critical depth, H, etc. (1,3,9,10). These flumes are seldom used for wastewater flow measurement purposes.

(d) Open Channel Flow Nozzles

The open channel flow nozzle is a combination of flume and sharp crested weir. Unlike sharp crested weirs, these devices operate well with wastewaters that contain high concentrations of suspended solids; however, they have poor head recovery characteristics. These devices are designed to be attached to the end of a conduit, flowing partially full, and must have a free fall discharge. Open channel flow nozzles are designed so there is a predetermined relationship between the depth of liquid within the nozzle and the flowrate. The Kennison nozzle has a cross-sectional shape such that the relationship between the flowrate and head is linear. These nozzles require a length of straight conduit immediately upstream from the nozzle, and the slope of the conduit must be within the limits of the nozzle calibration specifications. The profile of a parabolic and a Kennison type open flow nozzle is shown in Figure VI-13.

Open flow nozzles are factory calibrated and are ordinarily supplied as part of a flow measurement system. Calibration and installation data for each nozzle should be supplied by/or obtained from the manufacturer. The accuracy of these devices is reported to be often better than $\pm$ 5 percent of the indicated flow (10).

(e) Slope - Area Method

The slope-area method consists of using the slope of the water surface, in a uniform reach of channel, and the average cross-sectional area of that reach, to estimate the flowrate of an open channel. The flowrate is estimated from the Manning formula:

$$Q = 1.486/n\ AR^{2/3}S^{1/2} \qquad (7)$$

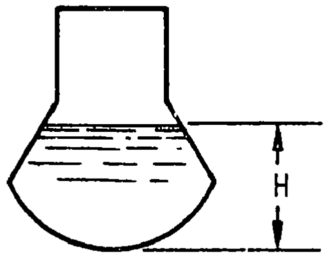
Where

Q = discharge in cfs

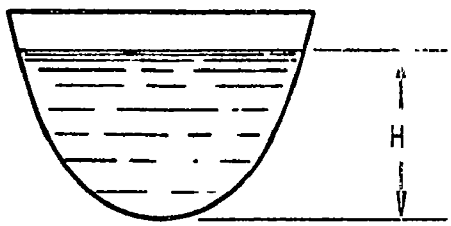
A = average area of the wetted channel cross-section in square feet

R = average hydraulic radius of the wetted channel in feet. (Average cross-sectional area divided by the average wetted perimeter.)

S = slope of the water surface, and



a. Linear (Kennison) Nozzle Profile ($Q \propto H$)



b. Parabolic Nozzle Profile ($Q \propto H^2$)

FIGURE VI-13
OPEN CHANNEL FLOW NOZZLE PROFILES (10)

n = a roughness factor depending on the character of the channel lining.

A long straight section of channel should be used for this estimation technique. Values of n may be obtained from hydraulic handbooks (6,7). It should be remembered that the slope in the equation is of the water surface and not the channel invert.

(f) Measurement by Floats

A crude but simple method of estimating flow in an open channel is by using floats. A straight reach of channel with uniform slope is necessary for this method. Three cross-sections are used. The purpose of the middle section is to provide a check on the velocity measurements between the beginning and end sections. The velocity is obtained by measuring the length of the reach and timing the passage of the float with a stopwatch. The flowrate is obtained by multiplying the resulting velocity by the average cross-sectional area of the section of channel used. Since surface velocities are higher than the average velocity of the channel, the velocities obtained by the float method should be corrected using the empirical factors presented in the USDI Water Measurement Manual (1).

4. Closed Conduit Flow Measurements

Closed conduit flow measurement systems present a special challenge to the field investigator. These systems, once installed, generally cannot be visually inspected, nor can the hydraulic responses of the systems be as easily evaluated as is the case with most open channel systems. One procedure for verifying the accuracy of closed conduit flow measurement systems in the field is to make an independent flow measurement at an acceptable location. The constant injection dilution technique, or the velocity area method, both of which were described earlier in this section, would be acceptable for this purpose. Another procedure includes inducing known pressures or voltages on the sensing system and verifying recorder response.

Some of the most commonly used closed conduit primary flow devices are presented and discussed briefly in this section. Several flow estimation techniques are also presented. The measurement accuracies quoted in this section apply only to the specific method or to the primary flow device being discussed. The total error involved in continuous flow measurement systems, which is the sum of the errors of each component, is beyond the scope of this discussion. The reader is referred to the list of references at the end of this chapter for such a discussion.

(a) Venturi Meter

The Venturi meter is one of the most accurate primary flow devices for measuring flowrates in pipes. Basically, the Venturi meter is a pipe segment (Figure VI-14) consisting of a converging section, a throat and a diverging section. A portion of the static head is converted in the throat section to velocity head. Thus, the static head in the throat of the Venturi is lower than in the converging section. This head differential is proportional to the flowrate. One of the advantages of the Venturi meter is that it has a low head loss.

The meter must be installed downstream from a straight and uniform section of pipe, at least 5-20 pipe diameters, depending upon the pipe diameter to throat diameter ratio. The accuracy of the Venturi is affected by changes in density, temperature, pressure, viscosity, and by pulsating flow. When used to measure flow in wastestreams containing high concentrations of suspended solids, special provisions must be made to insure that the pressure measuring taps are not plugged. The typical accuracy of Venturi meters is given at 1 to 2 percent (3,8,10).

There are a number of variations of the Venturi meter, generally called flow tubes, presently being used (10). Their principle of operation is similar to that of the Venturi, and they will not be discussed.

(b) Orifice Meters

The Orifice meter is one of the oldest flow measuring devices. Flow is measured by the difference in static head caused by the presence of the orifice plate. The differential pressure is related to the flowrate. The thin plate orifice is the most common variety, and consists of a round hole in a thin plate, which is generally clamped between a pair of flanges at a point in a pipe. The most common orifice plate consists of a sharp 90-degree corner on the downstream edge. Some orifice plates have a rounded edge facing into the direction of flow, and perhaps a short tube with the same diameter as the orifice

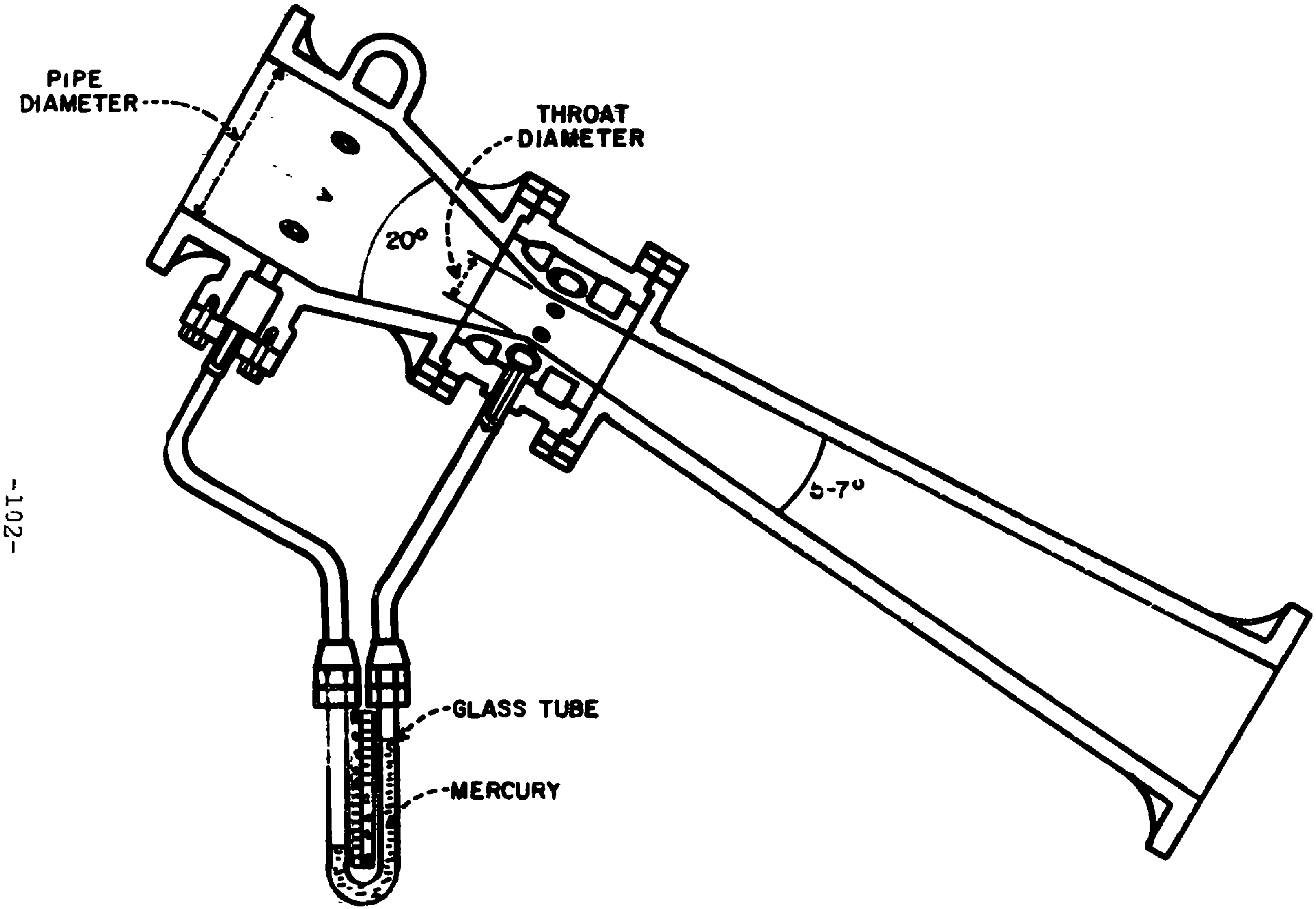


FIGURE VI - 14
VENTURI METER (15)

opening facing downstream. Pressure measuring taps are located upstream and downstream of the orifice plate to facilitate differential pressure measurements. Only one pressure tap is required if the orifice plate is located at the end of a pipe discharging at atmospheric pressure.

Orifice meters are of limited usefulness in measuring flowrates in wastestreams containing high suspended solids, since solids tend to accumulate upstream of the orifice plate. Orifice meters produce the highest head loss of any of the closed conduit flow devices, and are quite sensitive to upstream disturbances. It is not uncommon to need from 40 to 60 pipe diameters of straight pipe upstream of the installation. They can be quite accurate, 0.5%, although their usable range is small (5:1) unless rated in place (10).

(c) Flow Nozzles

A flow nozzle may consist of designs that approach the Venturi meter in one extreme and the orifice meter in the other. The basic principle of operation is the same as that of the Venturi meter. Typically, a flow nozzle has an entrance section and a throat, but lacks the diverging section of the Venturi (a typical flow nozzle is shown in Figure VI-15). A major advantage of the flow nozzle over the Venturi meter is that the flow nozzle can be installed between pipe flanges. They are intermediate in head loss between the Venturi and orifice meters. Like orifice meters, they are sensitive to upstream disturbances and 20 or more pipe diameters of straight pipe are required upstream from

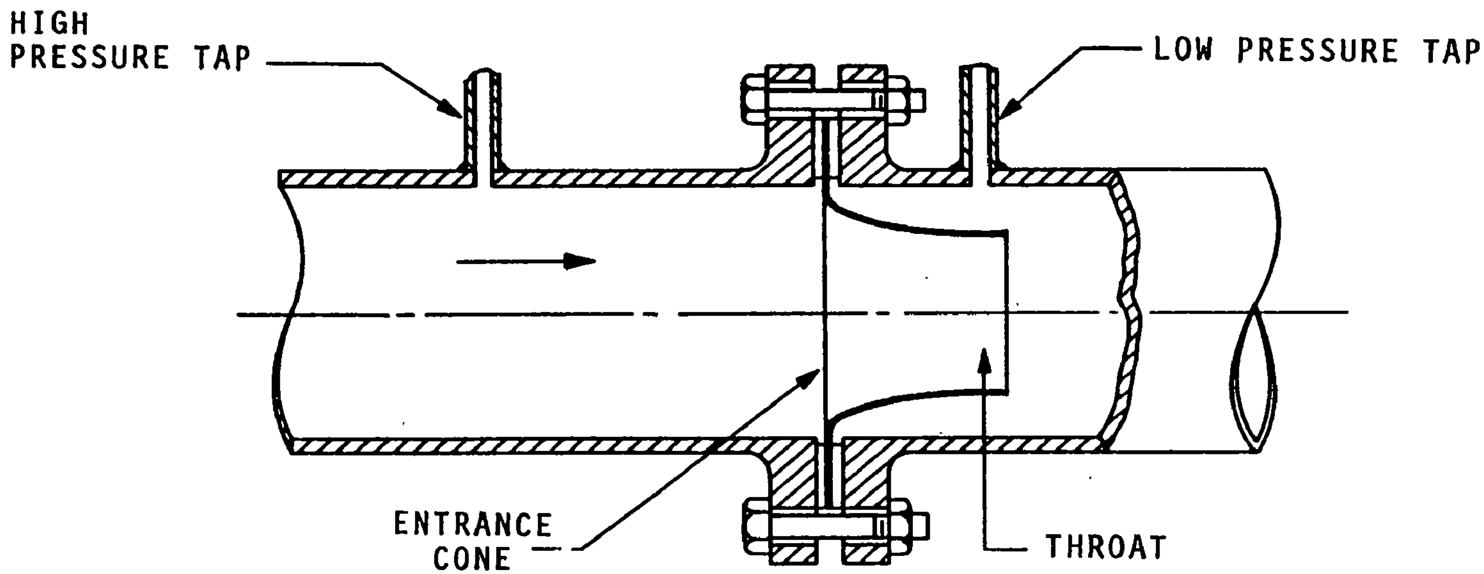


FIGURE VI-15
FLOW NOZZLE IN PIPE (10)

the flow nozzle for successful operation. Some flow nozzles are not recommended for use in measuring flowrates in high suspended solids wastestreams. Flow nozzle accuracies can approach those of Venturi meters (10).

(d) Electromagnetic Flowmeter

The electromagnetic flowmeter operates according to Faraday's Law of Induction. Namely, the voltage induced by a conductor moving at right angles through a magnetic field will be proportional to the velocity of the conductor through the field. In the electromagnetic flowmeter, the conductor is the liquid stream to be measured and the field is produced by a set of electromagnetic coils. A typical cross-section of an electromagnetic flowmeter is shown in Figure VI-16. The induced voltage is subsequently transmitted to a converter for signal conditioning.

Electromagnetic flowmeters have many advantages; they are very accurate (within $\pm$ 1 percent of full scale), have a wide flow measurement range, introduce a negligible head loss, have no moving parts, and the response time is rapid (10). However, they are expensive. Buildup of grease deposits or pitting by abrasive wastewaters can cause error. Regular checking and cleaning of the electrodes is necessary.

(e) Acoustic Flowmeters

Acoustic flowmeters operate on the basis of the difference in transit time between upstream and downstream directed sonic pulses. The difference in transit time is caused by the velocity

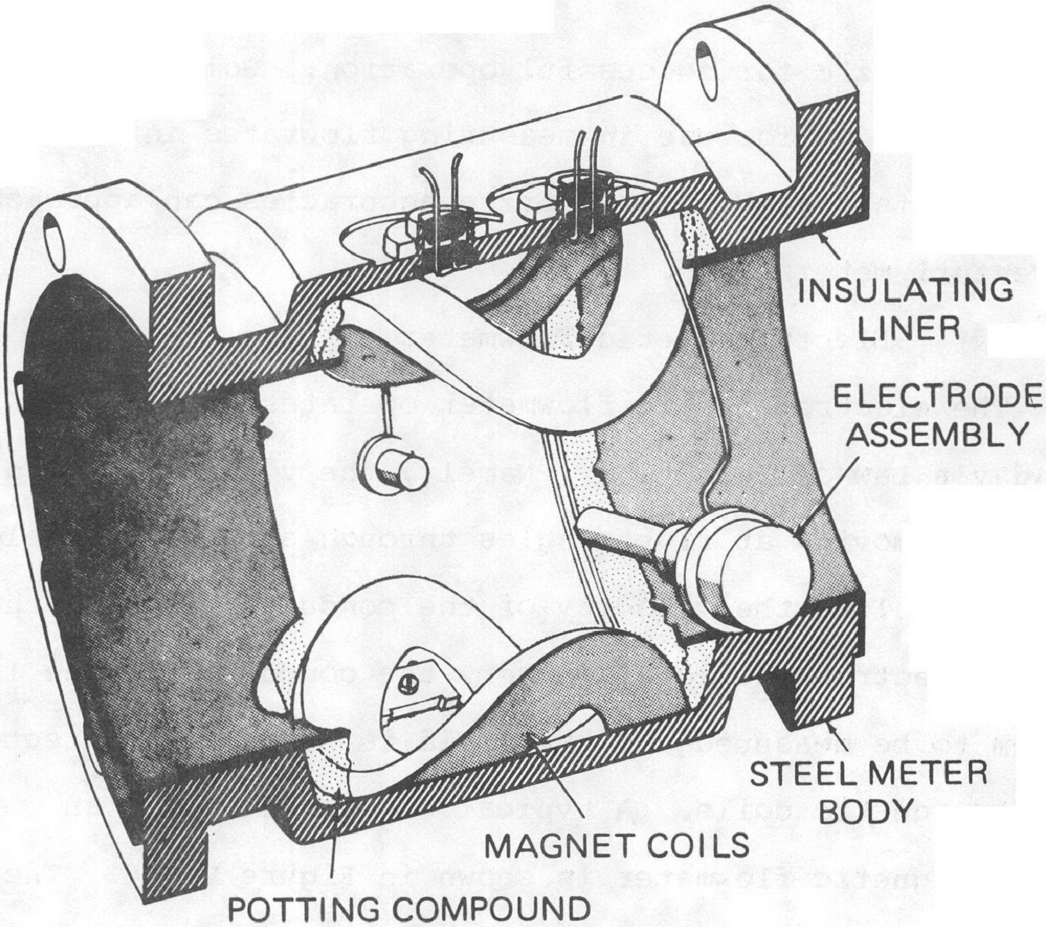


FIGURE VI - 16
ELECTROMAGNETIC FLOW METER (15)

of the water in the conduit. This time lag is proportional to the velocity, and hence the flowrate. Manufacturers employ various methods to take advantage of this principle. Some flowmeters use the acoustic doppler principle. According to the manufacturers, accuracies of one percent of full scale are achievable (3,10).

(f) Trajectory Methods

A number of methods for estimating the flowrate from the end of a pipe with a free discharge are available. All of these methods, whether theoretically or empirically derived, have in common the measurement of the issuing stream coordinates (Figure VI-17) in the vertical and horizontal directions. It should be emphasized that all of these methods are estimates--none of them is accurate enough for NPDES compliance purposes.

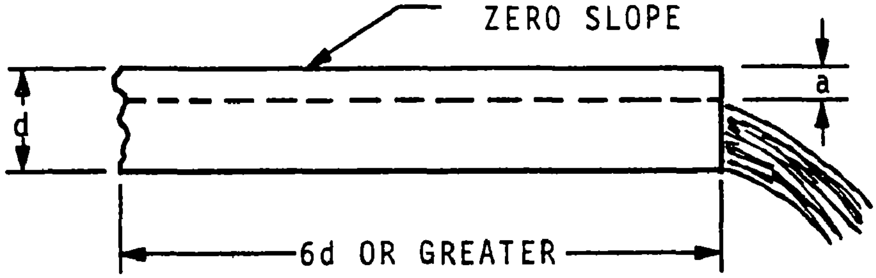
The California pipe method (Figure VI-17) uses a straight level section of pipe at least six pipe diameters in length as the primary flow device. The pipe must have a free discharge and must be only partially full. The distance from the crown of the pipe to the water surface (a) at the end of the pipe is related to the flowrate by the following equation:

$$Q = 8.69\ (1-a/d)^{1.88}\ d^{2.48} \qquad (8)$$

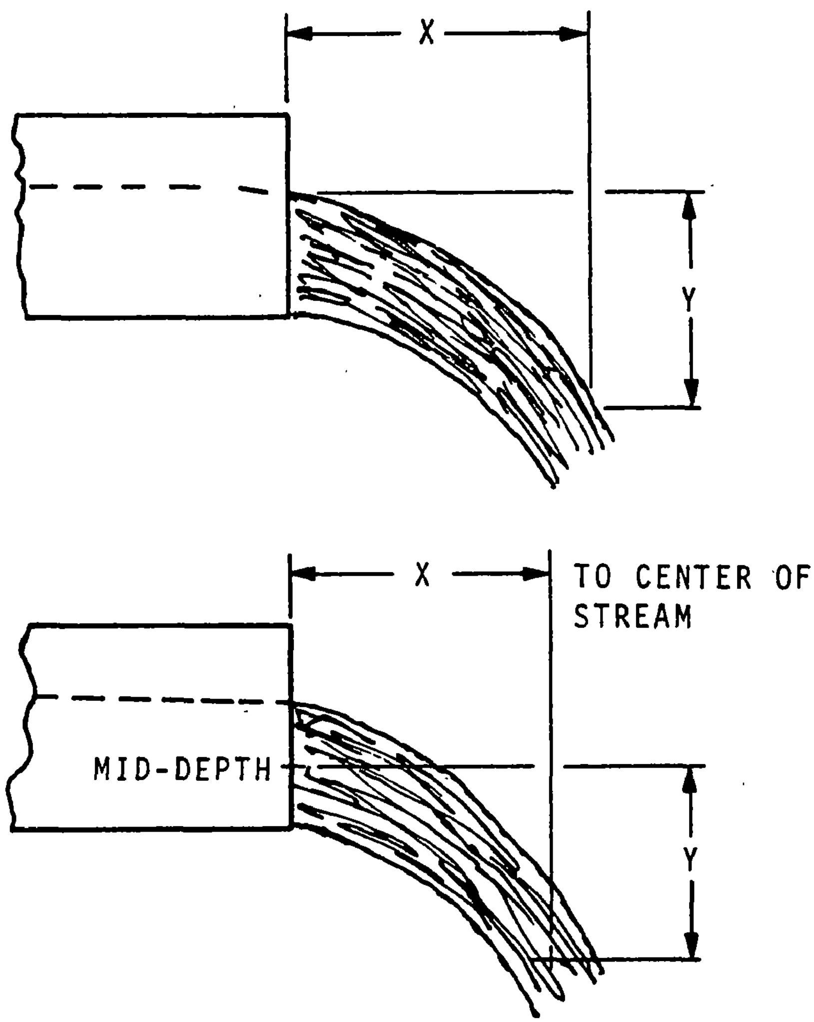
Where

Q = flowrate in cfs

d = diameter of pipe in feet



a. CALIFORNIA PIPE METHOD



b. PURDUE METHODS

FIGURE VI-17
TRAJECTORY METHODS (10)

It is recommended that a/d be restricted to values greater than 0.5. The experiments from which the above equation was derived used pipe diameters of from 3 to 10 inches (1,3,10).

The Purdue method involves the measurement of the horizontal (x) and the vertical (y) coordinates of the issuing stream at the end of a pipe, and the use of a set of curves that empirically relate these coordinates to the discharge. Curves for pipes 2, 3, 4, 5, and 6 inches are available (1,3).

If the water jet is treated as a freely falling body with constant horizontal velocity, the following equation results (3):

$$Q = A(g/2y)^{0.5} X \qquad (9)$$

Where

Q = flowrate in cfs

A = cross-sectional area of the issuing stream

X & Y = horizontal and vertical trajectory coordinates measured as shown in Figure VI-17

(g) Pump Curves

Pump curves, supplied by pump manufacturers, have been used extensively to estimate flows in closed conduits. Where pumps are operated on a cyclic basis, a timer hooked to a pump gives an estimate of the total flow. However, there are so many variables present in pump and piping installations that it is likely that most pump curves are not accurate enough for NPDES compliance purposes. When pump curves are used for NPDES compliance wastewater flow measurements, these curves should be verified by making an independent flow measurement.

(h) Use of Water Meters

Municipal and process water meters have been used to estimate industrial wastewater flows when all other methods have failed or are not usable. The use of water meters should be viewed with caution. All consumptive uses of water must be accounted for and subtracted from the meter readings. Also, water meters are often poorly maintained and their accuracy is questionable. When water meters have to be used, the municipality or utility that has responsibility for the meters should be consulted as to when the meters were last serviced or calibrated.

REFERENCES - SECTION VI

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NPDES COMPLIANCE INSPECTION REPORT *(Coding Instructions on back of last page)*

TRANSACTION CODE		NPDES	YR MO DA	TYPE	INSPEC-TOR	FAC TYPE	TIME
1	5 (2)	3 – 11	12 – 17	18	19	20	a.m. / p.m.

REMARKS

21 – 64

65 – 70 | ADDITIONAL

SECTION A - Permit Summary

NAME AND ADDRESS OF FACILITY *(Include County, State and ZIP code)*		EXPIRATION DATE
		ISSUANCE DATE
RESPONSIBLE OFFICIAL	TITLE	PHONE
FACILITY REPRESENTATIVE	TITLE	PHONE

SECTION B - Effluent Characteristics *(Additional sheets attached ________)*

PARAMETER/ OUTFALL		MINIMUM	AVERAGE	MAXIMUM	ADDITIONAL
	SAMPLE MEASUREMENT				
	PERMIT REQUIREMENT				
	SAMPLE MEASUREMENT				
	PERMIT REQUIREMENT				
	SAMPLE MEASUREMENT				
	PERMIT REQUIREMENT				
	SAMPLE MEASUREMENT				
	PERMIT REQUIREMENT				
	SAMPLE MEASUREMENT				
	PERMIT REQUIREMENT				

SECTION C - Facility Evaluation *(S = Satisfactory, U = Unsatisfactory, N/A = Not applicable)*

	EFFLUENT WITHIN PERMIT REQUIREMENTS		OPERATION AND MAINTENANCE		SAMPLING PROCEDURES
	RECORDS AND REPORTS		COMPLIANCE SCHEDULE		LABORATORY PRACTICES
	PERMIT VERIFICATION		FLOW MEASUREMENTS		OTHER:

SECTION D - Comments

SECTION E - Inspection/Review

SIGNATURES	AGENCY	DATE
INSPECTED BY		
INSPECTED BY		
REVIEWED BY		

ENFORCEMENT DIVISION USE ONLY

COMPLIANCE STATUS

☐ COMPLIANCE

☐ NONCOMPLIANCE

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Sections F thru L: Complete on all inspections, as appropriate. N/A = Not Applicable	PERMIT NO.

SECTION F - Facility and Permit Background

ADDRESS OF PERMITTEE IF DIFFERENT FROM FACILITY *(Including City, County and ZIP code)*	DATE OF LAST PREVIOUS INVESTIGATION BY EPA/STATE
	FINDINGS

SECTION G - Records and Reports

RECORDS AND REPORTS MAINTAINED AS REQUIRED BY PERMIT. ☐ YES ☐ NO ☐ N/A *(Further explanation attached ______)*
DETAILS:

(a) ADEQUATE RECORDS MAINTAINED OF:			
(i) SAMPLING DATE, TIME, EXACT LOCATION	☐ YES	☐ NO	☐ N/A
(ii) ANALYSES DATES, TIMES	☐ YES	☐ NO	☐ N/A
(iii) INDIVIDUAL PERFORMING ANALYSIS	☐ YES	☐ NO	☐ N/A
(iv) ANALYTICAL METHODS/TECHNIQUES USED	☐ YES	☐ NO	☐ N/A
(v) ANALYTICAL RESULTS *(e.g., consistent with self-monitoring report data)*	☐ YES	☐ NO	☐ N/A
(b) MONITORING RECORDS *(e.g.,flow, pH, D.O., etc.)* MAINTAINED FOR A MINIMUM OF THREE YEARS INCLUDING ALL ORIGINAL STRIP CHART RECORDINGS *(e.g. continuous monitoring instrumentation, calibration and maintenance records).*	☐ YES	☐ NO	☐ N/A
(c) LAB EQUIPMENT CALIBRATION AND MAINTENANCE RECORDS KEPT.	☐ YES	☐ NO	☐ N/A
(d) FACILITY OPERATING RECORDS KEPT INCLUDING OPERATING LOGS FOR EACH TREATMENT UNIT.	☐ YES	☐ NO	☐ N/A
(e) QUALITY ASSURANCE RECORDS KEPT.	☐ YES	☐ NO	☐ N/A
(f) RECORDS MAINTAINED OF MAJOR CONTRIBUTING INDUSTRIES *(and their compliance status)* USING PUBLICLY OWNED TREATMENT WORKS.	☐ YES	☐ NO	☐ N/A

SECTION H - Permit Verification

INSPECTION OBSERVATIONS VERIFY THE PERMIT. ☐ YES ☐ NO ☐ N/A *(Further explanation attached ______)*
DETAILS:

(a) CORRECT NAME AND MAILING ADDRESS OF PERMITTEE.	☐ YES	☐ NO	☐ N/A
(b) FACILITY IS AS DESCRIBED IN PERMIT.	☐ YES	☐ NO	☐ N/A
(c) PRINCIPAL PRODUCT(S) AND PRODUCTION RATES CONFORM WITH THOSE SET FORTH IN PERMIT APPLICATION.	☐ YES	☐ NO	☐ N/A
(d) TREATMENT PROCESSES ARE AS DESCRIBED IN PERMIT APPLICATION.	☐ YES	☐ NO	☐ N/A
(e) NOTIFICATION GIVEN TO EPA/STATE OF NEW, DIFFERENT OR INCREASED DISCHARGES.	☐ YES	☐ NO	☐ N/A
(f) ACCURATE RECORDS OF RAW WATER VOLUME MAINTAINED.	☐ YES	☐ NO	☐ N/A
(g) NUMBER AND LOCATION OF DISCHARGE POINTS ARE AS DESCRIBED IN PERMIT.	☐ YES	☐ NO	☐ N/A
(h) CORRECT NAME AND LOCATION OF RECEIVING WATERS.	☐ YES	☐ NO	☐ N/A
(i) ALL DISCHARGES ARE PERMITTED.	☐ YES	☐ NO	☐ N/A

SECTION I - Operation and Maintenance

TREATMENT FACILITY PROPERLY OPERATED AND MAINTAINED. ☐ YES ☐ NO ☐ N/A *(Further explanation attached ______)*
DETAILS:

(a) STANDBY POWER OR OTHER EQUIVALENT PROVISIONS PROVIDED.	☐ YES	☐ NO	☐ N/A
(b) ADEQUATE ALARM SYSTEM FOR POWER OR EQUIPMENT FAILURES AVAILABLE.	☐ YES	☐ NO	☐ N/A
(c) REPORTS ON ALTERNATE SOURCE OF POWER SENT TO EPA/STATE AS REQUIRED BY PERMIT.	☐ YES	☐ NO	☐ N/A
(d) SLUDGES AND SOLIDS ADEQUATELY DISPOSED.	☐ YES	☐ NO	☐ N/A
(e) ALL TREATMENT UNITS IN SERVICE.	☐ YES	☐ NO	☐ N/A
(f) CONSULTING ENGINEER RETAINED OR AVAILABLE FOR CONSULTATION ON OPERATION AND MAINTENANCE PROBLEMS.	☐ YES	☐ NO	☐ N/A
(g) QUALIFIED OPERATING STAFF PROVIDED.	☐ YES	☐ NO	☐ N/A
(h) ESTABLISHED PROCEDURES AVAILABLE FOR TRAINING NEW OPERATORS.	☐ YES	☐ NO	☐ N/A
(i) FILES MAINTAINED ON SPARE PARTS INVENTORY, MAJOR EQUIPMENT SPECIFICATIONS, AND PARTS AND EQUIPMENT SUPPLIERS.	☐ YES	☐ NO	☐ N/A
(j) INSTRUCTIONS FILES KEPT FOR OPERATION AND MAINTENANCE OF EACH ITEM OF MAJOR EQUIPMENT.	☐ YES	☐ NO	☐ N/A
(k) OPERATION AND MAINTENANCE MANUAL MAINTAINED.	☐ YES	☐ NO	☐ N/A
(l) SPCC PLAN AVAILABLE.	☐ YES	☐ NO	☐ N/A
(m) REGULATORY AGENCY NOTIFIED OF BY PASSING. *(Dates ______ ______)*	☐ YES	☐ NO	☐ N/A
(n) ANY BY-PASSING SINCE LAST INSPECTION.	☐ YES	☐ NO	☐ N/A
(o) ANY HYDRAULIC AND/OR ORGANIC OVERLOADS EXPERIENCED.	☐ YES	☐ NO	☐ N/A

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SECTION J - Compliance Schedules

PERMITTEE IS MEETING COMPLIANCE SCHEDULE. ☐ YES ☐ NO ☐ N/A *(Further explanation attached ______)*

CHECK APPROPRIATE PHASE(S):

- ☐ (a) THE PERMITTEE HAS OBTAINED THE NECESSARY APPROVALS FROM THE APPROPRIATE AUTHORITIES TO BEGIN CONSTRUCTION.
- ☐ (b) PROPER ARRANGEMENT HAS BEEN MADE FOR FINANCING *(mortgage commitments, grants, etc.)*.
- ☐ (c) CONTRACTS FOR ENGINEERING SERVICES HAVE BEEN EXECUTED.
- ☐ (d) DESIGN PLANS AND SPECIFICATIONS HAVE BEEN COMPLETED.
- ☐ (e) CONSTRUCTION HAS COMMENCED.
- ☐ (f) CONSTRUCTION AND/OR EQUIPMENT ACQUISITION IS ON SCHEDULE.
- ☐ (g) CONSTRUCTION HAS BEEN COMPLETED.
- ☐ (h) START-UP HAS COMMENCED.
- ☐ (i) THE PERMITTEE HAS REQUESTED AN EXTENSION OF TIME.

SECTION K - Self-Monitoring Program

Part 1 – Flow measurement *(Further explanation attached ______)*

PERMITTEE FLOW MEASUREMENT MEETS THE REQUIREMENTS AND INTENT OF THE PERMIT. DETAILS:	☐ YES	☐ NO	☐ N/A
(a) PRIMARY MEASURING DEVICE PROPERLY INSTALLED.	☐ YES	☐ NO	☐ N/A
TYPE OF DEVICE: ☐ WEIR ☐ PARSHALL FLUME ☐ MAGMETER ☐ VENTURI METER ☐ OTHER *(Specify ______)*			
(b) CALIBRATION FREQUENCY ADEQUATE. *(Date of last calibration ______)*	☐ YES	☐ NO	☐ N/A
(c) PRIMARY FLOW MEASURING DEVICE PROPERLY OPERATED AND MAINTAINED.	☐ YES	☐ NO	☐ N/A
(d) SECONDARY INSTRUMENTS *(totalizers, recorders, etc.)* PROPERLY OPERATED AND MAINTAINED.	☐ YES	☐ NO	☐ N/A
(e) FLOW MEASUREMENT EQUIPMENT ADEQUATE TO HANDLE EXPECTED RANGES OF FLOW RATES.	☐ YES	☐ NO	☐ N/A

Part 2 – Sampling *(Further explanation attached ______)*

PERMITTEE SAMPLING MEETS THE REQUIREMENTS AND INTENT OF THE PERMIT. DETAILS:	☐ YES	☐ NO	☐ N/A
(a) LOCATIONS ADEQUATE FOR REPRESENTATIVE SAMPLES.	☐ YES	☐ NO	☐ N/A
(b) PARAMETERS AND SAMPLING FREQUENCY AGREE WITH PERMIT.	☐ YES	☐ NO	☐ N/A
(c) PERMITTEE IS USING METHOD OF SAMPLE COLLECTION REQUIRED BY PERMIT. IF NO, ☐ GRAB ☐ MANUAL COMPOSITE ☐ AUTOMATIC COMPOSITE FREQUENCY ______	☐ YES	☐ NO	☐ N/A
(d) SAMPLE COLLECTION PROCEDURES ARE ADEQUATE.	☐ YES	☐ NO	☐ N/A
(i) SAMPLES REFRIGERATED DURING COMPOSITING	☐ YES	☐ NO	☐ N/A
(ii) PROPER PRESERVATION TECHNIQUES USED	☐ YES	☐ NO	☐ N/A
(iii) FLOW PROPORTIONED SAMPLES OBTAINED WHERE REQUIRED BY PERMIT	☐ YES	☐ NO	☐ N/A
(iv) SAMPLE HOLDING TIMES PRIOR TO ANALYSES IN CONFORMANCE WITH 40 CFR 136.3	☐ YES	☐ NO	☐ N/A
(e) MONITORING AND ANALYSES BEING PERFORMED MORE FREQUENTLY THAN REQUIRED BY PERMIT	☐ YES	☐ NO	☐ N/A
(f) IF (e) IS YES, RESULTS ARE REPORTED IN PERMITTEE'S SELF-MONITORING REPORT.	☐ YES	☐ NO	☐ N/A

Part 3 – Laboratory *(Further explanation attached ______)*

PERMITTEE LABORATORY PROCEDURES MEET THE REQUIREMENTS AND INTENT OF THE PERMIT. DETAILS:	☐ YES	☐ NO	☐ N/A
(a) EPA APPROVED ANALYTICAL TESTING PROCEDURES USED. *(40 CFR 136.3)*	☐ YES	☐ NO	☐ N/A
(b) IF ALTERNATE ANALYTICAL PROCEDURES ARE USED, PROPER APPROVAL HAS BEEN OBTAINED.	☐ YES	☐ NO	☐ N/A
(c) PARAMETERS OTHER THAN THOSE REQUIRED BY THE PERMIT ARE ANALYZED.	☐ YES	☐ NO	☐ N/A
(d) SATISFACTORY CALIBRATION AND MAINTENANCE OF INSTRUMENTS AND EQUIPMENT.	☐ YES	☐ NO	☐ N/A
(e) QUALITY CONTROL PROCEDURES USED.	☐ YES	☐ NO	☐ N/A
(f) DUPLICATE SAMPLES ARE ANALYZED. ______ % OF TIME.	☐ YES	☐ NO	☐ N/A
(g) SPIKED SAMPLES ARE USED. ______ % OF TIME.	☐ YES	☐ NO	☐ N/A
(h) COMMERCIAL LABORATORY USED.	☐ YES	☐ NO	☐ N/A
(i) COMMERCIAL LABORATORY STATE CERTIFIED.	☐ YES	☐ NO	☐ N/A

LAB NAME ____________________

LAB ADDRESS ____________________

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SECTION L - Effluent/Receiving Water Observations *(Further explanation attached ______)*

OUTFALL NO.	OIL SHEEN	GREASE	TURBIDITY	VISIBLE FOAM	VISIBLE FLOAT SOL	COLOR	OTHER

(Sections M and N: Complete as appropriate for sampling inspections)

SECTION M - Sampling Inspection Procedures and Observations *(Further explanation attached ______)*

- ☐ GRAB SAMPLES OBTAINED
- ☐ COMPOSITE OBTAINED
- ☐ FLOW PROPORTIONED SAMPLE
- ☐ AUTOMATIC SAMPLER USED
- ☐ SAMPLE SPLIT WITH PERMITTEE
- ☐ CHAIN OF CUSTODY EMPLOYED
- ☐ SAMPLE OBTAINED FROM FACILITY SAMPLING DEVICE

COMPOSITING FREQUENCY ______________________ PRESERVATION ______________________

SAMPLE REFRIGERATED DURING COMPOSITING: ☐ YES ☐ NO

SAMPLE REPRESENTATIVE OF VOLUME AND NATURE OF DISCHARGE ______________________

SECTION N - Analytical Results *(Attach report if necessary)*

Instructions
for Completion of the
NPDES Compliance Inspection Report
(EPA Form 3560-3)

Overview

The intent of the NPDES Compliance Inspection Report form is to provide standard, reviewable information about an inspection to Enforcement. All inspections will be conducted and all reports will be completed as if they may lead to enforcement action. The form defines the minimum amount of information that Enforcement should receive. Regional and State inspectors may elect to include additional information, as the circumstances warrant.

Both Compliance Evaluation Inspections (CEIs) and Compliance Sampling Inspections (CSIs) of municipal and non-municipal facilities will be conducted using the same type of Compliance Inspection Report form (EPA Form 3560-3). Using the same form and format will minimize the reporting burden on inspectors and permittees because identical elements of compliance (e.g., permittee records and self-monitoring program, etc.) are examined in both CEIs and CSIs. Although the form may be used for either inspection, a completed form will be credited in only one category of the Formal Program Reporting System (FPRS). A completed form contains all the information appropriate to the accomplished inspection. A completed form is, by definition, also what will be accepted by the Enforcement Director of the agency responsible for enforcing the permit. Procedures for the distribution of the completed form should be planned with the Enforcement Director. Users should note that the top of page 1 serves as a coding sheet for entries into the Water Enforcement National Data Base (WENDB).

The Compliance Inspection Report consists of two major parts. The first part, sections A-L, is completed for all inspections, as appropriate. The second part, sections M-N, is completed only for CSIs. For the checklists, sections G through K, each lead statement will summarize deficiencies covered in the section. Each item in the checklist (except Section I items (n) & (o)) is written so that a "yes" answer is positive, indicating some degree of permit compliance. If there are no problems in a section, all the answers will be yes (with the exceptions noted above).

Throughout the form, numerous opportunities exist to attach additional explanations. These explanations should be attached only when necessary. Although a narrative is not appropriate when a simple yes, no, or N/A will do, inspectors must adequately document their observations. However, lengthy narratives will defeat the purpose of the checklists. Nonetheless, if further explanation is deemed necessary, it should be attached and noted on the form.

A brief review of each section follows. For further explanation of Compliance Inspections, consult the appropriate manuals. (NPDES Compliance Evaluation Inspection Manual - U.S. EPA, Office of Water Enforcement and NPDES Compliance Sampling Manual - U.S. EPA, Office of Water Enforcement).

Keypunch Summary

This lead information is used to identify the facility and the inspection date, type and agency. The data can be keypunched on one card and entered directly into the Water Enforcement National Data Base (WENDB). Entries in WENDB will assist tracking of inspection results and will be used for reporting in FPRS. To be part of the WENDB, the data should be reported as follows:

Column 1	Transaction Code - Use N, C, or D for New, Change or Delete. All inspections will be new unless there is an error in the data keypunched into WENDB.
Column 2	Card Code - always 5 for this card.
Columns 3-11	NPDES - The NPDES permit number. (The State permit number may be accommodated in the remarks or additional spaces).
Columns 12-17	Inspection Date - entered in the year/month/day format (e.g. 77/06/30 = June 1977).
Column 18	Inspection Type - An inspection will fall into one of two possible categories 'C' for Compliance Evaluation or 'S' for Compliance Sampling.

Column 19 — Inspector Code - An inspection may be performed by the Region, State or NEIC (U.S. EPA National Enforcement Investigations Center). It may also be the result of a joint effort. (Credit in FPRS for a joint inspection is given to the lead agency.) Acceptable codes for WENDB are:

- R - EPA Regional inspections
- S - State inspections
- J - Joint EPA and State inspections - EPA lead
- T - Joint EPA and State inspections - State lead
- N - NEIC inspections

Column 20 — Facility Type - This code describes the type of facility that was inspected. Acceptable codes are:

1 - Municipal - Publicly-Owned Treatment Works (POTWs) with 1972 Standard Industrial Classification (SIC) 4952

2 - Industrial - Other than Municipal, Agricultural, and Federal facilities.

3 - Agricultural - Those facilities classified with 1972 SIC 0111-0971.

4 - Federal - Those facilities identified as Federal by EPA Regional office.

Columns 21-70 — Remarks - This remarks field provides the inspector with a vehicle to store descriptive information about the inspection. There is no set format within this 50-position field. Individual Regions or States may choose to set aside portions of this field for their own specific needs.

The "Time" and "Additional" boxes can also describe the inspection, but will not be keypunched. Supplementary information that the performing agency or Region needs may be entered in the Additional box, e.g., STORET numbers, basin codes, etc.

Section A - Permit Summary

This section provides the summary information required to further identify the inspected facility. Most of the elements are self explanatory; however, the last two lines may require explanation. "Responsible Official" is the individual required to sign the Discharge Monitoring Report or is responsible for wastewater management at the facility. "Facility Representative" is the individual who acted as a contact during the inspection.

Section B - Effluent Characteristics

Effluent Characteristics contains a summary of those parameters (e.g. BOD, pH, flow) that are regulated by the permit and any other parameters that are measured but not regulated by the permit. If more than one outfall is inspected, the parameter and outfall should be indicated and additional sheets attached as required. If the inspection will not include samples, it may be advisable, but is not required, to substitute the data from the latest Discharge Monitoring Report in the "Sample Measurement" row before performing the inspection. However, if self-monitoring data are entered in the spots for sampling data, they should be clearly identified as such to avoid confusing the reviewer. The column marked "Additional" is for the performing agency's or Region's own requirements, e.g., design data, comments or explanations of the measurements.

Section C - Facility Evaluation

The Facility Evaluation provides a summary evaluation of the inspection results. The evaluations made in this section should be documented and supported by notation in the appropriate checklist portions of the form and by any additional comments as required.

Section D - Comments

Little space is allowed for comments here. Rather than fragmenting the narrative detailing comments and possible recommendations, the form allows detailed comments in an attachment, on the back of the form, or in Section N. The Section D comments should be used to flag lengthy comments (e.g. "Recommendations on p.4") or used for those inspections which only merit abbreviated comments. Procedures for making recommendations and comments should be worked out with the Enforcement Director of the organization responsible for the permit. All comments or recommendations that are made should be documented and supported by the checklist portions of the form.

Section E - Inspection Review

This section provides the inspector's and reviewer's names and agencies. Compliance status should be determined only by the Enforcement personnel.

Section F - Facility and Permit Background

If the permittee's address is different from that of the facility, it should be so indicated. If the facility was inspected previously, the date and findings summary should be noted before performing the current inspection.

Section G - Records and Reports

This portion of the form documents that the records and reports maintained by the permittee are in compliance with permit requirements. As mentioned earlier, if the checklist does not adequately represent the situation, further explaation should be attached and so indicated.

Section H - Permit Verification

Each inspection should identify discrepancies, if any, between the issued permit and actual conditions. Again, if further explanation is necessary, it should be provided and so indicated.

Section I - Operation and Maintenance

Each inspection of an operating facility should evaluate its operation and maintenance. Operating facilities include those on final limits and those in the process of being upgraded.

Section J - Compliance Schedule

The compliance schedule progress should be evaluated when the permittee is on a compliance schedule. Any grant-related inspections of facilities should be coordinated with Regional Construction Grants personnel. The current phase of compliance schedule status should be marked on the form.

Section K - Self-Monitoring Program

The permittee's flow measurement, sampling, and laboratory procedures should be checked, as appropriate, on all inspections. If deficiencies are noted, additional pertinent information should be provided, if necessary. For example, if the laboratory is not calibrating or maintaining the equipment satisfactorily, the calibration or maintenance intervals should be noted. If parameters other than those required by the permit are analyzed, the parameters and analytical methods should be noted. If the permittee laboratory, flow-measurement, or sampling procedures are not inspected, an explanation should be provided (e.g., contract lab off the premises).

Section L - Effluent/Receiving Water Observations

Visual observations made during the inspection should be noted, as applicable, for each outfall. The inspector's observations are subjective and qualitative, but serve to focus attention on potential treatment problems. Discharge of floating solids or visible foam in other than trace amounts is prohibited by the permit. Thus, observations of greater than trace amounts represent permit violations and indicate poor treatment.

Section M - Sampling Inspection Procedures and Observations

The performing agency's or Region's sampling procedures should be noted for each sampling inspection. Details documenting the procedures should be provided (e.g., the composite time interval).

Section N - Analytical Results

If the analytical results or laboratory report from a sampling inspection provides more information than can be inserted in Section C, the additional information should be noted in this part or attached to the report form. This section also offers more space for comments or additional materials (e.g. flow diagrams) as the situation merits.