CUTTHROAT FLUME

PHOTOS
RATING CURVE
TECHNICAL DOCUMENT

Sevier River, Leamington Canyon, Fall 2021

GREAT BASIN
ENVIRONMENTAL
& AQUATICS

Contents

Photos

Drawing- Parts

Photos

Photos 1 and 2. Cutthroat flume, Model GBECT-16s. A 16 inch throat with a max cfs of 6.0 cfs. Stainless steel model. Top photo inlet, bottom outlet.

Photos 3 and 4. Cutthroat flume, Model GBECT-16. A 16 inch throat with a max cfs of 6.0 cfs., flowing at 2 cfs. Galvanized steel model, 14 gauge. This is a free flow conditions.

GREAT BASIN ENVIRONMENTAL & AQUATICS

Photos 5 and 6. Cutthroat flume, Model GBECT-12. A 12 inch throat with a max cfs of 8.0 cfs., flowing at 4.97 cfs. Galvanized steel model. 12 gauge. This is a free flow conditions. Bottom photo is during assembly.

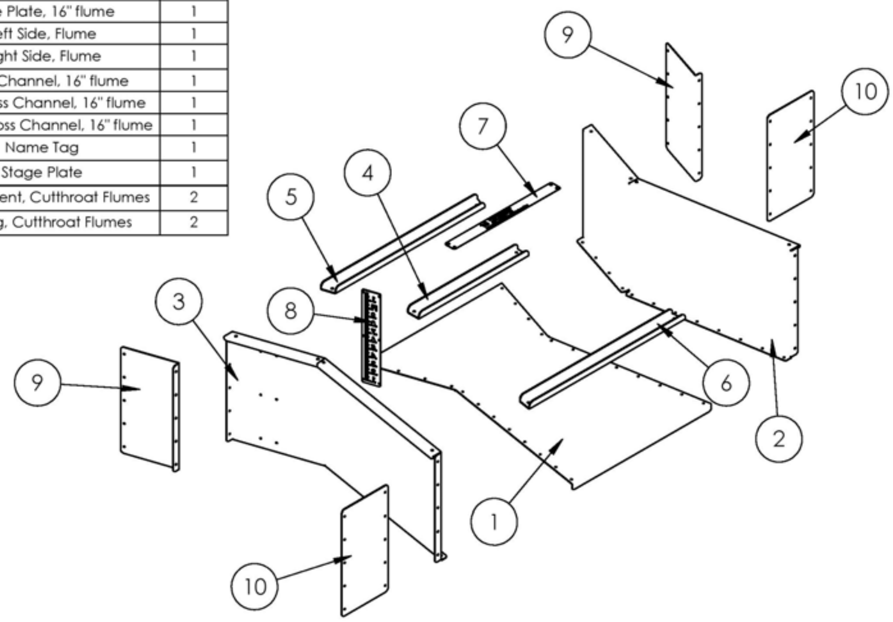
Photos 7. Cutthroat flume, Model GBECT-16. A 16 inch throat with a max cfs of 6.0 cfs., flowing at 1.0 cfs. Galvanized steel model. 14 gauge. This is a free flow conditions.

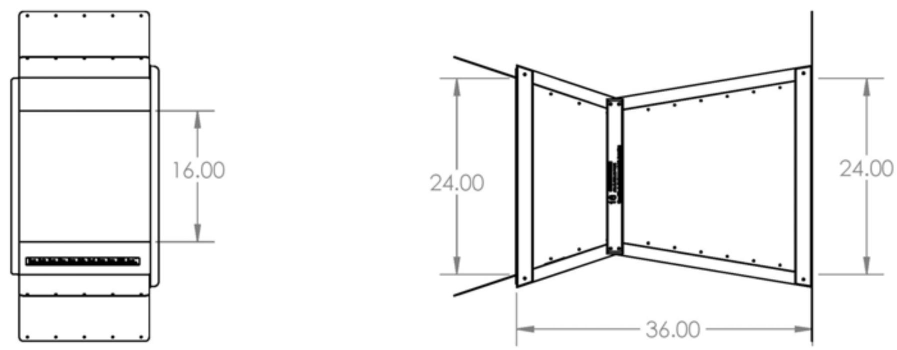
Photos 8. Cutthroat flume, Model GBECT-24. A 24 inch throat with a max cfs of 16.0 cfs. Galvanized steel model, 12 gauge.

GREAT BASIN ENVIRONMENTAL & AQUATICS

GBECT-16 **1 Per Assy**

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	GBECT-16-001	Base Plate, 16" flume	1
2	GBECT-16-002	Left Side, Flume	1
3	GBECT-16-003	Right Side, Flume	1
4	GBECT-16-004	Cross Channel, 16" flume	1
5	GBECT-16-005	Inlet Cross Channel, 16" flume	1
6	GBECT-16-006	Outlet Cross Channel, 16" flume	1
7	GBECT-16-007	Name Tag	1
8	GBECT-01	Stage Plate	1
9	GBECT-02	8" Wing Bent, Cutthroat Flumes	2
10	GBECT-03	8" Wing, Cutthroat Flumes	2





GBEA

Drawing 1. Cutthroat flume, GBECT-16, parts.

RATING TABLES

THREE SIZES
OF CUTTHROAT FLUMES

8" x 3 ft - 2.97 cfs maximum @ 1 ft
Model, GBECT-08

16" x 3 ft - 6.04 cfs Maximum @ 1 ft
Model, GBECT-16

&

24" x 54" - 16.09 cfs maximum @ 1.5 ft
Model, GBECT-24

FREE FLOW CONDITIONS ONLY

GREAT BASIN
ENVIRONMENTAL
& AQUATICS

Model GBECT-08, Free Flow Only

CUTTHROAT FLUME 8" X 3FT – 2.97 CFS MAXIMUM @ 1 FT

H_a is located at the stage plate (units - feet)

cfs = 2.970(H_a $^{1.84}$) gpm = 1332(H_a $^{1.84}$)

H_a	cfs	gpm	acre ft/day	H_a	cfs	gpm	acre ft/day
0.1	0.043	19.25	0.09	0.56	1.022	458.32	
0.11	0.051	22.94		0.57	1.056	473.49	
0.12	0.060	26.93		0.58	1.090	488.89	
0.13	0.070	31.20		0.59	1.125	504.51	
0.14	0.080	35.76		0.6	1.160	520.36	2.30
0.15	0.091	40.60	0.18	0.61	1.196	536.43	
0.16	0.102	45.72		0.62	1.232	552.72	
0.17	0.114	51.11		0.63	1.269	569.23	
0.18	0.127	56.78		0.64	1.307	585.97	
0.19	0.140	62.72		0.65	1.344	602.93	2.66
0.2	0.154	68.93	0.30	0.66	1.383	620.10	
0.21	0.168	75.40		0.67	1.421	637.50	
0.22	0.183	82.14		0.68	1.461	655.12	
0.23	0.199	89.14		0.69	1.501	672.96	
0.24	0.215	96.40		0.7	1.541	691.01	3.05
0.25	0.232	103.92	0.46	0.71	1.582	709.28	
0.26	0.249	111.70		0.72	1.623	727.77	
0.27	0.267	119.73		0.73	1.664	746.48	
0.28	0.285	128.02		0.74	1.707	765.40	
0.29	0.304	136.56		0.75	1.749	784.54	3.47
0.3	0.324	145.35	0.64	0.76	1.792	803.90	
0.31	0.344	154.39		0.77	1.836	823.47	
0.32	0.365	163.67		0.78	1.880	843.25	
0.33	0.386	173.21		0.79	1.925	863.25	
0.34	0.408	182.99		0.8	1.970	883.47	3.90
0.35	0.430	193.01	0.85	0.81	2.015	903.89	
0.36	0.453	203.28		0.82	2.061	924.53	
0.37	0.477	213.79		0.83	2.108	945.38	
0.38	0.501	224.55		0.84	2.155	966.45	
0.39	0.525	235.54		0.85	2.202	987.72	4.37
0.4	0.550	246.77	1.09	0.86	2.250	1009.21	
0.41	0.576	258.24		0.87	2.299	1030.91	
0.42	0.602	269.95		0.88	2.347	1052.82	
0.43	0.629	281.89		0.89	2.397	1074.93	
0.44	0.656	294.07		0.9	2.447	1097.26	4.85
0.45	0.683	306.49	1.35	0.91	2.497	1119.80	
0.46	0.712	319.14		0.92	2.548	1142.55	
0.47	0.740	332.02		0.93	2.599	1165.50	
0.48	0.770	345.13		0.94	2.650	1188.67	
0.49	0.799	358.48		0.95	2.703	1212.04	5.36
0.5	0.830	372.06	1.64	0.96	2.755	1235.62	
0.51	0.860	385.86		0.97	2.808	1259.40	
0.52	0.892	399.90		0.98	2.862	1283.39	
0.53	0.923	414.16		0.99	2.916	1307.59	
0.54	0.956	428.66		1	2.970	1332.00	5.89
0.55	0.989	443.38	1.96				

cfs = cubic feet/second gpm = gallons/minute

Caution !

If H_a is greater than 1 ft the values in this chart are not valid.

Model GBECT-16, Free flow Only

CUTTHROAT FLUME 16" X 3FT - 6.04 CFS MAXIMUM @ 1 FT

H_a is located at the stage plate (units - feet)

cfs = 6.04(H_a $^{1.84}$) gpm = 2710(H_a $^{1.84}$)

H_a	cfs	gpm	acre ft/day	H_a	cfs	gpm	acre ft/day
0.1	0.087	39.171	0.17	0.56	2.078	932.47	
0.11	0.104	46.68		0.57	2.147	963.34	
0.12	0.122	54.79		0.58	2.217	994.66	
0.13	0.141	63.48		0.59	2.288	1026.45	
0.14	0.162	72.75		0.6	2.360	1058.69	4.68
0.15	0.184	82.60	0.36	0.61	2.432	1091.38	
0.16	0.207	93.01		0.62	2.506	1124.53	
0.17	0.232	103.99		0.63	2.581	1158.13	
0.18	0.257	115.52		0.64	2.657	1192.18	
0.19	0.284	127.61		0.65	2.734	1226.68	5.42
0.2	0.313	140.24	0.62	0.66	2.812	1261.62	
0.21	0.342	153.41		0.67	2.891	1297.02	
0.22	0.372	167.12		0.68	2.971	1332.86	
0.23	0.404	181.36		0.69	3.052	1369.15	
0.24	0.437	196.14		0.7	3.133	1405.88	6.21
0.25	0.471	211.44	0.93	0.71	3.216	1443.06	
0.26	0.507	227.26		0.72	3.300	1480.68	
0.27	0.543	243.60		0.73	3.385	1518.74	
0.28	0.581	260.46		0.74	3.471	1557.24	
0.29	0.619	277.83		0.75	3.558	1596.18	7.05
0.3	0.659	295.71	1.31	0.76	3.645	1635.56	
0.31	0.700	314.10		0.77	3.734	1675.38	
0.32	0.742	333.00		0.78	3.824	1715.63	
0.33	0.785	352.40		0.79	3.914	1756.32	
0.34	0.830	372.30		0.8	4.006	1797.44	7.94
0.35	0.875	392.69	1.73	0.81	4.099	1839.00	
0.36	0.922	413.59		0.82	4.192	1880.99	
0.37	0.969	434.97		0.83	4.287	1923.41	
0.38	1.018	456.85		0.84	4.382	1966.27	
0.39	1.068	479.21		0.85	4.479	2009.56	8.88
0.4	1.119	502.06	2.22	0.86	4.576	2053.27	
0.41	1.171	525.40		0.87	4.675	2097.42	
0.42	1.224	549.22		0.88	4.774	2141.99	
0.43	1.278	573.52		0.89	4.874	2186.99	
0.44	1.333	598.30		0.9	4.976	2232.42	9.86
0.45	1.390	623.56	2.75	0.91	5.078	2278.27	
0.46	1.447	649.30		0.92	5.181	2324.55	
0.47	1.506	675.51		0.93	5.285	2371.25	
0.48	1.565	702.19		0.94	5.390	2418.38	
0.49	1.626	729.34		0.95	5.496	2465.93	10.89
0.5	1.687	756.96	3.34	0.96	5.603	2513.90	
0.51	1.750	785.05		0.97	5.711	2562.30	
0.52	1.813	813.61		0.98	5.820	2611.11	
0.53	1.878	842.63		0.99	5.929	2660.35	
0.54	1.944	872.12		1	6.040	2710.00	11.97
0.55	2.011	902.06	3.99				

cfs = cubic feet/second gpm = gallons/minute

Caution !

If H_a is greater than 1 ft the values in this chart are not valid.

Model GBECT-24 - Free Flow Only

CUTTHROAT FLUME 24" X 54" - 16.09 CFS MAXIMUM @ 1.5 FT

H_a is located at the stage plate (units - feet)

cfs = 8.01($H_a^{1.72}$) gpm = 3595($H_a^{1.72}$)

H_a	cfs	gpm	acre ft/day	H_a	cfs	gpm	acre ft/day
0.1	0.153	68.50	0.30	0.81	5.575	2502.03	
0.11	0.180	80.70		0.82	5.694	2555.40	
0.12	0.209	93.73		0.83	5.814	2609.24	
0.13	0.240	107.57		0.84	5.935	2663.54	
0.14	0.272	122.19		0.85	6.057	2718.31	12.00
0.15	0.307	137.59	0.61	0.86	6.180	2773.55	
0.16	0.343	153.74		0.87	6.304	2829.25	
0.17	0.380	170.64		0.88	6.429	2885.42	
0.18	0.419	188.26		0.89	6.555	2942.05	
0.19	0.460	206.61		0.9	6.682	2999.13	13.25
0.2	0.503	225.67	1.00	0.91	6.811	3056.68	
0.21	0.547	245.42		0.92	6.940	3114.68	
0.22	0.592	265.87		0.93	7.070	3173.14	
0.23	0.639	286.99		0.94	7.201	3232.06	
0.24	0.688	308.79		0.95	7.334	3291.42	14.54
0.25	0.738	331.25	1.46	0.96	7.467	3351.24	
0.26	0.790	354.37		0.97	7.601	3411.51	
0.27	0.843	378.13		0.98	7.736	3472.22	
0.28	0.897	402.54		0.99	7.873	3533.39	
0.29	0.953	427.59		1	8.010	3595.00	15.88
0.3	1.010	453.26	2.00	1.01	8.148	3657.06	
0.31	1.069	479.56		1.02	8.288	3719.56	
0.32	1.128	506.47		1.03	8.428	3782.50	
0.33	1.190	534.00		1.04	8.569	3845.88	
0.34	1.252	562.14		1.05	8.711	3909.71	17.27
0.35	1.317	590.88	2.61	1.06	8.854	3973.97	
0.36	1.382	620.21		1.07	8.999	4038.68	
0.37	1.449	650.14		1.08	9.144	4103.81	
0.38	1.517	680.65		1.09	9.290	4169.39	
0.39	1.586	711.75		1.1	9.437	4235.40	18.70
0.4	1.656	743.43	3.28	1.11	9.585	4301.84	
0.41	1.728	775.69		1.12	9.734	4368.72	
0.42	1.801	808.51		1.13	9.884	4436.02	
0.43	1.876	841.91		1.14	10.035	4503.76	
0.44	1.952	875.87		1.15	10.187	4571.93	20.19
0.45	2.028	910.38	4.02	1.16	10.340	4640.52	
0.46	2.107	945.46		1.17	10.493	4709.54	
0.47	2.186	981.09		1.18	10.648	4778.99	
0.48	2.267	1017.26		1.19	10.804	4848.86	
0.49	2.348	1053.99		1.2	10.960	4919.16	21.72
0.5	2.431	1091.26	4.82	1.21	11.118	4989.88	
0.51	2.516	1129.07		1.22	11.276	5061.02	
0.52	2.601	1167.41		1.23	11.436	5132.58	
0.53	2.688	1206.29		1.24	11.596	5204.56	
0.54	2.776	1245.71		1.25	11.758	5276.96	23.30
0.55	2.865	1285.65	5.68	1.26	11.920	5349.78	
0.56	2.955	1326.12		1.27	12.083	5423.02	
0.57	3.046	1367.11		1.28	12.247	5496.67	
0.58	3.139	1408.62		1.29	12.412	5570.74	
0.59	3.232	1450.66		1.3	12.578	5645.23	24.93
0.6	3.327	1493.20	6.59	1.31	12.745	5720.13	
0.61	3.423	1536.27		1.32	12.913	5795.44	
0.62	3.520	1579.84		1.33	13.081	5871.16	
0.63	3.618	1623.92		1.34	13.251	5947.29	
0.64	3.718	1668.51		1.35	13.422	6023.83	26.60
0.65	3.818	1713.60	7.57	1.36	13.593	6100.79	
0.66	3.920	1759.20		1.37	13.765	6178.15	
0.67	4.022	1805.29		1.38	13.939	6255.92	
0.68	4.126	1851.89		1.39	14.113	6334.09	
0.69	4.231	1898.98		1.4	14.288	6412.67	28.32
0.7	4.337	1946.56	8.60	1.41	14.464	6491.66	
0.71	4.444	1994.63		1.42	14.641	6571.05	
0.72	4.552	2043.20		1.43	14.819	6650.85	
0.73	4.662	2092.25		1.44	14.997	6731.04	
0.74	4.772	2141.79		1.45	15.177	6811.64	30.08
0.75	4.884	2191.82	9.68	1.46	15.357	6892.64	
0.76	4.996	2242.32		1.47	15.539	6974.04	
0.77	5.110	2293.31		1.48	15.721	7055.85	
0.78	5.224	2344.78		1.49	15.904	7138.04	
0.79	5.340	2396.72		1.5	16.088	7220.64	31.89
0.8	5.457	2449.14	10.82				

cfs = cubic feet/second gpm = gallons/minute

Caution !

If H_a is greater than 1.5 ft, the values in this chart are not valid. Free Flow Only

Selection and Installation of Cutthroat Flumes

for

Measuring Irrigation and Drainage Water

Gaylord V. Skogerboe, Ray S. Bennett, Wynn R. Walker
Colorado State University, Experiment Station
in cooperation with
Agricultural Engineering Department
College of Engineenng
December 1973

Selection and Installation of Cutthroat Flumes for Measuring Irrigation and Drainage Water

Colorado State University
Experiment Station, Fort Collins
Technical Bulletin 120

Selection and Installation of Cutthroat Flumes for Measuring Irrigation and Drainage Water

by

Gaylord V. Skogerboe
Ray S. Bennett
Wynn R. Walker

Colorado State University
Experiment Station
in cooperation with
Agricultural Engineering Department
College of Engineering

December 1973

12/73 2.75M(8472)

Abstract

SELECTION AND INSTALLATION OF CUTTHROAT FLUMES FOR MEASURING IRRIGATION AND DRAINAGE WATER

The Cutthroat flume has been developed for operation under both free flow and submerged flow conditions. The flume has a flat bottom, vertical walls, and a zero-length throat section. The most obvious advantage of a Cutthroat flume is economy of fabrication due to the flat bottom and elimination of the throat section common to other flow measuring flumes. Another advantage is that all flumes have the same convergence and divergence ratios, thereby allowing the same forms or patterns to be used for any throat width. The use of a consistent geometric shape has facilitated the development of generalized free flow and submerged discharge relations. Any flume length between 1.5 feet and 9 feet can be used, while throat widths between 1 inch and 6 feet have been investigated. The differences between free flow and submerged flow conditions are discussed and the necessary criteria for determining which flow regime exists are established. The transition submergences are given for the range of flume sizes investigated. For free flow, the ratio of inlet flow depth to flume length should preferably be less than 0.4. The accuracy of discharge measurement for submerged flow rapidly deteriorates above submergences of 95 percent. Examples are given which illustrate the design procedure for determining flume size, as well as obtaining the free flow and submerged flow ratings. Proper installation and maintenance procedures for Cutthroat flumes are described.

KEYWORDS - *drainage, flow measurement, *flumes, *hydraulics, hydraulic structures, *irrigation, *measuring instruments, open channel flow, subcritical flow.

Table of Contents

List of Figures

List of Tables

Nomenclature

B:	Entrance and exit width for Cutthroat flume, feet
C_1:	Free flow coefficient
C_2:	Submerged flow coefficient
h_a:	Upstream flow depth, feet
h_b:	Downstream flow depth, feet
Δh:	Difference in flow depth, $(h_a - h_b)$, feet
K_1:	Free flow flume length coefficient
K_2:	Submerged flow flume length coefficient
L:	Length of the Cutthroat flume, feet
M:	Constriction ratio for Cutthroat flume, (W/B)
n_1:	Free flow exponent
n_2:	Submerged flow exponent
Q:	Discharge through the flume, cubic feet per second (cfs)
S:	Submergence, (h_b/h_a)
S_t:	Transition submergence, the value of submergence at which the flow changes from free flow to submerged flow
W:	Flume throat width, feet

Introduction

Procedures and methods for more accurate measurement and improved management of water are continually being sought to make better use of our water resources. Of all the devices and structures developed for measuring water, measuring flumes are among the most widely accepted and used. The most common measuring flume is the Parshall flume developed by Ralph Parshall (1926) at Colorado State University.

The problem of determining the flow rate in open channels is one which has been considered for many years. The rapidly increasing value of water is commanding new interest in the development of new open channel flow measuring devices. Water measuring devices are important for: (a) water conservation; (b) equitable distribution of water; (c) determining the amount of available water; (d) meeting legal requirements; and (e) successful management of the available supply.

A water measuring flume consists of an open channel structure containing a constricted section. The constriction is formed by either raising the floor or by reducing the width between the sidewalls, or both. The discharge characteristics are the same for both types; however, the raised floor is usually classified as a weir rather than a flume. Also, unless great care is taken in designing the raised floor section, some of the self cleaning properties may be lost.

A flow measuring device which has been recently developed is the Cutthroat flume (Skogerboe, Hyatt, Anderson, and Eggleston, 1967). The original studies have been extended by Bennett (1972) in rating a group of Cutthroat flumes which have the same geometric shape. Then, since all of the flumes are basically similar, the flow behavior, or discharge characteristics, of other Cutthroat flume sizes can be predicted. Because of this similarity, the behavior of all flumes intermediate in size to those tested is capable of being predicted within a degree of accuracy suitable for field use.

In flat gradient channels, it may be desirable to install a flume to operate under conditions of submerged flow rather than free flow in order to: (1) reduce energy losses, and (2) place the flume on the channel bed to minimize the increase in water surface elevation upstream from the flume. The purpose of the research efforts reported herein was to develop a flume which would operate satisfactorily under both free flow and submerged flow conditions.

Development of Flume

Previous studies by Robinson and Chamberlain (1960) and Hyatt (1965) indicate that a flume having a flat bottom is satisfactory for both free flow and submerged flow operation. The advantages of a level flume floor, as opposed to the inclined floor in the throat and exit sections of the Parshall flume are: (a) ease of construction; (b) the flume can be placed inside a concrete-lined channel; and (c) the flume can be placed on the channel bed.

Ackers and Harrison (1963) recommend a maximum convergence of 3:1 for a flume inlet section. Experimental work indicated that this recommendation had merit, and consequently a 3:1 convergence (Fig. 1) was used in developing a flat-bottomed flume.

Earlier studies regarding the length of the throat section in flow measuring flumes, discussed in a preceding report (Skogerboe, Hyatt and Eggleston, 1967), showed that flow depths measured in the exit section of a flume resulted in more accurate submerged flow calibration curves than calibrations employing flow depth measurements in the throat section. The water surface profile changes rapidly in the throat section as compared with the exit section where the water surface profile is more nearly horizontal. Consequently, a flow depth in the exit section of the flat-bottomed flume was selected for measurement.

The earlier study by Hyatt (1965) indicated that when the divergence of the flume exit section exceeded 6:1 (for every 6 parts of length, the width increases by 1 part), separation would occur, and a major portion of the flow would adhere to one of the sidewalls. Although numerous divergences and lengths of exit section were tested, the 6:1 divergence proved most satisfactory as a balance between flow separation and fabrication costs.

Since the downstream flow depth was to be measured in the exit section, there appeared to be no apparent advantage in having a throat section. Consequently, testing was initiated with a flat-bottomed flume having only an entrance and an exit section. The flume performed very well. One distinct hydraulic advantage of removing the throat section was improved flow conditions in the exit section. The converging inlet section tended to confine the flow into a jet which traveled along the flume centerline, thus assisting in the prevention of flow separation.

The rectangular flat-bottomed flume, which resulted from the testing program, is illustrated in Fig. 1. Since the flume has no throat section (zero throat length), the flume was given the name "Cutthroat" by the developers (Skogerboe, Hyatt, Anderson, and Eggleston, 1967).

The most obvious advantage of a Cutthroat flume is economy, since fabrication is facilitated by a flat-bottom and removal of the throat section (zero throat length). Another advantage is that every flume length has the same entrance and exit section lengths, which allows the same forms or patterns to be used for any desired throat width.

The Cutthroat flume can operate either as a free or submerged flow structure as indicated in this report. Methods for obtaining submerged flow calibration curves and free flow tables are developed and their use illustrated. Discussion and examples regarding the practical aspects of installing, operating and maintaining the structures are given.

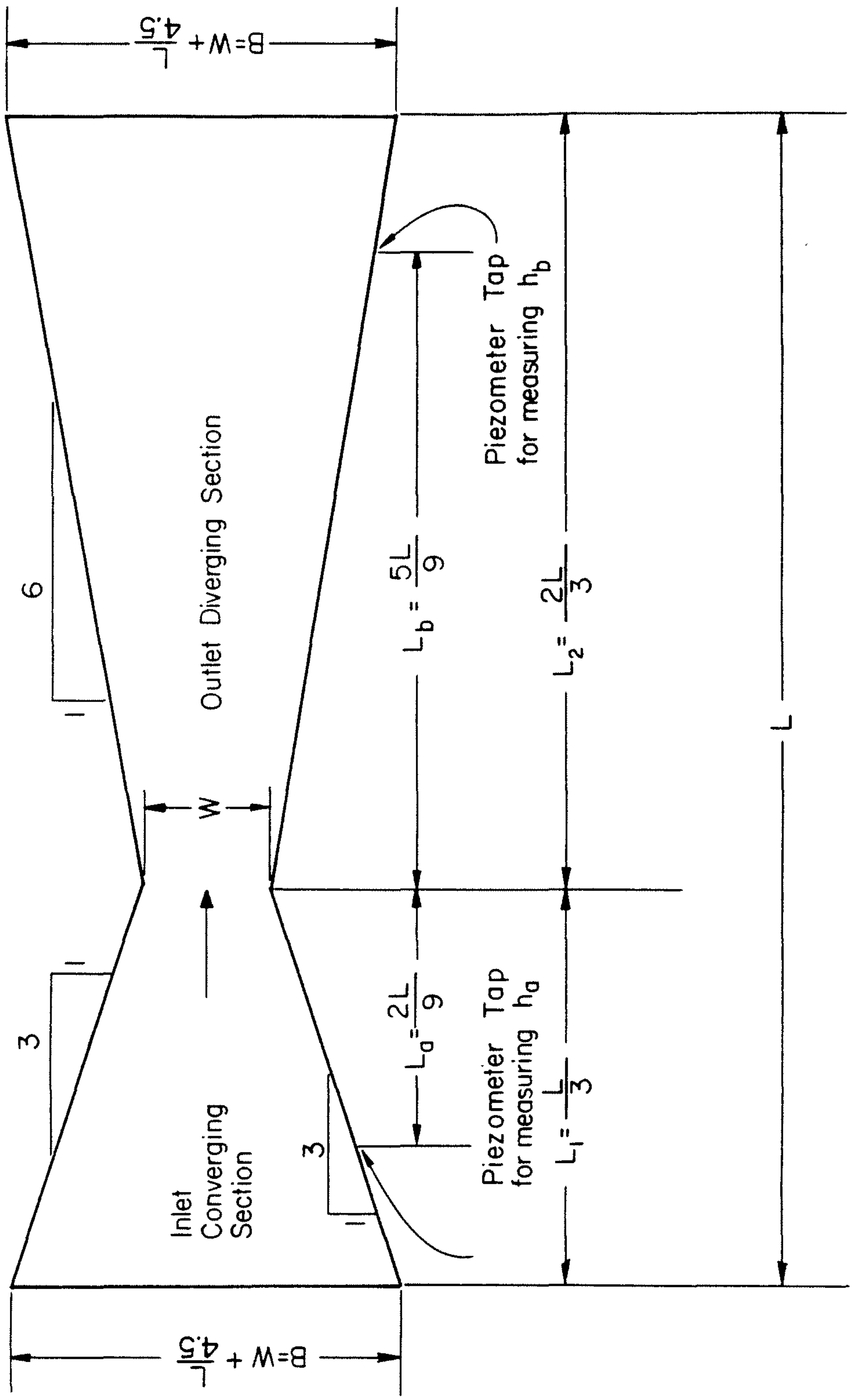


Figure 1. Definition sketch of a Cutthroat flume.

Free Flow Analysis

Under free flow conditions, critical depth occurs in the vicinity of minimum width, W , which is called the flume throat or the flume neck. The attainment of critical depth makes it possible to determine the flow rate knowing only an upstream depth (e.g., h_a). This is possible because whenever critical depth occurs in the flume the upstream depth, h_a , is not affected by changes in the downstream depth, h_b , as shown in Fig. 2 (water surface profiles i and ii). This results in a unique relation between discharge, Q , and upstream flow depth, h_a .

For free flow operation, the flow rate, Q , is plotted as a function of upstream depth, h_a . When these two variables are plotted on logarithmic paper, all of the points will fall on a straight line as shown in Fig. 3. The equation for this free flow rating can be written as:

$$Q = C_1 h_a^{n_1} \quad . . . . (1)$$

where Q = flow rate, in cubic feet per second, C_1 = free flow coefficient, which is the value of Q when h_a is 1.0 foot; which is the slope of the free flow rating when plotted on logarithmic paper.

The value of n_1 was found to be dependent only upon the flume depth, L . Therefore, the value of n_1 is a constant for all Cutthroat flumes of the same length, regardless of the throat width, W . Furthermore, the values of n_1 for the flumes tested plotted as a smooth curve as shown in Fig. 4. Therefore, the value of n_1 can be determined for any flume length between 1.5 feet and 9 feet by simply reading the value from the graphs shown in Fig. 4.

The value of the free flow coefficient is a function of both flume length, L , and throat width, W . This relationship is:

$$C_1 = K_1 W^{1.025} \quad . . . . (2)$$

where C_1 = the free flow coefficient; K_1 = the flume length coefficient; and W = the throat width in feet. The values of K_1 can be obtained from Fig. 4.

Having obtained the values for n_1 and C_1 for the flume being used, the discharge can now be calculated for any h_a by using Eq. 1, provided free flow conditions exist in the flume. For accurate discharge measurements, the recommended ratio of flow depth to flume length (h_a/L) should be equal to or less than 0.4, with increasing values of this ratio resulting in greater inaccuracies because of higher approach velocities and a more rapidly changing water surface profile at the flume cross-section where h_a is measured.

Example 1. A free flow rating is needed for a Cutthroat flume of length, L = 4.0 feet and width W = 1.167 feet. From Fig. 4 the value of n_1 is 1.75 and the value K_1 is 4.15. Then, using Eq. 2 the value of the free flow coefficient, C_1 is calculated.

$$\begin{aligned} C_1 &= K_1 W^{1.025} \\ &= 4.15\ (1.167)^{1.025} \\ &= 4.15\ (1.172) \\ &= 4.86 \end{aligned}$$

Now, knowing the values of n_1 and C_1 , the flow rate through the flume can be calculated for any value of h_a using Eq. 1. Assuming h_a = 1.20 feet

$$\begin{aligned} Q &= C_1 h_a^{n_1} \\ &= 4.86\ (1.20)^{1.75} \\ &= 4.86\ (1.38) \\ &= 6.70 \text{ cfs} \end{aligned}$$

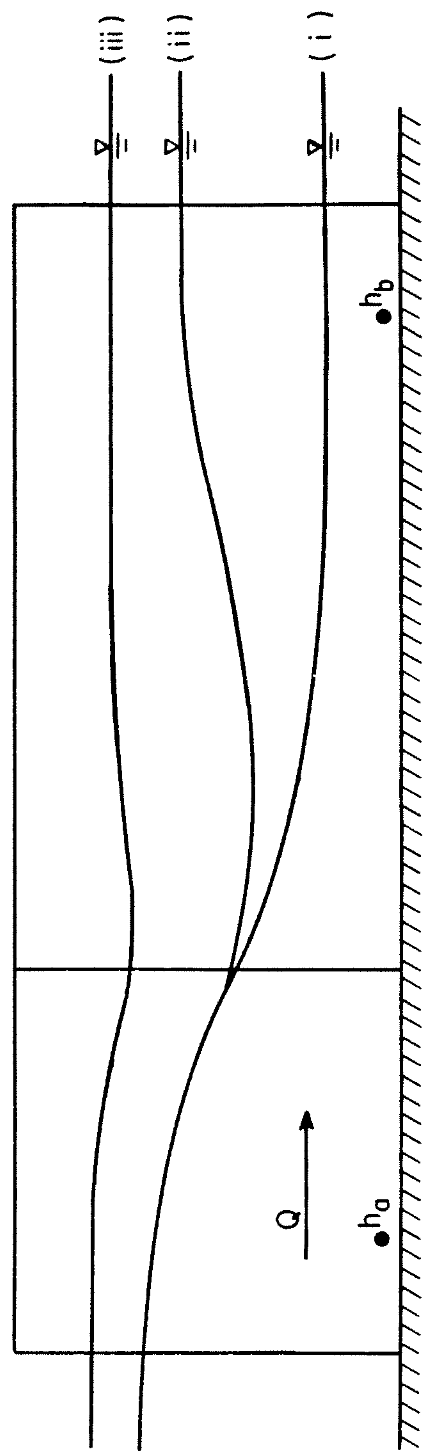


Figure 2. Illustration of flow conditions in a Cutthroat flume.

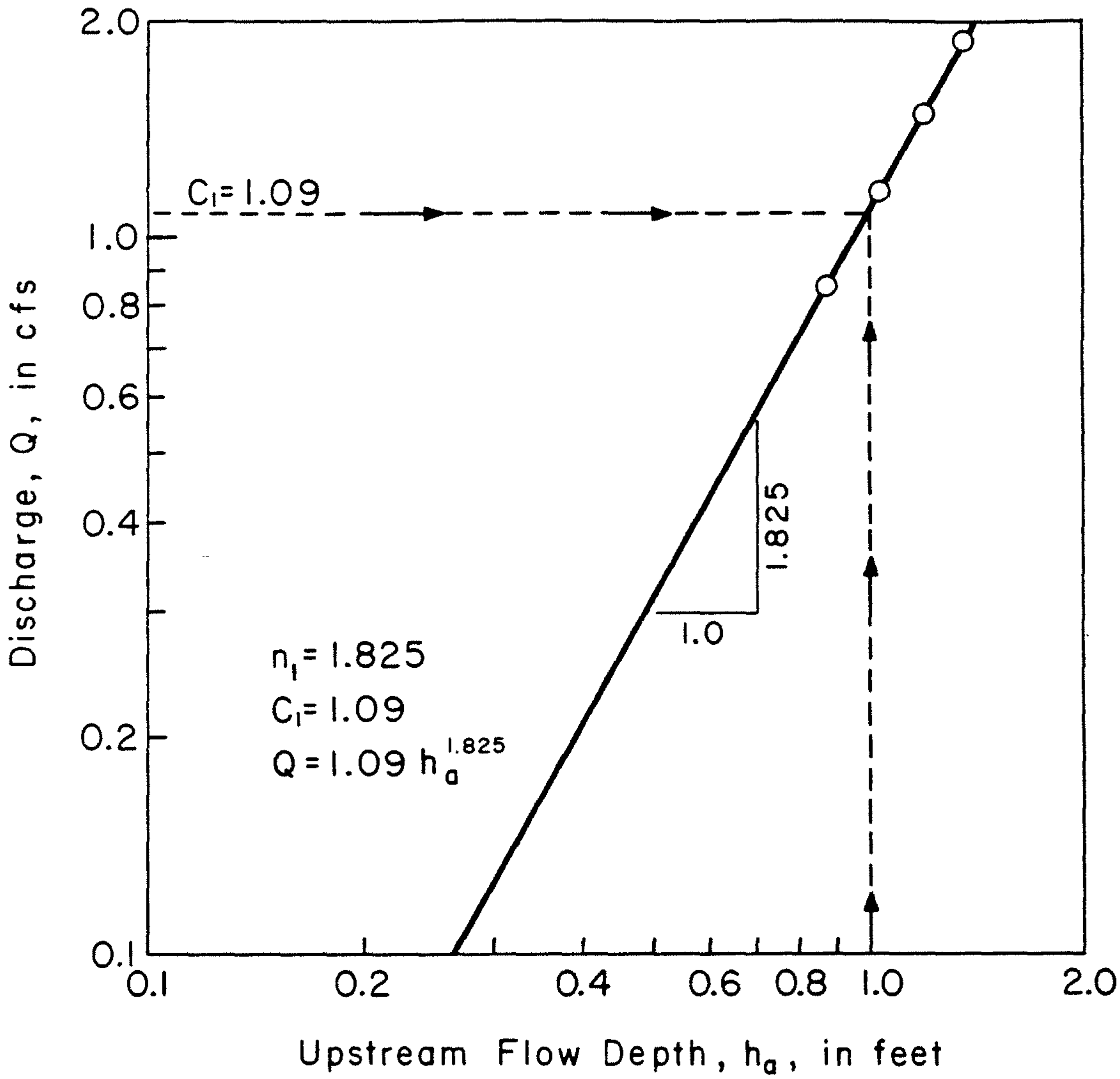


Figure 3. Typical free flow rating curve showing actual data points and development of free flow equation.

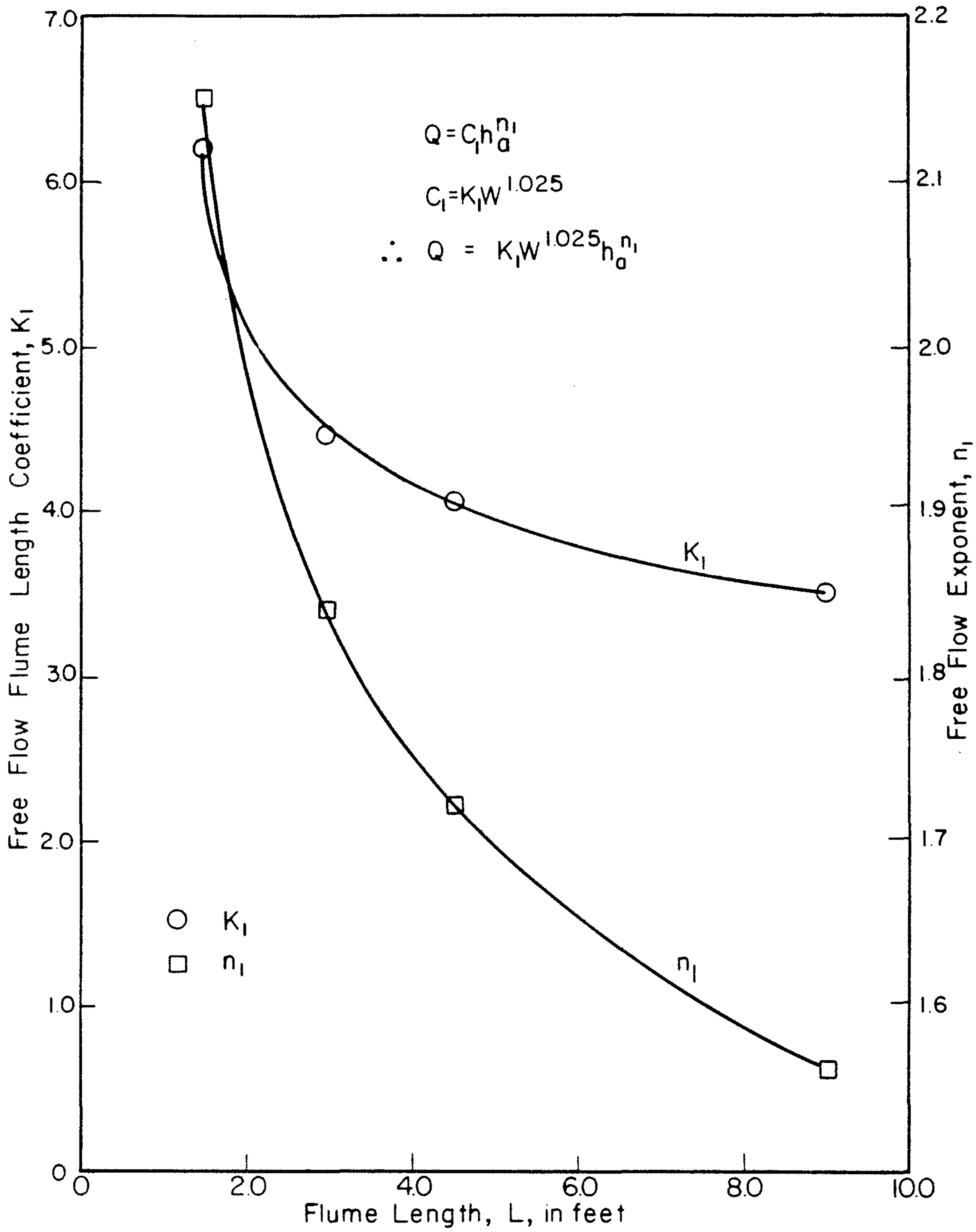


Figure 4. Generalized free flow ratings for Cutthroat flumes.

Submerged Flow Analysis

When the flow conditions are such that the downstream flow depth, h_b , is raised to the extent that the flow depths at every point through the structure become greater than critical depth (resulting in a change in the upstream depth) the flume is operating under submerged flow conditions as shown in Fig. 2 (water surface profile iii). A flume operating under submerged flow conditions requires that two flow depths be measured, one upstream (h_a) and one downstream (h_b) from the flume neck (also called the flume throat). The submergence, S , is defined as the ratio, often expressed as a percentage, of the downstream depth to the upstream depth.

$$S = h_b/h_a \quad \ldots\ldots\ldots \quad (3)$$

Submerged flow calibration curves are determined for the Cutthroat flume by preparing logarithmic plots of the parameters describing submerged flow. The discharge, Q , is the ordinate; the difference in upstream and downstream depths of flow, h_a-h_b , is the abscissa; and the submergence, h_b/h_a , is the varying parameter (Fig. 5). Lines are then drawn connecting points of equal submergence. These are straight lines having a slope identical to the slope of the free flow rating curve (which is n_1) for the same geometry.

From the submerged flow plots, an equation has been developed (Skogerboe, Hyatt, Anderson, and Eggleston, 1967) which describes the flow rate through the Cutthroat flume. The equation is:

$$Q = \frac{C_2\ (h_a-h_b)^{n_1}}{(-\log S)^{n_2}} \quad \ldots\ldots\ldots (4)$$

where C_2 = submerged flow coefficient; and n_2 = submerged flow exponent.

The value of C_2 and n_2 must be determined from a plot of the submerged flow data. This can be accomplished by determining the discharge intercept at $h_a - h_b = 1$ ($\Delta h = 1$), denoted by the symbol $Q_{\Delta h}$ and recognizing that $(h_a-h_b)^{n_1}$ is equal to one, when $h_a - h_b = 1$. Thus, Eq. 4 can be reduced to

$$Q_{\Delta h} = C_2\ (-\log S)^{-n_2} \quad \ldots\ldots\ldots (5)$$

By plotting $Q_{\Delta h}$ against $-\log S$ on logarithmic paper as shown in Fig. 6, a linear relationship should result, where C_2 is the value of $Q_{\Delta h}$ at $-\log S = 1$ and n_2 is the slope of the straight line.

The value of n_2 was also found to be dependent only on the flume length, L . Therefore, like n_1 , the value of n_2 is constant for all Cutthroat flumes of the same length regardless of the throat width. The values of n_2 for the experimental flumes are plotted on a smooth curve as shown in Fig. 7. Therefore, the value of n_2 can be obtained for any flume length between 1.5 feet and 9 feet by simply reading the value from the graph in Fig. 7.

The submerged flow coefficient is a function of both flume length and throat width. This relationship is:

$$C_2 = K_2 W^{1.025} \quad \ldots\ldots\ldots (6)$$

where C_2 = the submerged flow coefficient; K_2 = the flume length coefficient; and W = the throat width, in feet. The value of K_2 can be obtained from Fig. 7.

Having determined the values of n_2 and C_2 for the flume being used, the flow rate under submerged flow conditions can now be calculated for any combination of h_a and h_b by using Eq. 4. At high values of submergence (above 95 percent), small errors in reading h_a and h_b result in significant errors in calculating the discharge. Thus, as the submergence is increased above 95 percent, the discharge error becomes greater.

Example 2. A submerged flow rating is needed for a Cutthroat flume of length, L = 4.0 feet and width, W = 1.167 feet. From Fig. 4 the value of n_1 is 1.75. The values of n_2 and K_2 are found from Fig. 7 and are equal to 1.43 and 2.37, respectively. Knowing K_2 , the value of C_2 can be calculated using Eq. 6.

$$\begin{aligned} C_2 &= K_2\ (W)^{1.025} \\ &= 2.37\ (1.167)^{1.025} \\ &= 2.37\ (1.172) \\ &= 2.78 \end{aligned}$$

Knowing the values of n_1 , n_2 , and C_2 , the flow rate through the flume can be calculated for any value of h_a and h_b . Assuming h_a = 1.20 feet and h_b = 1.10 feet,

$$\begin{aligned} S &= 1.10/1.20 \\ &= 0.92 \\ Q &= \frac{C_2\ (h_a-h_b)^{n_1}}{(-\log S)^{n_2}} \\ &= \frac{2.78\ (1.20-1.10)^{1.75}}{(-\log 0.92)^{1.43}} = \frac{2.78(0.1)^{1.75}}{(0.0362)^{1.43}} \\ &= \frac{2.78\ (0.0178)}{0.0088} \\ &= 5.63 \text{ cfs} \end{aligned}$$

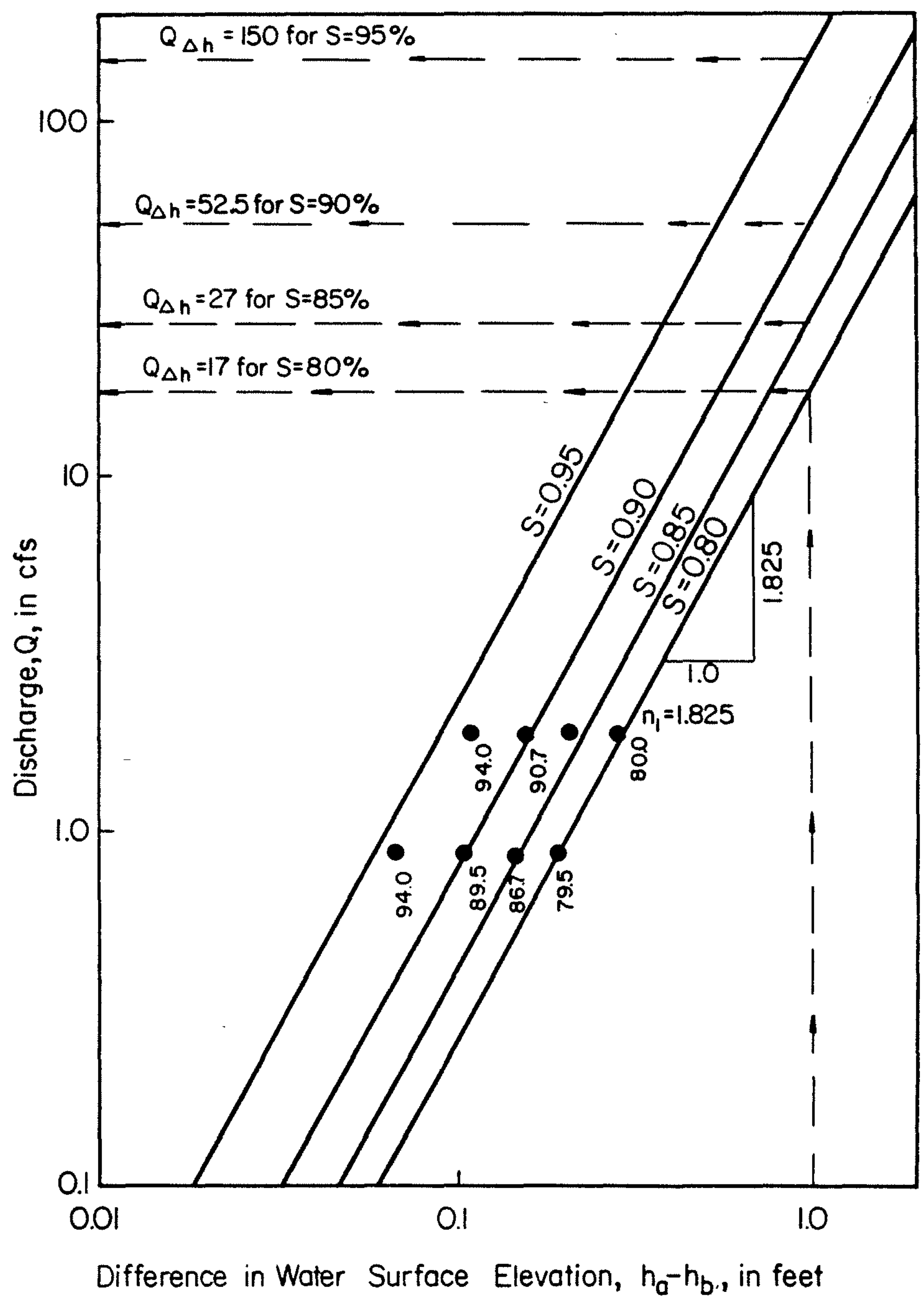


Figure 5. Typical submerged flow rating curve.

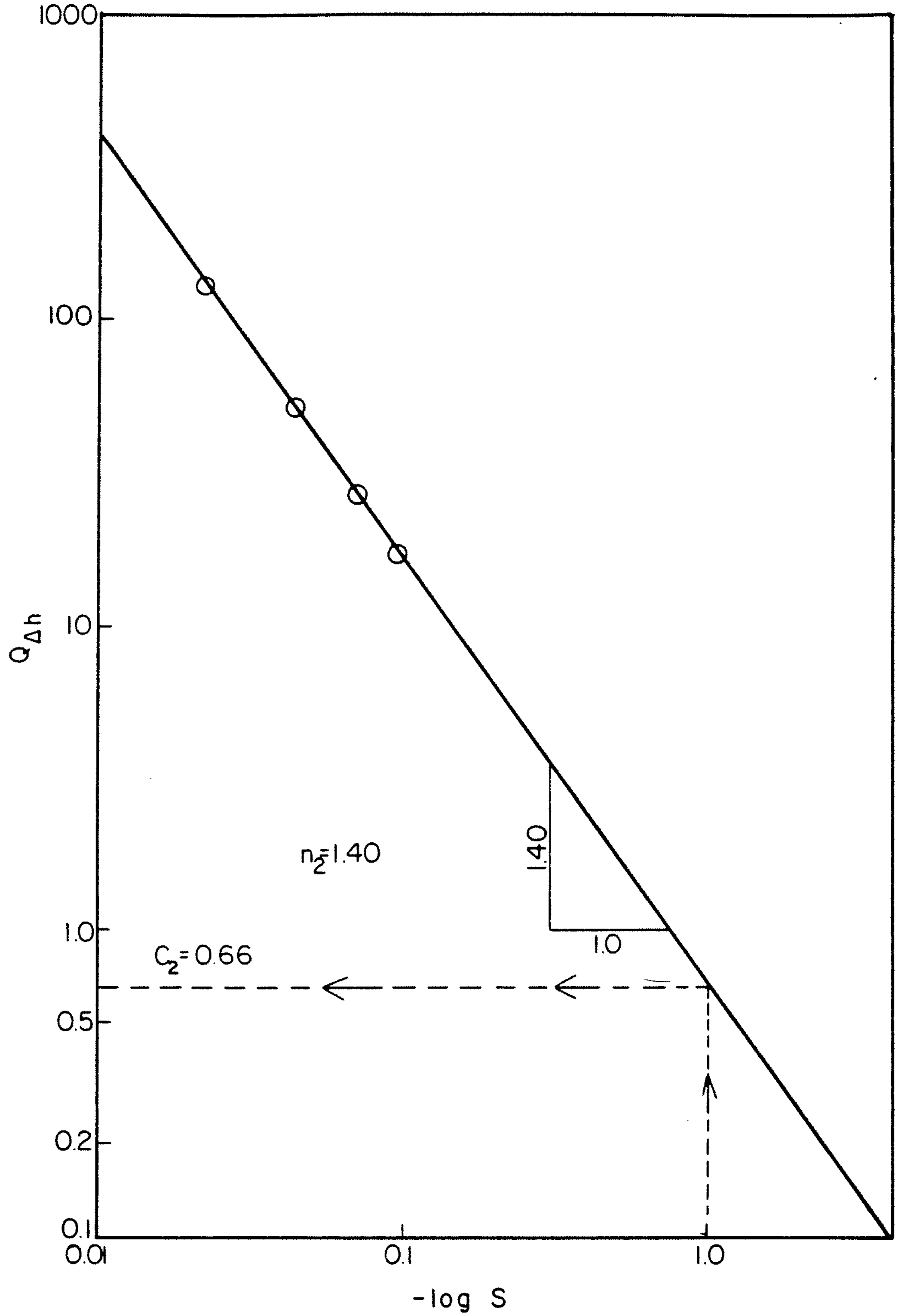


Figure 6. Typical plot for developing submerged flow coefficient, C_2 , and submerged flow exponent, n_2 .

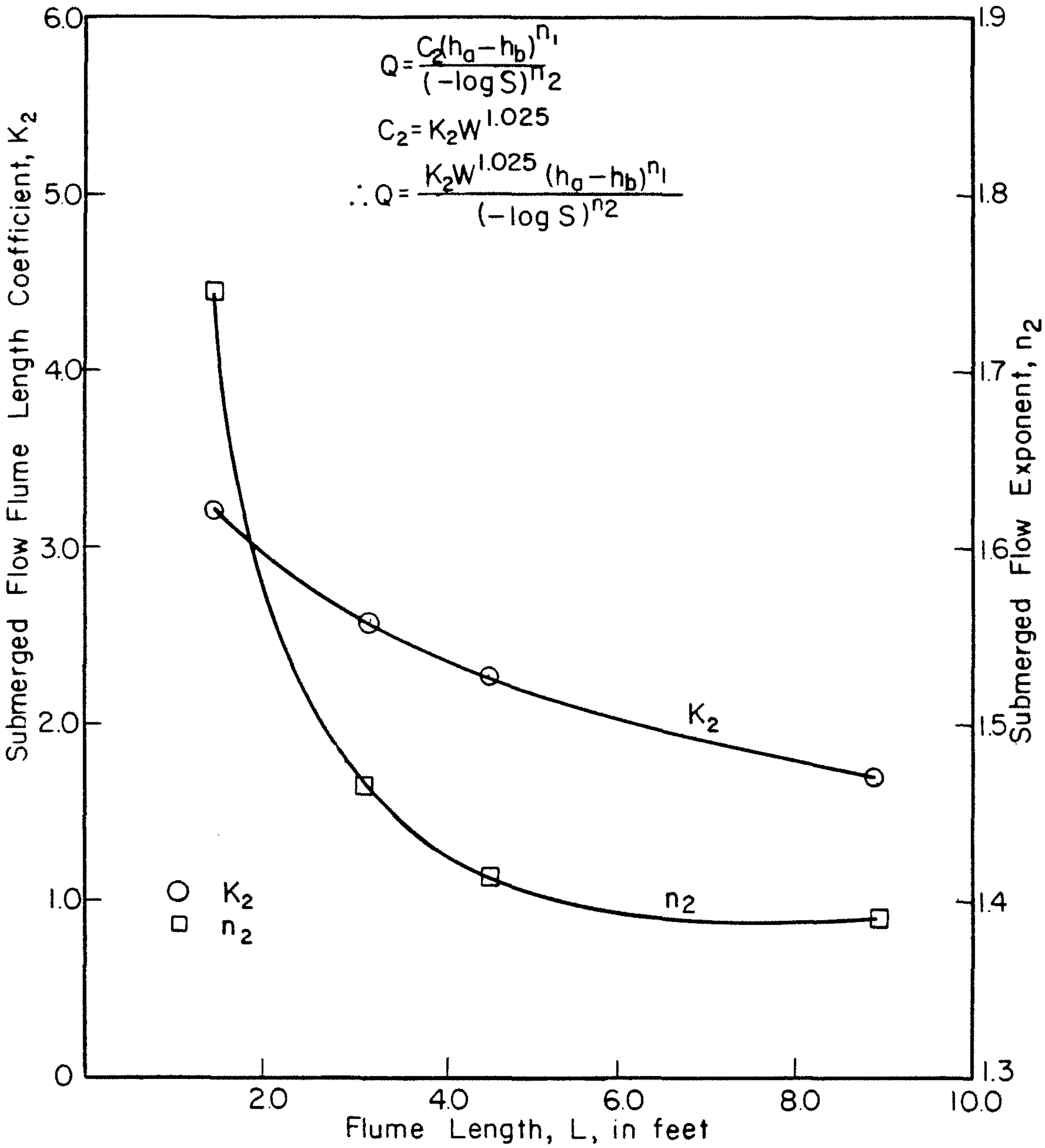


Figure 7. Generalized submerged flow ratings for Cutthroat flume.

Transition Submergence

The transition submergence, S_t , is the value of submergence at which the discharge passes from free flow to submerged flow, or vice versa (Fig. 2, water surface profile ii). Under this unique condition, both the free flow equation and the submerged flow equation will predict the same value of discharge.

To determine the transition submergence, S_t , the free flow and submerged flow equations (Eqs. 1 and 4) are set equal to one another.

$$C_1 h_a^{n_1} = \frac{C_2\ (h_a - h_b)^{n_1}}{-\log\ (h_b/h_a)^{n_2}} \quad . . . . . . (7)$$

Dividing both sides of Eq. 7 by $h_a^{n_1}$ in order to obtain an expression containing only the submergence and known values of coefficients and exponents, and then recognizing that the submergence is really the transition submergence, Eq. 7 can be reduced to:

$$(-\log\ S_t)^{n_2} = (C_2/C_1)\ (1 - S_t)^{n_1} . . . . .(8)$$

Equation 8 can be solved by trial and error to obtain the transition submergence.

In order to determine whether free flow or submerged flow conditions exist in a Cutthroat flume, or any flow measuring flume, it is necessary to calculate the submergence, which is then compared with the transition submergence to determine which flow equation should be used. If the submergence is less than the transition submergence, then free flow conditions exist. The flume is operating under submerged flow conditions if the submergence is greater than the transition submergence.

The values obtained for the coefficients and exponents for some common flume sizes are listed in Table 1. The relationship of these values with flume length are shown in Fig. 8. Table 2 has been prepared to provide a ready reference for converting the submergence, S (or transition submergence, S_t) to -log S .

Table 1. Summary of coefficients, exponents, and transition submergences for selected Cutthroat flume sizes.

Flume	4"x3'	8"x6'	12"x9'
C_1	1.458	2.468	3.500
n_1	1.840	1.645	1.560
K_1	4.500	3.740	3.500
C_2	0.836	1.346	1.700
n_2	1.475	1.390	1.380
K_2	2.580	2.040	1.700
S_t	0.650	0.740	0.800
Flume	**8"x3'**	**16"x6'**	**24"x9'**
C_1	2.970	5.011	7.130
n_1	1.840	1.645	1.560
K_1	4.500	3.740	3.500
C_2	1.703	2.734	3.463
n_2	1.475	1.390	1.380
K_2	2.580	2.040	1.700
S_t	0.650	0.740	0.800
Flume	**12"x3'**	**24"x6'**	**36"x9'**
C_1	4.500	7.618	10.780
n_1	1.840	1.645	1.560
K_1	4.500	3.740	3.500
C_2	2.580	4.155	5.236
n_2	1.475	1.390	1.380
K_2	2.580	2.040	1.700
S_t	0.650	0.740	0.800
Flume	**16"x3'**	**32"x6'**	**48"x9'**
C_1	6.030	10.210	14.498
n_1	1.840	1.645	1.560
K_1	4.500	3.740	3.500
C_2	3.457	5.569	7.038
n_2	1.475	1.390	1.380
K_2	2.580	2.040	1.700
S_t	0.650	0.740	0.800

Table 2. Values of -log S knowing the submergence, S .

S	-log S	S	-log S
0.65	0.1871	0.83	0.0809
0.66	0.1805	0.84	0.0757
0.67	0.1739	0.85	0.0706
0.68	0.1675	0.86	0.0655
0.69	0.1612	0.87	0.0605
0.70	0.1549	0.88	0.0555
0.71	0.1487	0.89	0.0506
0.72	0.1427	0.90	0.0458
0.73	0.1367	0.91	0.0410
0.74	0.1308	0.92	0.0362
0.75	0.1249	0.93	0.0315
0.76	0.1192	0.94	0.0269
0.77	0.1132	0.95	0.0223
0.78	0.1079	0.96	0.0177
0.79	0.1024	0.97	0.0132
0.80	0.0969	0.98	0.0088
0.81	0.0915	0.99	0.0044
0.82	0.0862		

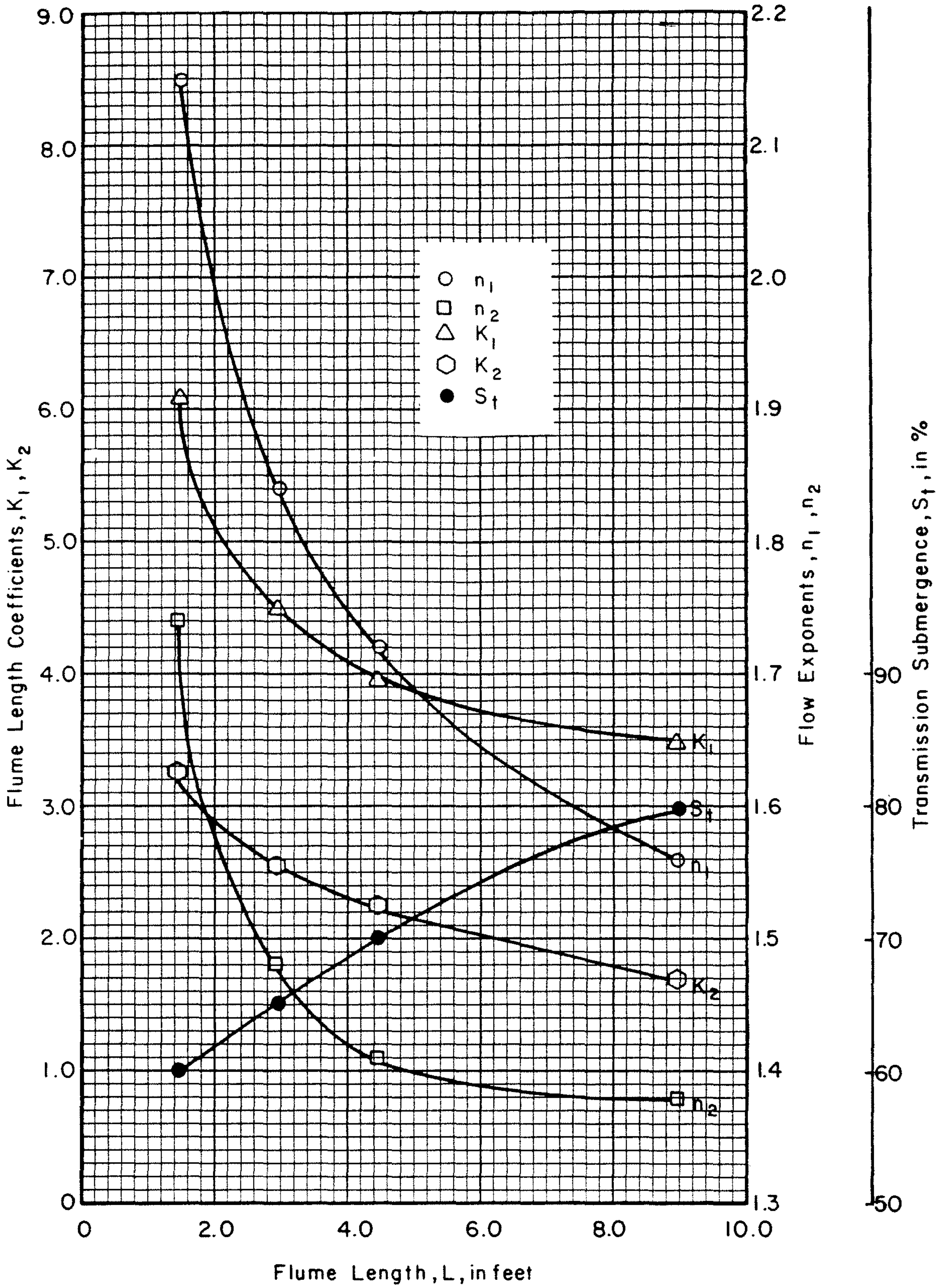


Figure 8. Generalized free flow and submerged flow coefficients and exponents and S_t for Cutthroat flumes.

Installation of Cutthroat Flumes

Any water measuring device must be properly installed to yield adequate results. The first consideration prior to installing a flume is the location or site of the structure. The flume should be placed in a straight section of channel. If operating conditions require frequent changing of the discharge, the flume may be conveniently located near a point of diversion or regulating gate. However, care should be taken to see that the flume is not located too near a gate because of unstable or surging effects which might result from the gate operation. Also, a Cutthroat flume should not be located immediately downstream from a constriction (e.g., culvert, gate, bridge pier, etc.).

After the site has been selected, it is necessary to determine certain design criteria. The maximum quantity of water to be measured, the depth of flow in the channel corresponding to this discharge, and the allowable head loss through the flume must be determined. For design purposes, the head loss may be taken as the difference in water surface elevation between the flume entrance and exit, which is approximately equal to $h_a - h_b$. The downstream depth of flow will remain essentially the same after installation of the flume as it was prior to installation, but the upstream depth will increase by the head loss. The allowable increase in upstream depth may be limited by the height of the canal banks upstream from the flume. Such a limiting condition dictates the minimum flume size, and may require operation as a submerged flow structure. Economic factors limit the maximum flume size.

A properly installed flume is aligned straight with the channel and should be level longitudinally and laterally. Flumes tend to settle in time, with the exit usually becoming lower than the entrance.

The most important dimension in constructing a Cutthroat flume is the throat width, W. One of the principal advantages of a Cutthroat flume is that an error in constructing the throat width can be taken into account by writing new free flow and submerged flow ratings using Eq. 2 for free flow and Eq. 6 for submerged flow. If a particular throat width is desired for a concrete Cutthroat flume, a steel angle could be embedded in the concrete, at the throat section.

The experience of the authors, both in the laboratory and field, indicates that a transition structure between the open channel and Cutthroat flume is not necessary. However, the ratio of flow depth to flume length (h_a/L) should be 0.4, or less. For most installations in flat gradient channels, this will insure that approach conditions will satisfy the laboratory conditions under which the ratings were developed

Measurements may be made in the flume by the use of staff gages or stilling wells (Fig. 9). Only fair accuracy is obtained from the use of staff gages. When used, a staff gage should be set vertically at the specified location for h_a and h_b along the converging or diverging wall. The staff gage must be carefully referenced to the elevation of the flume bottom. Use of stilling wells is recommended, however, for accuracy. Stilling wells have the advantage of providing a calm water surface compared with the fluctuation or "bounce" of the water surface that usually exists within the flume. Stilling wells are also necessary if continuous recording instruments are to be used. Under submerged flow conditions, two stilling wells placed adjacent to each other (Figs. 9b and 9c) are very desirable and facilitate the use of a double head recording instrument for obtaining a continuous record with time of h_a and h_b.

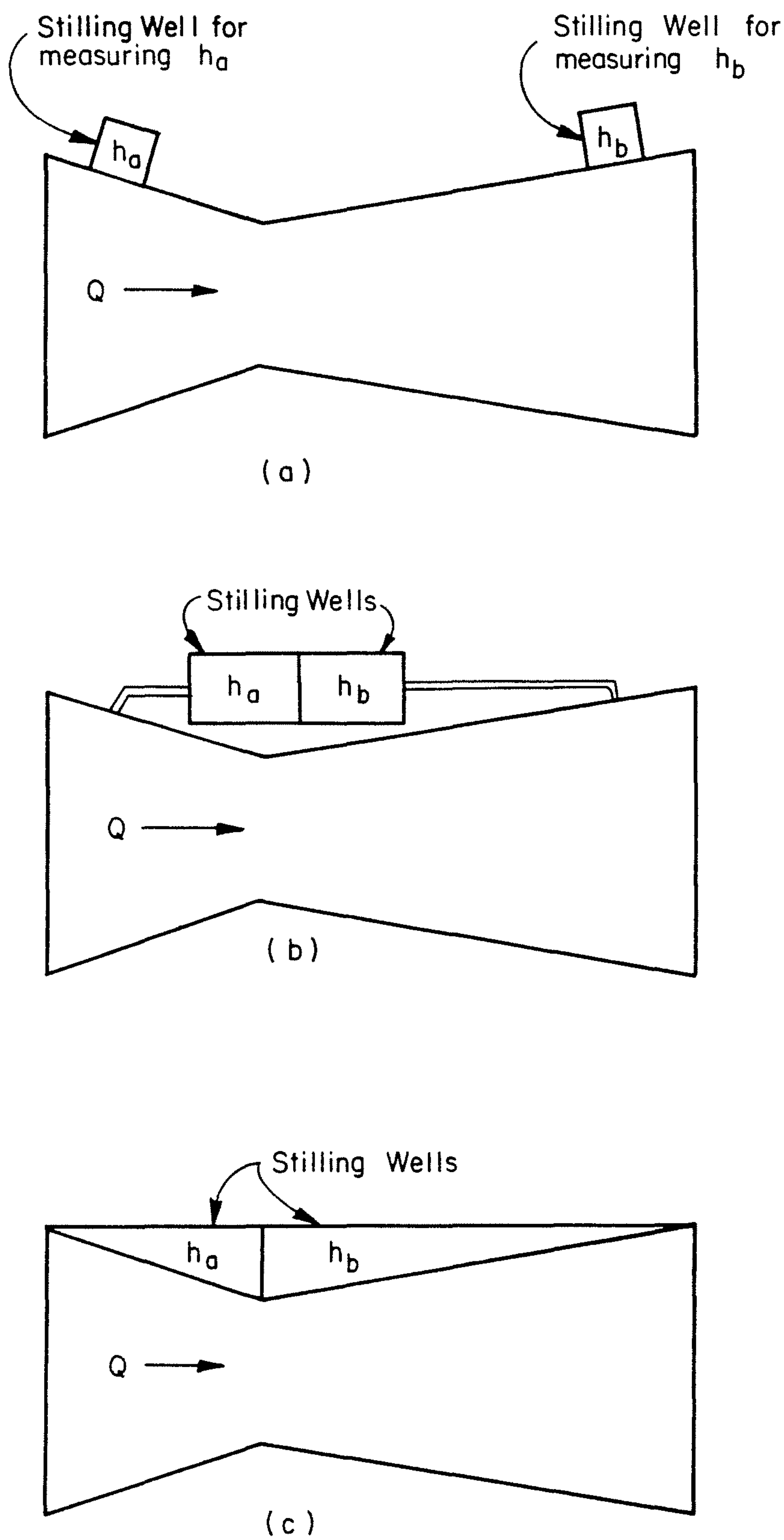


Figure 9. Plan view of Cutthroat flume showing various methods of constructing stilling wells.

Flume Installation to Insure Free Flow

If circumstances allow, it is preferable to have a flow measuring device operate under free flow conditions. The obvious advantage is that only the upstream flow depth need be measured to determine the discharge. The procedure to follow for installing a Cutthroat flume to operate under free flow conditions is listed below.

1. Determine the maximum flow rate to be measured.
2. At the site selected for installing the flume, locate the high water line on the canal bank and determine the maximum depth of flow.
3. Using Eq. 1, calculate the depth of water that corresponds to the maximum discharge capacity of the canal for a selected flume size.
4. Place the floor of the flume at an elevation which does not exceed h_a multiplied by the transition submergence $(S_t h_a)$ below the high water line (Fig. 10). Generally, the flume bottom should be placed as high as grade and other conditions permit to insure free flow.

Example 3. A Cutthroat flume of length, L = 4.0 feet and throat width, W = 1.167 feet is to be installed for free flow operation (Fig. 10). The maximum flow rate in the channel is 7 cfs.

The transition submergence for this flume can be determined from Fig. 8 as S_t = 68.2%. From Example 1, C_1 = 4.86 and n_1 = 1.75. From Eq. 1, the value of h_a that corresponds to 7 cfs can be calculated.

$$h_a = \left(\frac{Q}{C_1}\right)^{1/n_1}$$

$$h_a = \left(\frac{7}{4.86}\right)^{1/1.75} = (1.44)^{0.57}$$

$$= 1.23 \text{ feet}$$

The downstream flow depth, h_b, becomes

$$h_b = h_a S_t$$

$$= 1.23\ (0.682) = 0.84 \text{ feet}$$

Therefore, the floor of the flume should be placed no lower than 0.84 feet below the high water line in the canal.

Example 4. Suppose the Cutthroat flume size necessary to measure a maximum discharge of 12.5 cfs under free flow conditions must be found. Presently, the maximum flow depth in the canal is 0.95 foot and the head loss does not exceed 0.33 foot. Under these conditions, the maximum downstream flow depth would be 0.95 foot and the maximum upstream flow depth 1.28 feet (0.95 + 0.33 = 1.28). The submergence would be 74 percent (0.95 ÷ 1.28 = 0.74). From Fig. 8, we find that the only flumes with a transition submergence greater than 74 percent are those with a length of 6 feet. Therefore, a 9-foot flume length could be used. To select the proper flume size, enter Table 3 in the appendix under 2-foot flume to obtain a value of h_a corresponding to a discharge of 12.5 cfs. For this discharge value, the upstream depth is 1.44 feet, which is greater than the allowable maximum upstream depth of 1.28 feet. Hence, the 2-foot flume will have the capacity to measure the desired discharge, but will produce too great a head loss (1.44 - 0.95 = 0.49 foot). Consequently, a larger flume size is necessary to satisfy the imposed conditions. From Table 3, we find that the 3-foot flume has an upstream depth of 1.10 feet for a discharge of 12.5 cfs, and since this value is less than the restrictive depth of 1.28, it would be selected for use in this particular situation. A larger flume could be used, but the economic factors would make such a selection undesirable. Proper installation of the flume is shown in Fig. 11.

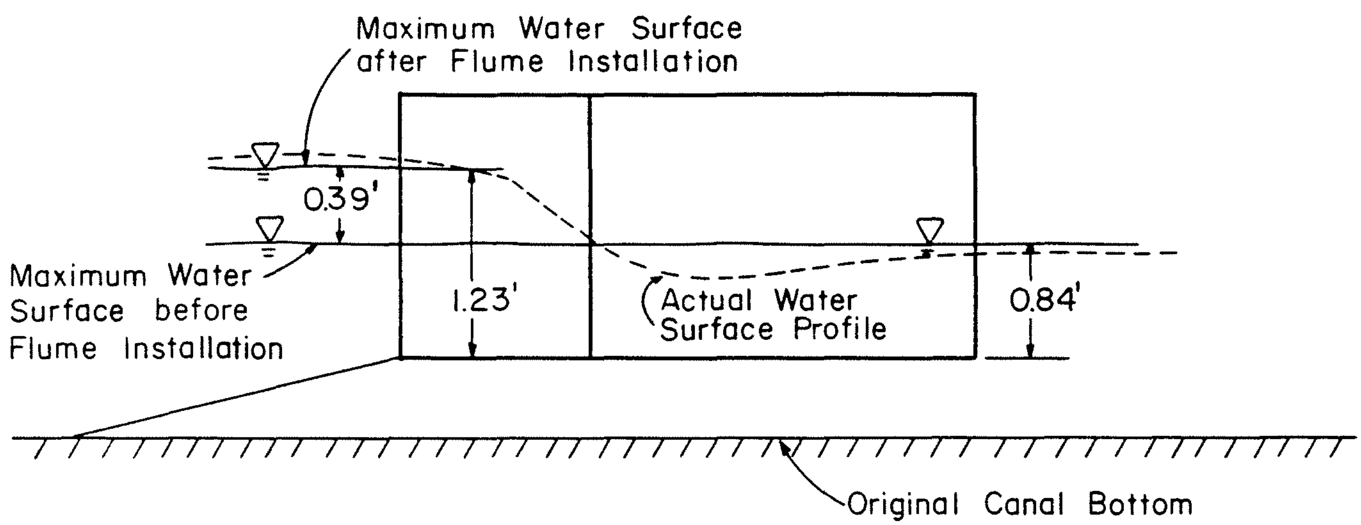


Figure 10. Installation of 14 inch throat width and 4-foot length Cutthroat flume.

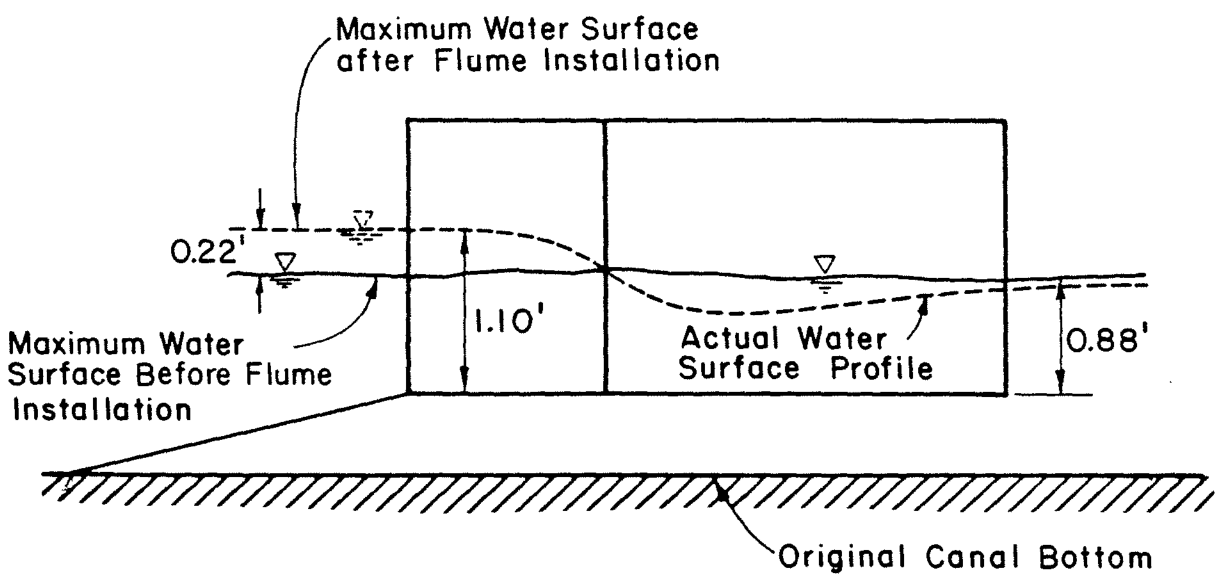


Figure 11. Installation of 3-foot throat width and 9-foot length Cutthroat flume.

Flume Installation for Submerged Flow

The existence of certain conditions, such as insufficient grade or the growth of moss and vegetation, sometimes makes it impossible or impractical to install a flume to operate under free flow conditions. Where such situations exist, a flume may be set in the canal to operate under submerged flow conditions. The principal advantage of submerged flow operation is the smaller head loss which occurs in the flume as compared with free flow. This reduction in head loss may mean that the canal banks upstream from the flume do not have to be raised to enable the same maximum flow capacity in the canal that existed prior to the installation of the flume. When a flat-bottomed Cutthroat flume is installed to operate under submerged flow conditions, the flume floor may be placed at the canal bottom. This placement will allow quicker drainage of the canal section upstream from the flume, particularly for flow rates which are less than the maximum discharge. The following procedure should be used in placing a Cutthroat flume to operate under submerged flow conditions.

1. Determine the maximum flow rate to be measured
2. On the canal bank, where the flume is to be installed, locate the high water line to determine the maximum flow depth.
3. Giving consideration to the amount of free-board in the canal at maximum discharge and maximum flow depth, determine how much higher the water surface can be raised in the canal upstream from the flume location.
4. With the floor of the flume being placed at essentially the same elevation as the bottom of the canal, the maximum depth of flow (step 2) becomes h_b , and the additional amount that the water surface in the canal can be raised (step 3), becomes $h_a - h_b$. Using this information, the submergence, h_b/h_a , can be computed.
5. Select the flume length desired. Then, from Fig. 8 determine the values of S_t , n_1 , K_2 , and n_2 that correspond to the chosen flume length.
6. Calculate the value of C_2 using the following equation

$$C_2 = \frac{Q(-\log S)^{n_2}}{(h_a-h_b)^{n_1}}$$

7. The throat width, W , can now be calculated by,

$$W = \left(\frac{C_2}{K_2}\right)^{0.976}$$

The value of W obtained from these equations is the smallest value that can be used and not exceed the upstream depth which was determined in step 4. If this value is not a convenient dimension, it should always be rounded upward. If the throat width is rounded downward, the allowable head loss will be exceeded.

Example 5. A Cutthroat flume is to be installed for submerged flow operation. The maximum flow rate in the channel is 7 cfs. The maximum flow depth in the channel is 1.5 feet. The maximum amount that the upstream depth can be raised is 0.2 feet. A flume length of 9 feet is selected. From Fig. 8 the values of S_t, n_1, n_2, and K_2 are determined as follows:

$$S_t = 0.80$$
$$n_1 = 1.560$$
$$n_2 = 1.380$$
$$K_2 = 1.70$$
$$h_a = 1.7 \text{ feet}$$
$$h_b = 1.5 \text{ feet}$$
$$S = 0.88$$
$$-\log S = 0.0555$$

From Eq. 4,

$$C_2 = \frac{Q(-\log S)^{n_2}}{(h_a - h_b)^{n_1}} = \frac{7(0.0555)^{1.380}}{(0.2)^{1.560}} = \frac{7(0.0179)}{(0.081)} = 1.55$$

From Eq. 6,

$$W = \left(\frac{C_2}{K_2}\right)^{0.976} = \left(\frac{1.55}{1.70}\right)^{0.976} = (0.912)^{0.976} = 0.914 \text{ feet}$$

Therefore, a flume width of 1 foot should be used. The flume would be installed at the elevation of the original floor of the canal.

Maintenance of Cutthroat Flumes

After a Cutthroat flume has been properly installed, periodic maintenance is required to insure satisfactory operation. Moss may collect on the walls of the entrance section and must be removed. In some channels, debris may collect on the floor of the entrance section, and should be removed. Walls of steel Cutthroat flumes may become encrusted and this should be removed with a steel-wire brush. Once the walls have been scraped clean, applying asphaltic paint will add to the life of the flume and delay the build-up of encrustation.

Commonly, Cutthroat flumes (or any other type of flow measuring flumes) will "settle" after being in operation for a period of time. The levelness of the entrance floor should be checked after a few months of operation, and again at the end of the season or year.

Either "settling" or improper installation can cause a flume to tilt sideways as illustrated in Fig. 12. If the settling is minor, the discharge can still be estimated with fair accuracy by measuring the flow depths on both sides of the flume. By employing the average of the two readings when using the discharge equations or rating tables, the discharge can be determined.

Settlement near the entrance section of a Cutthroat flume is illustrated in Fig. 13. And again, if the settlement is not too great, the discharge can be estimated with fair accuracy.

Settlement occurs most commonly near the exit section, as illustrated in Fig. 14. Settlement is more likely at the outlet because of channel erosion immediately downstream from the flume caused by the jetting action of the water. Use of the flow depths h_a or h_a and h_b to obtain the discharge from the equations or tables will yield values less than the true discharge. The discrepancy between the estimated discharge and the true discharge becomes greater as the amount of settlement increases. Satisfactory solutions to this problem include raising the lower end of the flume so that it is level again or placing a new level floor in the flume.

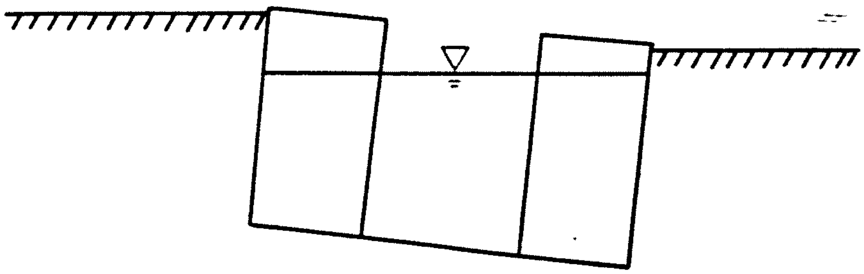


Figure 12. Cutthroat flume tilted sideways.

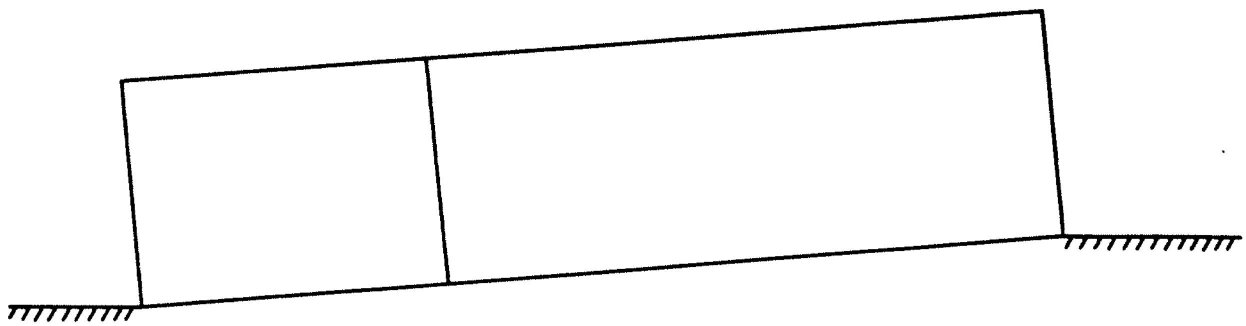


Figure 13. Settlement of Cutthroat flume at inlet section.

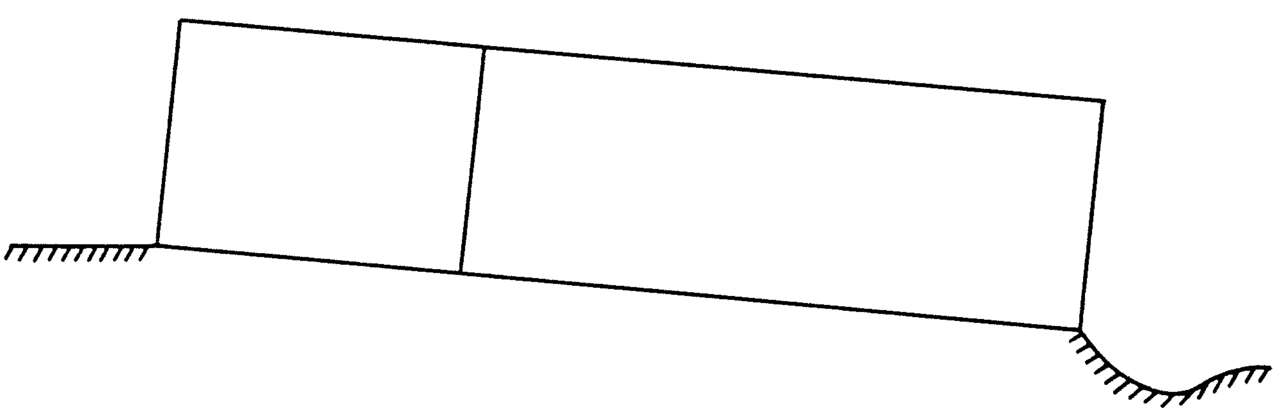


Figure 14. Settlement of Cutthroat flume at exit section.

References

Ackers, P., and Harrison, A. J. M., 1963. Critical-depth flumes for flow measurements in open channels. Hydraulic Research Paper No. 5. Hydraulics Research Station, Department of Scientific and Industrial Research. Wallingford, Berkshire, England. April.

Bennett, R. S., 1972. Cutthroat flume discharge relations. Thesis presented to Colorado State University, Fort Collins, Colorado, in partial fulfillment of requirements for the degree of Master of Science.

Hyatt, M. L., 1965. Design, calibration, and evaluation of a trapezoidal measuring flume by model study. Thesis presented to Utah State University, Logan, Utah, in partial fulfillment of requirements for the degree of Master of Science.

Parshall, R. L., 1926. The improved Venturi flume. Transactions, American Society of Civil Engineers, Vol. 89, pp. 841-880.

Robinson, A. R., and Chamberlain, A. R., 1960. Trapezoidal flumes for open channel flow measurement. Transactions, ASAE, 3(2):120-124, 128.

Skogerboe, G. V., Hyatt, M. L. and Eggleston, K. O., 1967. Design and calibration of submerged open channel flow measurement structures: Part 1, Submerged Flow. Report WG31-2, Utah Water Research Laboratory, College of Engineering, Utah State University, Logan, Utah. February.

Skogerboe, G. V., Hyatt, M. L., Anderson, R. K., and Eggleston, K. O., 1967. Design and calibration of submerged open channel flow measurement structures: Part 3, Cutthroat flumes. Report WG31-4, Utah Water Research Laboratory, College of Engineering, Utah State University, Logan, Utah. April.

Skogerboe, G. V., and Hyatt, M. L., 1967. Analysis of submergence in flow measuring flumes. Journal of the Hydraulics Division, ASCE, Vol. 93, No. HY4, Proc. Paper 5348, July, pp. 183-200.

Skogerboe, G. V., and Hyatt, M. L., 1967. Rectangular Cutthroat flow measuring flumes. Journal of the Irrigation and Drainage Division, ASCE, Vol. 93, No. IR4, December, pp. 1-13.

Skogerboe, G. V., Bennett, R. S. and Walker, W. R., 1972. Generalized discharge relations for Cutthroat flumes. Journal of the Irrigation and Drainage Division, ASCE, Vol. 98, No. IR4, December, pp. 569-583.