# LONG CRESTED WEIR DESIGN

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## INTRODUCTION

The need for flexible irrigation water deliveries in order to efficiently meet the changing demands for irrigation water created by farm management practices, variable soil intake rate, and crop evapotranspiration (Merriam (6)). As the flexibility of irrigation water deliveries increases so does the variability of the canal flow rates. Measurements of delivery flow rates on a canal system with flexible water deliveries indicate that approximately 67% of the hourly flow rate measurements taken during the "steady" flow portion of the delivery ranged from 4 to 29% of the average flow rate (Clemmens and Dedrick (3)).

Each time the flow in the canal is modified to meet changes in demand at some point along the system all intervening turnouts and check structures between the head of the canal and the location of the required change should be re-regulated to insure that: 1) flow through individual turnout flow rates remains relatively constant, and 2) the flow rate modification can be accomplished at the desired downstream location.

It is important for the water user to have flexibility in frequency, rate and duration of water deliveries, but once the flow rate has been selected and turned out to the farm it should remain relatively constant until the user needs to change flow rate. Constant flow rates require less labor on the farm, allows more uniform application of water, and minimizes the need to spill a portion of the delivered water. Surface irrigation systems forced to use variable flow rates during the irrigation set cause variations in the advance time, which will reduce the uniformity of infiltration. Irrigators using siphon tubes with water supplies that have variable flow rates will spill a portion of the delivered water in anticipation of the flow rate falling during the "set". This water is spilled over temporary check dams used to raise the water surface in the delivery ditch above the field level. The flow rate can fall by the amount of water being spilled before the flow through the siphon tube will be significantly affected. If the flow rate should increase, the excess will be spilled in the same way. Some of the water delivered to the farm is spilled either in anticipation of a decrease in flow rate or as a result of an increase in the flow rate. These losses and additional labor required to control the water on the farm can be minimized by reducing the variability of the flow rate through canal turnouts. This can be accomplished with additional labor to regulate canal turnouts and check structures or by reducing the magnitude of the variations in head in the canal system and reducing the sensitivity of the turnout to changes in head.

### Canals and Turnout Controls

The ideal combination of a canal weir or check structure and the canal turnout would accommodate large flow rate changes in the canal, as much as 40 to 50% and the same time result in very small flow rate changes through the turnout. The objective would be to keep the turnout flow rate change so small that re-regulation of the turnout is not necessary.

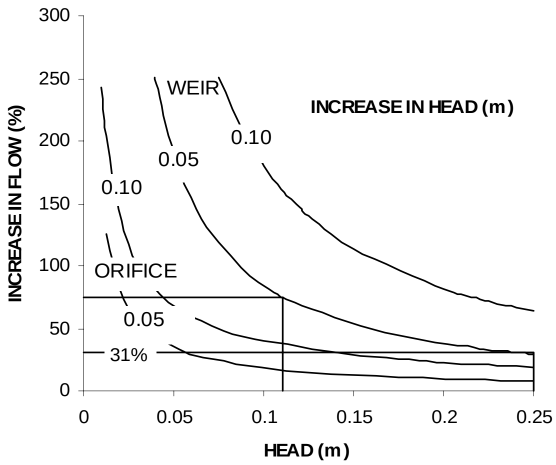



**FIG. 1. Increase in Flow with Weirs and Orifices resulting From an Incremental Increase in Head (m)**

The effects of head on weirs and orifices are demonstrated in Figure 1. If a weir has an initial or starting head of 0.11 m and the head increased by 0.05 m the flow rate would increase by nearly 75%. The same 0.05 m increase in head would result in a 31% increase in flow if the initial head was 0.25 m.

A similar illustration can be made using submerged orifice turnout, except an initial head of 0.11 m and the head increased by 0.05 m the flow rate would increase by nearly 75%. The same 0.05-m increase in head would result in a 31% increase in flow if the initial head was 0.25 m.

A similar illustration can be made using submerged orifice turnout, except an initial head of 0.11 m and an increase in head of 0.05 m will result in an increase in flow rate of only 21%. If the initial head was 0.25 m and was increased by 0.05 m it would result in an increase in flow of less than 10%. This example indicates that variation in turnout flow rate can be minimized by using: a) an orifice turnout, b) a head on the turnout that is as large as possible, and c) a head on the canal weir that is small compared to the head that is on the turnout. Using small heads on the canal weir combined with large flow rates will increase the required weir crest length. In many typical installations the canal weir length is nearly equal to the width of the canal. Increasing the length beyond the canal width requires the use of long crested weirs.

## Long Crested Weirs

The concept of a long crested weir is simple: provide more weir length than is possible with typical weirs, which are installed across the canal with the crest perpendicular to the centerline of the canal. The additional weir length makes it possible to pass the design flow rate with smaller heads. From an operations point view this means that large changes in flow rate over the long crested weir will result in smaller changes in head and small changes in flow into the lateral or farm turnouts upstream of the weir. Long crested weirs are used to control the water surface elevation and are not intended to be used for flow measurement.

Long crested weirs have been used in many different applications in water resource development within the United States but have not been used to any great extent in the canals used to distribute irrigation water. The Bureau of Reclamation (3) has developed design procedures for side outlet spillways, bathtub spillways, morning glory spillways, and side outlet waste ways for canal systems (1). The names are descriptive of the shapes used in the design of these structures. All of these applications of the long crested weirs have one feature in common: The weir length has been expanded to allow the safe passage of a large flow rate with relatively small increase in water surface elevation upstream of the structure.

Hay and Taylor (4) have developed design and performance criteria for labyrinth long crested weirs used in spillway design. They describe the spillway on the Beni Bahdel Dam in Algeria which uses a labyrinth weir with a total length of 1200 m in a channel width of only 80 m. Kraatz and Mahajan (5) describe design procedures for diagonal, duckbill, and Z type weirs. This group of weirs is used in small canal distribution systems in the Mediterranean region from Spain to Cyprus and North Africa. A typical installation is shown in Figure 2. This particular weir is part of a delivery system in Relizione, Algeria. Plan views of typical diagonal and duckbill weirs are shown in Figure 3.

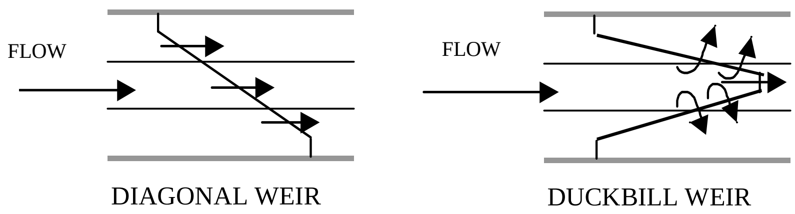



**FIG. 2. Plan View of a Diagonal Weir and a Duckbill Weir.**

The "Z-type" not shown is the combination of two or more duckbill weirs set side by side in the channel. The selection of a single duckbill or Z-type seems to be based on design preference and/or construction limitations established by the site configuration, construction techniques, and materials.

**Long Crested Weir Design Considerations**

There are two basic considerations in designing a long crested weir: 1) The turnout head to the canal weir head ratio ($H_{to}/H_c$) should be maximized within the practical limits of each installation, and 2) The structure should be configured to obtain maximum performance from the expanded weir length.

Most of the work done with long crested weirs seems to have concentrated on establishing the geometry of the weir with very little consideration integrating the design of the long crested weir with the design of the farm turnout. The proper combination of weir length and head ratios ($H_{to}/H_c$) can keep flow variation through the turnout below a system's ability to measure those changes.

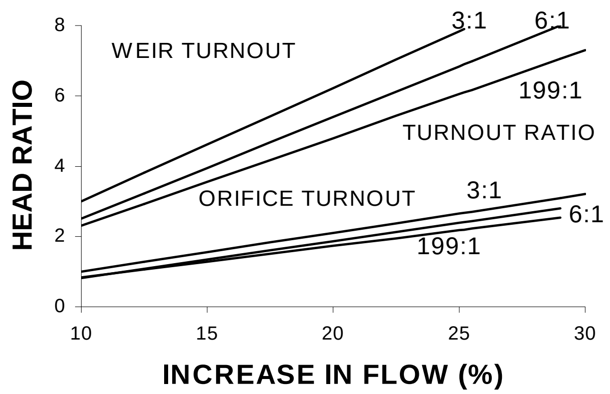



**FIG. 3. Required Head Ratio ($H_{to}/H_c$): to Limit Turnout Flow Increase to 4%**

The relationships illustrated in Figure 4 could be used by designers to estimate the required heat ratio to keep the flow variation through a turnout within acceptable limits. A minimum head ratio of 1.8 (from figure 4) with an orifice turnout and a turnout ratio of 199:1 would keep the turnout flow rate variations within 4% while at the same time the canal flow rate could increase by up to 20%. The turnout ratio is defined as the ratio of the flow rate passing over the canal weir compared to the flow rate passing through the turnout. If the weir turnout is used, the required head ratio ($H_{to}/H_c$) would need to be approximately 4.9 to maintain the same level of control as an orifice turnout. Practical and/or physical constraints may prevent the construction of the weir and turnout with the ideal head ratio, but the ratio should be made as large as possible to reduce the sensitivity to the changes in head.

**Diagonal Weirs**: The following guidelines for establishing the configuration (geometry) of a long crested weir are based on the work done with labyrinth weirs by Hay and Taylor (4). The work by Hay and Taylor compares the performance of the long crested weir to the normal weir length or flow rate. In this way all work is referenced to the performance of the normal sharp crested weir installed normal to the centerline of the canal.

### Sediment Deposits

Long crested weirs are effective sediment traps. If the irrigation water carries a significant amount of sediment, the weir should be installed with sluice gates for the removal of the deposition behind the weir. If sediment is allowed to accumulate behind the weir, the head requirements are increased and the available freeboard is reduced. To simplify the sluicing of sediment, the duckbill should be installed facing downstream as shown in Figure 3. If a gate is installed in the face of the duckbill some allowance should be made for any interference with the hydraulic performance of the structure. If the gate is to be left open during normal operations, the design flow rate for the long crested weir can be reduced by the amount of water passing through the sluice gate.

### Flow Rate (Q)

The flow rate ($m^3/s$) over a diagonal weir can be calculated using Eq. 1, where C is a coefficient for the type of weir crest, L is the effective weir length defined by Eq. 3, and H is the height of water above the weir crest, assuming the velocity of the water as it approaches the weir is negligible.

$$Q = CLH^{3/2} \tag{1}$$

The coefficient at 1.85 can be connected to English units for flow on Diagonal weir – 3.0.

$$Q = 3.0(Ln - 0.2H)H^{3/2} \tag{2}$$

The effective length ($L_e$) of the weir is defined by Eq. 3 shown below:

$$L_e = L_n - 0.2H \tag{3}$$

Where ($L_n$) is the actual length of the weir, normal to the centerline of the canal.

### Weir Crest Coefficient (C)

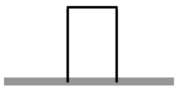
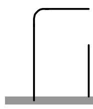
Selecting the correct weir coefficient is difficult. The coefficient changes with head on the weir. Equation 3 illustrates the effects of head on a weir coefficient for a well aerated sharp crested weir.

$$C_w = 1.778 + \left[\frac{H_w}{W_h}\right] \tag{4}$$

For practical purposes, the coefficient can be estimated as 1.85.

Special case: When the head on the weir is less than about two times the breadth of the weir section it begins to function like a broad crested weir. Kraatz and Mahajan (5) suggest that the coefficient for broad crested weirs ranges between 1.5 to 1.6 $m^3/s$. Listed in Table 1 are coefficients for two weir section shapes and three types of long crested weirs, (i.e., diagonal, duckbill, of Z type) suggested by Kraatz and Mahajan (5).

**Table 1. Weir Coefficients from Kraatz and Mahajan (5)**
These are metric coefficients.

| WEIR SECTION | WEIR TYPE | | |
|---|---|---|---|
| | DIAGONAL | DUCKBILL | Z TYPE |
|  | 1.50 | 1.42 | 1.37 |
|  ROUNDED UPSTREAM | 1.68 | 1.59 | 1.50 |

The long crested weirs are used to control the water surface elevation and are not intended to be used for flow measurement. As a result, it is not critical to know the exact value of the weir coefficient. Once a weir section, weir coefficient and length have been selected, the design can be tested to determine the possible effects of the uncertainties about the weir coefficient. This information can then be used to increase in the length of the weir or modify freeboard requirements.

Normal Weir Length ($L_n$)- In rectangular channel sections the maximum length for a typical contracted weir should be the width of the channel minus four times the head on the weir. For a trapezoidal channel section as shown in Figure 5, the normal length should be limited to that portion of the width where the weir head to weir height ratio ($H/W_h$) can be kept below 0.5.

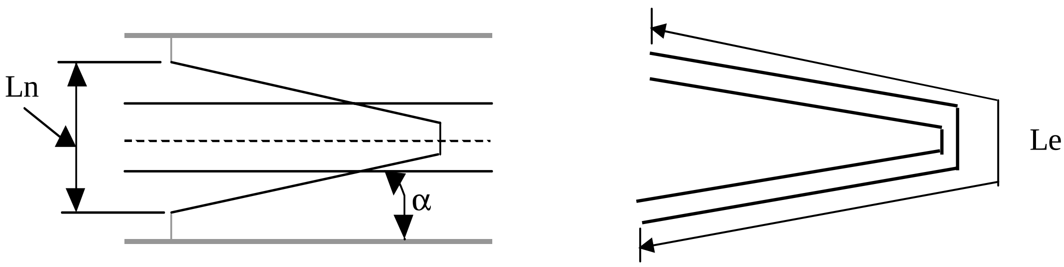



**FIG. 4. Plan View of Duckbill Weir.**

**Weir Head (H)**

Generally the head should be as small as possible to improve performance of the weir. The ratio of normal weir length to the weir head ($L_n$/H) must be 2.0 or larger in order to minimize nappe interference.

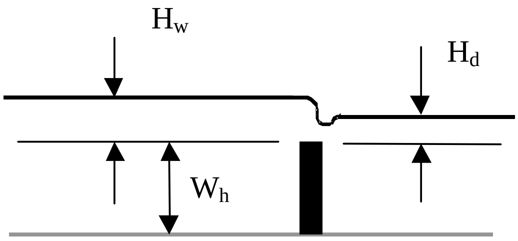



**FIG. 5. Elevation View of Weir and Channel Section**

**Weir Height ($W_h$)**

The ratio of weir head to weir height ($H/W_h$) should be 0.5 or less. For weirs installed in trapezoidal channels this ratio may vary from something much smaller than 0.5 in the center of the channel to values greater than one at the very edge of the weir where the side wall of the canal slopes up toward the weir crest. Ignoring the effects of the floor elevation will result in an over estimation of the flow rate for a given head.

**Long Crested Weir Length ($L_e$)**

Very little increase in weir capacity is obtained when the length of the duckbill long crested weir is greater than eight times the normal weir length ($Le = 8 \xi L_n$). When the weir head to weir height ratio ($H/W_h$) is greater than 0.25 the length should be limited to approximately six times the normal weir length ($Le = 6 \xi L_n$). The required expanded weir length is a function of the design flow rate ($Q_d$), the weir head to weir height ratio and the weir coefficient. Table 2 shown below is based on work done by Hay and Taylor (4), accounts for the effects of the weir head to weir height ratio ($H/W_h$). If the actual weir section is not a sharp crested weir, the length must be modified for the selected weir section.

**Table 2. Weir Length Ratio Wr = ($L_e/L_n$)**

| Weir Length Ratio (Le/Ln) | | | | | |
|---|---|---|---|---|---|
| Lw/Ln | Ratio of weir Head to Weir Height | | | | |
| | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
| 1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 2 | 2.00 | 2.00 | 2.00 | 2.10 | 2.20 |
| 3 | 3.00 | 3.05 | 3.15 | 3.33 | 3.50 |
| 4 | 4.00 | 4.10 | 4.33 | 4.65 | 5.90 |
| 5 | 5.05 | 5.26 | 5.77 | 7.99 | - |
| 6 | 6.09 | 6.71 | 8.20 | - | - |
| 7 | 7.22 | 8.10 | - | - | - |
| 8 | 8.30 | - | - | - | - |

The required weir length ($L_e$) can be computed using Eq. 5 and the normal weir length ratio ($W_r$) obtained from Table 1 and the appropriate weir coefficient for both the normal sharp crested weir ($C_s$) and for the actual weir crest section ($C_d$) use for the long crested weir.

$$\mathrm{Le} = \mathrm{Ln}\frac{\mathrm{Cs}}{\mathrm{Cd}}\mathrm{W}r \qquad (5)$$

**Weir Angle (%)**

The angle α is formed between the major segment of the long crested weir with the sides of the canal and is shown in Figure 5. This angle should be as large as possible. The minimum value of the angle α can be estimated using Eq. 6 shown below:

$$\alpha = 0.75 \mathrm{Sin}^{-1}\left[\frac{\mathrm{Ln}}{\mathrm{Le}}\right] \quad (6)$$

The angle ∀can range from zero to 90 degrees but should not be smaller than the value computed with Eq. 6. The performance of the weir improves as the angle α approaches 90 degrees. As α gets smaller a larger portion of the flow must essentially make a 90-degree turn before passing over the weir which decreases the effectiveness of the expanded weir crest length.

**Submergence ($Q_{Sub}$)**

The capacity must be derated to submergence. The lower flow rate calculated could be applied to either the diagonal or the duckbill weir. The possibility of submergence should be evaluated. If the weir should become submerged at some point in the operation, advantages gained by installing the long crested weir could be significantly diminished by higher head requirement as well as unstable flow conditions. The submerged flow rate can be computed using Eq. 7 shown below, where H is the weir on the head and $H_d$ is the height of the downstream water above the weir crest. The definitions of H and $H_d$ are shown in Figure 6.

$$\mathrm{Qsub} = \mathrm{Q}\left[1 - \left(\frac{\mathrm{Hd}}{\mathrm{H}}\right)^{1.5}\right]^{0.385} \quad (7)$$

**Design Steps for Duckbill Long Crested Weir**

*It should be emphasized that design criteria are not exact, as there have been conflicting laboratory data for Long Crested Weirs. Also, details such as the weir wall thickness and the shape of the boundaries are very important. Nevertheless, this procedure will provide approximate design criteria. Once should always install a prototype and evaluate its performance before duplicating the design.*

Design Steps – The design of a long crested weir for water surface control should minimize the flow variation through the turnout by maximizing the head on the turnout and minimizing the head on the canal weir. Minimizing the head on a weir maximizes the length of weir required to pass a given flow rate. The final design configuration should fall within the limits discussed in "Design Considerations."

1) **Maximizing Allowable Water Height** – Establishing the maximum allowable water surface elevation upstream from the weir maybe as simple as subtracting a reasonable allowance for freeboard from the total depth of the canal at that location or it may require an analysis of the backwater curve created by the weir and the effects it may have on the upstream structures.

2) **Minimum Weir Height** – The minimum weir height can be controlled by one of the following considerations: The first is the minimum head required by the turnout at that location. During low canal flows it is important that the canal weir be high enough to allow the turnout to operate properly. The second consideration for selecting the minimum weir crest height has to do with the height of water on the downstream side of the weir. If possible the weir should be set high enough to eliminate the chance of submergence.

3) **Maximum Weir Head** – This is the difference between the maximum water surface and the minimum weir height. For small systems it may be necessary to check the ratio of the normal weir length ($L_n$) to the weir head (H). If the ratio of the normal weir length ($L_n$) to the weir head (H). If the ratio of ($L_n$/H) is less than two then the weir height should be raised to increase the weir length to head ratio.

4) **Minimum Weir Head** – The minimum head is a function of the maximum duckbill weir length, which can be estimate using a expanded weir length ratio of 6.0 (a ratio of 8 might be used where $H/W_h$ ratio is less than 0.25). When $L_e/L_n$ = 6.0, the maximum weir length is approximately 6 times the normal weir length $L_n$. The minimum head can be computed using Eq. 1, the maximum flow rate, and an estimate of the weir coefficient.

5) **Required Weir Length –** The selected design head must be between the limits set in steps 3 and 4. The final selection of the expanded weir length (Le) should be made on the basis of the cost of the structure and the degree of control provided by the expanded weir. The maximum head will tend to minimize the weir length and the cost of the structure. The minimum weir head will maximize the weir length and the cost of the structure. The minimum weir head will maximize the weir length and cost but will also minimize the variation of head at the structure for a given range of flow rates. The following steps should be completed for both the maximum and minimum weir heads:

   a. Using Eq. 1 compute the capacity of a normal sharp crested weir installed with its axis perpendicular to the centerline of the canal. If submergence is a problem then the estimate of the normal weir flow should be modified using Eq. 3.
   b. Compute the ratio of the design flow rate to the normal weir capacity ($Q_d/Q_n$).
   c. Compute the ratio of weir height to weir head ($H/W_h$).
   d. Using the results flow ratio ($Q_d/Q_n$) and the weir head to weir height ratio ($H/W_h$) obtain the required weir length ratio ($W_r$) from Table 2.
   e. Compute the ratio of weir crest coefficients, the crest coefficient for the weir section that will be used to the sharp crested coefficient ($C_s/C_d$).
   f. Compute the required expanded weir length ($L_e$) for the long crested weir using Eq. 4.

## Conclusion

Integration of the design of the turnout with long crested weirs can result in turnouts that are relatively insensitive to changes in the canal flow. This result in more stable flow to the farm, reducing the labor rewired on the farm to control the water and at the same time allows more uniform application of the water. If the turnouts and check structures do not have to be re-regulated each time there is a change in flow rate, it will take less labor to operate the system. Greater flexibility in water deliveries can be accommodated with less labor.

## APPENDIX I. REFERENCES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## APPENDIX II. NOTATION

The following symbols are used in this paper:

$C$ = weir coefficient, $m^5/s$;

$C_d$ = weir coefficient used for long crested weir, $m^5/s$;

$C_s$ = Sharp crested wier coefficient, $m^5/s$;

$H$ = head, height of water above weir crest; m;

$H_c$ = head of canal weir, height of water above weir crest, m;

$H_d$ = height of water above weir crest on downstram side, m;

$H_{to}$ = head on canal turnout, height of water above turnout, m;

$L_e$ = effective length of weir crest; m

$L_n$ = length of weir installed with its crest perpendicular to the center line of the canal, m;

$Q$ = flow rate, $m^3/s$;

$Q_d$ = design flow rate, $m^3/s$;

$Q_n$ = flow rate of a normal weir installed with its crest perpendicular to the center line of the canal, $m^3/s$;

$Q_{Sub}$ = flow rate of a submerged weir, $m^3/s$;

$W_h$ = height of weir crest above canal floor, m;

$W_r$ = ratio of long crested weir length and normal weir length;

$\alpha$ = the angle formed by the canal sides and the major segment of the long crested weir, deg.;