# Estimation of Direct Runoff:

Engineering Hydrology
110401454

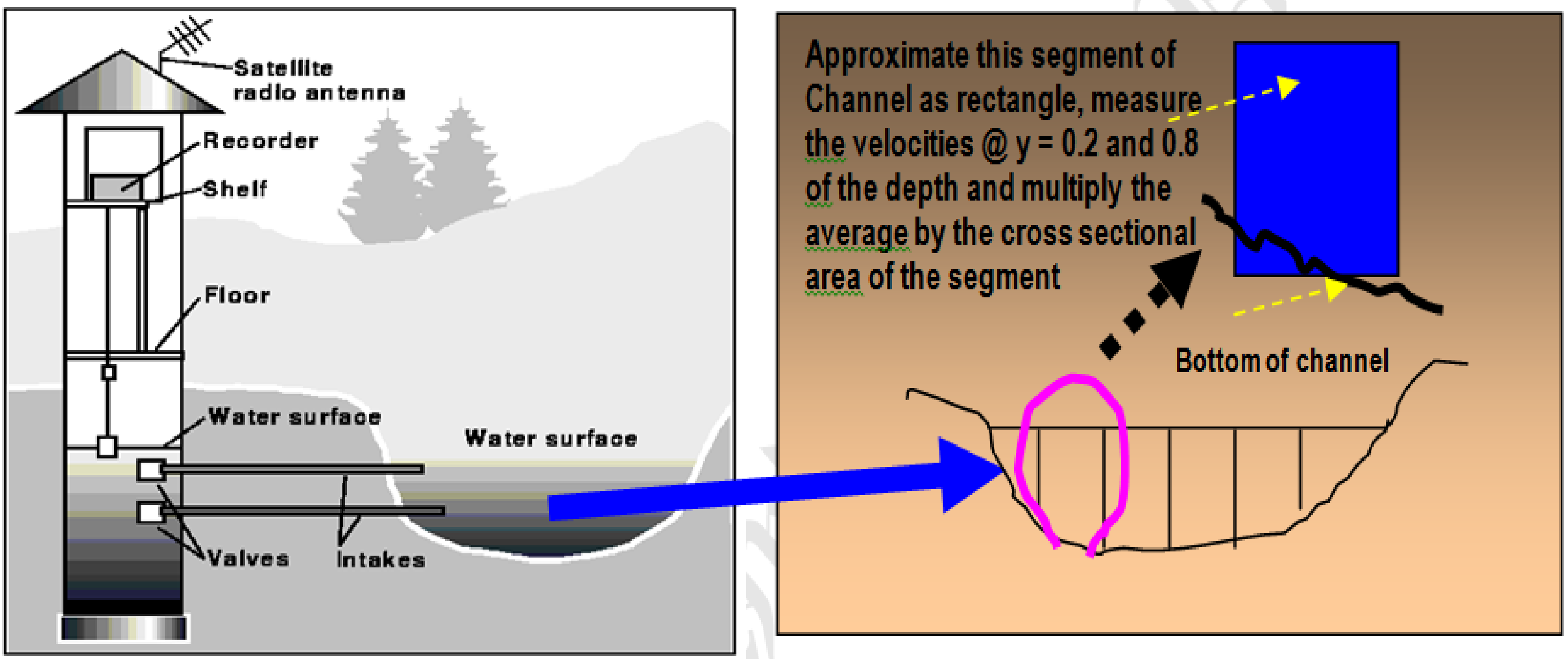
Dr. Ahmed Bdour
Fall 2013-2014

## **Runoff:**

**Surface runoff is a term used to describe the flow of water, from rain, snowmelt, or other sources, over the land surface. Runoff is a major component of the water cycle**

## Measuring Stream Gage:

Stream gage is an automated equipment housed in the an enclosed gauging station where stream stage can be continuously monitored and reported to high accuracy. The equipment is powered by linking battery-powered stage recorders with satellite radios that enable transmission of stage data to computers.

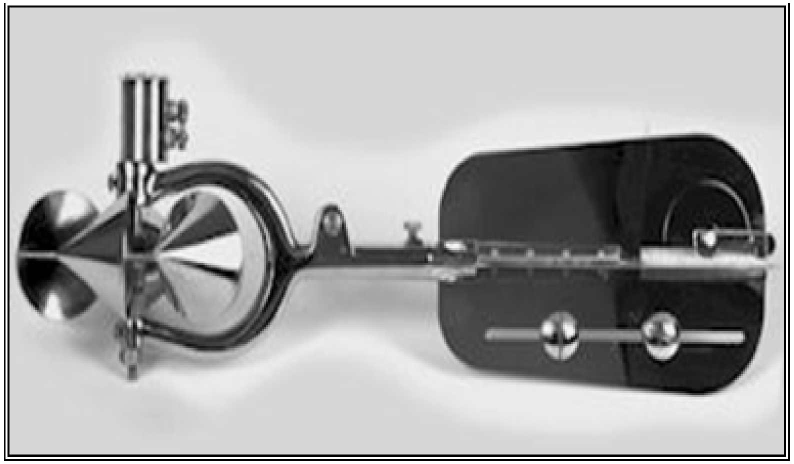



From USGS

## Measurement of Discharge:

### a) Floating Devices, Current Meter (From USGS)

The USGS Type AA current meter is commonly known as the Price-type current meter. This current meter is suspended in the water using a cable with sounding weight or wading rod (taking the tail section off) and will accurately measure streamflow velocities from 0.1 to 25 feet per second (0.025 to 7.6 meters per second). The main features of this meter are the uniquely designed bucket wheel shaft bearings and the two post contact chamber. The bucket wheel has six conical shaped cups, is five inches in diameter.



From USGS

## b) Weirs:

## Rectangular Weir:

Equation: Kinetic Energy is Neglected

$H + V_1^2/2g = h + V_2^2/2g$

$V_2 = SQRT[2g(H-h)]$

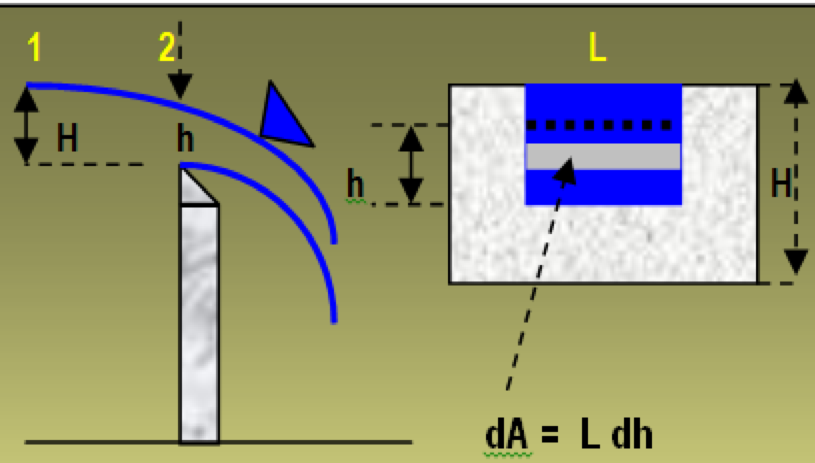
Flow through dh of area Ldh is:

$dQ = L dh\ SQRT[2g(H-h)]$

Integrating from $0 \rightarrow H$

$$Q = 2/3\ C_d\ L\ (2g)^{1/2}\ H^{3/2}$$

Where: $C_d$: Discharge coefficient



## V-Notch Weir:

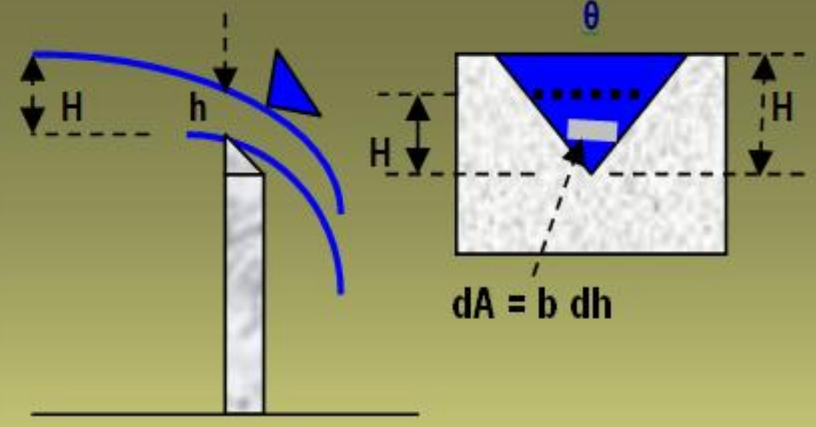
$dA = b\, dh$

$dA = 2h \tan \theta/2\, dh$

Since: $V_2 = SQRT[2g(H-h)]$

$dQ = C_d\,(2h \tan \theta/2\, dh)\, SQRT[2g(H-h)]$

Integrating from $0 \rightarrow H$




$$Q = 8/15\, C_d\, (2g)^{1/2} \tan \theta / 2\, H^{5/2}$$

Where: $C_d$: Discharge coefficient and θ is the V-notch angle

# Broad - Crested Weir:

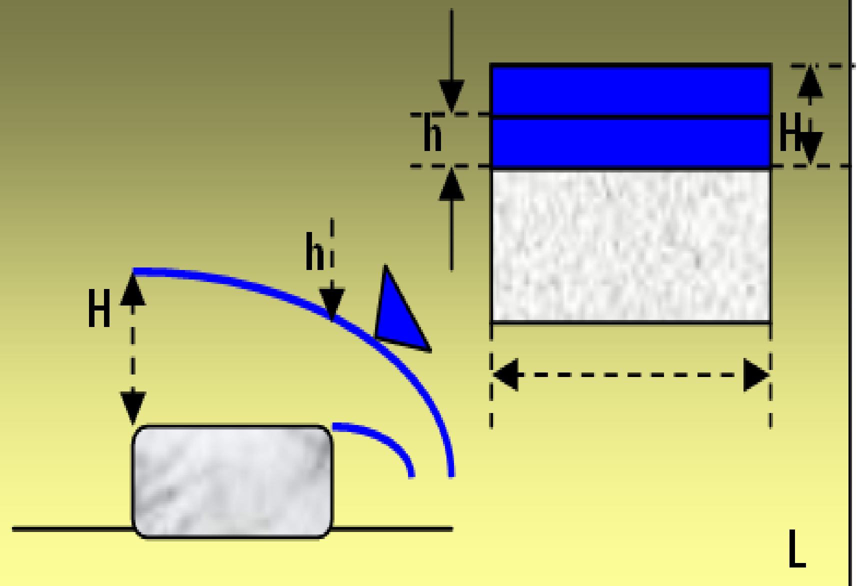
$H = h + v^2/2g$

$Q = C_d\, L\, h\, SQRT[2g(H-h)]$

$Q = C_d \sqrt{2g}\, L\, (2/3\, H)\, SQRT[H-2/3\, h)$ Then:

$$Q = 0.385\, C_d\, (2g)^{1/2}\, b\, H^{3/2}$$

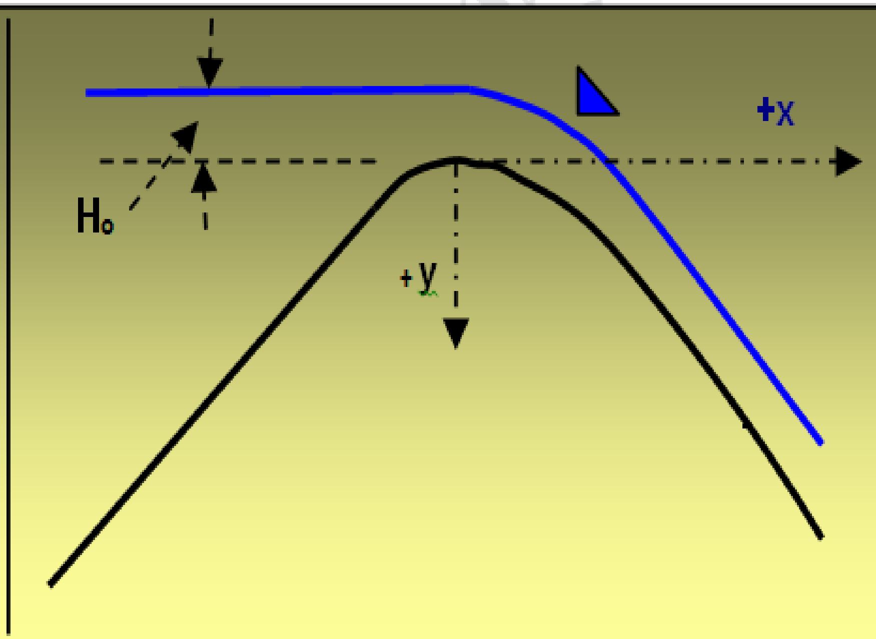
Where: $C_d$: Discharge coefficient



# Overflow Spillways:

$$Q = 2/3\ C_d\ L\ (2g)^{1/2}\ H_o^{3/2}$$

Where: $C_d$: Discharge coefficient

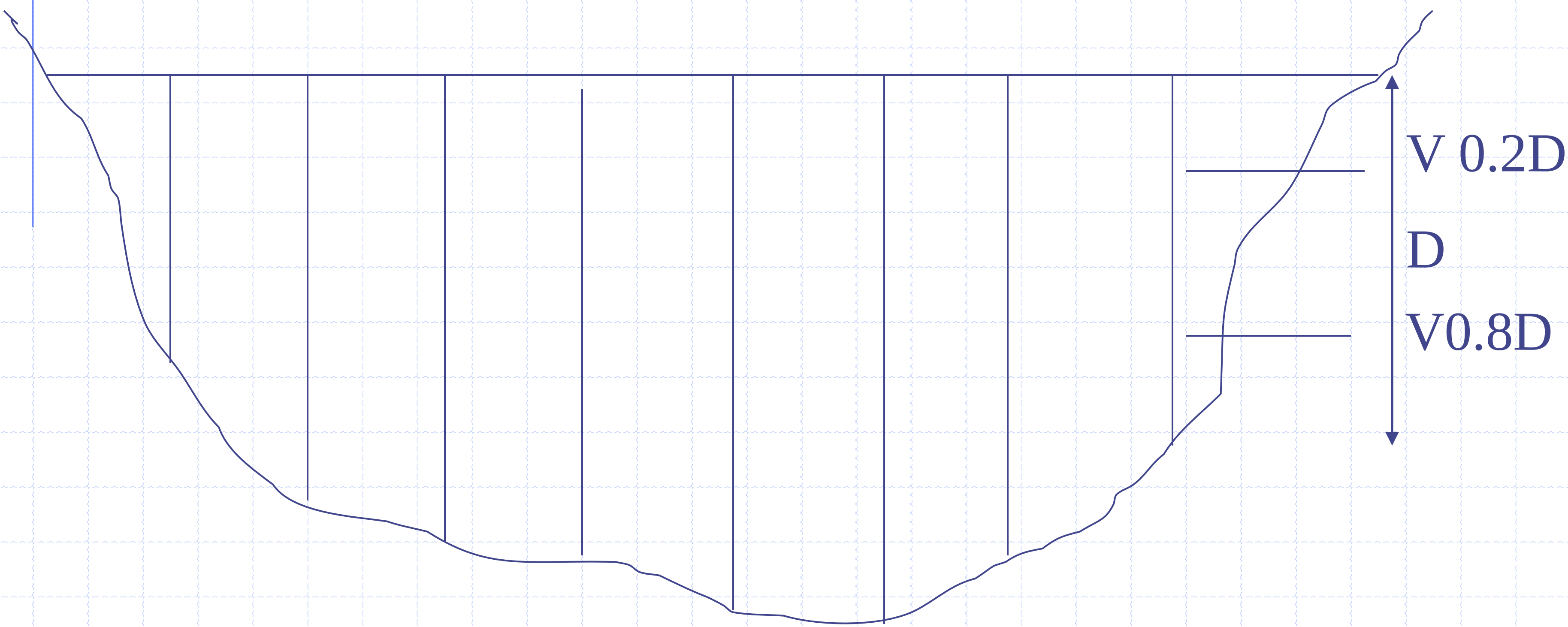


# Stream Flow Measurements (Contd.)

- Considering the velocity profile with depth, average value of velocity can be obtained at 0.6 of the depth. i.e. V = average velocity is at about 0.6 D.
- An alternative of using the 0.6 D velocity is to take 0.2 and 0.8 velocities and obtain the averages.
- The latter method is more accurate but in a shallow cross-section, the velocity at 0.2 D may be difficult to measure so use a single value at 0.6 D.

# Determination of Discharges

Velocity-Area station Method




Average Discharge = V x area of Segment

# Measurement of Discharges Contd.

- First divide the cross-section of the stream into vertical sections such that no section carries more than 10 % of the total flow.
- Take soundings to determine various depths. The sections are of a known width and so the discharge can be calculated if the velocities are taken along the 0.2 D and 0.8 D **<u>OR</u>** 0.6 D alone.

# Discharge Measurements Contd.

- Flow in one segment,

  $q$ = average velocity($v_{av}$)x area of segment($a_i$).

- Area of each segment can be calculated using the trapezoidal formula.
- Total discharge, Q is equal to:

(average velocity x area of segments)

$$Q = \Sigma q_i = \Sigma v_i a_i$$

2. Moving Boat Method : for large rivers

3. Chemical gagging :concentration of Chemical tracer

4. Ultrasonic :

5. Indirect Methods :

Measure flow depth (y) to get Q by :

- * Flow measured structures : such as weirs , orifices , …

* Slope-area methods : such as Chezy , Manning , Hayzen

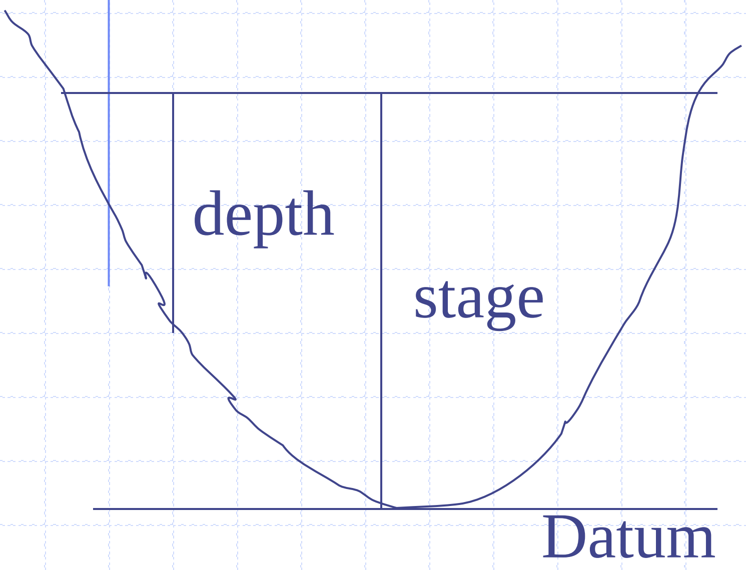
# Stage-Discharge Relations (Rating Curves)

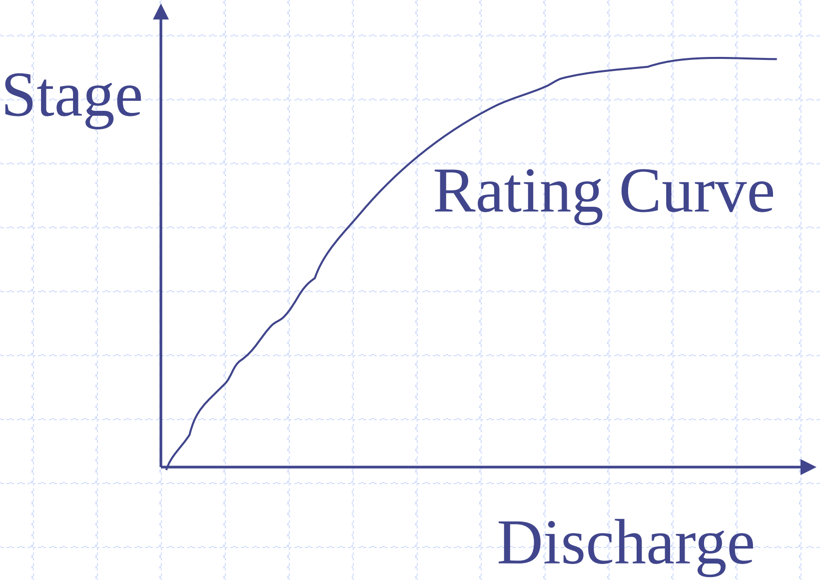
Stage-discharge relation is a plot of on arithmetic graph with discharge on the horizontal axis and the corresponding gauge height on the vertical axis. The relation of stage to discharge is not always unique relationship. The rise and the fall of flood waves and the backwater development caused by intersecting streams and other forms disturbances may affect the slope of the energy line which in turn affects the discharge. Therefore, in order to obtain a correct correlation between stage and discharge, an auxiliary stage near the main station is required.

# STAGE-DISCHARGE RELATIONS

- Simultaneous measurements of stage and discharge provide a calibration graph known as stage-discharge relations or rating curve.
- **Stage:** Height of stream level measured from an arbitrary datum.
- **Depth:** Measured from the bottom of the channel.
- The datum can also be the mean sea level. A plot of stage Vs discharge is made to obtain a rating curve.

# Rating Curve Graph



# Rating Curve (Contd.)

- The essence of the rating curve is that when the curve is established for a particular stream, subsequent determinations of discharges are merely obtained by dipping a measuring stick to measure the stage.
- Discharge is then read from the rating curve.
- The rating curve should be checked from time to time for accurate measurements.

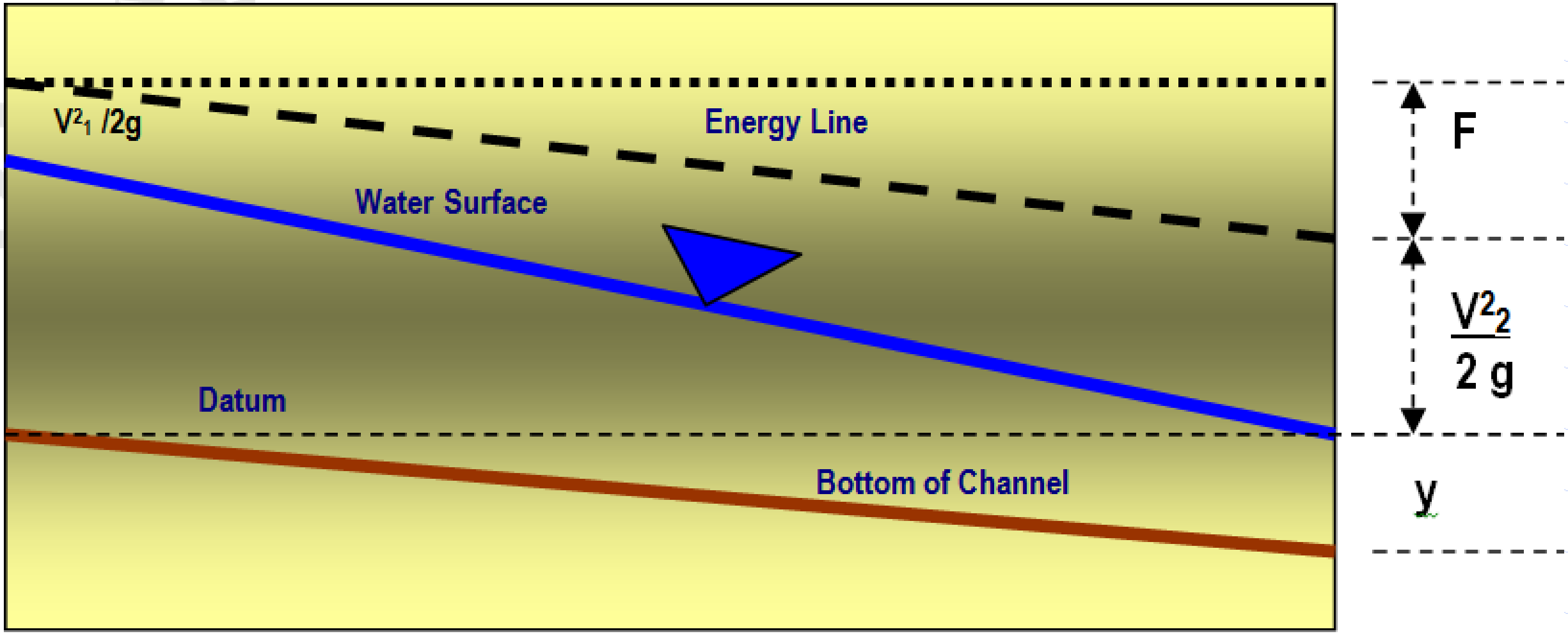
## Constant Fall Rating Curve:

If the slope of the energy line is approximately the same as the slope of the water surface, the discharge is proportional to the square root of the water surface (Manning & Chezy Equations):

$Q = f(S^{1/2})$

The ratio of any two discharges Q and $Q_0$ at a given station corresponding to the same stage but different slopes S and $S_0$, then,

$Q/Q_0 = (S/S_0)^{1/2}$



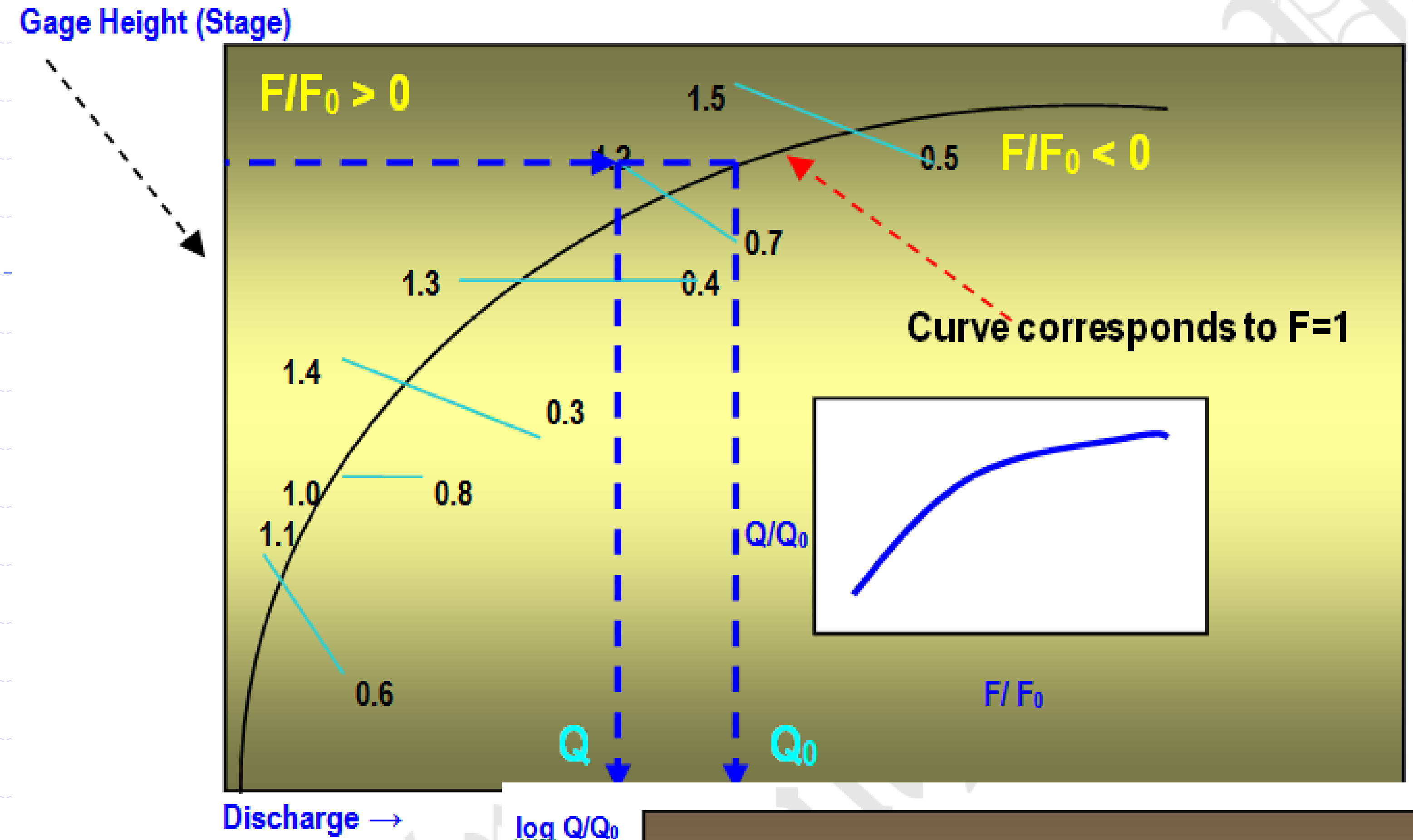
**From above, it is evident that if we establish an auxiliary stage downstream from the main gage, then:**

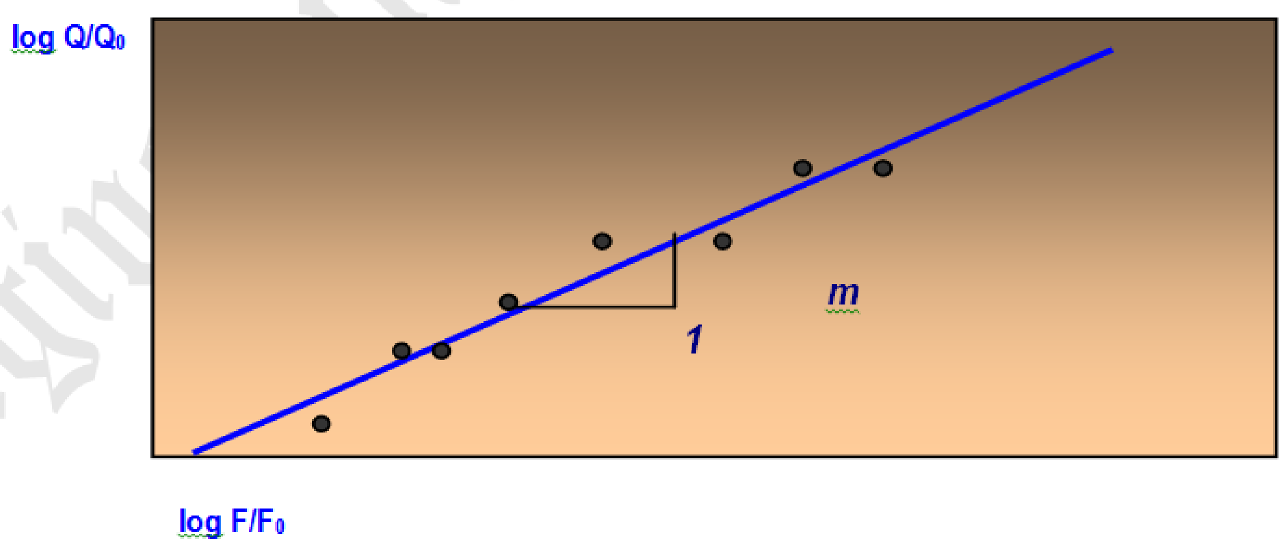
$$Q/Q_0 = (F/F_0)^m$$

**Where $F_0$ is constant fall that corresponds to $Q_0$, and m is constant between 0.4 and 0.6.**

## Methodology:

a) Make series of current meter measurements to calculate y Vs.Q corresponding to fall F.
b) By interpolation, draw a curve that corresponds to F=1. This is the boundary that separates $F/F_0 > 0$ from $F/F_0 < 0$ values.
c) It is now possible to Find $Q_0$ from reading base stage.
d) Plot correction curve $Q/Q_0$ vs. $F/F_0$.
e) By measuring Q and F for a given base stage, find the corresponding $Q_0$ from the correction curve.
f) Plot the data $Q/Q_0$ vs. $F/F_0$ on log – log scale to obtain *m*.
g) The above equation can now be used to obtain any value of Q with the help of simultaneous measurement at the base gage and the auxiliary gage.


Gage Height (Stage)
F/F0 > 0
1.5
1.2
0.5
F/F0 < 0
0.7
1.3
0.4
Curve corresponds to F=1
1.4
0.3
1.0
0.8
1.1
Q/Q0
0.6
F/ F0
Q
Q0
Discharge →


log Q/Q0
m
1
log F/F0

Illustrative Example:

For a given river, the following data were obtained by stream gauging. Estimate the flow rate when the main gage reads 30.0 ft and auxiliary gage reads 28.0 ft.

| Main Stage, ft | Auxiliary Stage | Q (cfs) |
| --- | --- | --- |
| 30 | 29.0 | 250 |
| 30 | 27 | 470 |

Solution:

$Q_1 / Q_2 = [(F_1/L) / (F_2/L)]^m$

$250/470 = [(30-29)/(30-27)]^m \rightarrow 0.5319 = 0.3333^m \rightarrow m = \log(0.5319) / \log(0.3333) = 0.5746$

$250/Q_3 = (1/2)^{0.5746} \rightarrow Q_3 = 250 / 0.5^{0.5746} = 372.32$ cfs

## Estimation of Direct Runoff:

### Infiltration Index:

Infiltration indices are straight-line approximation of infiltration rate separating direct runoff from infiltration. Unlike actual infiltration, which decreases with time, infiltration indices under estimate infiltration during the early part of the storm and over estimate infiltration at the latter part. Unfortunately, the use of indices would not produce accurate results when soil conditions are dry to near dry prior to the storm but are best suited when applied to initially wet to saturated soil when rate of infiltration is near equilibrium conditions.

## Φ-Index:

It is an average rate of infiltration which is distributed over a time-intensity graph of a given storm. Φ – Index is constructed such that the area above the index represents the volume of observed runoff. When Φ – Index is constructed, surface retention and evaporation are considered losses and should be added to the infiltration, so that the area above the index can only represents the actual runoff.

**Φ-Index = Total basin recharge / duration of rainfall**

**PHI INDEX, Φ:**

**A simple way of approximating the amount of direct surface runoff is through the use of Φ-Index. It is defined as the average rainfall intensity above which the volume of excess rain equals direct runoff. The value of Φ is adjusted (up or down) such that the computed direct runoff equal that of excess rain.**

**Method of Estimating Φ:**

- **Estimate the volume of direct runoff ($V_o$)**
- **Plot rainfall intensity vs. time.**
- **Make initial value of Φ.**
- **Compute the excess rain volume above Φ (V).**
- **Check if $V=V_o$.**
- **Adjust Φ until the volume until $V=V_o$.**

**Unfortunately the Φ-Index determined from a single storm is not generally applicable to other storms.**

Example:

Construct the Φ-Index for the storm shown in figure A if the net rain is 15 mm and 2 mm of depression storage at first hour.

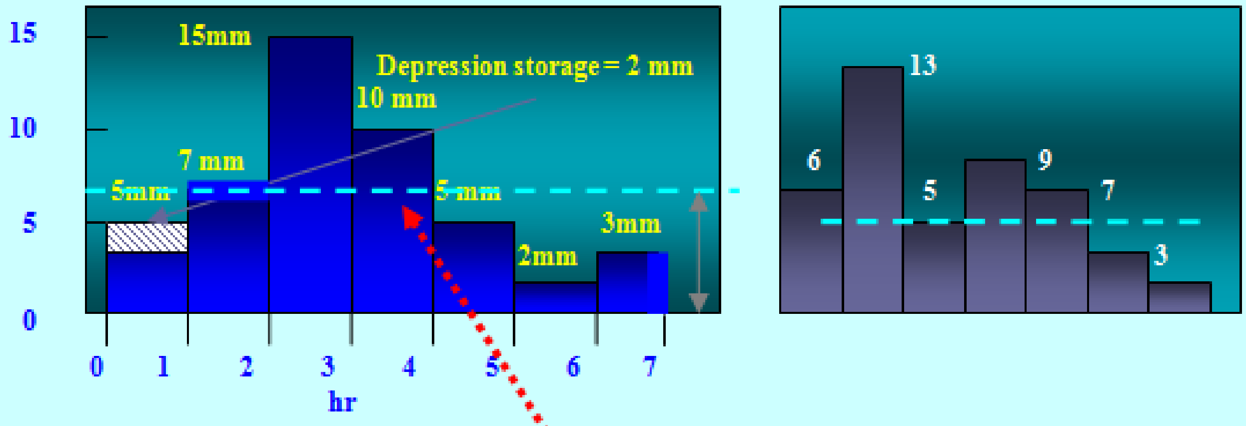



Figure A

Figure B

Let Φ-Index be $3 \le \Phi \le 5$ then:

$$(7-\Phi)(1) + (15-\Phi)(1) + (10-\Phi)(1) + (5-\Phi)(1) = 15$$

$37 - 4\Phi = 15$ then $\Phi = 22/4 = 5.5$ ( NG )

Let Φ-Index be $5 \le \Phi \le 7$ then: $(7-\Phi)(1) + (15-\Phi)(1) + (10-\Phi)(1)) = 15$

$32 - 3\Phi = 15$ then $\Phi = 17/3 = 5.6$ mm/hr (OK)

Note: If the total rainfall had been distributed as shown in figure B, and if the total runoff is 15 mm as was before, the resulting Φ-Index would have been 5 mm/hr. This suggests that the Φ index is associated with a given storm and it should represent an average value of many storm situations and not a single storm event