STUDY OF THE BEAVER CREEK MEASURING FLUMES

Report

to

Rocky Mountain Forest and Range Experiment Station

Fort Collins, Colorado

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ACKNOWLEDGEMENT

This study was conducted for the Rocky Mountain Forest and Range Experiment Station using the Hydraulic facilities at Colorado State University. Mr. Marvin D. Hoover, Chief, Division of Watershed Management Research for the Experiment Station collaborated on the study. The study was under the general technical and administrative supervision of Dr. A. R. Chamberlain, Chief of the Civil Engineering Section and Acting Dean of Engineering. The interest of the Agricultural Research Service, Western Soil and Water Conservation Research Branch is also acknowledged.

These flumes were designed for measurement of flow in steep mountain streams. This report presents the findings of a large 1:2 model study and the results of field measurements. Phases of the study covered the effect of approach conditions, construction deviations and development of a generalized rating curve. Field measurements were considered in the development of the rating curve.

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STUDY OF THE BEAVER CREEK RATING FLUMES

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INTRODUCTION AND REVIEW

The initial studies to develop a design for the flumes were reported by Chamberlain in 1957 (1). Special problems which were considered in the development of the device were: (a) measurement of a large range of flows, (b) flows with heavy sediment and debris loads, and (c) flows which might be in the super-critical range of velocity approaching the structure. Using the design based on this study, several of the structures were built on the Beaver Creek Watershed in Arizona by the Rocky Mountain Forest and Range Experiment Station.

Additional studies were made utilizing a 1:6 scale model and were reported by Robinson (2), (3). A limited number of field measurements were available and were correlated with the model results. Many of the field measurements were of doubtful accuracy because of methods used and difficulty in measuring high velocity flow in trapezoidal sections using current meters.

For the 1:6 model study, approach conditions were varied over a wide range. The roughness in the channel was changed as was the shape of the channel. Since no field measurements were available for flows above 30 cfs, model results were correlated with field measurements below this flow and the results projected to a maximum flow of about 300 cfs.

It was found (2) that super-critical velocities would exist within the approach or upper section of the flume only at the lower discharges ($Q < 6.0$ cfs). When this was recognized and the model was made to conform, there was not a wide deviation of the data depending on the approach conditions. For the 1:6 model the only conditions which should have been considered were those for an abrupt transition and the trapezoidal approach channel with three degrees of strip roughness. From the field data, it seemed that the rating curve could be duplicated by one of these conditions. Indications were that the roughness strips with 3-13/32 inch spacing more nearly fit the field data so these data were used to extend the rating curve beyond 30 cfs. From 10 to 30 cfs the relationship was determined by interpolation between the model and field data and below 10 cfs, field data were used entirely. However, there was considerable scatter of the data from the field measurements.

This report presents the results of a 1:2 model study and an analyses of additional field measurements. Considered are the effects of approach conditions, the structure being skewed about its centerline due to construction errors, and effect of the bottom throat dimension at the intake pipes being less than the nominal dimension. A standard rating curve is presented which was developed using all the available data.

For the low flow measurements in the flumes, it is proposed to use 120° V-notch weir plates. These plates will be bolted to the downstream face of the flume. The present stilling wells will be used for determining the depth of flow over the weirs. It is planned that the weirs be removed before periods of high flow. However, in the event that flows occur in excess of the weir capacity, while the plate is in place, a rating curve for this situation was determined. An existing equation for flow through a 120° V-notch weir will be used when the weir is not being overtopped.

FIELD AND MODEL STUDIES

The general design of the flume is given in fig. 1. Basically, it consists of a trapezoidal section with sidewalls at a 30 degree angle from horizontal. The entrance section has a 5-foot wide, flat bottom narrowing to a 1-foot width in the throat or control section. The entire structure was given a 5 percent slope in the direction of flow. The intake pipes to the recorder well were placed midway of the downstream section. A view of one of the field structures conveying a flow of approximately 30 cfs is shown as fig. 2.

To date, fourteen of the structures have been built in the field by the Forest and Range Experiment Station. These were built of concrete with the resultant dimensions shown in table 1. This summary was prepared from drawings furnished by Experiment Station personnel. From this tabulation, it is noted that the sidewall angle is very near 30 degrees. There are some variations in the bottom slope but overall the slope is near 5 percent for most of the flumes. The width of the upstream section (section A and B, see fig. 1) is very close to the nominal 5-foot dimension. Section D is important since this is the point at which depth is measured. Originally the bottom width at this section averaged 0.95 for all the flumes. Recently, a grinder was used to make the area between sections C and D more exact. A filler was also used to build up the section where needed. Measurements made after this was completed are shown as the second entry (table 1) for the total width of section D. An average of these dimensions is 0.97 foot.

From table 1, it is noted that some of the flumes were built slightly off from true alignment. For a study of the effect of skewness, the flume from watershed 9 was modeled to 1:2 scale and a complete range of discharges were observed. Figure 3 shows the basic dimensions used for this model.

The current meter method was used for most of the discharge measurements made in the flumes. The measurements were made in both the entrance and downstream sections. Several methods for current meter measurement were used. Because of the difficulty in holding the meter fixed on the sloping flume sidewall, the integration method was extensively used. The 0.5 and 0.6 depth methods were also used particularly when the depths were shallow.

In general, there was difficulty in measurement of higher flows in the upper section because of large eddys along the sidewalls. Because of these eddys it was necessary to correct the discharge measurements since velocity components near the sidewalls were sometimes in the upstream direction. Measurements made in the lower section were probably more representative since the eddys did not exist at this location. However, the high super-critical velocities made current meter measurement difficult.

The large 1:2 model of the measuring structure is shown in fig. 4. This model was constructed in the large testing channel located near Bellvue, Colorado. Flows through the model were measured on a standard rectangular weir. This weir is adjustable in width so that a large range of flows can be accurately measured. The velocities through the model were scaled using the Froude relationship. For the 1:2 model the relationship for discharge is

$$Q_m = 0.177\ Q_P$$

The approach conditions for this model were changed from one with an abrupt cutoff wall to that of a flat floor, level with the flume approach floor. The latter case was found to more nearly duplicate the field situation.

For measurement of low flows, the 120° V-notch weir bolted to the end of the flume will be used. Figure 5 shows the weir in place on the model and one condition of flow through the structure at approximately 98 cfs prototype discharge. The top of the weir blade is designed to be 1.0 feet above the flume floor with the weir notch being 0.5 foot deep.

ANALYSIS OF DATA

Effect of Approach Conditions

During the earlier study with the 1:6 model (3) the approach conditions were varied over a wide range. A certain roughness pattern was selected as being representative of the roughness condition in the prototype. Preliminary tests using the 1:2 model and similar roughness patterns gave results which indicated that the prototype situation was not being duplicated. This was as a result of many more field measurements being available than during the 1:6 model tests.

Two of the conditions shown on fig. 6 reflect the effect of a change in approach conditions. These are the cases of an abrupt entrance transition and for a flat approach floor on the same level with the entrance floor of the flume. The latter condition had been suggested by Forest Service personnel as ~~being more~~ representative of the field condition. The first case was analogous to the fully contracted weir in regard to entrance condition.

A study of these two ratings in fig. 6 reveal that there is very little difference in the relationship of depth to discharge. For this plot, the discharge and depth from the 1:2 model have been converted to prototype measurements. For a given depth the discharge was less for the case of the fully contracted entrance throughout most of the range. At the lowest flows the relationships were the same. The maximum difference was in the order of 8 to 9 percent for flows in the range of 20 to 30 cfs.

The results of field measurements on seven of the flumes are given in figs. 7, 8 and 9. These represent measurements made on two different years for seven watersheds. Because of a lack of measurements, data for the other watersheds are not shown. Almost all of the measurements were made with current meters with a very few at the lower flows made volumetrically. Those measurements made in the upper section were corrected for the adverse velocity components. Approximately one-half of the current meter measurements were made in the lower section. The depth is that indicated in the stilling well. It would be assumed that these seven watersheds represent the range of approach conditions which would be encountered in the entire fourteen.

An examination of figs. 7, 8 and 9 reveals that the same general trend of rating curve exists for the flumes with the possible exception of the one on watershed 7. Here the indication is for more flow at the lower depths and less at the greater ones. The curve which is shown is common with the three plots and represents the best fit for the data above a flow of 1 cfs. The dotted relationship below 1 cfs is taken from the 1958 report (2).

<u>Effect of Nonsymmetry</u>

An examination of table 1 reveals that the flume of watershed 7 was one of those in which there were discrepancies in construction of the throat section, i.e., skewed. The same is true for the construction of 9, 11 and 13 with 9 being selected for modeling the effect of this nonsymmetry. In order to study this effect, the model flume shown in fig. 3 was constructed. This included the flat approach floor as was used for one of the conditions in the tests of the exact flume. The results of this calibration is shown on fig. 6 with a tabulation of flows given in table 2. It should be noted that the throat width at the intake pipes was 0.48 foot or 0.96 foot prototype.

The data in table 2 show that there is a reduction of discharge for the skewed model in excess of the reduction because of area. The percentage reduction in area is a maximum at the shallower depth and decreases to less than 1 percent difference at the greatest depth. As an overall comparison, the discharge for a given depth was decreased from 3.3 to 5.7 percent as a result of the model structure being nonsymmetrical.

The overall reduction in discharge which was noted for the skewed model was not apparent from the field measurements. Flumes 7, 9 and 13 were all nonsymmetrical as shown in table 1. Data from each are plotted on figs. 7, 8, and 9 and do not show the trend indicated by the model. The flume for watershed 7 seemed to have a slightly different relationship as was previously noted. In view of these discrepancies, which cannot be explained at this time, a standard rating curve to be used for all the flumes is recommended.

Standard Rating

In the development of a standard rating curve for the flumes both field and model data were used. An examination of table 1 shows that the bottom throat dimension varies from 0.94 to 1.00 foot with an average of 0.97 for the field structures. For this width and with a flow depth of 0.2 foot the deviation in area from a flume of exact dimensions is only 2.2 percent. At a bottom width of 0.94 this difference is 4.4 percent. The maximum difference in area occurs at the shallower depth. Since the discharge is directly proportional to area then the maximum deviation in discharge because of difference in area would also be 4.4 percent for the Beaver Creek flumes. This difference is so small that it can be disregarded in determining a standard rating curve.

Given on fig. 10 is a rating curve for the flumes based on the previous analysis. For flows in excess of 2 cfs, the curves shown on figs. 7, 8 and 9 for the field measurements and that on fig. 6 for the model with the flat approach floor are identical with the curve given on fig. 10. In the range of 1 to 2 cfs the relationship from figs. 7, 8 and 9 was used. Below 1 cfs the dotted portion represents the trend determined in the earlier study (2). The flume without the weir placed on the end could not be expected to have a reasonable accuracy below 1 cfs.

Rating with 120° V-notch Weir

For measuring flows less than 0.8 cfs, the 120° V-notch weir plate will generally be used. There is always a possibility that flash floods may occur while the plate is in place. To prepare for this eventuality, a rating curve was determined with the plate in place on the model. The data determined in this manner are shown as fig. 11. The depth is that measured at the stilling well location but referenced to the bottom of the weir notch.

Until the weir is overtopped a standard rating (shown on fig. 11) for the 120° V-notch weir will be used. It is noted that once this overtopping occurs a very flat rating curve exists up to flows of approximately 15 cfs. In this range, a large increase in flow results in a small change in depth. Above 15 cfs the relationship changes to more nearly duplicate the head-discharge relationship commonly found for a weir.

COMMENTS AND INTERPRETATIONS

The new rating curve shown as fig. 10 is based on a comparison of model data and field measurements. Above a flow of 2 cfs the same relationship was found for all of the field data and the model when equipped with a flat approach floor. This approach condition for the model would be analogous to a weir with full contractions on the sides but fully suppressed on the bottom. This was observed to be the common field condition.

The rating differs from the one proposed in the earlier report (2) for flows between 10 cfs and 300 cfs. At these points the flows coincide but between the points flows are lower for the new relationship. Actually the results for the 1:6 model with abrupt transition coincide very closely with the rating given on fig. 10 for flows in excess of 20 cfs.

It was decided that one standard rating curve should be used for all the flumes since a comparison of field flow data did not show that a significant difference existed where the throat dimension was less than nominal or the structure was skewed. The model results did show that a difference might exist but, in the prototype case, the interaction of other factors tended to compensate for this difference.

It should be emphasized that without the 120° V-notch weir in place, the accuracy of the flume is questionable for flows below 1 cfs. If used without the weir, in this range, frequent volumetric measurements should be made and a rating determined for each individual flume.

Field discharge measurements should be continued particularly since construction protuberances and indentions have been corrected in the area around the intake pipes. This is a zone of super-critical flow and these features could have caused separation near the intake and a resulting error in water depth as shown by the stilling well. Discharge measurements should be made as accurately as possible by personnel familiar with the use of current meters under nonstandard conditions.

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2. Robinson, A. R. Trapezoidal measuring flumes for determining discharges of steep ephemeral streams. Colorado State University Research Foundation, Civil Engineering Section, Report CER59ARR1, February, 1959.

3. Robinson, A. R. Model study of a trapezoidal flume for measurement of stream discharge. Colorado State University Research Foundation, Civil Engineering Section, Report CER59ARR57, January, 1960.

Table 1 - Summary of Physical Field Measurements - Forest Service Flume

Flume No.	Section	Bottom Dimensions From ℄ to Left	From ℄ to Right	Total Width		Angle of Sidewall Left Side	Right Side	Bottom Slope
1	A	2.46	2.42	4.88		28° 50'	29° 15'	
	B	2.44	2.48	4.92		29 35	29 15	.034
	C	.48	.52	1.00		28 30	30 50	.040
	D	.50	.52	1.02	(.98)*	29 15	29 35	.060
	E	.46	.50	.96		29 25	29 15	.056
2	A	2.44	2.46	4.90		29 40	29 50	
	B	2.40	2.44	4.84		28 50	29 50	.036
	C	0.50	0.52	1.02		28 50	28 25	.054
	D	.44	.46	.90	(.98)	29 40	29 35	.032
	E	.44	.46	.90		28 50	30 40	.076
3	A	2.48	2.50	4.98		28 50	30 5	
	B	2.46	2.48	4.94		29 15	30 5	.054
	C	0.48	0.52	1.00		29 40	29 15	.032
	D	.48	.48	.96	(.97)	29 15	29 15	.050
	E	.48	.50	.98		29 15	28 50	.050
4	A	2.50	2.50	5.00		27 30	28 10	
	B	2.50	2.50	5.00		29 15	28 50	.052
	C	0.50	0.50	1.00		29 40	29 40	.038
	D	.50	.50	1.00	(.98)	29 40	29 40	.052
	E	.44	.50	0.94		29 40	29 55	.076
5	A	2.48	2.48	4.96		30 5	30 5	
	B	2.48	2.48	4.96		30 5	29 15	.040
	C	0.50	0.64	1.14		28 20	29 15	.040
	D	.44	.60	1.04	(1.00)	29 15	23 40	.064
	E	.34	.60	.94		29 15	30 5	.064
6	A	2.44	2.50	4.94		30 5	30 5	
	B	2.40	2.44	4.84		30 5	30 5	.045
	C	0.50	0.5	1.0		29 15	29 40	.045
	D	.48	.48	.96	(.97)	29 15	29 15	.048
	E	.48	.48	.96		29 15	29 15	.072
7	A	2.50	2.50	5.00		30 5	29 15	
	B	2.40	2.44	4.84		30 50	30 5	.050
	C	.72	.24	.96		29 40	30 35	.050
	D	.72	.24	.96	(.97)	30 5	30 35	.050
	E	.72	.12	.84		30 5	29 40	.050

Table 1 - Summary of Physical Field Measurements - Forest Service Flume
Continued

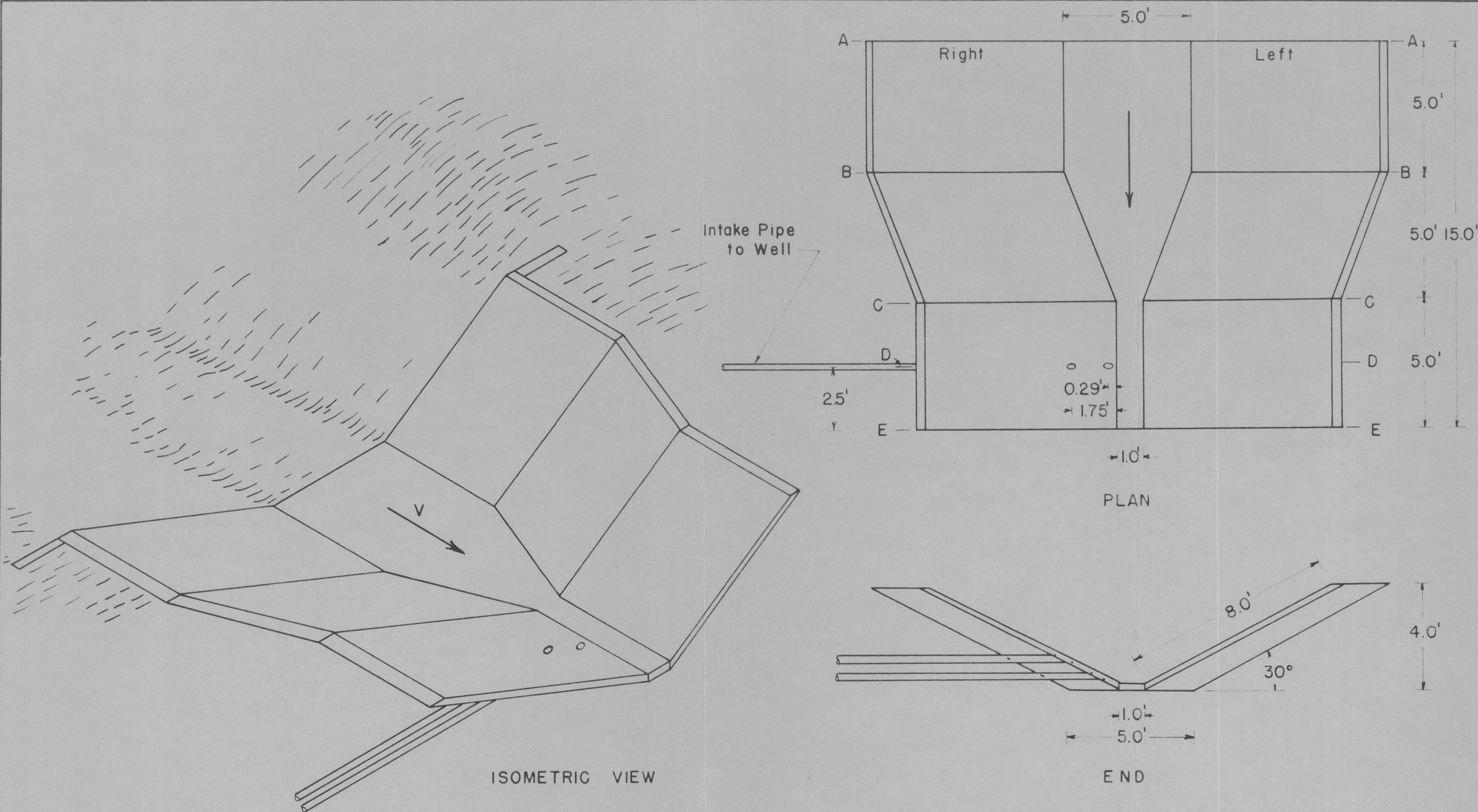
Flume No.	Section	Bottom Dimensions From ℄ to Left	Bottom Dimensions From ℄ to Right	Bottom Dimensions Total Width	Angle of Sidewall Left Side	Angle of Sidewall Right Side	Bottom Slope
8	A	2.50	2.46	4.96	29° 40'	29° 40'	
	B	2.50	2.30	4.80	29 15	30 5	.056
	C	0.48	0.48	0.96	28 50	29 40	.036
	D	.48	.40	.88 (.98)	28 50	29 15	.052
	E	.44	.44	.88	28 50	29 15	.052
9	A	2.47	2.48	4.95	30 57	31 00	
	B	2.54	2.36	4.90	31 26	30 57	.059
	C	0.90	0.08	.98	29 27	29 17	.057
	D	.86	.08	.94 (.96)	29 36	29 27	.028
	E	.81	.12	.93	29 34	29 51	.029
10	A	2.44	2.48	4.92	30 35	30 35	
	B	2.40	2.44	4.84	30 35	30 35	.052
	C	0.44	0.52	0.96	29 15	29 40	.036
	D	.44	.48	.92 (.97)	29 15	29 40	.048
	E	.44	.48	.92	30 5	30 5	.064
11	A	2.46	2.50	4.96	30 5	29 40	
	B	2.46	2.46	4.92	30 5	30 5	.053
	C	0.80	0.20	1.00	29 40	29 15	.053
	D	.80	.14	.94 (.98)	29 40	29 40	.036
	E	.84	.08	.92	29 40	29 40	.064
12	A	2.40	2.48	4.88	29 40	30 5	
	B	2.40	2.48	4.88	29 40	30 5	.042
	C	0.60	0.44	1.04	29 40	29 40	.044
	D	.50	.44	.94 (.96)	29 40	29 40	.064
	E	.44	.44	.88	29 40	29 40	.064
13	A	2.46	2.48	4.94	30 5	30 5	
	B	2.46	2.48	4.94	30 5	30 35	.042
	C	0.74	0.26	1.0	30 5	28 50	.044
	D	.64	.26	.90 (.94)	30 5	29 15	.066
	E	.66	.30	.96	30 50	29 40	.066
14	A	2.44	2.46	4.90	29 40	29 15	
	B	2.40	2.50	4.90	29 40	30 5	.056
	C	0.50	0.50	1.00	29 40	30 5	.056
	D	.46	.50	.96 (.99)	29 40	30 5	.044
	E	.44	.46	.90	29 40	29 40	.044

* Width after flumes corrected - average 0.97 ft.

Table 2 - Comparison of Discharges and Areas for the Exact and Skewed 1:2 Models

Prototype Depth ft	Prototype Discharge Exact Flume cfs	Prototype Discharge Skewed Flume cfs	Flow Difference %	Throat Area Difference* %
.2	1.09	1.02	6.4	3.1
.5	4.90	4.55	7.1	2.2
.8	11.1	10.3	7.2	1.8
1.0	16.8	15.6	7.2	1.5
1.5	37.8	35.2	6.9	1.2
2.0	74.5	70.2	5.8	.9
2.5	133.0	127.0	4.5	.8
3.0	222.0	212.0	4.5	.7

* Flume area at the intake pipe location is smaller for the skewed flume since the prototype width is 0.96.



Note: Bottom of the flume has a slope of 5 percent.

Fig. 1 Flume for flow measurement on streams with steep slopes.

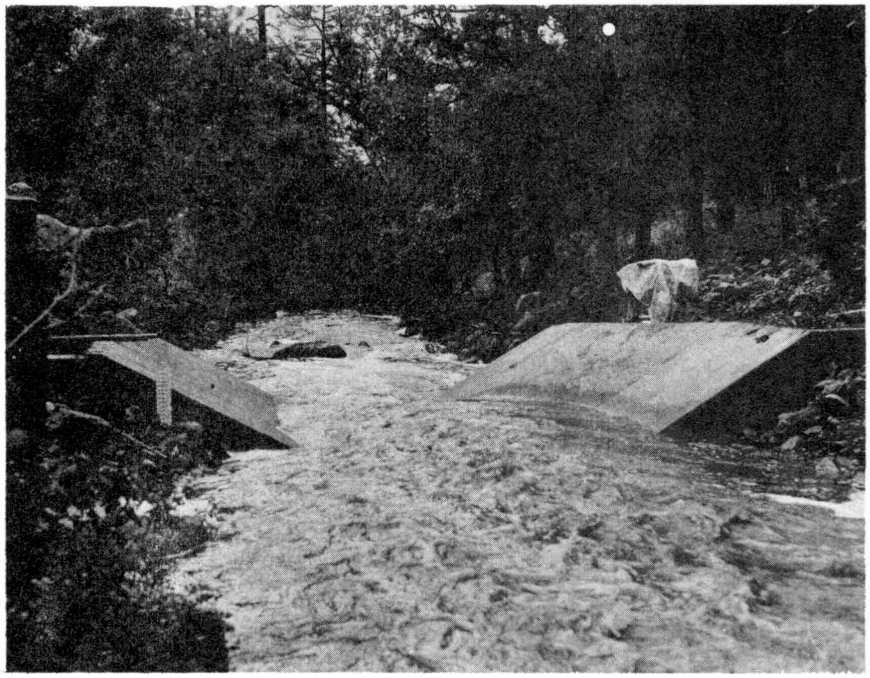


Fig. 2. Field Structure - Forest Service Flume
Discharge 30 cfs.

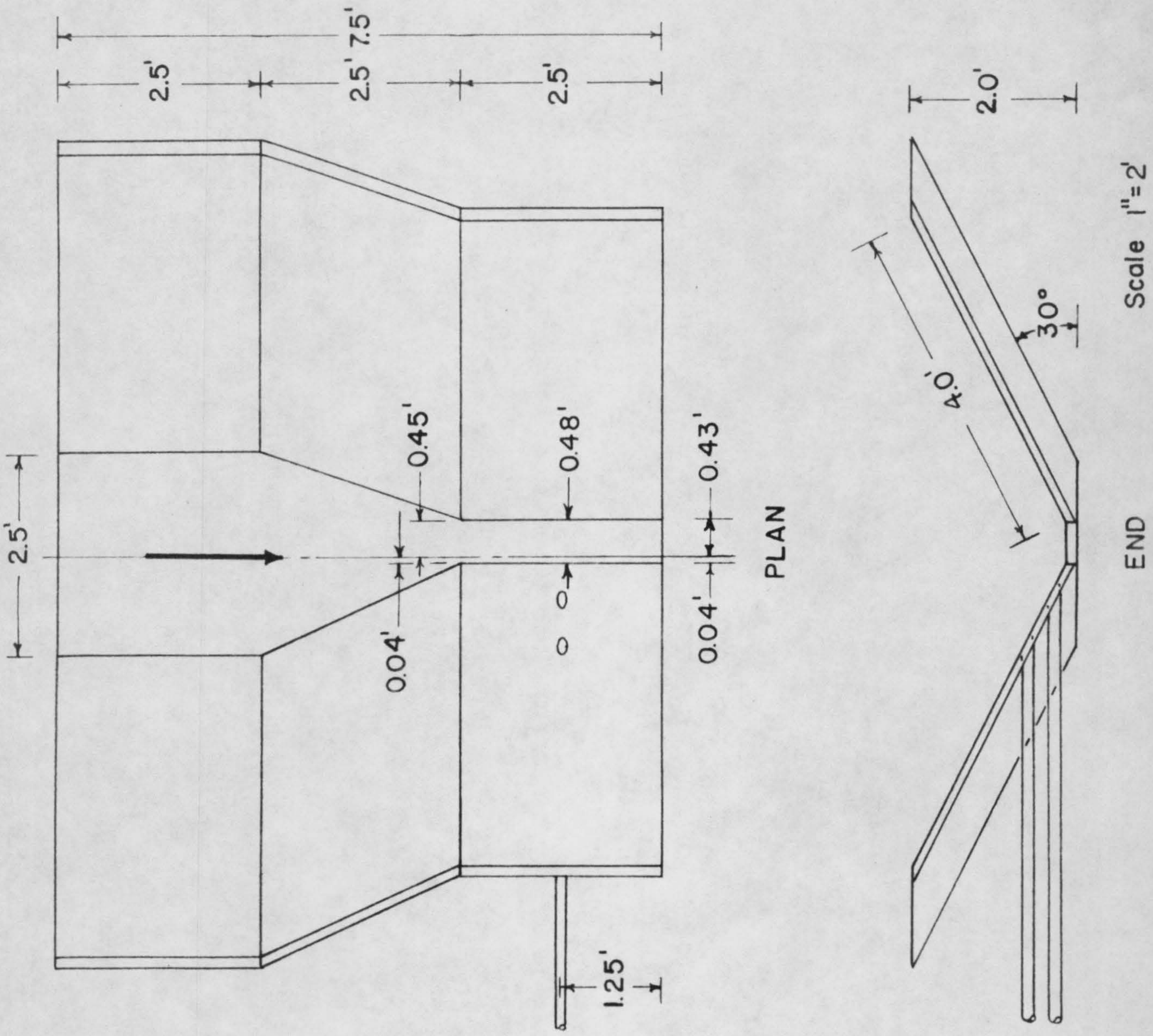


Fig. 3 Distorted 1:2 Model — Forest Service Flume

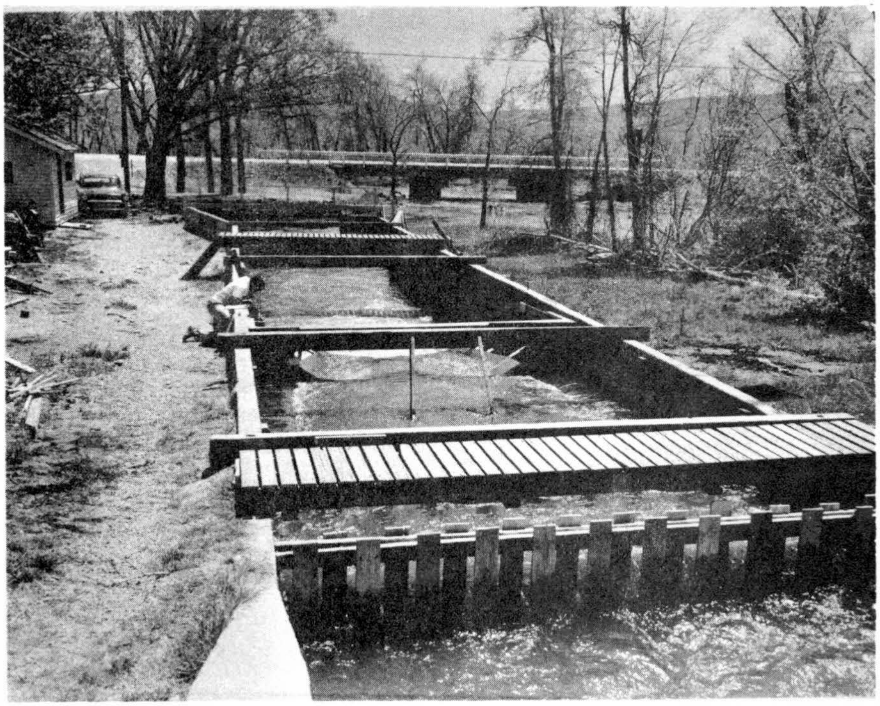
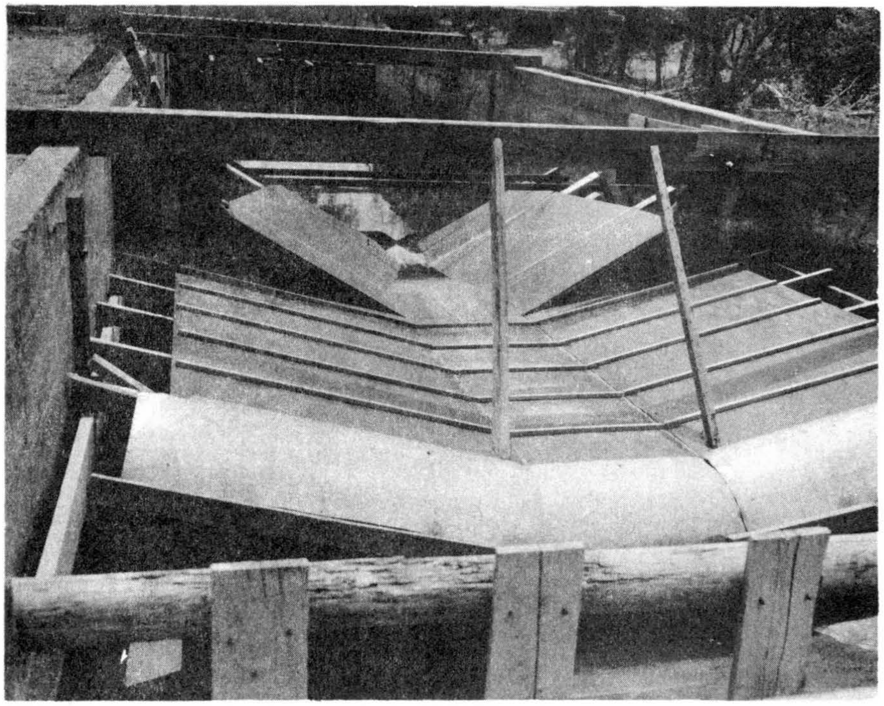


Fig. 4. 1:2 Model of the Forest Service Flume
Model Discharge 29.0 cfs, Prototype
Discharge 164 cfs.



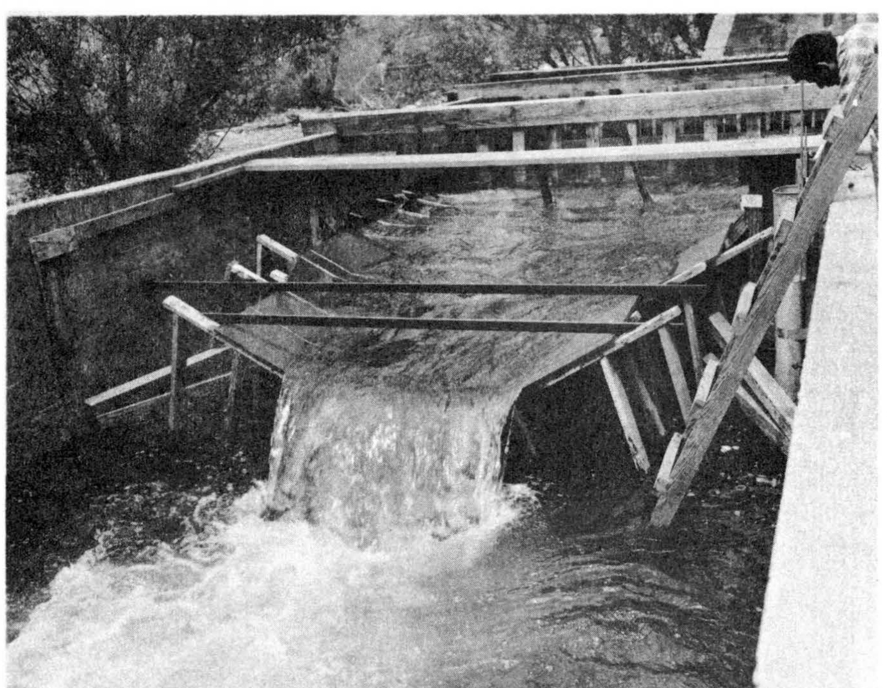


Fig. 5. Model with 120° V-notch Weir on Downstream End. Lower View Prototype Discharge 98 cfs.

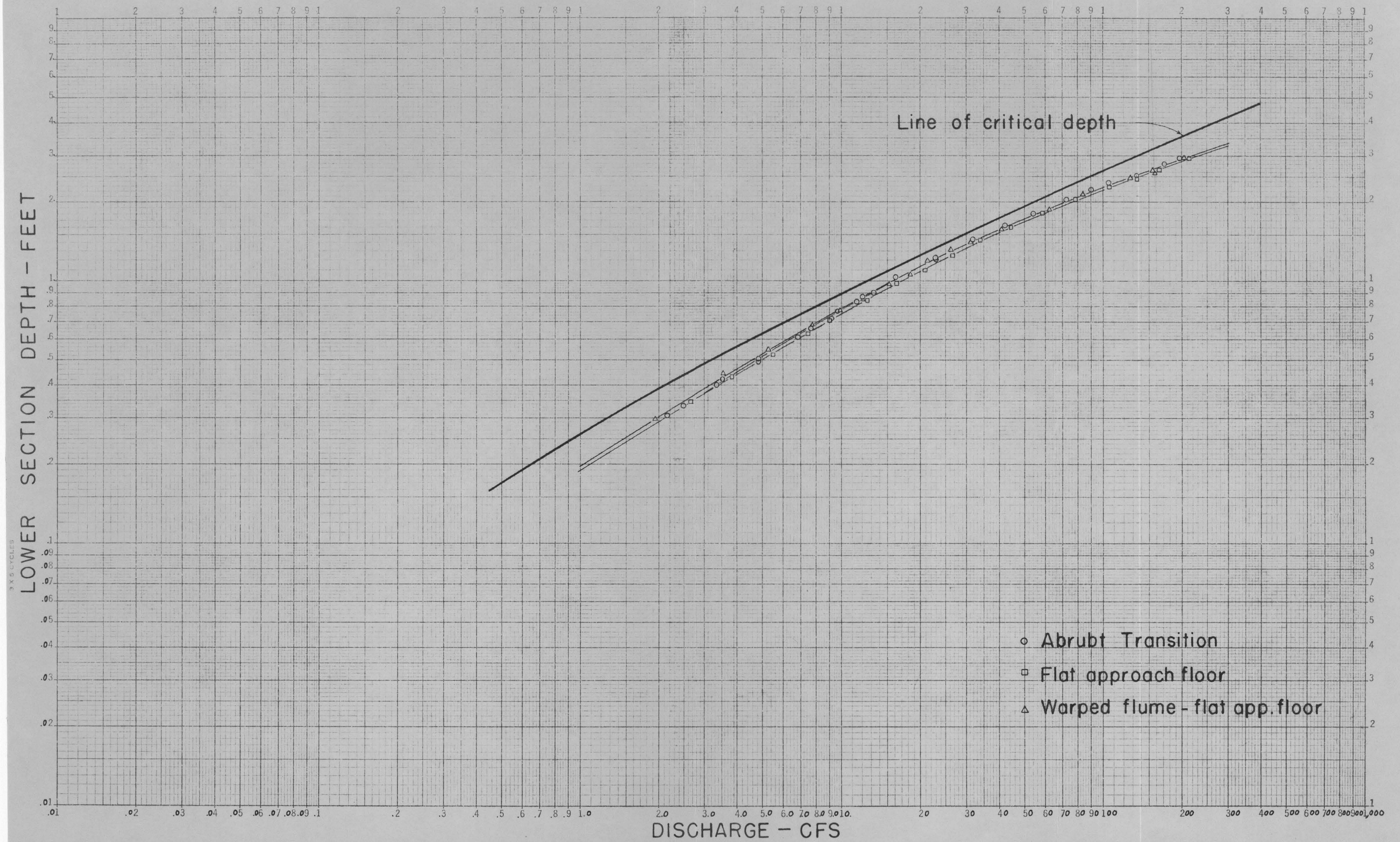


FIGURE 6 MODEL DISCHARGE MEASUREMENTS FOR THE FOREST SERVICE FLUME

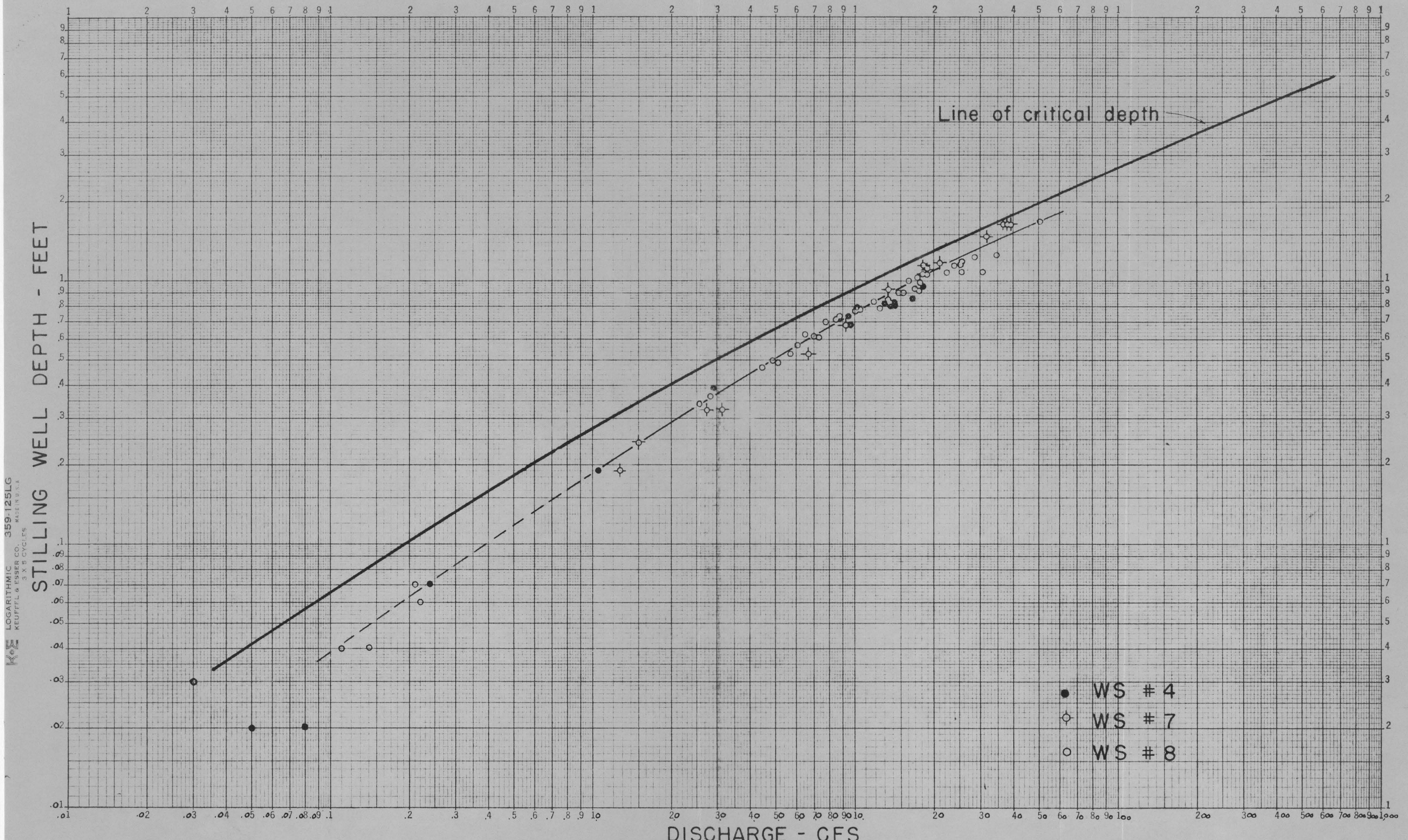


FIGURE 7 FIELD DISCHARGE MEASUREMENTS FOR THE FOREST SERVICE FLUME

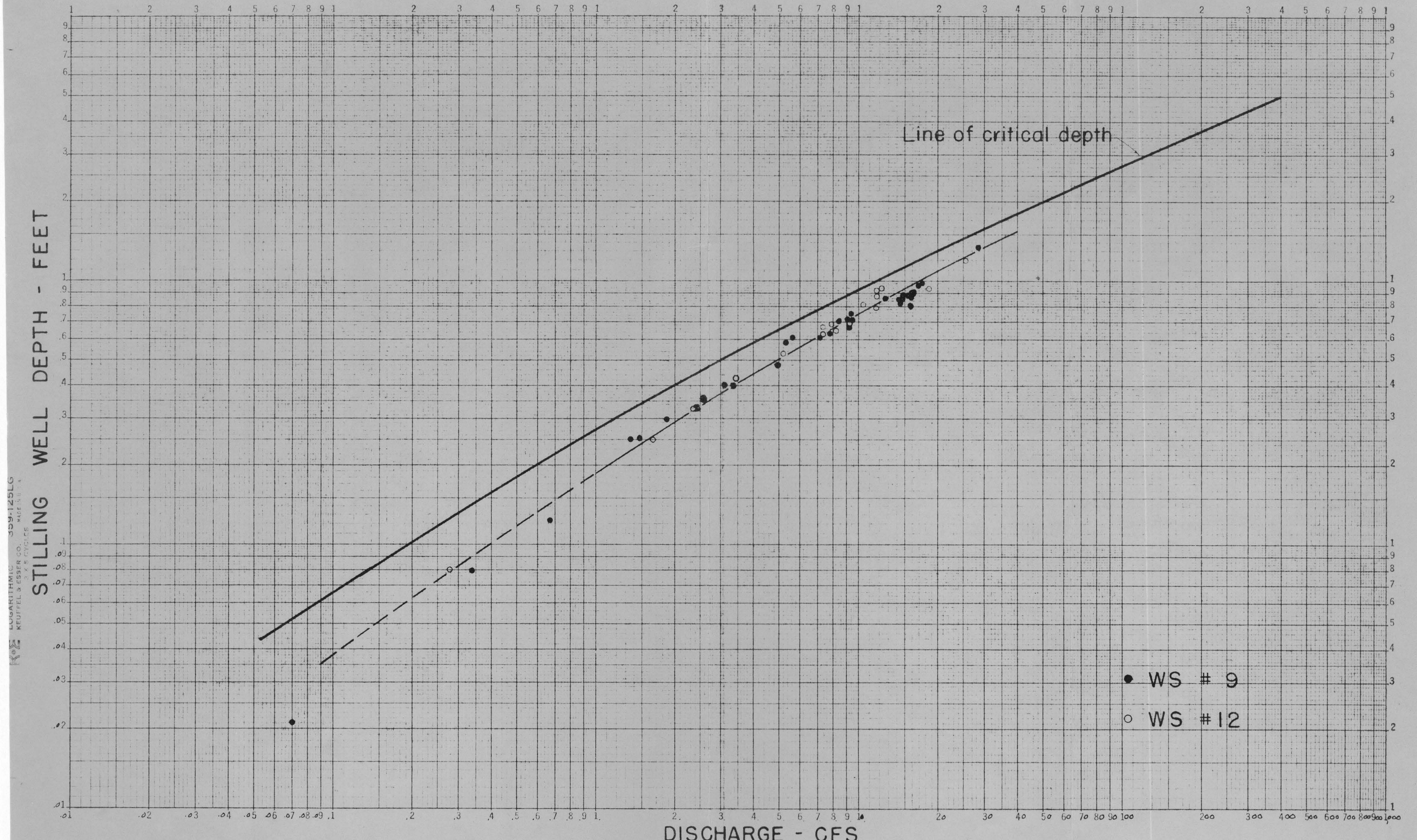


FIGURE 8 FIELD DISCHARGE MEASUREMENTS FOR THE FOREST SERVICE FLUME

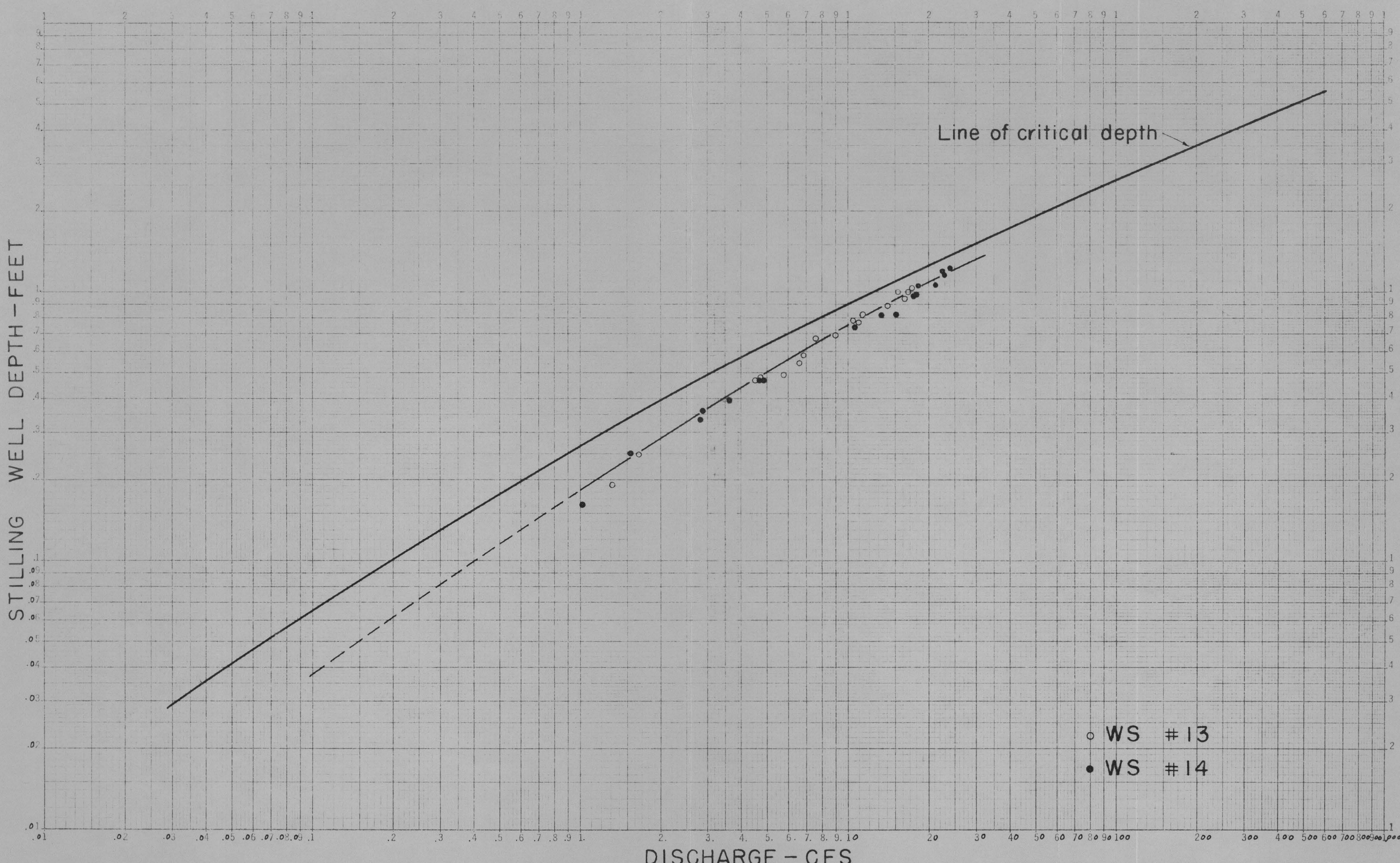


FIGURE 9 DISCHARGE MEASUREMENTS FOR THE FOREST SERVICE FLUME

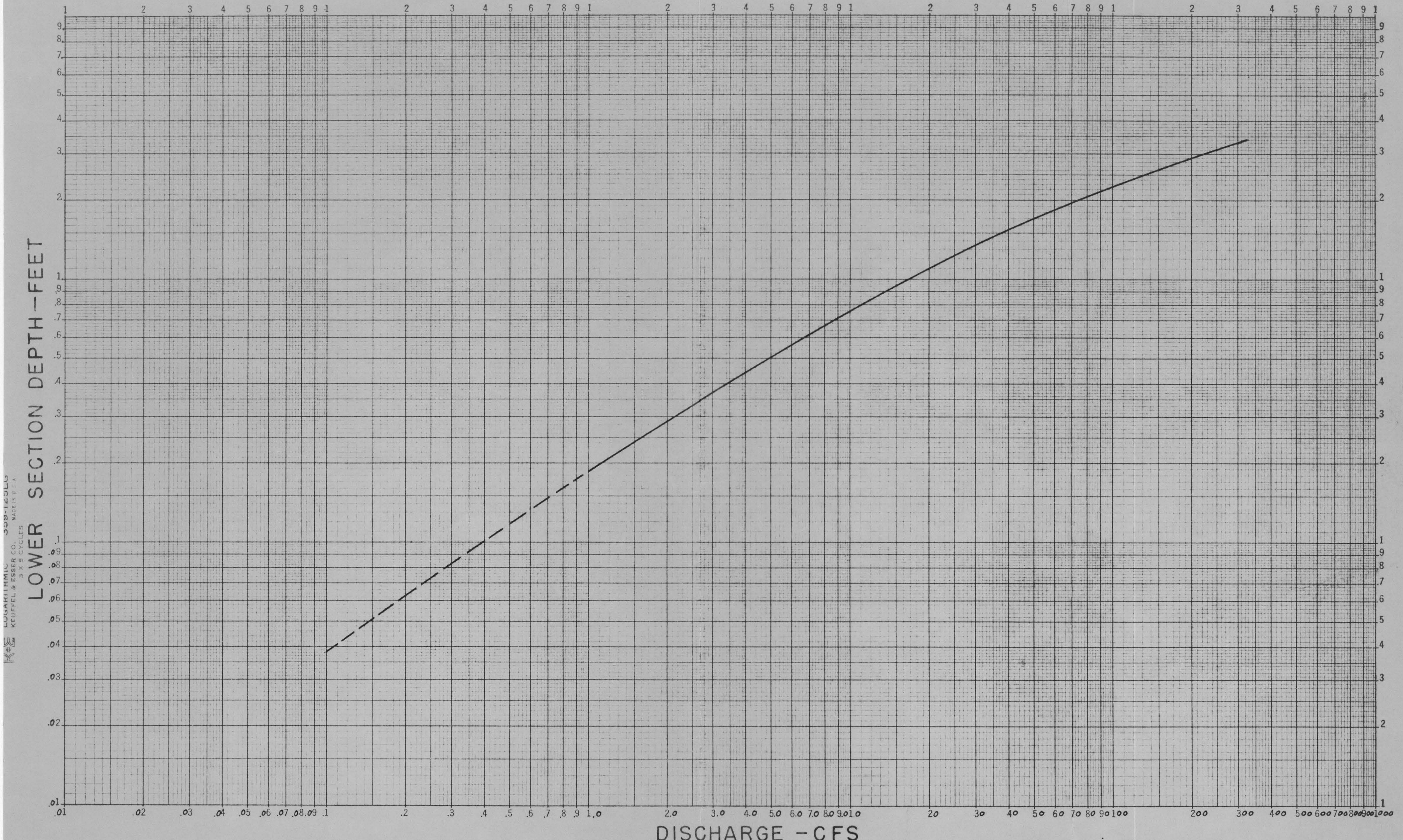


FIGURE 10 RATING CURVE FOR THE FOREST SERVICE FLUME

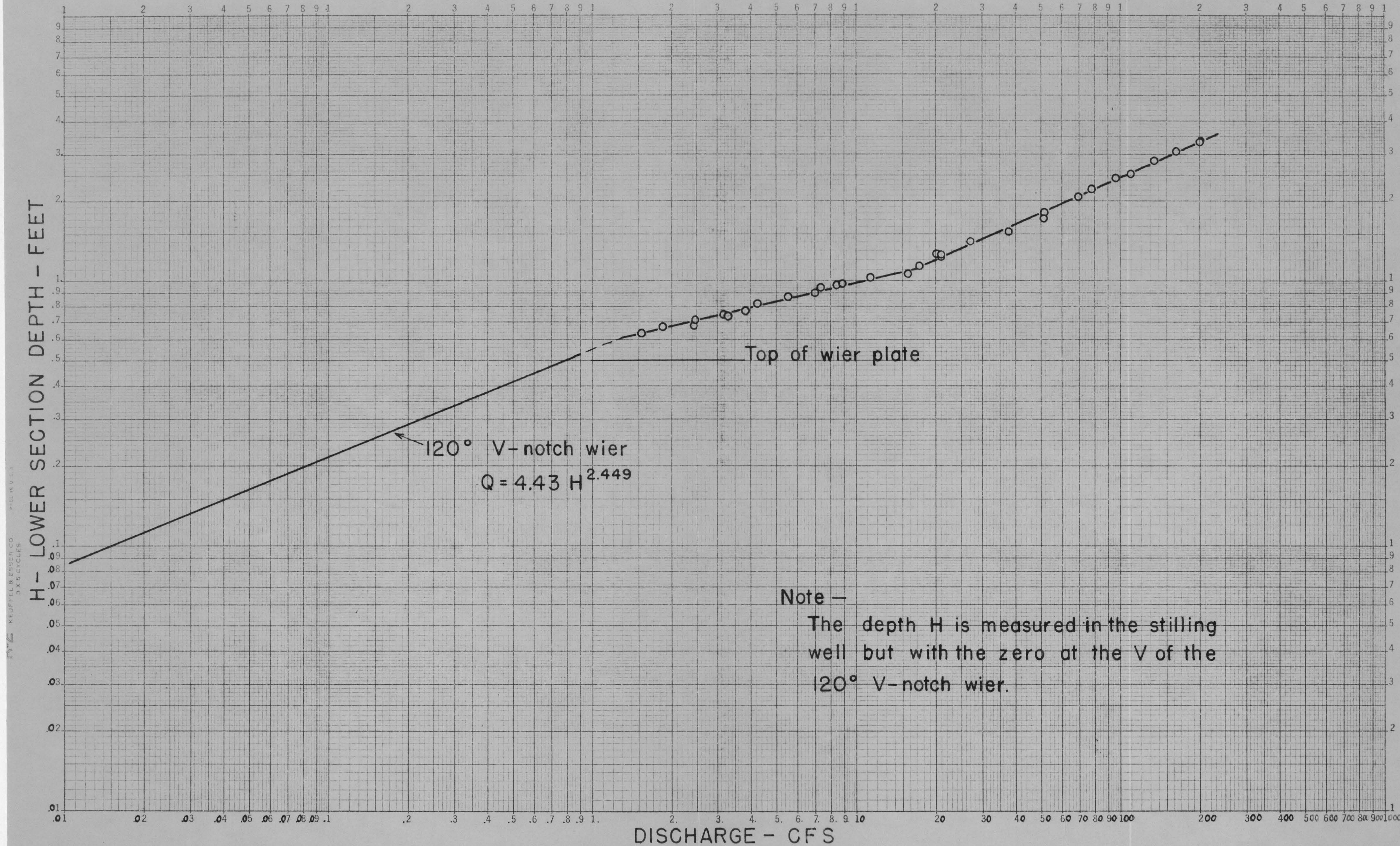


FIGURE II RATING CURVE FOR THE FOREST SERVICE FLUME WITH 120° V-NOTCH WIER IN PLACE