REPORT ON

TRAPEZOIDAL MEASURING FLUMES FOR DETERMINING DISCHARGES IN STEEP EPHEMERAL STREAMS

Prepared for the

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

by

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FOREWORD

Results of model studies and comparison to prototype behavior of trapezoidal measuring flumes are presented in this report. These flumes are designed for flow measurement in steep mountain streams. The study was conducted for the Rocky Mountain Forest and Range Experiment Station in collaboration with Marvin D. Hoover, Chief, Division of Watershed Management Research. The study was under the general technical and administrative supervision of A. R. Chamberlain, Chief of the Civil Engineering Section. The cooperation of the Agricultural Research Service, Western Soil and Water Management Research Branch is also acknowledged.

The design for the flumes was one which was developed earlier in the Hydraulic Laboratory, Colorado State University, Fort Collins, Colorado. The present model study was for the purpose of a better understanding of the field operation of the device. Field measurements were also used as a basis for determining the necessary operational characteristics in the model.

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INTRODUCTION

During 1956, model tests were made of a trapezoidal flume for the measurement of flows in steep mountain streams. Special problems which were encompassed were the measurement of a large range of flows, flows with heavy sediment and debris loads, and flow regimes which might be super-critical, sub-critical or in the transition zone.

Based on the recommendations derived from this study, several of the structures have been built in the field by the Rocky Mountain Forest and Range Experiment Station and have been operating. A number of field measurements of discharge have been made. Further model studies were initiated during 1958 and observations were made based on the field measurements.

This report is intended to correlate the results of the model studies and field measurements and to make recommendations relative to future field measurements and to the general operation of the device.

MODEL STUDIES

The model which was studied during 1956 has been reported by Chamberlain (1). This model was built on a 1:7 scale ratio at a 5 percent slope and the approach conditions were varied to simulate the expected field conditions. The flume sidewalls had a 30-degree slope from the horizontal with the approach channel sidewalls at 15 degrees. There was an abrupt transition consisting of a vertical wall between the channel and upstream end of the flume for the adopted design.

Calibration data were obtained for three roughness conditions of the upstream channel, i.e. (1) no roughness in the plywood approach channel which was 12 feet long, (2) 1-inch square pieces of ½-inch plywood nailed to the channel on 4-inch centers and (3) 1-inch square pieces of 3/4-inch plywood on 4-inch centers.

The recommended design from this study (fig. 1) was used for the more recent model study. This model was built to a 1:6 scale ratio and installed in a rectangular channel which was 4 feet wide. As in the case of the field installations, the structure was placed on a 5-percent grade. The approach channel was varied from the 4-foot rectangular section to one which had sidewalls at 30 degrees from the horizontal to another where the sidewalls were at 15 degrees. In the latter two cases, the botton slope was 5 percent and the width of the flat portion was the same as the flume entrance section.

The approach conditions for the measuring flume were varied over a wide range. For one case, a very abrupt transition was simulated by merely using the 4-foot wide channel as an approach. In the case of the channel approach with 30-degree sidewalls, there was no transition into the measuring structure since the channel had the identical shape of the entrance to the flume. The only condition tested with this installation was that of a smooth channel. For the approach channel with sidewalls at 15 degrees, there was also an abrupt transition into the measuring flume but to a lesser extent than when the 4-foot wide rectangular channel was used. For this condition four degrees of roughness were used. These consisted of (1) a smooth channel, the others of strip roughness ½ inch high and 13/16-inch wide placed transversely across the bottom and sides at (2) 3-13/32- (3) 6-13/16- and (4) 10¼-inch spacings.

The flows were measured by calibrated orifice or venturi meters in the pump discharge lines. The depths were measured by a traveling point gage, both of the water surface in the flume and in wells connected to piezometer openings.

FIELD MEASUREMENTS

A number of discharge measurements have been made by Forest Service personnel on the field installations. These measurements have primarily utilized the velocity head rod with a few measurements being made with current meters. Flows ranging from 0.1 to 31.0 c.f.s. have been measured with most of the higher flows being measured at one structure. The measurements were made in both the upper (approach) and the lower (throat) sections of the flume.

The velocity determinations were all made across the sections over the portion above the horizontal floor. Attempts at measurement over the sloping sidewalls have not been successful. The discharge was determined using an average velocity as determined by these measurements. Several methods were used in determining the mean velocities in a vertical plane by use of the current meter. A three-point method with velocities measured at 0.2, 0.6 and 0.8 of the depth from the surface was commonly used.

ANALYSIS OF DATA

For this report all of the data is presented in terms of the prototype or field structure. For the different models this relationship is

1:6 Model	1:7 Model
$d_p = 6\ d_m$	$d_p = 7\ d_m$
$Q_p = 88.18\ Q_m$	$Q_p = 129.6\ Q_m$

where d is the depth at a given section and Q is the discharge. The subscripts p and m denote prototype and model.

In the original study of this structure it was thought that super-critical velocities might exist in the approach or upper section of the measuring flume for all flows. That this exists for the lower range of flows is shown on Fig. 2 where the depth in the upper section is plotted against the discharge. Shown on this figure is a line which is termed the "Line of Critical Depth". This was determined from the equation

$$\frac{Q^2T}{gA^3} = 1 \qquad (1)$$

which is the relationship for determining the approximate critical depth in a trapezoidal section. The width of water surface T and the area A are both functions of the depth and g is the acceleration due to gravity (32.2 ft. per sec.^{2}). When a point falls below this line, when plotted on Fig. 2, the velocity is super-critical and sub-critical when the point is above.

It should be noted from Fig. 2 that the data for the field measurements indicate that the velocities for the lower discharges are in the super-critical range. At about 5 c.f.s. there is a transition zone extending to 8 c.f.s. where the velocity changes to sub-critical. Beyond this point the velocities remain sub-critical to the maximum measured discharge of 30 c.f.s. All of the higher flows were measured on the same watershed.

The velocities in the upper section were all in the super-critical range for the tests on the 1:7 model. The same is true for the series with smooth approach channels for the 1:6 model. The lowest velocities in the upper section were noted for the 1:6 model with an abrupt transition from a 4-foot wide channel. The 1:6 model with a 15-degree approach channel and strip roughness gave velocities which were sub-critical throughout the testing range. It was not possible to extend these data to the lower prototype flows because of increasingly important boundary effects in the model.

From Fig. 2, it is noted that the 1:6 model with 15-degree trapezoidal approach channel and roughness strips at 3-13/32-inch spacing more nearly represented the prototype conditions. Here the velocities were sub-critical in the range above 8 c.f.s. and the relationship is very near that for the field measurements. It would therefore seem that these data could be used to extend the rating curve for the prototype structure.

Since the field structure is not likely to be affected by submergence, the depth at the center of the throat section has been used to determine a rating curve for the flume. This is the point at which the intake pipe to the recorder well is attached. Fig. 3 shows the relationship using the depth at this point. As would be expected, the flows from both prototype and model are in the super-critical range in this section. The magnitude of the velocity in the upper section affects the relationship in the lower section. The 1:6 model which indicated super-critical velocities in the approach section for the cases of smooth, trapezoidal approach channels had higher, super-critical velocities in the throat section than the other cases. The relationship of the 1:6 model with smooth 30-degree trapezoidal approach section and that for the 1:7 model with two different types of roughness corresponded very closely when the depth in the upper section was used. The relationships were not the same when the lower section depths were used. This difference cannot be explained at this time.

A provisional rating curve for field use has been developed and is shown in Fig. 4. For flows less than 10 c.f.s. the relationship was determined from a curve fit to the field data shown on Fig. 3. The 1:6 model results with 15-degree trapezoidal approach channel and roughness strips at 3-13/32-inch spacing was used to determine the prototype relationship for flows greater than 40 c.f.s. Between 10 and 40 c.f.s., the relationship was determined by interpolating between the model and prototype data.

COMMENTS AND INTERPRETATIONS

It is interesting to note the effect of geometry and roughness of the approach channel on the relationship of depth and discharge. A fairly good correlation was noted between the prototype measurements and the results from the 1:6 model with roughness in the approach channel. Since the field measurements for the higher discharges were all made at essentially one location, it is possible that slightly different relationships may be found at the other locations with different upstream conditions.

Some uncertainties exist as to the accuracy of the field measurements. This arises from the fact that the velocity measurements are made over a relatively small percent of total flow area (for large flows) because of the difficulty in measuring over the sloping sidewalls. The average velocity from the measurements made at either edge of the horizontal floor was assumed to apply over the triangular areas. For those measurements made in the lower section, this assumption is probably valid since it was found from pitot tube measurements in a similar model that the velocities were almost uniform across the section. Fairly large errors are likely to occur if this method is used for measurements in the upper section near the upstream end of the structure. It has been observed in both the model and prototype that large eddies and vortices occur in this area due to curvilinear flow and separation around the upstream edges. For this reason measurements made in the upstream section should be near the beginning of the transition section (see Fig. 1).

Measurements in the laboratory utilizing the velocity head rod gave results which might indicate that velocity determinations made in the flume with this device are doubtful. A maximum variation of +12.5 percent in the discharge as determined by the velocity head rod in the upper section and that determined by an orifice was noted. This variation when used in the lower section was -12.2 percent. Wilm (2) pointed out the limitations in using the rod when the velocities are super-critical. These results would indicate that the device should not be used in the lower section, since the velocities are definitely super-critical.

It would seem that the current meter method would be more desirable in making discharge measurements and that the integration method be used. In this method (3) the meter is slowly lowered and raised between the water surface and the bottom several times. Using this method would also simplify the measurements on the sloping sidewalls since the meter does not remain fixed.

Super-critical velocities which exist in the upper section at the lower flows are probably due to the slope of the floor of the structure. When the discharge reaches 5 c.f.s., the throat begins to act as the control so that the flow changes to sub-critical in the approach section.

From studies of other models it was found that simulated deposits of material to depths of 6 to 8 inches in the upstream section of the measuring flume would have a negligible effect on the rating curve. This was true whether one-half or all of the floor area was covered.

Model results indicate that the water depths as actually measured in the lower section and those as indicated in the recorder well may not closely correspond. This is due to separation and high velocities past the upstream edge of the throat section. The depths will always be lower in the recorder well due to this occurrence. The intake pipes to the recorder wells should always be flush with the sides of the measuring flumes. Any protrusion or discontinuity in this vicinity will affect the water level in the well.

RECOMMENDATIONS FOR FIELD STUDIES

Based on the model studies and an examination of the field discharge measurements, the following recommendations are made regarding future field measurements.

(1) Each structure should be accurately measured to determine the exact dimensions after construction.

(2) The velocity head rod should not be used in the lower section. If necessary, it could be used in the upper section but the accuracy may also be doubtful.

(3) The integration method using the current meter might give more accurate results and eliminate some of the difficulties in measuring over the sloping sidewalls.

(4) Duplicate flow measurements should be made where practicable.

(5) The measurement of higher flows are needed as well as the measurement of these flows through different flumes. The range of 10 to 40 c.f.s. is particularly important since there are uncertainties in this area in defining a rating curve.

(6) Measurements in the upper section should be made 9 inches upstream from the beginning of the transition section so that the depths can be better correlated with the model. In the lower section, these measurements should always be made in the center of the section, directly in line with the outlet pipe.

(7) The water depth in the recorder well referenced to the elevation of the floor at the outlet pipe should be noted before and after a discharge measurement is made.

SUGGESTIONS FOR FUTURE STUDIES

The need for further field measurements on existing structures has been previously discussed. The following are items which need further study in the laboratory.

(1) Models of larger sizes need to be constructed and tested. Plans for the possible construction of a 1:2 model are being made.

(2) A simplified transition for the entrance to the flume needs to be developed so as to minimize the eddies and vortices which form in the upper section.

(3) Instrumentation which would replace the recorder well is needed.

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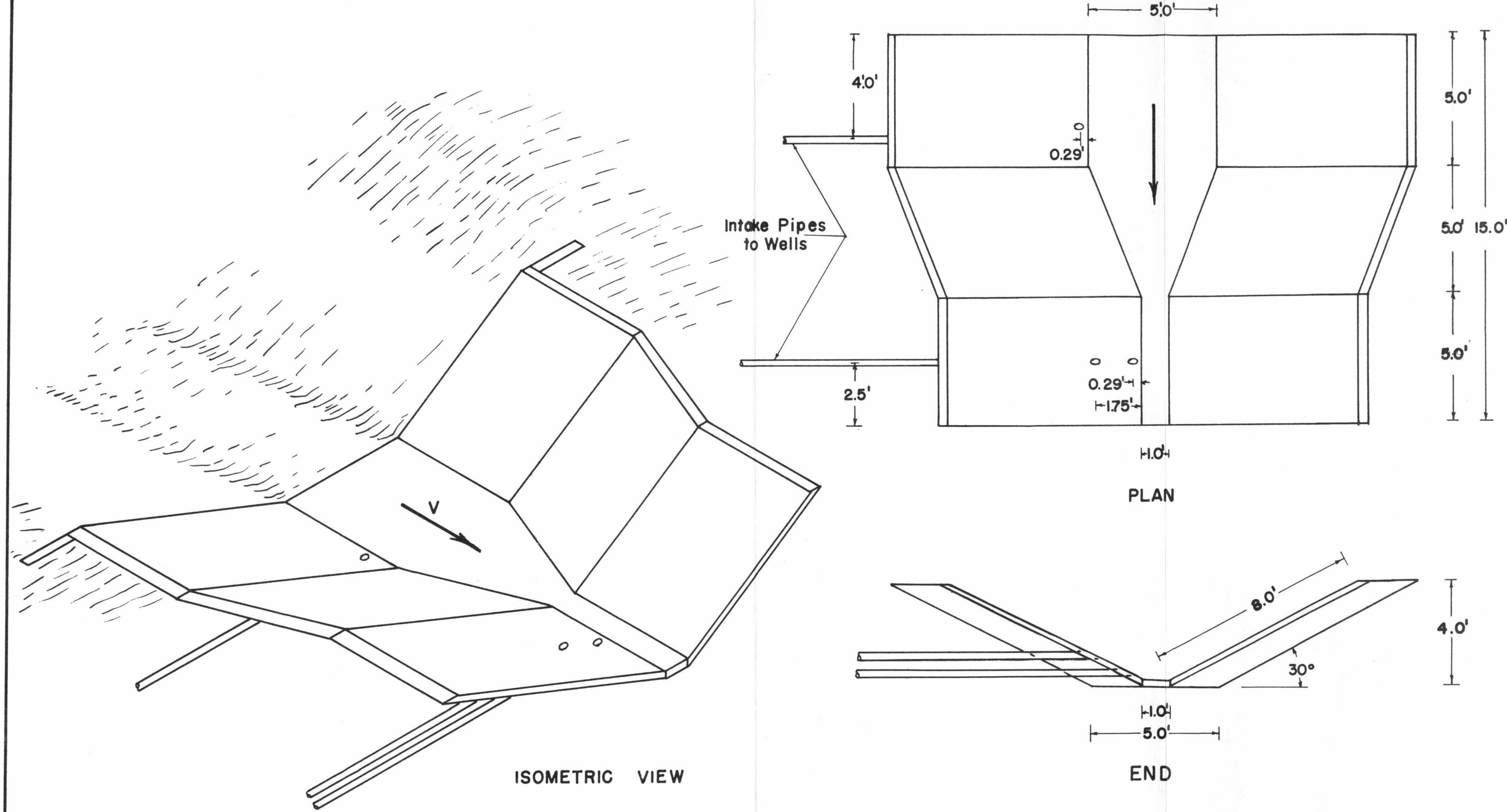
3. Rohwer, Carl. The Rating and Use of Current Meters. Colorado Agricultural Experiment Station Technical Bulletin No. 3, May 1933, pp. 33-35, 82, 124, 127.



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

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

Scale 1" = 4' February, 1959

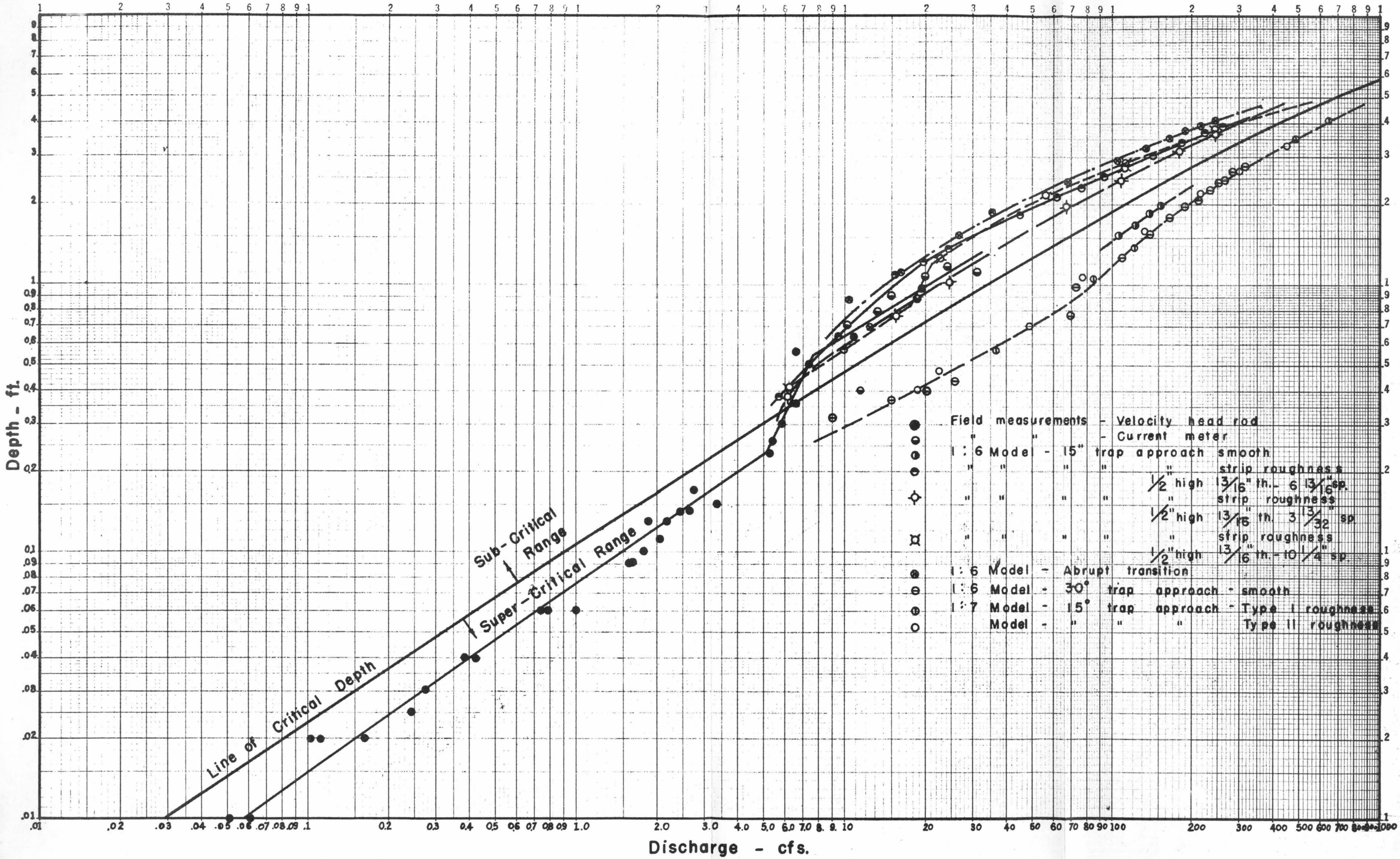


Fig 2 Depth in the Upper Section as a Function of the Discharge for the F. S. Trapezoidal Measuring Flume

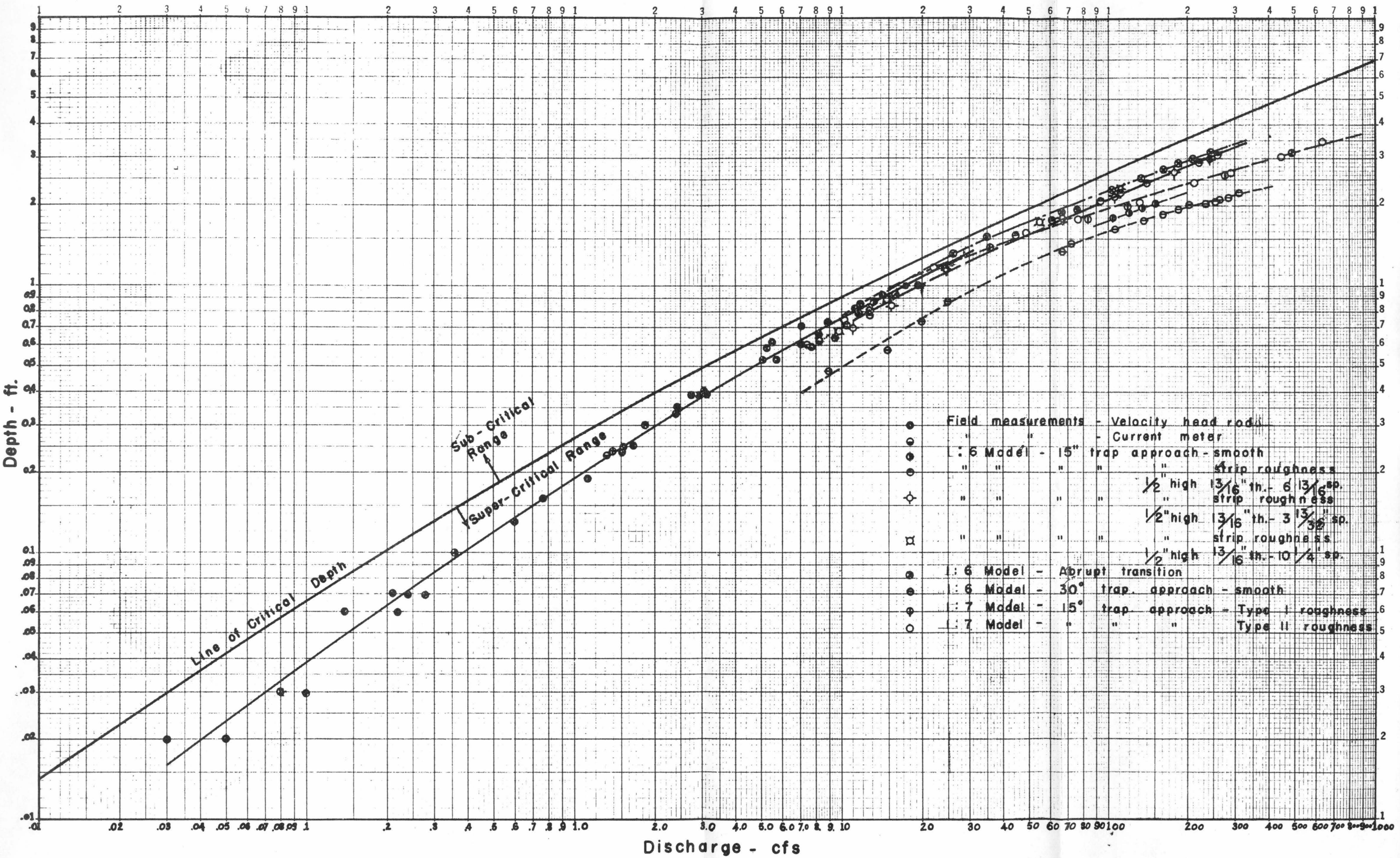


Fig. 3 Depth in the Lower Section as a Function of the Discharge for the F.S. Trapezoidal Measuring Flume

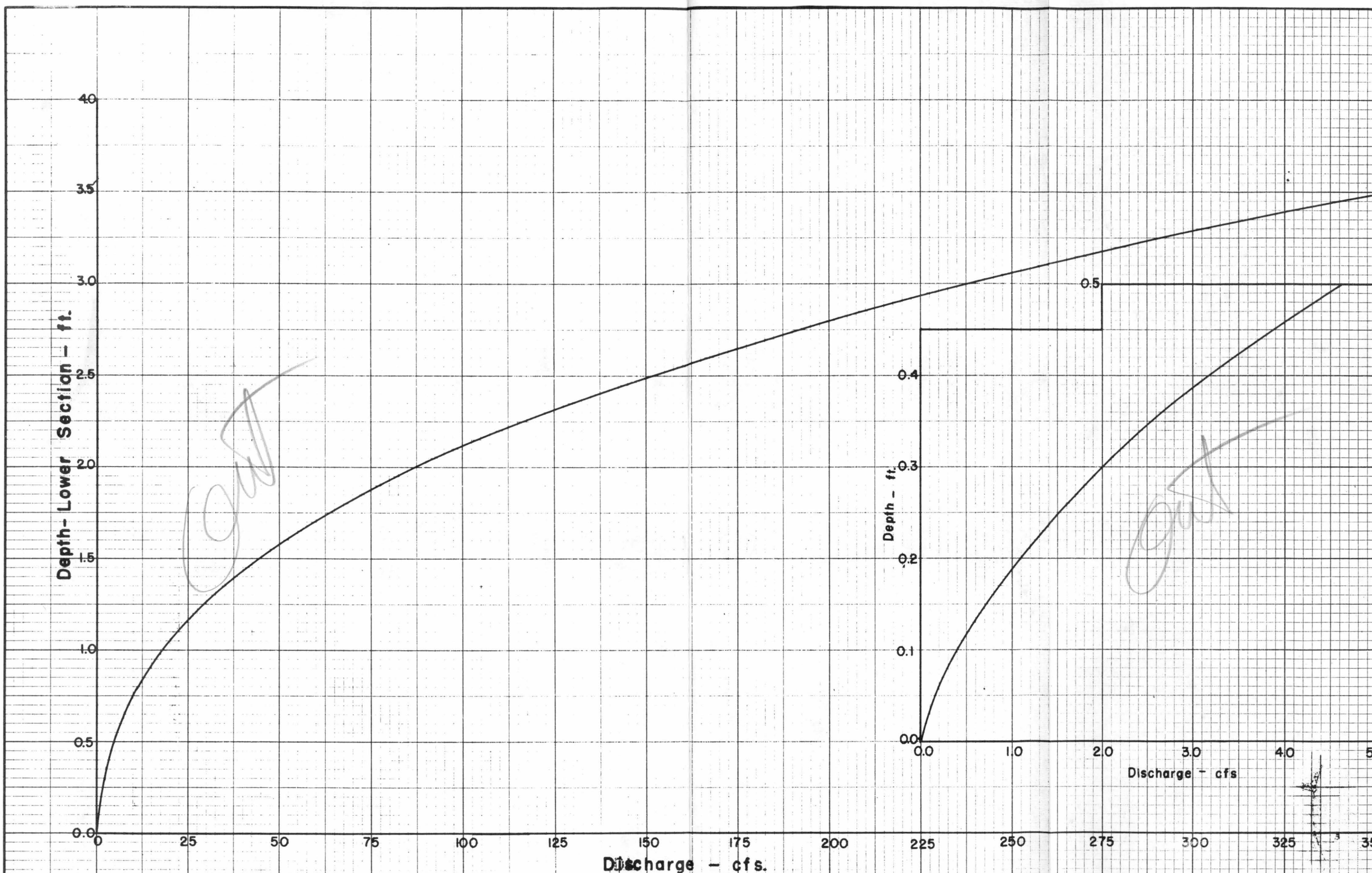


Fig. 4 Provisional Rating Curve For The Forest Service Trapezoidal Measuring Flume