Research Technical Completion Report

FLOW MEASUREMENT USING RAMPED BROAD CRESTED WEIRS

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Submitted to:
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ABSTRACT

A low cost flow measurement device that will provide real-time data is needed for use in irrigation water distribution. In addition it must be easily calibrated, require low operating head, and require little if any periodic current meter measurements to verify the rating curve. The project goal was to evaluate the use of computer calibrated ramped broad crested weirs in establishing a stable stage-discharge relation within the head constraints of most irrigation canals. Structures were built in six canals in southeastern Idaho. Design discharges ranged from 100 to 600 cubic feet per second, while tailwater depths ranged from 2.75 to 5.45 feet. The required head loss at the design discharges ranged from 0.29 to 0.50 feet. Weirs were calibrated using as-built dimensions in the computer model and the calibration was verified by current metering the canals every two weeks during the summer of 1986. The current metered flows and weir predicted flows usually differed less than 3 percent. Two of the weirs experienced submergence problems due to construction anomalies rather than weir characteristics. Recalibration using as-built dimensions in the computer model allows construction tolerances to be relaxed. Due to this and the simple geometry, ramped broad crested weirs are less than 1/5 the cost of an equivalent Parshall flume. Both Water District 1 and the involved canal companies were pleased with the performance of the weirs.

LIST OF FIGURES

Figure

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mined by current meter measurements. The evaluation process also was to include an annual cost evaluation of the broad crested weirs in comparison with other methods for measuring flow such as the Parshall flume and current metering.

PROJECT AREA DESCRIPTION

All of the land under the juristiction of Water District 1 was included in the project area. Water District 1 extends from the Idaho - Wyoming border to Milner Dam in south central Idaho, or an area approximately 200 miles long and 60 miles wide. It includes all of the Upper Snake River in Idaho and most of its tributaries. The project area includes over 1,300,000 irrigated acres that are served by more than 300 canals and pumps. The canals divert water at flow rates ranging from less than five cubic feet per second (cfs) to over 3000 cfs. Canal widths range from 3 to over 70 feet, while depths vary from 6 inches to over 9 feet. Seven major reservoirs, having a combined capacity of over 4,000,000 acre-feet, store water to supplement natural flow supplies during the summer [12].

Irrigation on the Upper Snake River Plain began about 1880. Early development was on lands adjacent to the river or within reach of short canals. Many of the canals in the project area were constructed by hand by private companies or groups of farmers. Federal legislation such as the Homestead Act, the Carey Act of 1894 and the Reclamation Act of 1902 stimulated the rapid expansion of irrigated acreage in the early 1900's. The combination of these acts provided for the transfer of public lands to individuals for private reclamation and financing for large-scale reclamation projects such as the construction of dams, reservoirs, and canals.

to carry the maximum decreed quantity of water. When additional water rights were acquired by a canal, it was enlarged only enough to carry the additional flow. In addition, much of the Snake River Plain is underlain by hundreds of feet of layered basalt. Due to this, the topography tends to be flat. In many areas the basalt is only covered with a thin layer of soil. The flat topography and shallow basalt greatly increased the construction cost because either the depth or width had to be increased for the canal to have the same capacity as a canal with a steeper slope. Since the depthwas limited by the underlying basalt, the width had to be increased. In order to reduce the amount of labor, materials, and required land, the canals were designed to be as small as possible, which results in very little head available for use in flow measurement.

In addition, most canals were constructed to serve smaller areas than are now being irrigated. Also, crop production has expanded from hay, grain, and pasture to include high water consuming crops such as potatoes and sugar beets. In many cases, rather than enlarge the canal to handle the increased demand, freeboard and head available for flow measurement were sacrificed.

Measuring procedures on canals in the St. Anthony, Idaho Falls, and Blackfoot areas, as well as the Magic Valley, were evaluated to determine the need for and suitability of specific devices to improve water measurement capability.

tween the number of revolutions per unit of time and the velocity of the water or calibration can be determined by the U.S. Bureau of Standards or at other hydraulic laboratories.

The Price type meter, developed by the U.S. Geological Survey ,is the most common vertical axis current meter and is the type used by Water District No. 1. It has a tail vane to keep it pointed into the current and may be suspended either from a wading rod or a cable.

There are many types of propeller meters such as Hoff meters, Haskell meters, Neyrpic "Dumas" meters and Ott meters. The latter was the type used in this research to check the calibration of the weirs. According to the U.S. Bureau of Reclamation [1], propeller meters are less sensitive than Price type meters to velocity components not parallel to the meter axis.

Current meters should be cleaned and checked after each use to see if they are functioning properly, and calibrated once a year to insure their accuracy. Care must be taken to prevent damage during transport.

The velocity measurements are taken at a cross section perpendicular to the direction of flow. This cross section is called the rating section. Velocity measurements are made at selected intervals across the channel and the discharge is calculated using the continuity equation (Equation 1). By locating a staff gage at the rating section, a relationship may be established between the canal stage and discharge. The plot of this relationship is the canal discharge rating curve. This method of determining the flow rate requires no head loss and is very good for sediment laden and very large streams. It is a labor intensive procedure, and unless the rating section is located at a control section, where there is a stable stage-discharge relationship, corrections must be applied to the rating

$$Q_i = W * D * V_{ave} \qquad \text{Equation 2.}$$

where, Q_i = incremental discharge
W = section width
D = section depth
V_{ave} = average velocity through the section

The accuracy of flow rate determination by current metering depends on some combination of current meter accuracy and the accuracy of the spacial sampling of the velocity. A basic assumption of current metering is that the velocity is sampled at the depth where the point velocity is equal to the average velocity of that section. If a logrithmic velocity distribution exists, the average velocity is the geometric average of the point velocities at two-tenths and eight-tenths of the depth. If the velocity distribution is not logrithmic, this relation may or may not hold. While no literature could be found that quantified the overall accuracy of a current meter traverse, Kulin [10] reports that standard current meter calibration is within 2 percent of the actual velocities assuming that the current meter is in good operating condition.

The time required to current meter a canal is approximately 5 minutes per section using the two point method. Therefore, a 20 foot wide canal that is divided into 12 sections takes about one hour to current meter.

Critical Depth Weirs and Flumes

Thin-Plate Weirs

Thin-plate weirs, such as sharp-crested, Cipolletti, V-notch, and rectangular weirs are very common in smaller canals. According to Kraatz [11], their advantages are simplicity, low cost, and ease of installation. Their disadvantages are that they require a high head loss, are sensitive to the flow distribution in the approach channel, and are suceptable to from being abutted next to diversions. When the submergence exceeds 50-60%, two head measurements are required and a correction must be applied to the unsubmerged rating table.

Broad Crested Weirs

The four basic types of broad crested weirs are rectangular profile, round nose horizontal crested, vertically moveable crested, and ramped broad crested (RBC) [9]. (Figure 1). All of the different types of broad crested weirs follow the discharge equation given below by Equation 3. Broad crested weirs have nearly straight flow lines through the throat and require only a single upstream depth measurement for discharge determination.

Prior to the use of computer modeling, most broad crested weirs were designed by scaling up laboratory models using Froude modeling techniques [7]. Replogle [5] reports that most of the reluctance to use this type of broad crested weir was due to the requirement of constructing standard sizes and shapes. The resulting structure required expensive forms for concrete construction, close construction tolerances, and extensive channel modification to make the stream conform to the weir.

$$Q = C_D * C_V * BC * h_1^x \qquad \text{Equation 3.}$$

where, Q = discharge
C_D = discharge coefficient
C_V = velocity coefficient
BC = width of the weir
h_1 = sill referenced head
x = between 1.5 - 2.5

Ramped broad crested (RBC) weirs differ from the other types of broad crested weirs in that they have a converging and an optional diverging ramp. A computer model has been developed by Bos, et al [4] for use in designing this type of weir. The computer model has allowed the relaxation of the former restrictions and allows the weir to be tailored to fit the channel configuration. Due to their streamlined shape, sedimentation is not a problem as with other types of broad crested weirs. The RBC weir was used exclusively for this project and it's design, operation, and limitations are the main topic of this thesis.

Long Throated Flumes

Long throated flumes force the flow through critical depth by gradually contracting the width of the channel. Bos, et al [4] reports thatthey require very little head loss, pass debris and sediment very well, and can be custom built for specific sites. The same computer model that is used to model RBC weirs can be used for long throated flumes. It is also possible to combine the sill of the broad crested weir with the throat contraction of the long throated flume for use in flow measurement. The hydraulic characteristics of RBC weirs are similar to long throated flumes. For a more detailed discussion of long throated flumes reference [4] is recommended.

Other Devices

There are many other types of devices that can be used to measure flow in open channels such as submerged orifices, cut-throat flumes, H-flumes, SCS profile weirs, and cylindrical crested weirs to name a few. These devices were not considered for use in this project for three main reasons. The first is that they are only available in standard sizes, so the

$$H = Z + d\cos(\Theta) + \alpha V^2/2g \qquad \text{Equation 5.}$$

where, Z - distance from the datum to the channel bottom
d - depth of flow
Θ - angle of the channel bottom from horizontal
α - velocity distrobution coefficient
V - average velocity in the channel
g - gravitational constant

See Figure 2.

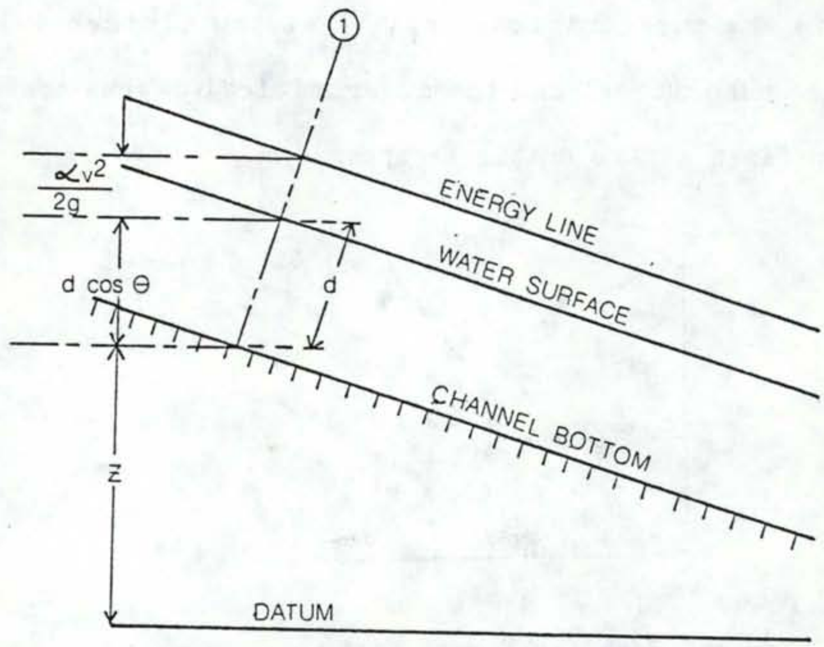

Figure 2. Energy in Open Channel Flow.

The specific energy for a given section is the sum of the pressure head and the velocity head or

$$E = d\cos(\Theta) + \alpha V^2/2g \qquad \text{Equation 6.}$$

or if the slope is small and $\alpha = 1$

$$E = y + V^2/2g \qquad \text{Equation 7.}$$

Substituting $V = Q/A$ into Equation 7 yields

Substituting Equation 12 into Equation 11 yields

$$\frac{dE}{dy} = 1 - \frac{V^2}{gD} \qquad \text{Equation 13.}$$

By definition, at critical depth specific energy is a minimum or

$$dE/dy = 0 \qquad \text{Equation 14.}$$

Combining Equations 13 and 14 yields

$$\frac{V^2}{2g} = \frac{D}{2} \qquad \text{Equation 15.}$$

Solving Equation 15 for y at a given discharge will yield the critical depth. Note that this depth is completely independent of the flow resistance factor.

Since the location of critical depth in a flow measuring device is not known exactly, it cannot be measured and used to calculate the discharge directly. However the depth upstream from the weir can be measured and related to the critical depth to calculate the flow rate.

The total energy head at the control section is

$$H_c = y_c + \frac{Vc^2}{2g} = y_c + \frac{Dc}{2} = y_c + \frac{Ac}{2Tc} \qquad \text{Equation 16.}$$

and at section 1 upstream from the control section is

$$H_1 = h_1 + \frac{V1^2}{2g} = h_1 + \frac{Q^2}{A1^2 * 2g} \qquad \text{Equation 17.}$$

See Figure 4.

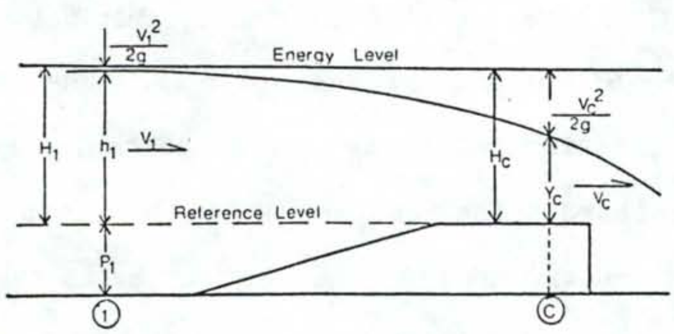

Figure 4. Energy Levels at the Gaging and Control Sections.

calculate friction losses in the approach channel and energy distribution coefficients and the process is repeated taking these factors into account.

Equations 13 and 14 can be combined to yield

$$1 = \frac{V^2}{gD} \qquad \text{Equation 25.}$$

or

$$1 = \frac{V}{(gD)^{1/2}} \qquad \text{Equation 26.}$$

The expression on the right hand side is defined as the Froude number and at critical depth is equal to unity. The expression $(gD)^{1/2}$ is defined as the celerity of small gravity waves and is the speed with which a small gravity wave will propagate due to a momentary change in the local depth [6]. In supercritical flow the Froude number is greater than one, therefore

$$V > (gD)^{1/2}$$

and the waves cannot propagate upstream. However, when the flow is subcritical the Froude number is less than one, therefore

$$V < (gD)^{1/2}$$

and the effects of a disturbance downstream can be felt upstream. Thus, it is very important to design the structure so that it forces the flow through critical depth at every tailwater depth encountered. If critical depth is not achieved then the tailwater can advance upstream and effect the head-discharge relationship. Since the flow upstream from the weir is subcritical, the effects of the weir (i.e. the increased water level) propagate upstream. This is why the head measurement is made upstream from the weir rather than downstream.

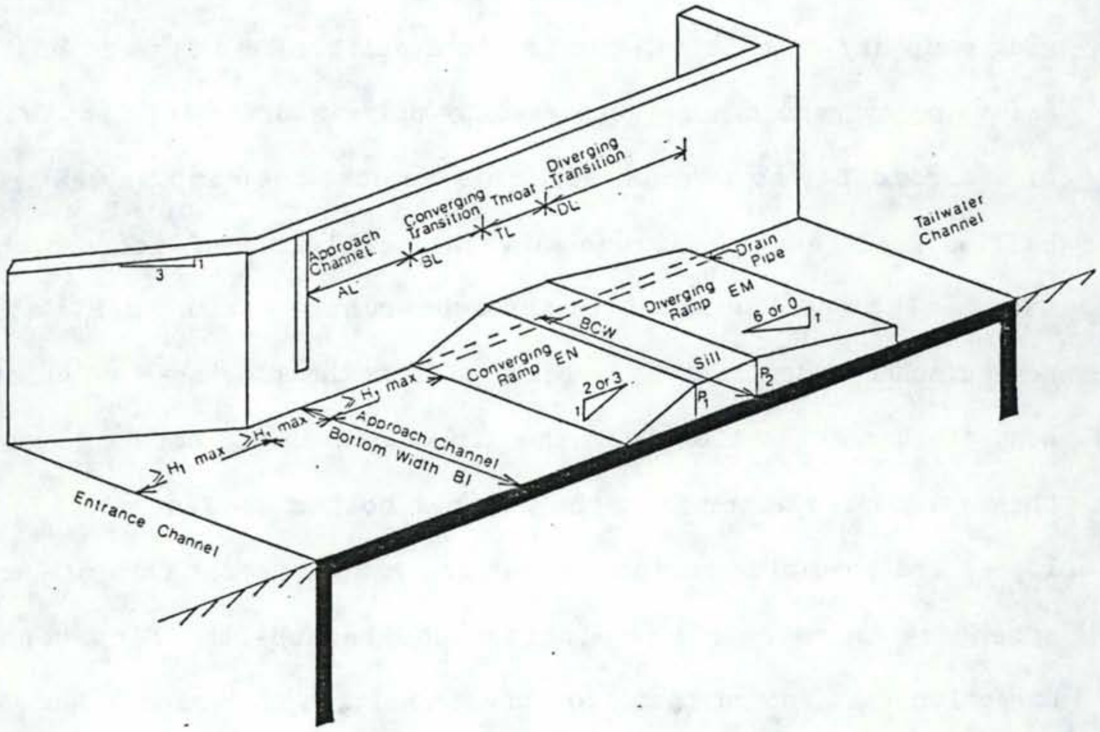

Figure 5. Ramped Broad Crested Weir.

throat length (H1/TL) should be less than 0.7. At ratios larger than this, streamline curvature is too great for the mathematical model to apply. At the minimum discharge, H1/TL should be greater than 0.07. The model is unable to reliably account for the frictional effects at H1/TL ratios smaller than this.

The sill height must be large enough to insure that the tailwater does not affect the flow in the throat. The sill height referenced to the upstream channel (P1) must be greater than the sill height referenced to the downstream channel (P2) in order for the mathematical model to apply. If P1 is less than P2, then the head loss and modular limit calculations prevent damage to the downstream channel. The amount of protection required is a function of the downstream sill height and the discharge per unit width, and varies from an end sill and riprap to a stilling basin.

If the canal is used only seasonally, then a drain pipe should be provided to allow the water upstream from the weir to drain (Figure 5). The size of the drain pipe depends on the volume of water upstream from the weir.

ADVANTAGES AND DISADVANTAGES OF BROAD CRESTED WEIRS

According to Bos, et al [4], broad crested weirs have the following major advantages over Parshall flumes, cutthroat flumes, H-flumes, and sharp crested weirs. Using the computer program, a rating table with an error less than 2% can be generated for a structure. The approach channel, throat, and tailwater channel cross sections may be any shape that can be described mathematically. The throat cross section can be shaped so that the entire range of discharges can be accurately measured. Once the structure is built, and assuming that none of the previously discussed dimensional criteria have been violated, the rating table can be generated using the as-built dimensions. This allows for the construction specifications to be looser than for other types of flumes, and results in lower construction costs.

The head loss required to maintain modular flow is comparable to an equivalent Parshall flume and can be accurately estimated for an arbitrary device using boundry layer theory. Flow is modular when the tailwater does not effect the head-discharge relationship. Bos [9] reports that broad crested weirs can measure flow accurately up to 95% submergence while requiring only one head measurement. By comparison, Parshall flumes reasonably smooth water surface at the gaging section, the Froude number should be less than 0.5 and preferably less than 0.2 for a distance equal to 30 times $h1_{max}$ upstream from the structure.

<u>ERRORS IN FLOW MEASUREMENT USING BROAD CRESTED WEIRS</u>

According to Replogle [7], the three sources of error experienced when using broad crested weirs to measure flow are primary calibration error, construction anomalies, and zero registration error of the gage. Laboratory rating of broad crested weirs using a weighing-tank standard have shown the primary calibration of the devices to be within one percent. Since a rating table can be generated for the as-constructed dimensions, the error due to construction anomalies is less than one percent as long as the dimensional criteria previously discussed are met. Zero registration error can also be reduced to one percent by proper location of the gage. Laboratory tests have shown that the computer model is accurate to two percent, and that field verification with current meters is accurate to five percent. In order for the stage-discharge relation to be predicted accurately, parallel flow must exist in the approach channel, converging transition, and the throat.

Replogle [4],[5],[7] has studied the effects on the discharge induced by a one percent change in various dimensions. Zero registration of the gage was found to be the most important dimension. A one percent error in gage setting produced a one and a half to two percent change in the discharge. Errors in defining the dimensions of the throat produce a nearly equal error percentage wise in the discharge. A one degree sill slope in the direction of flow, can produce up to a three percent error in the discharge and is the most difficult factor to correct. A sloping or

PROCEDURE

SELECTION OF CANALS

To more effectively evaluate the performance of broad crestedweirs, a wide variety of canals with respect to design discharge and flow depth was chosen to be monitored. The following is the procedure used to determine which canals would benefit the most from the installation of a broad crested weir or other measuring device.

Determination of Design Flows

The design flow for each canal was determined by totaling all of the water rights served by that canal, or using historical maximum measured flow rates, whichever was greater.

Discharge Groupings

Thirty five canals which were divided into three approximately equal groups based on design discharge were selected for evaluation. The discharge groupings were: over 500 cfs, 250-500 cfs, and 100-250 cfs. Canals under 100 cfs were not evaluated.

Determination of Rating Curve Shifts

From past current meter measurements, the average shift in the rating curve and the standard deviation of the shifts was calculated using Water District No.1 records from 1982 - 1984. A three year record length was chosen because it was long enough to give a good representation of the average shift, but short enough to take into account only current channel conditions. A shorter record lenth was used if there had been channel modifications within the past three years. For further information on shifts in the rating curves see the section titled "Explanation of Shifts" indicates the canals eliminated and the reasons why. Table 3 shows the canals in the Idaho Falls area that were selected for final recommendation that broad crested weirs be installed.

Table 2. Idaho Falls Area Canals Eliminated.

Canal	Reason for Elimination
Anderson	insufficient freeboard, poor alignment
Porter	poor alignment
Blackfoot	insufficient freeboard
Woodville	insufficient freeboard
Boomer	insufficient freeboard

Table3. IdahoFallsAreaCanalsSelected for Final Recommendation.

> 500 cfs	250-500 cfs	100-250 cfs
Eagle Rock	Sunnydell	Rudy
Great Western	Corbett Slough	Clark and Edwards
	Danskin	

Measuring Devices Constructed

In the spring of 1986, broad crested weirs were installed in the Eagle Rock, Great Western, Clark and Edwards, and Danskin canals. In addition, weirs were installed in the Island and Twin Groves canals due to the favorable response generated by the canal companies.

DESIGN OF BROAD CRESTED WEIRS

Determination of Channel Geometry

In order to use the DESIGN computer program, the channel must be

DESIGN computer program, which is a modified version of the FLUME program written by Clemmens [4]. The DESIGN program was created for this project to eliminate the trial and error procedure required to design using the FLUME program. A copy of this program and instructions for it's use are in Appendix B.

SENSITIVITY ANALYSES

Theoretical Effects of Changing the Converging Ramp Slope and the Material Roughness

Sensitivity analyses were performed to determine the theoretical effects on the device rating curve by changing the converging ramp slope from 2 to 3:1 and in variations in the concrete or material roughness for a typical structure. In both cases the effects on the rating were less than 1% of the flow (Table 4). The calculations are in Appendix C.

Table 4. Effects of Changing Converging Ramp Slope and Material Roughness.

	Converging Ramp Slope		Material Roughness Height, ft		
	2	3	0.007	0.0007	0.00007
Discharge	129.58	129.50	128.68	129.58	129.93
Percent Difference	0.06		0.69	0.27	

Theoretical Effects of Moss on Broad Crested Weirs

One of the reasons for shifting of rating curves for canals flowing at normal depth is the growth of moss during the summer months. The theoretical effect of moss on a broad crested weir was investigated using the FLM program. Since the flow through the control section is critical, and the critical depth for a given flow and channel geometry is unique, moss will feet in the upstream and downstream water levels and a 3 inch diameter drain pipe, it was found that the flow in the drain pipe will be 0.4 cfs. This value is independent of the flow rate, depending only on the head differential. The calculations are in Appendix C.

<u>Sensitivity of Current Meter Measurement to an Error in the Depth</u>

Current meter rods are usually graduated in 0.10 foot increments. Errors in depth measurement can be due to water "running up" the rod as in Figure 7 or because of interpolation between marked increments. It is standard practice to estimate the depth to the nearest 0.05 feet. This means that the depth can be over or under estimated by as much as 0.025 feet in slowly moving water, and possibly by as much as 0.05 feet if the water is flowing swiftly. The resulting percent error in the calculated area, and thus on the calculated discharge, is shown in Table 6 for various depths. Table 6 indicates that current metered flows may be off by an appreciable amount if the flow is shallow and swift. The error in flow due to and error in depth for the canals studied for this project should be less than 2%.

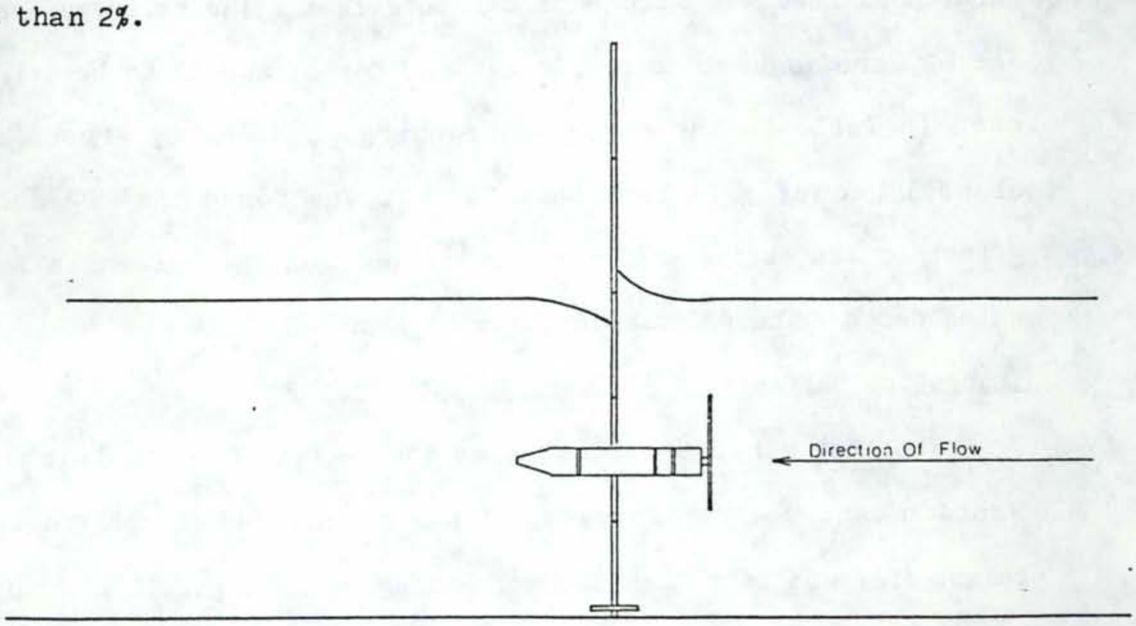

Figure 7. Water "Running Up" the Current Meter Rod.

Table 7. Effects of Errors in Estimating B1, Z1, B2, and Z2.

B1	Z1	B2	Z2	Q	Percent Difference in Q from the reference
20	1	20	1	184.77	0.00
18	1	20	1	187.17	+1.30
20	1	18	1	184.77	0.00
18	1	18	1	187.17	+1.30
20	1.5	20	1	183.19	-0.86
18	1.5	20	1	185.01	+0.13
22	1.5	20	1	181.80	-1.61
12	3	20	1	185.97	+0.65

were generated. The warning states that the head loss and modular limit calculations may be in error. The difference between P1 and P2 was 0.02 feet or less in all of the cases, so its effect was negligible as will be shown in the Results and Discussion section.

To determine the theoretical effect of P1 being greater than P2, a rating table was produced for the device installed in the Great Western canal assuming that P1 was equal to P2. This rating table was then compared to the rating table generated using actual weir dimensions. This comparison showed that the effect on the discharge rating and the maximum allowable tailwater depth was insignificant. The calculations are in Appendix C.

CONSTRUCTION AND STRUCTURAL CONSIDERATIONS

Guidelines for Construction

The following are the construction guidelines that were given to the contractors to try to insure that the structures were built correctly:

1. The top of the sill must be PERFECTLY LEVEL.
2. The bottom of the staff gage must be the same elevation as the top of the sill.
3. A cutoff wall, extending to a depth of 3 feet or until

would be required for construction. The section was of average size (Q=235 cfs and BC=18 ft) and would require 30 cubic yards of concrete to construct. For this section, it was determined that 1340 pounds of No. 4 bars, costing approximately $250, would be necessary. The calculations are in Appendix C.

Structural Strength of the Sill

For structures that have a long throat length, such as the one designed for the Eagle Rock canal, the sills would probably be poured as a slab suspended between two supports to decrease the amount of concrete required. To insure that the sills would not collapse due to the weight of the water, an analysis was performed to determine if the maximum allowable bending moment was greater that the bending moment induced by the weight of the water. A five foot, simply supported span of unit width was assumed, as was a head on the sill of 3.4 feet. These values were the largest encountered in the designs performed for this project. A steel requirement of #4 bars on 16 inch centers located 4.5 inches from the top of the sill was assumed. This requirement provided a factor of safety of three for the design load and dimensions. The calculations are in Appendix C.

DATA COLLECTION

As-Built Dimensions

In the spring of 1986, the constructed dimensions of the structures were measured before the water was turned into the canals. A level was used to determine the sill heights and to check the sill for slope and undulations. As can be seen in Table 8, most of the dimensions were controlled with sufficient accuracy except for the sill heights of the Eagle Rock and Danskin devices and the width of the Danskin device. The

Table 8. Design and Constructed Dimensions.

Dimension	Great Western		Eagle Rock		Island	
	Design	As-Built	Design	As-Built	Design	As-Built
Approach Channel Bottom Width (B1)	32.0	32.1	29.7	30.0	17.4	19.2
Approach Channel Side Slope (Z1)	0	0	0	1	0	0
Throat Width (BC)	32.0	32.1	29.7	29.7	17.4	17.6
Throat Side Slope (ZC)	0	0	0	0	0	0
Tailwater Channel Bottom Width (B2)	32.0	32.0	26.0	26.0	17.0	17.0
Tailwater Channel Side Slope (Z2)	2	2	1.5	1.5	1	1
Length to Staff Gage (AL)	4.0	4.0	4.0	-	4.0	4.0
Length to Stilling Well Inlet (AL)	4.0	11.3	4.0	9.2	4.0	2.3
Converging Ramp Length (BL)	3.0	3.0	6.0	6.2	2.0	2.0
Converging Sill Height (P1)	1.5	1.51	3.0	1.99	1.0	1.02
Converging Ramp Slope (EN)	2	1.99	2	3.12	2	1.96
Throat Length (TL)	5.0	5.0	5.0	5.0	4.0	4.1
Diverging Ramp Length (DL)	0.0	0.0	0.0	4.7	0.0	0.0
Diverging Sill Height (P2)	1.5	1.49	3.0	2.65	1.0	1.01
Diverging Ramp Slope (EM)	0	0	0	1.75	0	0
Sill Levelness						
Up to Downstream	0	0.02	0	0.03	0	0.02
Side to Side	0	0.03	0	0.05	0	0.02

Table 9. Staff Gage Error.

Canal	Staff Gage Error and Correction, ft
Twin Groves	+0.04
Island	+0.05
Clark and Edwards	+0.01
Eagle Rock	-
Great Western	0.00
Danskin	+0.03

Site Conditions

The site conditions were noted at the time of the current meter measurements and slides were taken of the structures and of flow characteristics, such as excessive submergence, that might have been afecting the performance of the structures. This information was later used to help explain why certain structures didn't perform as expected.

Data Analysis

The data gathered was analysed as soon as possible so that necessary corrections could be made. After the current meter data was analysed, the gage readings were corrected to take into account that some staff gages were not referenced to the top of the sill, and then the weir flow rates were read from the rating tables. The percent difference in the flow rates was calculated using Equation 27.

$$\% Q = \frac{Q_{cm} - Q_W}{Q_W} * 100 \qquad \text{Equation 27.}$$

Where, $\% Q$ = percent difference between the current metered flow and the weir predicted flow

Q_{cm} = current metered flow

Q_W = weir predicted flow

poor compared to the other structures, the current metered and weir predicted flows differed by only 2 percent if the submerged measurement is excluded (Table 16).

The current metered flows for the Twin Groves canal compared well to the weir predicted flows except for at the highest two measured flow rates (Table 10). Due to the constructed geometry of the structure, the rating section is only about 1.5 feet upstream from the start of the converging ramp. At high flow rates, the rating section is in the area of drawdown and the weir influences the velocity distribution. The two-point method of current metering assumes a logrithmic velocity distribution and that the true average velocity is equal to the average of the velocities at 0.2 and 0.8 of the depth. At high flows, the flow is accelerating at the rating section and the velocity distribution is no longer logrithmic. Chow [6] reports that the velocity distribution coefficient can be as high as 2.0 upstream from weirs. Due to the effect of the weir at high discharges, the average of the velocities at 0.2 and 0.8 of the depth is greater than the true average velocity. At lower flows, the area of drawdown does not extend as far upstream and the velocity distribution in the rating section is nearly logrithmic.

The current metered flows for the Great Western canal were similarly affected by the weir because the rating section is only 2 feet upstream from the start of the converging ramp (Table 11). The variation in the percent difference between the current metered and weir predicted flow rates is less than for the Twin Groves canal because the variation in the maximum to minimum discharge is less. It is felt that if the rating section was further upstream that the current metered and weir predicted flow rates would agree better. At high flow rates it is believed that the

Table 12. Clark and Edwards Canal Current Meter Results.

Date	Current Metered Flow, cfs	Weir Flow, cfs	Percent Difference
5/20	47.7	51.4	-7.20*
6/18	97.1	93.5	3.85
7/1	132.4	123.2	7.47**
7/15	104.3	105.5	-1.14
7/29	99.9	105.5	-5.31*
8/11	86.5	93.5	-7.49*
8/26	71.1	72.6	-2.09
9/9	73.0	71.9	1.53
9/22	62.3	60.4	3.25

* - weir was submerged

** - H1/TL exceeded, flow above design flow

Table 13. Eagle Rock Canal Current Meter Results.

Date	Current Metered Flow, cfs	Weir Flow, cfs	Percent Difference
7/17	765.0	741.4	3.24
7/30	620.6	613.9	1.09
8/8	576.7	556.0	3.72
8/26	435.0	429.0	1.41
8/26	439.2	429.0	2.38
9/9	300.7	300.8	-0.03
9/22	297.3	296.5	0.26

Table 14. Great Western Canal Current Meter Results.

Date	Current Metered Flow, cfs	Weir Flow, cfs	Percent Difference
5/20	149.6	146.7	1.98
6/5	495.2	476.6	3.90
6/18	461.4	431.4	6.95
7/1	497.5	456.6	8.96
7/15	478.7	459.4	4.20
7/30	417.8	401.3	4.11
8/12	405.4	393.2	3.10
8/26	389.0	372.1	4.54
9/9	330.9	321.2	3.02
9/23	313.4	309.0	1.42

Table 17. Distance from Rating Section to Converging Ramp.

Canal	Distance from Rating Section to Converging Ramp, ft.
Twin Groves	1.5
Island	4.0
Clark and Edwards	2.0
Eagle Rock	7.0
Great Western	2.0
Danskin	3.5

RELATION OF RESULTS TO PREVIOUS LITERATURE

The results obtained by this project agree well with those previously reported. When the weirs were constructed so that the criteria put forth by Bos and Replogle were met, such as with the structure in the Island canal, the current metered and weir predicted flows agreed well. All of the submergence problems can be attributed to construction anomalies rather than to the weir.

CURRENT METER COMPARISION

The problem with checking the calibration of the weirs by current metering is that a current meter is not a standard. As Kulin [10] reports, the calibration of a current meter is only within two percent of the actual velocities. There is also an error associated with the spacial and temporal samplings of the velocity and with the depth measurements. In order to examine the accuracy of the Ott meter used on this project, Marty Gergen of Water District 1 current metered the canals with a Price AA meter at the same time as the author current metered them with an Ott meter. The results of this experiment are shown in Table 18. The mean value of the percent difference is -1.285 percent and the standard deviation is 2.019.

The agreement between the two current meters was greater than expected. This can primarily be attributted to the cross section at which rate. The effect that the moss had on the calibration of the device is approximately the same as the effect that was predicted using the computer model. It appears that the accumulation of moss is site specific and is independent of the velocity in the throat. This is due to the fact that theClark and Edwards canal has one of the highest throat velocities ofany of the canals in this project.

EFFECTS OF CONSTRUCTION ANOMALIES

One of the major advantages of ramped broad crested weirs is that construction tolerances can be relaxed because the weirs can be calibrated using as-built dimensions. There are however limits to the allowable differences between the design and as-built dimensions. The design and as-built dimensions for the six RBC weirs constructed for this project are shown in Table 8.

Several of the as-built dimensions caused warnings to be generated by the FLM program when the rating tables were generated. The converging ramp slope for the Twin Groves device is 1.89 horizontal to 1 vertical. This produces a warning stating that flow separation may occur, however no flow separation was visible for the discharge range encountered. The upstream sill height (P1) is greater than the downstream sill height (P2) for the Twin Groves, Island, and Great Western canals (Table 20). This condition caused warnings to be generated stating that the modular limit and head loss calculations may be in error. Due to the fact that these canals rated as well as the others, either the amount that P1 is greater than P2 is insignificant or the factor of safety added to the sill height is great enough so that any errors in the headloss and modular limit calculations are taken care of by the additional sill height.

Table 21. Sill Slopes in the Direction of Flow.

Canal	Throat Length, ft	Elevation Difference, ft	Angle, degrees
Twin Groves	3.1	0.05	0.92
Island	4.1	0.02	0.28
Clark & Edwards	3.5	0.01	0.16
Great Western	4.95	0.02	0.23
Danskin	4.5	0.05	0.64
Eagle Rock	5.0	0.03	0.34

RESPONSES FROM INVOLVED PARTIES

In September of 1986, the various parties that were involved with this project were contacted for input regarding the broad crested weirs. All of the water users that were contacted were very pleased with the performance of the weirs [21], [22], [23], [24], [25]. They felt that they were receiving more water than in the past because of the stable rating curves. They believe that they were not receiving all of the water that they were entitled to when the canals were rated at normal depth sections and shifts in the rating curves were applied. No delivery problems were experienced, but some canals had problems with erosion of the downstream channel. This was easily solved by ripraping the channel downstream from the weir.

Water District No. 1 was also pleased with the performance of the weirs [27]. They have confidence in their accuracy due to the close agreement of the current metered and weir predicted flow rates. The stable rating curves provide real-time data and aid in managing the available water more efficiently. Disputes with water users have also been reduced since shifts no longer have to be applied to the rating curves.

While there were several reasons as to why other canal companies were reluctant to install broad crested weirs such as financial considerations and doubts about delivery, it was discovered that most canal companies thought that they would lose water because of the more accurate flume was choosen that required approximately the same head loss as a RBC weir for each canal. The average sized Parshall flume was one-sixth the amount of concrete that would be required to construct the six equivalent Parshall flumes. The cost to current meter the "average" canal is the cost to current meter all of the canals divided by the total number of canals.

The useful life of the average RBC weir, Parshall flume, and current meter was assumed to be 30 years. A 10 percent interest rate and a 3 percentinflation rate were also assumed. This resulted in an effective interest rate of approximately 7 percent (Appendix C). In addition, an annual maintenance cost of 3 percent of the initial cost was assumed for the RBC weir and Parshall flume and 5 percent of the initial cost for the current meter.

Since the canal companies were responsible for the construction of the weirs built for this project, several concrete contractors were contacted to obtain construction cost data. Most of them agreed that to construct the average structure it would cost approximately $125 per cubic yard of concrete [15],[16]. If the structure was constructed by a canal company, the construction cost would be less due to the fact that it would be constructed during their off-season by laborers that would probably otherwise be idle. Also, there would be no cost associated with contractor profit. It was estimated that a canal company could construct a RBC weir for a little more than half of what it would cost for a contractor to build one [18].

There are very few Parshall flumes of the size that would be required for this project. Due to this, cost data for their construction are scarce. An estimate of $600 per cubic yard of concrete was obtained from the United States Bureau of Reclamation [19]. The reason that this is so much larger

Construction Quality

The broad crested weirs constructed for this project were built by canal companies rather than by a concrete contractor due to economic reasons. Any future structures built in the project area will likely be constructed by canal companies also. As shown in Table 8, the canal companies were able to construct the weirs to dimensions sufficiently close to the design dimensions for the structures to operate properly. Generally, the constructed dimensions were within a tenth of a foot of the design dimensions, but sometimes the differences were as much as a foot (Table 8). This was acceptable only because the weirs could be recalibrated with the as-built dimensions using the FLM program. Parshall flumes on the other hand must be constructed to exact specifications due to the fact that flow is rapidly varied in the throat. It is doubtful that canal companies could construct a Parshall flume to the required tolerances.

Head Loss

The topography in the project area is very flat, and for this project, the flow measurement structure had to be installed upstream from the first diversion. These two factors necessitated a structure that requires a small amount of head loss to function properly. The available head loss was usually less than 1.5 feet. All of the RBC weirs designed for this project require less than 0.5 feet of head loss at the design flows. The only other type of structure that met the head loss limitation is the Parshall flume. A comparison of the required head losses between Parshall flumes and RBC weirs is in Table 22. A submergence of 85 percent at the design flow was assumed for the Parshall flumes.

The required head loss for a RBC weir is a function of the design flow and tailwater depth. In order for the actual head loss (Equation 28) to be structures that have a staff gage in the approach channel, depending on the Froude number. A device that is less sensitive to head measurements, that is a change in head results in a small change in discharge, is preferable because the error due to the head measurement is reduced. Structures that have a large discharge per unit width (Q/W), such as the Eagle Rock and the Great Western devices, are less sensitive to errors in head measurements than structures with a smaller Q/W ratio, such as the Clark and Edwards and Twin Groves devices (Table 23). The Clark and Edwards structure has the roughest water surface at the gage, but it is still possible to read the gage within 0.03 feet. The water surface is smooth enough to read the gages to within 0.01 feet at all of the other sites.

Table 23. Sensitivity of RBC Weirs to Head Measurement Error.

Canal	Discharge per Unit Width, cfs/ft	Percent Change in Flow Due to a 0.01' Change in Depth	Change in Flow Rate Due to a 0.01' Change in Depth, cfs
Twin Groves	10.1	0.762	1.52
Clark and Edwards	10.4	0.776	0.81
Danskin	11.8	0.659	1.65
Island	13.1	0.652	1.63
Eagle Rock	20.3	0.462	2.77
Great Western	20.8	0.491	3.29

due to the effective lowering of the gage by moss build up, plugged stilling well inlets, or errors in referencing the gage to the top of the sill. The throat should be scraped to remove moss and the inlets to the stilling well flushed on a regular basis. In addition, the gages should be checked at the beginning and end of each irrigation season to insure that they are referenced to the top of the sill.

15. Hoffman, Nyal, Concrete Contractor, telephone conversation, Filer, Idaho, 9/8/86.

16. Pruitt, Lorren, A & B Irrigation Co., telephone conversation, Rupert, Idaho, 9/8/86.

17. Gergen, Marty, Hydrographer, Idaho Department of Water Resources, telephone conversation, Idaho Falls, Idaho, 9/3/86.

18. Diehl, Ted, President, Northside Canal Co., telephone conversation, Jerome, Idaho, 9/8/86.

19. Johnson, Bob, Cost Estimator, United States Bureau of Reclamation, telephone conversation, Boise, Idaho, 9/3/86.

20. Newnan, Donald G., Engineering Economic Analysis, Second Edition, Engineering Press, Inc., 1983, pp. 328-335.

21. Singleton, Brent, President, Fremont-Madison Irrigation Co., telephone conversation, St. Anthony, ID, 9/18/86.

22. Avery, Leo, Ditch Rider, Clark and Edwards Canal Co., telephone conversation, Ririe, ID, 9/16/86.

23. Steele, Jim, President, Progressive Irrigation Co., telephone conversation, Idaho Falls, ID, 9/16/86.

24. Thiel, Louis, President, New Sweden Irrigation Co., telephone conversation, Idaho Falls, ID, 9/16/86.

25. Taylor, Vern, President, Danskin Canal Co., telephone conversation, Blackfoot, ID, 9/16/86.

26. Weatherly, Gary, Engineer, Kennewick Irrigation Co., telephone conversation, Kennewick, WA, 9/16/86.

27. Swank, Lyle, Deputy Water Master, Idaho Department of Water Resources, telephone conversation, Idaho Falls, ID, 9/16/86.

downstream control, it may be some lower discharge, cfs

Diverging Ramp Length (DL) - the horizontal length of the diverging ramp, ft

Diverging Ramp Slope (EM) - the slope of the diverging ramp, horizontal to vertical

Diverging Sill Height (P2) - the elevation difference between the downstream channel bottom and the top of the sill, ft

DL - length of the diverging ramp, ft

Downstream Sill Referenced Head (h2) - the downstream piezometric head referenced to the top of the sill, ft

Downstream Total Energy Head (H2) - the total downstream head referenced to the top of the sill, the sum of the downstream sill referenced head and the downstream velocity head, ft

EM - diverging ramp slope, horizontal to vertical

EN - converging ramp slope, horizontal to vertical

Froude Number (Fr) - the ratio of inertial to gravity forces

Fr - Froude Number = V/[(g*(A/B))**0.5]

h1 - upstream sill referenced head, ft

H1 - total upstream head = upstream sill referenced head + upstream velocity head, ft

h2 - downstream sill referenced head, ft

H2 - total downstream head = downstream sill referenced head + downstream velocity head, ft

HHIGH - highest h1 value for rating table calibration, ft

HINC - head increment the rating table will be incremented by, ft

HLOW - lowest h1 value for rating table calibration, ft

Tailwater Channel Bottom Width (B2) - the channel bottom width downstream of the structure, ft

Tailwater Channel Side Slope (Z2) - the side slope of the tailwater channel, horizontal to vertical

Throat - the section in which critical depth, and thus discharge control, occurs

Throat Length (TL) - the longitudinal length of the sill, ft

Throat Side Slope (ZC) - the side slope of the throat, horizontal to vertical

TL - throat length, ft

Upstream Channel Bottom Width (B1) - the channel bottom width at the gage, ft

Upstream Channel Side Slope (Z1) - the side slope at the gage, horizontal to vertical

Upstream Sill Referenced Head (h1) - the upstream peizometric head referenced to the top of the sill, ft

Upstream Total Energy Head (H1) - the total upstream head referenced to the top of the sill, the sum of the upstream sill referenced head and the downstream velocity head, ft

YDS - maximum tailwater depth at the design flow

Z1 - side slope in section 1

Z2 - side slope in section 2

ZC - side slope in section C

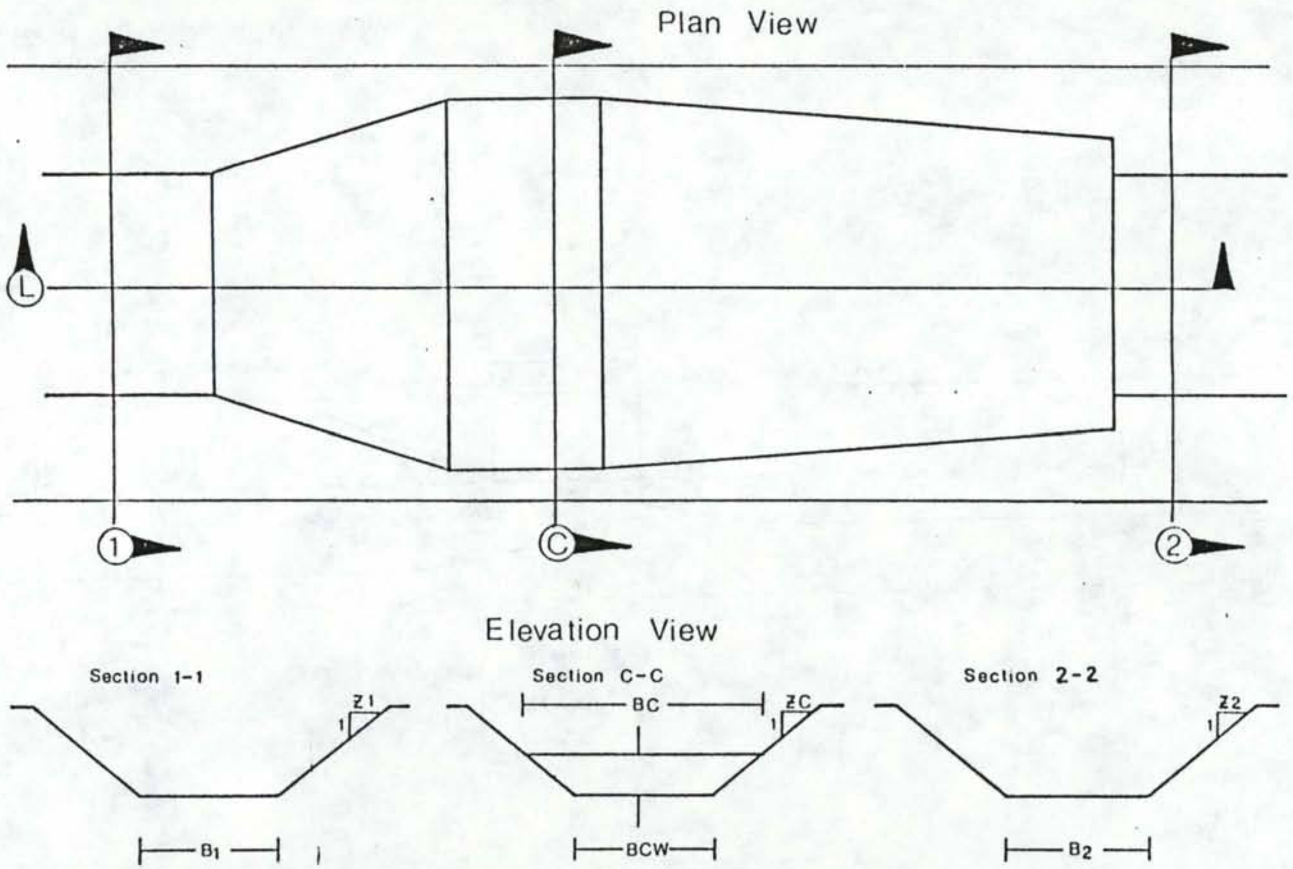

Figure 10: Ramped broad crested weir in plan view

APPENDIX B

COMPUTER PROGRAMS AND USERS GUIDE

USE OF THE DESIGN PROGRAM

The DESIGN program, a modified version of the FLM program, was created to eliminate the trial and error procedure required to design using FLM. It is written in FORTRAN and is set up to run on an IBM PC. It displays a series of prompts asking for cross section, profile, and head data. The profile dimensions AL, TL, P1, and P2 are then adjusted to meet the criteria discussed in the first part of this thesis. The program is written for English units (length [=] ft, discharge [=] cfs), but can easily be modified to accept metric units by changing the gravitational constant and the kinematic viscosity of water. The only cross section shape option available with this program is trapezoidal. It was set up this way to increase the speed with which the program runs. The cross section of most irrigation canals can be approximated fairly well as a trapezoid, but if not, the DESIGN program can be used to give approximate dimensions, and then the FLM program, which has multiple cross section profile options, can be used to yield the final design. The following are the steps and prompts displayed to use DESIGN to design a broad crested weir for a specific canal.

After a suitable site has been selected, determine the design discharge and corresponding tailwater depth. Usually this will be the maximum discharge, but in canals with artificial control of the tailwater, this may occur at a lower flow rate. The corresponding tailwater depth should be the maximum depth encountered at the design discharge throughout the year. This usually occurs at the peak of the growing season, when the retardence to the flow due to vegetation is a maximum.

<u>Prompt 5</u> - ENTER B1,Z1,BCW,ZC,B2,Z2

These values remain constant during the iterative process. In order to minimize the amount of construction materials required, the widths should be the smallest allowable without causing overtopping of the banks. As the width decreases, the sill referenced head increases for a given flow rate. The depth upstream of the weir is the sum of the sill height and the sill referenced head, and must be less than the canal depth. If available head loss is small, make the weir dimensions the same as the channel dimensions, even though this will result in a more expensive structure.

<u>Prompt 6</u> - ENTER INITIAL VALUES FOR AL,EN,TL,P1,P2,EM,RK

As long as reasonable values are entered for each variable, the program will iterate to a final design. To decrease the number of iterations required, and thus increase the speed, the initial values should be estimatedso that they are as near as possibleto the final values.

<u>Prompt 7</u> - ENTER HLOW, HINC, HHIGH, QD, YDS, DELTA

The profile dimensions will be adjusted by an increment equal to DELTA until all the design criteria are met at the design flow. A rating table will be generated starting with a sill referenced head equal to HLOW, incremented by HINC, and ending at a sill referenced head equal to HHIGH. Depending on the values chosen for HLOW and HHIGH, the design flow may or may not be in the rating table. If a small HINC increment is to be used, it is faster to run the program twice. The first run use a larger increment to get approximate dimensions, and then use these dimensions and the smaller increment in the second run.

Now, the message, "THE ITERATIVE PROCESS BEGINS", will appear on the screen, followed by a series of warning messages. The warning messages are generated during each iteration, and may or may not be taken care of by

Prompt 1 - OUTPUT LOCATION: TERMINAL(0), PRINTER (6)

Enter "0" if you want the output to be displayed on the screen, or "6" if a printout is desired.

Prompt 2 - RUN ID?

This is a 30 character name used to identify the run.

Prompt 3 - SELECT UNITS FOR FLUME DIMENSIONS
(1) METERS (2) FEET

This is the units that the as-built dimensions were measured in. Enter the appropriate number.

Prompt 4 -

SHAPE OPTION	ADDITIONAL SHAPES FOR THROAT
(1) SIMPLE TRAPEZOID	(5) COMPLEX TRAPEZPOID
(2) CIRCLE	(6) TRAPEZOID IN CIRCLE
(3) U-SHAPE	(7) TRAPEZOID IN U-SHAPE
(4) PARABOLA	(8) TRAPEZOID IN PARABOLA

INPUT 3 SHAPE OPTIONS. (APPROACH,THROAT,TAILWATER)

This is where the cross sectional shapes of the approach, throat, and tailwater channels are input. The approach and tailwater channels can be any of the first four shapes, while the throat can be any of the shape options. Input the shape options in the following order: approach, throat, tailwater

Prompt 5,6,7 - Channel Cross Section - Shape Option - Appropriate Dimension

Once the shape options are entered, the program will ask for the appropriate dimensions for each channel cross section. The appropriate dimensions for each shape option are given below in Table 25.

Prompt 8 - SELECT (1) STATIONARY OR (2) MOVEABLE THROAT

Moveable throat broad crested weirs are beyond the scope of this manual. For more information on them, refer to reference [1].

Table 25 cont'.

SHAPE OPTION	VARIABLES
	ZC = SIDE SLOPE FOR TRAPEZOID
TRAPEZOIDAL THROAT IN PARABOLA	DC = FOCUS OF PARABOLA PC = HEIGHT TO TRAPEZOIDAL BOTTOM FROM CHANNEL INVERT BC = BOTTOM WIDTH FOR TRAPEZOID ZC = SIDE SLOPE FOR TRAPEZOID

Prompt 9 - INPUT THE DISTANCE BETWEEN THE CONV RAMP AND THE GAGE, THE CONV RAMP LENGTH, THE THROAT LENGTH, THE SILL HEIGHT RELATIVE TO THE APPROACH CHANNEL, THE SILL HEIGHT RELATIVE TO THE TAILWATER CHANNEL, THE DIVERGING TRANSITION RATIO, AND THE ABSOLUTE ROUGHNESS HEIGHT OF THE MATERIAL
(AL,EN,TL,P1,P2,EM,RK)

Input the appropriate as-built dimensions.

```
Prompt 10 - SELECT OUTPUT DEPTH UNIT OPTION -- (J1)
            (1)  METER              (3)  FEET
            (2)  MM                 (4)  INCH
            SELECT OUTPUT DISCHARGE UNIT OPTION -- (J2)
            (1)  CU-METER/SEC  (3)  CFS   (5)  AC-FT/HR
            (2)  LIT/SEC       (4)  GPM   (6)  MI
            (7)  MLIT/HR       (8)  MGD
            INPUT J1,J2 ?
```

J1 is the unit the sill referenced head will have in the rating table, and J2 is the unit for the discharge.

```
Prompt 11 - **NOTICE**  THE UNITS FOR THE FOLLOWING
                        SHOULD BE -- "J1", "J2"
            INPUT THE LOWEST HEAD FOR CALIBRATION,
            THE INCREMENT IN HEAD VALUES,
            THE HIGHEST HEAD FOR CALIBRATION,
            AND THE INCREMENTAL DISCHARGE VALUE FOR THE INVERSE
            RATING TABLE
            SET QINC = 0 TO SKIP INVERSE RATING TABLE OPTION
            (HLOW,HINC,HHIGH,QINC)
```

The inverse rating table has the discharge as the independent variable and the sill referenced head as the dependent variable. QINC is the value by which the discharge is incremented by in the inverse rating table. To skip the inverse rating table option, enter "0" for QINC.

<u>Prompt 17</u> - INPUT THE GAGE READING AND CURRENT METERED FLOW

Enter the sill referenced head on the weir at the time of the measurement, and the flow rate determined by the alternative method.

<u>Prompt 18</u> - WHICH HEAD UNIT IS USED FOR FIELD DATA -- (J1)

```
(1)  METER                 (3)  FEET
(2)  MM                    (4)  INCH
WHAT IS THE DISCHARGE UNIT -- (J2)
(1)  M3/SEC      (3)  CFS      (5)  AC-FT/HR
(2)  LIT/SEC     (4)  GPM      (6)  MI
(7)  ML/HR       (8)  MGD
INPUT J1,J2 --
```

Enter the appropriate head and discharge units.

<u>Prompt 19</u> - DO YOU WANT TO SAVE FIELD DATA COMPARISON? (1)YES

To have the results from the field data comparison stored in a file, enter "1", if not enter "0". If "1" was entered:

<u>Prompt 20</u> - OUTPUT FILE NAME

Enter a name for the output file. The program will create it and then store the field data comparison results in it.

<u>Prompt 21</u> - NEXT RUN

```
(0)  STOP
(1)  NEXT RUN WITH ALL NEW INPUT
(2)  FOR SAME SHAPES WITH NEW PROFILE DATA
(3)  FOR SAME FLUME WITH DIFFERENT OUTPUT
     FORMAT
(4)  FOR SAME RUN WITH DIFFERENT OUTPUT
     LOCATION
```

If "0" is entered, the program terminates and you are returned to the system.

If "1" is entered, you go back up to the first prompt and go through the entire program again.

If "2" is entered, prompts 2, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, and 21 are displayed in sequence.

If "3" is entered, prompts 2, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, and 21 are displayed in sequence.

If "4" is entered, prompts 1, 12, 13, 14, 15, 16, 17, 18, 19, 20, and 21

Table 26 Cont'.

WARNING	CAUSE FOR WARNING	ACTION TAKEN
		HLOW, HINC, HHIGH, and then terminates.
9	Limits on H1/TL exceeded. H1/TL < 0.007 or H1/TL > 0.7	Prints warning - indicating which limit is exceed.
-	Approach section Froude number > 0.50.	Prints warning for each output line where the Froude number > 0.50.

THE DESIGN COMPUTER PROGRAM

```
$NOTSTRICT
$STORAGE:2
      PROGRAM design
C*********************************************************************
C PROGRAM FOR COMPUTING ACTUAL DISCHARGE OVER LONG THROATED FLUMES*
C     BY A. J. CLEMMENS DEC. 5,1980                                  *
C             AMENDED MARCH 8, 1982   AMENDED MAY 21,1985            *
C             AMENDED JUNE 18, 1982   AMENDED JULY 30,1985           *
C*********************************************************************
C    THE STATEMENTS IN THIS PROGRAM FOLLOW THE THEORY GIVEN IN       *
C    CHAPTER 9 OF 'FLOW MEASURING AND REGULATING FLUMES'             *
C    BY BOS REPLOGLE AND CLEMMENS                                    *
C    THE INPUT VARIABLES ARE AS FOLLOWS:                             *
C                                                                    *
C      CROSS SECTIONS                                     UNITS      *
C        APPROACH CHANNEL                                            *
C          B1 = BOTTOM WIDTH                            feet         *
C          Z1 = SIDE SLOPES  (HORIZONTAL TO VERTICAL)   ---- TO 1    *
C        THROAT                                                      *
C          BC = BOTTOM WIDTH                            feet         *
C          ZC = SIDE SLOPES                             ---- TO 1    *
C        TAILWATER CHANNEL                                           *
C          B2 = BOTTOM WIDTH                            feet         *
C          Z2 = SIDE SLOPES                             ---- TO 1    *
C                                                                    *
C      PROFILES                                                      *
C          AL = DISTANCE BETWEEN RAMP AND GAUGE         feet         *
C          BL = CONVERGING RAMP LENGTH                  feet         *
C          TL = THROAT LENGTH                           feet         *
C          EN = CONVERGING RAMP SLOPE                                *
C          P1 = SILL HEIGHT (UPSTREAM)                  feet         *
C          P2 = SILL HEIGHT (DOWN STREAM)               feet         *
C          EM = DIVERGING TRANS. RATIO (HORZ/VERT)      ---- TO 1    *
C                                                                    *
C      MATERIAL ROUGHNESS =RK                           feet         *
```

```
     5 FT',
     6/,5X,'EM=DIVERGENT RAMP SLOPE (USUALLY 0 OR 6), HORZ TO
     6VERT',
     7/,5X,'RK=MATERIAL ROUGHNESS HEIGHT (USUALLY TAKEN AS
     7 0.0007FT)',/)
      WRITE(IO,4007)
4007 FORMAT(1X,'HEAD AND DISCHARGE VARIABLES',/
     1/,5X,'HLOW=LOWEST SILL REFERENCED HEAD TO BE CALIBRATED, FT',
     2/,5X,'HINC=INCREMENT IN HEAD VALUES, FT',
     3/,5X,'HHIGH=HIGHEST SILL REFERENCED HEAD TO BE CALIBRATED,
     3 FT',
     4/,5X,'QD=DESIGN DISCHARGE, CFS',
     5/,5X,'YDS=TAILWATER NORMAL DEPTH AT THE DESIGN FLOW, FT',
     6/,5X,'DELTA=INCREMENT BY WHICH DIMENSIONS ARE ADJUSTED, FT')
5     WRITE(*,'(33H ENTER THE DATA FILENAME(OR CON:) )')
      READ(*,'(A63)') INFILE
      IF(INFILE(1:1).EQ.':') STOP
      IF(INFILE(1:4).EQ.'CON:'.OR.INFILE(1:4).EQ.'con:') THEN
       INTERACTIVE=.TRUE.
      ELSE
       INTERACTIVE=.FALSE.
      ENDIF
      OPEN(II,FILE=INFILE,STATUS='OLD',IOSTAT=IER)
      IF(IER.NE.0) THEN
       WRITE(*,'(35HTHERE IS AN ERROR IN THE INPUT FILE ,I5)')IER
       GO TO 5
      ENDIF
      WRITE(*,'(31H ENTER OUTPUT FILENAME(OR PRN:) )')
      READ(*,'(A63)') OUTFILE
      OPEN(IO,FILE=OUTFILE,STATUS='NEW')
      IF(INTERACTIVE) WRITE(*,4000)
4000 FORMAT(1X,'ENTER THE RUN ID',/)
      READ(II,2000) (IDN(I),I=1,10)
      IF(INTERACTIVE) WRITE(*,4001)
4001 FORMAT(1X,'ENTER B1,Z1,BCW,ZC,B2,Z2',/)
      READ(II,*) B1,Z1,BCW,ZC,B2,Z2
      IF(INTERACTIVE) WRITE(*,4002)
4002 FORMAT(1X,'ENTER INITIAL VALUES FOR AL,EN,TL,P1,P2,EM,RK',/)
      READ(II,*) AL,EN,TL,P1,P2,EM,RK
      IF(INTERACTIVE) WRITE(*,4003)
4003 FORMAT(1X,'ENTER HLOW,HINC,HHIGH,QD,YDS,DELTA',/)
      READ(II,*) HLOW,HINC,HHIGH,QD,YDS,DELTA
      WRITE(*,4008)
4008 FORMAT(1X,'THE ITERATIVE PROCESS BEGINS',/)
      W=0
      KL=0
      W2=0
 630  DL=EM*P2
      BC=BCW+2.*P1*ZC
      EL=10.*(P2+TL/2.)-DL
      IF(P1.EQ.0.) GO TO 1
      BL=P1*EN
      GO TO 2
1     EN=99.999
```

```
      WRITE(*,1042)
 420  IF(IW.EQ.0) WRITE(*,1037)
C
C*********************************************************************
C     INITIALIZE VALUES                                               *
C*********************************************************************
      N=0
      JP=0
      DO 100 J=ILOW,IHIGH,IINC
      SH1=FLOAT(J)/1000.
      KOUNT=0
      G=32.18
      VK=1.22E-5
      IDEAL=0
      ALF1=1.0
      ALFC=1.0
      DH1=0.0
      Y1=P1+SH1
C
C*********************************************************************
C     CRITICAL FLOW SECTION                                           *
C*********************************************************************
      YC=0.7*SH1
 10   YCOLD=YC
C******** COMPUTE Q ********
      Q=SQRT(G*A(3)**3/B(3)/ALFC)
C******** COMPUTE YC ********
      H1=SH1+ALF1*(Q/A(1))**2/2./G
      YC=H1-A(3)/2./B(3)-DH1
C******** HAS YC CONVERGED ? ********
      RER=(YC-YCOLD)/YC
      KOUNT=KOUNT+1
      IF(KOUNT.LE.100) GO TO 15
      IF(RER.GT.0.005) GO TO 14
      YC=(YC+YCOLD)/2.
      Q=(Q+QOLD)/2.
      QOLD=Q
      GO TO 16
 14   WRITE(IO,1038) YC,YCOLD,Q,QOLD
      GO TO 150
 15   IF(ABS(RER).GT.0.0001) GO TO 10
C
C*********************************************************************
C     FIRST TIME THROUGH ?                                            *
C*********************************************************************
 16   IF(IDEAL.EQ.1) GO TO 20
C
C*********************************************************************
C     SET IDEAL QI = Q                                                *
C*********************************************************************
      QI=Q
      IDEAL=1
      GO TO 30
C
```

```
      DC=A(3)/B(3)
      WIDE=1.5*(DC/RC)-0.5
      IF(WIDE.LT.1.0) WIDE=1.0
      IF(WIDE.GT.2.0) WIDE=2.0
      FULL=0.025*(TL/RC)-0.05
      IF(FULL.LT.0.) FULL=0.0
      IF(FULL.GT.1.0) FULL=1.0
      ALFC=1.+(3.*E*E-2.*E**3.)*WIDE*FULL
      ALF1=1.04
      GO TO 10
C
C***********************************************************************
C     COMPUTE MODULAR LIMIT                                            *
C***********************************************************************
 70   Y2=YC+P2
      KOUNT=0
      EKSI=1.2
      IF(EM.LE.0) GO TO 80
      EKSI=(ALOG10(114.59*ATAN(1/EM))-0.165)/1.742
 80   V2=Q/A(2)
      H2T=Y2-P2+V2*V2/(2.*G)
      R2=A(2)/WP(2)
      DHE=0.00235*EL*V2*V2/(2.*R2*G)
      DHD=0.00235*DL*(VC*VC/RC+V2*V2/R2)/(4.*G)
      DHK=EKSI*(VC-V2)**2/(2.*G)
      DH2=DHE+DHD+DHK
      H2=H1-DH1-DH2
      RER=(H2-H2T)/H2
      IF(ABS(RER).LT.0.001) GO TO 90
      Y2=Y2*(H2+P2)/(H2T+P2)
      KOUNT=KOUNT+1
      IF(KOUNT.GT.100) GO TO 85
      GO TO 80
 85   WRITE(IO,1041) H2,H2T
      H2=(H2+H2T)/2.
C
C***********************************************************************
C     PRINT OUTPUT                                                     *
C***********************************************************************
 90   FML=H2/H1
      DH=H1-H2
      D1=A(1)/B(1)
      FRN=Q/A(1)/SQRT(G*D1)
      IF(FRN.GT.0.5) WRITE(IO,1039)
      CD=Q/QI
      N=N+1
      QG(N)=Q
      HG(N)=SH1
      H1L=H1/TL
      JP=JP+1
      OUT1(JP,1)=SH1
      OUT1(JP,2)=Q
      OUT1(JP,3)=FRN
      OUT1(JP,4)=H1L
```

```
 620 TL=TL+DELTA
     W2=2.0
     GOTO 680
C*****************************************************************
C    COMPUTE SILL HEIGHT                                          *
C*****************************************************************
 640 Y2=YC+P2
     KOUNT=0
     EKSI=1.2
     IF(EM.LE.0)GOTO 650
     EKSI=(ALOG10(114.59*ATAN(1./EM))-0.165)/1.742
 650 V2=QD/A(2)
     H2T=Y2-P2+V2*V2/(2.*G)
     R2=A(2)/WP(2)
     RC=AC/(BC+2.*YC*SQRT(1.+ZC**2))
     DHE=0.00235*EL*V2*V2/(2.*G*R2)
     DHD=0.00235*DL*(VC*VC/RC+V2*V2/R2)/(4.*G)
     DHK=EKSI*(VC-V2)**2/(2.*G)
     DH2=DHE+DHD+DHK
     H2=E-DH2
     RER=(H2-H2T)/H2
     IF(ABS(RER).LT.0.001)GOTO 660
     Y2=Y2*(H2+P2)/(H2T+P2)
     KOUNT=KOUNT+1
     IF(KOUNT.GT.100)STOP
     GOTO 650
 660 DIFF=Y2-YDS
     IF((DIFF.GE.0).AND.(W.EQ.1.0))GOTO 690
     IF(DIFF.LT.0)GOTO 670
     P1=P1-DELTA
     P2=P2-DELTA
     IF(P1.LE.1.0)GOTO 675
     GO TO 680
 670 P1=P1+DELTA
     P2=P2+DELTA
 675 W=1.0
 680 KL=KL+1
     IF(KL.GT.50)STOP
     GOTO 630
 690 WRITE(IO,2001) (IDN(J),J=1,10)
     WRITE(IO,1000)AL
     WRITE(IO,1001)B1,BL
     WRITE(IO,1002)Z1,TL
     WRITE(IO,1003)DL,EL
     WRITE(IO,1004)BC,ZC,P1
     WRITE(IO,1005)EN
     WRITE(IO,1006)B2,P2
     WRITE(IO,1007)Z2,EM
     WRITE(IO,1008)RK
     WRITE(IO,1069)QD,YDS
     WRITE(IO,1009)
     WRITE(IO,1010)
     WRITE(IO,1011)
     DO 998 JJ=1,JP
```

```
     *24HEXPAND ENOUGH DOWNSTREAM/15X,20HOF FLUME. HEAD LOSS ,
     *17HAND MODULAR LIMIT/15X,28HCALCULATIONS MAY BE IN ERROR)
 1035 FORMAT(/10X,18HWARNING  IWARN = 5/15X,18HTAILWATER CHANNEL ,
     *21HBOTTOM ABOVE APPROACH/15X,21HCHANNEL BOTTOM. HEAD ,
     *22HLOSS AND MODULAR LIMIT/15X,28HCALCULATIONS MAY BE IN ERROR)
 1036 FORMAT(/10X,18HCAUTION  IWARN = 6/15X,20HDIVERGING TRANSITION,
     *20H TOO FLAT. DIVERGING/15X,25HRAMP SLOPE SET AT 10 TO 1)
 1037 FORMAT(/10X,11HNO WARNINGS)
 1038 FORMAT(/15X,36HDEPTH AND DISCHARGE DID NOT CONVERGE/20X,
     *20HCHECK WARNINGS ABOVE/20X,5HYC = ,F8.6,4H  = ,F8.6/20X,
     *5HQ  = ,F8.6,4H  = ,F8.6/20X,18HPROGRAM TERMINATED)
 1039 FORMAT(15X,40HCAUTION - FROUDE NUMBER GREATER THAN 0.5)
 1040 FORMAT(/10X,18HCAUTION  IWARN = 7/15X,
     *31HROUGHNESS VALUE IS OUT OF RANGE)
 1041 FORMAT(10X,40HMODULAR LIMIT CALCS DID NOT CONVEGE H2=,
     *F7.4,5H H2T=,F7.4)
 1042 FORMAT(/10X,18HCAUTION  IWARN = 7/15X,
     *31HROUGHNESS VALUE IS OUT OF RANGE/15X,15HSET TO 0.0002 M)
 1043 FORMAT(/10X,18HWARNING  IWARN = 8/15X,
     *20HERROR IN HEAD LIMITS/15X,6HHLOW =,F8.4/15X,
     *6HHINC =,F8.4/15X,6HHHIGH=,F8.4/15X,18HPROGRAM TERMINATED)
 1044 FORMAT(/10X,18HCAUTION  IWARN = 9/15X,
     *25HH1/L RATIO LESS THAN 0.07)
 1045 FORMAT(/10X,18HCAUTION  IWARN = 9/15X,
     *24HH1/L RATIO MORE THAN 0.7)
 2000 FORMAT(10A2)
 2001 FORMAT(5X,10A2)
      END
C*********************************************************************
C                                                                    *
C     FUNCTIONS                                                      *
C                                                                    *
C*********************************************************************
C     FUNCTIONS TO COMPUTE FLOW AREAS                                *
C*********************************************************************
      FUNCTION A(I)
      COMMON B1,Z1,BC,ZC,B2,Z2,Y1,YC,Y2,YB
      GO TO (10,20,30,40),I
C******** AREA OF APPROACH ********
 10   A=Y1*(B1+Z1*Y1)
      RETURN
C******** TAILWATER AREA ********
 20   A=Y2*(B2+Z2*Y2)
      RETURN
C******** CONTROL SECTION AREA ********
 30   A=YC*(BC+ZC*YC)
      RETURN
C******** ENTRANCE TO THROAT FLOW AREA ********
 40   A=YB*(BC+ZC*YB)
      RETURN
      END
C*********************************************************************
C     FUNCTIONS TO COMPUTE TOP WIDTH OF FLOW                         *
C*********************************************************************
```

```
      DATA ID5/'C ','C ','  ','  ','HR','  ','  ','  '/
      DATA CO1/1.0,0.3048,1000.,304.8,3.28084,1.0,
     1         39.37,12./
      DATA CO2/1.0,0.028317,1000.,28.317,35.3147,1.0,15850.2,448.83,
     1         2.91859,0.08265,1412.58,40.,3.56,0.1019,22.82,0.6463/
      END
C               *******************************
C               *******************************
C               **        PROGRAM FLUME      **
C               *******************************
C               *******************************
C
C     *****************************************************************
C     *PROGRAM FOR COMPUTING ACTUAL DISCHARGE OVER LONG THROATED FLUMES*
C     *****************************************************************
C     *                                                               *
C     *  THE DOCUMENTATION AND THEORY FOR THIS PROGRAM ARE CONTAINED  *
C     *  IN 'FLUME: A COMPUTER MODEL FOR ESTIMATING FLOW THROUGH LONG- *
C     *  THROATED MEASURING FLUMES' BY CLEMMENS, REPLOGLE, AND BOS.   *
C     *   (PUBLISHED BY USDA ARS )                                    *
C     *                                                               *
C     *  FURTHER EXPLANATIONS ON THE USE OF THESE FLUMES IS FOUND IN  *
C     *  'FLOW MEASURING FLUMES FOR OPEN CHANNEL SYSTEMS'             *
C     *  BY BOS, REPLOGLE AND CLEMMENS  (JOHN WILEY & SONS  1984)     *
C     *                                                               *
C     *  PROGRAMED BY   : A. J. CLEMMENS    FOR SIMPLE TRAPEZOID      *
C     *  MODIFIED  BY   : S. S. CHENG       FOR VARIABLE SHAPES       *
C     *  PROGRAM NAME   : FLUME                                       *
C     *                                                               *
C     *  SUBROUTINES    :                                             *
C     *     (1) CRTFL   : CRITICAL FLOW CALCULATION                   *
C     *     (2) GAUGE   : GAUGE DIMENSION CALCULATIONS                *
C     *     (3) FIELD   : INPUT FIELD DATA FROM FILE AND COMPARE WITH *
C     *                   COMPUTED DISCHARGE                          *
C     *     (4) OUTP1   : INITIAL DATA PRINT OUT                      *
C     *     (5) OUTP2   : RATING TABLE PRINT OUT                      *
C     *     (6) OUTP3   : FIELD DATA COMPARISON PRINT OUT             *
C     *                                                               *
C     *  FUNCTIONS      :                                             *
C     *     (1) AREA    : AREA AT DEPTH "Y"                           *
C     *     (2) WIDE    : TOP WIDTH AT DEPTH "Y"                      *
C     *     (3) WETP    : WETTED PERIMETER AT DEPTH "Y"               *
C     *                                                               *
C     *  UPDATED        : JUNE 1984                                   *
C     *                                                               *
C     *****************************************************************
C
      COMMON/IOUNT/ II,IO,IT,IFL1,IFL2,IFL3,IFL4
      COMMON/UNITS/ ID1(4),ID2(8),ID3(8),ID4(8),ID5(8)
      COMMON/CONVR/ CO1(2,4),CO2(2,8),G,VK
      COMMON/TITLE/IDN(15),ITIME(5),IYEAR
      COMMON/APRCH/B1,Z1,D1,ISHP1
      COMMON/THROT/BC,ZC,DC,PC,ZC2,ZC3,DC1,DC2,CBL,ITROT
      COMMON/TALWT/B2,Z2,D2,ISHP2
```

```
C          THE X IS REPLACED BY 1,C OR 2 AS INDICATED.
C          THE UNITS FOR INPUT DIMENSIONS ARE SPECIFIED IN LINE 3.
C          (SEE FIGURE 2.1)
C
C               LINE 5 - APPROACH CHANNEL CROSS-SECTION DATA (X=1)
C               LINE 6 - THROAT CROSS-SECTION DATA (X=C)
C               LINE 7 - TAILWATER CHANNEL CROSS-SECTION DATA (X=2)
C               ---------------------------------------------------
C
C          SHAPE OPTION 1 - SIMPLE TRAPEZOID
C   BX   = BOTTOM WIDTH FOR SECTION X
C   ZX   = SIDE SLOPE (HORIZONTAL TO VERTICAL) FOR SECTION X
C
C          SHAPE OPTION 2 - CIRCLE
C   DX   = DIAMETER OF CIRCLE FOR SECTION X
C
C          SHAPE OPTION 3 - U-SHAPED
C   DX   = DIAMETER OF CIRCLE FOR SECTION X
C
C          SHAPE OPTION 4 - PARABOLA
C   DX   = FOCUS OF PARABOLA FOR SECTION X
C
C          SHAPE OPTION 5 - COMPLEX TRAPEZOIDAL THROAT
C   BC   = BOTTOM WIDTH FOR SECTION C
C   ZC   = FIRST SIDE SLOPE (HORIZONTAL TO VERTICAL) FOR SECTION C
C   ZC2  = SECOND SIDE SLOPE (HORIZONTAL TO VERTICAL) FOR SECTION C
C   ZC3  = THIRD  SIDE SLOPE (HORIZONTAL TO VERTICAL) FOR SECTION C
C   DC1  = DEPTH AT JUNCTION BETWEEN FIRST AND SECOND SIDE
C          SLOPE FOR SECTION C
C   DC2  = DEPTH AT JUNCTION BETWEEN SECOND AND THIRD SIDE
C          SLOPE FOR SECTION C
C
C          SHAPE OPTION 6 - TRAPEZOIDAL THROAT IN CIRCLE
C   DC   = DIAMETER OF PIPE
C   PC   = HEIGHT OF TRAPEZOID BOTTOM FROM CHANNEL INVERT
C   BC   = BOTTOM WIDTH FOR TRAPEZOID (*)
C   ZC   = SIDE SLOPE FOR TRAPEZOID
C     (*) FOR A BOTTOM SILL IN A CIRCLE, SPECIFY A BOTTOM WIDTH (BC)
C         WIDER THAN THE SECTION WIDTH AT PC, AND A FLAT SIDE SLOPE.
C
C          SHAPE OPTION 7 - TRAPEZOIDAL THROAT IN U-SHAPE
C   DC   = DIAMETER OF PIPE
C   PC   = HEIGHT OF TRAPEZOID BOTTOM FROM CHANNEL INVERT
C   BC   = BOTTOM WIDTH FOR TRAPEZOID (*)
C   ZC   = SIDE SLOPE FOR TRAPEZOID
C     (*) FOR A BOTTOM SILL IN A U-SHAPE, SPECIFY A BOTTOM WIDTH (BC)
C         WIDER THAN THE SECTION WIDTH AT PC, AND A FLAT SIDE SLOPE.
C
C          SHAPE OPTION 8 - TRAPEZOIDAL THROAT IN PARABOLA
C   DC   = FOCUS OF PARABOLA
C   PC   = HEIGHT OF TRAPEZOID BOTTOM FROM CHANNEL INVERT
C   BC   = BOTTOM WIDTH FOR TRAPEZOID
C   ZC   = SIDE SLOPE FOR TRAPEZOID
C
```

```
C
C
C                 LINE 11 - DEPTH AND DISCHARGE INCREMENT
C                 ---------------------------------------
C
C                   (UNITS SPECIFIED IN LINE 10)
C   HLOW  = LOWEST HEAD FOR CALIBRATION
C   HINC  = INCREMENT IN HEAD VALUES
C   HHIGH = HIGHEST HEAD FOR CALIBRATION
C   QINC  = INCREMENT IN DISCHARGE VALUES FOR INVERSE RATING (SET
C           TO ZERO TO SKIP THIS OPTION)
C
C
C                 LINE 12 - SAVE DATA FOR PLOT OPTION
C                 -----------------------------------
C
C   F1 - STORE DATA FROM ORIGINAL RATING TABLE
C   F2 - STORE DATA FOR WALL GAUGE PLOT
C     YES = 1 : CREATE FILE AND STORE DATA
C     NO  = 0 : NO FILE CREATED
C
C            LINE 12A - INPUT FILE NAME FOR RATING TABLE DATA (F1=1)
C            LINE 12B - INPUT FILE NAME FOR WALL GAUGE DATA (F2=1)
C                         (FILE NAMES ARE LIMITED TO 6 CHARACTERS)
C
C
C                 LINE 13 - ANALYZE FIELD DATA OPTION
C                 -----------------------------------
C
C        YES = 1 : READ FIELD DATA FOR COMPARISON
C        NO  = 0 : NO FIELD DATA COMPARISON
C            LINE 13A - INPUT FILE NAME FOR FIELD DATA
C            LINE 13B - INPUT UNITS FOR FIELD DATA (SEE LINE 10)
C            LINE 13C - STORE DATA FOR FIELD DATA COMPARISON
C                   YES = 1 : CREATE FILE AND STORE DATA
C                   NO  = 0 : NO FILE CREATED
C                     LINE 13C1 - INPUT FILE NAME FOR FIELD
C                                 DATA COMPARISON
C
C
C                 LINE 14 - CONTINUATION OPTION
C                 -----------------------------
C
C       = 0 : STOP
C       = 1 : READ ALL NEW INPUT DATA, STARTING AT LINE 1
C       = 2 : READ NEW PROFILE DIMENSIONS, ETC
C             READS LINE 2, THEN SKIPS TO LINE 8
C       = 3 : READ NEW OUTPUT UNITS, ETC
C             READS LINE 2, THEN SKIPS TO LINE 10
C       = 4 : READS NEW INPUT UNIT NUMBER, THEN
C             SKIPS REMAINING INPUT AND RERUNS
C
C  THE USER SHOULD NOTE THAT THE LENGTH OF THE DIVERGING TRANSITION
C (DL) IS BASED ON THE PRODUCT OF P2*EM. THUS WHEN P2=0, THEN DL=0, SO
```

```
C
    1 IERR=0
      JUMP=0
      IF(KEY.NE.1.AND.KEY.NE.4) GO TO 6
      WRITE(IT,2000)
      READ(II,*) IO
      IF(IO.NE.0.AND.IO.NE.6) IO=6
      IF(KEY.EQ.4) GO TO 75
    6 WRITE(IT,2003)
C     ***-------------
C     *** INPUT TITLE
C     ***-------------
      READ(II,2047) (IDN(I),I=1,15)
      GO TO (2,40,50,75,999),KEY
C     ***-----------------------
C     *** SELECT THE INPUT UNITS
C     ***-----------------------
    2 WRITE(IT,2004)
      READ(II,*) IOPT1
C     ***------------------------
C     *** SELECT THE FLUME SHAPES
C     ***------------------------
    3 WRITE(IT,2005)
      READ(II,*) ISHP1,ITROT,ISHP2
      IF(ISHP1.LT.5) GO TO 4
      WRITE(IT,2006)
      ISHP1=1
    4 IF(ISHP2.LT.5) GO TO 5
      WRITE(IT,2007)
      ISHP2=1
C     ***--------------------------------
C     *** INPUT THE APPROACH CHANNEL DATA
C     ***--------------------------------
    5 GO TO (11,12,13,14),ISHP1
   11 WRITE(IT,2008)
      READ(II,*)B1,Z1
      GO TO 20
   12 WRITE(IT,2010)
      READ(II,*) D1
      GO TO 20
   13 WRITE(IT,2011)
      READ(II,*) D1
      GO TO 20
   14 WRITE(IT,2012)
      READ(II,*) D1
   20 CONTINUE
C     ***------------------------------
C     *** INPUT THE THROAT SECTION DATA
C     ***------------------------------
      GO TO (21,22,23,24,25,26,27,28),ITROT
   21 WRITE(IT,2013)
      READ(II,*)BC,ZC
      GO TO 30
   22 WRITE(IT,2015)
```

```
 50 WRITE(IT,2029)
C      ***------------------------
C      *** SELECT THE OUTPUT UNITS
C      ***------------------------
       WRITE(IT,2030)
       READ(II,*)JOPT1,JOPT2
 70 WRITE(IT,2031)ID1(JOPT1),ID2(JOPT2),ID3(JOPT2),ID4(JOPT2),
   1                 ID5(JOPT2)
C      ***-----------------------------------------
C      *** SELECT THE DEPTH & DISCHARGE INCREMENTS
C      ***-----------------------------------------
       READ(II,*) HLOW,HINC,HHIGH,QINC
C      ***-------------------------------------------------
C      *** DECIDE WHETHER TO STORE DATA FOR PLOTS OR NOT
C      ***-------------------------------------------------
 75 WRITE(IT,2057)
       READ(II,*)NPLOT(2),NPLOT(1)
C      ********************************************************
C      ***    CHECK ERROR  & PRINT WARNING MESSAGES IF ANY    ***
C      ********************************************************
 80 COEF1=CO1(IOPT1,JOPT1)
       COEF2=CO2(IOPT1,JOPT2)
       IF(MOVE.EQ.1) GO TO 90
       P1=Y1/4.
       P2=P1+DP
 90 DL=EM*P2
       IF (DL.LT.0.0) DL=0.0
       EL=10.*(P2+TL/2.)-DL
       IF(P1.EQ.0.) GO TO 101
       EN=BL/P1
       GO TO 102
101 EN=99.999
102 ILOW=HLOW/HINC+0.5
       IHIGH=HHIGH/HINC+0.5
C
C     ***---------------------------------------------
C     ***  CHECK THE MAXIMUM HEAD AND HEAD INCREMENTS
C     ***---------------------------------------------
C
       IF(MOVE.EQ.2.AND.HHIGH/COEF1.GT.Y1) GO TO 104
105 IF(ILOW.LE.0) ILOW=1
       INO=IHIGH-ILOW
       IF(INO.GT.300) GO TO 104
       IF(ILOW.LE.0) GO TO 104
       IF(ILOW.LE.IHIGH) GO TO 103
104 WRITE(IO,2033)HLOW,HINC,HHIGH,ID1(JOPT1)
       WRITE(1,2033)HLOW,HINC,HHIGH,ID1(JOPT1)
       GO TO 750
103 IW=0
       I=0
C     ***-----------------------------------------------------------
C     *** CHECK IF THROAT AREA GREATER THAN APPROACH CHANNEL AREA
C     ***-----------------------------------------------------------
       IF(MOVE.EQ.1) GO TO 106
```

```
      IF(EN.LE.3.01) GO TO 350
      IW=2
      IERR=IERR+1
      WRITE(IO,2037) EN
C     ***-----------------------------------
C     *** CHECK IF RAMP IS STEEPER THAN 2 : 1
C     ***-----------------------------------
  350 IF(EN.GE.1.99) GO TO 360
      IW=3
      IERR=IERR+1
      WRITE(IO,2038) EN
C     ***-------------------------------------------------------------
C     *** CHECK IF TAILWATER CHANNEL BOTTOM IS ABOVE APPROACH CHANNEL
C     ***-------------------------------------------------------------
  360 DP=P2-P1
      IF(MOVE.EQ.1) GO TO 365
      IF(BL/HHIGH.GE.0.25) GO TO 365
      IW=3
      IERR=IERR+1
      WRITE(IO,2061)
  365 IF(DP.GT.-0.001) GO TO 370
      IW=5
      IERR=IERR+1
      WRITE(IO,2039)
C     ***------------------------------------------
C     *** CHECK IF DIVERGING TRANSITION FLATTER THAN 10 :1
C     ***------------------------------------------
  370 IF(EM.LE.10.) GO TO 380
      IW=6
      IERR=IERR+1
      EM=10
      WRITE(IO,2040)
C     ***---------------------------------
C     *** CHECK IF ROUGHNESS IS OUT OF RANGE
C     ***---------------------------------
  380 IF(RK.GE.0.000001) GO TO 390
      IW=7
      IERR=IERR+1
      WRITE(IO,2041)
  390 IF(RK.LE.0.01) GO TO 400
      IW=7
      IERR=IERR+1
      RK=0.0002
      WRITE(IO,2042)
C     ***-----------------
C     *** CHECK THE H/L RATIO
C     ***-----------------
  400 IF(HLOW.GE.0.04*COEF1*TL) GO TO 405
      IW=9
      WRITE(IO,2065) HLOW,ID1(JOPT1)
      WRITE(1,2065) HLOW,ID1(JOPT1)
      GO TO 750
  405 IF(HLOW.GE.0.07*COEF1*TL) GO TO 410
      IW=9
```

```
      DO 200 J=ILOW,IHIGH
      SH1=FLOAT(J)*HINC
C
      Y1=P1+SH1/COEF1
      CALL CRTFL(IERR,JOPT1,JOPT2,NPLOT,N,Y1,SH1,HG,QG,COEF1,COEF2,
     1           QQ,QI,H1,CD,FRN,CV,DDH,YY2,FML)
      IF(IERR.NE.0) GO TO 230
      CALL OUTP2(JOPT1,JOPT2,SH1,QQ,FRN,CD,CV,DDH,YY2,FML,H1,NPLOT)
      IF(FRN.GE.0.7) GO TO 230
  200 CONTINUE
      GO TO 230
C
C     **************************************
C     ***** MOVABLE WEIR CALCULATIONS *****
C     **************************************
C
  210 DO 220 J=ILOW,IHIGH
      SH1=FLOAT(J)*HINC
      P1=Y1-SH1/COEF1
      P2=P1+DP
      CALL CRTFL(IERR,JOPT1,JOPT2,NPLOT,N,Y1,SH1,HG,QG,COEF1,COEF2,
     1           QQ,QI,H1,CD,FRN,CV,DDH,YY2,FML)
      IF(IERR.NE.0) GO TO 230
      CALL OUTP2(JOPT1,JOPT2,SH1,QQ,FRN,CD,CV,DDH,YY2,FML,H1,NPLOT)
      IF(FRN.GE.0.7) GO TO 230
  220 CONTINUE
  230 IF(NPLOT(2).NE.1) GO TO 240
      WRITE(IO,2060)NAME
      CLOSE (IFL1)
C
C     ********************************
C     ***** GAUGE VS. DISCHARGE *****
C     ********************************
C
  240 IF(QINC.GT.1.E-5)
     1CALL GAUGE(N,IOPT1,JOPT1,JOPT2,NPLOT,QINC,QG,HG)
C
C     ********************************
C     ***** CURVE FIT FOR H-Q  ******
C     ********************************
C
      CALL CURVE(HG,QG,HHIGH,N,JOPT1,JOPT2)
C
C     ********************************
C     ***** FIELD DATA COMPARISON ***
C     ********************************
C
      CALL FIELD(IOPT1,NPLOT,HG,QG)
C
C     ********************************
C     ***** RERUN OPTIONS    *********
C     ********************************
C
  750 WRITE(IT,2032)
```

```
     1        ' (1)  METER              (3)  FEET '/
     2        ' (2)  MM                 (4)  INCH')
2030 FORMAT(' SELECT OUTPUT DISCHARGE UNIT OPTION -- (J2) '/
     1 ' (1) CU-METER/SEC        (3) CFS         (5) AC-FT/HR'/
     2 ' (2) LIT/SEC             (4) GPM         (6) MI      '/
     3 ' (7) MLIT/HR             (8) MGD'/
     4 ' INPUT J1,J2 ?')
2031 FORMAT(' ** NOTICE ** THE UNITS FOR THE FOLLOWING    '/
     1        '              SHOULD BE  --   ',A2,' , ',4A2//
     2        ' INPUT THE LOWEST HEAD FOR CALIBRATION,',/,
     3        ' THE INCREMENT IN HEAD VALUES,',/,
     4        ' THE HIGHEST HEAD FOR CALIBRATION,',/,
     5        ' AND THE INCREMENTAL DISCHARGE VALUE FOR THE INVERSE',
     6        ' RATING TABLE',/,' SET QINC=0 TO SKIP INVERSE RATING',
     7        ' TABLE OPTION',/,' (HLOW,HINC,HHIGH,QINC)')
2032 FORMAT(' NEXT RUN (0) STOP'/
     1  '          (1) NEXT RUN WITH ALL NEW INPUT'/
     2  '          (2) FOR SAME SHAPES WITH NEW PROFILE DATA'/
     3  '          (3) FOR SAME FLUME WITH DIFFERENT OUTPUT FORMAT'/
     4  '          (4) FOR SAME RUN WITH DIFFERENT OUTPUT LOCATION')
2033 FORMAT(/10X,'WARNING IWARN = 8   RUN TERMINATED'/
     1    15X,'HLOW =',F10.4,'  HINC =',F10.4,' HHIGH =',F10.4,1X,A2/)
2034 FORMAT(/10X,'WARNING IWARN = 1'/
     1         15X,'ERROR IN CROSS SECTION DATA - AREA EXPANDS'/
     2         15X,'PROGRAM TERMINATED CHECK FOLLOWING DATA '
     3 /5X,'Y1,B1,Z1,D1,A1 ARE '/5X,5F7.3/
     4 5X,'YC,BC,ZC,DC,PC,DC1,ZC2,DC2,ZC3,A3 ARE '/5X,10F7.3)
2035 FORMAT(/10X,'WARNING IWARN = 1'/
     1         15X,'CAUTION - HIGH FROUDE NUMBERS MAY RESULT'/
     2         15X,'OR PROGRAM MAY NOT CONVERGE'/
     3         15X,'CHECK FOLLOWING DATA ' /
     4  5X,'Y1,B1,Z1,D1,A1,TW1 ARE'/5X,6F7.3/
     5  5X,'YC,BC,ZC,DC,PC,DC1,ZC2,DC2,AC3,A3,TW3 ARE'/5X,11F6.2)
2036 FORMAT(/10X,'WARNING IWARN = 4'/
     1         15X,'CHANNEL MAY NOT EXPAND ENOUGH'/
     2         15X,'DOWNSTREAM OF FLUME, HEAD LOSS AND MODULAR LIMIT'/
     3         15X,'CALCULATIONS MAY BE IN ERROR')
2037 FORMAT(/10X,'CAUTION IWARN = 2  EN =',F6.2/
     1         15X,'RAMP IS FLATTER THAN 3 TO 1'/
     2         15X,'CALIBRATION STILL GOOD')
2038 FORMAT(/10X,'WARNING IWARN = 3  EN =',F6.2/
     1         15X,'RAMP IS STEEPER THAN 2 TO 1'/
     2         15X,'CALIBRATION MAY BE IN ERROR DUE TO FLOW SEPERATION'/
     3         15X,'LENGTHEN RAMP OR USE ROUND RAMP')
2039 FORMAT(/10X,'WARNING IWARN = 5'/
     1         15X,'TAILWATER CHANNEL BOTTOM ABOVE APPROACH',
     2         ' CHANNEL BOTTOM.'/15X,'HEAD LOSS AND MODULAR LIMIT',
     3         ' CALCULATIONS MAY BE IN ERROR')
2040 FORMAT(/10X,'CAUTION IWARN = 6'/
     1        15X,'DIVERGING TRANSITION TOO FLAT.'/
     2        15X,'DIVERGING RAMP SLOPE SET AT 10 TO 1')
2041 FORMAT(/10X,'CAUTION IWARN = 7'/
     1         15X,'ROUGHNESS VALUE IS OUT OF RANGE ')
2042 FORMAT(/10X,'CAUTION IWARN = 7'/
```

```
      SUBROUTINE CRTFL(IERR,J01,J02,NPLT,N,Y1,SH1,HG,QG,HCO,QCO,
     1   QQ,QI,H1,CD,FRN,CV,DDH,YY2,FML)
      DIMENSION HG(1),QG(1),NPLT(1)
      COMMON/IOUNT/ II,IO,IT,IFL1,IFL2,IFL3,IFL4
      COMMON/UNITS/ ID1(4),ID2(8),ID3(8),ID4(8),ID5(8)
      COMMON/CONVR/ CO1(2,4),CO2(2,8),G,VK
      COMMON/TITLE/IDN(15),ITIME(5),IYEAR
      COMMON/APRCH/B1,Z1,D1,ISHP1
      COMMON/THROT/BC,ZC,DC,PC,ZC2,ZC3,DC1,DC2,CBL,ITROT
      COMMON/TALWT/B2,Z2,D2,ISHP2
      COMMON/PROFL/AL,BL,TL,P1,P2,EM,RK,DL,EL,EN
      IERR=0
      KOUNT=0
      IDEAL=0
      ALF1=1.
      ALFC=1.
      DH1=0.
C        ***-----------------
C        *** EQUATION (9.12 OR 3.12)   *(SEE NOTE ABOVE)
C        ***-----------------
         YC=0.7*SH1/HCO
      WP1=WETP(ISHP1,Y1,B1,Z1,D1,0.,0.,0.,0.,0.)
      A1=AREA(ISHP1,Y1,B1,Z1,D1,0.,0.,0.,0.,0.,DUM)
      TW1=WIDE(ISHP1,Y1,B1,Z1,D1,0.,0.,0.,0.,0.)
  210 YCOLD=YC
      A3=AREA(ITROT,YC,BC,ZC,DC,PC,DC1,ZC2,DC2,ZC3,CBL)
      TW3=WIDE(ITROT,YC,BC,ZC,DC,PC,DC1,ZC2,DC2,ZC3)
C        ***-----------------------
C        *** EQUATION (9.7), (9.28)
C        ***-----------------------
         Q=SQRT(G*A3**3/TW3/ALFC)
C           ***-----------------------
C           *** EQUATION (9.3),(9.29)
C           ***-----------------------
            H1=ALF1*(Q/A1)**2/(2.0*G)+SH1/HCO
         IF(DH1.LT.YC) GO TO 212
         WRITE(IO,2004)
         RETURN
C        ***-----------------------
C        *** EQUATION (9.6),(9.20)
C        ***-----------------------
 212     YC=H1-A3/2./TW3-DH1
      RER=(YC-YCOLD)/YC
      KOUNT=KOUNT+1
      IF(KOUNT.LE.100) GO TO 215
      IF(RER.GT.0.005) GO TO 214
      YC=(YC+YCOLD)/2.
      Q=(Q+QOLD)/2.
      QOLD=Q
      GO TO 216
  214 WRITE(IO,2001)YC,YCOLD,Q,QOLD
      IERR=1
      RETURN
  215 IF(ABS(RER).GT.0.0001) GO TO 210
```

```
C          *** EQUATION (9.13)
C          ***-----------------
           CF=CFL-XL*(CFX-CFXL)/TL
  260 WP3=WETP(ITROT,YC,BC,ZC,DC,PC,DC1,ZC2,DC2,ZC3)
C        ***-----------------
C        *** EQUATION (9.30)
C        ***-----------------
         RC=A3/WP3
C          ***-----------------
C          *** EQUATION (9.19)
C          ***-----------------
           DHL=CF*TL*VC**2/(2.*RC*G)
      V1=Q/A1
C        ***-----------------
C        *** EQUATION (9.30)
C        ***-----------------
         R1=A1/WP1
C           ***-----------------
C           *** EQUATION (9.19)
C           ***-----------------
            DHA=0.00235*AL*V1*V1/(2.*R1*G)
C        ***-----------------
C        *** EQUATION (9.33)
C        ***-----------------
         YB=YC+0.625*(SH1/HCO-YC)
      A4=AREA(ITROT,YB,BC,ZC,DC,PC,DC1,ZC2,DC2,ZC3,DUM)
      WP4=WETP(ITROT,YB,BC,ZC,DC,PC,DC1,ZC2,DC2,ZC3)
      VB=Q/A4
C        ***-----------------
C        *** EQUATION (9.30)
C        ***-----------------
         RB=A4/WP4
C           ***-----------------
C           *** EQUATION (9.32)
C           ***-----------------
            DHB=0.00235*BL*(V1*V1/R1+VB*VB/RB)/(4.*G)
C       ***-----------------
C       *** EQUATION (9.21)
C       ***-----------------
        DH1=DHA+DHB+DHL
C
C      *******************************************
C      * COMPUTE ENERGY DISTRIBUTION COEFFICIENTS *
C      *******************************************
C        ***-----------------
C        *** EQUATION (9.26)
C        ***-----------------
         E=1.77*SQRT(CFL)
C             ***-----------------
C             *** EQUATION (9.27)
C             ***-----------------
              WIDTH=1.5*(A3/TW3)/RC-0.5
              IF(WIDTH.LT.1.0) WIDTH=1.0
              IF(WIDTH.GT.2.0) WIDTH=2.0
```

```
      KOUNT=KOUNT+1
      IF(KOUNT.GT.100) GO TO 285
      GO TO 280
  285 WRITE(IO,2002)H2,H2T
      H2=(H2+H2T)/2.
C         ***-----------------
C         *** EQUATION (9.38)
C         ***-----------------
  290   IF(Y2.LT.0) GO TO 295
        FML=H2/H1
        DH=H1-H2
        GO TO 300
  295 FML=0
      DH=0
      Y2=0
  300 SSH1=SH1*YC/(H1*HCO)
      ACH1=AREA(ITROT,YC,BC,ZC,DC,PC,DC1,ZC2,DC2,ZC3,DUM)
      ACSH=AREA(ITROT,SSH1,BC,ZC,DC,PC,DC1,ZC2,DC2,ZC3,DUM)
      CV=(ACH1/ACSH)*SQRT(H1/SH1*HCO)
C             ***-----------------
C             *** EQUATION (9.33)
C             ***-----------------
              FRN=Q/A1/SQRT(G*A1/TW1)
         IF(FRN.GT.0.5) WRITE(IO,2003)
C         ***-----------------
C         *** EQUATION (9.1)
C         ***-----------------
          CD=Q/QI
      N=N+1
      QG(N)=Q*QCO
      HG(N)=SH1
      QQ=QG(N)
      DDH=DH*HCO
      YY2=Y2*HCO
      RETURN
 2001 FORMAT(/15X,'DEPTH AND DISCHARGE DID NOT CONVERGE'/
     1        15X,'CHECK WARNING ABOVE '/
     2        20X,'YC  = ',F8.6,'      = ',F8.6/
     3        20X,'Q   = ',F8.6,'      = ',F8.6/
     4        20X,'RUN TERMINATED')
 2002 FORMAT(/10X,'MODULAR LIMIT CALCS DID NOT CONVERGE'/
     1        10X,'H2   = ',F7.4,'  H2T  = ',F7.4)
 2003 FORMAT(/10X,'CAUTION - FROUDE NUMBER GREATER THAN  0.5')
 2004 FORMAT(/10X,'HEADLOSS IS GREATER THAN YC - H/L TOO LOW'/
     1   15X,'RUN TERMINATED'/)
      END
C
C
C     *****************************************************************
C     *                                                               *
C     *  THIS SUBROUTINE DETERMINES THE VERTICAL AND SIDE SLOPE      *
C     *  DISTANCES FOR MARKING WALL GAUGES IN DISCHARGE UNITS.       *
C     *  OPTIONS ARE AVAILABLE FOR VARIABLE OUTPUT UNITS AND DATA    *
C     *  CAN BE OUTPUT TO A FILE FOR GAUGE PLOTTING WITH PROGRAM     *
```

```
  120 WRITE(IO,3018)QINT,SH1,SHS
      GO TO 60
  130 WRITE(IO,3019)QINT,SH1,SHS
      GO TO 60
  140 WRITE(IO,3016)QINT,SH1,SHS
      GO TO 60
  160 WRITE(IO,3017)QINT,SH1,SHS
      GO TO 60
  300 GO TO (310,320,330,340,310,360,310,330),JOPT2
  310 WRITE(IO,3005)QINT,SH1,SHS
      GO TO 60
  320 WRITE(IO,3003)QINT,SH1,SHS
      GO TO 60
  330 WRITE(IO,3004)QINT,SH1,SHS
      GO TO 60
  340 WRITE(IO,3001)QINT,SH1,SHS
      GO TO 60
  360 WRITE(IO,3002)QINT,SH1,SHS
      GO TO 60
  500 GO TO (510,520,530,540,510,560,510,530),JOPT2
  510 WRITE(IO,3015)QINT,SH1,SHS
      GO TO 60
  520 WRITE(IO,3013)QINT,SH1,SHS
      GO TO 60
  530 WRITE(IO,3014)QINT,SH1,SHS
      GO TO 60
  540 WRITE(IO,3011)QINT,SH1,SHS
      GO TO 60
  560 WRITE(IO,3012)QINT,SH1,SHS
      GO TO 60
   50 CONTINUE
      GO TO (105,305,105,505),JOPT1
  105 GO TO (115,125,135,145,115,165,115,135),JOPT2
  115 WRITE(IO,3020)QINT,SH1
      GO TO 60
  125 WRITE(IO,3018)QINT,SH1
      GO TO 60
  135 WRITE(IO,3019)QINT,SH1
      GO TO 60
  145 WRITE(IO,3016)QINT,SH1
      GO TO 60
  165 WRITE(IO,3017)QINT,SH1
      GO TO 60
  305 GO TO (315,325,335,345,315,365,315,335),JOPT2
  315 WRITE(IO,3005)QINT,SH1
      GO TO 60
  325 WRITE(IO,3003)QINT,SH1
      GO TO 60
  335 WRITE(IO,3004)QINT,SH1
      GO TO 60
  345 WRITE(IO,3001)QINT,SH1
      GO TO 60
  365 WRITE(IO,3002)QINT,SH1
      GO TO 60
```

```
C    ********************************************************************
C    *                                                                  *
C    *  THIS SUBROUTINE READS FIELD DATA FROM A FILE AND COMPUTES      *
C    *  THE DISCHARGE FOR EACH HEAD VALUE READ.  THIS MODEL OR          *
C    *  PREDICTED DISCHARGE IS COMPARED WITH THE MEASURED DISCHARGE.    *
C    *  THE DATA READ CAN BE IN A VARIETY OF UNITS AND THE COMPARISON *
C    *  CAN BE OUTPUT TO A FILE FOR PLOTTING OF FURTHER ANALYSIS.       *
C    *                                                                  *
C    ********************************************************************
C
C
      SUBROUTINE FIELD(IOPT1,NPLT,HG,QG)
      COMMON/IOUNT/ II,IO,IT,IFL1,IFL2,IFL3,IFL4
      COMMON/UNITS/ ID1(4),ID2(8),ID3(8),ID4(8),ID5(8)
      COMMON/CONVR/ CO1(2,4),CO2(2,8),G,VK
      COMMON/TITLE/IDN(15),ITIME(5),IYEAR
      COMMON/APRCH/B1,Z1,D1,ISHP1
      COMMON/THROT/BC,ZC,DC,PC,ZC2,ZC3,DC1,DC2,CBL,ITROT
      COMMON/TALWT/B2,Z2,D2,ISHP2
      COMMON/PROFL/AL,BL,TL,P1,P2,EM,RK,DL,EL,EN
      DIMENSION HG(1),QG(1),NPLT(1)
      CHARACTER*64 NAME1,NAME2
      WRITE(IT,3001)
      READ(II,*)IFLD
    1 IF(IFLD.NE.1) RETURN
      WRITE(IT,3003)
      READ(II,3013)NAME1
      OPEN(IFL3,FILE=NAME1,STATUS='NEW',IOSTAT=IOS,ERR=998)
      WRITE(IT,3004)
      READ(II,*)SH1,QF
      WRITE(IFL3,*)SH1,QF
      WRITE(IT,3005)
      WRITE(IT,3007)
      READ(II,*)J1,J2
      HCOE=CO1(IOPT1,J1)
      QCOE=CO2(IOPT1,J2)
      NPLT(3)=1
      WRITE(IT,3009)
      READ(II,*)JFE
      N=0
      IF(JFE.NE.1) GO TO 20
      WRITE(IT,3011)
      READ(II,3013)NAME2
      OPEN(IFL4,FILE=NAME2,STATUS='NEW',IOSTAT=IOS,ERR=999)
   20 WRITE(IO,3015) IDN
      WRITE(IO,3017)ID1(J1),ID2(J2),ID3(J2),ID4(J2),ID5(J2),ID2(J2),
     1 ID3(J2),ID4(J2),ID5(J2),ID2(J2),ID3(J2),ID4(J2),ID5(J2)
      IF(JFE.EQ.1) WRITE(IFL4,3030) IDN,IOPT1,J1,J2
      IF(JFE.EQ.1)
     1 WRITE(IFL4,3017)ID1(J1),ID2(J2),ID3(J2),ID4(J2),ID5(J2),ID2(J2),
     2 ID3(J2),ID4(J2),ID5(J2),ID2(J2),ID3(J2),ID4(J2),ID5(J2)
C
C    ***---------------------------
C    ***  INPUT FIELD DATA FROM FILE
```

```
C   *  FUNCTION FOR COMPUTING AREA OF FLOW AS A FUNCTION OF  "Y"      *
C   *                                                                 *
C   *******************************************************************
C
C
      FUNCTION AREA(ISHP,Y,B,Z,D,P,D1,Z2,D2,Z3,BL)
      PI=3.14159265358
      BL=0.
C
C   *****************************************************
C   *                                                   *
C   *  ISHP = SHAPE OPTION                              *
C   *       = 1 FOR SIMPLE TRAPEZOID                    *
C   *       = 2 FOR CIRCLE                              *
C   *       = 3 FOR U - SHAPE                           *
C   *       = 4 FOR PARABOLA                            *
C   *       = 5 FOR COMPLEX TRAPEZOID                   *
C   *       = 6 FOR TRAPEZOID IN CIRCLE                 *
C   *       = 7 FOR TRAPEZOID IN U - SHAPE              *
C   *       = 8 FOR TRAPEZOID IN PARABOLA               *
C   *                                                   *
C   *****************************************************
C
      GO TO (10,20,30,40,50,60,80,100),ISHP
C
C     ********************************
C     *    SIMPLE TRAPEZOID          *
C     ********************************
C     ********************************
C     *                              *
C     *                              *
C     *   Y    = WATER DEPTH         *
C     *   B    = BOTTOM WIDTH        *
C     *   Z    = SIDE SLOPE          *
C     *                              *
C     ********************************
C
   10 AREA=Y*(B+Z*Y)
      RETURN
C
C     ********************************
C     *           CIRCLE             *
C     ********************************
C     ********************************
C     *                              *
C     *    Y      = WATER DEPTH      *
C     *    D      = DIAMETER         *
C     *    R      = RADIUS           *
C     *    THETA  = ANGLE            *
C     *                              *
C     ********************************
C
   20 R=0.5*D
   21    THETA=2.0*ACOS((R-Y)/R)
```

```
C
   50 IF(Y-D1)10,10,52
C        ***-----------------
C        ***   D1 < Y < D2
C        ***-----------------
   52   B1=B+2.0*Z*D1
        A1=D1*(B+Z*D1)
        IF(Y-D2)53,53,54
   53   A2=(Y-D1)*(B1+Z2*(Y-D1))
        AREA=A1+A2
        RETURN
C        ***------------
C        ***   D2 < Y
C        ***------------
   54     B2=B1+2.0*Z2*(D2-D1)
          A2=(D2-D1)*(B1+Z2*(D2-D1))
          A3=(Y-D2)*(B2+Z3*(Y-D2))
          AREA=A1+A2+A3
          RETURN
C
C     *********************************
C     *       TRAPEZOID IN CIRCLE      *
C     *********************************
C     ************************************************
C     *                                              *
C     *   D       = DIAMETER                         *
C     *   R       = RADIUS                           *
C     *   Y       = WATER DEPTH TO SILL              *
C     *   YPC     = WATER DEPTH TO BOTTOM OF CIRCLE  *
C     *   P       = SILL HEIGHT                      *
C     *   B       = BOTTOM WIDTH                     *
C     *   Z       = SIDE SLOPE                       *
C     *   BL      = WIDTH OF SECTION AT P            *
C     *   YO      = DEPTH OF INTERSECTION OF CIRCLE & TRAP*
C     *   THETA   = ANGLE                            *
C     *                                              *
C     ************************************************
C
   60 R=0.5*D
C     ***--------------------
C     *** CHECK FOR FLAT SILL
C     ***--------------------
      YPC=Y+P
      THETA=ACOS((R-P)/R)
      BL=2.0*R*SIN(THETA)
      IF(BL.LT.B) GO TO 70
C
C     *********************
C     *    FOR TRAPEZOID   *
C     *********************
C       ***********************************************
C       *  FIND THE INTERSECTION OF CIRCLE & TRAPEZOID  *
C       ***********************************************
        A1=1.0+Z**2
```

```
C
C
C    **********************
C    *   FOR TRAPEZOID    *
C    **********************
C      ***************************************************
C      *  FIND THE INTERSECTION OF CIRCLE & TRAPEZOID    *
C      ***************************************************
       A1=1.0+Z**2
       A2=B*Z-2.0*P*Z*Z-D
       A3=(P*Z)**2-B*Z*P+B*B/4.0
       Y0=(-A2+SQRT(A2**2-4.0*A1*A3))/(2.0*A1)
     IF(Y0.GT.R) GO TO 85
C
C    ***_____________
C    ***   Y0 < R
C    ***_____________
       IF(YPC-Y0) 10,10,82
C
C       ***_____________
C       ***   Y0 < Y
C       ***_____________
82          A1=(Y0-P)*(B+(Y0-P)*Z)
            FI=2.0*ACOS((R-Y0)/R)
            A2=0.5*R**2*(FI-SIN(FI))
     IF(YPC-R)62,84,84
C
C           ***_________________________
C           ***   Y0 < YPC & R < YPC
C           ***_________________________
84           A3= D*(YPC-R)+0.5*PI*R**2
             AREA=A1-A2+A3
             RETURN
C
C    ******************
C    *   FOR R < Y0   *
C    ******************
C      ****************************************************
C      * FIND THE INTERSECTION OF TRAP. AND VERTICAL WALL *
C      ****************************************************
C
85     Y0=P+(R-0.5*B)/Z
       IF(YPC.LE.Y0) GO TO 10
C
C       ***_____________
C       ***   Y0 < Y
C       ***_____________
          A1=(Y0-P)*(B+(Y0-P)*Z)
          A2=2.0*(YPC-Y0)*R
          AREA=A1+A2
          RETURN
C
C    ********************
C    *   FOR FLAT SILL  *
```

```
      A2=X0*Y0/0.75
      A3=X*YPC/0.75
      AREA=A1-A2+A3
      RETURN
C
C     *********************
C     *   FOR FLAT SILL   *
C     *********************
  110 A1=BL*P/1.5
      X=SQRT(2.0*D*YPC)
      A2=X*YPC/0.75
      AREA=A2-A1
      RETURN
      END
C
C
C   *******************************************************************
C   *                                                                 *
C   *  FUNCTION FOR COMPUTING TOP WIDTH AS A FUNCTION OF Y            *
C   *                                                                 *
C   *******************************************************************
C
C
      FUNCTION WIDE(ISHP,Y,B,Z,D,P,D1,Z2,D2,Z3)
C
C   ************************************************
C                                                  *
C     ISHP = SHAPE OPTION                          *
C          = 1 FOR SIMPLE TRAPEZOID                *
C          = 2 FOR CIRCLE                          *
C          = 3 FOR U - SHAPE                       *
C          = 4 FOR PARABOLA                        *
C          = 5 FOR COMPLEX TRAPEZOID               *
C          = 6 FOR TRAPEZOID IN CIRCLE             *
C          = 7 FOR TRAPEZOID IN U - SHAPE          *
C          = 8 FOR TRAPEZOID IN PARABOLA           *
C                                                  *
C   ************************************************
C
      GO TO (10,20,30,40,50,60,80,100),ISHP
C
C     *******************************
C     *       SIMPLE TRAPEZOID      *
C     *******************************
C     *******************************
C     *                             *
C     *   Y    = WATER DEPTH        *
C     *   B    = BOTTOM WIDTH       *
C     *   Z    = SIDE SLOPE         *
C     *                             *
C     *******************************
C
   10 WIDE=B+2.0*Z*Y
      RETURN
```

```
C     *                                           *
C     *   Y    = WATER DEPTH                      *
C     *   B    = BOTTOM WIDTH                     *
C     *   Z    = FIRST SIDE SLOPE                 *
C     *   Z2   = SECOND SIDE SLOPE                *
C     *   Z3   = THIRD SIDE SLOPE                 *
C     *   D1   = DEPTH AT FIRST JUNCTION          *
C     *   D2   = DEPTH AT SECOND JUNCTION         *
C     *                                           *
C     *********************************************
C
   50 IF(Y-D1)10,10,52
C
C     ***__________________
C     ***   D1 < Y < D2
C     ***__________________
   52   B1=B+2.0*Z*D1
        IF(Y-D2)53,53,54
   53   WIDE=B1+2.0*Z2*(Y-D1)
        RETURN
C
C       ***____________
C       ***   D2 < Y
C       ***____________
   54     B2=B1+2.0*Z2*D2
          WIDE=B2+2.0*Z3*(Y-D2)
          RETURN
C
C     ***********************************
C     *       TRAPEZOID IN CIRCLE       *
C     ***********************************
C     **************************************************
C     *                                                *
C     *   D       = DIAMETER                           *
C     *   R       = RADIUS                             *
C     *   Y       = WATER DEPTH TO SILL                *
C     *   YPC     = WATER DEPTH TO BOTTOM OF CIRCLE    *
C     *   P       = SILL HEIGHT                        *
C     *   B       = BOTTOM WIDTH                       *
C     *   Z       = SIDE SLOPE                         *
C     *   BL      = WIDTH OF SECTION AT P              *
C     *   YO      = DEPTH OF INTERSECTION OF CIRCLE & TRAP*
C     *   THETA   = ANGLE TO WATER SURFACE             *
C     *   FI      = ANGLE TO INTERSECTION              *
C     *                                                *
C     **************************************************
C
   60 R=0.5*D
      YPC=P+Y
      THETA=ACOS((R-P)/R)
C     ***____________________
C     *** CHECK FOR FLAT SILL
C     ***____________________
      BL=2.0*R*SIN(THETA)
```

```
C       *  FIND THE INTERSECTION OF CIRCLE & TRAPEZOID   *
C       **************************************************
        A1=1.0+Z**2
        A2=B*Z-2.0*P*Z*Z-D
        A3=(P*Z)**2-B*Z*P+B*B/4.
        Y0=(-A2+SQRT(A2**2-4.0*A1*A3))/(2.0*A1)
      IF(Y0.GT.R)  GO TO 85
C
C     ***____________
C     ***    Y0 < R
C     ***____________
        IF(YPC-Y0)10,10,62
C
C     ******************
C     *   FOR R < Y0   *
C     ******************
C       **************************************************
C       * FIND THE INTERSECTION OF TRAP AND VERTICAL WALL *
C       **************************************************
C
   85   Y0=(D-0.5*B)/Z+P
        IF(YPC.LE.Y0) GO TO 10
C
C        ***____________
C        ***    Y0 < Y
C        ***____________
   86      WIDE=D
           RETURN
C
C     *********************
C     *   FOR FLAT SILL   *
C     *********************
C
   90 DI= R-YPC
      IF(YPC-R)63,86,86
C
C     **********************************
C     *     TRAPEZOID IN PARABOLA      *
C     **********************************
C     ******************************************************
C     *                                                    *
C     *   D     = FOCUS                                    *
C     *   Y     = WATER DEPTH TO SILL                      *
C     *   YPC   = WATER DEPTH TO BOTTOM OF CIRCLE          *
C     *   P     = SILL HEIGHT                              *
C     *   B     = BOTTOM WIDTH                             *
C     *   Z     = SIDE SLOPE                               *
C     *   BL    = WIDTH OF SECTION AT P                    *
C     *   Y0    = DEPTH OF INTERSECTION OF PARABOLA & TRAP *
C     *   X0    = HALF WIDTH AT INTERSECTION               *
C     *                                                    *
C     ******************************************************
C
  100 YPC=Y+P
```

```
C     *        SIMPLE TRAPEZOID               *
C     *****************************************
C     *****************************************
C     *                                       *
C     *   Y    = WATER DEPTH                  *
C     *   B    = BOTTOM WIDTH                 *
C     *   Z    = SIDE SLOPE                   *
C     *                                       *
C     *****************************************
C
   10 WETP=B+2.0*Y*SQRT(1.0+Z**2)
      RETURN
C
C     *****************************************
C     *               CIRCLE                  *
C     *****************************************
C     *****************************************
C     *                                       *
C     *     Y       = WATER DEPTH             *
C     *     D       = DIAMETER                *
C     *     R       = RADIUS                  *
C     *     THETA   = ANGLE                   *
C     *                                       *
C     *****************************************
C
   20 R=0.5*D
   21    THETA=2.0*ACOS((R-Y)/R)
         WETP=R*THETA
         RETURN
C
C     *****************************************
C     *             U - SHAPE                 *
C     *****************************************
C     *****************************************
C     *                                       *
C     *   Y       = WATER DEPTH               *
C     *   D       = DIAMETER                  *
C     *   R       = RADIUS                    *
C     *   THETA   = ANGLE                     *
C     *                                       *
C     *****************************************
C
   30 R=0.5*D
      IF(Y-R)21,21,35
C
C        ***____________
C        ***   R < Y
C        ***____________
   35      WETP=R*PI+2.0*(Y-R)
           RETURN
C
C     *****************************************
C     *            PARABOLA                   *
C     *****************************************
```

```
C     *  R       = RADIUS                                *
C     *  Y       = WATER DEPTH TO SILL                   *
C     *  YPC     = WATER DEPTH TO BOTTOM OF CIRCLE       *
C     *  P       = SILL HEIGHT                           *
C     *  B       = BOTTOM WIDTH                          *
C     *  Z       = SIDE SLOPE                            *
C     *  BL      = WIDTH OF SECTION AT P                 *
C     *  YO      = DEPTH OF INTERSECTION OF CIRCLE & TRAP*
C     *                                                  *
C     ****************************************************
C
   60 R=0.5*D
      YPC=Y+P
      FI=ACOS((R-P)/R)
C        ***--------------------
C        *** CHECK FOR FLAT SILL
C        ***--------------------
         BL=2.0*R*SIN(FI)
         IF(BL.LT.B) GO TO 70
C
C     ***********************
C     *    FOR TRAPEZOID    *
C     ***********************
C       ********************************************
C       * FIND THE INTERSECTION OF CIRCLE & TRAPEZOID *
C       ********************************************
        A1=1.0+Z**2
        A2=B*Z-2.0*P*Z*Z-D
        A3=(P*Z)**2-B*Z*P+B*B/4.
        YO=(-A2+SQRT(A2**2-4.0*A1*A3))/(2.0*A1)
        IF(YPC-YO)10,10,62
   70   YO=P
   62      W1=B+2.0*(YO-P)*SQRT(1.0+Z*Z)
           IF(BL.LT.B) W1=BL
           DD=R-YO
           FI=2.0*ACOS(DD/R)
           W2=R*FI
           THETA=2.0*ACOS((R-YPC)/R)
           W3=R*THETA
           WETP=W3-W2+W1
         RETURN
C
C     **********************************
C     *     TRAPEZOID IN U - SHAPE     *
C     **********************************
C     ****************************************************
C     *                                                  *
C     *  D       = DIAMETER                              *
C     *  R       = RADIUS                                *
C     *  Y       = WATER DEPTH TO SILL                   *
C     *  YPC     = WATER DEPTH TO BOTTOM OF CIRCLE       *
C     *  P       = SILL HEIGHT                           *
C     *  B       = BOTTOM WIDTH                          *
C     *  Z       = SIDE SLOPE                            *
```

```
C     **************
   85 IF(YPC-Y0)86,86,87
C
C       ***_____________
C       ***    Y < Y0
C       ***_____________
   86     WETP=B+2.0*(YPC-P)*SQRT(1.0+Z*Z)
          RETURN
C
C       ***_____________
C       ***    Y0 < Y
C       ***_____________
   87     W1=B+2.0*(Y0-P)*SQRT(1.0+Z*Z)
          WETP=2.0*(YPC-Y0)+W1
          RETURN
C
C     ****************
C     *   FOR SILL   *
C     ****************
C
   90 FI=2.0*ACOS((R-P)/R)
      W1=R*FI-BL
      IF(YPC-R)70,70,95
C     ***___________
C     ***    R < Y
C     ***___________
   95   WETP=R*PI+2.0*(YPC-R)-W1
        RETURN
C
C     ************************************
C     *     TRAPEZOID IN PARABOLA        *
C     ************************************
C     *****************************************************
C     *                                                   *
C     *   D     = FOCUS                                   *
C     *   Y     = WATER DEPTH TO SILL                     *
C     *   YPC   = WATER DEPTH TO BOTTOM OF CIRCLE         *
C     *   P     = SILL HEIGHT                             *
C     *   B     = BOTTOM WIDTH                            *
C     *   Z     = SIDE SLOPE                              *
C     *   BL    = WIDTH OF SECTION AT P                   *
C     *   Y0    = DEPTH OF INTERSECTION OF PARABOLA & TRAP*
C     *   X0    = HALF WIDTH AT INTERSECTION              *
C     *                                                   *
C     *****************************************************
C
  100 YPC=P+Y
C       ***___________________
C       *** CHECK FOR FLAT SILL
C       ***___________________
        BL=2.0*SQRT(2.0*D*P)
        IF(BL.LT.B) GO TO 110
C
C     **********************
```

```
      IF(M.NE.1) M=3
      CBX=CBL
C
C     ****************************************
C     ***** PRINT THE CROSS SECTION DATA *****
C     ****************************************
C
C     ***** APPROACH CHANNEL *****
C
      GO TO (11,12,13,14),ISHP1
   11 WRITE(IO,5021)
      WRITE(IO,5002)B1,ID1(M),Z1
      GO TO 20
   12 WRITE(IO,5023)
      WRITE(IO,5005)D1,ID1(M)
      GO TO 20
   13 WRITE(IO,5024)
      WRITE(IO,5005)D1,ID1(M)
      GO TO 20
   14 WRITE(IO,5025)
      WRITE(IO,5008)D1,ID1(M)
   20 WRITE(IO,5014)
C     *****_________________
C     ***** THROAT SECTION
C     *****_________________
      GO TO (21,22,23,24,25,26,27,28),ITROT
   21 WRITE(IO,5021)
      WRITE(IO,5003)BC,ID1(M),ZC
      GO TO 30
   22 WRITE(IO,5023)
      WRITE(IO,5006)DC,ID1(M)
      GO TO 30
   23 WRITE(IO,5024)
      WRITE(IO,5006)DC,ID1(M)
      GO TO 30
   24 WRITE(IO,5025)
      WRITE(IO,5009)DC,ID1(M)
      GO TO 30
   25 WRITE(IO,5022)
      WRITE(IO,5003)BC,ID1(M),ZC
      WRITE(IO,5012)DC1,ID1(M),ZC2,DC2,ID1(M),ZC3
      GO TO 30
   26 WRITE(IO,5026)
      IF(CBL.GT.BC) CBX=BC
      WRITE(IO,5015)DC,ID1(M),PC,ID1(M),CBX,ID1(M),ZC
      GO TO 30
   27 WRITE(IO,5027)
      IF(CBL.GT.BC) CBX=BC
      WRITE(IO,5015)DC,ID1(M),PC,ID1(M),CBX,ID1(M),ZC
      GO TO 30
   28 WRITE(IO,5028)
      IF(CBL.GT.BC) CBX=BC
      WRITE(IO,5016)DC,ID1(M),PC,ID1(M),CBX,ID1(M),ZC
   30 WRITE(IO,5017)
```

```
5010 FORMAT(10X,'FOCUS                    D2 =',F7.3,3X,A2)
5012 FORMAT(10X,'1ST DEPTH               DC1 =',F7.3,3X,A2/
   1         10X,'2ND SIDE SLOPE         ZC2 =',F7.3,2X,': 1'/
   2         10X,'2ND DEPTH              DC2 =',F7.3,3X,A2/
   3         10X,'3RD SIDE SLOPE         ZC3 =',F7.3,2X,': 1')
5014 FORMAT(/8X,'THROAT SECTION')
5015 FORMAT(10X,'DIAMETER                 DC =',F7.3,3X,A2/
   1         10X,'SILL HEIGHT             PC =',F7.3,3X,A2/
   2         10X,'BOTTOM WIDTH            BC =',F7.3,3X,A2/
   3         10X,'SIDE SLOPE              ZC =',F7.3,2X,': 1')
5016 FORMAT(10X,'FOCUS                    DC =',F7.3,3X,A2/
   1         10X,'SILL HEIGHT             PC =',F7.3,3X,A2/
   2         10X,'BOTTOM WIDTH            BC =',F7.3,3X,A2/
   3         10X,'SIDE SLOPE              ZC =',F7.3,2X,': 1')
5017 FORMAT(/8X,'TAILWATER CHANNEL')
5018 FORMAT(/5X,'PROFILE DATA')
5019 FORMAT(8X,'LENGTH FROM GAGE TO CONV RAMP    AL =',F7.3,3X,A2/
   1         8X,'CON RAMP LENGTH                  BL =',F7.3,3X,A2/
   1         8X,'THROAT LENGTH                    TL =',F7.3,3X,A2/
   2         8X,'DIV RAMP LENGTH                 *DL =',F7.3,3X,A2/
   3         8X,'LENGTH TO SEC 2                 *EL =',F7.3,3X,A2/
   4         8X,'CON SILL HEIGHT                  P1 =',F7.3,3X,A2/
   5         8X,'CON RAMP SLOPE                  *EN =',F7.3,2X,': 1'/
   6         8X,'DIV SILL HEIGHT                  P2 =',F7.3,3X,A2/
   7         8X,'DIV RAMP SLOPE                   EM =',F7.3,2X,': 1'/
   8        /8X,'MATERIAL ROUGHNESS               RK =',F8.7,2X,A2/)
5020 FORMAT(8X,'LENGTH TO GAUGE          AL =',F7.3,3X,A2/
   1         8X,'CON TRAN RADIUS          RL =',F7.3,3X,A2/
   1         8X,'THROAT LENGTH            TL =',F7.3,3X,A2/
   2         8X,'DIV RAMP LENGTH         *DL =',F7.3,3X,A2/
   3         8X,'LENGTH TO SEC 2         *EL =',F7.3,3X,A2/
   4         8X,'MAXIMUM DEPTH            Y1 =',F7.3,3X,A2/
   6         8X,'BOTTOM DROP              DP =',F7.3,3X,A2/
   7         8X,'DIV RAMP SLOPE           EM =',F7.3,2X,': 1'/
   8        /8X,'MATERIAL ROUGHNESS       RK =',F8.7,2X,A2/)
5021 FORMAT(8X,'SIMPLE TRAPEZOID')
5022 FORMAT(8X,'COMPLEX TRAPEZOID')
5023 FORMAT(8X,'CIRCLE ')
5024 FORMAT(8X,'U - SHAPE ')
5025 FORMAT(8X,'PARABOLA')
5026 FORMAT(8X,'TRAPEZOID IN CIRCLE')
5027 FORMAT(8X,'TRAPEZOID IN U-SHAPE ')
5028 FORMAT(8X,'TRAPEZOID IN PARABOLA')
5029 FORMAT(/8X,'STATIONARY WEIR'/
   1          8X,'---------------')
5030 FORMAT(/8X,'MOVABLE WEIR'/
   1          8X,'------------')
     END
C
C
C     *****************************************************************
C     *                                                               *
C     *  THIS SUBROUTINE PROVIDES A VARIABLE FORMAT FOR THE OUTPUT    *
C     *  DEPENDING ON THE UNITS SYSTEM CHOSEN - FOR RATING TABLE      *
```

```
3011 FORMAT(F12.2,F9.1,2F7.3,F8.4,F9.3,F8.2,F9.2,F7.3)
3012 FORMAT(F12.2,F9.2,2F7.3,F8.4,F9.3,F8.2,F9.2,F7.3)
3013 FORMAT(F12.2,F9.3,2F7.3,F8.4,F9.3,F8.2,F9.2,F7.3)
3014 FORMAT(F12.2,F9.4,2F7.3,F8.4,F9.3,F8.2,F9.2,F7.3)
3015 FORMAT(F12.2,F9.4,2F7.3,F8.4,F9.3,F8.2,F9.2,F7.3)
3016 FORMAT(F12.3,F9.1,2F7.3,F8.4,F9.3,F8.3,F9.3,F7.3)
3017 FORMAT(F12.3,F9.2,2F7.3,F8.4,F9.3,F8.3,F9.3,F7.3)
3018 FORMAT(F12.3,F9.3,2F7.3,F8.4,F9.3,F8.3,F9.3,F7.3)
3019 FORMAT(F12.3,F9.4,2F7.3,F8.4,F9.3,F8.3,F9.3,F7.3)
3020 FORMAT(F12.3,F9.4,2F7.3,F8.4,F9.3,F8.3,F9.3,F7.3)
     END
C
C
C    ****************************************************************
C    *                                                              *
C    *  THIS SUBROUTINE PROVIDES A VARIABLE FORMAT FOR THE OUTPUT   *
C    *  DEPENDING ON THE UNITS SYSTEM CHOSEN - FOR FIELD DATA       *
C    *                                                              *
C    ****************************************************************
C
C
     SUBROUTINE OUTP3(JFE,J01,J02,SH1,QF,QQ,QI,H1L,CD1,CD2,DIFF)
     COMMON/IOUNT/ II,IO,IT,IFL1,IFL2,IFL3,IFL4
     GO TO (100,300,100,500),J01
 100 GO TO (110,120,130,140,110,160,110,130),J02
 110 ASSIGN 3020 TO JFM
     GO TO 888
 120 ASSIGN 3018 TO JFM
     GO TO 888
 130 ASSIGN 3019 TO JFM
     GO TO 888
 140 ASSIGN 3016 TO JFM
     GO TO 888
 160 ASSIGN 3017 TO JFM
     GO TO 888
 300 GO TO (310,320,330,340,310,360,310,330),J02
 310 ASSIGN 3005 TO JFM
     GO TO 888
 320 ASSIGN  3003 TO JFM
     GO TO 888
 330 ASSIGN 3004 TO JFM
     GO TO 888
 340 ASSIGN 3001 TO JFM
     GO TO 888
 360 ASSIGN 3002 TO JFM
     GO TO 888
 500 GO TO (510,520,530,540,510,560,510,530),J02
 510 ASSIGN 3015 TO JFM
     GO TO 888
 520 ASSIGN 3013 TO JFM
     GO TO 888
 530 ASSIGN 3014 TO JFM
     GO TO 888
 540 ASSIGN 3011 TO JFM
```

```
      WRITE(IO,102) A,BB,U
      WRITE(IO,103) R
      WRITE(IO,104) ID1(J01),ID2(J02),ID3(J02),ID4(J02),ID5(J02),
     1ID2(J02),ID3(J02),ID4(J02),ID5(J02),
     2ID2(J02),ID3(J02),ID4(J02),ID5(J02)
      GO TO (100,300,100,500),J01
  100 GO TO (110,120,130,140,110,160,110,130),J02
  110 ASSIGN 3020 TO JFM
      GO TO 888
  120 ASSIGN 3018 TO JFM
      GO TO 888
  130 ASSIGN 3019 TO JFM
      GO TO 888
  140 ASSIGN 3016 TO JFM
      GO TO 888
  160 ASSIGN 3017 TO JFM
      GO TO 888
  300 GO TO (310,320,330,340,310,360,310,330),J02
  310 ASSIGN 3005 TO JFM
      GO TO 888
  320 ASSIGN  3003 TO JFM
      GO TO 888
  330 ASSIGN 3004 TO JFM
      GO TO 888
  340 ASSIGN 3001 TO JFM
      GO TO 888
  360 ASSIGN 3002 TO JFM
      GO TO 888
  500 GO TO (510,520,530,540,510,560,510,530),J02
  510 ASSIGN 3015 TO JFM
      GO TO 888
  520 ASSIGN 3013 TO JFM
      GO TO 888
  530 ASSIGN 3014 TO JFM
      GO TO 888
  540 ASSIGN 3011 TO JFM
      GO TO 888
  560 ASSIGN 3012 TO JFM
888   DO 60 I=1,N
      QC=A*(H(I)+BB)**U
      QE=QC-Q(I)
      QEP=100*QE/Q(I)
      WRITE(IO,JFM) H(I),Q(I),QC,QE,QEP
60    CONTINUE
      RETURN
101   FORMAT(///1X,'DISCHARGE EQUATION',5X,15A2//
     1 5X,'EQUATION  Q = A * (SH1 +B)**U'//
     2 10X,'Q IN ',4A2,'   SH1 IN ',A2/)
102   FORMAT(5X,'COEFFICIENT VALUES'/10X,'A = ',G15.4/
     1 10X,'B = ',G15.4/10X,'U = ',F15.4/)
103   FORMAT(5X,'GOODNESS OF FIT'/
     2 10X,'COEFFICIENT OF DETERMINATION (LN) R2 = ',F6.3/)
104   FORMAT(5X,'DATA'/
     1 8X,'SH1',6X,'Q',5X,'Q(CALC)    ERROR   %ERROR'/
```

```
      WRITE(1,100)
      RETURN
100   FORMAT(1X,'DATA ERROR ON CURVE FIT')
      END
C
C*****************************************************************
C                                                                *
C       FUNCTION ASINH - FOR ARC-HYPERBOLIC SIN                  *
C             DELETE IF AVAILABLE ON FORTRAN COMPILER            *
C                                                                *
C*****************************************************************
C
      FUNCTION ASINH(S)
      ASINH=LOG(S+SQRT(1+S*S))
      RETURN
      END
```

flow.

Then a depth adjustment to account for the maximum negative shift was calculated by subtracting the maximum negative shift from the shift at the time that the current meter measurement was taken. Finally, the maximum downstream depth was calculated by adding the two depth adjustments to the depth at the time of the current meter measurement. This procedure is illustrated in Example 1.

Example 1 - Calculation of Maximum Downstream Depth

Given: From past current meter records, the design flow has been established as 300 cfs and the maximum negative shift as -0.30 ft. The current meter measurement nearest to the design flow had a discharge of 293 cfs, a depth of 3 ft, and a shift of +0.10 ft. From the rating curve, the gage height at 300 cfs is 3.40 ft and at 293 cfs is 3.34 ft.

Wanted: The maximum downstream depth at the design flow

Solution:

1. Calculate the depth correction due to the discharge difference.

   D1 = gage height @ 300 cfs - gage height @ 293 cfs

   = 3.40 - 3.34

   = 0.06 ft

2. Calculate the depth correction due to the maximum shift.

   D2 = actual shift - maximum negative shift

   = 0.10 - (-0.30)

   = 0.40 ft

The Hazen-Williams equation for head loss is

$$Hl = \frac{V^{1.85} * L}{(1.318 * C)^{1.85} * R^{1.17}} + K * \frac{V^2}{2g} \qquad \text{Equation 31.}$$

Assume minor loss coefficients

Entrance	K = 0.50
Exit	K = 1.00
Total	K = 1.50

Solving Equation A2.4 for the velocity by trial and error yields

$V = 7.5$ fps

From continuity

$Q = 7.5 \text{ fps} * 0.049 \text{ ft}^2$

$= \underline{0.37 \text{ cfs}}$

STRUCTURAL STRENGHT OF THE SILL

Assume:

Span length (L) = 5 feet
Depth of water (y) = 3.4 feet
Compressive strength of the concrete (f'c) = 3000 psi
#4 bars on 16 inch centers set 4.5 inches below top of sill
Yield strenth of the steel (f_y) = 40,000 psi
Span is of unit width

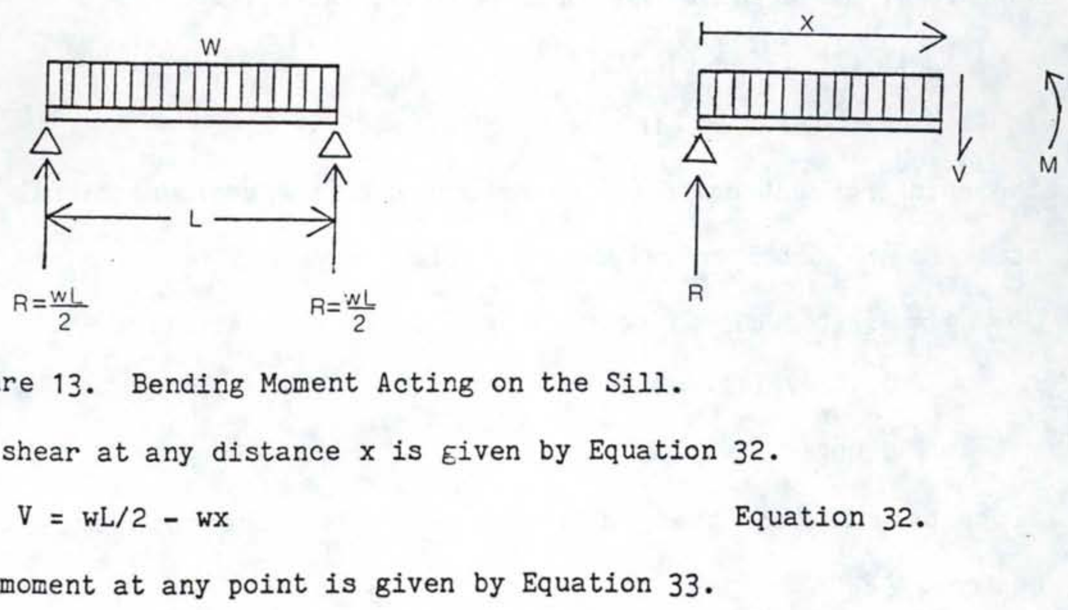

Figure 13. Bending Moment Acting on the Sill.

The shear at any distance x is given by Equation 32.

$$V = wL/2 - wx \qquad \text{Equation 32.}$$

The moment at any point is given by Equation 33.

$$M = \int V dx \qquad \text{Equation 33.}$$

Equation 36.

$$a = \frac{p * fy * d}{0.85 * f'c} \qquad \text{Equation 36.}$$

$$= \frac{0.0027 * 40000 * 4.5}{0.85 * 3000}$$

$$= 0.191 \text{ inches}$$

The distance between the compressive force acting on the concrete and the tensile force action on the steel is given by Equation 37.

$$z = d - a/2 \qquad \text{Equation 37.}$$

$$= 4.5 - 0.191/2$$

$$= 4.4 \text{ inches}$$

Since the beam is underreinforced, the tensile strength of the steel controls. The maximum allowable tensile force is given by Equation 38.

$$N_t = A_s * f_y \qquad \text{Equation 38.}$$

$$= 0.147 * 40000$$

$$= 5880 \text{ lbs.}$$

For equalibrium to be satisfied, the compressive force in the concrete is equal to the tensile force in the steel.

The maximum allowable bending moment is given by Equation 39.

$$M_{allow} = N_t * z \qquad \text{Equation 39.}$$

$$= 5880 * 4.4/12$$

$$= 2156 \text{ lb*ft}$$

Since the maximum allowable bending moment is more than the maximum bending moment (2156 v. 656 lb*ft), the steel requirement is sufficient.

QUANTITY OF STEEL REQUIRED FOR AN AVERAGE SIZE DEVICE

The structure that was designed for the Sunnydell canal was analyzed because it was average sized. It would require 31 cubic yards of con-

Converging Ramp Length	BL = 4 ft
Throat Length	TL = 4 ft
Converging Sill Height	P1 = 2 ft
Diverging Sill Height	P2 = 2 ft
Diverging Ramp Slope	EM = 0 : 1
Material Roughness Height	RK = varies

Rating Table for RK = 0.007 ft

SH1 FT	Q CFS	FR1	H1/TL	CD	CV	DH FT	Y2-P2 FT	MODULAR LIMIT
.800	43.4847	.082	.202	.9660	1.018	.214	.585	.736
1.200	81.8926	.126	.307	.9764	1.033	.270	.926	.780
1.600	128.6794	.166	.413	.9820	1.049	.310	1.282	.812

Rating Table for RK = 0.0007 ft

SH1 FT	Q CFS	FR1	H1/TL	CD	CV	DH FT	Y2-P2 FT	MODULAR LIMIT
.800	44.0042	.083	.202	.9776	1.019	.211	.588	.740
1.200	82.6214	.127	.307	.9851	1.034	.265	.930	.784
1.600	129.5843	.167	.413	.9889	1.050	.305	1.287	.815

Rating Table for RK = 0.00007 ft

SH1 FT	Q CFS	FR1	H1/TL	CD	CV	DH FT	Y2-P2 FT	MODULAR LIMIT
.800	44.1932	.083	.203	.9818	1.019	.210	.589	.741
1.200	82.8886	.128	.307	.9882	1.034	.264	.932	.785
1.600	129.9335	.168	.413	.9916	1.050	.303	1.289	.817

Using a sill referenced head equal to 1.60 ft

$$\% \text{ difference } 0.007 - 0.0007 = \frac{128.68 - 129.58}{129.58} * 100$$

$$= -0.70 \%$$

$$\% \text{ difference } 0.0007 - 0.00007 = \frac{129.93 - 129.58}{129.58} * 100$$

$$= 0.27 \%$$

1.200	82.5481	.127	.307	.9842	1.034	.266	.930	.783
1.600	129.4952	.167	.413	.9882	1.049	.306	1.286	.815

Using a sill referenced head equal to 1.60 ft,

$$\% \text{ difference } 2 - 3 = \frac{129.50 - 129.58}{129.58} * 100$$

$$= -0.06 \%$$

THEORETICAL EFFECTS OF MOSS

The following weir dimensional data was assumed for when there was no moss.

Cross Section Data

Approach Channel

Bottom Width B1 = 20 ft

Side Slope Z1 = 0 : 1

Throat Section

Bottom Width BC = 20 ft

Side Slope ZC = 0 : 1

Tailwater Channel

Bottom Width B2 = 20 ft

Side Slope Z2 = 0 : 1

Profile Data

Length from Gage to Conv. Ramp AL = 4 ft

Converging Ramp Length BL = 4 ft

Throat Length TL = 4 ft

Converging Sill Height P1 = 2 ft

Diverging Sill Height P2 = 2 ft

Diverging Ramp Slope EM = 0 : 1

Material Roughness Height RK = 0.0007 ft

Using a sill referenced head of 1.60 ft,

$$\% \text{ difference} = \frac{129.25 - 129.58}{129.58} * 100$$

$$= -0.25 \%$$

To study the effects of effectively lowering the gage because of moss build up, several canals rating tables were studied as to their sensitivity to a 1/4 inch change in gage height (Table 27).

Table 27. Theoretical Effect of Moss.

Canal	Flow Nearest to Design Flow	Flow at 0.02' Higher Gage Reading	% Difference in Flow
Great Western	671.6	678.2	0.98
Eagle Rock	599.9	605.5	0.93
Island	250.4	253.5	1.24
Clark and Edwards	105.5	107.1	1.52

SENSITIVITY OF TWIN GROVES RATING TABLE TO B1, Z1, B2, AND Z2

The following weir dimensional data was used to determine the sensitivity of the Twin Groves rating table to errors in estimating B1, Z1, B2, and Z2.

Cross Section Data

Approach Channel

Bottom Width B1 = varies

Side Slope Z1 = varies

Throat Section

Bottom Width BC = 20.1 ft

Side Slope ZC = 0 : 1

Tailwater Channel

Bottom Width B2 = varies

Side Slope Z2 = varies

Profile Data

Length From Gage To Conv Ramp AL = 14.3 ft

1.900	172.7460	.242	.642	.9935	1.072	.292	1.590	.853
2.000	187.1744	.251	.677	.9942	1.075	.299	1.679	.858
2.100	202.0171	.258	.712	.9946	1.078	.306	1.770	.861

Case 5 Rating Table for Twin Groves B1=20, Z1=1.5, B2=20, Z2=1

SH1 FT	Q CFS	FR1	H1/TL	CD	CV	DH FT	Y2-P2 FT	MODULAR LIMIT
1.900	169.2590	.206	.633	.9932	1.050	.320	1.552	.837
2.000	183.1954	.213	.667	.9937	1.052	.329	1.640	.841
2.100	197.5066	.219	.701	.9941	1.054	.338	1.728	.844

Case 6 Rating Table for Twin Groves B1=18, Z1=1.5, B2=20, Z2=1

SH1 FT	Q CFS	FR1	H1/TL	CD	CV	DH FT	Y2-P2 FT	MODULAR LIMIT
1.900	170.8924	.228	.637	.9935	1.060	.321	1.563	.837
2.000	185.0140	.235	.672	.9939	1.062	.331	1.651	.841
2.100	199.5300	.242	.706	.9943	1.065	.340	1.740	.845

Case 7 Rating Table for Twin Groves B1=22, Z1=1.5, B2=20, Z2=1

SH1 FT	Q CFS	FR1	H1/TL	CD	CV	DH FT	Y2-P2 FT	MODULAR LIMIT
1.900	168.0144	.188	.630	.9930	1.042	.319	1.544	.837
2.000	181.8022	.194	.664	.9935	1.044	.328	1.632	.841
2.100	195.9647	.200	.698	.9939	1.045	.337	1.719	.844

Assume that B1 = B2 = 20 ft, Z1 = Z2 = 1:1, and the sill referenced head = 2.00 ft as a reference.

% Difference between the reference and Case 1 $= \frac{184.77 - 184.77}{184.77} * 100$

$= 0.00\%$

% Difference between the reference and Case 2 $= \frac{187.17 - 184.77}{184.77} * 100$

$= 1.30\%$

% Difference between the reference and Case 3 $= \frac{185.97 - 184.77}{184.77} * 100$

$= 0.65\%$

% Difference between the reference and Case 4 $= \frac{187.17 - 184.77}{184.77} * 100$

$= 1.30\%$

Converging Sill Height	P1 = varies
Diverging Sill Height	P2 = varies
Diverging Ramp Slope	EM = 0 : 1
Material Roughness Height	RK = 0.0007 ft

Rating Table for P1 = 1.51 and P2 = 1.49 ft

SH1 FT	Q CFS	FR1	H1/TL	CD	CV	DH FT	Y2-P2 FT	MODULAR LIMIT
2.600	459.4293	.303	.565	.9946	1.115	.389	2.261	.861

Rating Table for P1 = 1.51 and P2 = 1.51 ft

SH1 FT	Q CFS	FR1	H1/TL	CD	CV	DH FT	Y2-P2 FT	MODULAR LIMIT
2.600	459.4287	.303	.565	.9946	1.115	.412	2.213	.853

<u>CONCRETE REQUIREMENTS FOR RBC WEIRS</u>

Great Western

floor	= 32 * 30 * 0.5	= 480 cu. ft.
walls	= 6 * 30 * 0.67 * 2	= 241
cut-off walls	= 3 * 32 * 0.5 * 2	= 96
wing walls	= 6 * 6 * 0.67 * 4	= 96
ramp	= 3.4 * 32 * 0.5	= 55
sill	= 5 * 32 * 0.5	= 80
sill supports	= 1.5 * 32 * 0.5 * 2	= 48
	total	= 1072 cu. ft. = 39.7 cu. yds.

Eagle Rock

floor	= 30 * 30 * 0.5	= 450 cu. ft.
walls	= 30 * 8 * 0.67 * 2	= 323
cut-off walls	= 30 * 3 * 0.5 * 2	= 90
wing walls	= 6 * 8 * 0.67 * 4	= 129
ramp	= 6.7 * 30 * 0.5	= 101
sill	= 5 * 30 * 0.5	= 75
sill supports	= 3 * 30 * 0.5 * 2	= 90
	total	= 1258 cu. ft. = 46.6 cu. yds.

Danskin

floor	= 20.5 * 25 * 0.5	= 256 cu. ft.
walls	= 20.5 * 7 * 0.5 * 2	= 144
cut-off walls	= 25 * 3 * 0.5 * 2	= 75
wing walls	= 3 * 7 * 0.5 * 4	= 42
ramp	= 9 * 25 * 0.5	= 113
sill	= 3.5 * 25 * 0.5	= 44

total = 171.6 cu. ft. = 6.4 cu. yds.

15-foot throat

<u>floor</u>		
approach	= 25 * 3 * 0.5	= 37.5 cu. ft.
conv. trans.	= 20 * 25 * 0.5	= 250
throat	= 15 * 4 * 0.5	= 30
div. trans.	= 16.67 * 10 * 0.5	= 83.3
<u>walls</u>		
cut-off	= 25 * 3 * 0.5 * 2	= 75
approach	= 4 * 6 * 0.5 * 2	= 24
conv. trans.	= 25 * 6 * 0.5 * 2	= 150
throat	= 4 * 7 * 0.5 * 2	= 28
div. trans.	= 10 * 7 * 0.5 * 2	= 70
d.s. wing	= 3 * 6 * 0.5 * 2	= <u>18</u>
		total = 765.8 cu. ft. = 28.4 cu. yds.

25-foot throat

<u>floor</u>		
approach	= 35 * 3 * 0.5	= 52.5 cu. ft.
conv. trans.	= 30 * 25 * 0.5	= 375
throat	= 25 * 6 * 0.5	= 75
div. trans.	= 27.15 * 13 * 0.5	= 176.5
<u>walls</u>		
cut-off	= 35 * 3 * 0.5 * 2	= 105
approach	= 4 * 7 * 0.5 * 2	= 28
conv. trans.	= 25 * 7 * 0.5 * 2	= 175
throat	= 6 * 8 * 0.5 * 2	= 48
div. trans.	= 13 * 8 * 0.5 * 2	= 104
d.s. wing	= 3 * 7 * 0.5 * 2	= <u>21</u>
		total = 1160 cu. ft. = 43.0 cu. yds.

<u>INTEREST RATE WITHOUT INFLATION</u>

Equation 40 was obtained from reference [20].

$$i = i' + f + i' * f \qquad \text{Equation 40.}$$

where, i = interest rate
f = inflation rate
i' = interest rate without inflation

$i = 10\%$
$f = 3\%$

Substituting i and f into Equation 40 yields

$$0.10 = i' + 0.03 + 0.03i'$$

= 17760 * 0.0806
= $1431/yr

annual maintenance cost = $17760 * 3%
= $533/yr

total annual cost of an average Parshall flume = $1964/yr

CURRENT METERING COSTS

cost data

salary = $1540/month
current meter 6 months per year
responsible for 76 canals
vehicle mileage = 9000 miles/year
mileage cost = $0.22/mile
current meter equipment cost = $1200

assume: the cost of vehicle operation and salary increase at the inflation rate

annual salary cost / canal = $1540/mo. * 6 mo. / 76 canals
= $121

annual vehicle cost / canal = 9000 miles/yr * $0.22/mile / 76 canals
= $26

annual current meter equipment cost per canal = $1200(A/P,7%,30)/76
= 1200 * 0.0806 / 76
= $1

annual current meter maintenance cost per canal
= $1200 * 5% * (A/P,7%,30)/76 canals
= 60 * 0.0806 / 76
= $ 0.06

total annual current metering cost / canal = $148