CHAPTER ONE

Precipitation

Hydrology: Means science of water which deals with the spatial and temporal of characteristics of the earth's water in all its aspect such as: occurrence, circulation, distribution, physical and chemical properties and impact on environment and living things.

Engineering Hydrology: Deal with all these aspects which are pertinent to planning, design, and operation of hydrologic engineering projects for the control and use of the available water.

Hydrology applications: in the

1-Design and operation of water resources projects

2-To estimate the magnitudes of flood flows at different times in the year.

3-To decide reservoir capacity , spillway discharge.

4-To decide dimensions of hydraulic structures.

Hydrologic Cycle:

The total water of earth excluding deep ground water, is in constant circulation from the earth (including oceans) to atmosphere and back to the earth and the oceans. This cycle of water amongst, earth, oceans, and atmospheric system is known as hydrologic cycle.

Precipitation

Moisture is always present in the atmosphere even in clouded less day, for precipitation to occur some mechanism is required to cool the air sufficiently to bring it to or near saturation.

Formation of fog or cloud drops or ice crystals generally requires the presence of condensation or freezing nuclei on which the drops from these nuclei are small particles of various substance ranging (0.1-10)µm in diameter.

Forms of precipitation:

1-Drizzle: Some time called mist , consists of tiny. Water drops, usually with diameter between 0.1 and 0.5mm (0.004-0.02)in.

2-Rain:consist of water drops mostly larger than 0.5mm (0.02in) in diameter.

3-Glaze:Is the ice coating generally clear and smooth but usually containing some air pockets formed on exposed surface by the freezing of supper cooled water drops deposited by rain or drizzle.

4-Snow: Is composed of white ice crystals in complex form often mixed simple crystals and agglomerated in to snowflakes which may reach several inches in diameter.

5-Hail:Is precipitation in the form of balls or irregular ice, range from5 to 125mm(0.2-over5in) in diameter.

6-Sleet:Solid grains ice formed by the freezing of rain drops or freezing of largely of sub freezing air near the earth surface.

Types of precipitation:

Precipitation is often typed according to the factor mainly responsible for lifting the air to effect the large scale cooling required for significant amount of ppt.

1-Cyclonic ppt: result from lifting of air converging in to lower pressure area for cyclone.

2-Convective ppt: caused by the natural rising of water lighter air in colder denser surrounding.

3-Orographic ppt: results from the mechanical lifting over mountain barriers.

Terminal velocity:

There are three forces acting in a falling rain drop:

1-Gravity force , Fg

2-Bouyancy force ,Fb

3-Drag force ,Fd, due to friction between drop and surrounding air.

The volume of sphere $\frac{\pi D^3}{6}$

$$Fg = \rho_w \, g \, \frac{\pi D^3}{6}$$

$$Fb = \rho_a \, g \, \frac{\pi D^3}{6}$$

$$Fd = C_d \, \rho_a \, A \, \frac{V^2}{2}$$

Where:

D = drag coefficient

V = falling velocity

A =cross section area = $\frac{\pi D^2}{4}$

IF the drop is released from result it will accelerate unit it reaches its terminal velocity Vt , at which the three forces are balanced.

Fd = Fg _ Fd

Let V = Vt

$$C_d\ \rho_a \frac{\pi D^2}{4}\frac{Vt^2}{2} = \rho_w\ g\frac{\pi D^3}{6} - \rho_a\ g\ \frac{\pi D^3}{6}$$

$$Vt = \sqrt{\frac{8\left(\rho w\ \frac{\pi D^3}{6} - \rho a\ \frac{\pi D^3}{6}\right)}{Cd\ \ \rho a\ \pi\ D^2}}$$

$$Vt = [\frac{4\ g\ D}{3\ Cd}\left(\frac{\rho w}{\rho a} - 1\right)]^{1/2}$$

Drag coefficient for spherical rain drop at standard atmospheric pressure (101.3 kpa) & air temp. (20C°)

Drop Diameter	Drag Coefficient
0.2	1.2
0.4	1.66
0.6	1.07
0.8	0.515
1	0.671
2	0.517
3	0.503
4	0.559
5	0.66

Example: Calculate the terminal velocity for (1mm)diameter rain drop falling in still air at stander atmosphere (101.3kpa) and air temp. (20c°).

Solution:

C_d = 0.671 from table

($\rho_w=998\ \frac{kg}{m^3}$ & $\rho_a=1.2\frac{kg}{m^3}$) at 20c°

$$Vt=\left[\frac{4\ g\ D}{3\ Cd}\left(\frac{\rho w}{\rho a}-1\right)\right]^{1/2}$$

$$Vt = \left[\frac{4*9.81*0.001}{3*0.671}\left(\frac{998}{1.2} - 1\right)\right]^{1/2}$$

Vt = 4.02 m/sec

Precipitation Gauge Network:

For an existing network of rain gauge stations, we need to know the adequacy of the rain gauge station & the number of the rain gauge stations N required for a desired accuracy.

N:is given by : $N = \left(\frac{Cv}{\epsilon}\right)^2$

Ɛ= maximum error in percent

Cv = the coefficient of variation of the rainfall values at the existing m stations in percent.

$$Cv = \frac{\delta m-1}{p}*100$$

$\sigma m-1$: stanadard deviation

$$\sigma m-1 = \sqrt{\frac{\sum_{i=0}^{m}(\rho i-\rho)2}{m-1}}$$

ρi: ppt. measured at the station

ρ: mean ppt. where $\rho = \frac{\sum_{i=0}^{m} \rho i}{m}$

$$\mathcal{E} = \text{is usually taken as } 10\%$$

Example: A catchment has eight rain gauge stations. the annual rainfall recorded by these gauges in a given year are listed in the table, below, what should be the min. number of rain gauge stations in the catchment for estimating the mean rainfall with an error less than 7%.

Solution:

Rain gauge	Annual Rainfall	$\rho i - \rho$	$(\rho i - \rho)^2$
A	80.0	-32.1	1030.4
B	87.6	-25.3	640.09
C	102	-10.9	118.81
D	160.8	47.9	2294.4
E	120.4	7.5	56.25
F	90.8	-2.1	4.41
G	142.3	29.4	864.36
H	98.5	-14.9	207.36
Total	903.2		5216.1

$$\rho = \frac{\sum_{i=0}^{m} \rho i}{m}$$

$\rho = \frac{903.2}{8}$ =112.9cm

$\sigma m - 1 = \sqrt{\frac{\sum_{i=0}^{m} (\rho i - \rho)^2}{m-1}} = \sqrt{\frac{5216.1}{7}} = 27.298$

$Cv = \frac{\sigma m-1}{\rho} * 100 = \frac{27.298}{112.9} * 100 = 24.18$

$N = (\frac{Cv}{\varepsilon})^2 = (\frac{24.18}{7})^2 = 11.93$

Estimation of Missing Data:

The missing is estimated using the rainfall data of the neighboring rain gauge stations, by:

1-Simple Arithmetic Mean:

$$px = \frac{1}{3}(pA + pB + pC)$$

When the variation is less than 10%

2-Normal Ratio Method:

$$px = \frac{1}{3}\left(\frac{Nx}{NA}pA + \frac{Nx}{NB}pB + \frac{Nx}{NC}pC\right)$$

When the variation is more than 10%

$$\text{Variation} = \frac{Nmax - Nmin}{Nmin} * 100$$

Example: Estimate the missing data for the station x according to the following information:

Station	Normal Annual ppt(cm)	ppt(cm)
A	44.1	4.2
B	36.8	3.5
C	47.2	4.8
X	38.5	px

Solution:

$$\text{Variation} = \frac{\text{Nmax} - \text{Nmin}}{\text{Nmin}} * 100$$

$$\text{Variation} = \frac{47 - 36.8}{36.8} * 100$$

Variation = 28.26% > 10%

Use normal ratio method

$$px = \frac{1}{3}\left(\frac{\text{Nx}}{\text{NA}}\text{pA} + \frac{\text{Nx}}{\text{NB}}\text{pB} + \frac{\text{Nx}}{\text{NC}}\text{pC}\right)$$

$$px = \frac{1}{3}\left(\frac{38.5}{44.1} * 4.2 + \frac{38.5}{36.8} * 3.5 + \frac{38.5}{47.2} * 4.8\right)$$

$$px = 3.743\ \text{cm}$$

Average Depth of Precipitation over an Area:

The average depth of rainfall over an area can be estimated by one of the following methods:

1-Arithamtic Mean Method:

This method is suitable if the rain gauge stations are uniformly distributed over the area and the rainfall variation in not large.

$$p = \frac{\text{p1} + \text{p2} + \text{p3} + \cdots + \text{pn}}{\text{n}}$$

Where:

$p1, p2, p3, pn$: depths of rainfall measured at stations 1,2,3,n

n:total number of stations.

Example: The average depth of annual precipitation as obtained at the rainfall stations for a specified catchment is shown in the fig.

.Determine the average depth of ppt. using the Arithmetic mean method.

Solution:

$$p = \frac{p1 + p2 + p3 + pn}{n}$$

$$p = \frac{1}{11}[20.3 + 88.1 + 60.9 + 54.7 + 48.1 + 45.8 + 60 + 84 + 93.2 + 140.6 + 154] = 77.23\text{cm}$$

2- Theisson Polygon Method:

This method takes in to account The non uniform distribution of the gauges by using weightage factor for each rain gauge.

$$p = \sum_{i=0}^{m} pi \frac{Ai}{\sum A}$$

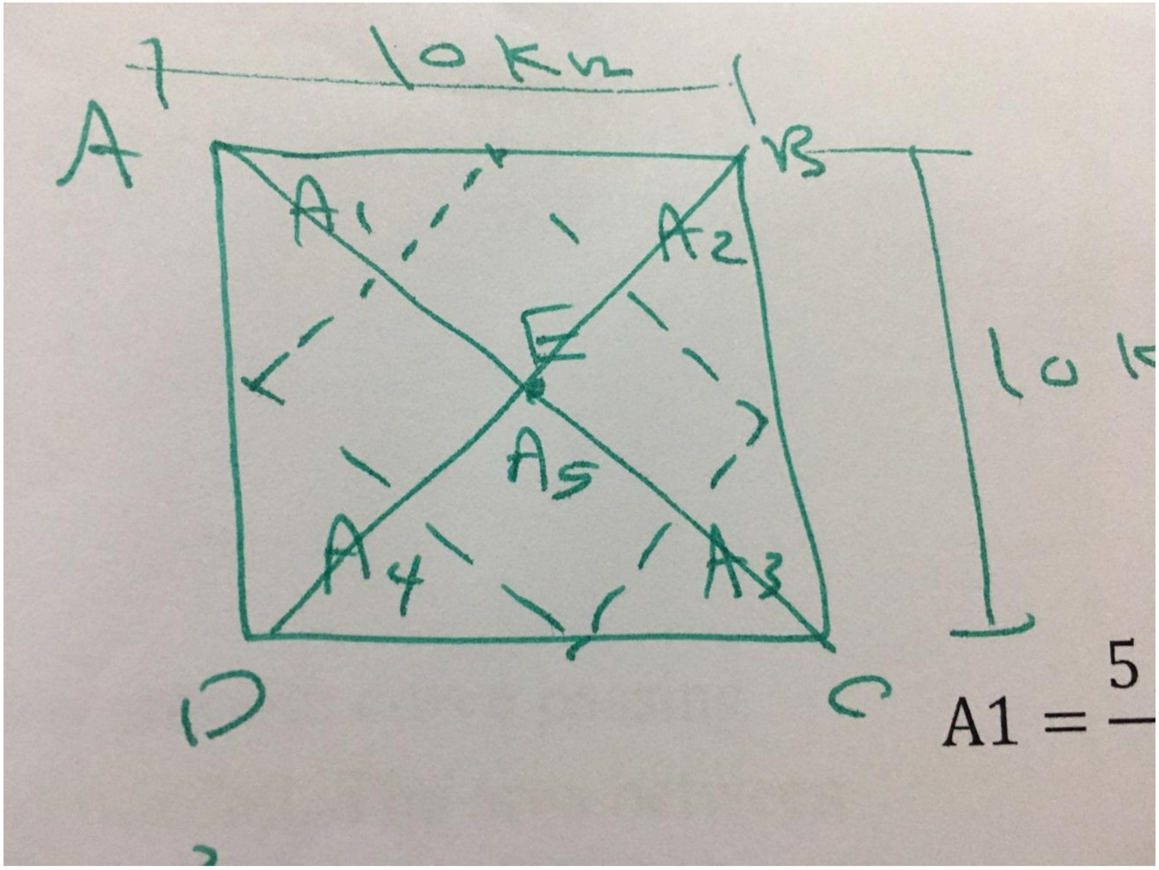
Where:

$\frac{Ai}{\sum Ai}$ is termed as weightage factor for the i^{th} rain gauge.

Example: Given the catchment shown in the figure .determine the average depth of ppt. using Theisson polygon method.

Solution:

Rain gauge	Pi(mm)	A(m^2)	$Pi\frac{Ai}{\sum Ai}$
A	15	12.5	1.875
B	22	12.5	2.75
C	30	12.5	3.75
D	22	12.5	2.75
E	20	50	10
Total		$\sum$ =100	21.125mm



Total Area=10*10=100m^2

$$A1 = \frac{5*5}{2} = 12.5\text{m}^2$$

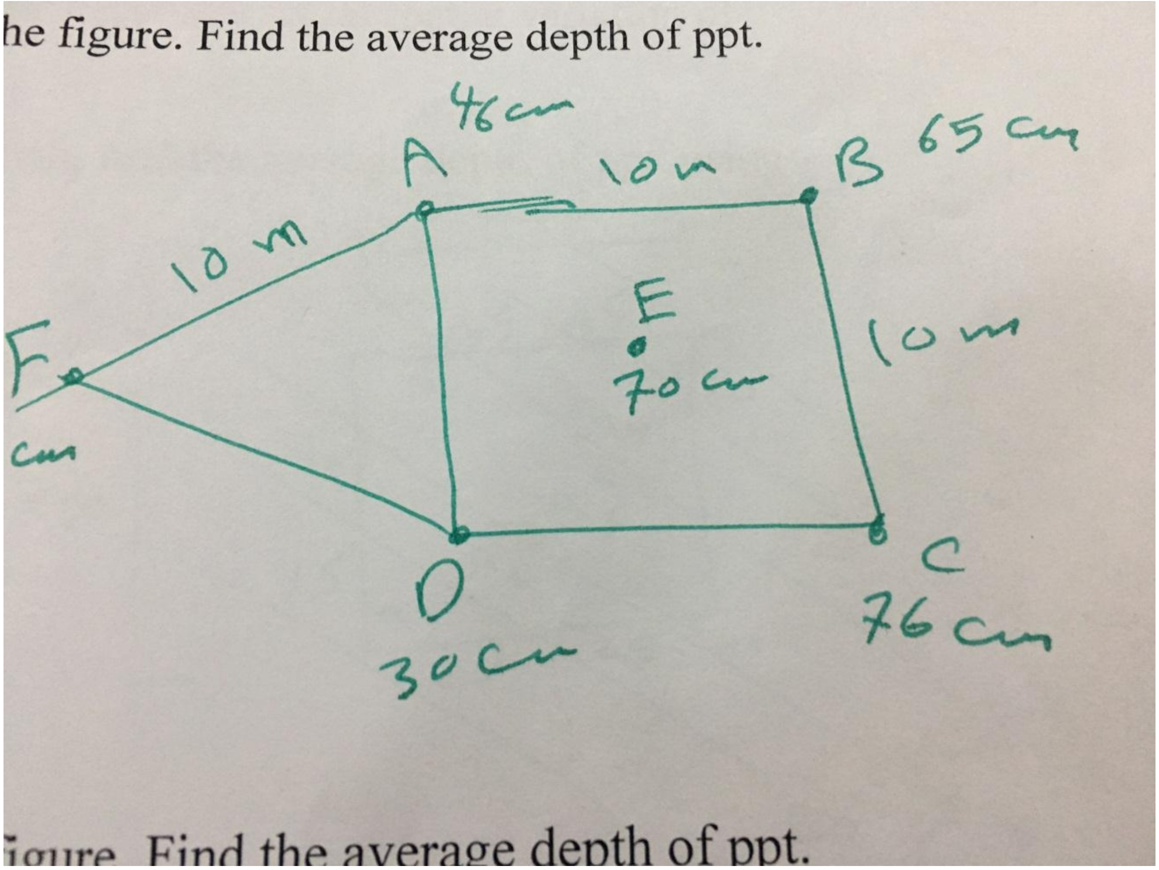
$$A1 = A2 = A3 = A4 = 12.5\text{m}^2$$

$$A5 = AT - (A1 + A2 + A3 + A4)$$

$$A5 = 100 - 4 * 12.5 = 50\text{m}^2$$

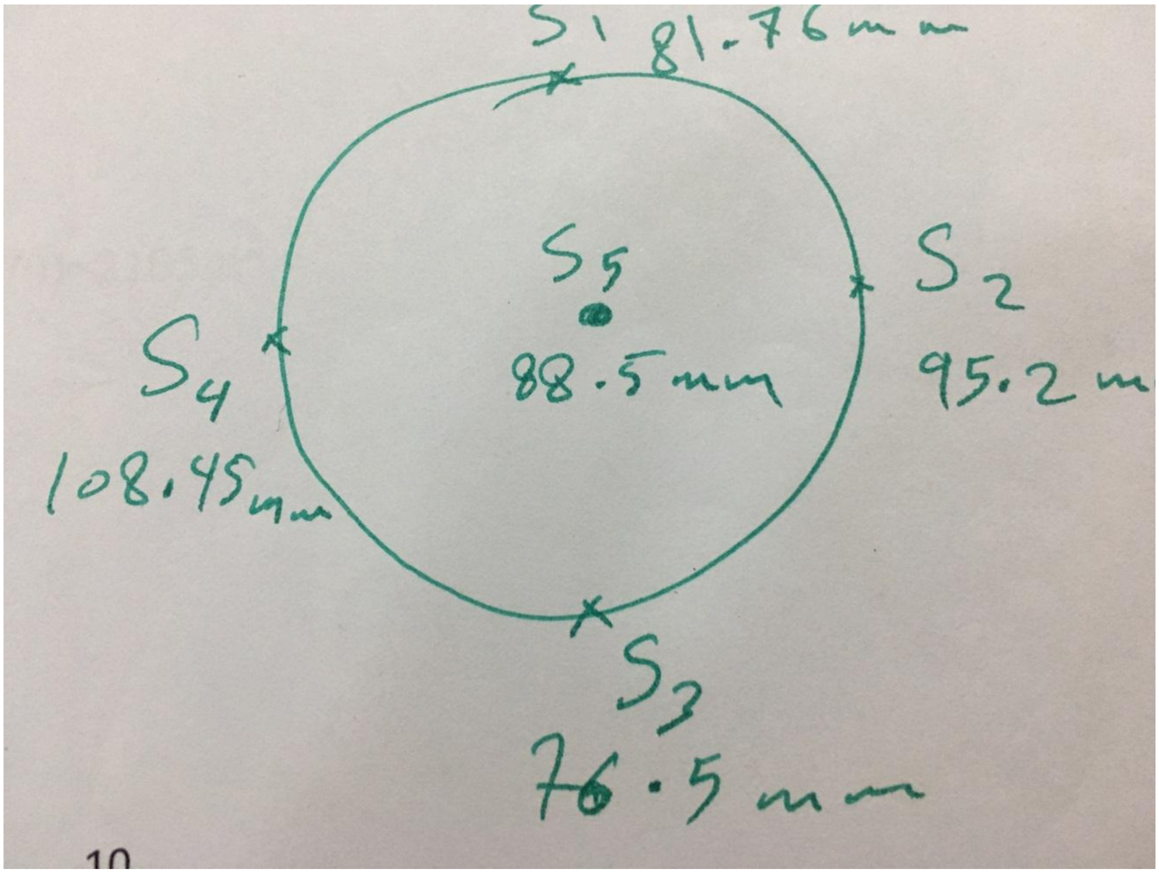
$$p = 2.112cm$$

H.W1/Given the catchment in the figure. Find the average depth of ppt.



H.W2/Given the catchment in the figure. Find the average depth of ppt.

When R=6m



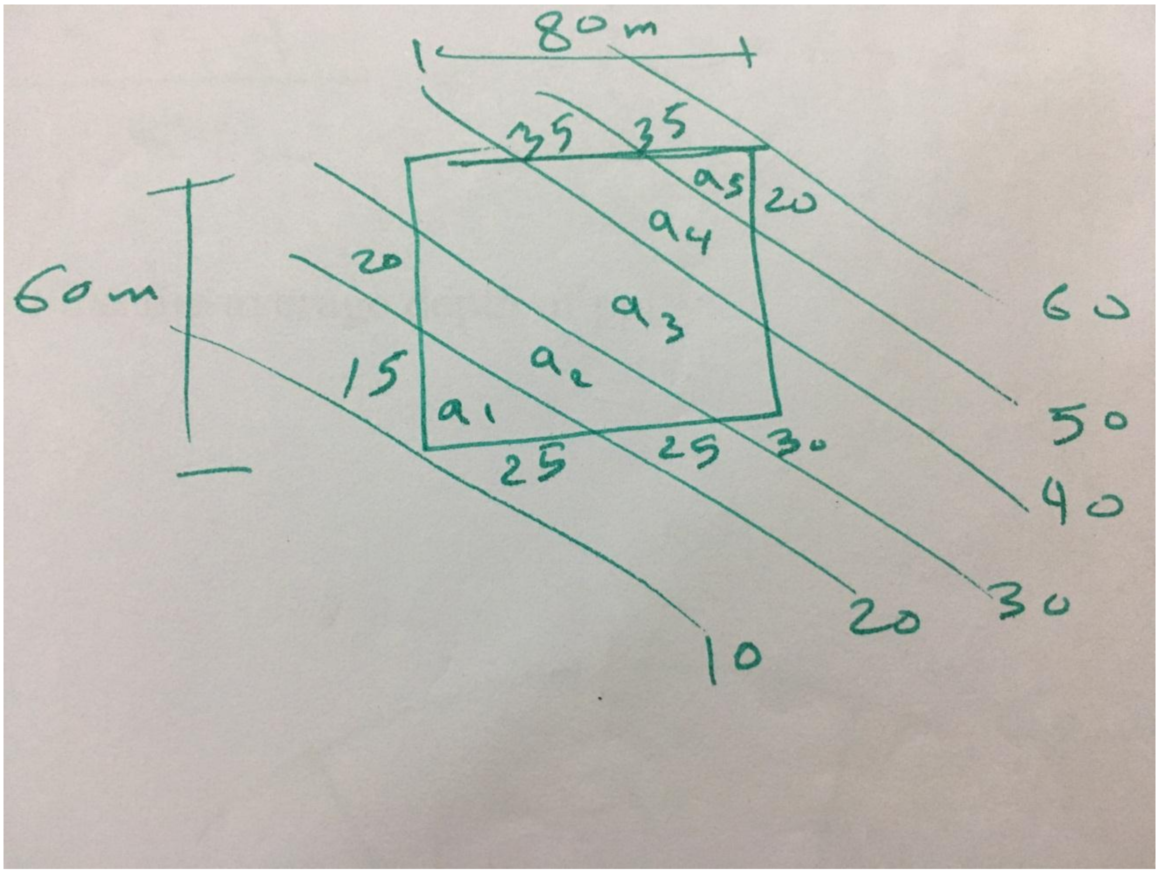
3-Isohyetal Method:

The isohyet is a contour of equal rainfall, draw smooth curve passing through all points indicating the same value of rainfall. The area between two adjacent isohyets is measured by planimeter

$$P=\frac{1}{A}\,[\text{ Area betweentwo adjacent isohyetal}] * [\text{mean of the two adjacent isohyets values}]$$

This is the best method because it considers actual spatial variation of rainfall.

Example: For the catchment shown, find the average depth of ppt. using Isohyetal method.



Solution:

Total Area=60*80=4800m^2

Isohyets	Pi(mm)	Ai(mm)	PiAi
10-20	15	187.5	2812.5
20-30	25	687.5	17187.5
30-40	35	2105	73675
40-50	45	1470	66150
50-60	55	350	19250

A1=$\frac{25*15}{2} = 187.5\text{m}^2$

A2=$\frac{50*35}{2} = 687.5\text{m}^2$

A5=$\frac{25*15}{2} = 350\text{m}^2$

A4=$\frac{70*52}{2} - \text{A5} = 1470\text{m}^2$

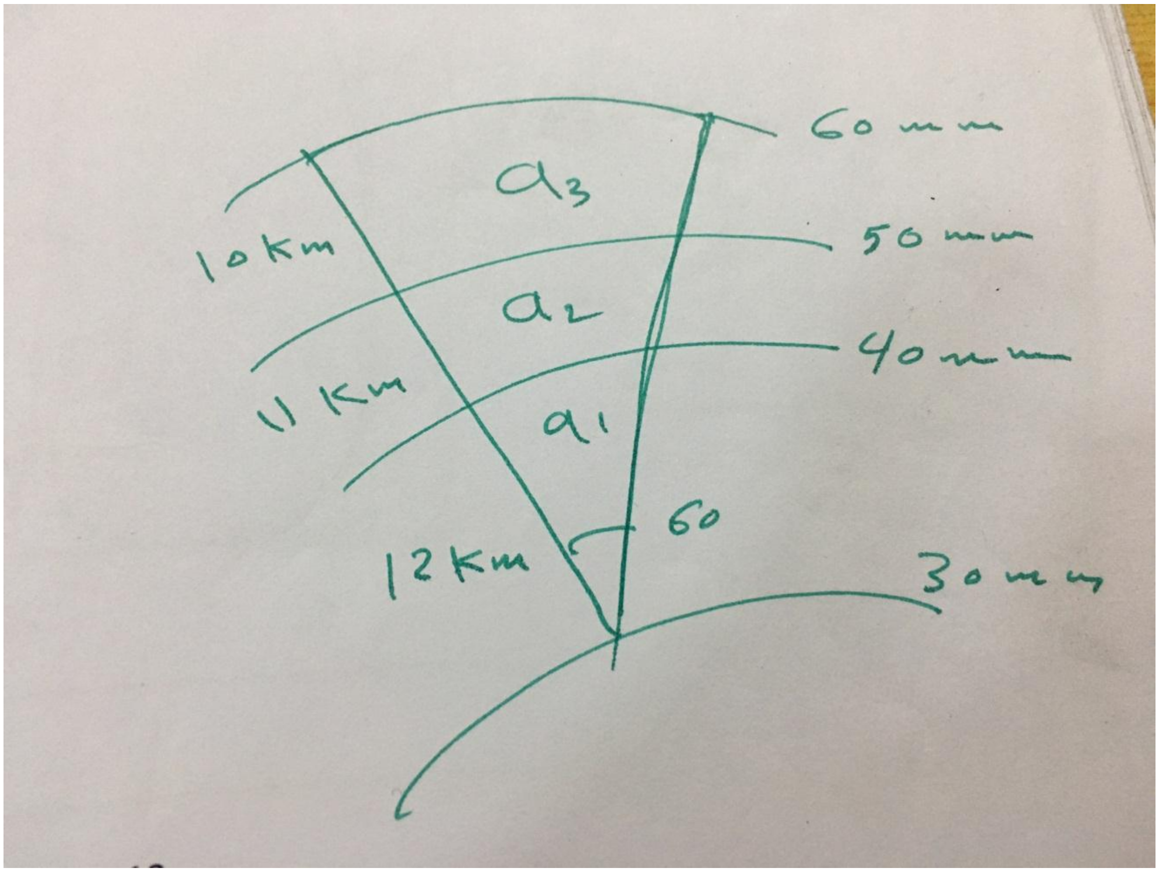
A3=AT-(A1+A2+A4+A5)

A3=4800-(187.5+687.5+350+1470)=2105m^2

$P = 37.307$

H.W3/Using Isohyetal method. Find the average depth of ppt.

Note:Area=$\frac{\theta r^2}{2}$



Measurement of precipitation

Precipitation is measured in depth of water (mm) ppt. gauges are classification in to two types:

1-Non-Recording gauge:

Only collected rain water, gives the total amount of rainfall during the measurement interval.

Symons rain gauge

A glass bottle & funnel with brass rim are put in a metallic cylinder

Rain water falls in to the glass bottle through the funnel, rainfall observation are taken twice daily at 8:30am & 5:30pm.

2-Recording rain gauge:

Automatically record the intensity of rainfall and the time of accordance in the form of trace marked on graph paper warped round a revolving drum.

There are many types of recording rain gauges

1-Tipping bucket rain gauge

2-Weighing bucket rain gauge

3-Siphon rain gauge

4-Radar measurement of ppt

5-Satellite measurement of ppt

1-Tipping bucket rain gauge

When 0.25mm of rainfall is collected in a bucket, it tilts and empties its water in to a bigger storage tank, when one of the two buckets tills, it transmitted to an electric circuit causing a pen to make a mark on a revolving drum.

Each mark indicates 1.25mm of rain in the duration between two marks.

2-Weighting bucket rain gauge

The increasing weight of rain water in the bucket moves the plat form.

This movement transmitted to a pen which make a mark of accumulated amount of rainfall on graduated chart warped round clock driven revolving drum. The slope of the curve at any time gives intensity of rainfall at that time.

3-Siphon rain gauge:

Called float type rain gauge, it has a chamber contain light &hollow float ,the vertical movement of float on account of rise in the water level in the chamber transmitted by a mechanism to move a pen on clock driven revolving chart.

4-Radar measurement of ppt:

Radar transmits a pulse of electromagnet energy as a beam in a direction determined by movable antenna. The beam width and shape are determined by the antenna size and configuration.

The radiated wave which travels at the speed of light is partially reflected by cloud or ppt.

and return to the radar where it is received by the same antenna.

5-Satellite measurement of ppt:

Satellites are used to get required information on ppt over areas where gauge networks are un existent or over oceans.

If may be used to estimate rainfall amounts for one month or longer.

The chief problem is the satellite cannot measure rainfall directly and solution requires evaluation of rainfall coefficient of the amount and type of cloud and rainfall intensity.

Test of Consistency of Records [Double Mass Carve]

The trend of the rainfall records at station (x) may be changed after some years due to:

A-change in Environment
B -change in building, plant,…..
-A break in the slope of the resulting plot points to the inconsistency of the data indicating a change in ppt. regime of station (x).

$$S1 = \frac{H_{\circ} - H1}{X_{\circ} - X1}$$

$$S2 = \frac{H_{\circ} - H2}{X_{\circ} - X2}$$

$$\frac{S1}{S2} = \frac{\frac{H_{\circ} - H1}{X_{\circ} - X1}}{\frac{H_{\circ} - H2}{X - X2}}$$

$$\frac{S1}{S2} = \frac{H - H1}{H - H2}$$

$$(H_{\circ} - H2)\frac{S1}{S2} = H_{\circ} - H1$$

$$H2 = y$$

$$H_{\circ} - y = \frac{S2}{S1}(H_{\circ} - H1)$$

$$y = H_{\circ} - \frac{S2}{S1}(H_{\circ} - H1)$$

Example: The annual rainfall at station (x) and the average annual of 18st . Surrounding are given in the table below. Check the consistency of the records at station (x) and show the year in which the change in regime occur.

Solution:

Year	Annual Rainfall	Annual Rainfall 18st.	accumulative station(x)	accumulative station(18)	Y
1952	31	23	31	23	93.4
1953	38	35	69	58	120.8
1954	44	30	113	88	152.4
1955	32	27	145	115	175.5
1956	27	25	173	191	195.5
1957	32	28	205	169	218.7
1958	49	36	254	205	254
1959	28	28	282	233	282
1960	25	25	307	253	309
1961	22	24	329	282	309
1962	28	33	357	315	309
1963	17	23	374	339	309
1964	22	36	397	375	309

$$y = H_{\circ} - \frac{S2}{S1}(H_{\circ} - H1)$$

$$y1 = 254 - \frac{0.9}{1.25}(254 - 31) = 93.4$$

$$y2 = 254 - \frac{0.9}{1.25}(254 - 96) = 120.3$$

The year(1958)

CHAPTER TWO

RUNOFF

Runoff : Is that portion of ppt. that makes its way towards , lakes, streams and oceans as surface and sub surface flow .By using water balance equation:

$$\text{ppt.} + \text{Irr.} - \text{Evap.} - \text{Trans.} = \Delta S$$

$$\therefore R = ppt. - E - \Delta S$$

After satisfying the requirements of evapotranspiration

, interception, infiltration into the ground and storage, the runoff flows into streams.

Infiltration:

Is the passage of water from the soil surface into the soil, and its different from percolation which the gravity flow of water within the soil.

OR

Infiltration:

Is the process by which water enters the soil from the ground surface. Infiltration provide the soil moisture deficiency the excess water moves downwards by the force of gravity. This is called (percolation).

Percolation:

Is the movement of water within the soil (the tow phenomena of infiltration and percolation are interrelated).

The Infiltration capacity:

The max. rate at which water can enter the soil in a given condition.

The infiltration capacity (f) is high at the beginning of storm when soil is dry, its decreases as the soil becomes saturated until it reaches a constant value(f_c).

To find the infiltration capacity at time (t.) after the beginning of storm use the following eq. :

$f_t = f_c + (f_\circ - f_c)\, e^{-kt}$

Where:

$f_\circ$: initial infiltration capacity.

f_c: limiting constant value of infiltration capacity.

Note**:** the values $f_{c,}$ $f_\circ$,k depend upon type and conditions of soil.

Factors affecting infiltration rate:

1- soil moisture: when soil is dry infiltration rate is high because there is strong capillary attraction for the moisture as the soil becomes saturated , the infiltration rate decrease.

2-Type of soil medium: The infiltration rate depend upon type of soil , texture , amount of clay and colloids in soil and thickness and depth of the permeable layer.

3-Permeability: Infiltration will continue only if the infiltrated water is transmitted by the soil.

4-Compaction of soil: Compaction reduces the infiltration rate.

5-Avilable storage in soil stratum: It depends on the thickness of stratum , porosity , water content of soil .The infiltration is more if the available storage is large.

6-Depth of surface detention: The rate of infiltration increases as the depth of surface detention increases.

7-Temperature of water: An increase in temperature causes a reduction in viscosity of water leading to increase infiltration rate.

8-Vegetal cover: The dense vegetal cover over the surface of soil increases infiltration rate . It provides protection of soil surface against impact of rain drops.

9-Other factors : A large numbers of other factors , attract the rate of infiltration such as water quality , turbidity , salt content , entrapped air in soil pores.

Measurements of infiltration capacity:

It can be measured in the field using , infiltrometer , there are two types of infiltrometer:

1-Flooding type infiltrometer :it consist of metal cylinder open at both ends(22.5 cm) diameter , (60 cm) long .

The cylinder is put in the ground by plate and hammer about (10 cm) length of the cylinder above soil surface is (55 cm) filled with water gradually water infiltration occurs, water is added in the cylinder to keep the water level steady , reading are taken at regular intervals to determine the rate and amount of infiltration.

2-Rainfall simulator type infiltrometer : water is applied in a form of spray ,water is applied on a plot of (2 x 4)m in a form of artificial rain at uniform rate various intensities of rainfall can be simulated:

Infiltration = rainfall – surface runoff

Infiltration indices:

ϕ- Index : the average rate of rainfall where the volume of excess rainfall of that rate is equal to volume of surface runoff ,the value of Φ-index can be derive from rainfall hyetograph by trail and error .

To determine the value of ϕ-index a horizontal line is drawn on the hyetograph .So that the shaded area above the line is equal to the volume of surface runoff.

Hyetograph : is the graph demonstrate the relation between time and intensity of rainfall.

The area below the horizontal line represent all kinds of losses including interception , depression ,storage and infiltration.

If shaded area ≠ volume of measured surface runoff, then the horizontal line must be shifted upward or downward till the condition is satisfied.

w-index: average rate of infiltration during the period when rainfall intensity exceeds the infiltration rate.

$$\boldsymbol{w - Index = \frac{P - R - S}{tf}}$$

w-Index = average rate of infiltration(cm/hr)

p = total storm ppt. (cm)

R = total surface runoff (cm)

S = depression and interception (cm)

t_f = time period when the rainfall intensity exceeds infiltration rate (rainfall period)(hr).

The min. value of w-Index is called (w- min. index), it is obtained when the soil is very wet . the losses are very little they are neglected , then

w- index = ϕ – index

EXAMPLE 1; for a storm of 3 hr duration , the rainfall rates are :

time period(min)	Rainfall rate(cm/hr)
30	1.4
30	3.4
30	4.8
30	3.2
30	2
30	1.2

Determine ϕ-index and w-index if surface runoff is 3.4 cm ?

Solution:

1-Assume ϕ-index is more than 1.4 cm/hr

R = ((3.4-ϕ)+(4.8-ϕ)+(3.2-ϕ)+(2-ϕ))^x 30/60

3.4=6.7-2ϕ

Φ=1.65 cm/hr >1.4 cm/hr ok

2-total precipitation:

P=(1.4+3.4+4.8+3.2+2+1.2)^x 30/60 =8 cm

$$w - index = \frac{p - R - S}{t_f}$$

$$= \frac{8 - 3.4 - 0}{3} = 1.53\,\frac{cm}{hr}$$

EXAMPLE 2; for a storm of 2 hr duration , rainfall rates are :

Time period(min)	20	20	20	20	20	20
Rainfall rate (cm/hr)	2.5	2.5	10	7.5	5.1	1.25

Φ-index is 3 cm/hr, estimate surface runoff and w-index ?

Solution:

R=((10-3)+(7.5-3)+(5.1-3))x $\frac{20}{30} = 4.53\ cm$

$$w - index = \frac{9.62 - 4.53}{2} = 2.55\,\frac{cm}{hr}$$

GRAPHICAL REPRESENTATION OF FLOW:

Flow mass curve: it is accumulative flow volume verses time

Demand :is the required storage capacity of the reservoir to meet the demand

EXAMPLE1; the following table gives the mean monthly flow of stream in leap year . determine the min. storage capacity required to satisfy a demand of 50 m^3/sec

Solution:

Month	Mean monthly flow(m^3/sec)	Days in month	Monthly flow volume (cumec .day)	Accumulative volume(cumec.day)
Jan	60	31	1860	1860
Feb	50	29	1450	3310
Mar	40	31	1240	4550
Apr	28	30	840	5390
May	12	31	372	5762
Jun	20	30	600	6362
Jul	50	31	1550	7912
Aug	90	31	2740	10652
Sep	100	30	3000	13652
Oct	80	31	2480	16132
Nov	75	30	2250	18382
Dec	70	31	2170	20552

H.W. 6 draw flow mass curve?

EXAMPLE 2; the yield of water from a catchment area during each successive month is (1.4,2.1,2.8,8.4,11.9,11.9,7.7,2.8,2.52,2.24,1.96,1.68)* 10^6 m^3 . Determine the capacity required to allow the above volume of water to be drawn off at uniform rate assuming that no losses.

Solution:

1- By analytical method

Totalinflow= (1.4+2.1+2.8+8.4+11.9+11.9+7.7+2.8+2.52+2.24+1.96+1.68)*10^6=57.4*10^6 m^3

Monthly demand=$\frac{57.4*10^6}{12} = 4.78 * 10^6$ m^3

Storage required =((8.4+11.9+11.9+7.7)*10^6-(4.78*4)*10^6)=20.78*10^6 m^3

2- By flow mass curve :

The accumulative inflow= 57.4*10^6 m^3

The flow mass curve must be drawn by plotting the accumulative inflow as ordinate against time as abscisa

The monthly demand =$\frac{57.4*10^6}{12} = 4.78 * 10^6$ m^3

The storage required =8.04+12.74=20.78*10^6 m^3

H.W. 7 Draw flow mass curve

FLOW DURATION CURVE:

Is a graphical plot of discharge against the corresponding percent of time the stream discharge was equaled or exceeded .the stream flow data are arranged in descending order of stream discharges percentage probability , Pp of any flow is given as:

$$P_P = \frac{m}{N+1} * 100$$

EXAMPLE 1; the observed mean monthly flows of a stream for water year (June - May) are given in the table below .Plot the flow duration curve and estimate the flow that can be expected 75% of the time in a year.

Solution:

Month	Flow(m^3/sec)	Flowin descending order	Rank(m)	$P_P=\frac{m}{N+1} * 100$
Jun	15	44	1	7.7
Jul	16	40	2	15.4
Aug	44	35	3	23.1
Sep	40	31	4	30.8
Oct	35	30	5	38.5
Nov	31	23	6	46.2
Dec	30	21	7	53.8
Jan	21	18	8	61.5
Feb	23	16	9	69.2
Mar	18	15	10	76.9
Apr	15	15	11	84.6
May	8	8	12	92.31

H.W. 8 draw flow duration curve ,find the dependability of the flow 30 m^3/sec

EXAMPLE2; the following table gives the class interval of daily mean discharges of stream flow , and gives the numbers of days for which the flow in the stream belonged to that class for 4 years. Estimate 80% dependable flows for the stream.

Solution:

Daily mean discharges (m^3/sec)	No. of days for the flow and stream belonged the class 1995	1996	1997	1998	total	Acc.	$p_p = \frac{m}{N+1} * 100$
150-125	0	1	4	2	7	7	0.48
124.5-100	2	5	8	4	19	26	1.78
99.5-75	20	52	40	48	160	186	12.72
74.5-50	95	90	100	98	383	569	38.92
49.5-40	140	125	117	124	506	1075	73.53
39.5-30	71	75	65	50	261	1336	91.38
29.5-20	15	10	20	21	66	1402	95.9
19.5-10	15	8	10	18	51	1453	99.32
9.5-5	7	0	1	0	8	1461	99.93
Total	365	366	365	365	1461		

H.W.9 find Q_{50}

FLOODS

Flood represents an annual high stage in river such that the river over flows its banks and thus in undates the adjoining land .flood causes huge losses of life and properties besides disrupting all human activities resulting into large economic losses.

Estimating of peak flood:

1. Rational method
2. Empirical method
3. Unit hydrograph method
4. Flood frequency method

1.Rational method:

Q=C i A

Q=peak flood.

C=runoff coff. depending upon catchment nature and the rainfall intensity.

i=the mean intensity of rainfall (mm/hr)for duration equal to or exceeding (t_c)

t_c=critical time

$$i=\frac{a}{b+t_c}$$

a , b=constants depending upon catchment nature.

A= catchment area(Km^2)

Return period (T_r):

$T_r = \frac{1}{p_p}$

For example the 100 years flood is a flood which has probability of being exceeds once in every 100 years.

EXAMPLE1; catchment area of 40 Km^2, the runoff coff. is 0.35 ,the rainfall intensity duration relationships are:

i(mm/hr)=$\frac{500}{20+t_{min}}$ for $t_r = 10\ year$

i(mm/hr)=$\frac{399}{19+t_{min}}$ for $t_r = 20\ year$

Estimate the runoff flood for (10 years) and (20 years)for catchment length =60 m ,critical time =15 min.

solution:

for t_r=10 year

i=$\frac{500}{20+t_{min}}$ → i=$\frac{500}{20+15} = 14.285\,\frac{mm}{hr}$

Q=C i A

Q=0.3$\frac{14.285}{1000*3600} * 40 * 1000^2 = 55.55\ m^3/sec$

Probability of being exceed $\frac{1}{T_r} = \frac{1}{10} = 10\%$

For $T_r = 20\ year$

i=$\frac{399}{19+15} = 12.871\ \frac{mm}{hr}$

Q=c i A

Q=0.3$\frac{12.871}{1000*3600} * 40 * 1000^2 = 50.053$ m^3/sec

$$p_p = \frac{1}{T_r} = \frac{1}{20} = 5\%$$

2. Empirical method:

H=aQ^b

A=aQ^b

Q=peak flood

H=water height

A=catchment area

a ,b=constants depending upon catchment nature.

EXAMPLE1; the following measurements were conducted for a river .find the peak flood for river height =27 m

Solution:

H(m)	Q(m^3/sec)	Y=Ln(H)	X=Ln(Q)	XY	X^2
28.07	10	3.33	2.3	7.65	5.29
29.1	10.2	3.37	2.32	7.81	5.38
39.58	12.1	3.67	2.49	9.13	6.2
25.56	9.5	3.24	2.25	7.29	5.06
11.34	6.2	2.42	1.82	4.4	3.31
33.36	11	3.5	2.34	8.36	5.71
25.56	9.5	3.24	2.25	7.29	5.06
Total		$\sum\square = 22.77$	∑x=15.82	∑xy=51.93	$\sum x^2$=34.9

By using the empirical method

$H=aQ^b$ solving by least square method

Ln H=Ln a+ b Ln Q

Y=A+BX

$\sum Y=NA+B\sum X$ …1

$\sum Xy=A\sum X+B\sum X^2$ …2

$A=\frac{\sum Y-B\sum X}{N}$, $B=\frac{\sum XY-A\sum X}{\sum X^2}$

∴ A=- 0.00551 =Ln a →a=0.994

B=1.441=b

∴ $H=0.994\ Q^{1.441}$

$Q=\left(\frac{27}{0.994}\right)^{\frac{1}{1.441}}=9.857$

H.W.10 find the peak flood for catchment area of 1300 m^2

$A(m^2)$	$Q(m^3/sec)$
1225.13	10
1290.33	10.2
2010.83	12.1
1071.04	9.5
1347.106	6.2
1672.18	11
1071.048	9.5

Stream flow measurement

Stream flow: the water which constitutes the flow in the surface stream is called stream flow.

River stage: the river stage has been defined as the height of the water surface in the river at a given section above any arbitrary datum. It is usually expressed in meters. In many cases, the datum is taken as the mean sea level. Sometimes the datum may be selected at or slightly below the lowest point on the river bed.

Measurement of stage:

1-Manually type Gauges:

Vertical staff gauge:

It can be attached to a bridge pier or any other existing structure , it is read manually by noting the level of water surface in contact with it .

Sometimes the gauges may be placed in an inclined position up the stream bank , it must be properly anchored to the slope of the natural bank of the river channel .

Suspended weight gauge:

A weight attached to a rope is lowered from a fixed reference point on a bridge till it touches the water surface , by substracting the length of the rope lowered from the reduced level of the fixed reference point the stage is obtained.

$g= a-L$

2-Recording type gauges :

Automatic stage recorder : It is consists of a float tied to one end of a cable running over a pulley . To the other end of the cable a counter weight always keeps the cable in the tension . Any change in water surface makes the float either to rise or lower and this in turn makes the pulley rotate , this movement make a pen arm rests on a clock-driven drum warpped with a chart.

A float type automatic stage recorder requires a shelter in the form of a stilling well.

This stilling well gives protection to the float and counter weight from floating debris .

Discharge measurement

1- By Area-Velocity method :

Q = V * A

Current meter :

1- Cup type current meter (price current meter)
2- Propeller type current meter

The principle involved in both the meter is that the water flowing past the rotating element of the water makes revolve due to the speed of the rotating elements is directly proportional to the velocity of water .

V = a + b N

a and b : consists of the water

N : speed of the water in revolutions per second (rev / sec)

2-Average velocity across a vertical

1- Single point method
   $V = V_{0.4}$ (for shallow depth)
2- Two point method
   $V = (V_{0.2} + V_{0.8}) / 2$
   (This given a better result of average velocity)
3- Three point method :
   $V = (V_{0.2} + 2 V_{0.4} + V_{0.8}) / 4$
   This method is preferred in very deep streams

3-Discharge measurement by moving boat method :

In this method the data are collected while the observer is on a boat which is rapidly traversing the cross-section which may called **Dynamic approach**

Static approach the observer in a stationary position.

4- **Discharge measurement by slope-area method :**
   Chezy eq. $Q = C\sqrt{R\,S} * A$
   Manning eq. $Q = \frac{1}{n} R^{2/3} S^{1/2} A$
5- **Dilution method :**

In this method a solution of a stable chemical such as common salt or sodium dichromate or radioactive chemical known as the tracer , is injected into the stream at either a constant rate or all at once .

When the tracer is introduced into stream at a constant rate its called the plateau method

When introduced all at once its called gulp method

Mass balance eq.

$Q C_{\circ} + q C_1 = (Q + q) C_2$

$Q = q \frac{(C1-C2)}{(C2-C_{\circ})}$

If $C_{\circ} = 0$

$Q = q\left(\frac{C1}{C2} - 1\right)$

Q : river discharge

$C_\circ$: tracer conc. In river

q : discharge of tracer

C_1 : conc. of tracer

6- **Electromagnetic induction method :**
Electromagnetic field (emf)
Electrods provided at the sides of the channel section measure the emf produces due to the flow in river .

In Electromagnetic method :
$Q = k_1\left(\frac{E\,d}{I} + k_2\right)^n$
Q : rate of flow
d : depth of flow
E : emf induced
I : the current
k_1 , k_2 , n : system constants

7- **Ultrasonic method :** using ultrasonic signals
In ultrasonic method :
$t_1 = \frac{L}{u+V_p}$
$t_2 = \frac{L}{u-V_p}$
L : the path from A to B

$\frac{1}{t_1} - \frac{1}{t_2} = \frac{2\,V_p}{L} = \frac{2\,V\cos\theta}{L}$

$V = \frac{L}{2\cos\theta}\left(\frac{1}{t_1} - \frac{1}{t_2}\right)$

u : velocity of sound in water

u + V_p : a signal emitted at A travel with a speed of u + V_p

u - V_p : speed from B to A

V_p : V cos θ

t_1 : time from the signal to travel from A to B

t_2 : time from B to A

8- The mid section method

Q=VA

V=a+bN

Stage-Discharge Relation

$Q = K g^b$ using least square method

Ln Q = ln k + b ln g

$Q = K(g - a)^b$

$a = \frac{g_1 g_3 - g_2^2}{g_1 + g_3 - 2g_2}$

Q : discharge

g : stage

k , a , b : constant

CHAPTER THREE

Hydrograph

The runoff measured at the gauging station which vary with time, a single peak hydrograph consists of:

1-Rising Limb: or concentration curve , represents continuous increase of discharges or runoff at the watershed.

2-Crest Segment: the runoff from all parts of the watershed outlet simultaneously, the runoff attains the peak (maximum value).

3-Recession Limb: starts at the point of inflection (the end of crest segment) and continuous till the natural ground water flow.

Hydrograph Component :-

The water which constitutes stream flow may reach the stream channel by several paths from the point where it reaches the earth as ppt. :

1. Over land flow (surface runoff) : It is the water which travels over the ground surface to a channel.
2. Inter flow (sub surface runoff) : Is the water which infiltrates the Soil surface and move through the upper Soil layer until it reaches a stream channel.
3. Base flow : Is the water which percolate downward until it reaches the water table . The ground water may discharge into stream as ground water flow.

Separation of Hydrograph into its components :-

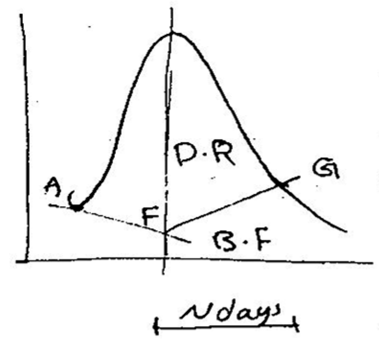
Method I

$N : L\ A^{0.2}$ L : 0.8 if A in (Km^2)

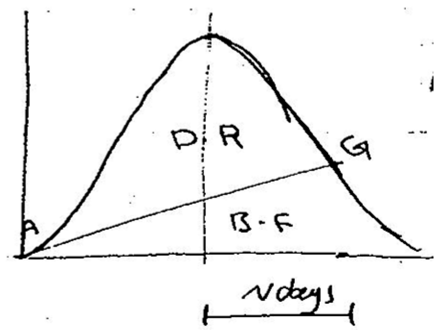
N : No. of days

A : catchment Area L : 1 if A in ($mile^2$)

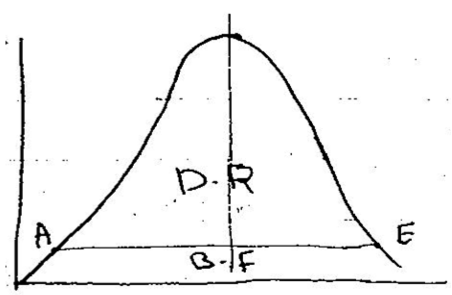
L : unit factor



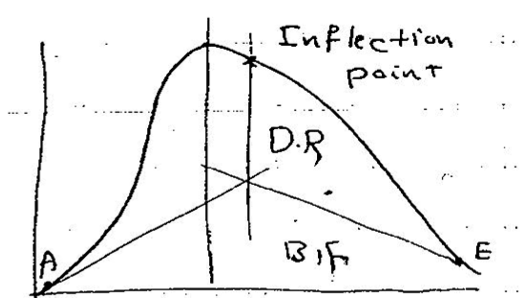
Method II



Method III



Method IV



This method is used when . The base flow is large and reach the stream quickly .

Method 1

1. أول شيء رسم الهايدروكراف Hydrograph .
2. حدد خط الذروة .
3. A(Starting point) .
4. احسب N من القانون N : L $A^{0.2}$.
5. وتحرك من خط الذروة بمسافة N وأرسم أو احدد نقطة G .
6. أصل بخط مماسي من A بخط يقطع خط الذروة بحيث يقطعه في F وصل بين F & G .
7. كل شيء للأسفل Base flow .
8. كل شيء للأعلى Direct flow .

Method 2

1. ارسم Hydrograph .
2. حدد A .
3. حدد خط الذروة .
4. قيس مسافة N من خط الذروة واصل بين G & A .

Method 3

1. ارسم Hydrograph .
2. أحدد A (Starting Point) .
3. أحدد E (End Point) .
4. أصل بين A & E .

Method 4

1. ارسم الهيدروكراف.
2. نحدد A .
3. مماس للأعلى من (A) .
4. مماس للأعلى من End Point (E) .
5. يتقاطعون في F .
6. كل شيء للأسفل B.F.(Base flow) .
7. كل شيء للأعلى D.R.(Direct runoff)

Ex: Separate given hydrograph in to its components, find the direct run off depth , the catchment area is 450 km^2 , use method IV.

Time (day)	Q (cumecs)	B.F		D.R
1	1.8	1.8		0
2	3	2.3		0.7
3	4.5	3		42
4	90	3.8		86.2
5	65	4.4		60.6
6	35	4.1		30.4
7	20	3.9		16.1
8	13	3.6		9.4
9	9	3.4		5.6
10	6.5	3.1		3.4
11	5	2.9		2.1
12	4	2.8		1.2
13	3	2.7		0.3
14	2.6	2,6		0
15	2.3	2.3		0

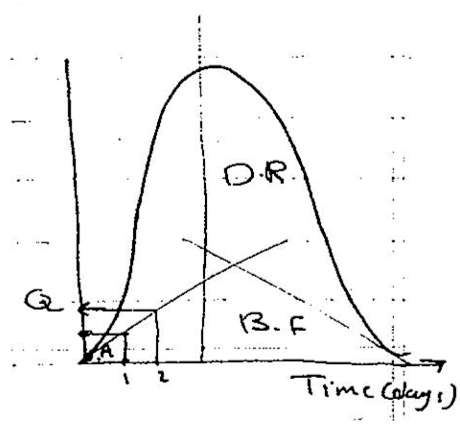
Sol:

Volume of Direct run off = 258.5 ×24 × 60 × 60

= 22334400 m^3

Depth of Direct Run off = $\frac{volume}{Area} = \frac{22334400}{(450)(1000)^2 m^2}$

= 4.96 cm



H.W (11) :

Solve the same example by using Method II catchment Area (7777 milc^2)

Ex: Separate the given hydrograph in to its components using method II , Area is 5033km^2.

Time (day)	Q (cumecs)	B.F	D.R
1	15	13	2
2	30	16	14
3	150	19	131
4	1500	24	1476
5	2000	29	1971
6	1200	35	1165
7	250	42	202
8	110	50	60
9	60	60	0
10	40	40	0
11	25	25	0
12	18	18	0
13	14	14	0
14	12	12	0
			$\sum = 5027$

Sol:

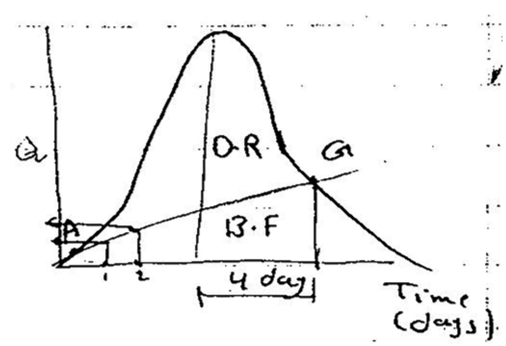
$N = 0.8\ A^{0.2}$

$= (0.8)\ (5033)^{0.2} = 4.4 = 4$ days

Vol. of D.R $= 5027 \times 24 \times 60 \times 60$

$= 434332800\ m^3$

Depth of D.R $= \frac{434332800}{5033(1000)^2} = 8.6$ cm



H.W (12) Solve The Same Example Use Method IV

Unit Hydrograph:

Is the direct runoff hydrograph resulting from one centimeter or one inch or one millimeter of excess rainfall generated uniformly over a catchment area at constant rate for an effective duration.

EX :- The following table lists the ordinates of - run off hydrograph in response to a rainfall 21.9mm during the first two hours, 43.9mmin the next two hours, and 30.9mm during the last two hours of the rainfall which lasted for six hours , Catchment area is 133.1km^2 , find :-

1. unit hydrograph
2. ϕ - Index.

Time (hr)	Q (cumecs)	Base flow (Cumecs)	Direct runoff (cumecs)	UH (Cumecs)
0	0	0	0	0
2	171	1.43	16957	20.41
4	393	2.86	390.14	46.9
6	522	4.29	517.71	62.3
8	297	5.71	291.29	35.05
10	133	7.14	125.86	15.15
12	51	8.57	42.43	5.11
14	10	10	0	0
16	10	10	0	0
18	10	10	0	0
Total			1537	184.46

Sol :- Draw and use method 3

Direct runoff Volume = 1537 × 2 × 3600 = 11066400m^3

D.R depth = $\frac{11066400\ m^3}{1331.1\ \times 10^6 m^2} = 8.31cm$

U H Volume = 184.46 × 2 ×3600 = 1331712

UH depth = $\frac{13311712\ m^3}{1331.1\ \times 10^6 m^2} = 0.995 \simeq 1\ cm$

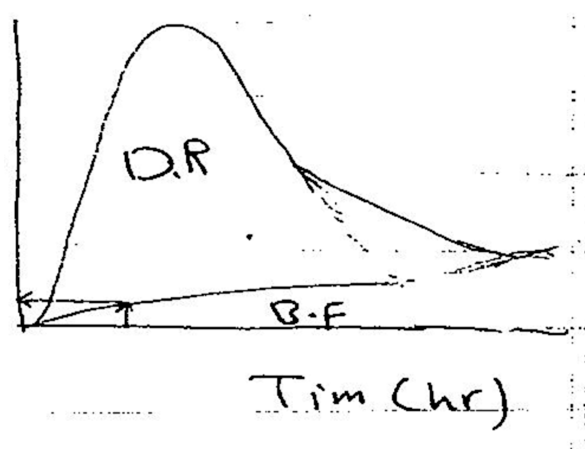
Total Rainfall depth

21.69 + 43.1 + 30.9 = 95.9 mm

Losses due to abstraction = 95.9 - 83.1 = 12.8 mm

$$\therefore\ \phi - Index = \frac{12.8\ mm}{6\ hr} = 2.13\ \frac{mm}{hr}$$

Q - Index = $\frac{\text{عمق الخسائر}}{\text{زمن المطرة الكلية}}\ (mm/hr)(Q)$



H.W (13) :

Given below are the ordinates of 6 hr UH. Calculate the Ordinates of Direct Runoff hydrograph due to rainfall excess of 3.5 cm. Draw the two hydrograph.

Time (hr)	UH (Cumecs)
0	0
3	25
6	50
9	85
2	125
15	160
18	185
21	160
24	110
27	60
30	36
33	25
36	16
39	8
42	0

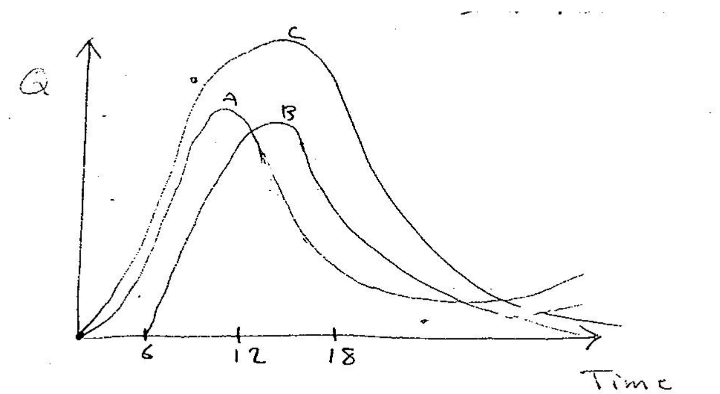
EX: Two storms each of 6 hr duration and having excess Values of 3cm and 2cm respectively , the 6hr UH for the catchment is given in the table below . Calculate the resulting direct runoff hydrograph , Note that the 2cm D.RH occurs after 3 cm DRH by 6 hr.

Time (hr)	6 hr UH	DRH of 3cm	DRH of 2cm	DRH of 5 cm
0	0	0	0	0
3	25	75	0	75
6	50	150	0	150
9	85	255	50	305
12	125	375	100	475
15	160	480	170	650
18	185	555	250	805
21	172.5	517.5	320	837.5
24	160	480	370	850
27	110	330	345	675
30	60	180	320	500
33	36	108	220	328
36	25	75	120	195
39	16	48	72	120
42	8	24	50	74
45	2.7	8.1	32	40.1
48	0	0	16	16
51	0	0	10.6	10.6
			0	5.4
			0	0

Hydrograph A = 3cm DRH *

Hydrograph B = 2cm DRH

Hydrograph C = 5cm DRH



H.W(14) : Draw the three hydrographs

Conversion of the Duration of Unit hydrograph

By Summation Curve [S - Curve Method]

Is a hydrograph produced by a continuous effective rainfall at a Constant rate for infinite Period. It is obtained by Summation of infinite Series at D-hr Unit hydrograph Spaced by D-hr apart .

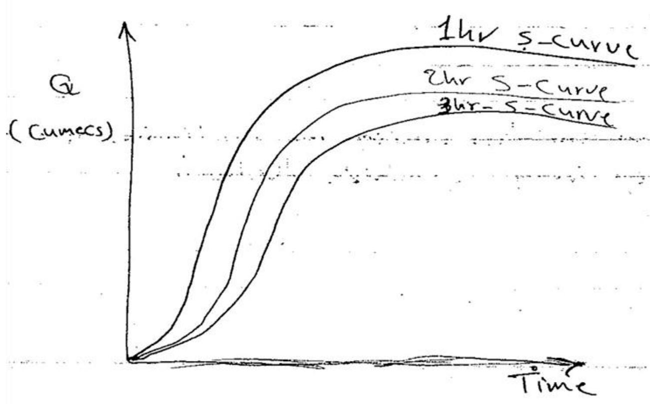
Ex : given the following UH , Find :-

1hr S - Curve

2hr S - Curve

3hr S - Curve

Sol :-



Time (hr)	UH (Cumecs)	1hr (S - Curve)	2hr (S - Curve)	3hr (S - Curve)
0	0	0	0	0
1	10	10	10	10
2	20	30	20	20
3	33	63	43	33
4	47	110	67	57
5	55	165	98	75
6	62	227	129	95
7	48	275	146	105
8	35	310	164	110
9	25	335	171	120
10	15	350	179	120
11	10	360	131	120
12	5	365	184	125
13	2	365	183	122
14	0	367	184	120

Ex: Given 4hr UH, derive the ordinates of 12hr UH using S - Curve Method .

Time (hr)	4 hr UH	S - Curve	12hr lagged S-curve	Abstraction	12hrUH
0	0	0	-	0	0
4	20	20	-	20	6.7
8	80	100	-	100	33.3
12	130	230	0	230	76.6
16	150	380	20	360	120
20	130	510	100	410	136.7
24	90	600	230	320	123.3
28	52	652	380	272	40.7
32	27	674	510	169	56.3
36	15	694	600	94	31.3
40	5	699	652	47	15.71
44	0	699	674	20	6.7
48	0	699	694	5	1.7
52	0	699	699	0	0
		-	699		
		-	699		
		-	699		

H.W. (15)

Using S - curve Method to derive 2hr UH from . The Ordinates of 4hr UH.

Time (hr)	4hr UH (cumecs)
0	0
2	8
4	20
6	43
8	80
10	110
12	130
14	146
16	150
18	142
20	130
22	112
24	90
26	70
28	52
30	38
32	27
34	20

H.W(16)

Given 2hr UH , Derive 3 hr UH

Time (hr)	2hr UH (cumecs)
0	0
1	70
2	170
3	260
4	370
5	410
6	340
7	250
8	170
9	120
10	100
11	80
12	60
13	40
14	20
15	16
16	0

CHAPTER FOUR

RESESRVOIR

Reservoir :- Any water Collected in a pool or Lake may be termed as reservoir . The water stored in a reservoir may be used for different Purposes.

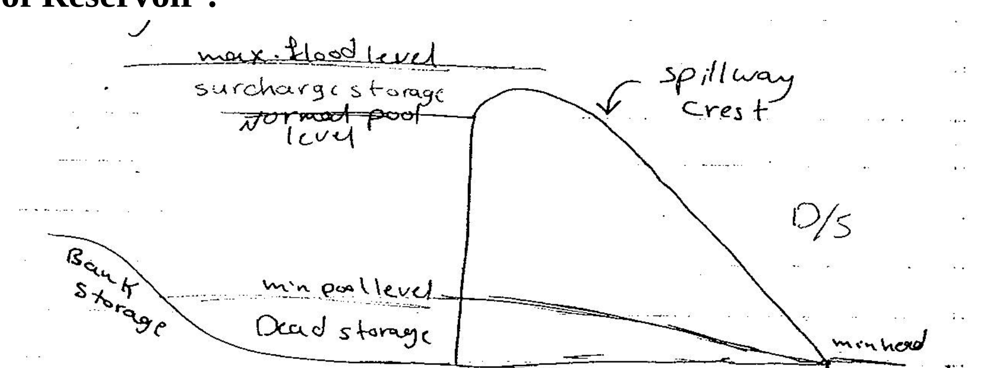
Purposes of Reservoirs :

1. Storage and Control for water in irrigation .
2. Storage and diversion of water for domestic uses .
3. Water supply for industries .
4. Development of Hydropower .
5. Increasing water depth for navigation.
6. Storage space for flood control.
7. Reclamation of low land.
8. Recreation.

Classification of Reservoirs :-

1. Storage Reservoir .
2. Flood Control Reservoir .
3. Distribution Reservoir .
4. Multi purposes Reservoir .

Storage Zones of Reservoir :



normal pool level :-

Normal Pool Level :-

Is the max. elevation to which the reservoir water surface will rise during normal operation Condition.

Max. Pool level:-

The max water elevation reached during flood

Useful Storage :-

The volume of water Stored in the reservoir between min pool level and normal pool level.

Surcharge Storage :-

The Volume of water stored between the normal pool level and max flood level.

Bank Storage :-

when the reservoir is filled up certain amount of water seeps into the permeable reservoir banks , this water comes out as soon as the reservoir depleted.

Storage Eq:-

$$\frac{\Delta s}{\Delta t} = \bar{I} - \bar{O}$$ $\Delta S = S_2 - S_1$, $\Delta t = t_2 - t_1$

$$\bar{O} = \frac{O_1 + O_2}{2}$$

$$\bar{I} = \frac{I_1 + I_2}{2}$$

$\frac{\Delta s}{\Delta t}$ = Rate of change in storage .

EX : The following data are given in the table for a reservoir , at 10 A.M . There are 0.492 ha.m of water in the reservoir. How much water in the reservoir at 8 P.M.

Time (hr)	Inflow $\left(\frac{m^3}{sec}\right)$	Outflow $\left(\frac{m^3}{sec}\right)$
10	0.596	0.885
12	0.741	0.741
14	1.196	0.569
16	1.358	0.341
18	1.368	0.228
20	1.026	0.228

$$\frac{\Delta s}{\Delta t} = \bar{I} - \bar{O}$$

Δs = net flow

Sol :-

Time	$\bar{I}$	$\bar{O}$	Net flow	Δt	Δs
10 – 12	0.66	0.748	-0.138	2	-0.276
12 – 14	0.968	0.655	0.313	2	0.626
14 – 16	1.367	0.435	0.435	2	1.824
16 – 18	1.453	0.284	0.284	2	2.338
18 -20	1.197	0.228	0.228	2	1.938
					$6.45\ \frac{m^3}{sec}$. Hr

$\Delta s = \frac{6.45 \times 3600}{10000} = 2.322$ ha.m

Total water in the reservoir

2.322 + 0.492 = 2.819 ha.m

EX: The runoff for a river along with the probable demand in (M cum) is given below :-

a. can the flow in river cater to the demand

b. what is the max uniform demand that can be made and what is the storage capacity required to meet the demand

Month	inflow	demand	deficit	Acc. deficit	Acc. Excess
Jan.	135	60	75	-	75
Feb.	23	55	-32	32	-
Mar.	27	80	-53	85	-
Ape.	21	102	-81	166	-
May	15	100	-85	251	-
Jun	90	121	-31	332	-
Jul	120	38	82	-	82
Aug	185	30	155	-	237
Sep.	112	25	87	-	324
Oct.	87	59	28	-	352
Nov.	63	85	-22	22	-
Dec.	42	75	-33	55	-
Total	870				

a. The max - Cumulative is 332 Mm^3 , The Cumulative excess shows that the reservoir will be filled in October.

b. Max. uniform demand = $\frac{870}{12}$ = 72.5 Mm^3 ,

storage required = (135 + 120 + 185 + 112 + 87) - (72.5 * 5) = 261.5 Mm^3

Available storage Capacity of a Reservoir :-

It is most important function is to store water during Flood and to release it later . The available storage Capacity of a reservoir depends upon the topography of the Site and height of the dam.

To determine the available storage Capacity of a reservoir up to certain level water, engineering Survey are usually Conducted .

Area - Elevation Curve :-

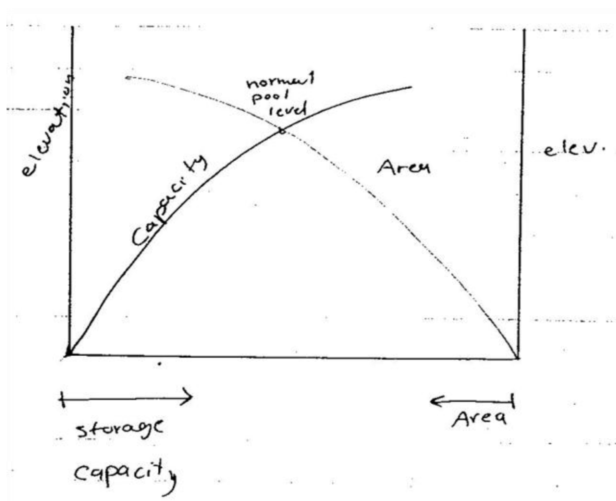
From the Contour Plan , the water spread area of the reservoir at any elevation is determined by measuring the area enclosed the corresponding contour.

A planimeter is used for measuring the area. An elevation area curve is then drawn between the surface area as abscissa and the elevation as ordinate.

Elevation - Capacity Curve :-

The storage Capacity of the reservoir at any elevation is determined from the water spread area at various elevation. The following formula are commonly used to determine the storage capacity.

$\Delta V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)$ cone formula



Area - Capacity Curve

Example: Draw Area-Capacity curve from the following information.

Elevation(m)	Area(km^2)	ΔV	V
295	2.48	0	0
300	7.862	24.596	24.596
305	8.901	41.88	66.476
310	15.538	60.332	126.808
315	18.608	85.25	212.25

Solution:

$$\Delta V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)$$

$$= \frac{5}{3}\left(2.48+7.862+\sqrt{2.48 * 7.862}\right) = 24.596$$

H.W 17: A reservoir has the following areas enclosed by contours of various elevations. Draw the Area Capacity Curve , and determine the capacity of a reservoir.

Elevation	Area
200	150
220	175
240	210
260	270
280	320
300	400

Area-Elevation Relation:

$A=K(H-a)^b$

1-From H_1 find A_1

From H_3 find A_3

2-$A_2=\sqrt{A_1A_3}$

From A_2 find H_2

3- $a=(H_1H_3-H_2^2)/(H_1+H_3-2H_2)$

4-Using Least Square Method:

$A=K(H-a)^b$

$\ln A=\ln K+b\ln(H-a)$

$Y=\ln A$, $B=b$, $X=\ln(H-a)$

$Y=A+BX$

$\Sigma Y=NA+B\Sigma X$ -----------------1

$\Sigma XY=A\Sigma X+B\Sigma X^2$ ---------2

Example: Draw Area-Elevation Relation for H1=290m, H3=305m

Solution:

H	**A**	**Y=LnA**	**X=Ln(H-285)**	**X^2**	**XY**
290	1.1	0.095	1.609	2.588	0.153
295	2.3	1.029	2.302	5.299	2.357
300	5	1.609	2.70	7.29	4.344
305	7.9	2.066	2.995	5.978	5.051
310	12.2	2.501	3.218	10.356	8.048

$\Sigma Y=7.3$ $\Sigma X=12.832$ $\Sigma X^2=39.545$

$\Sigma XY=21.112$

From rating curve:

$H_1=290m$, $A_1=1.1km^2$

$H_3=305m$, $A_3=7.9km^2$

$A_2=\sqrt{A_1 A_3}$,A2=2.947km^2

From $A_2= 2.947km^2$, $H_2=295m$

$a=(H_1H_3-H_2^2)/(H_1+H_3-2H_2)$

$a=(290)(305)-(295)^2/(290+305-2*295)$

a=285

$A=K(H-a)^b$

7.3=5A+B(12.832)

$21.42=A(12.832)+B(39.545)$

$B=1.477,\ A=-2.322$

$A=0.098(H-285)^{1.474}$

Elevation-Capacity Relation:

$V=K(H-A)^b$

1-From H_1 find V_1

From H_3 findV_3

2-$V_2=\sqrt{V_1V_3}$

From V_2 find H_2

3- $a=(H_1H_3-H_2^2)/(H_1+H_3-2H_2)$

4-Using Least Square Method:

$V=K(H-a)^b$

$\text{Ln } V=\text{Ln } K+b\text{Ln}(H-a)$

$Y=\ln V$, $B=b$

$Y=A+BX$

$\Sigma Y=NA+B\Sigma X$ ----------------1

$\Sigma XY=A\Sigma X+B\Sigma X^2$ ---------2

H.W 18:Derive Elevation-Capacity Relation for the same Example

RESERVOIR SEDIMENTATION :

Stage of Sedimentation:

1-EROSION AND WEATHERING:

Erosion can be done by:

1-water erosion.

2-wind erosion.

3-ice erosion.

4-gravity erosion.

1-water erosion:

a-sheet erosion: is the detachment of the material from the land surface by rain drops impact and subsequent removal over land flow.

b-channel erosion: is the removal and the transport of the material by concentrated flow.

2-wind erosion:

The rate of the wind erosion is influenced by such factors:

a-wind velocity.

b-reaches.

c-moisture content.

d-particle size.

e-Roughness of the surface.

3-ice erosion: due to freezing of water in the fractures of the soil.

4-gravity erosion: it is occur when forces caused by the weight of material exceed forces of resistance or sheering strength of the material such as land slide, sloughing of slope.

2-TRANSPORTATION:

a-bed load: movement of particles on the bed rolling, sliding, and jumping.

b-suspension load: movement of particles through the fluid of the flow as suspended materials

1-ripple or comb tooth.

2-ripple with dune.

3-dune.

4-flat surface.

5-sandy wave.

6-antinode.

3-SEDIMENTATION:

Trap Efficiency: is the ratio between the total sediment in the reservoir to the total sediment comes by the flow.

Trap Efficiency= capacity/inflow

=C/I

Example 1:

Find the probable life of the reservoir with initial capacity of 30Mm^3, if the average annual flow is 60Mm^3 and the average annual sedimentation in flow is 200000 Ton, assumed the specific weight of the sediments equal to 1.2 gm/cm^2, assume that 80% of the initial capacity will fill with sediments.

Capacity inflow ratio	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Trap eff.	87	93	95	95.5	96	96.5	97	97	97	97.5

Solution:

Capacity of reservoir	**C/I**	**Trap eff.**	**Average Trap eff**	**Vol. of sed**	**Capacity vol**	**No. of years**
30	0.5	0.96				
			0.9575	0.9575*0.166*10^6	6	37.6
24	0.4	0.955				
			0.9525	0.9525*0.166*10^6	6	37.8
18	0.3	0.95				
			0.94	0.94*0.166*10^6	6	38.3
12	0.2	0.93				
			0.9	0.9*0.166*10^6	6	40
6	0.1	0.87				
						153.7

The weight of the sedimentation=200000 Ton

$200000*1000000=2*10^{11}$gm

Vol. of sediment=$2*10^{11}/1.2*10^{6}=0.166*10^{6}m^{3}$

At 100%, C/I=30/60=0.5,Trap eff.=0.96

At 80%,C/I=24/60=0.4,Trap eff,=0.955

Vol. of sediments=$0.166*10^6 m^3$

Capacity volume=$6Mm^3=6*10^6 m^3$

No. of years=$6*10^6\ m^3/0.9575*0.166*10^6 m^3/yr$

=37.6 yr

Example 2:

Work out the life of the reservoir before its capacity is reduced to 20% of the initial capacity from the following sedimentation data, catchment area is $1000km^2$, reservoir capacity is 10000 ha.m, average annual flow amount is 15cm of runoff, average annual sediment is 0.36 million tones, specific gravity is $1.2gm/cm^3$

Solution :

$I=[15cm*1000km^2*10^6 m^2/km^2]/[100cm/m*10^4 m^2/ha]$

=15000 ha.m

C=10000ha.m

Volume of sediment=$[0.36*10^6*10^3]/[1.2*10^{-3}*10^6*10^4]$=30 ha.m

Capacity of reservoir	C/I	Trap eff.	Average Trap eff	Vol. of sed	Capacity vol	No. of years
10000	0.67	0.98				
			0.97	30*0.97=29.1	2000	69
8000	0.53	0.96				
			0.95	28.5	2000	70
6000	0.4	0.94				
			0.92	27.6	2000	72
4000	0.27	0.90				
			0.87	25.1	2000	77
2000	0.13	0.84				
						288 yr

CHAPTER FIVE

EVAPORATION

Evaporation: is the process by which water from liquid state passes in to vapor state.

Sublimation: water converted from solid state to vapor state without passing through liquid state.

Transpiration: water passes from liquid to vapor state through plant metabolism.

Evapotranspiration: the process by which water is evaporated from wet surfaces and transpired by plants together.

Factors effecting evaporation:

1-Radiation;

If the annual solar radiation is large the annual evaporation is also large, evaporation need continuous supply of energy.

2-Vapor pressure:

$$Relative\ humidity = \frac{e}{e_s}$$

Where;
e: actual vapor pressure.
e_s: saturated vapor preure.

Note: when humidity increases, evaporation decreases.

3-Temperature: Temperature depends on solar radiation, if temperature increases, evaporation increases too.

$E \propto T$

4-Wind: the wind motion give a chance for evaporation, higher wind velocities may cause higher evaporation.

5-Atmospheric pressure: if atmospheric pressure decreases, evaporation increases, because the vapor presser of air also decrease and thus increase the vapor pressure deficit.

$$E \propto \frac{1}{P}$$

6-Water Quality:

The presence of solute in water reduces the evaporation, evaporation decreases by one percent for every one percent increase in salinity.
Specific gravity of salty water is 1.03 gm/cm^3.
Specific gravity of fresh water is 1 gm/cm^3.

When specific gravity increases, evaporation decreases.

Evaporation of sea is 2 to 3 % less than the evaporation from fresh water.

7-Size of water surface:

The depth of evaporation from larger surface is less compared to evaporation from smaller surface.

8-Nature of evaporation surfaces:

1-land surface: evaporation decreases with dry soils

2-snow surface: evaporation occur when the vapor pressure of the overlying air is less than the vapor pressure.

3- water bodies.

H.W : what is the reason of:

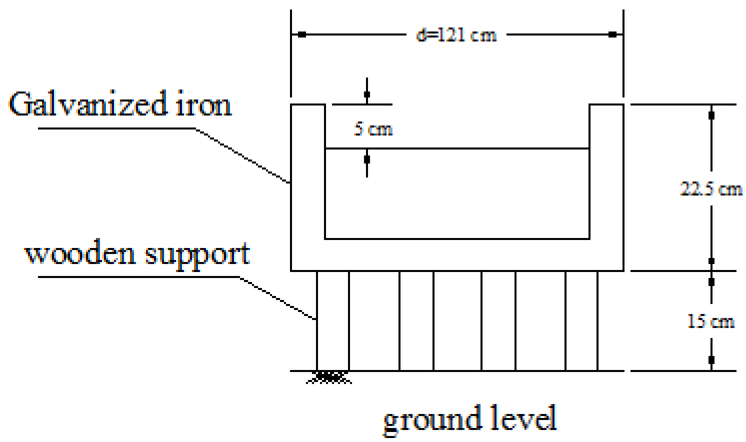
1. In the sea, the evaporation increases in the winter more than in the summer.
2. The evaporation increases at night more than at day.

Measurement of Evaporation:

There are seven types of measurement apparatus, the most common are:

1. Class A pan.
2. Colorado pan.

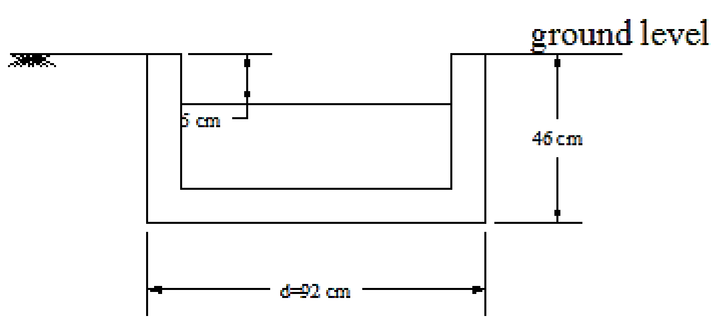
Surface pan:



$$E_{lake} = K \times E_{pan}$$

In lake there is infiltration therefore , there is correction factor (K = 0.7).

Sunken pan:



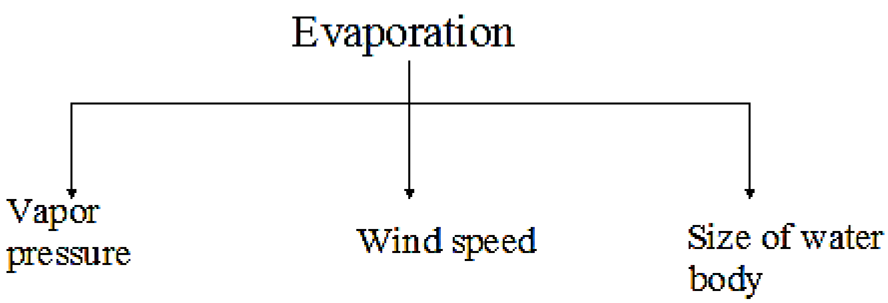
$$E_{lake} = K \times E_{pan}$$

Where; K = 0.75

Measurement of Evaporation:

By empirical relation

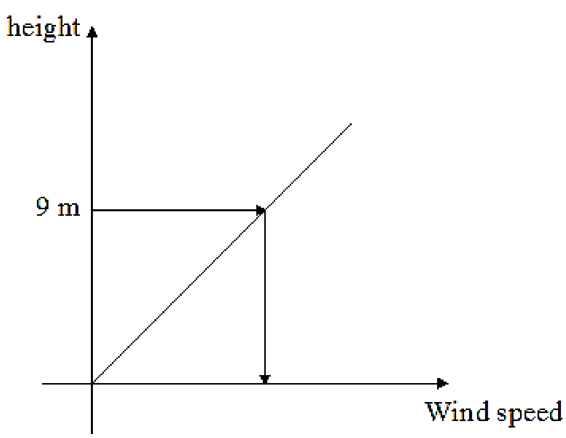
Meyer's equation:



$$E = k(e_s - e)(1 + \frac{U_9}{16})$$

Where;

E: evaporation from lake (mm/Hg).
U_9 : wind speed at 9 m above ground.
k = 0.5 for small areas.
k = 0.36 for big areas.



$$U_h = C(h)^{1/7}$$
$$U_9 = C(9)^{1/7}$$

Example:

A reservoir of surface area 250 ha had the following data: water temperature 20^0 C, relative humidity 40 %, wind velocity at 2 m above ground is 20 Km/hr, e_s = 17.5 mm Hg, Find:

1. Average daily evaporation.
2. Volume of water evaporated during one week.

Solution:

$$E = k(e_s - e)(1 + \frac{U_9}{16})$$

Relative humidity $= \frac{e}{e_s} = 40\ \%$

$$\frac{e}{17.5} = 40\ \% \Rightarrow e = 7\ mm\ Hg$$

$$U_2 = Ch^{1/7} \Rightarrow 20 = C\left(2^{1/7}\right) \Rightarrow C = 18.125$$

$$U_9 = C9^{1/7} = 24.7$$

$$k = 0.36\ for\ big\ area$$

$$E = 10\ mm\ Hg$$

$$A = 250\ ha = 250 \times 10^4 m^2 = 2.5 \times 10^6 m^2$$

$$V = E \times A = \frac{10\ (\frac{mm}{day})}{1000} \times 2.5 \times 10^6 = 25000\ m^3/day$$

$$V = 25000\ \frac{m^3}{day} \times \frac{7day}{week} = 175000 \frac{m^3}{week}$$

Estimation of Evaporation by Water Budget Equation:

$$E = \Delta s + I + P - O - O_g$$

Where;

I : surface inflow into he lake.

P :precipitation of the lake.

E : evaporation from lake.

O_g : subsurface seepage.

O : subsurface outflow.

$\Delta s = s_1 - s_2$

s_1 : storage at the beginning of the interval (Δt).

s_2 : storage in the lake at the end of the interval (Δt).

$$\therefore E = s_1 - s_2 + I + P - O - O_g$$

Example:

At the beginning of a given day a reservoir has surface area 20 Km^2. The inflow to the reservoir during the day is 30 m^3/sec and the reservoir outflow is 15 m^3/sec. The day was dry and the seepage may be assumed to be negligible. Determine reservoir evaporation when by the end of the day reservoir level decreased 1 cm.

Solution:

$I = 30\ m^3/\sec = 30\ \frac{m^3}{sec} \times 24 \times 3600 = 2.592 \times 10^6 m^3$

$O = 15\ m^3/\sec = 15 \frac{m^3}{sec} \times 24 \times 3600 = 1.296 \times 10^6\ m^3$

$O_g = 0, = 0$, (given).

$\Delta s = 1\ cm\ \times A = 0.01\ m\ \times 20 \times 10^6 = 0.2 \times 10^6 m^3$

$\therefore E = (0.2 + 2.592 - 1.296) \times 10^6 m^3 = 1.496 \times 10^6 m^3$

$E_{depth} = \frac{1.496 \times 10^6 m^3}{20 \times 10^6 m^2} = 0.0748\ m = 7.48\ cm$

Transpiration:

Factors affecting Transpiration

1-Plant factors:

The extent of the root system in moisture absorption, leaf arrangement and structure, leaf area.

2-Soil factors:

Available water: is the moisture content in the soil between the field capacity and wilting point.

3-Climatic factors:

Solar radiation, light intensity, atmospheric pressure, temp., wind.

Evapotranspiration:

Evaporation + Transpiration = Consumptive use

Factor effecting Evapotranspiration:

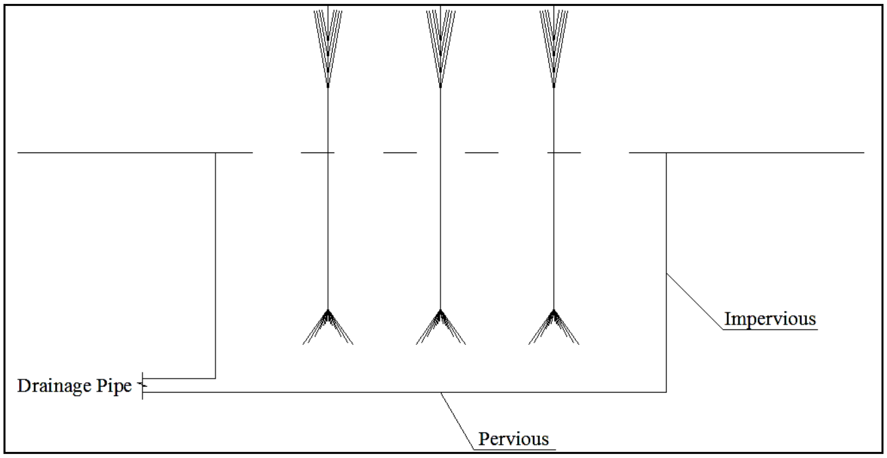
1. Meteorological factors.
2. Density of vegetation.
3. Soil moisture.
4. Age of plants.
5. Adjoining lands.
6. Surface of leaves.

Estimation of Evapotranspiration:

1. Lysimeter method.
2. Empirical method.

Lysimeter method:

E_t is measured with a Lysimeter also known as evapotranspirator which is consist of small tank in which the plants are grown, cylindrical tank about 60 to 90 cm in diameter, and 180 cm deep. The Lysimeter is filled with soil and plants grown in it. Lysimeter is buried in the ground.



E_t : is equal to the loss of water during the period of growth the plant. These losses determined by moisture sampling.

Estimation of Evaporation by Empirical Relation:

Blaney-Criddle Equation:

Is based on the data collected from the ariad western zone of the United State, and is commonly used all the world over.

$$E_t = 2.59\, K \sum P_n \frac{T_c}{100}$$

Where;

T_c : monthly mean temperature in Fahrenheit.

P_n: sunshine hours.

K : coefficient determined for each crop.

Example:

K for certain crop is 0.65, calculate the consumptive use for the season from Nov. to Feb. using Blaney-Criddle equation.

Months	Nov.	Dec.	Jan.	Feb.
T_i	16.5	13	11	19.5
P_n	7.19	7.15	7.3	7.03

Solution:

$$E_t = 2.59\,K \sum P_n \frac{T_c}{100}$$

$$\sum P_n = 7.19 + 7.15 + 7.3 + 7.03 = 28.67$$

$$T_c = \frac{16.5 + 13 + 11 + 19.5}{4} = 13.75$$

$$T_F = 1.8T_c + 32 = 1.8 * 13.75 + 32 = 59\ F$$

$$E_t = 2.59 * 0.65 * 28.67 * \left(\frac{59}{100}\right) = 26.86\ cm$$

CHAPTER SIX

WIND

Wind:

It is an air motion measured by Anemometer.

Wind velocity depend on:

1. Thermal turbulence.
2. Mechanical turbulence.

Wind is caused by differences in the atmospheric pressure. When a difference in atmospheric pressure exists, air moves from the higher to the lower pressure area, resulting in winds of various speeds.

Globally, the two major driving factors of large-scale wind patterns (the atmospheric circulation) are the differential heating between the equator and the poles (difference in absorption of solar energy leading to buoyancy forces) and the rotation of the planet.

is usually expressed in terms of the direction from which it **Wind direction** originates. For example, a *northerly* wind blows from the north to the south. Weather vanes pivot to indicate the direction of the wind. At airports, windsocks indicate wind direction, and can also be used to estimate wind speed by the angle of hang.

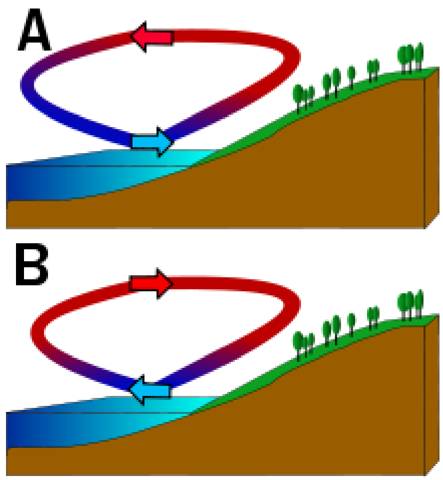
Wind measurement Cup-type anemometer with vertical axis, a sensor on a remote meteorological station

Wind speed is measured by anemometers, most commonly using rotating cups or propellers.

When a high measurement frequency is needed (such as in research applications), wind can be measured by the propagation speed of ultrasound signals or by the effect of ventilation on the resistance of a heated wire.

Another type of anemometer uses pitot tubes that take advantage of the pressure differential between an inner tube and an outer tube that is exposed to the wind to determine the dynamic pressure, which is then used to compute the wind speed.

Sea and Land Breeze

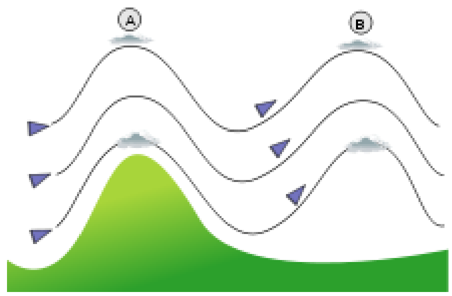


A: Sea breeze (occurs at daytime), B: Land breeze (occurs at night)

In coastal regions, sea breezes and land breezes can be important factors in a location's prevailing winds. The sea is warmed by the sun more slowly because of water's greater specific heat compared to land.[44] As the temperature of the surface of the land rises, the land heats the air above it by conduction. The warm air is less dense than the surrounding environment and so it rises. This causes a pressure gradient of about 2 millibars from the ocean to the land. The cooler air above the sea, now with higher sea level pressure, flows inland into the lower pressure, creating a cooler breeze near the coast. When large-scale winds are calm, the strength of the sea breeze is directly proportional to the temperature difference between the land mass and the sea. If an offshore wind of 8 knots (15 km/h) exists, the sea breeze is not likely to develop.

At night, the land cools off more quickly than the ocean because of differences in their specific heat values. This temperature change causes the daytime sea breeze to dissipate. When the temperature onshore cools below the temperature offshore, the pressure over the water will be lower than that of the land, establishing a land breeze, as long as an onshore wind is not strong enough to oppose it.

Mountains and Valleys Breeze



Over elevated surfaces, heating of the ground exceeds the heating of the surrounding air at the same altitude above sea level, creating an associated thermal low over the terrain and enhancing any thermal lows that would have otherwise existed, and changing the wind circulation of the region. In areas where there is rugged topography that significantly interrupts the environmental wind flow, the wind circulation between mountains and valleys is the most important contributor to the prevailing winds. Hills and valleys substantially distort the airflow by increasing friction between the atmosphere and landmass by acting as a physical block to the flow, deflecting the wind parallel to the range just upstream of the topography, which is known as a barrier jet. This barrier jet can increase the low level wind by 45%. Wind direction also changes because of the contour of the land.

If there is a pass in the mountain range, winds will rush through the pass with considerable speed because of the Bernoulli principle that describes an inverse relationship between speed and pressure. The airflow can remain turbulent and erratic for some distance downwind into the flatter countryside. These conditions are dangerous to ascending and descending airplanes. Cool winds accelerating through mountain gaps have been given regional names.

In mountainous areas, local distortion of the airflow becomes severe. Jagged terrain combines to produce unpredictable flow patterns and turbulence, such as rotors, which can be topped by lenticular clouds. Strong updrafts, downdrafts and eddies develop as the air flows over hills and down valleys.

Orographic precipitation occurs on the windward side of mountains and is caused by the rising air motion of a large-scale flow of moist air across the mountain ridge, also known as upslope flow, resulting in adiabatic cooling and condensation. In mountainous parts of the world subjected to relatively consistent winds (for example, the trade winds), a more moist climate usually prevails on the windward side of a mountain than on the leeward or downwind side. Moisture is removed by orographic lift, leaving drier air on the descending and generally warming, leeward side where a rain shadow is observed. Winds that flow over mountains down into lower elevations are known as downslope winds. These winds are warm and dry.

plot of wind vectors at various heights in the troposphere, **Hodograph** which is used to diagnose vertical wind shear

Effect of wind

Erosion can be the result of material movement by the wind

Desert dust migration

Effect on plants, Wind dispersal of seeds, Wind also limits tree growth

Effect on animals, Cattle and sheep are prone to wind chill caused by a combination of wind and cold temperatures

Sound generation, **Wind causes the generation of sound. The movement of air causes movements of parts of natural objects, such as leaves or grass. These objects will produce sound if they touch each other. Even a soft wind will cause a low level of environmental noise. If the wind is blowing harder, it may produce howling sounds of varying frequencies. This may be caused by the wind blowing over cavities, or by vortices created in the air downstream of an object. Especially on high buildings, many structural parts may be a cause of annoying noise at certain wind conditions. Examples of these parts are balconies, ventilation openings, roof openings or cables.**

High winds are known to cause damage, depending upon their strength. Infrequent wind gusts can cause poorly designed suspension bridges to sway.

Wind speed variation with altitude can be represented by a simple empirical power law:

$$\frac{U}{U_1} = \left[\frac{Z}{Z_1}\right]^{\propto}$$

Where;

U : wind speed at Z height.

U_1 : wind speed at Z_1 height.

The reference height for surface when measured is usually 10 m.

α= 0.25 for unstable condition.

α = 0.5 for stable condition.

Example:

Estimate the wind speed at a stack height 250 m, if the wind speed has been measured on clear sunny day is 3 m/sec at a top of 10 m tower.

Solution:

Clear sunny day = unstable condition

Then, α= 0.25

$$\frac{U}{U_1} = \left[\frac{Z}{Z_1}\right]^{\propto}$$

$$\frac{U}{U_{10}} = \left[\frac{Z}{Z_{10}}\right]^{\propto}$$

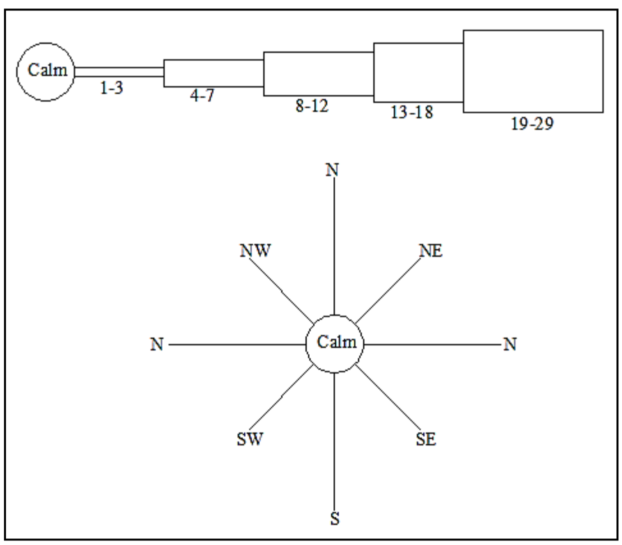
$$\frac{U}{3} = \left[\frac{250}{10}\right]^{0.25} \Rightarrow U = 6.7\ m\ /sec$$

Wind Rose:

Wind rose is a graphic picture of velocity and the direction from which the wind came.

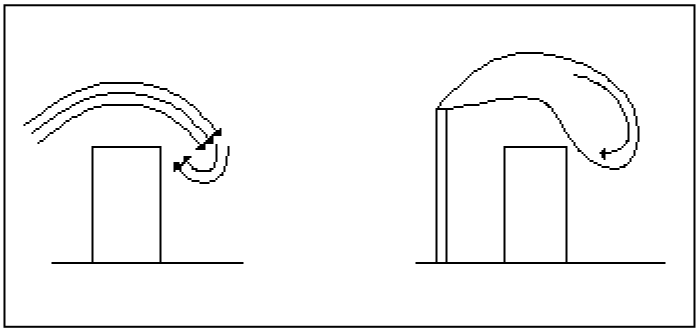
There are four features of wind rose:

1. The orientation of each segment shows the direction from which the wind came.
2. The width of each segment is proportional to the wind speed.
3. The length of each segment is proportional to the percent of time.
4. The sum of all parts plus the percent of clam must equal to 100 %.

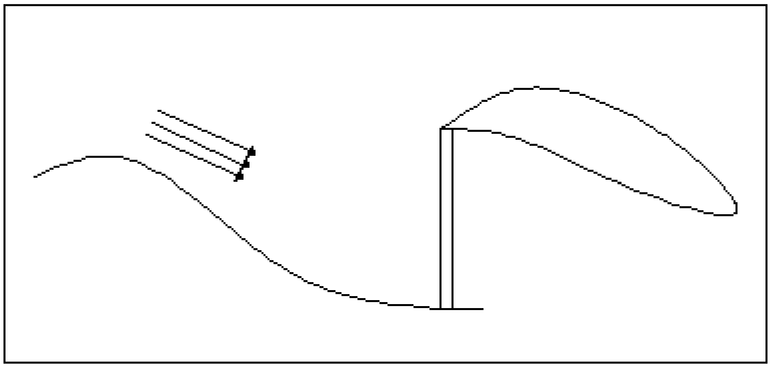


Aerodynamic Effects on Structures:

- The flow around a building is characterized by the formation of a cavity behind the building.
- When the stack is situated adjacent to the building the plume may entrained in the flow pattern.
- The stack height should be at least 2.5 times the height of the surrounding building.
- If the stack height is below this value the plume is trapped in the weak zone of the building and the pollutants remain because of very poor mixing.



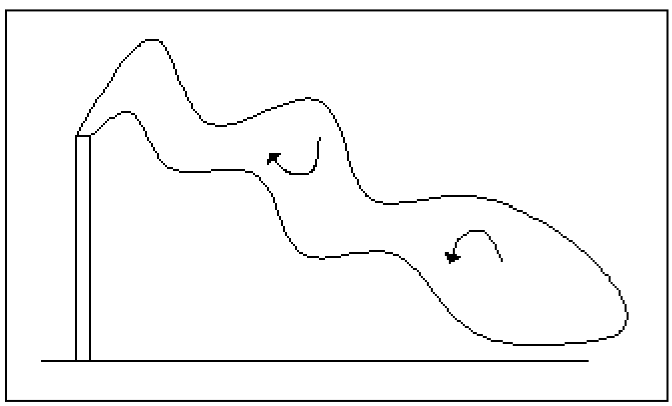
- Plume emitting from a stack in deep valley can be carried to the ground when wind blows over a cliff (this condition is known as down wash).
- If the velocity of the plume through the stack is equal or less than wind velocity then the plume may carried down ward on the back side of the stack.



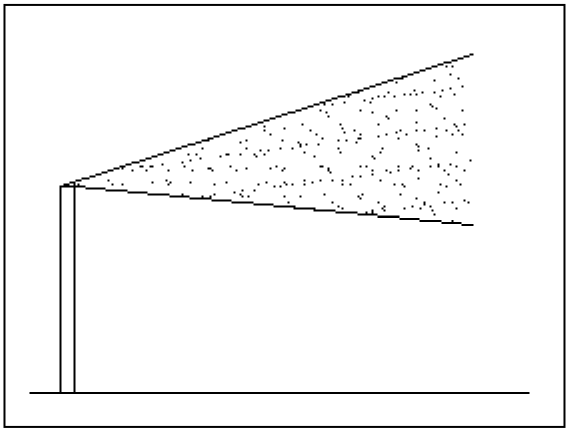
Plume Behaivor:

There are six classifications:

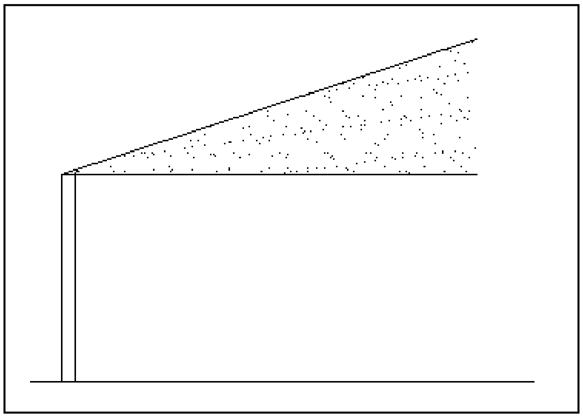
1. Looping:
   - Light to moderate wind speed.
   - Hot summer afternoon.
   - Large scale of thermal eddies carry portion of the plume to the ground level for short time period.



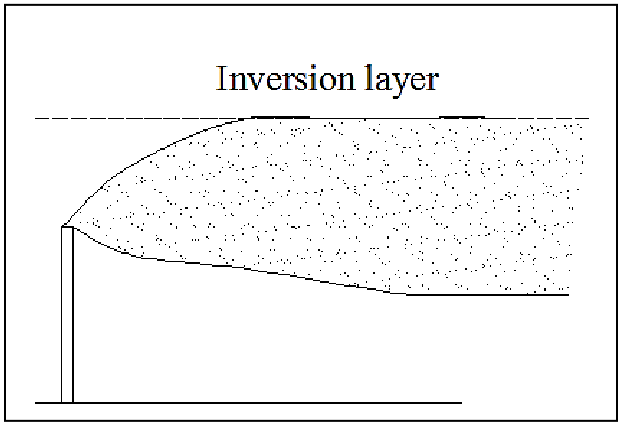
2. Conning:
   - Natural condition.
   - Moderate to light wind speed
   - Cloudy sky during day and night.
   - The plume shape like a cone.
   - The pollutants are carried downward far before reaching the ground level.



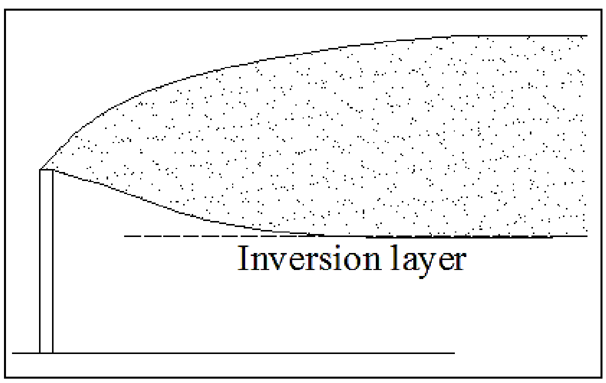
3. Fanning:
   - Very light wind speed.
   - Observed at night and early morning.
   - The plume travel parallel to the ground and does not contribute to the ground pollution.



4. Fumigation:
   - Occur when inversion layer is breaking during the day by sun heat.
   - Thermal mixing will occur.
   - More common in summer season.
   - Clear sky and light wind.
   - Last for 30 min usually.



5. Lofting:
   - Inversion exists only below the plume.
   - The pollutants are emitted above the inversion layer and dispersed vigorously in the upward direction.
   - The toe of inversion layer acts as barrier.
   - It is the major goal of the tall stack operation.



6. Trapping:
   - Occur when the plume coated between two inversion layers.
   - The plume diffused with limited vertical height (unstable layer).

CHAPTER SEVEN

GOUND WATER

GROUND WATER: or subsurface water refers to the water that occurs below the surface of earth. The main source of ground water is infiltration. The infiltrated water after meeting the soil moisture deficiency percolate deeply and becomes ground water.

The formation below the earth's surface is divided in to two zones by an irregular surface called the water table. At all points on the water table the pressure is atmospheric. The zone between the ground surface and the water table is called unsaturated zone or the vadose zone. In the vadose zone the soil pores my contain either air or water or both. Hence it iscalled the zone of aeration.

-it is more than resource.
-it is a part of hydrologic cycle.
-it leads to environmental problems like land subsidence.

-it is a key to understand geological process like generation of earth quakes, migration and accumulation of petroleum.

OCCURANCE OF GROUND WATER: Ground water occurs at various locations below the earth's surface depending on the physical properties of various formation that exist.

Aquifer: formation which contain ground water and at the same time which are sufficiently permeable to transmit and yield water in usable quantities.

Unconfined Aquifer: An aquifer having water table in it , for this aquifer water table serves as the upper surface of zone of saturation while a less permeable or impermeable layer defines its lower boundary.

Confined Aquifer: When an aquifer is sandwiched between two layers of much less permeable material than it, for example a sandy layer between two clay layers.

Aquiclude: A geological formation which is saturated and which may contain large amount of water because of its high porosity but cannot transmit water as it is relatively impermeable, for example a clay layer.

Aquitard: It is a saturated geological formation which is poorly permeable and hence it dose not yield water freely to wells. It may transmit vertically appreciable quantities of water to or from adjacent aquifer, for example sandy clay.

Aquifuge: An impervious geological formation which neither contains nor transmits water such as solid granite rock.

Leaky Aquifer: An aquifer bond by one or two aquitards,it is called also semiconfined aquifer.

Perched Ground Water: When a ground water body is separated from the main ground water by a relatively impermeable stratum of small areal extent and by the zone of aeration above the main body of ground water, wells tapping ground water from these sources yield only temporarily or small quantities of water.

Influent and Effluent: if the water table of an unconfined aquifer intersects a surface stream, then aquifer contributes water to the stream. Such stream is called an effluent stream, if a surface stream runs well above the water table , water flows from the stream to the aquifer. Such stream is called an influent stream.

AQUIFER PARAMETERS:

Porosity: the ratio of volume of pore space Vv, to the volume of the formation V.

$n=\frac{Vv}{V}$

Specific Yield: is the ratio of the volume of water which will drain freely from the material to the volume of the formation.

$Sy=\frac{Wy}{V}$

Specific Retantion: is defined as the ratio of the volume of water retained Wr in the material to the total volume of the material, when a saturated material is dewatered

$Sr=\frac{Wr}{V}$

n=Sy+Sr

Storage Coefficient: is defined as the volume of water that an aquifer release from or takes in to storage per unit surface area of the aquifer per unit drop of water table in the case of an unconfined aquifer and per unit drop of piezometric surface in the case of confined aquifer, it is known as Storativity.

Permeability: is a measure of material capacity to transmit water or any other fluid through it interstices.

$V = Ki = -K\frac{dh}{dl}$

K is the hydraulic conductivity or the coefficient of permeability.

V is the velocity of water through porus media.

is the hydraulic gradient. $\frac{dh}{dl}$ or i

The negative sign indicates that the flow takes place in the direction of falling head.

Transmissivity: also known as Transmissibility, it is the product of the hydraulic conductivity K, and the thickness of the aquifer b and is expressed in units of m^2/day.

STEADY FLOW IN UNCONFINED AQUIFER

Dupuit equation: $q=\frac{K}{2L}(h_1^2-h_2^2)$

Example: Streams A and B are separated by an aquifer formation of width 3.5 km and the depths of flow in them are 18.6 and 12.2 m respectively. Compute the flow from stream A to stream B if the hydraulic conductivity of the aquifer is 0.1 mm/s.

Solution :

L=3.8km =3800m, h_1=18.6m , h_2=12.2m

K=0.1 mm/s= (0.1/1000)*60*60*24=8.64 m/day

$q=\frac{K}{2L}(h_1^2-h_2^2)$

$=\frac{8.64}{2x3800}(18.6^2-12.2^2)$

=0.224 m^3/day

STEADY FLOW IN CONFINED AQUIFER

$$\mathbf{q=\frac{T}{L}(h_1-h_2)}$$

Example: The formation of length 6.4 km between two streams A and B is made up two layers. The bottom layer is pervious with a thickness of 8m and hydraulic conductivity of 36 m/day. The upper layer is impervious. Find the discharge from stream A to stream B if the depth of water in them are 16m and 13.5m respectively.

Solution:

$\mathbf{q=\frac{T}{L}(h_1-h_2)}$

K=36 m/day, L=6.4 km=6400 m, h_1=16 m, h_2= 13.5 m

$q=\frac{36x8}{6400}(16-13.5)= 0.1125\ m^3/day$

STEADY FLOW IN UNCONFINED AQUIFER WITH RECHARGE FROM RAINFALL

$$\mathbf{q=\frac{K}{2L}(h_1^2-h_2^2) + f\,[x- \frac{L}{2}]}$$

Example: Find the discharge in to streams A and B when the rain falls with an intensity which is always more than the infiltration capacity of the aquifer and which may be taken as 0.3 cm/h, K=8.64 m/day, L=3800 m, h_1= 18.6 m, h_2= 12.2 m

Solution:

$\frac{K}{2L}(h_1^2-h_2^2) = 0.22\ m^3/day$

f=0.3cm/h= 0.072 m/day

$q=\frac{K}{2L}(h_1^2-h_2^2) + f\,[x- \frac{L}{2}]$

$= 0.224 + 0.072\ (x- 1900)$

The discharge in to the stream from left

$q_1= 0.224 + 0.077\ (0- 1900) = - 136.576\ m^3/day$

since the positive direction is towards the stream on right, the negative indicates that the flow of 136.576 m^3/day is taking place in to the stream on left.

Similarly the discharge in to the stream on right is obtained as

$q_2 = 0.224 + 0.072(3800 - 1900) = 137.024\ m^3/day$

we can verify that q1 +q2 is exactly equal to the total recharge in to the formation between the streams

$q_1 + q_2 = 136.576 + 137.024 = 237.6$ m3/day

total recharge =(3800 x 1) x 0.072 = 273.6 m^3/day

STEADY RADIAL FLOW TO WELLS

Dupuit- Forchheimer Assumptions:

1- The flow is horizontal and uniformly distributed in a vertical section.
2- The velocity of flow is proportional to the tan of the hydraulic gradient instead of the sine of the hydraulic gradient.

Another Simplified Assumptions

3-the well is pumped at constant rate.

4-the well fully penetrates the aquifer.

5-the aquifer is homogeneous , isotropic, horizontal and infinite horizontal extent.

6-water is released from storage in the aquifer in immediate response to a drop in water table or piezometric surface.

Steady Radial Flow to a Well in Unconfined Aquifer:

$$Q=\frac{\pi K\,(\mathbf{h1-h2})}{\ln(\frac{r1}{r2})}$$

Example: An un confined aquifer has thickness of 30 m. A fully penetrating 20 cm diameter well in this aquifer is pumped at rate of 35 lit/s. The drawdown measured is two observation wells located at distances of 10 m and 100 m from the well are 7.5 m and 0.5 m respectively. Determine the average hydraulic conductivity of the aquifer. At what distance from the well the drawdown is insignificant?

Solution:

$$Q=\frac{\pi K\,(\mathrm{h1-h2})}{\ln(\frac{r1}{r2})}$$

Q=35 lit/s =0.035 m3/s, r_1=100 m, r_2=10 m, H=30 m, S_1=0.5 M and S_2= 7.5 m

h_1= H-S_1 = 30-0.5= 29.5 m

h_2=H-S_2 = 30-7.5= 22.5 m

K=7.04745 x 10^{-5} m/s

=6.089 m/day

Let R be the radius of influence where the drawdown is zero

Then $$Q=\frac{\pi K\,(\mathbf{h1-h2})}{\ln(\frac{R}{r1})}$$

$$\ln(\frac{R}{r1})=\frac{\pi K\,(\mathbf{h1-h2})}{Q}$$

$$\frac{R}{r1}=1.207$$

R= 1.207 x 100 = 120.7 m

Steady Radial Flow to a Well in confined Aquifer:

In terms of drawdown in the wells

$$Q = \frac{2\pi\, T\ (S2 - S1)}{\ln(\frac{r1}{r2})}$$

Example:In an artesian aquifer of 8 m thick, a 10 cm diameter wells pumped at a constant rate of 100 lit/minute. The steady state drawdown observed in two wells located at 10m and 50m distances from the center of the well are 3m and 0.05m respectively. Compute the transmissivity and the hydraulic conductivity of the aquifer.

Solution:

$$Q = \frac{2\pi\, T\ (S2 - S1)}{\ln(\frac{r1}{r2})}$$

Q= 100 lit/min = 0.00167 m3/s

r_2=10m , and r_1= 50m

$\ln\left(\frac{r1}{r2}\right) = 1.60944$

$(S2 - S1) = 3 - 0.05 = 2.95$ m

T= 1.4472 x10 $^{-4}$ m^2/s

T=12.5 m^2/day

The permeability of the aquifer

K=T/ b

K= 1.4472 x10 $^{-4}$/ 8

= 1.809 x10 $^{-4}$m/s

= 1.563 m/day

Unsteady Radial Flow to a Well in a Confined Aquifer:

Theis Method **Z**= $\frac{Q}{4\,\pi\,T}\ \int\ \frac{e}{u}$ du

Z=$\frac{Q}{4\,\pi\,T}\ W(u)$

W(u)= [- 0.577216 – ln u + u - $\frac{u}{2.2} + \frac{u}{3.3} - \frac{u}{4.4} + \frac{u}{5.5} - \cdots$]

Z= the drawdown in m in observation well at a distance r from the pumping well after t seconds since the pumping began.

Q= the constant pumping rate from the well in m3/s.

T =the transmissivity of the aquifer in m^2/s

U= $\frac{r2\ S}{4\ T\,t}$

S= the storage coefficient of the aquifer

S=$\frac{4\,T\,t}{r2/t}$

Example: The depth of well is 80 m with transmissivity of 60 m2/day and storativity of 0.0014, the well discharge is 500 m3/day, well diameter is 50 cm. find pumping lift after six months if the water table found at 5 m below soil surface.

Solution:

U= $\frac{r2\ S}{4\ T\,t}$

=2.025 x 10^{-9}

W(u)= 19.45 from table or eq.

Z=$\frac{Q}{4\,\pi\,T}\ W(u)$

Z= 12.8 M

Pumping lift = 12.8 + 5 = 17.8 m

Unsteady Radial Flow to a Well in Unconfined Aquifer:

Safe yield: The amount of water which can be withdrawn from it annually without producing any undesirable effect. Any withdrawal in excess of safe yield is called overdraft.

Open well: Large diameter wells dug down to the water bearing strata, they derive water from the formations close to the ground surface, these wells are shallow with depth 10 to 20 m, the side wells are lined with stone masonry, therefore the water entry in to the well only from the bottom.

Maximum yield or Critical yield : The yield of the well corresponding to the critical depression head

Maximum safe yield: The yield of the well corresponding to the working head.

Specific yield: The specific capacity of the open well, it has dimensions T^{-1}, the cross sectional area of flow in to the well at its base equal to 4/3 times the plan area of the well due to cavity formation at the bottom.

$Q \alpha H$

$Q=K H$

$Q=\frac{K}{A} A H$

$Q= C A H$

Specific yield for known working head: C = K/A

Specific yield due to recuperating: $C =\frac{2.303}{T} \log \frac{h1}{h2}$

Example: What should be the diameter of an open well to give a safe yield of 4.8 lit/s. assume the working head as 3.75m and subsoil consist of fine sand.

Solution:

$Q= C A H$

Q=4.8 lit/s= 17.28 m^3/h

H= 3.75m

C= 0.5 h^{-1} for fine sand (from table)

A= Q/ C H , A=9.216 m^2 , A= $\pi d/4$, d= 3.43 m diameter of the well

Example: During a recuperating test conducted on an open well in a region, the water level in the well was depressed by 3 m and it was observed to rise by 1.75 m in 75 minutes. (a) what is the specific yield of open wells in that region? (b) what could be the yield from a well of 5 m diameter under a depression head of 2.5 m? (c) what should be the diameter of the well to give a yield of 12 lit/s under a depression head of 2 m?

Solution:

h1=3 m

h2=3 – 1.75 = 1.25 m

T= 75 minutes = 1.25 h

$C= \frac{2.303}{T} \log \frac{h1}{h2}$

$C= \frac{2.303}{1.25} \log \frac{3}{1.25}$

$C= 0.7\ h^{-1}$

$Q= C\ A\ H = 0.7 \times \frac{\pi \times 5 \times 5}{4} \times 2.5 = 34.36\ m^3/h$

A= Q/ CH

$Q= 12\ lit/s = 43.2\ m^3/h$

$A= 30.86\ m^2$

d= 6.27 m

CHAPTER EIGHT

HYDROELECTRIC POWER PLANTS

Hydropower:

It is the power that extracted from the natural potential of usable water resources.

Electrical Power:

Is generated from thermal, thermonuclear or hydroelectrical plants, hydroelectric generators are driven by water turbines, while thermal plants use steam turbines and fossil fuel or nuclear fuel. In addition diesel and gas turbine are used to provide an emergency stand by.

Demand for Electrical Power:

The power demand is defined as the load which consumers choose at any instant to connect to the supplying power system. The system should have enough capacity to meet the expected demand and the unexpected break down and maintenance shut down.

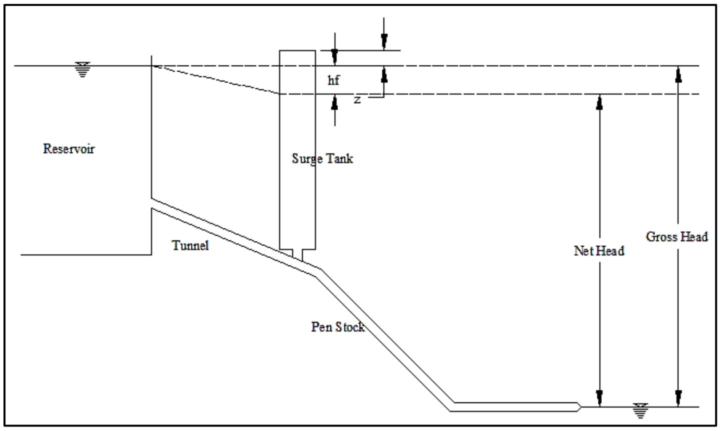
The water falling from high level source drives turbines, which in turn drive generators that produce electricity.

The hydroelectric power is given by:

$$P = \eta \rho g h Q$$

Where;

P : power (watt)
η : turbine efficiency
Q : flow rate (m^3/sec)
h : water head (m)



Typical Power Planet Layout

Penstocks: the pen stocks are pipe of large diameter usually of steel pipe or concrete, used conveying water from the source (reservoir) to the power house.

They are high pressure pipe lines designed to with stand stress developed because of water hummer pressures created by sudden change in power demand (values closures and opening) by sudden change in power demands.

Penstocks can be divided into Two Parts:

1. Long low pressure tunnel.
2. Short high pressure (pen stock) close to the turbine machine separated by a surge tank.

Surge tank: they are a chamber close to a machine their purpose is the protection of long pressure tunnel in medium and high head plants against high water hummer pressures caused by sudden rejection of land.

The surge tanks convert those fast pressure (water pressure) oscillations into much slower and lower fluctuations due to mass oscillation in the surge chamber.

Example 1:

It is intended to design hydroelectric power plant across the stream, the net head at the plant site is 20 m, turbine efficiency 90 %. Find the discharge required to develop a power rate of 7.95 MW.

Solution:

$$P = \eta \rho g h Q$$

$$Q = \frac{7.95 * 10^6}{0.9 * 1000 * 9.81 * 20} = 45 \frac{m^3}{sec}$$

Example 2:

Determine economical diameter of penstock pipe of 500 m long to carry water to turbine having output 1000 KW at 90 % efficiency against 150 m head. Assume friction factor 0.23.

Solution:

Transmission loss for a minimum diameter (H/3)

$$\frac{H}{3} = \frac{150}{3} = 50 = hf$$

Head available for turbine = 150 -50 =100 m

$$P = \eta \rho g h Q$$

$$Q = \frac{P}{\eta \rho g h} = \frac{1000 * 1000}{0.9 * 1000 * 9.81 * 100} = 1.13\ cumes$$

$$D^5 = \frac{16 f L Q^2}{2 g \pi^2 hf} = \frac{16 * 0.23 * 500 * 1.13^2}{2 * 9.81 * \pi^2 * 50}$$

$$D^5 = 0.024$$

Then, D = 0.5 m

Example 3:

A pen stock 2000 m long and 4 m in diameter has surge tank 20 m in diameter, discharge 30 cumes, friction factor 0.018, normal reservoir level 500 m. determine maximum and minimum water level in the tank.

Solution:

$$velocity\ in\ the\ tunnel = \frac{Q}{A} = \frac{30}{\frac{\pi}{4} * 4^2} = 2.34\frac{m}{sec}$$

Friction head loss in pen stock

$$hf = \frac{fLV^2}{2gD} = \frac{0.018 * 2000 * 2.34^2}{2 * 9.81 * 4} = 2.62\ m$$

maximum upsurge $Z_{max} = V\sqrt{\frac{LA_t}{gA_s}} = 2.34 * \sqrt{\frac{2000*\frac{\pi}{4}*4^2}{9.81**\frac{\pi}{4}*2^2}} = 6.83\ m$

maximum water level in surge tank = 500 + 6.83 – 2.62 = 504.21 m

maximum down surge = $\sqrt{Z^2 + hf^2} = \sqrt{6.83^2 + 2.62^2} = 7.31\ m$

minimum water level in tank = 500 – 7.31 = 492.67 m