Weirs

Lecture on Sharp- and Broad-crested Weirs

Thank you to Monica Prycel, Erick Ritter, and Chris Roberts

Background

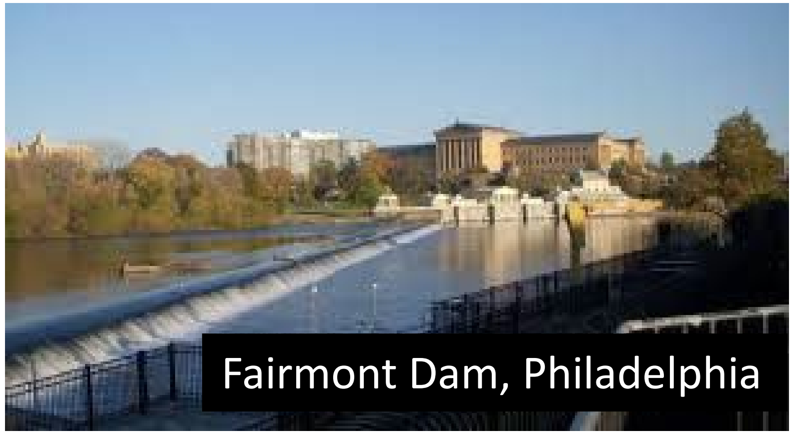
- Weirs are overflow structures that alter the flow so that:

1. Volumetric flow rate can be calculated,
2. Flooding can be prevented, or
3. Make a body of water more navigable

- There are numerous types of weirs that have one or more of the functions listed above

Background


Stream level Control Weir


Fairmont Dam, Philadelphia


Canal Level Control Weir

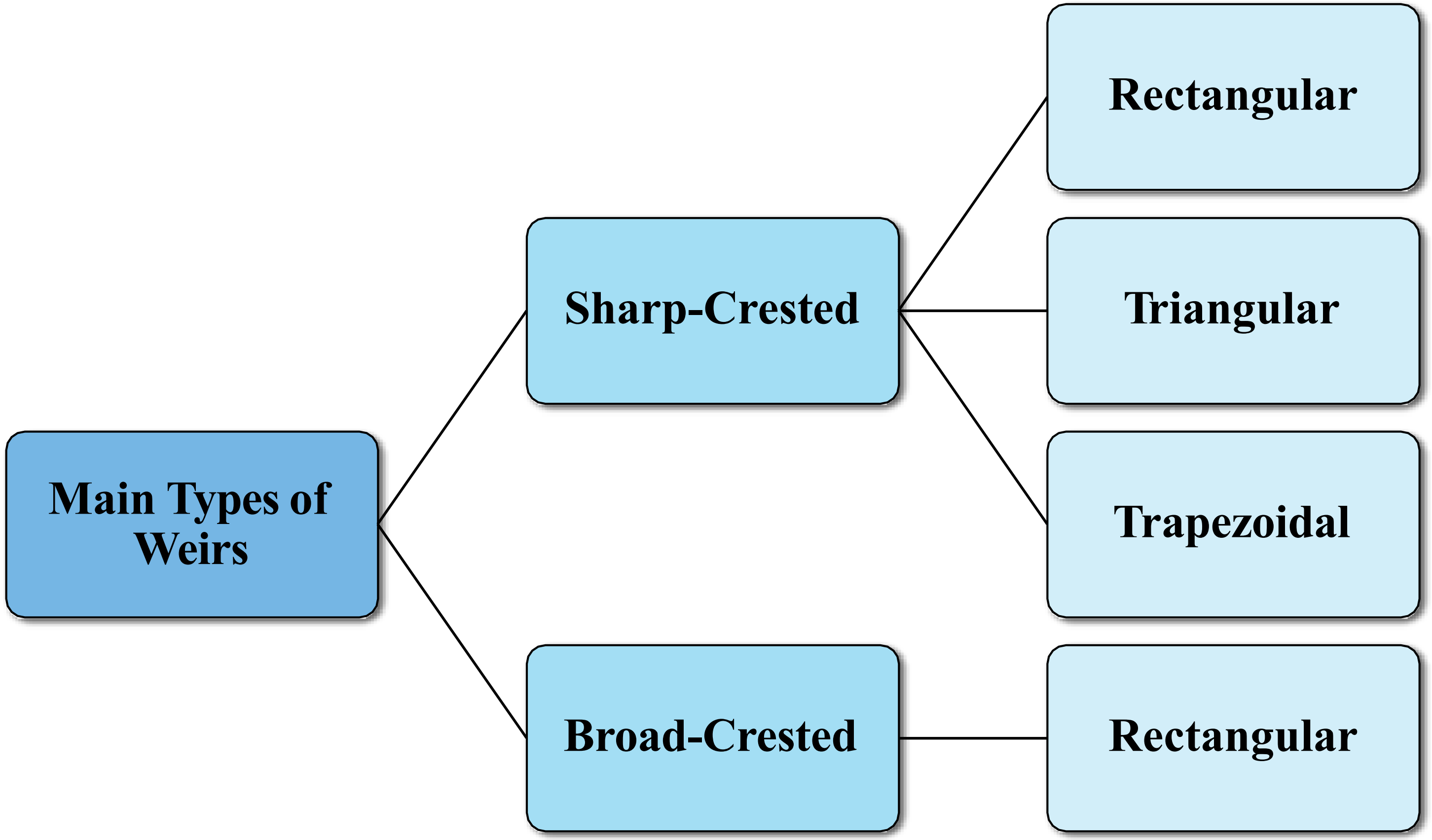

South Holston Dam, TN


Diversion Weir

Background

https://www.youtube.com/watch?v=YkR79oDAgOg

Types of Weirs



Sharp- vs. Broad-Crested Weirs

SHARP-CRESTED WEIR

- Critical depth (y_c) occurs off the crest of the weir
- Usually used to:

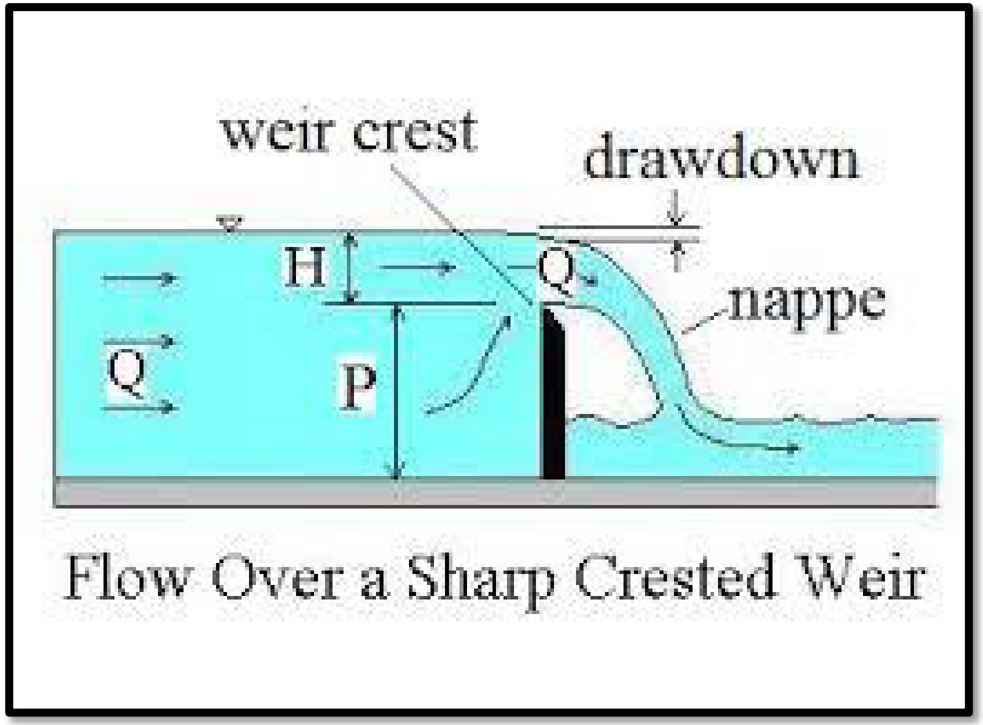
1. Measure the discharge of smaller rivers and canals
2. Change water elevation of smaller rivers and canals

BROAD-CRESTED WEIR

- Critical depth (y_c) occurs at the crest of the weir
- Usually used to:

1. Measure the discharge of larger rivers and canals
2. Change water elevation of larger rivers and canals

Sharp-Crested Weirs



Sharp-Crested Weir Background

- There are three main types of sharp-crested weirs:

1. Rectangular—Measure Discharge and Change Water Elevations

2. Triangular—Measure Discharge (shown in previous slide)

3. Trapezoidal—Measure Discharge and Change Water Elevations with Large Head

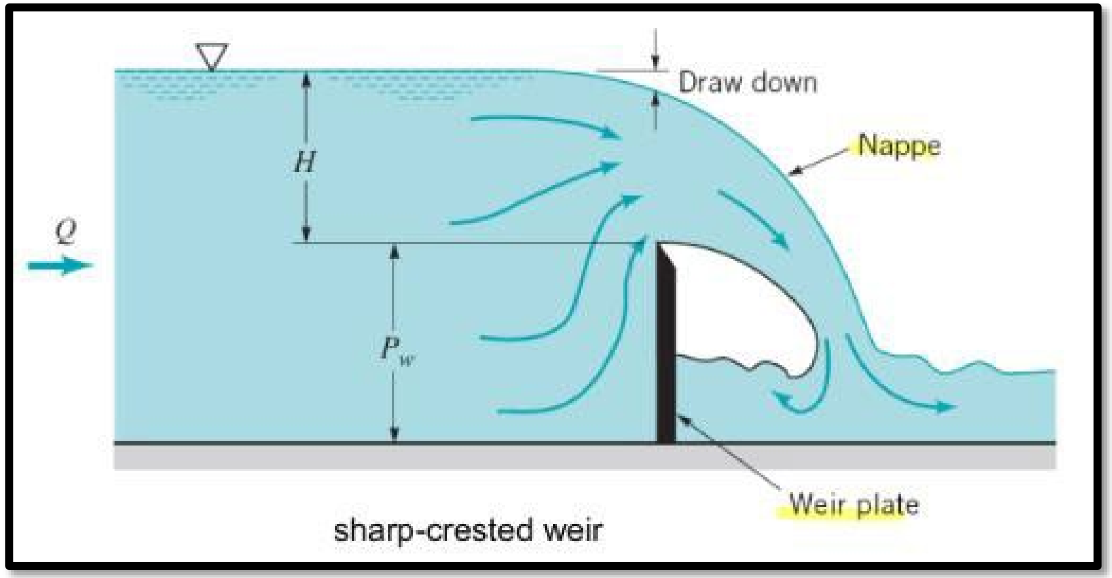
- Regardless of the type, sharp-crested weirs are usually used for smaller rivers and canals

Sharp-Crested Weir Visual

- Sharp crested weirs differ from broad crested weirs due to the detached water surface falling away from the downstream edge of the structure, known as a free-falling nappe

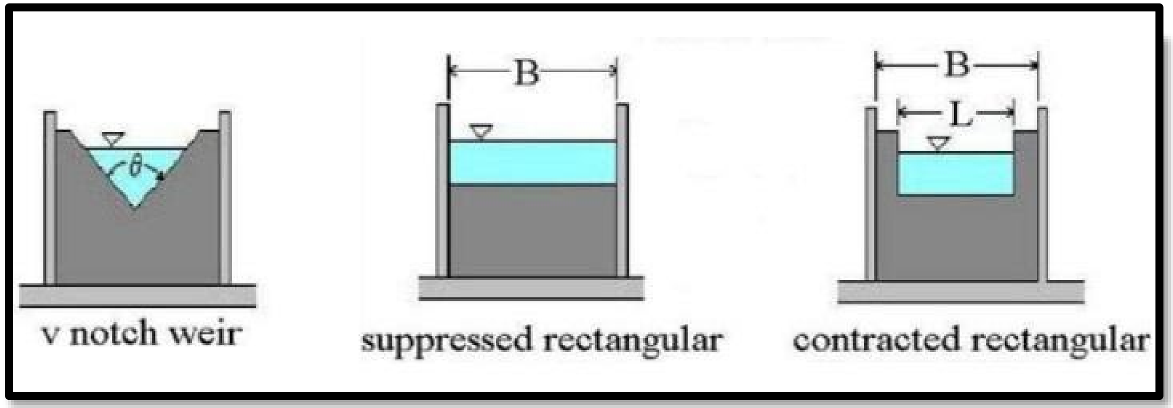
- The flow surfaces at the top and bottom of the nappe are exposed to the air and at atmospheric pressure

- A nappe that clings to the weir must be avoided in order to improve the accuracy of the weir discharge calculation



Sharp-Crested Weir
Design Consideration

- The weir plate should be made of smooth metal free of rust and nicks
- When the plate thickness exceeds 1/8th inch, the downstream edge of the crest should be beveled to allow the nappe to detach from the weir
- When the width of the weir crest is equal to the width of the channel (suppressed shape), the air pocket under the nappe may become entrained and collapse, causing inaccurate flow calculations



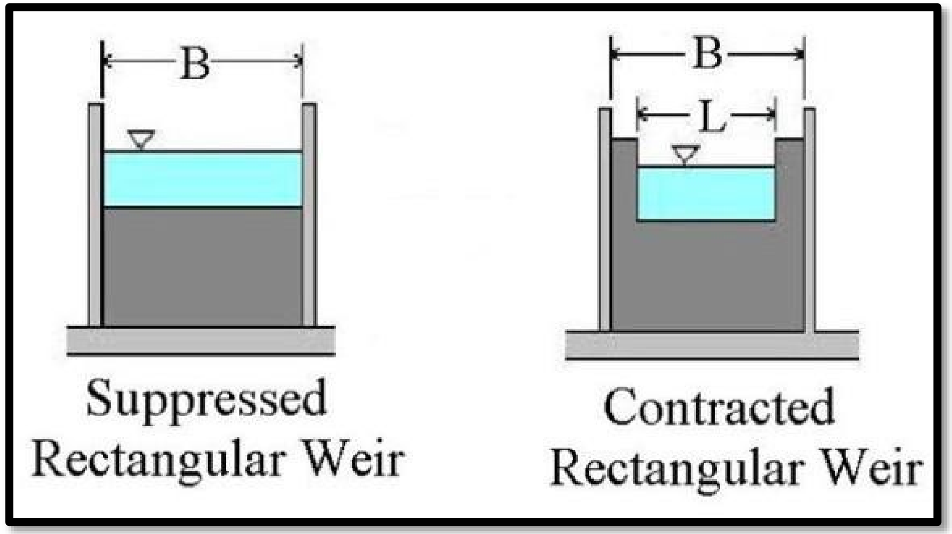
Sharp-Crested Weir Placement

Whenever possible:

- Sharp-crested weirs should be placed at the end of a long pool free of vegetation, and head(H) should be measured upstream at a distance at least 4-5 times the head to avoid drawdown errors
- Flow upstream of the weir should be sub-critical, with an approach velocity of less than 0.5 ft/s to achieve the greatest accuracy
- The weir should have a span perpendicular to the flow of the channel
- The face of the weir should be vertical, leaning neither up or downstream
- The depth of water flowing over the weir should not be less than 2”
- Rip-rap should be placed downstream of the weir to dissipate energy and prevent scouring in the channel

Sharp-Crested Weir Rectangular/Suppressed

- Used to control water up- and downstream of weir
- Typically have higher discharge values
- Two main types:
  - Suppressed weir- crest is across the width of channel
  - Contracted weir - has notch cut into it, adding to the head loss



Sharp-Crested Weir Rectangular/Suppressed Discharge

- Rectangular and suppressed weirs have the general discharge equation (below), but differing weir lengths that the water flows over

  $Q = C_D \, B \, H^{3/2}$

  $C_D = 3.22[1.78] + 0.4[0.22]\, H/P$ [] for SI units

- Where:
  - Q (m^3/s) is the volumetric flow rate over the weir
  - C_D is the discharge coefficient usually ranging from 3.24 to 3.62 [1.80] to [2.20] for SI units
  - H (m) is the head over the weir (from the weir crest to the upstream water surface)
  - P (m) is the height of the weir plate
  - B (m) is the width of the channel
  - g is the acceleration of gravity

Sharp-Crested Weir Rectangular/Contracted Discharge

- Rectangular and contracted weirs have the same general discharge equation (below), but differing weir lengths and a factor to account for the shape (contractions)

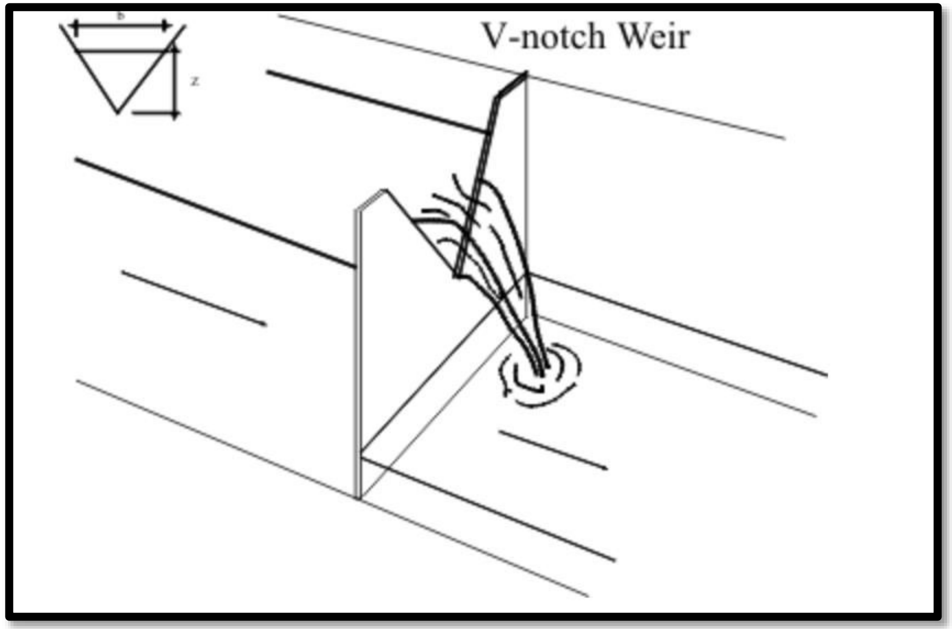
  $Q = C_D\ (L - nH/10)\ H^{3/2}$ C_D here must be determined via experiments

  $Q = 3.33[1.84]\ (L - 0.2H)\ H^{2/3}$ for "standard" contracted weir   [] for SI units

- Where:
  - Q (m^3/s) is the volumetric flow rate over the weir
  - C_D is the discharge coefficient
  - H (m) is the head over the weir (from the weir crest to the upstream water surface)
  - P (m) is the height of the weir plate
  - L (m) is the width of the contracted notch
  - n=1 (contraction on one end, =2 for contraction on both ends)
  - g is the acceleration of gravity

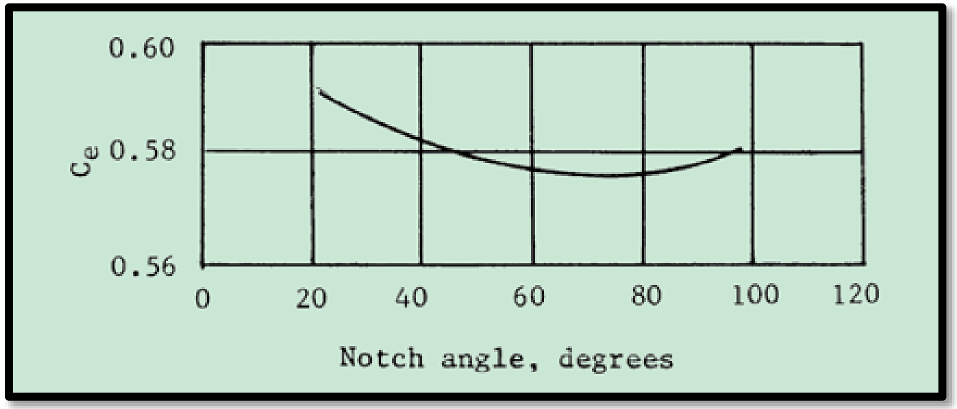
Sharp-Crested Weir
V-Notch (Triangular)

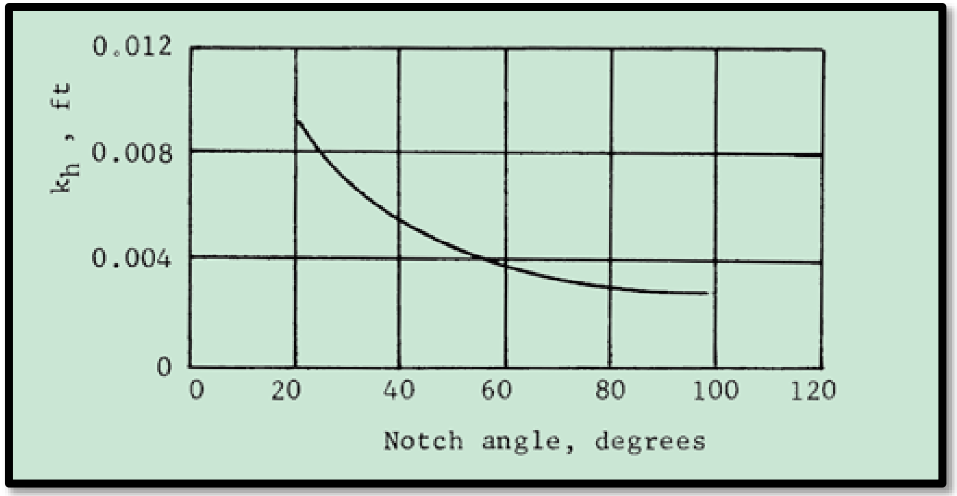
- Used in cases of small discharge
- Best weir to measure discharge in an open channel
- Highest accuracy when measuring flow rate (usually +/- 2%)



Sharp-Crested Weir
V-Notch (Triangular) Discharge

- Calculating discharge across a V-Notch weir is more complicated:
  - $Q = \frac{8}{15}\sqrt{2g}C_e \tan\left(\frac{\theta}{2}\right) H^{5/2}$
  - $H = h_u + K_h$
- Where:
  - Q (m^3/s) is flow over V-Notch weir
  - C_e, K_h can be found using the graphs to the right
  - h_u (m) is the head flowing through the notch
  - θ (degrees) is the notch angle
  - g is the acceleration of gravity (9.81 m/s^2)
- When θ=90° this equation can be simplified to:
  - $Q = 2.49[1.34]\ H^{2.48}$ [] SI units
  - for 0.2 ft < H < 1.25 ft





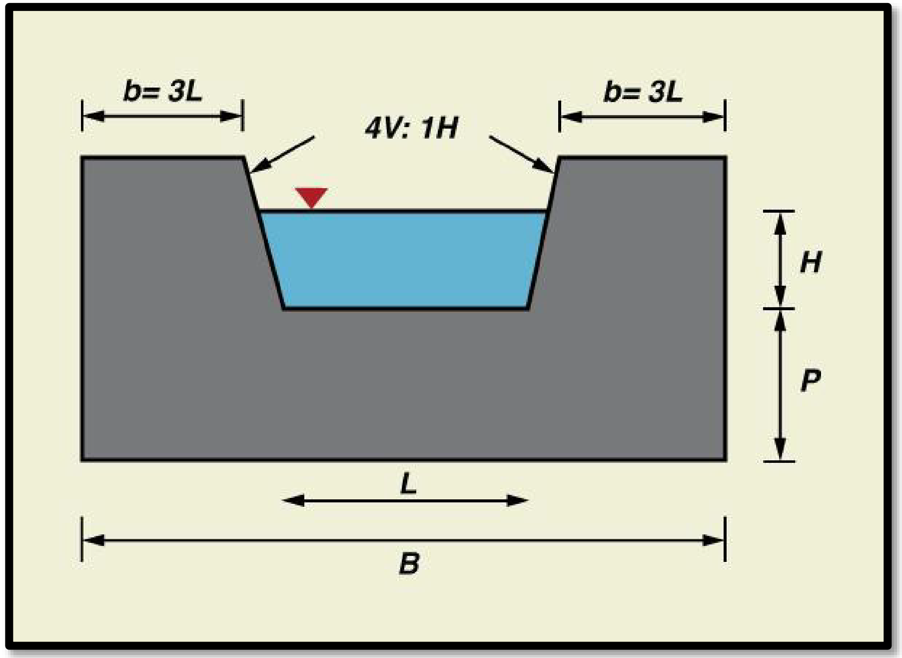
Sharp-Crested Weir Cippoletti (Trapezoidal)

- Cippoletti weirs are trapezoidal shaped with notch side slopes of 4:1 (vertical:horizontal)

- Combination of a rectangular and triangular weir

- These weirs are commonly used for irrigation

- Used when discharge is too great for a rectangular weir



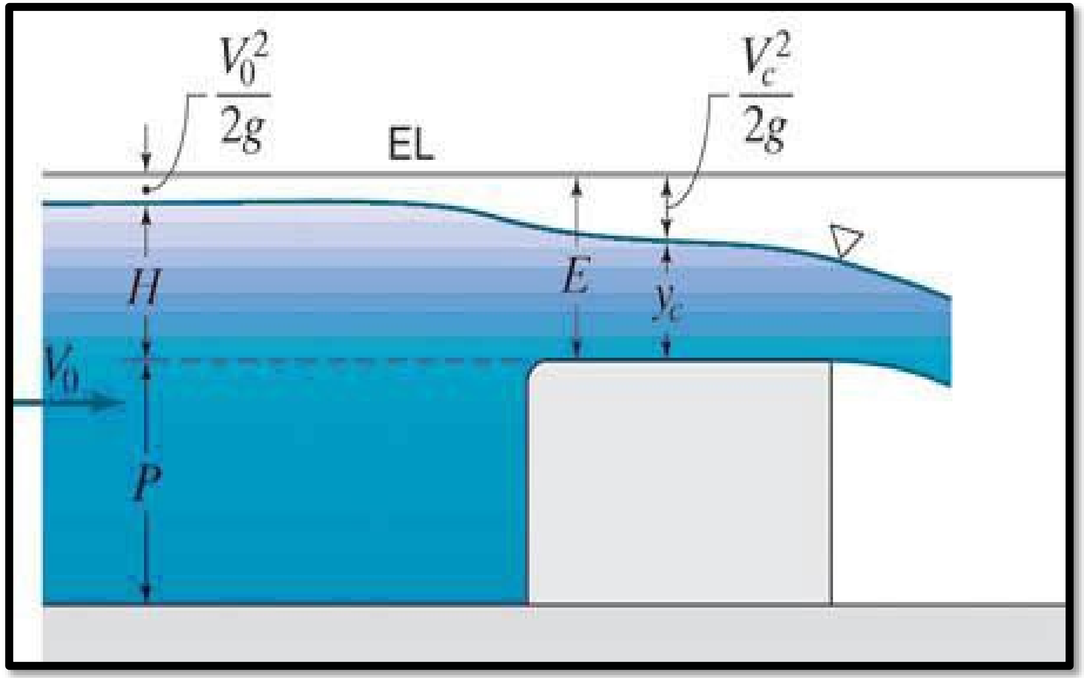
Sharp-Crested Weir
Cippoletti (Trapezoidal) Discharge

- Discharge for a Cippoletti Weir is calculated as follows:

$$Q = 3.367[1.858]\ L\ H^{3/2} \quad [\,]\ \text{SI Units}$$

- Contractions in the free-flowing nappe occur in non-suppressed weirs because water travelling along the faces of the weir cannot instantaneously “turn” around the corners of the weir plate
- A weir is fully contracted if B>4H and partially contracted if 0<B<4H
- The presence of contractions requires a discharge correction factor, but Cippoletti weirs are designed so that no correction is required

Broad-Crested Weir



Broad-Crested Weir Background

- Typically sturdier than sharp-crested weirs
- Used in medium to large size rivers and canals (sturdier)
- Used as a flow measurement and water level regulator
- Necessary for flow to be in subcritical range—ensures smooth water surface

Broad-Crested Weir
Pros and Cons

PROS

- Cost effective installation
- Small head loss
- Durable
- Capable of passing floating debris
- Best for measuring discharge in small to medium channels

CONS

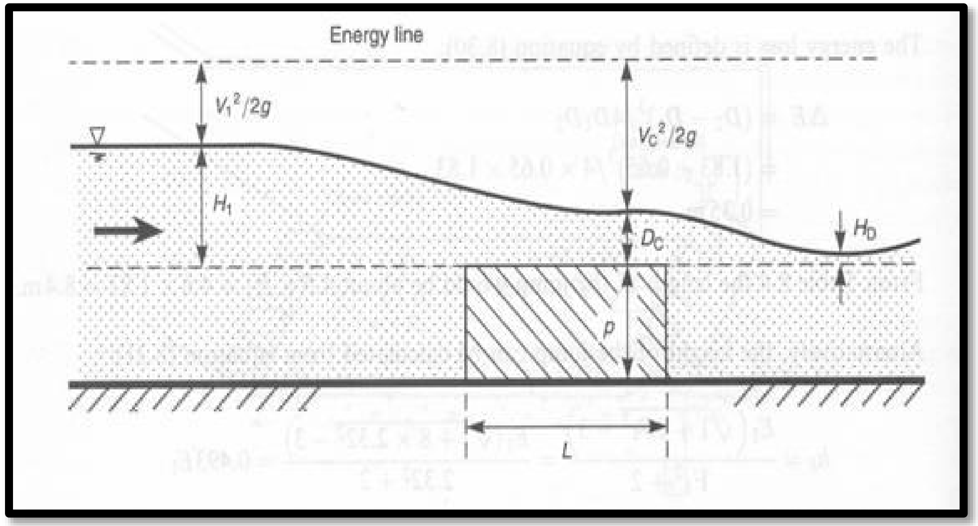
- Disrupt ecological life
  - While some fish may be able to jump/swim over the weir, other types of species cannot
- Channel upstream is prone to sediment deposition
- Head loss is across the weir
- Low sediment flow downstream
- Higher water levels upstream

Broad-Crested Weir Discharge

- Flow over a broad-crested weir is highly dependent on the weir's geometry
- Simply discharge can be calculated as follows:

$$Q = 0.433\sqrt{2g}\sqrt{\left(\frac{y_1}{y_1+h}\right)}LH^{3/2}$$

- Where:
  - Q = Volumetric flow rate
  - y_1 = total upstream waterdepth (H_1+p in image)
  - h = weir height (p in the image)
  - L = Width of the weir
  - H = Height of water head upstream in relation to the weir's crest
- The equation above can also be used for sharp-crested weirs if the design constants are known



Conclusion

- Weirs are highly useful hydraulic tools that allow engineers to control water height, velocity, and most importantly they can be used to calculate discharge

- Like many engineering tools, weirs do have some drawbacks:
  - The biggest drawback is the effect on ecologic life; not all types of species can pass over a weir
  - Additionally weirs can cause severe damage due to scouring

Works Referenced

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