R-90-19

LOWER COLORADO RIVER AUTHORITY WATER BOX CALIBRATIONS

October 1990

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Denver Office
Research and Laboratory Services Division
Hydraulics Branch

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.
R-90-19

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE

LOWER COLORADO RIVER AUTHORITY
WATER BOX CALIBRATIONS

5. REPORT DATE
October 1990

6. PERFORMING ORGANIZATION CODE
D-3750

7. AUTHOR(S)
Russell A. Dodge

8. PERFORMING ORGANIZATION REPORT NO.
R-90-19

[illegible]ESS

Bureau of Reclamation
Denver Office
Denver CO 80225

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS

Same

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
DIBR

15. SUPPLEMENTARY NOTES

Microfiche and hard copy available at the Denver Office, Denver, Colorado.

16. ABSTRACT

The LCRA (Lower Colorado River Authority) in Austin, Texas, requested the Bureau of Reclamation to study the implementation of rectangular stop plank style turnout structures for water measurement. A full-scale 4-foot and a 2/3-scale model of 6-foot LCRA water boxes were calibrated in the Denver Office laboratory in both weir and orifice modes of operation. It was determined that metal edges should be installed on the stop planks if the structures are to be used for water measurement. Metal edges were designed which could be installed and still allow the tongue-and-groove planks to be used for shutoff. The weir calibration was generalized in terms of unit discharge and can be applied for all box sizes. The orifice calibration was generalized in dimensionless form and can be used for all orifice lengths, openings, and elevations to within one orifice dimension of the box bottom.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- hydraulics/ water measurement/ orifices/ weirs

b. IDENTIFIERS-- Lower Colorado River Authority/ Austin/ Texas

c. COSATI Field/Group *COWRR:* *SRIM:*

18. DISTRIBUTION STATEMENT

19. SECURITY CLASS (THIS REPORT)
UNCLASSIFIED

20. SECURITY CLASS (THIS PAGE)
UNCLASSIFIED

21. NO. OF PAGES
15

22. PRICE

R-90-19

LOWER COLORADO RIVER AUTHORITY WATER BOX CALIBRATIONS

by

Russell A. Dodge

Hydraulics Branch
Research and Laboratory Services Division
Denver Office
Denver, Colorado

October 1990

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

The help of Mike Shoppa of LCRA is greatly appreciated. He provided drawings and data needed to model the water boxes and visited the laboratory to explain how the boxes are used in the field. Brent Mefford of the Denver Office supervised the study and performed the trial and error fits of the orifice calibration functions. The continued interest of Tim Flanigan of the Great Plains regional office is greatly appreciated.

CONTENTS

FIGURES

INTRODUCTION AND BACKGROUND

About 2,000 water boxes are used by LCRA (Lower Colorado River Authority) to deliver water to rice farmers of the Gulf Coast Irrigation District near Austin, Texas. In order to conserve water, the LCRA plans to improve their accountability of water delivered at each turnout by treating the water box turnouts as weirs or orifices. Water passes over the top stop planks when used as weirs; to create an orifice, spacers are placed between one set of the tongue-and-groove stop planks to separate them, thus forming rectangular orifices. LCRA requested that the hydraulic laboratory evaluate the water boxes and modes of operation as possible water measuring devices. If necessary these boxes will be modified and limits on their usage will be specified.

The conversion to a more precise measurement program will take place in two stages. The first stage, covering a 2,000-acre pilot project containing about 20 boxes, started in April 1990. The second stage will consist of converting the remaining boxes in 1991. The desired target water measurement accuracy is ± 10 percent.

Operators describe a "box of water" as 3,000 gal/min or 6.68 ft^3/s which, in a 4-foot box used as a weir, is assumed to occur at about 6 inches of head. Generally, after a mode of operation and position of planks have been selected at a site, the weir or orifice geometry is unchanged from then on. However, weir and orifice elevations, flow approach depth, and downstream submergence can vary considerably with time and between different measurement sites. In addition the edge shape of tongue-and-groove planks can change due to damage and wear. There can even be variation of milling of the wood. Thus, the present method is at best an estimate.

CONCLUSIONS

The following are based on laboratory observations, data, and calibration parameters:

- Metal-edged orifices and weirs installed in LCRA boxes are adequate measuring devices.

- Unit discharge equation 3a for the 4-foot box metal-edged weir should be used for all box sizes. The standard deviation for the weir equation is ± 2.0 percent discharge including the uncertainty of estimating between hundredth divisions on the staff gauges.

- Rounding of orifice and weir edges by poor machining or damage and wear can affect the discharge measurement considerably. Thus the use of wood blades is not recommended because of variation of the tongue-and-groove milling and inevitable damage and wear during use.

- The weir crest should be at least a distance equal to two maximum measuring heads from the invert of the box (immediately upstream of the weir crest). Weir lengths should be measured for each box after setting the blade level as a precaution against construction errors, form slipping and walls being out of plumb. Corrected values of blade length (L) should be used in the weir equations.

- Metal orifice and weir blades can be installed on the planks and still allow the tongue-and-groove to seal and shut off the flow.

- Because LCRA water boxes lack a field data base as measuring devices, it is recommended, especially during the early stages of the conversion program, that careful current meter checks be made for box sizes tested in the laboratory and those not tested.

- Flow through LCRA weirs seals against the slot projections and prevents nappe ventilation when the downstream water level rises to within 0.5 foot of the crest elevation. Therefore, the water surface downstream should be kept at least 0.5 foot below the weir crest.

- The metal-edged orifice coefficient curves on figure 1 can be used with equation 7 to determine discharge. The coefficient of discharge can be determined from the conic least square fit equations 9 and 10. The average standard deviation of the coefficient for elliptical orifice fits is 0.01. The discharge coefficients presented can be used for all sizes of boxes, orifice openings, orifice lengths, and elevations to within one orifice opening from of the upstream box bottom.

- The outside edge of the orifice opening spacers should be parallel and in line with plank slot projections. The length and opening should be measured for each box after each setting of blade level as a precaution against construction errors, form slipping, and walls being out of plumb.

- Staff gauge zero reference elevations and orifice dimensions should be determined after the wood planks have become water saturated. Orifice and weir installations and boxes should be checked routinely for tilting and shifting relative to the staff gauge.

- Since plugging occurs where it cannot easily be seen, the orifices need to be checked frequently for plugging with weeds and other debris.

- Sediment deposits on the bottom of the approach near shallow orifices can affect flow measurement accuracy. Special effort should be made to ensure that there is not a deposit that slopes up to the orifice edge. Sediment deposits upstream of the measuring head staff gauge and the stop planks should be cleaned out to a distance equal to at least six deposit depths.

- If the right and left measuring heads differ by more than 0.02 foot, turning and blocking baffles should be placed upstream to correct the difference to within 0.02 foot.

- The laboratory calibrations presented for the tongue-and-groove weirs and orifices (figs. 4 and 6) are not recommended for general use because they are based on wooden blades.

- The simultaneous use of weir and orifice flow should not be used for flow measurement. Discharges determined under this combined flow condition should be considered as rough estimates only.

THE MODEL

Test Plan

The following is basically the study plan as submitted to LCRA. The 4-foot box is the most commonly used. Therefore, this size was installed in the laboratory and tested first. The tests were directed mainly at determining the orifice and weir boundary and edge effects. It was expected that this would require tests of the orifices at different distances from the invert and different distances from the water surface. Weir and orifice tests with and without the slot protrusions might be required as well as tests of weirs with protruding slots with and without the spacers and their rods. A vertical center railroad track used as a brace in the 6-foot box would be removed to determine its effect on discharge. Then the 6-foot box unit discharge equation would be predicted from the 4-foot unit discharge equation and compared to a calibration done with a 2/3 scale 6-foot box installed in the laboratory. Depending upon the degree of this comparison, the remaining sizes of the boxes would be installed and tested. Due to the expense of converting 2,000 boxes to ideal weir and orifice measuring systems, it was decided that tests would be performed to attain an acceptable accuracy with the least amount of modification necessary.

Laboratory Installation and Measurements

The water box, weirs, and orifices were installed in a 6-foot-deep, 7-foot-wide, and 22-foot-long rectangular channel (fig. 5). Water was supplied to the model test channel using the standard laboratory water delivery system. Discharge through the model was measured with the volumetrically calibrated venturi meters that are a permanent part of the hydraulic laboratory equipment. The volumetric tank water measurement system can measure discharge to within less than ±1 percent. Thus with careful venturi differential readings the discharge measurements have a traceable accuracy of ±1 percent. Before passing through the water boxes, the water was distributed and stilled by passing it through a gravel baffle. The downstream submergence head was controlled by positioning a flap-type tailgate. Head measurements were made using metal staff gauges that have 0.01-foot minimum divisions. Therefore, bankside staff gauge readings can be estimated to ±0.005 foot.

WEIR CALIBRATIONS

Conditions for standard sharp-crested weirs specified in the Water Measurement Manual (Bureau of Reclamation, 1981 reprint) are:

- The weir crest elevation should be at least two maximum measuring heads above the approach channel invert.
- The approach flow area should be at least eight times the flow area above the crest.
- The velocity of approach should be less than 0.5 ft/s.
- The blade crest length should be greater than three maximum measuring heads.

- The approach channel to the weir should be straight for a distance equal to 10 average channel widths.

- The top of the weir blade should not be more than 1/16 inch thick and have a sharp upstream corner.

These conditions can only be relaxed at the expense of determining more complicated equations with variable discharge coefficients, obtaining specific site and geometry calibrations and making velocity of approach corrections. Additional improvements in the field may also be required such as installing baffles to correct approach flow distribution.

The prediction of hydraulic relations can frequently be approximated by a form of a power function, that is, they plot as straight lines on log-log graph paper. But exponents and coefficients derived in this manner do not generally relate directly to the actual physics. For example the coefficient has to assume dimensional units that are commensurate with the independent variable raised to its exponent to obtain the proper units for the dependent variable. However, statistical best fit parameters such as correlation coefficient, standard deviation and mean error can be used to tune coefficients of simplified equations to achieve predictions within the limits of experimental error. To a degree, varying the coefficients and exponents can compensate for poor compliance of the above-mentioned conditions for standard weirs.

Discharge (Q) and measuring head (H) can be equated as:

$$Q = C_d H^n \tag{1}$$

Dividing equation 1 by the crest length (L) results in the unit discharge form,

$$q = Q/L = (C_d/L)H^n \tag{1a}$$

letting

$$c = C_d/L$$

then

$$Q = qL = cLH^n \tag{1b}$$

Four-Foot Weir Calibrations

The calibration curve for the 4-foot box with flow over a stop plank tongue acting as a weir blade is shown on figure 6. The least square fit equations are

$$Q = 12.74 H_1^{1.381} \tag{2}$$

$$Q = 3.493 L H_1^{1.381} \tag{2a}$$

where:

H_1 = upstream head measured at the staff gauge.

The correlation coefficient for these equations is 0.9985 and the standard deviation (σ) is 1.8 percent discharge. Percent discharge was calculated as

$$Q_{\%} = 100\ [(Q_m - Q_e)/Q_m]$$

where:

Q_m = measured discharge.
Q_e = discharge based on least square fit equation.

Assuming a normal statistical distribution, 68.3 percent of the data points are expected to be within $\pm\sigma$, 95.4 percent to be within $\pm 2\sigma$ and 99.7 percent to be within $\pm 3\sigma$. The value of 3σ can be considered the maximum expected error. Any measured data pair that had a deviation greater than 3σ was considered to be a misreading and was removed from the least squares fit.

Rounding of weir blades has a considerable effect on accuracy. Ackers et al. (1978) found that at measuring heads of about 0.5 foot, the increase in the coefficient of discharge in percent is equal to the radius of rounding in millimeters. Thus, the use of tongue-and-groove wood weirs is not generally recommended because of variations in milling and inevitable damage and wear in time.

A method of incorporating metal blades is shown on figure 7. The metal blades could be used for weir or orifice configurations and still allow the tongue-and-groove to seal for shutting off the flow.

The equations for the metal-edged weir blade in a 4-foot box are

$$Q = 12.18H_1^{1.441} \tag{3}$$

$$Q = 3.340LH_1^{1.441} \tag{3a}$$

The correlation coefficient for this equation is 0.9984 and the standard deviation is 2.02 percent discharge. The calibration curve and measured data are shown on figure 2. Note that equation 3 is for one crest length (3.67 feet); therefore, equation 3a should be used to correct calibration for difference in crest length.

A comparison of calibrations between the sharp metal edge and the tongue plank edge indicates the sharp edge metal weir delivers about 10 percent less discharge than the plank tongue weir blade at the same head.

To investigate the sensitivity of weir discharge measurements to both precision of head measurement and zero elevation setting, equation 3 was used to compute discharge errors. For a zero or head reading error of one-half the minimum staff gauge division or ± 0.005 foot, the discharge error varies from ± 1 to ± 4 percent as head varies from 0.6 to 0.2 foot. Over the same head range, assuming the head reading or staff gauge zero is off ± 0.01 foot, additional errors in discharge ranging from ± 2.5 to ± 7 percent occur.

Six-Foot Metal Weir

The 2/3 scale model of a weir with a center rail support in a 6-foot box was calibrated similar to the 4-foot version. The influence of the support rail on the discharge calibration was determined by conducting flow calibrations with and without the rail in place (fig. 3). Within experimental error the rail was not found to affect the calibration. The best fit equations are

$$Q = 18.71H^{1.402} \tag{4}$$

$$Q = 3.30LH^{1.402} \tag{4a}$$

Note that equation 4 is for one crest length (5.70 feet). The correlation coefficient is 0.9993 and the standard deviation is 1.89 percent.

Equation 4a compares closely to equation 3a and since the 6-foot box is from model data where experimental errors are amplified by the scale ratio along with other possible minor scale effects, it is recommended that equation 3a be used for all sizes of weirs.

ORIFICE CALIBRATIONS

Conditions for standard orifices specified in the Water Measurement Manual (Bureau of Reclamation, 1981 reprint) are:

- The orifice blade should be at least two minimum orifice dimensions from all approach flow boundaries.
- The approach flow area should be at least eight times the orifice area.
- The velocity of approach should be less than 0.5 ft/s.
- The downstream submergence head (measured from the top orifice edge) should be greater than two minimum orifice dimensions.

As with weirs, these standard requirements can only be relaxed at the expense of defining more complicated equations with variable discharge coefficients, obtaining specific site and geometry calibrations and making velocity of approach corrections.

Submerged Orifice Theory

Rouse (1950) shows that the energy equation can be used to derive an approximate general orifice equation as follows

$$Q = C_c bL[2g(\Delta H + V_1^2/2g)]^{1/2} \tag{5}$$

where:

ΔH = $(H_1 - H_2)$.
H_1 = upstream measuring orifice head relative to orifice bottom
H_2 = submergence head relative to orifice bottom.
V_1 = approach velocity.
g = acceleration of gravity, 32.2 ft/s^2.
b = opening between planks.

L	=	length of orifice.
C_c	=	coefficient of contraction.

The coefficient of contraction, C_c, and the approach flow velocity head, $V_1^2/2g$, are governed by the flow geometry. These can be combined into a coefficient of discharge, C_d, where:

$$C_d = \phi(H_1/b, H_2/b) \tag{6}$$

Equation 5 can then be rewritten as:

$$Q = C_d bL(2gH_1)^{1/2} \tag{7}$$

Four-Foot Box Tests Using Tongue-and-groove Planks as Orifice Edges

Generalized calibration curves were developed from test data measured using three typical orifice configurations. Two 3-inch orifice geometries were tested, one with its bottom orifice edge 3.5 inches from and the other 8 inches from the invert of the box. The third orifice geometry was a 6-inch orifice located 8 inches above the box invert.

Tests of each orifice geometry were conducted at constant discharges equal to 1, 3/4, 1/2, and 1/4 boxes of water (6.68 ft^3/s). For each nominal discharge, the submergence head was reduced in increments and both the upstream and submergence head were measured. A typical plot of upstream head versus submergence head for a 3-inch opening is shown on figure 8. For high upstream and submergence heads, the curves approximate 45° lines; however, as the downstream water surface approaches the top of the orifice, it becomes influenced by the orifice jet. The curves then bulge towards the ordinate and then drop nearly vertical. The horizontal lines shown represent constant values of (H_2/b), one of the parameters of equation 6.

To develop coefficient of discharge curves, where the horizontal (H_2/b) lines (fig. 8) intersect the head curves the approach heads (H_1/b) are read from the abscissa. The corresponding discharge is interpolated between the associated venturi discharge measurements. Coefficient of discharge values can then be calculated and plotted against (H_1/b) for constant values of (H_2/b) (fig. 4). The data measured from the different orifice geometries tested plot within the scatter of each other. Therefore, the solutions to equation 6 as given on figure 4 can be applied as general submerged orifice calibrations for different orifice openings provided the orifice is located at least one orifice height above the approach box invert. The C_d values presented on figure 4 will apply to water boxes of similar geometry but different widths.

Coefficient of discharge values can be presented in tables or directly calculated by performing a least squares fit of the dimensionless submerged orifice parameters. The coefficient of discharge curves for each submergence value of (H_2/b) on figure 4 were fitted by least squares. The calibration of orifice control below radial gates could be approximated by a conic section of elliptical form (Buyalski, 1983). The conic form of the equation is

$$x^2 + y^2 = E^2(D + x)^2 \tag{8}$$

where:

x	=	the horizontal distance measured from the focus to the locus of point **p**.
y	=	the vertical distance measure from the focus to the locus of **p**.
E	=	the eccentricity equal to the ratio (r/d) (fig. 9).
D	=	the directrix equal to a constant distance measured from a fixed reference line to the focus.

Replacing x and y with the orifice calibration parameters given on figure 9 and solving for C_d, equation 8 becomes

$$C_d = \{E^2[D+(H_1/b-F)]^2 - (H_1/b-F)^2\}^{1/2} \tag{9}$$

where:

$$F = H_2/b + E^*D/(1+E) \tag{10}$$

The best fit values for (E) and (D) were found by a trial and error method (Box et al., 1978) based on calculating the variance of measured (C_d) values relative to calculated (C_d) values on a (E) versus (D) grid. After the variance was calculated for all grid intersection points, the center of the grid was adjusted to the minimum variance and the spread of the grid was reduced to increase resolution. This iterative process was repeated until increasing the grid resolution did not significantly alter the minimum variance. The mean standard deviation of the least square fit curves is 0.01 with a maximum of 0.02 and a minimum of 0.004. A plot of the curves and a table of (H2/b), (E), and (D) values are given on figure 4.

Six-Foot Box Orifice Tests With Tongue-and-Groove Planks

Tongue-and-groove orifice calibration data were also obtained with a 2/3 scale model of the 6-foot box orifice both with and without the center supporting rail track. Comparison of coefficients with and without the rail, assuming no change in orifice area due to the track, indicated that there was no significant effect of the rail on discharge. Comparing the 6-foot box coefficient data to the 4-foot calibrations on figure 4 indicates a shift of about +0.4 inch in the value of H1/b. It is believed that variation in the board milling and the projection of the slot relative to the length of opening contributed to the shift.

Metal-Edged Orifice Tests in 4-foot Box

The metal orifice was calibrated in the same manner as for the tongue-and-groove orifice. However, based on the previous test results only one orifice opening and elevation was considered necessary to determine the functional form of equation 5. Values of E and D for use in equation 8 are given for sharp-edged orifices on figure 1. The dashed line curving down and to the right is a suggested lower limit of long-term use because of difficulty of interpolating within the steep part of the (H_2/b) curves. As the curves become steeper at low values of (H_2/b) it is recommended that orifice geometries resulting in values of (H2/b) below 2 not be used.

From the dimensionless orifice plots, a relative comparison of discharge capacity under equivalent head conditions between the tongue-and-groove orifice and the sharp-edged orifice was determined.

The tongue-and-groove orifice provides increased capacity from 9 to 22 percent over that of the sharp-edged orifice, averaging 13 percent over the applicable head ranges.

Six-Foot Box With Metal Orifice Tests

Data were also obtained for the 6-foot box with metal-edged orifice. These also showed a shift in the 6-foot dimensionless data when compared to data from the 4-foot box. The shift was less than found for the wood plank orifices and was in the opposite direction, -(H1/b) from four-foot curves. Since the 6-foot box test results are from model data where experimental errors are amplified by the scale ratio along with other possible minor scale effects, it is recommended that the 4-foot box calibration equations be used for all box sizes. Current metering could be used in the field to determine if a shift in the dimensionless calibration parameters does occur.

APPLICATIONS

To use the calibrations in this report the upstream staff gauge (H_1) should be 2 feet from the stop planks for both weir and orifice measurements. For the orifice measurements the downstream staff gauge (H_2) should be in the delivery channel 3 feet downstream from the end of the side walls. The outside face of the spacer blocks and the edges of their rods should be in line and parallel to the plank slot projections.

A visual average of the staff gauge reading should be made and compared to a calculated average of observed high and low readings. Head should be estimated to at least one-half of the smallest staff gauge division or 0.005 foot. If the flow in the main supply canal is high, the water surface across the crest should be checked for level. A staff gauge on both of the approach side walls or at least a reference line above the high water line on the opposite side of the approach channel to make this check may be required. If staff gauge readings on opposing sides at a (H_1) distance from the planks differ by less than 0.02 foot they should be averaged. Differences of greater than 0.02 should be corrected by improving the approach conditions by installing turning and blocking baffles. The location and deflection angle of the baffles should be set by trial and checking that the depth of flow is relatively constant across the box width in front of the crest.

Typically weirs with good side ventilation can measure flow accurately with the downstream water level within 0.2 foot from the crest. However, the LCRA weirs do not exhibit adequate ventilation. The flow seals against the side slot projections at about 0.5 foot from crest elevation and therefore limits their use to downstream water levels 0.5 foot below the crest.

Sediment in front of shallow weirs or orifices (blade elevation less than 1 foot above the floor) can influence the discharge coefficient. The region in front of shallow measuring stations should be probed frequently to check for sediment deposits. Sediment deposits should be cleaned out to a distance equal to at least six deposit depths upstream from the measuring head staff gauge and the stop planks. Each time after the stop planks have been used to shut off the water for some period the lowest stop planks should be raised to sluice accumulated sediment through the box.

Rounding of orifice edges by poor machining or damage and wear will affect the discharge capacity. For example, Schuster (1970) cited a case of a 1-inch orifice that was rounded by 0.01 inch. The rounded edge resulted in a 3-percent increase of discharge. On a similar basis for a 3-inch orifice slot in a water box the discharge would increase 3 percent for each 1/32 inch radius of rounding.

Thus the use of wooden planks as blades is not recommended because of variation in the tongue-and-groove milling and inevitable damage and wear during use.

Submerged orifices are susceptible to plugging with weeds and other debris and may be difficult to see. Therefore, orifice boxes should be periodically checked for partial plugging and any debris removed.

The boxes should not be used for water measurement when operating with combined orifice and weir flow simultaneously. The back pressure under the weir nappe and on the orifice varies considerably with height of weir crest and orifice size and elevation.

As used in LCRA boxes, the weir and orifices are not standard water measuring devices. Thus they are lacking in terms of documented experience as measuring devices and quantity of field calibrations and checks that standard devices have. Therefore, it is recommended that careful current meter checks be made on the devices in the pilot project. It is recommended, especially during the early stages of the conversion program, that careful current meter checks be made for box sizes tested in the laboratory and those not tested. If consistent average deviation of discharge of 5 percent or more are apparent then the laboratory calibrations should be adjusted.

Orifice and weir lengths should be measured for each box after each setting of blade level as a precaution against construction errors, form slipping and walls being out of plumb. Measured values of blade length (L), not nominal length, should be used in the weir and orifice equations 3a and 7. Weir and orifice zero datums and orifice openings should be determined after the wood planks have become water saturated. The boxes should be checked routinely for tilting and shifting relative to the staff gauge.

BIBLIOGRAPHY

Ackers, P., et al., "Weirs and Flumes for Flow Measurement," John Wiley and Sons, 1978.

Box, G.E.P, et al., "Statistics for Experimenters," John Wiley and Sons, 1978.

Bureau of Reclamation, *Water Measurement Manual*," U.S. Department of Interior, 1967 Edition, 1981 Reprint.

Buyalski, C. P., "Discharge Algorithms for Canal Radial Gates," U.S. Department of Interior, Bureau of Reclamation, REC-ERC-83-9, 1983.

Rouse, H., Editor, "Engineering Hydraulics," John Wiley and Sons, 1950.

Schuster, J. C., Editor, "Water Measurement Procedures-Water Operators' Workshop," U.S. Department of Interior, Bureau of Reclamation, REC-OCE-70-38, 1970.

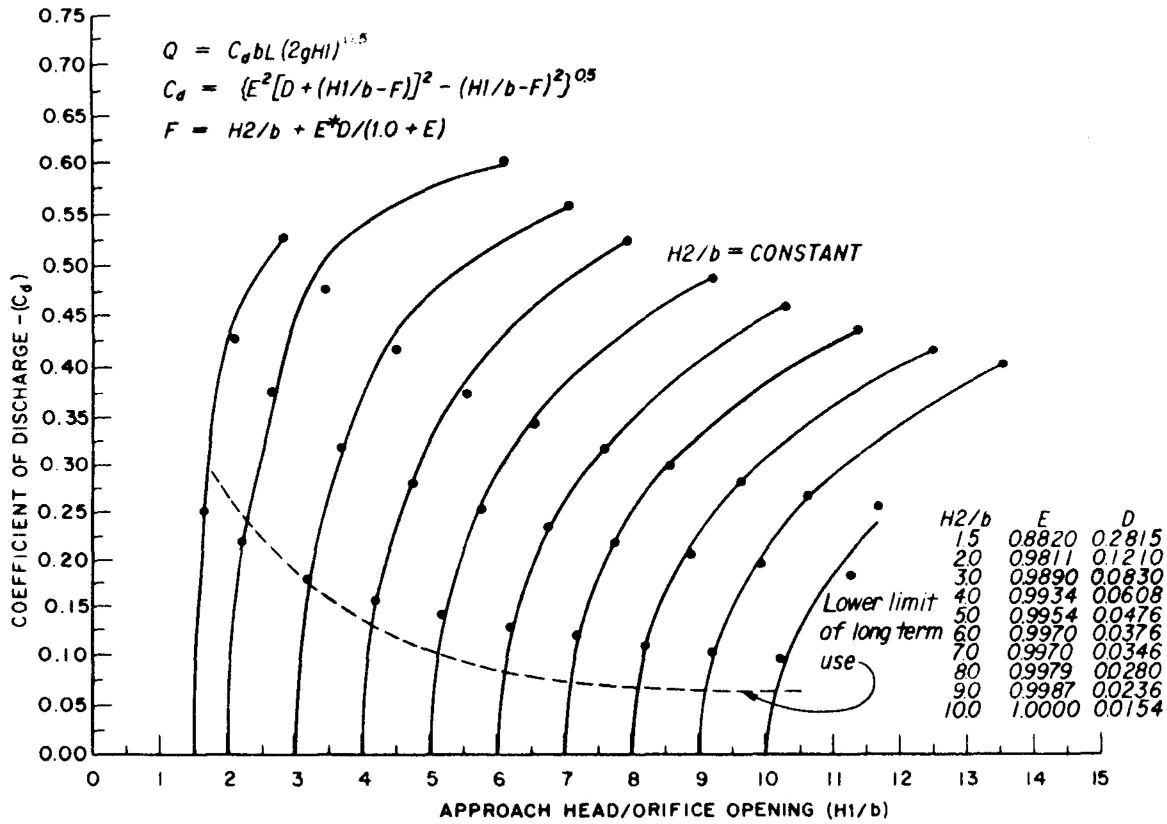

Figure 1. - Sharp-edged orifice water box calibration.

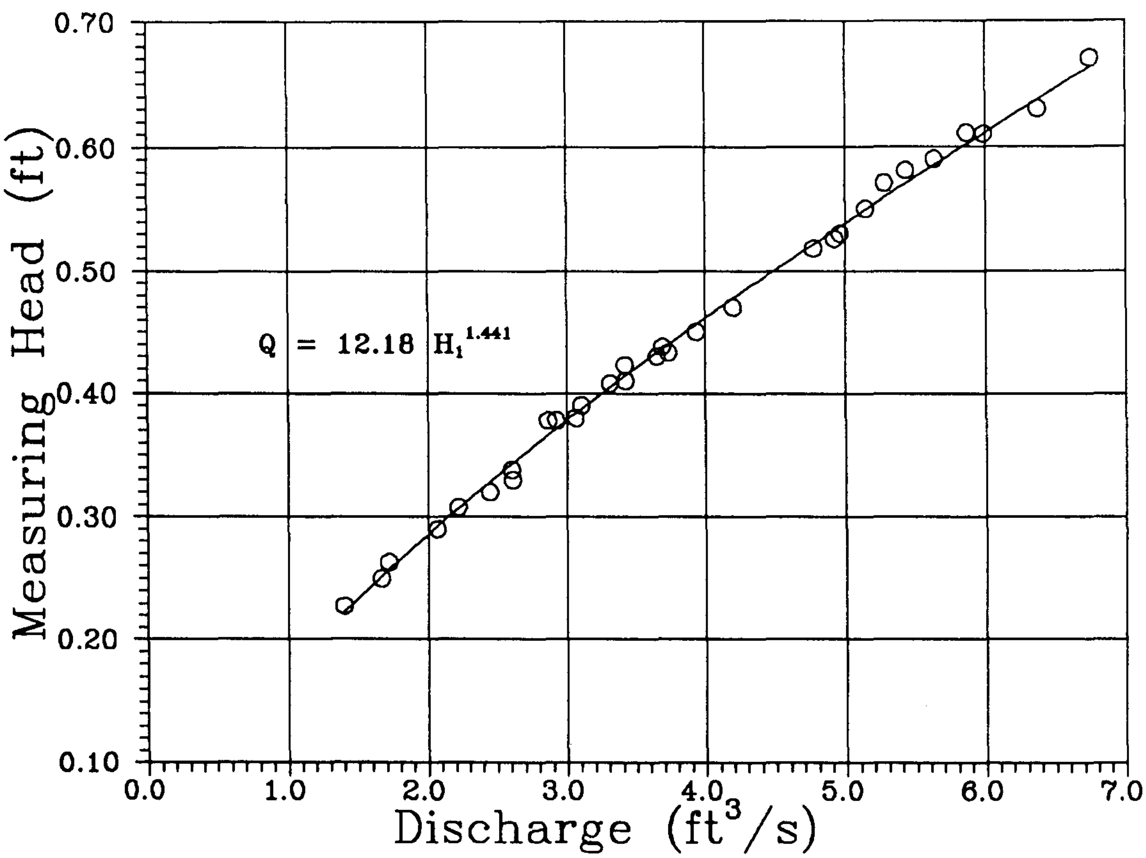

Figure 2. - Four-foot box metal-edged weir calibration.

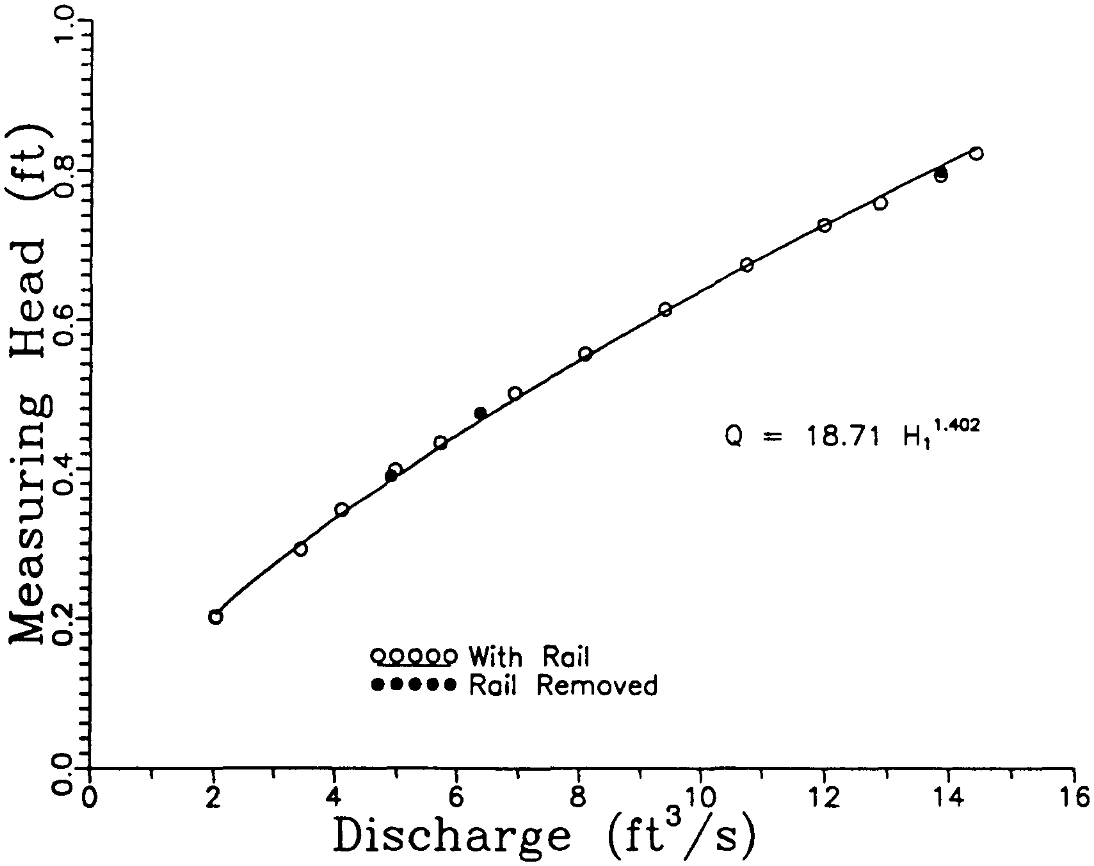

Figure 3. - Six-foot metal-edged weir calibration.

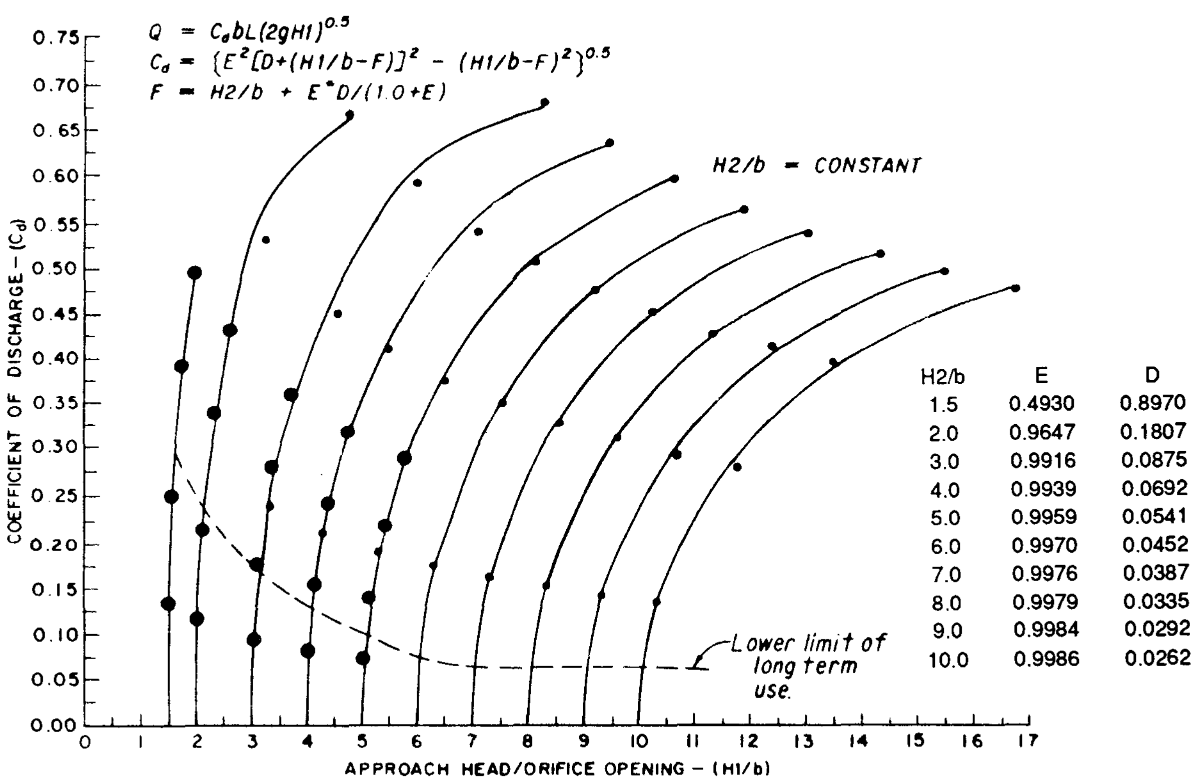

Figure 4. - Tongue-and-groove wood plank orifice water box calibration.

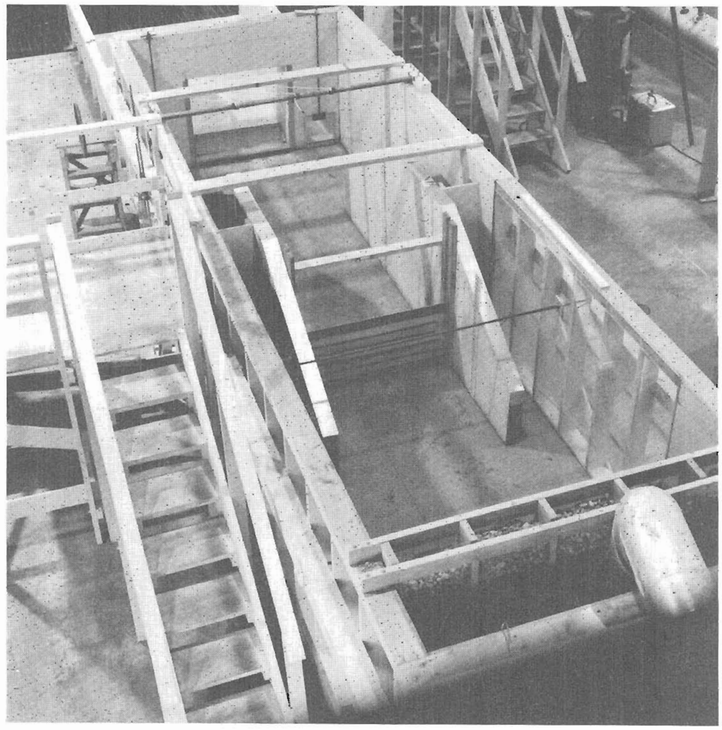

Figure 5. - Laboratory installation of water boxes.

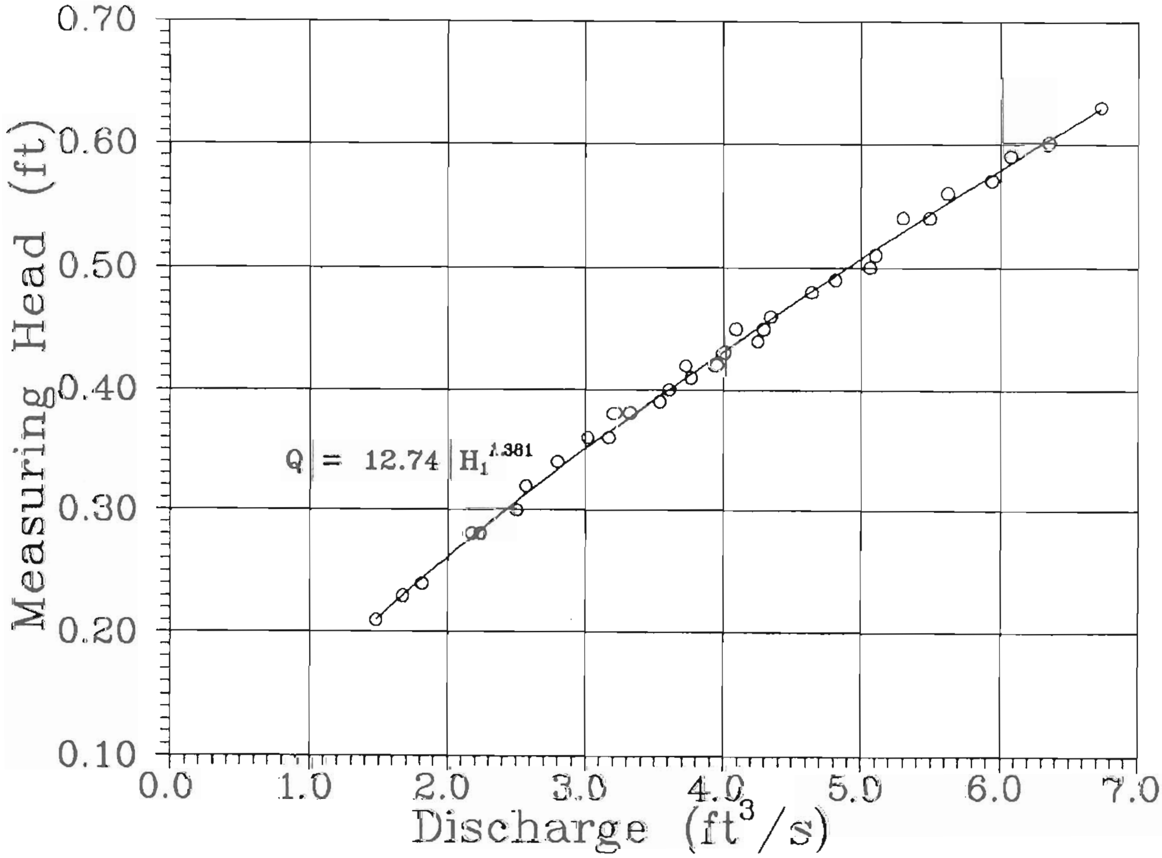

Figure 6. - Four-foot box tongue-and-groove weir calibration.

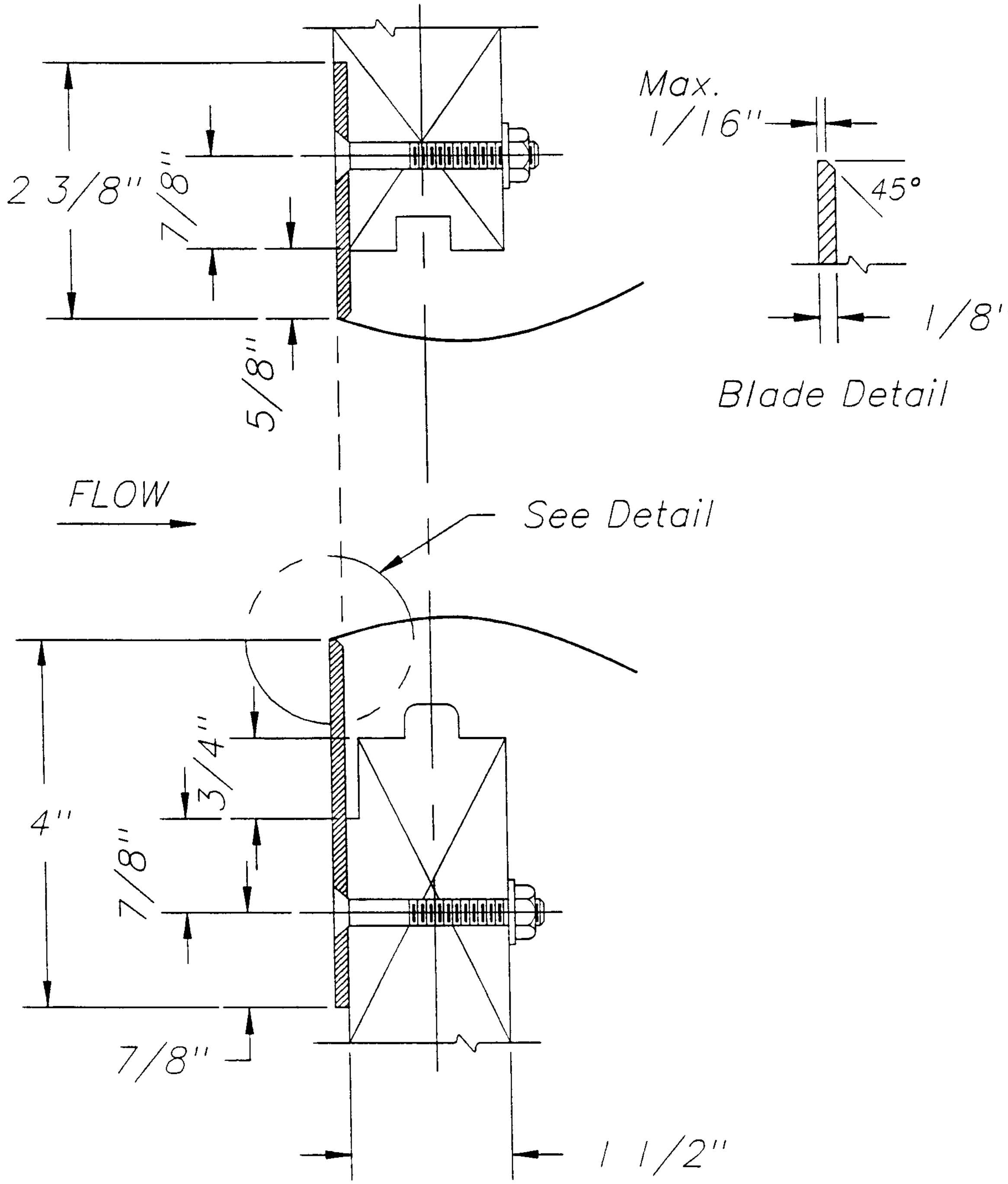

Figure 7. - Metal edges installed on tongue-and-groove planks.

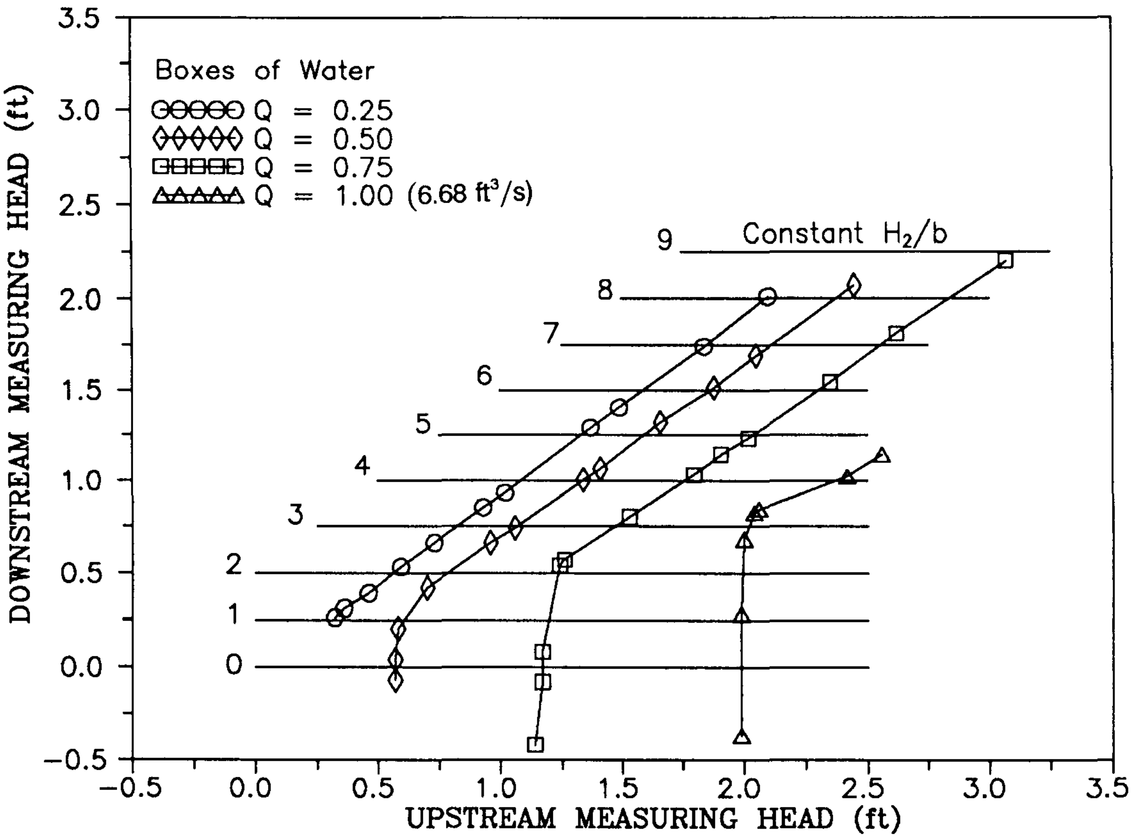

Figure 8. - Upstream head reading versus submergence head reading for a 3-inch orifice with discharge as third parameter.

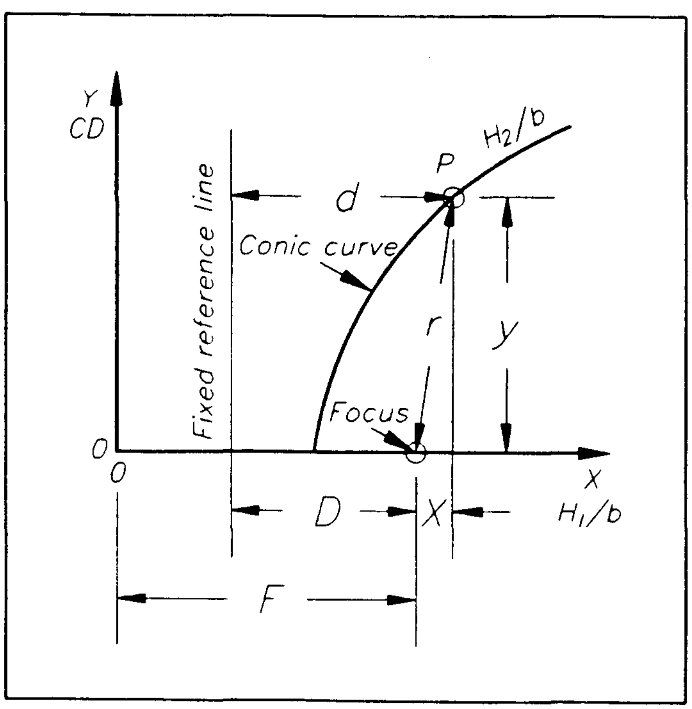

Figure 9. - Conic equation fit parameters.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1992—675-185/60,009 REGION NO. 8

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-7923A, PO Box 25007, Denver Federal Center, Denver CO 80225-0007.