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9. BSTRACT

A description of the "Cutthroat" flume, a simple yet accurate method of measuring water. It is suited especially to open irrigation channels on flat terrain, is relatively easy and inexpensive to construct, is self-cleaning, and can be used in a wide range of conditions under which irrigated agriculture is practiced. The most obvious advantage of a "Cutthroat" flume is economy, since fabrication is facilitated by a flat-bottom and removal of the throat section. 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 flume can operate either as a free flow or a submerged flow structure. Methods for obtaining submerged flow calibration curves have been developed, and free flow tables are available for various sized flumes.

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CUTTHROAT FLUMES FOR WATER MEASUREMENT

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PREFACE

This bulletin describes a simple yet accurate method of measuring water. It is especially suited for open irrigation channels on flat terrain. The device is relatively easy and inexpensive to construct and is self-cleaning. It should have application over a wide range of conditions where irrigated agriculture is practiced.

The Office of Agriculture, Technical Assistance Bureau (TA/AGR) is issuing a series of technical papers on subjects of primary importance to the developing countries. As is the case with previous issues in this series, this one treats its subject in a general sense and it does not attempt to deal with the particular problems of a specific country. This bulletin is the outgrowth of research efforts of Colorado State University, who has received an AID 211(d) institutional grant for strengthening research and training capacity in irrigation water delivery, in order to assist developing nations in agricultural production problems on small farms.

Additional copies of this Bulletin may be obtained from TA/AGR, through the U.S. Agency for International Development Missions (USAIDs), or through Regional Offices of AID overseas. Requests for more information regarding this publication may be directed to the authors or to this office.

Leon F. Hesser
Acting Director
Office of Agriculture
Technical Assistance Bureau
Agency for International
Development
Washington, D.C. 20523

CUTTHROAT FLUMES FOR WATER MEASUREMENT

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, 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.

WATER MEASURING FLUMES

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. 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.

The Parshall flume combines all of the attributes necessary to the solution of water measurement problems. It is accurate, entails a minimum of head loss and is self cleaning. The one drawback to the use of the Parshall flume, particularly in the less developed countries, is the difficulty of construction. The configuration of the throat section of a Parshall flume, including a sloping floor, makes its construction and field installation difficult.

THE CUTTHROAT 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 Parshall flume with an inclined floor in the throat and exit sections, 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. Subsequently, additional laboratory studies were conducted by Skogerboe, Hyatt, Anderson and Eggleston (1967) regarding the length of the throat section and the exit section. A 6:1 flume exit section eliminates many of the problems of flow separation in a measuring flume. Also, it was found that flow depth as measured in the exit section of a flat bottom flume was more accurate than measurement in the throat section.

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 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).

ADVANTAGES OF CUTTHROAT FLUME

The most obvious advantage of a "Cutthroat" flume is economy, since

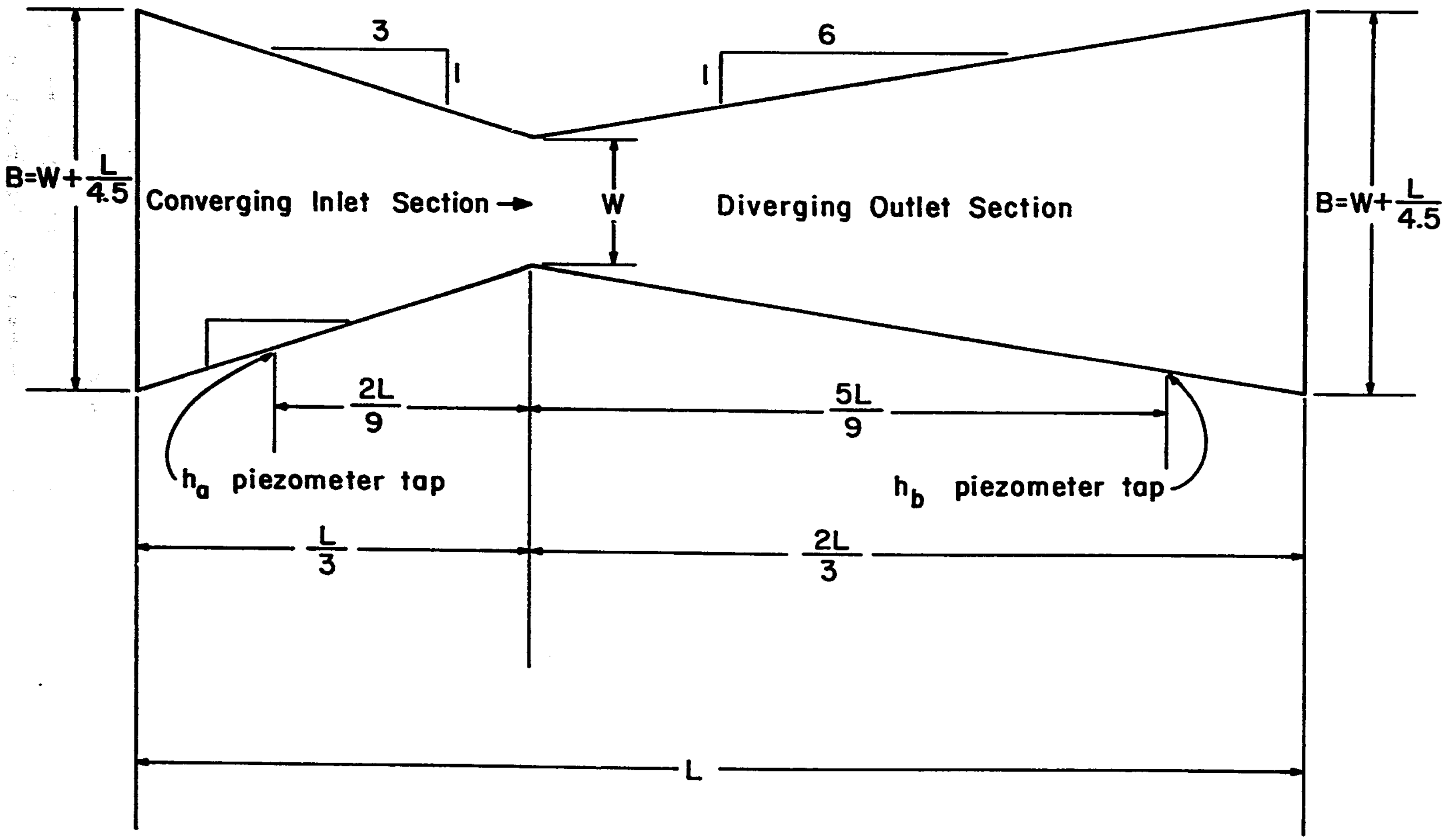


Fig. 1– Definition Sketch of Cutthroat flume.

fabrication is facilitated by a flat-bottom and removal of the throat section. 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 flume can operate either as a free flow or a submerged flow structure. Methods for obtaining submerged flow calibration curves have been developed and free flow tables are available for various sized flumes.

Since all of the flumes are basically similar, the flow behaviour, 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.

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 culvert, or any other type of constriction.

After the site has been selected for the flume, it is necessary to determine certain design criteria. The maximum quantity of water to be measured, the depth of flow necessary to obtain this discharge, and the allowable head loss through the flume must be determined. For design purposes, the head loss may be taken as the change in water surface elevation between the flume entrance and exit. 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 amount of head loss. The allowable increase in upstream depth may be limited by the height of canal banks upstream from the flume. Such a limiting condition may require increasing the flume size, or operating the flume as a submerged flow structure. Economic factors play a determining role in the flume size selected.

Proper installation requires the flume to be placed level in the channel. The flume should be aligned straight with the channel and should be level longitudinally and laterally. Note that with time the tendency is for the flume to settle with the exit 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 for whatever throat width is constructed. If a particular throat width is desired for a Cutthroat flume to be constructed with concrete, a steel angle could be placed at the throat cross-section which would be embedded in the concrete.

The only restriction is to follow the guideline of using a flow depth to flume length ratio (h_a/L) of 0.4, or less. For usual installations in flat gradient channels, this will insure that approach conditions will satisfy the conditions under which the laboratory ratings were developed.

Measurements may be made in the flume by the use of staff gages or stilling wells (Fig. 2). 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 of "bounce" of the water surface that may exist 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 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.

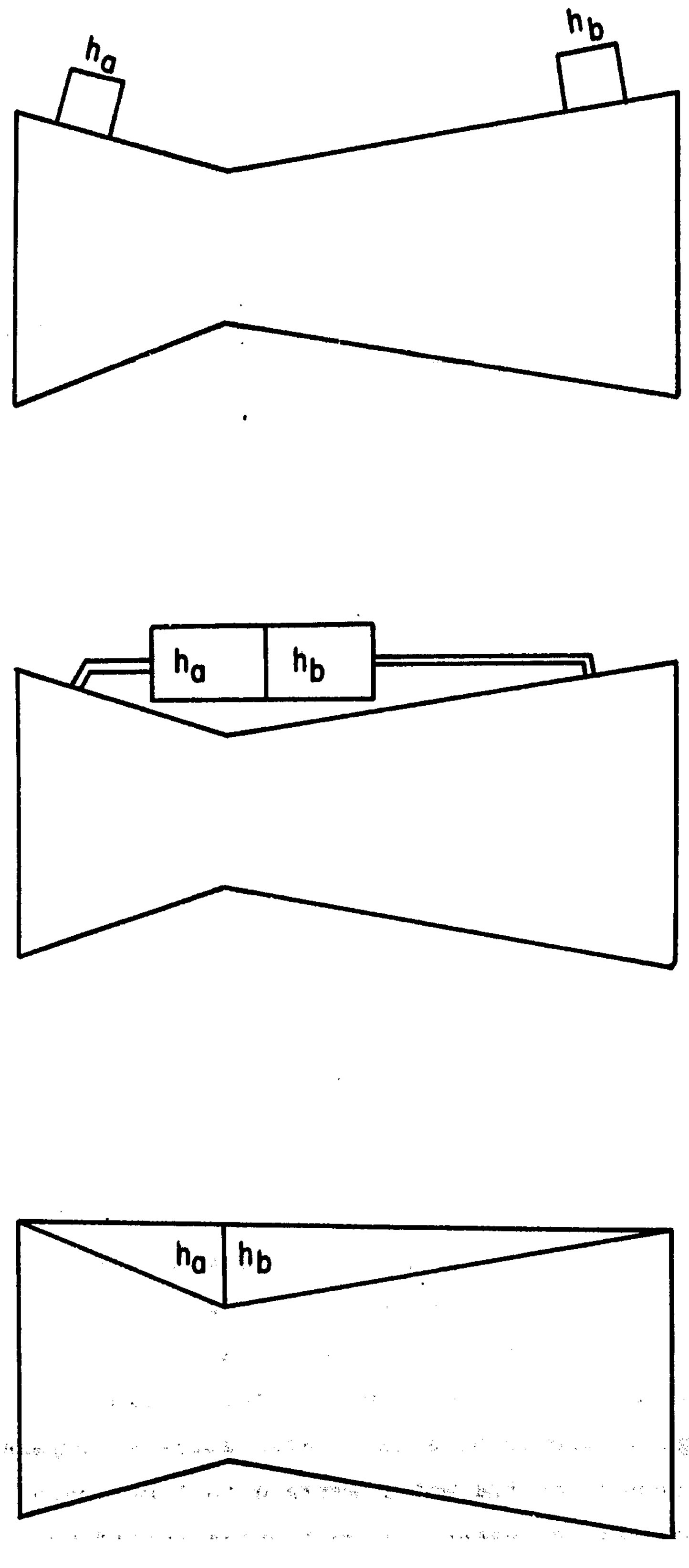


Fig. 2- Plan view of Cutthroat flume showing various methods for using stilling wells.

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 an upstream flow depth need be measureed to determine the discharge. Under free flow conditions, critical depth occurs in the vicinity of the flume neck. This critical depth makes it possible to determine the flow rate knowing only the upstream depth, 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. 3 (water surface profiles a and b), thereby resulting in a unique relation between discharge, Q, and upstream flow depth h_a.

In order to insure that free flow conditions will prevail, the flume may have to be installed above the original canal or ditch bottom. Fig. 4 illustrates how this is accomplished.

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 the flat-bottomed Cutthroat flume is installed to operate under submerged flow conditions, the flume floor may be placed level on the canal bottom. This placement will allow quicker drainage of the canal section upstream from the flume, and reduced seepage losses upstream from the flume, particularly for the flow rates which are less than the maximum discharge.

A flume operating under submerged flow conditions will have a water surface profile through the flume corresponding to profile c of Figure 3. This requires that both the upstream and downstream flow depths be measured.

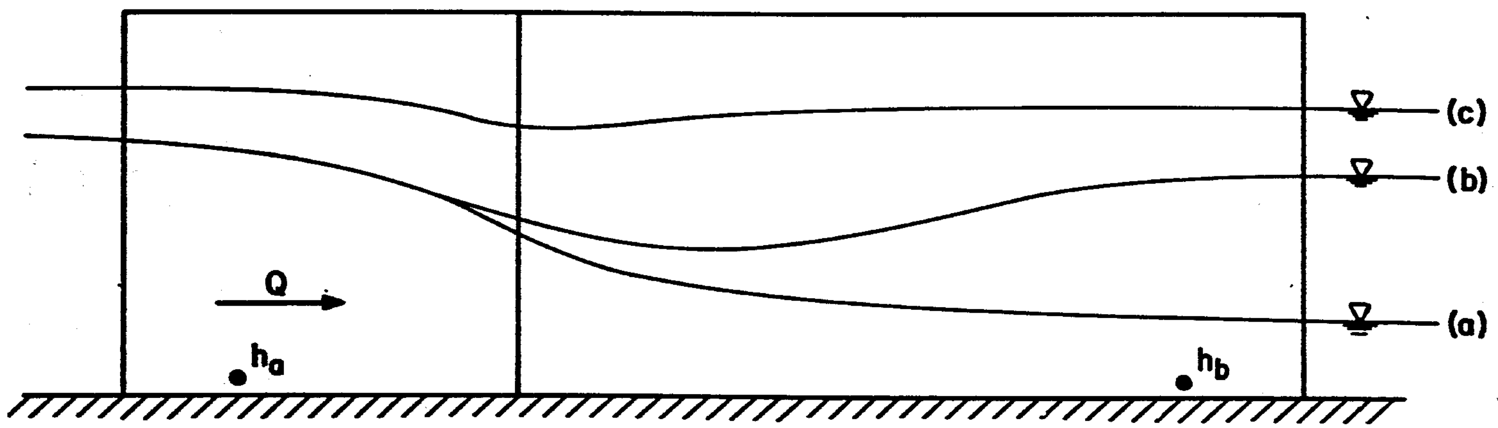
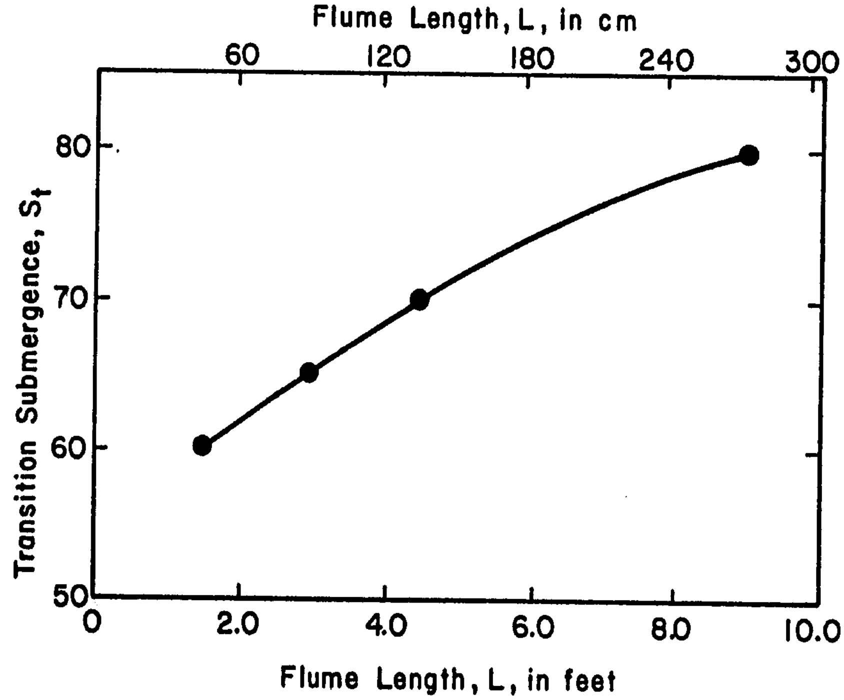


Fig. 3— Illustration of flow conditions in a Cutthroat flume.



Q = 12.5 cfs

From Table I, h_a = 1.10 feet

Transition Submergence = 80% = 0.80 (for L = 9.0 feet)

Allowable h_b = 0.80 x 1.10 feet = 0.88 feet

Therefore, set floor of Cutthroat flume 0.88 feet below the "Maximum Water Surface Before Flume Installation".

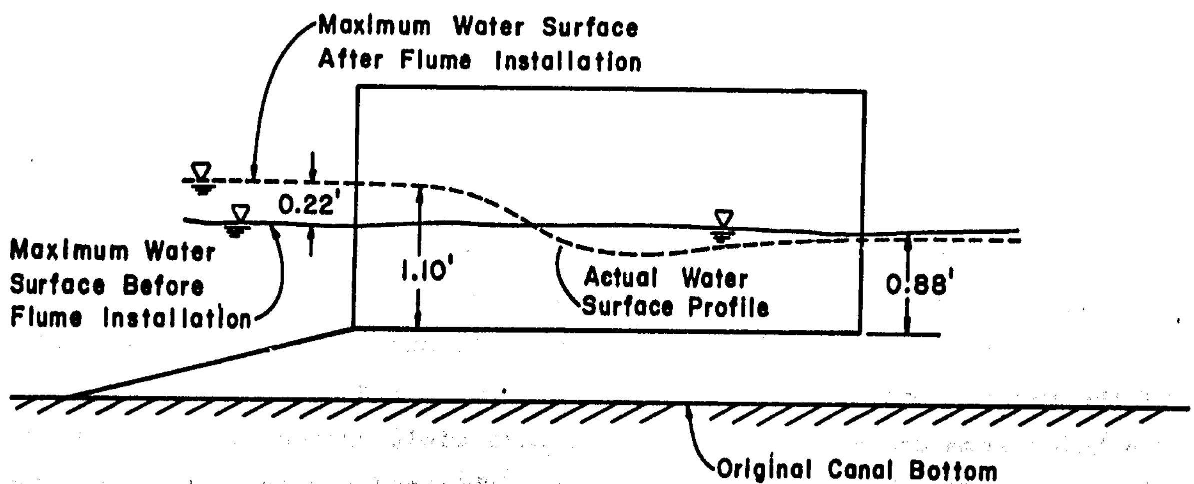


Fig. 4— Installation of 3-foot throat width and 9-foot length Cutthroat flume.

The submergence, S, is defined as the ratio, often expressed as a percentage, of the downstream depth to the upstream depth.

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 certain channels, debris may collect on the channel bed upstream from the entrance section, and should be removed. Walls of steel Cutthroat flumes may become encrusted and the encrustation 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. 5. 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. 6. 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. 7. 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. This 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.

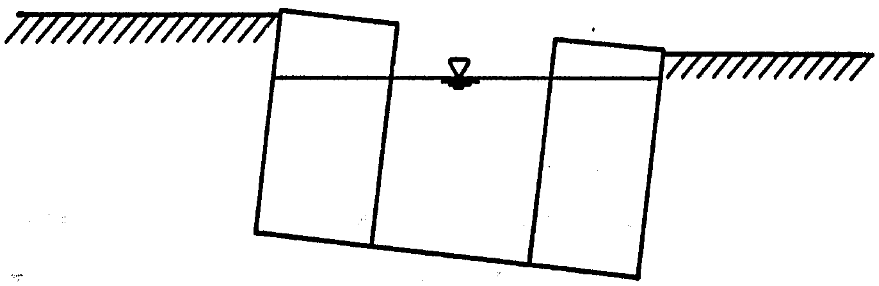


Fig. 5- Cutthroat flume tilted sideways.

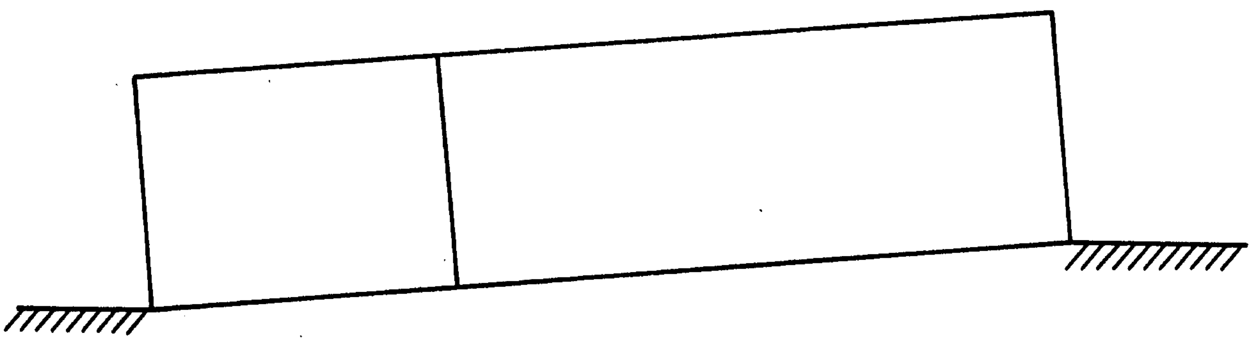


Fig. 6- Settlement of Cutthroat flume at inlet section.

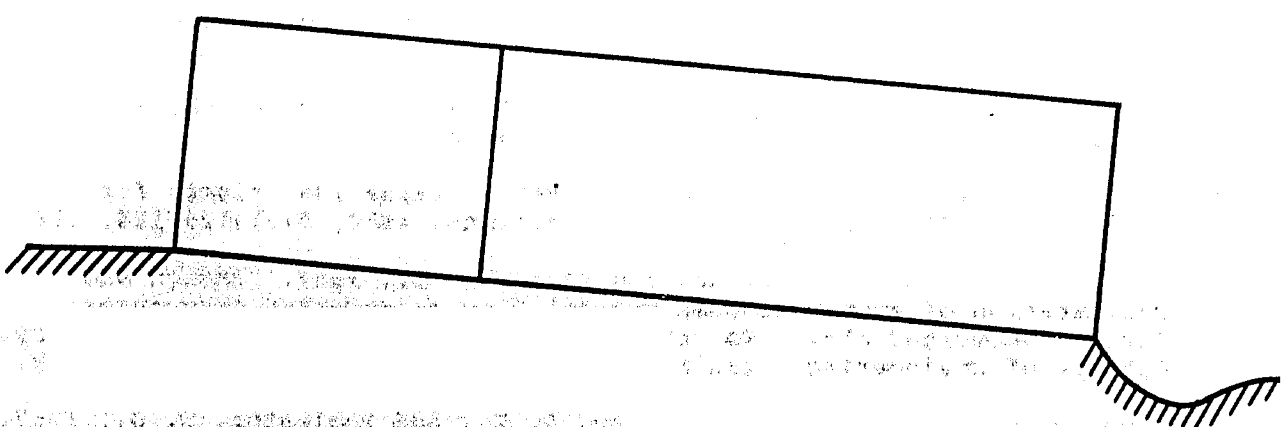


Fig. 7- Settlement of Cutthroat flume at exit section.

Tables 1 and 1A give the free flow calibrations for selected sizes of Cutthroat flumes in English and in Metric units. Also included are corresponding tables (2, 2A, 3 and 3A) for conditions of submerged flow. The range of discharges included covers most of the stream sizes currently being used for watercourses serving small irrigated parcels and should be very useful in adapting Cutthroat flumes as a practical device for water measurement. Complete calibration tables for larger flume sizes (up to 60 cfs capacity) may be obtained from the report by Skogerboe, Bennett & Walker (1972). Suffice to say, the Cutthroat flume merits serious consideration as a measuring device for on-farm water management in the less developed countries.

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, p 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 calibaration 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. Installation and field use of Cutthroat flumes for water management; CUSUSWASH Water Management Technical Report No. 19 pp 1-119.

Table 1 Free flow calibrations for selected Cutthroat flumes (Q,cfs)

h_a, ft	4INx3FT	8INx3FT	12INx3FT	h_a, ft	4INx3FT	8INx3FT	12INx3FT
.02	.00	.00	.00	1.02	1.51	3.09	5.54
.04	.00	.01	.01	1.04	1.57	3.20	5.74
.06	.01	.02	.03	1.06	1.62	3.32	5.95
.08	.01	.03	.05	1.08	1.68	3.43	6.16
.10	.02	.04	.08	1.10	1.74	3.55	6.37
.12	.03	.06	.11	1.12	1.80	3.67	6.58
.14	.04	.08	.14	1.14	1.86	3.79	6.80
.16	.05	.10	.18	1.16	1.92	3.91	7.02
.18	.05	.13	.23	1.18	1.98	4.04	7.25
.20	.08	.15	.28	1.20	2.04	4.17	7.48
.22	.09	.18	.33	1.22	2.10	4.30	7.71
.24	.11	.22	.39	1.24	2.17	4.43	7.94
.26	.12	.25	.45	1.26	2.23	4.56	8.18
.28	.14	.29	.51	1.28	2.30	4.69	8.42
.30	.16	.33	.58	1.30	2.36	4.83	8.66
.32	.18	.37	.66	1.32	2.43	4.97	8.91
.34	.20	.41	.73	1.34	2.50	5.10	9.16
.36	.22	.45	.82	1.36	2.57	5.25	9.41
.38	.25	.50	.90	1.38	2.64	5.39	9.67
.40	.27	.55	.99	1.40	2.71	5.53	9.93
.42	.30	.60	1.08	1.42	2.78	5.68	10.19
.44	.32	.66	1.18	1.44	2.85	5.83	10.46
.46	.35	.71	1.28	1.46	2.93	5.98	10.72
.48	.38	.77	1.38	1.48	3.00	6.13	11.00
.50	.41	.83	1.49	1.50	3.08	6.28	11.27
.52	.44	.89	1.60	1.52	3.15	6.44	11.55
.54	.47	.96	1.72	1.54	3.23	6.59	11.83
.56	.50	1.03	1.84	1.56	3.31	6.75	12.11
.58	.54	1.09	1.96	1.58	3.39	6.91	12.40
.60	.57	1.16	2.09	1.60	3.46	7.07	12.69
.62	.61	1.24	2.22	1.62	3.54	7.24	12.99
.64	.64	1.31	2.35	1.64	3.63	7.40	13.28
.66	.68	1.39	2.49	1.66	3.71	7.57	13.58
.68	.72	1.47	2.63	1.68	3.79	7.74	13.88
.70	.75	1.55	2.77	1.70	3.87	7.91	14.19
.72	.80	1.63	2.92	1.72	3.96	8.08	14.50
.74	.84	1.71	3.07	1.74	4.04	8.25	14.81
.76	.88	1.80	3.23	1.76	4.13	8.43	15.12
.78	.92	1.89	3.38	1.78	4.22	8.61	15.44
.80	.97	1.98	3.55	1.80	4.30	8.79	15.76
.82	1.01	2.07	3.71	1.82	4.39	8.97	16.09
.84	1.06	2.16	3.88	1.84	4.48	9.15	16.41
.86	1.11	2.26	4.05	1.86	4.57	9.33	16.74
.88	1.15	2.35	4.22	1.88	4.66	9.52	17.08
.90	1.20	2.45	4.40	1.90	4.75	9.70	17.41
.92	1.25	2.56	4.58	1.92	4.85	9.89	17.75
.94	1.30	2.66	4.77	1.94	4.94	10.08	18.09
.96	1.35	2.76	4.96	1.96	5.03	10.28	18.44
.98	1.41	2.87	5.15	1.98	5.13	10.47	18.79
1.00	1.46	2.98	5.34	2.00	5.22	10.67	19.14

Table 1A Free flow calibrations for selected Cutthroat flumes, metric units (Q,cms)

h_a, meters	10x90CM	20x90CM	30x90CM
.005	.000	.000	.000
.010	.000	.000	.000
.015	.000	.000	.000
.020	.000	.001	.001
.025	.000	.001	.001
.030	.001	.001	.002
.035	.001	.002	.002
.040	.001	.002	.003
.045	.001	.003	.004
.050	.001	.003	.004
.055	.002	.004	.005
.060	.002	.004	.006
.065	.002	.005	.007
.070	.003	.006	.008
.075	.003	.006	.009
.080	.003	.007	.011
.085	.004	.008	.012
.090	.004	.009	.013
.095	.005	.010	.014
.100	.005	.011	.016
.105	.006	.012	.017
.110	.006	.013	.019
.115	.007	.014	.021
.120	.007	.015	.022
.125	.008	.016	.024
.130	.008	.018	.026
.135	.009	.019	.028
.140	.010	.020	.030
.145	.010	.022	.031
.150	.011	.023	.034
.155	.012	.024	.036
.160	.012	.026	.038
.165	.013	.027	.040
.170	.014	.029	.042
.175	.014	.031	.045
.180	.015	.032	.047
.185	.016	.034	.049
.190	.017	.036	.052
.195	.018	.037	.054
.200	.018	.039	.057
.205	.019	.041	.060
.210	.020	.043	.062
.215	.021	.045	.065
.220	.022	.047	.068
.225	.023	.049	.071
.230	.024	.051	.074
.235	.025	.053	.077
.240	.026	.055	.080
.245	.027	.057	.083
.250	.0115	.059	.086

h_a, meters	10x90CM	20x90CM	30x90CM
.255	.029	.061	.089
.260	.030	.063	.092
.265	.031	.066	.096
.270	.032	.068	.099
.275	.033	.070	.102
.280	.034	.073	.106
.285	.035	.075	.109
.290	.037	.078	.113
.295	.038	.080	.116
.300	.039	.082	.120
.305	.040	.085	.124
.310	.041	.088	.127
.315	.043	.090	.131
.320	.044	.093	.135
.325	.045	.096	.139
.330	.046	.098	.143
.335	.048	.101	.147
.340	.049	.104	.151
.345	.050	.107	.155
.350	.052	.110	.159
.355	.053	.112	.164
.360	.054	.115	.168
.365	.056	.118	.172
.370	.057	.121	.177
.375	.059	.124	.181
.380	.060	.127	.185
.385	.062	.131	.190
.390	.063	.134	.195
.395	.065	.137	.199
.400	.066	.140	.204
.405	.068	.143	.209
.410	.069	.147	.213
.415	.071	.150	.218
.420	.072	.153	.223
.425	.074	.157	.228
.430	.076	.160	.233
.435	.077	.163	.238
.440	.079	.167	.243
.445	.080	.170	.248
.450	.082	.174	.253
.455	***	***	***
.460	***	***	***
.465	***	***	***
.470	***	***	***
.475	***	***	***
.480	***	***	***
.485	***	***	***
.490	***	***	***
.495	***	***	***
.500	***	***	***

Table 2 Submerged flow calibration for 4 in x 3 ft Cutthroat Flume (Q, cfs)

h_a, ft	$h_a - h_b$, ft: .02	.04	.06	.08	.10	.20	.30	.40	.50	.60	.70
.10	0	0	0	0	0	0	0	0	***	***	***
.20	.1	.1	.1	.1	.1	.1	.1	.1	***	***	***
.30	.1	.1	.1	.2	.2	.2	.2	.2	***	***	***
.40	.2	.2	.2	.3	.3	.3	.3	.3	***	***	***
.50	.2	.3	.3	.4	.4	.4	.4	.4	***	***	***
.60	.3	.4	.5	.5	.5	.6	.6	.6	***	***	***
.70	.4	.5	.6	.6	.7	.7	.8	.8	***	***	***
.80	.5	.6	.7	.8	.8	.9	1.0	1.0	***	***	***
.90	.6	.7	.8	.9	1.0	1.1	1.2	1.2	***	***	***
1.00	.7	.9	1.0	1.1	1.2	1.4	1.4	1.5	***	***	***
1.10	.8	1.0	1.2	1.3	1.3	1.6	1.7	1.7	1.7	1.7	1.7
1.20	.9	1.2	1.3	1.4	1.5	1.8	2.0	2.0	2.0	2.0	2.0
1.30	1.0	1.3	1.5	1.6	1.7	2.1	2.3	2.3	2.4	2.4	2.4
1.40	1.1	1.5	1.7	1.8	2.0	2.4	2.6	2.7	2.7	2.7	2.7
1.50	1.3	1.6	1.8	2.0	2.2	2.6	2.9	3.0	3.1	3.1	3.1
1.60	1.4	1.8	2.0	2.2	2.4	2.9	3.2	3.4	3.4	3.5	3.5
1.70	1.5	1.9	2.2	2.5	2.6	3.2	3.6	3.7	3.8	3.9	3.9
1.80	1.7	2.1	2.4	2.7	2.9	3.5	3.9	4.1	4.2	4.3	4.3
1.90	1.8	2.3	2.6	2.9	3.1	3.8	4.3	4.5	4.6	4.7	4.7
2.00	1.9	2.5	2.8	3.1	3.4	4.2	4.6	4.9	5.1	5.2	5.2

Table 2A Submerged flow calibration for 10 cm x 90 cm Cutthroat flume (Q, cms)

h_a, meters	h_a-h_b, meters: .010	.020	.030	.040	.050	.060	.070	.080	.090	.100	.110	.120
.025	0	0	0	0	0	0	0	0	0	0	***	***
.050	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	***	***
.075	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	***	***
.100	.004	.005	.005	.005	.005	.005	.005	.005	.005	.005	***	***
.125	.006	.007	.007	.008	.008	.008	.008	.008	.008	.008	***	***
.150	.008	.009	.010	.011	.011	.011	.011	.011	.011	.011	***	***
.175	.010	.012	.013	.014	.014	.014	.014	.014	.014	.014	***	***
.200	.012	.015	.016	.017	.018	.018	.018	.018	.018	.018	***	***
.225	.014	.018	.020	.021	.022	.022	.023	.023	.023	.020	***	***
.250	.017	.021	.023	.025	.026	.026	.027	.028	.028	.028	***	***
.275	.019	.024	.027	.029	.031	.032	.032	.033	.033	.033	.033	.033
.300	.022	.027	.031	.033	.035	.036	.037	.038	.038	.039	.039	.039
.325	.025	.031	.035	.038	.040	.042	.043	.044	.044	.045	.045	.045
.350	.028	.035	.039	.043	.045	.047	.048	.050	.050	.051	.051	.051
.375	.031	.039	.044	.047	.050	.053	.054	.056	.057	.057	.058	.058
.400	.034	.043	.048	.052	.056	.058	.060	.062	.063	.064	.064	.065
.425	.037	.047	.053	.058	.061	.064	.067	.068	.070	.071	.072	.072
.450	.040	.046	.058	.063	.067	.070	.073	.075	.077	.078	.079	.080

Table 3 Submerged flow calibrations for 8 in x 3 ft Cutthroat flume (Q, cfs)

h_a, ft	$h_a - h_b$, ft: .02	.04	.06	.08	.10	.20	.30	.40	.50	.60	.70
.10	0	0	0	0	0	0	0	0	0	0	0
.20	.1	.1	.2	.2	.2	.2	.2	.2	***	***	***
.30	.2	.3	.3	.3	.3	.3	.3	.3	***	***	***
.40	.4	.4	.5	.5	.5	.6	.6	.6	***	***	***
.50	.5	.6	.7	.7	.8	.8	.8	.8	***	***	***
.60	.7	.8	.9	1.0	1.1	1.2	1.2	1.2	***	***	***
.70	.3	1.0	1.2	1.3	1.3	1.5	1.5	1.5	***	***	***
.80	1.0	1.3	1.4	1.6	1.7	1.9	2.0	2.0	***	***	***
.90	1.2	1.5	1.7	1.9	2.0	2.3	2.4	2.4	***	***	***
1.00	1.4	1.8	2.0	2.2	2.4	2.8	2.9	3.0	***	***	***
1.10	1.6	2.1	2.3	2.6	2.7	3.3	3.5	3.5	3.5	3.5	3.5
1.20	1.9	2.3	2.7	2.9	3.1	3.8	4.0	4.1	4.2	4.2	4.2
1.30	2.1	2.6	3.0	3.3	3.6	4.3	4.6	4.8	4.8	4.8	4.8
1.40	2.3	3.0	3.4	3.7	4.0	4.8	5.2	5.4	5.5	5.5	5.5
1.50	2.6	3.3	3.8	4.1	4.4	5.4	5.9	6.1	6.2	6.3	6.3
1.60	2.8	3.6	4.1	4.6	4.9	6.0	6.5	6.9	7.0	7.1	7.1
1.70	3.1	4.0	4.5	5.0	5.4	6.6	7.2	7.6	7.8	7.9	7.9
1.80	3.4	4.3	4.9	5.4	5.8	7.2	7.9	8.4	8.6	8.7	8.8
1.90	3.7	4.7	5.4	5.9	6.3	7.8	8.7	9.2	9.5	9.6	9.7
2.00	4.0	5.0	5.8	6.4	6.9	8.5	9.4	10.0	10.3	10.5	10.6

Table 3A Submerged flow calibration for 20 cm x 90 cm Cutthroat flume, (Q, cms)

h_a, meters	$h_a - h_b$, meters: .010	.020	.030	.040	.050	.060	.070	.080	.090	.100	.110	.120
.025	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	***	***
.050	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	***	***
.075	.005	.006	.006	.006	.006	.006	.006	.006	.006	.006	***	***
.100	.008	.010	.010	.011	.011	.011	.011	.011	.011	.011	***	***
.125	.012	.014	.015	.016	.016	.016	.016	.016	.016	.016	***	***
.150	.016	.019	.021	.022	.022	.023	.023	.023	.023	.023	***	***
.175	.020	.024	.027	.028	.029	.029	.031	.031	.031	.031	***	***
.200	.024	.030	.033	.035	.036	.037	.037	.039	.039	.039	***	***
.225	.029	.036	.040	.043	.044	.046	.046	.049	.049	.049	***	***
.250	.034	.039	.047	.051	.053	.055	.056	.056	.059	.059	***	***
.275	.039	.049	.055	.059	.062	.064	.066	.066	.067	.070	.070	.070
.300	.045	.056	.063	.068	.071	.074	.076	.077	.078	.078	.082	.082
.325	.050	.063	.071	.077	.081	.085	.087	.089	.090	.091	.091	.096
.350	.056	.071	.080	.087	.092	.095	.098	.101	.102	.103	.104	.104
.375	.062	.078	.089	.096	.102	.107	.110	.113	.115	.117	.118	.118
.400	.069	.087	.098	.107	.113	.119	.123	.126	.128	.130	.132	.133
.425	.075	.095	.108	.117	.125	.131	.135	.139	.142	.144	.146	.148
.450	.082	.103	.118	.128	.136	.143	.148	.153	.156	.159	.161	.163