WRE 303

Hydrology

25/02/17

[Minjahan sir]

Sat + Sun
1st half

* Hydrology is science of water.

* **1.** sub surface water

saturated zone (ground water) — (river, lake, pond + atmosphere) + hydrosphere (0-15 km up from earth) (0-5 km down " ground)

unsaturated zone (soil water) (related to irrigation)

2. surface water.

so, 0-15 km (↑)
0-5 km (↓) → এই টুকু ground water

It mainly deals with hydrology.

(*) climatology / materiology → atmosphere related এর পানি

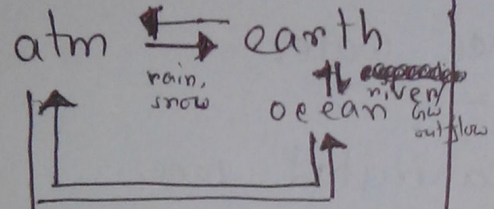
(*) Hydrology :

⇒ Its a branch of earth science which deals with waters of the earth; ~~their~~ - their occurance, circulation and distribution.

- their physical and chemical properties.

- their interaction with the environment including interaction with living things.

(*)



(*) circularly water cycle টি চলে।

(*) we are concerned about engineering hydrology.

(*) Hydrology is a multi-diciplinary subject.

(*) Engineering hydrology:

⇒ deals with planning, design and operation of engineering project.

(*) structure for use/control the water is called water resources structure.

(*) Municiple water supply → WASA/ city corp.

Rural " " → ~~local govt.~~ Public health dept

→ They deals with the drinking / domestic use.

→ Hydrologic design is the first step. for this hydrologic analysis is needed.

→ BRWTN controls the navigation.

→ Hydropower generation.

→ Recreation/ Esthetic value.

→ Water control : ⇒ Dam construction
→ (dry season এ পানির জন্য)
→ (Flood control)

⇒ Embankment construct

⇒ Coastal embankment

regulator : 2 দিকেই flow

sluice gate : 1 " " (country side → river side)

→ sedimentation control

<u>Purpose:</u>

(*) hydrologic process

→ GW flow

→ evaporation/Transporation (dead body, river etc) (Living body থেকে)
water → vapour

→ presipitation

(*) sun থেকে energy

→ infiltration

(*) → latent heat (body র temp
→ sensible heat (air থেকে)

→ River water flow

(*) hydrologic measurements

- Data analysis
- Estimation of runoff rainfall.
- Design.

Content :

- Hydrologic cycle.
- Weather and hydrology. (V. T. chow)

  climatology
  ৩০ বছরের গড়:

- Rainfall - runoff relations.
- Hydrograph and unit hydrograph.
- statistical methods in hydrology.

Ref. book :

1. Engineering hydrology
   - K.S. Subramanya.
2. Hydrology for engineers - R.K. Linsley, M.A. Kohler and J.H.L. Paulhus.
3. Applied Hydrology - V.T. Chow, D.R. Maidment & L.W. Mays.

Lec 2

26/02/17

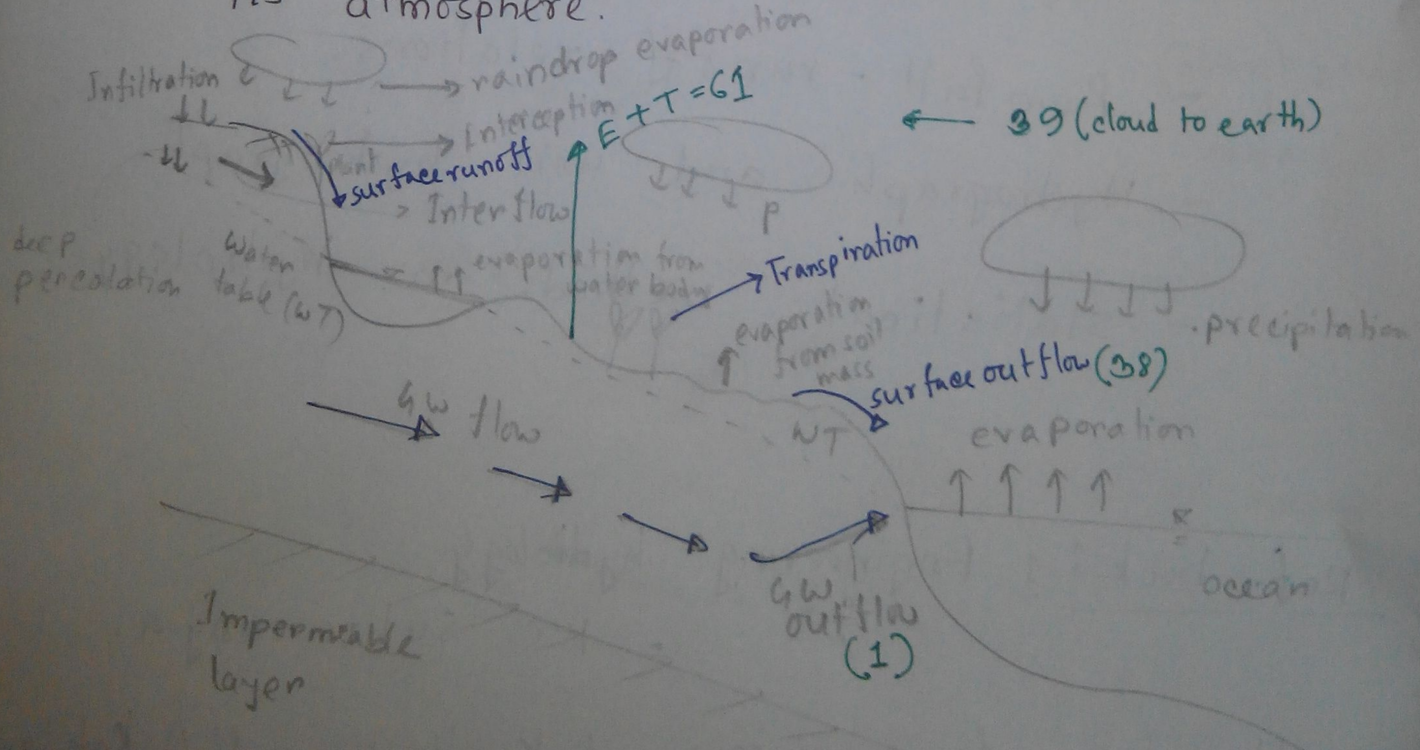
Chapter 1: Introduction

Hydrologic cycle

→ continuous cycle

→ circulation of water

It's a cycle representing endless circulation of water betn the earth and its atmosphere.



starts from ocean (by evaporation)

↓

condensation হয়ে cloud form

↓

precipitation

↓

raindrop evaporation

↓

Interception

↓

Infiltration

↓

Interflow (⟶ ⟶)

and deep percolation (↓↓)

and GW flow (⟶ ⟶)

and surface runoff

↓

evaporation from water body

〃 〃

↓

Transpiration.

* GW flow (1) << surface water (38)

* Interflow surface এ চলে আসে।

* **component:**

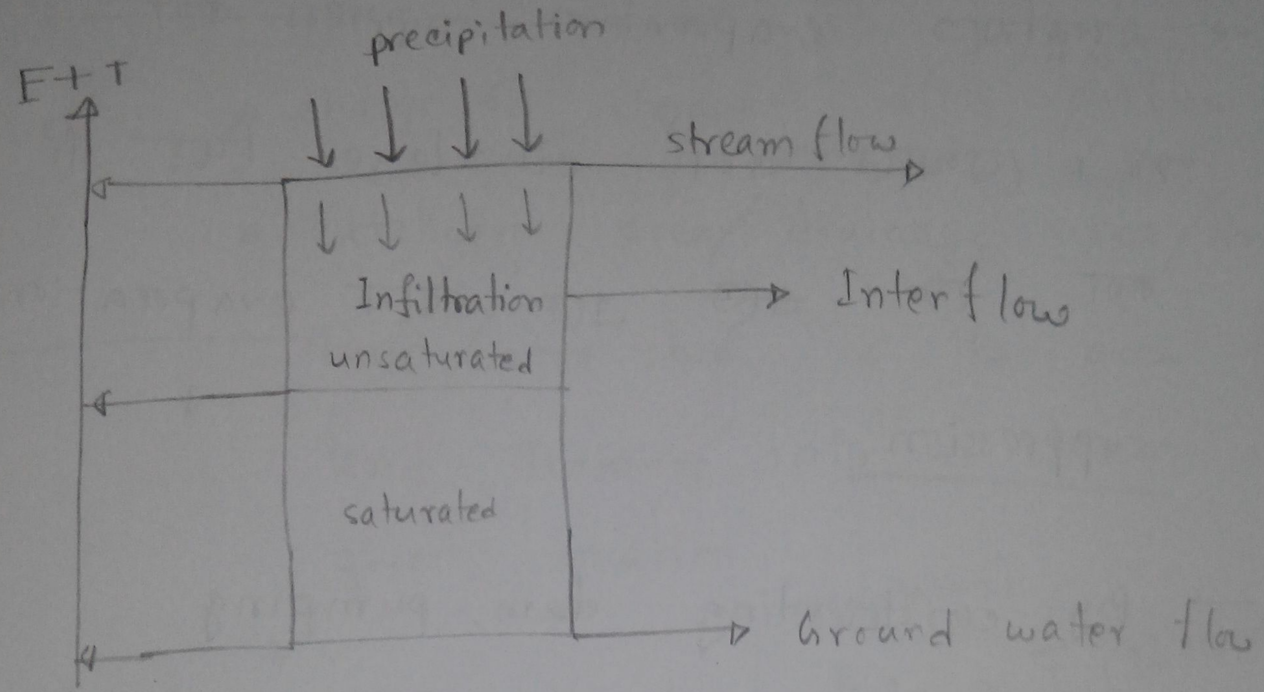
1. Transportation components (dynamic)
   - precipitation
   - evaporation (from water body)
   - Transpiration (Land + tree)

     যে veg থাকে land এ।
   - Infiltration
   - Runoff [surface runoff, interflow, ground water flow]

     (Base flow)

2. Storage components
   - storage of the land surface
   - soil moisture storage
   - Ground water storage

Transportation component এর inter dependence:



Human interferance:

→ বৃষ্টি হবার জন্য condension + dust particle এর দরকার। অনেক সময় বৃষ্টি না হলে chemical /salt দিয়ে দিতে পারি যাতে dust provide করবে। এতে বৃষ্টি হয়।

It's called artifical rain.

→ মরুভূমিতে evaporation suppress করা হয়। সেখানে একটি oil layer দিয়ে এটি করা হয়। ~~এতে~~ একে বলে <u>evaporation suppression.</u>

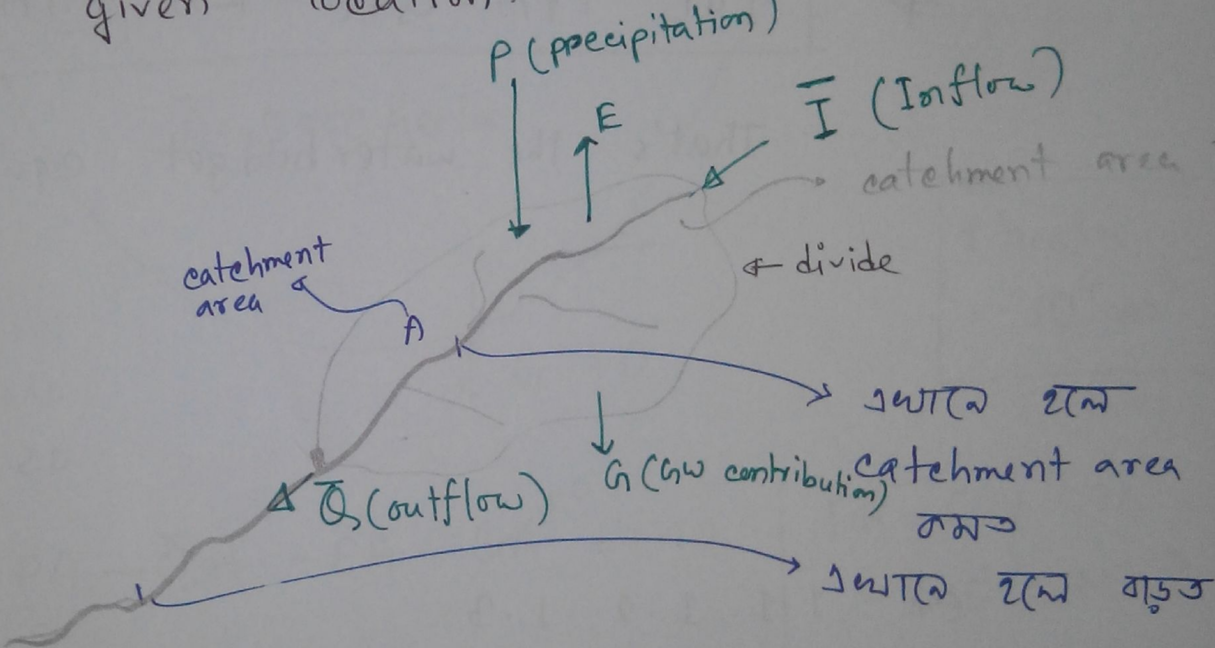
→ By constructing dam, pumping (Surface water কে অন্যভাবে divert করা)

→ waste water / solid water dump করা,

→ Cleaning forest for agriculture. (Infiltration + run off diff amount)

* Waterbudget equation :

- change of storage = inflow - outflow.
- catchment area / drainage area / drainage basin / water shed is the area of land draining into a stream at a given location.



- ridge দিয়ে like টেনে catchment area বের করা যায়। from the ~~m~~ elevation map we can do that.

- In an interval of time, Δt

mass (vol^m density) inflow − mass outflow = change in mass storage

If density is const. then mass = vol^m.

$$\therefore \forall_i - \forall_o = \Delta V$$

$$\Rightarrow \boxed{\bar{I}\Delta t + PA - \bar{Q}\Delta t - EA \underset{(+/-)}{-GA} = \Delta S}$$

That's the water budget eqn.

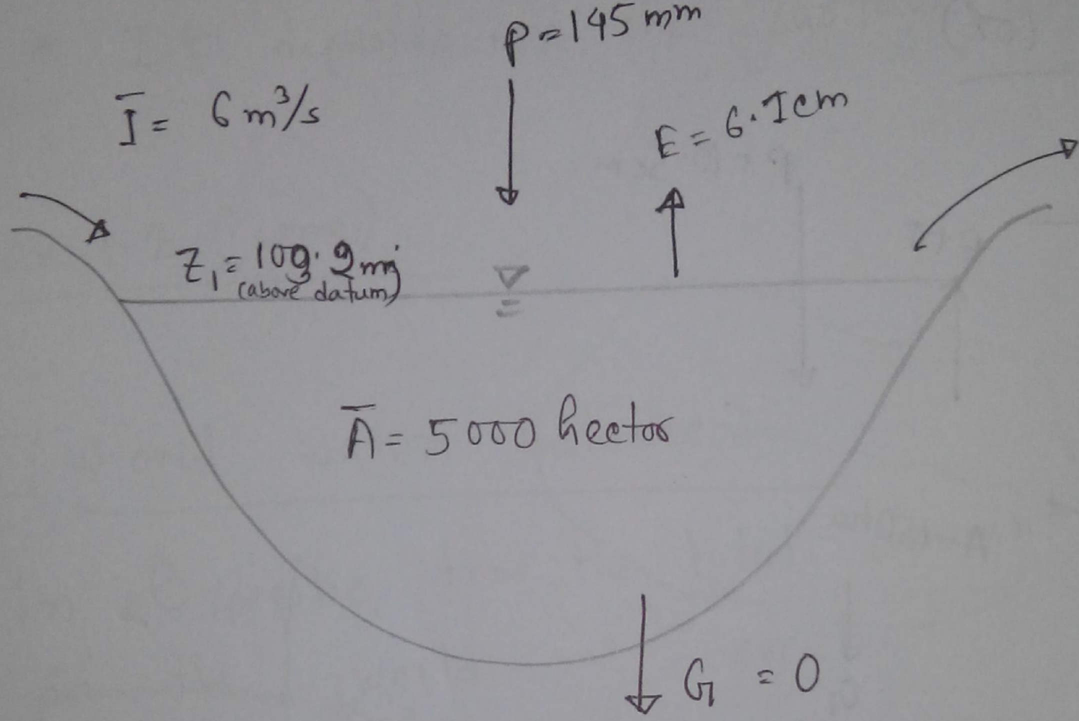
surface area × change in depth
$\Delta S = \Delta z A$

ex: 1.1, 1.2, 1.3

Lec 3 — 04/03/17

Ex 1.1 $\boxed{\text{Problem}}$ Type 1 : Water budget equ^n

Δt = 1 month (30days) $= \frac{30\times24\times60\times60}{10^6} = 2.592$ Ms.



1 hector $= 10^4\ m^2$

$$\bar{I}\Delta t + PA - \bar{Q}\Delta t - EA - \cancel{GA}^{0} = \Delta S$$

$\Rightarrow \Delta S = 15.552 + 7.25 - 16.848 - 3.05$

$= 2.904\ Mm^3$

(WL ↑)

$\Delta S = \Delta Z A$

$\Rightarrow \Delta Z = \frac{\Delta S}{A} = \frac{2.904\times10^6}{5000\times10^4} = 0.05808$ m rise

$\bar{I}\Delta t = 6\times2.592$

$= 15.552\ Mm^3$

$PA = \frac{145\times10^{-3}\times5000\times10^4}{10^6}$

$= 7.25\ Mm^3$.

$\bar{Q}\Delta t = 6.5\times2.592$

$= 16.848\ Mm^3$

$EA = \frac{6.1\times10^{-2}\times5000\times10^4}{10^6}$

$= 3.05\ Mm^3$

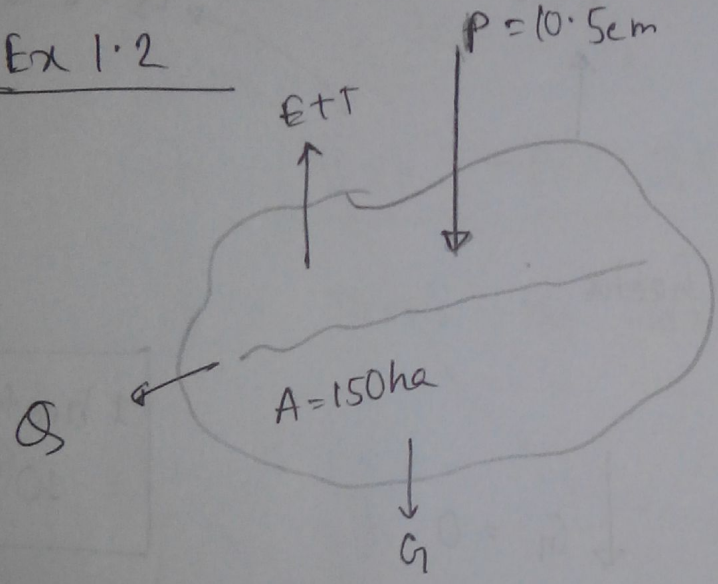
$z_2 = 103.2 + 0.058$

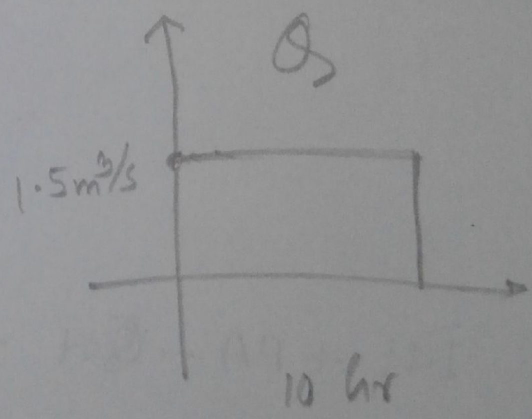
$= 103.258$ m above datum.

(Ans)

Exercise 1.3 (02)

Ex 1.2





dry ($\Delta S = 0$)

inflow = P

outflow = 10 hr এ Q

+ (E+T) + G

Q const

Q vary করলে

পারে।

* run-off co-efficient = $\dfrac{\text{run-off vol}^m}{\text{rain vol}^m \ (P)}$

* only loss is infiltration.

* It depends on the surface area.

<u>ex 1.3 (same)</u>

[x] <u>World water balance:</u>

→ In a specific time, the total amount of water in the world is const.

→ Total water = 1386 M km^3.

→ maximum water is saline.

→ fresh water = 2.5% (2.5% এর Polar ice = 1.7%)

∴ rest (usable fresh water = 0.8%)

Ground water = 0.76% [total usable freshwater → 0.95%)

Lakes and streams = 0.008%

others = 0.032%

[বাকি 5% surface water]

$\boxed{*}$ কতক্ষণ পানিটি কোথায় থাকলে it indicates dynamism of the system

$\boxed{*}$ Atmospheric water is the most dynamic
Surface " midium
Ground " least (Laminar)

So, GW এর model বানানো যায়, atmospheric এরটা possible না।

$\boxed{*}$ Residence time, T_r = the average duration of a particle of water to pass through a phase of hydrologic cycle.

$$T_r = \frac{\text{Vol}^m \text{ of water in the phase (Table 1.1)}}{\text{Average flow rate (outflow rate) in the phase}}$$

(Table 1.2)

☒ Global river water, $T_r = \dfrac{0.00212 \text{ M km}^3}{44700 \text{ km}^3/\text{yr}}$

$= \dfrac{0.00212 \text{ Mkm}^3}{44700 \text{ km}^3/\text{days}} \times 365$

$= 17.3$ days.

Type 2: Residence time

☒ Problem 1.6 (a), (b)

outflow
precipitation → Both (earth + ocean) add করো।

Ans = 8.2 days.

GW → 28,500 বছর লাগে।

05/03/17

Lec 4

Weather and hydrology (Sheet দেখো)

এখন only related to hydrology part

[*]

climate → long term atmospheric condition

weather → short " " "

[*] weather parameter :

→ rainfall / precipitation

→ temperature

→ Humidity / Vapour pressure

→ Wind speed

এর application বেশি

as river bank erosion এর এক কারণ এটি। ঝড়ে storm এর সময় stream বেশি, erosion বেশি।

⊛ wind speed measure করার process দিবেনা।

Hydrologic cycle এর energy source :

① Sun/solar radiation

② Wind/ Atmosferic ...

CHAPTER

3

ATMOSPHERIC WATER

Of the many meteorological processes occurring continuously within the atmosphere, the processes of precipitation and evaporation, in which the atmosphere interacts with surface water, are the most important for hydrology. Much of the water precipitated on the land surface is derived from moisture evaporated from the oceans and transported long distances by atmospheric circulation. The two basic driving forces of atmospheric circulation result from the rotation of the earth and the transfer of heat energy between the equator and the poles.

3.1 ATMOSPHERIC CIRCULATION

The earth constantly receives heat from the sun through solar radiation and emits heat through re-radiation, or *back radiation* into space. These processes are in balance at an average rate of approximately 210 W/m^2. The heating of the earth is uneven; near the equator, the incoming radiation is almost perpendicular to the land surface and averages about 270 W/m^2, while near the poles, it strikes the earth at a more oblique angle at a rate of about 90 W/m^2. Because the rate of radiation is proportional to the absolute temperature at the earth's surface, which does not vary greatly between the equator and the poles, the earth's emitted radiation is more uniform than the incoming radiation. In response to this imbalance, the atmosphere functions as a vast heat engine, transferring energy from the equator toward the poles at an average rate of about 4×10^9 MW.

If the earth were a nonrotating sphere, atmospheric circulation would appear as in Fig. 3.1.1. Air would rise near the equator and travel in the upper atmosphere toward the poles, then cool, descend into the lower atmosphere, and return toward the equator. This is called *Hadley circulation.*

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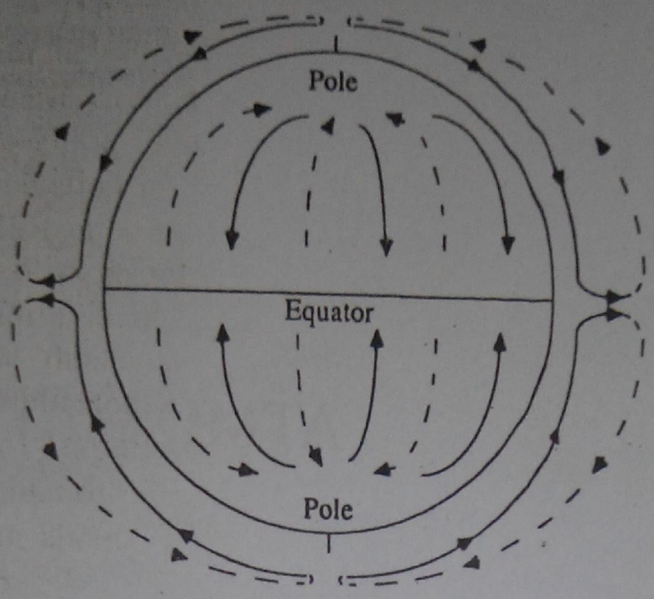


FIGURE 3.1.1
One-cell atmospheric circulation pattern for a nonrotating planet.

The rotation of the earth from west to east changes the circulation pattern. As a ring of air about the earth's axis moves toward the poles, its radius decreases. In order to maintain angular momentum, the velocity of air increases with respect to the land surface, thus producing a westerly air flow. The converse is true for a ring of air moving toward the equator—it forms an easterly air flow. The effect producing these changes in wind direction and velocity is known as the *Coriolis force*.

The actual pattern of atmospheric circulation has three cells in each hemisphere, as shown in Fig. 3.1.2. In the *tropical cell*, heated air ascends at the equator, proceeds toward the poles at upper levels, loses heat and descends toward the ground at latitude 30°. Near the ground, it branches, one branch moving toward the equator and the other toward the pole. In the *polar cell*, air rises at 60° and flows toward the poles at upper levels, then cools and flows back to 60° near the earth's surface. The *middle cell* is driven frictionally by the other two; its surface air flows toward the pole, producing prevailing westerly air flow in the mid-latitudes.

The uneven distribution of ocean and land on the earth's surface, coupled with their different thermal properties, creates additional spatial variation in atmospheric circulation. The annual shifting of the thermal equator due to the earth's revolution around the sun causes a corresponding oscillation of the three-cell circulation pattern. With a larger oscillation, exchanges of air between adjacent cells can be more frequent and complete, possibly resulting in many flood years. Also, monsoons may advance deeper into such countries as India and Australia. With a smaller oscillation, intense high pressure may build up around 30° latitude, thus creating extended dry periods. Since the atmospheric circulation is very complicated, only the general pattern can be identified.

The atmosphere is divided vertically into various zones. The atmospheric circulation described above occurs in the *troposphere*, which ranges in height from about 8 km at the poles to 16 km at the equator. The temperature in the troposphere decreases with altitude at a rate varying with the moisture content of

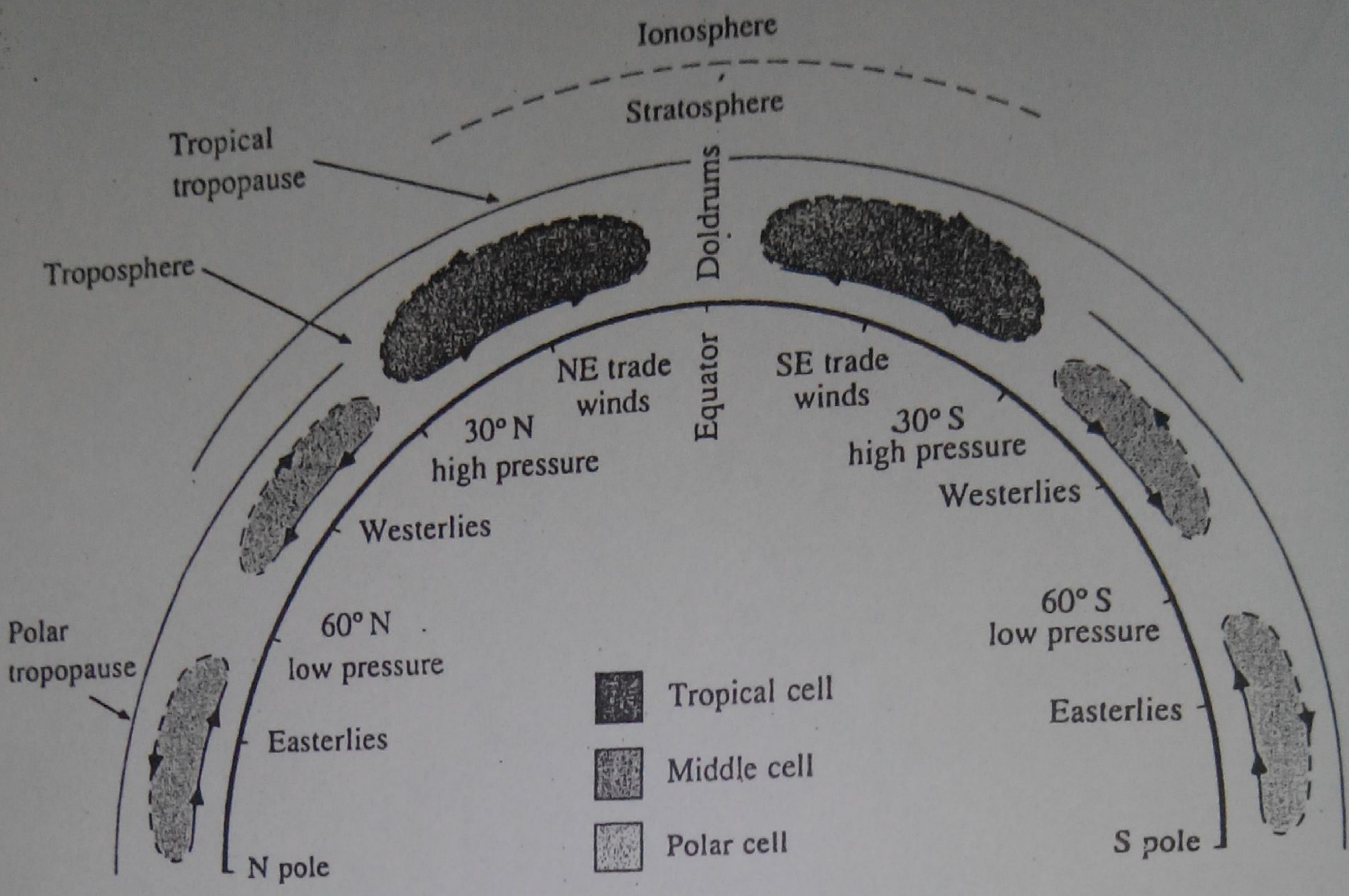


FIGURE 3.1.2
Latitudinal cross section of the general atmospheric circulation.

the atmosphere. For dry air the rate of decrease is called the *dry adiabatic lapse rate* and is approximately 9.8°C/km (Brutsaert, 1982). The *saturated adiabatic lapse rate* is less, about 6.5°C/km, because some of the vapor in the air condenses as it rises and cools, releasing heat into the surrounding air. These are average figures for lapse rates that can vary considerably with altitude. The *tropopause* separates the troposphere from the *stratosphere* above. Near the tropopause, sharp changes in temperature and pressure produce strong narrow air currents known as *jet streams* with speeds ranging from 15 to 50 m/s (30 to 100 mi/h). They flow for thousands of kilometers and have an important influence on air mass movement.

An *air mass* in the general circulation is a large body of air that is fairly uniform horizontally in properties such as temperature and moisture content. When an air mass moves slowly over land or sea areas, its characteristics reflect those of the underlying surface. The region where an air mass acquires its characteristics is its source region; the tropics and the poles are two source regions. Where a warm air mass meets a cold air mass, instead of their simply mixing, a definite surface of discontinuity appears between them, called a *front*. Cold air, being heavier, underlies warm air. If the cold air is advancing toward the warm air, the leading edge of the cold air mass is a *cold front* and is nearly vertical in slope. If the warm air is advancing toward the cold air, the leading edge is a *warm front*, which has a very flat slope, the warm air flowing up and over the cold air.

A *cyclone* is a region of low pressure around which air flows in a counterclockwise direction in the north

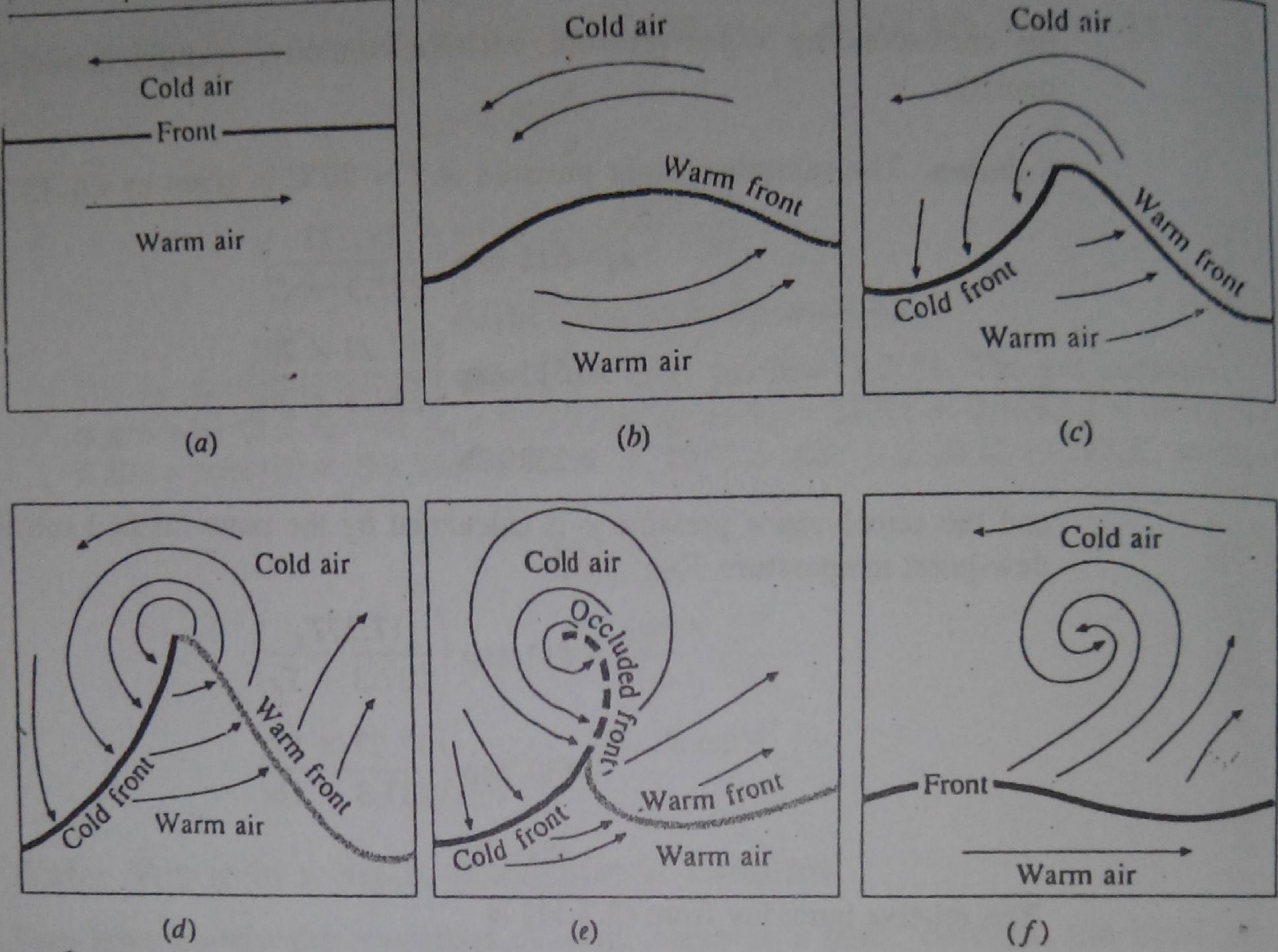


FIGURE 3.1.3
A plan view of the life cycle of a Northern Hemisphere frontal cyclone: (*a*) surface front between cold and warm air; (*b*) wave beginning to form; (*c*) cyclonic circulation and wave have developed; (*d*) faster-moving cold front is overtaking retreating warm front and reducing warm sector; (*e*) warm sector has been eliminated and (*f*) cyclone is dissipating.

hurricanes or *typhoons*. *Extratropical cyclones* are formed when warm and cold air masses, initially flowing in opposite directions adjacent to one another, begin to interact and whirl together in a circular motion, creating both a warm front and a cold front centered on a low pressure zone (Fig. 3.1.3). An *anticyclone* is a region of high pressure around which air flows clockwise in the northern hemisphere, counterclockwise in the Southern hemisphere. When air masses are lifted in atmospheric motion, their water vapor can condense and produce precipitation.

3.2 WATER VAPOR

Atmospheric water mostly exists as a gas, or vapor, but briefly and locally it becomes a liquid in rainfall and in water droplets in clouds, or it becomes a solid in snowfall, in hail, and in ice crystals in clouds. The amount of water vapor in the atmosphere is less than 1 part in 100,000 of all the waters of the earth, but it plays a vital role in the hydrologic cycle.

Vapor transport in air through a hydrologic system can be described by the Reynolds transport theorem [Eq. (2.1.9)] letting the extensive property B be the mass of water vapor. The intensive property $\beta = dB/dm$ is the mass of water vapor per unit mass of moist air; this is called the *specific humidity* q_v, and equals the ratio of the densities of water vapor (ρ_v) and moist air (ρ_a):

$$q_v = \frac{\rho_v}{\rho_a} \tag{3.2.1}$$

By the law of conservation of mass, $dB/dt = \dot{m}_v$, the rate at which water vapor is being added to the system. For evaporation from a water surface, $\dot{m}_v$ is positive and represents the mass flow rate of evaporation; conversely, for condensation, $\dot{m}_v$ is negative and represents the rate at which vapor is being removed from the system. The Reynolds transport equation for this system is the continuity equation for water vapor transport:

$$\dot{m}_v = \frac{d}{dt}\iiint_{\text{c.v.}} q_v\rho_a \, dV + \iint_{\text{c.s.}} q_v\rho_a \, \mathbf{V}\cdot d\mathbf{A} \tag{3.2.2}$$

Vapor Pressure

Dalton's law of partial pressures states that the pressure exerted by a gas (its vapor pressure) is independent of the presence of other gases; the vapor pressure e of the water vapor is given by the *ideal gas law* as

$$e = \rho_v R_v T \tag{3.2.3}$$

where T is the absolute temperature in K, and R_v is the gas constant for water vapor. If the total pressure exerted by the moist air is p, then $p - e$ is the partial pressure due to the dry air, and

$$p - e = \rho_d R_d T \tag{3.2.4}$$

where ρ_d is the density of dry air and R_d is the gas constant for dry air (287 J/kg·K). The density of moist air ρ_a is the sum of the densities of dry air and water vapor, that is, $\rho_a = \rho_d + \rho_v$, and the gas constant for water vapor is $R_v = R_d/0.622$, where 0.622 is the ratio of the molecular weight of water vapor to the average molecular weight of dry air. Combining (3.2.3) and (3.2.4) using the above definitions gives

$$p = \left[\rho_d + \left(\frac{\rho_v}{0.622}\right)\right] R_d T \tag{3.2.5}$$

By taking the ratio of Eqs. (3.2.3) and (3.2.5), the specific humidity q_v is approximated by

$$q_v = 0.622\frac{e}{p} \tag{3.2.6}$$

Also, (3.2.5) can be rewritten in terms of the gas constant for moist air, R_a, as

$$p = \rho_a R_a T \tag{3.2.7}$$

The relationship between the gas constants for moist air and dry air is given by

$$\begin{aligned} R_a &= R_d(1 + 0.608q_v) \\ &= 287(1 + 0.608q_v) \text{ J/kg·K} \end{aligned} \tag{3.2.8}$$

The gas constant of moist air increases with specific humidity, but even for a large specific humidity (e.g., $q_v = 0.03$ kg water/kg of moist air), the difference between the gas constants for moist and dry air is only about 2 percent.

For a given air temperature, there is a maximum moisture content the air can hold, and the corresponding vapor pressure is called the *saturation vapor pressure* e_s. At this vapor pressure, the rates of evaporation and condensation are equal. Over a water surface the saturation vapor pressure is related to the air temperature as shown in Fig. 3.2.1; an approximate equation is:

$$e_s = 611 \exp\left(\frac{17.27T}{237.3 + T}\right) \tag{3.2.9}$$

where e_s is in pascals (Pa = N/m^2) and T is in degrees Celsius (Raudkivi, 1979). Some values of the saturation vapor pressure of water are listed in Table 3.2.1.

The gradient $\Delta = de_s/dT$ of the saturated vapor pressure curve is found by differentiating (3.2.9):

$$\Delta = \frac{4098e_s}{(237.3 + T)^2} \tag{3.2.10}$$

where Δ is the gradient in pascals per degree Celsius.

The *relative humidity* R_h is the ratio of the actual vapor pressure to its saturation value at a given air temperature (see Fig. 3.2.1):

$$\boxed{R_h = \frac{e}{e_s}} \tag{3.2.11}$$

The temperature at which air would just become saturated at a given specific humidity is its *dew-point temperature* T_d.

Example 3.2.1 At a climate station, air pressure is measured as 100 kPa, air temperature as 20°C, and the wet-bulb, or dew-point, temperature as 16°C. Calculate

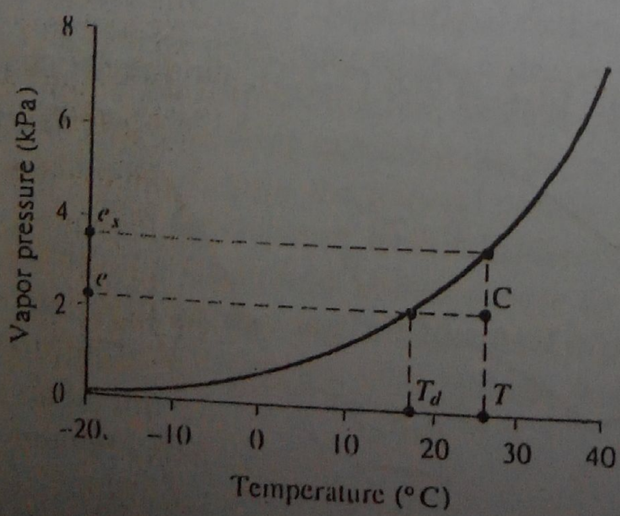


FIGURE 3.2.1
Saturated vapor pressure as a function of temperature over water. Point C has vapor pressure e and temperature T, for which the saturated vapor pressure is e_s. The relative humidity is $R_h = e/e_s$. The temperature at which the air is saturated for vapor pressure e is the dew-point temperature T_d.

the corresponding vapor pressure, relative humidity, specific humidity, and air density.

Solution. The saturated vapor pressure at $T = 20°C$ is given by Eq. (3.2.9)

$$e_s = 611 \exp\left(\frac{17.27T}{237.3 + T}\right)$$

$$= 611 \exp\left(\frac{17.27 \times 20}{237.3 + 20}\right)$$

$$= 2339 \text{ Pa}$$

and the actual vapor pressure e is calculated by the same method substituting the dew-point temperature $T_d = 16°C$:

$$e = 611 \exp\left(\frac{17.27T_d}{237.3 + T_d}\right)$$

$$= 611 \exp\left(\frac{17.27 \times 16}{237.3 + 16}\right)$$

$$= 1819 \text{ Pa}$$

The relative humidity from (3.2.11) is

$$R_h = \frac{e}{e_s}$$

$$= \frac{1819}{2339}$$

$$= 0.78$$

$$= 78\%$$

TABLE 3.2.1
Saturated vapor pressure of water vapor over liquid water

Temperature °C	Saturated Vapor Pressure Pa
−20	125
−10	286
0	611
5	872
10	1227
15	1704
20	2337
25	3167
30	4243
35	5624
40	7378

Source: Brutsaert, 1982, Table 3.4, p. 41. Used with permission.

and the specific humidity is given by (3.2.6) with $p = 100$ kPa $= 100 \times 10^3$ Pa:

$$q_v = 0.622\frac{e}{p}$$
$$= 0.622\left(\frac{1819}{100 \times 10^3}\right)$$
$$= 0.0113 \text{ kg water/kg moist air}$$

The air density is calculated from the ideal gas law (3.2.7). The gas constant R_a is given by (3.2.8) with $q_v = 0.0113$ kg/kg as $R_a = 287(1 + 0.608q_v) = 287(1 + 0.608 \times 0.0113) = 289$ J/kg·K, and $T = 20°\text{C} \doteq (20 + 273)\text{ K} = 293$ K, so that

$$\rho_a = \frac{p}{R_a T}$$
$$= \frac{100 \times 10^3}{289 \times 293}$$
$$= 1.18 \text{ kg/m}^3$$

Water Vapor in a Static Atmospheric Column

Two laws govern the properties of water vapor in a static column, the ideal gas law

$$p = \rho_a R_a T \tag{3.2.12}$$

and the *hydrostatic pressure law*

$$\frac{dp}{dz} = -\rho_a g \tag{3.2.13}$$

The variation of air temperature with altitude is described by

$$\frac{dT}{dz} = -\alpha \tag{3.2.14}$$

where α is the lapse rate. As shown in Fig. 3.2.2, a linear temperature variation combined with the two physical laws yields a nonlinear variation of pressure with altitude. Density and specific humidity also vary nonlinearly with altitude. From (3.2.12), $\rho_a = p/R_aT$, and substituting this into (3.2.13) yields

$$\frac{dp}{dz} = \frac{-pg}{R_a T}$$

or

$$\frac{dp}{p} = \left(\frac{-g}{R_a T}\right) dz$$

Substituting $dz = -dT/\alpha$ from (3.2.14):

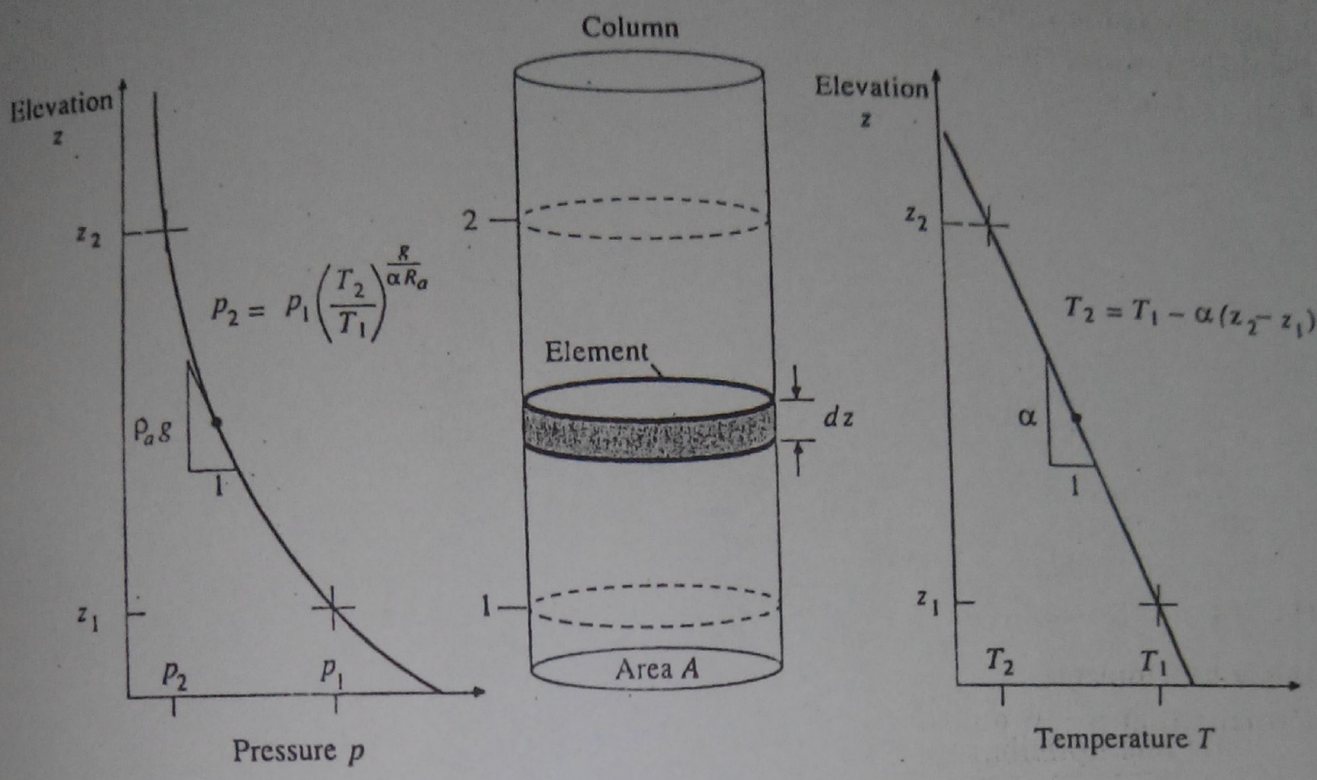


FIGURE 3.2.2
Pressure and temperature variation in an atmospheric column.

$$\frac{dp}{p} = \left(\frac{g}{\alpha R_a}\right)\frac{dT}{T}$$

and integrating both sides between two levels 1 and 2 in the atmosphere gives

$$\ln\left(\frac{p_2}{p_1}\right) = \left(\frac{g}{\alpha R_a}\right)\ln\left(\frac{T_2}{T_1}\right)$$

or

$$p_2 = p_1\left(\frac{T_2}{T_1}\right)^{g/\alpha R_a} \tag{3.2.15}$$

From (3.2.14) the temperature variation between altitudes z_1 and z_2 is

$$T_2 = T_1 - \alpha(z_2 - z_1) \tag{3.2.16}$$

Precipitable Water

The amount of moisture in an atmospheric column is called its *precipitable water*. Consider an element of height dz in a column of horizontal cross-sectional area A (Fig. 3.2.2). The mass of air in the element is $\rho_a A\,dz$ and the mass of water contained in the air is $q_v \rho_a A\,dz$. The total mass of precipitable water in the column between elevations z_1 and z_2 is

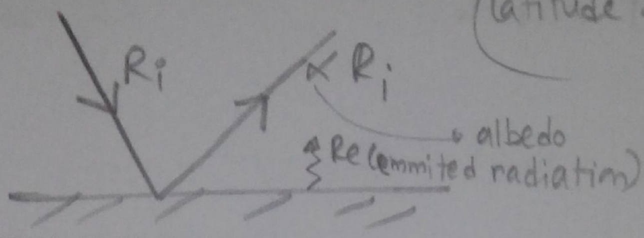
$$m_p = \int_{z_1}^{z_2} q_v \rho_a A\,dz \tag{3.2.17}$$

① Solar radiation :

R_a ———————————— Solar constant / Extra-terrestrial radiation

(latitude & time এর উপর depend করে)

$R_i \approx 0.75 R_a$
(clearday হলে)
cloud হলে $R_i \downarrow$



normal earth এর জন্য 0.23

α = albedo = ratio of amount of solar radiation reflected by the surface to the amount ~~of~~ incident upon it.

depends on surface type
[white হলে ↑↑ (max)]
[white snow হলে 95% reflect]

net radiation, $\boxed{R_n = (1-\alpha) R_i - R_e}$

* Latent heat transfer (for E + T)
* Sensible " "
  - → heat (Temp)
  - → humidity

* Solar radiation মাপার যন্ত্র actinometer or radio meter.

* আবহাওয়া মাপা হয় daily sunshine hour এর উপর ভিত্তি করে

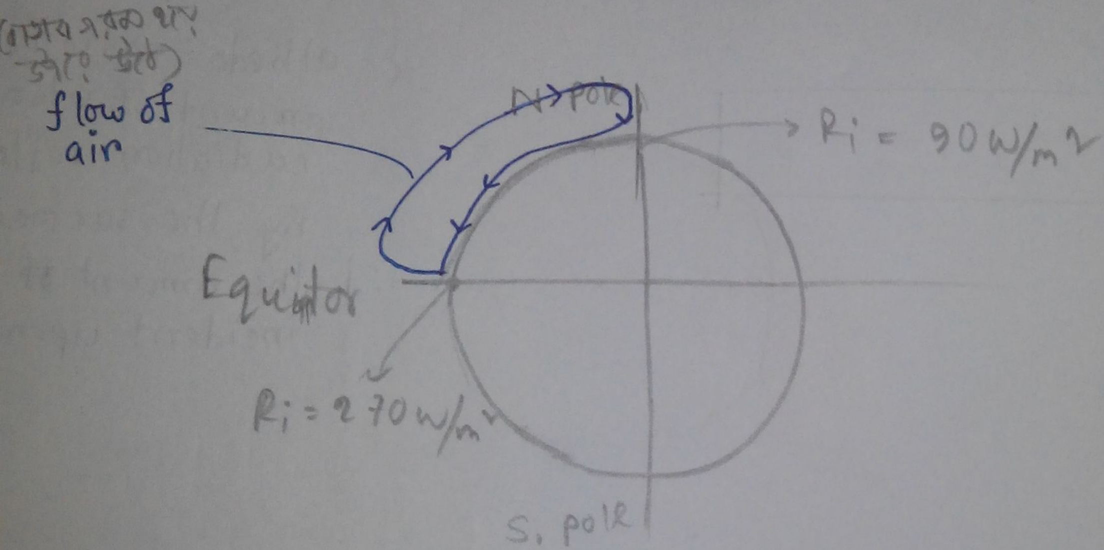
n = sunshine hour

② Atmospheric circulation:

→ কেন হয়?

= → uneven heating of the earth.

→ rotation of earth



* Assuming earth to be non-rotating sphere, বাতাস গরম হয়ে উপরে উঠে northpole এর দিকে যাবে, cooling down হবে, pressure diff এর জন্য back করবে। It's called Hadley circulation. It's single cell circulation.

* But actuall earth is rotating west → east.

Scanned by CamScanner

এবং এর জন্য একটি force সৃষ্টি হয়। It's called coriolis-force. It's the apparent force arising from the earth rotation & causing the changes in wind direction & velocity.

* pole এর দিকে গেলে radius ↓.

  r ↓ velocity ↑

* pole থেকে equiator এর দিকে radius ↑

  r ↑ vel ↓

* এবং এটি westerlised develop করবে এবং বাতাস আসছে। মনে হবে পশ্চিম থেকে

  vice versa.

এটি 3 cell circulation. It's called general atmospheric circulation. এটি Troposphere এ হয়।

* কিছু dry air চলে আসে from (Polar → middle)
" wet " " " from (middle → Polar)

* Because of vegetation, undulation of earth surface it will change.

* এই oscillation হাড়াও কিছু occassionally oscillation হয়। It's called cyclone.

* **Cyclone**: A region of low pressure around which air flows in a counter clock wise direction in ~~a~~ the northern ~~hemisphpl~~ hemisphere.

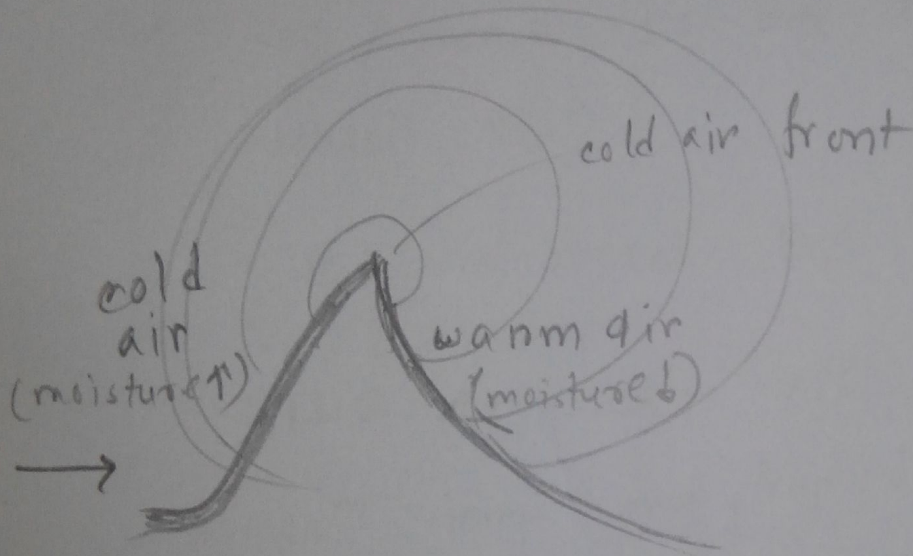
Cyclone is of 2 types:

① Tropical cyclone (forms at low latitude (5°-10°))
+ pre moonsoon এ ১৫ ঝড় হয়, ocean এ depression create হয় inlow pressure zone for condensation it acquires energy. It hits the land

(USA এ herikane
South Asia এ Typhoon)

and depression এর জন্য বৃষ্টি হয়ে থাকে।)

② Extra tropical cyclone : (forms at when warm air and cold air masses interact and whirl together in a circular motion.



cold air front যে warm air overtake করে তখন circular air সৃষ্টি হয়।
একসময় cold air front warm air front কে overtake করে বৃষ্টিপাত ঘটায়।

Lec 5

Temperature

→ E+T depends on temp

→ ঘরের মাঝে পানি রাখলেও E হয় because of temp in air.

→ day / month এর avg temp কই? কিভাবে data collect করে?

= Bd metrological Dept (BMD)

কীভাবে avg calc করি?

= max^m temp, min temp diff আর্দ্রতা নিয়ে note করি

Mean daily temp, $T_{avg} = \frac{T_{max} + T_{min}}{2}$.

(x) air ঢুকতে পারে + sun প্রবেশ করতে পারবেনা এমন অবস্থা করতে হবে।

(x) দিনে ভোরে (min), দুপুরে (max) নেয়া হয়।

long term avg (30 yrs এর hydrology তে)

[*] **Normal temperature** :- avg value for a day, month or even year over a specific 30 yr period.

11th March এর normal temp = last 30 yrs এর 11th march এর avg

[*] **Lapse rate** : Rate of decrease of temperature with altitudes.

It depends on the moisture content of the area.

heat শোষিত হবে না, latent heat এ convert

Dry-adiabatic lapse rate (decrease of tem with altitude of dry adiab.)

9.8 °c/km.

Saturated-adiabatic lapse rate

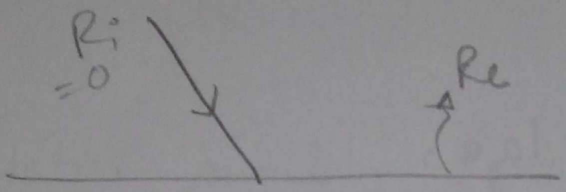
6.5°/km.

temp কমলে → condensation → heat generate ↓ বায়ু কে heat up

তাই কম rate এ decrease করে।

- Temperature inversion:

☒ Earth surface এর temp আসে যায়। সেখান থেকে heat emit করে, এবং earth surface cool down.



Increase of temp with altitudes is known as temp inversion.

☒ Water vapour / humidity: (e) — partial pressure which is exerted by the vapour.

→ E + T এর জন্য important

→ Vapour pressure এর diff এর জন্য E হয়। যদি না থাকে Then E হবেনা।

expressed in two ways.

i. specific humidity

ii. Relative " (air max^m ধারণ করতে পারে তার কতখানি আছে (%))

i. specific humidity, q_v: mass of water vapour per unit mass of moist air.

$$q_v = \frac{\text{density of water vapour}}{\text{density of moist air}}$$

$$= \frac{\rho_v}{\rho_a}.$$

from ideal gas law,

atm pressure, $p = \rho_a . R_a . T.$

R_a → gas const for moist air.

$$\boxed{R_a = (1+0.604\, q_v) R_d}$$

$R_d = 287.5$ Joule/kg-k

R_d : gas const for dry air

$$\boxed{\rho_a = \frac{p}{R_a T}}.$$

e, R_v = gas const for water vapour

e → vapour pressure exerted by water vapour

$$\boxed{R_a \approx R_d}$$

1% or 2% diff

$$\frac{R_d}{0.622} \simeq \frac{R_a}{0.622}$$

$e = \rho_v R_v T$

Here, R_v = gas const for water vapour

$$\rho_v = \frac{e}{R_v T}$$

$$q_v = \frac{R_a}{R_v} \cdot \frac{e}{p} = 0.622 \cdot \frac{e}{p}$$

ii. Relative humidity, $R_h = \frac{e}{e_s} \times 100$

e_s is a func of temp.

$$e_s = 611\, e^{\frac{17.27T}{237.3+T}}$$ (Pascel এ থাকে)

Actual vapour pressure : saturation pressure @ wrt dew point temp

$$e = 611\, e^{\frac{17.27T_d}{237.3+T_d}}$$

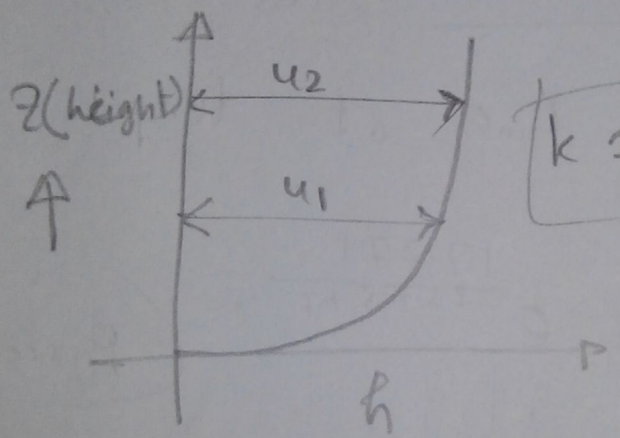
T_d = dew point temp

- the temp at which air would just become saturated at a given specific humidity.

(Wet bulb, dry bulb নিয়ে sling cyclometer এ নিয়ে wet bulb এর temp এ যাবে humidity 100% হয়।)

*] **Wind speed :** → Anemometer দ্বারা wind speed

⇒ পাখা ঘোরার ঘূর্ণন calibrated থাকলে wind speed মাপতে পারব,



$$\boxed{k \simeq \frac{1}{7}}$$

$$\frac{u_1}{u_2} = \left(\frac{z_1}{z_2}\right)^k$$

① Logarithmic

② power law profile.

Lec 6 12/09/17

Type 3: Humidity & Pressure

Data given:

atm, pressure, p = 100 kPa,

$T = 20^\circ c$

Dewpoint temp, $T_d = 16^\circ c$

Find: vapour pressure, e = ?

Rel. humidity, R_h = ?

ρ_a = ?

Soln:

$$e_s = 611\, e^{\frac{17.27 \times 20}{237.3 + 20}}$$

$$= 2339 \text{ Pascal}$$

$$e = 611\, e^{\frac{17.27 \times 16}{237.3 + 16}}$$

$$= 1819 \text{ Pa.} \quad \text{(Ans)}$$

Relative humidity, $R_h = \frac{e}{e_s} \times 100$

$$= \frac{1819}{2339} \times 100$$

$$= 78\%$$

$$\rho_a = \frac{P}{R_a T}$$

$$R_a = (1 + 0.608\, q_v) 287$$

$$q_v = 0.622 \frac{e}{P}$$

$$= 0.622 \times \frac{1819}{100 \times 10^3}$$

$$= 0.0113$$

$$R_a = (1 + 0.608 \times 0.0113) \times 287$$

$$= 289 \ \text{J/kg-k}$$

$$\rho_a = \frac{100 \times 10^3}{289\,(20 + 273)}$$

$$= 1.18 \ \text{kg/m}^3$$

* Problem:

Data given, $P = 101.1\ kPa$, $T = 25^\circ c$, $T_d = 20^\circ c$

find : e, R_h, q_v, ρ_a.

* Problem:

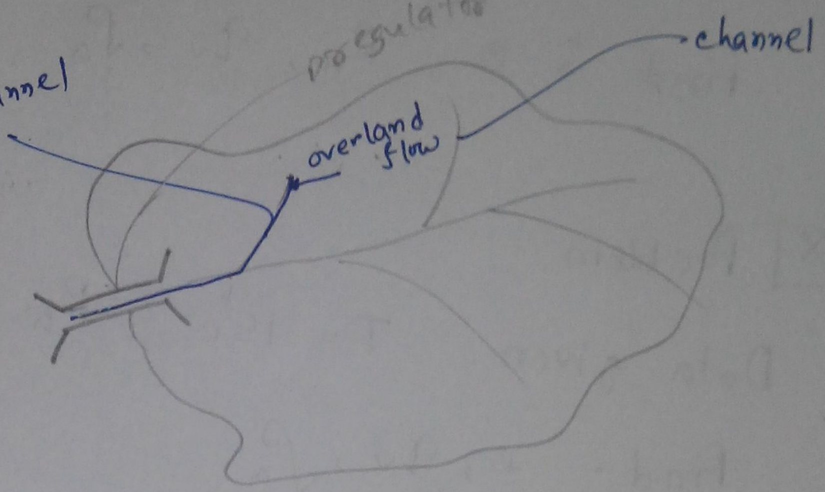
Data given: $T = 15^\circ c$, $R_h = 35\%$, $P = 101.3\ kPa$,

Find: e, q_v, ρ_a.

CT → lec 2 - ~~এর~~ পর্যন্ত (short ques)
next রবিবার (19 আগস্ট)

Chapter 5 Run-off

☒ Rainfall run-off relationship :



surface run-off (outlet এ যায় not in stream)
- → overland flow
- → openchannel flow

⊗ regulator design
⊗ pump দিয়ে পানি drainage করতে হতে পারে,
⊗ এই run-off জানা লাগে।

run-off is the overland flow.

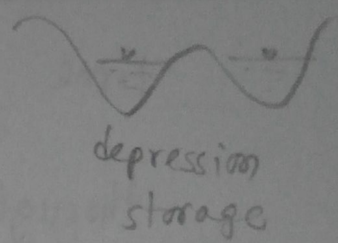
→ head build up করতে হবে।

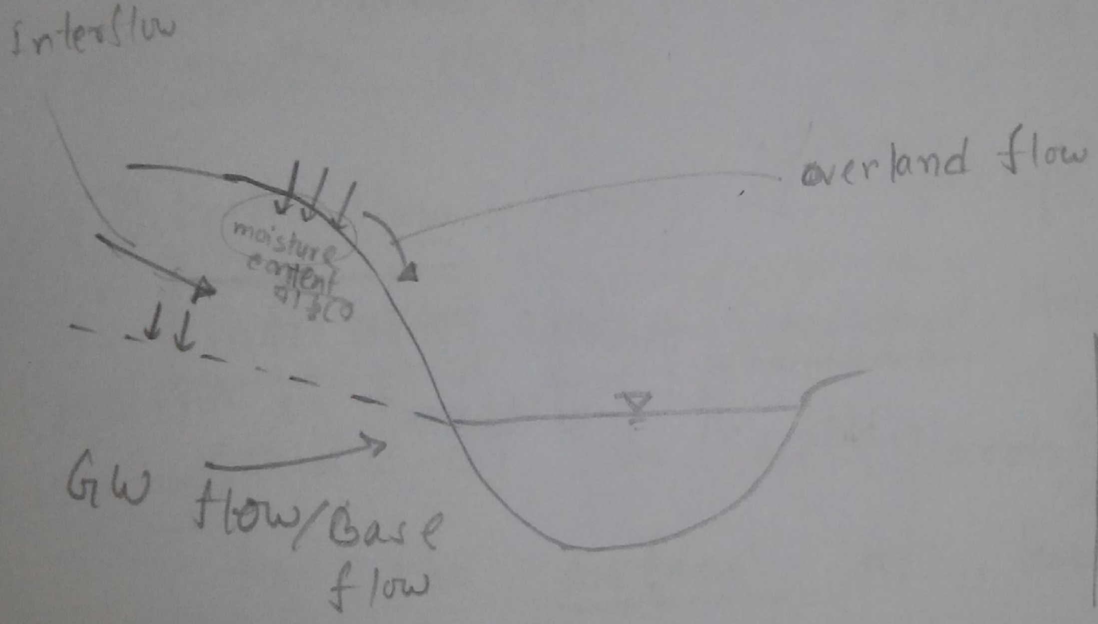
→ E + Infiltration + Depression fill করার পরও বাকিটা run off।

def^n: Run-off is draining or flowing off percipitation from a catchment area through a surface channel.

$R = P - \text{Losses}$ (ওদের retention বাদে)

- → E, T (কম)
- → Infiltration
- → Depression storage
- → initial loss
  - interception





dry season এ base flow থেকে পানি আসে।

Routes of run-off :

overland flow

GW flow

Interflow

Surface run-off: The flow which travels all the time over the surface as overland flow and through channel as open channel flow to reach the catchment outlet.

Both overland flow + open channel flow is surface run-off.

(*) to the stream → surface run-off
to the outlet of catchment → overland flow

(*) Difference betn overland flow and surface run-off.

(*) Rainfall ~~an~~ in ~~access~~ excess of flow is excess rainfall.

(*) Overland flow → the excess rainfall which moves over the land surface to reach the smaller channels.

slow + quick inter flow

(*) Inter flow – part of precipitation ~~tow~~ that $\boxed{\text{infiltrates}}$, $\boxed{\text{moves}}$ $\boxed{\text{laterally}}$ through upper crusts of the soils, and $\boxed{\text{returns back}}$ to the surface at location away from the point of entry.

unsaturated zone →

(*) Base flow – the $\boxed{\text{delayed}}$ flow (কোনো সময়? that reaches the stream essentially as GW flow.

saturated zone →

Show in a diagram diff routes (path, to a $\boxed{\text{stream}}$ due to storm ??

→ surface runoff X X

(কেন stream এ আসেনা, outlet এ যায়)

19/03/17

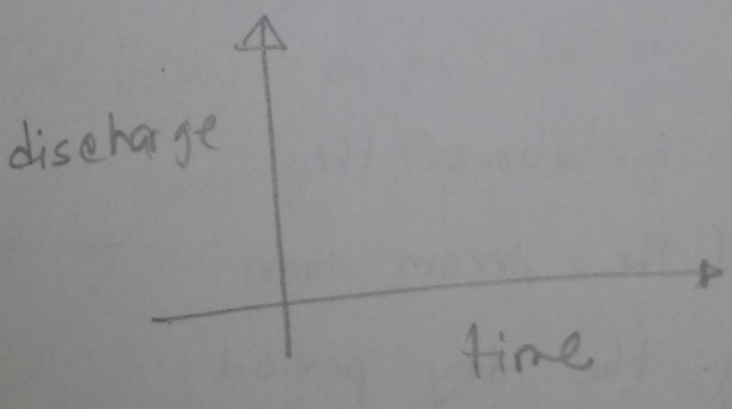
Lec 7

* Run-off
  - → Direct run-off ≃ surface run-off + promt interflow. (→ part of run-off which enters the stream immediately after the rainfall) — যত তাড়াতাড়ি যায়
  - → Base flow. (saturated zone দিয়ে যে পানি stream-এ আসে)

promt interflow negligable.

তাই, direct run-off ≃ surface-runoff

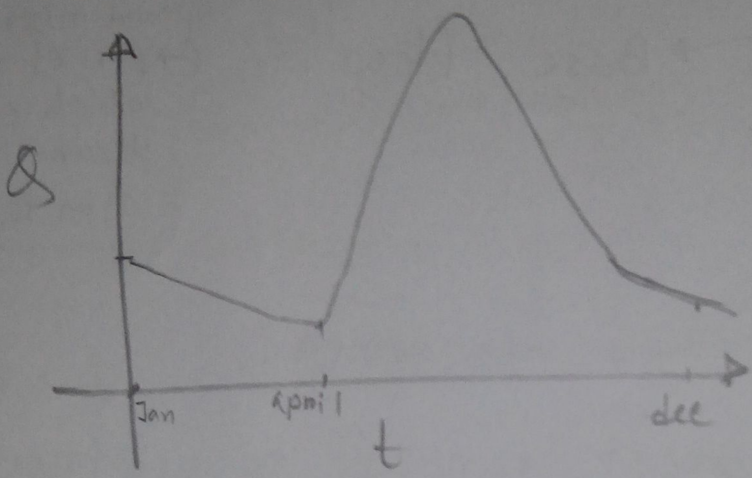
* Classification of stream (based on annual hydrograph):



hydrograph (প্রতি বছরের জন্য) (water year এর জন্য)

water yr → starts from 1st april to 31th march

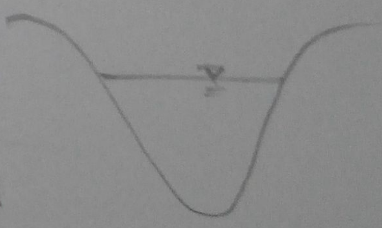
i. perennial stream:



→ always carries some flow.

→ considerable base flow throughout the year. (moonsoon এর পর base flow (যত নদীতে পানিতে থাকে)

→ GWT is above the bed of the stream even during the dry period



Bd (border) trans-river

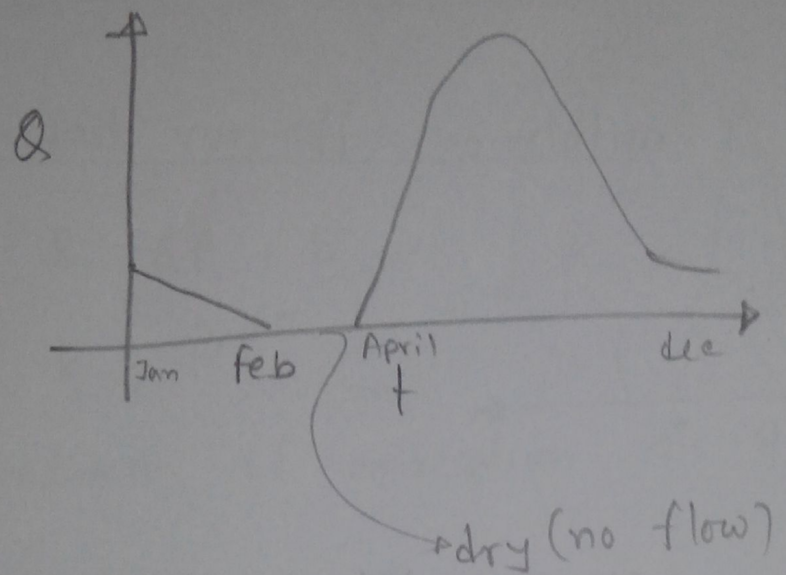
India → 54

Myanmer → 3

Total = 57

(2) compariver perenial stream/river to intermittent stream

ii Intermittent stream :

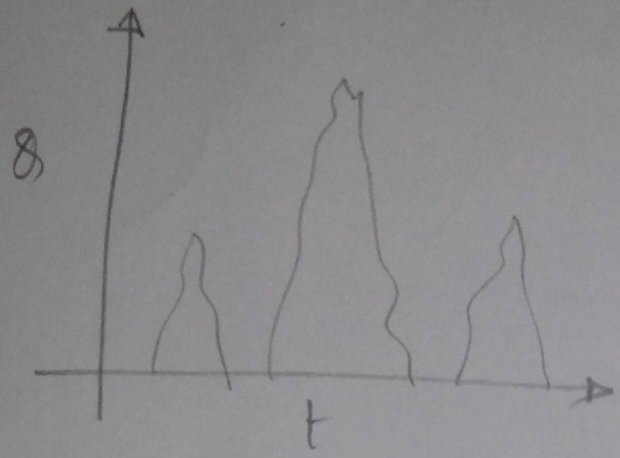


→ becomes dry during the dry period

→ limited contribution from GW.

→ GWT drops below the bed level during the dry season.

iii. Ephemeral stream :



→ No base flow contribution.

→ Series of short duration spikes marking flash flow's in response to storm.

→ becomes dry soon after the end of the stream flow.

Lec 8

20/03/17

* Estimation of run-off

i. <u>Rainfall run-off co-relation</u> :

$$R = aP + b$$

$$R = \beta P^m$$

Co-efficient of co-relation 0.6–1 এর মধ্যে হলে okay.

ii. <u>Empirical equ^n</u> : যে catchment এর জন্য developed তার জন্যই applicable (Bd এর জন্য নেই)

iii. <u>Water simulation / hydrologic model</u> :

(HMS hydrodynamic, hydrologic) (Hecras)

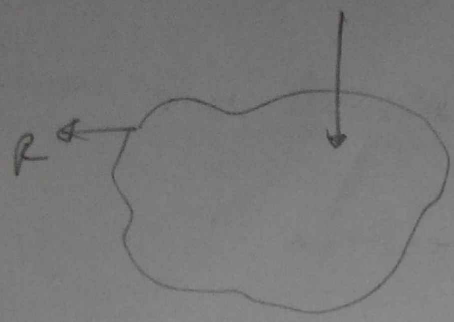
$$R = P - L$$

L → infiltration loss (E+T loss) climatic characteristics

L → depends on soil, vegetation etc (basin characteristics)

⊛ এভাবে software develop করতে পারি। elev. data দিতে হয়
এটি catchment এ কত R হয়।

$R = P - L$



input → climate & basin characteristic
+
output → runoff.

এভাবে hydrologic model prepare করা হয়,

- HEC-HMS
- SWAT (Soil water assesment too)
- Standform Watershed Model (SWM) → ৩৪
- MIKE-SHE

→ এই commercial model দিয়ে catchment এর characteris, data, দিলে run-off পাওয়া যায়।

Step:
ⓐ Model development; describe all relationships.
input = data
output = runoff.

ⓑ Model calibration: কোন time এর input, output both known থাকলে ঐ দিয়ে দেখা হয় model কেমন হয়। Then adjust

তার measured & simulated value match করানো

হয়। এতে বলে calibration

exceptable range of adjustment →

Model

ⓒ Validation / verification:

model calibrate করার পর validation করা।

ⓓ Application of model:

(কিছু data change করে simulate করিয়ে

দেখা কীভাবে run-off change হয়।

Soil conservation service

curve no

iv. SCS - CN method :→ simple + predictable + conceptual method.

→ India adopt করেছে।

Initial loss

Infiltration loss

From continuity,

$$P = R + I_a + F_a \quad \text{——— (1)}$$

Actual run-off

Actual infiltration

hypothetis used,

$$\frac{R}{\boxed{P - I_a}} = \frac{F_a}{\boxed{S}} \quad \text{——— (2)}$$

[perfectly impervious surface/ no infiltration loss]

max^m potential run-off

max^m potential retention/ infiltration

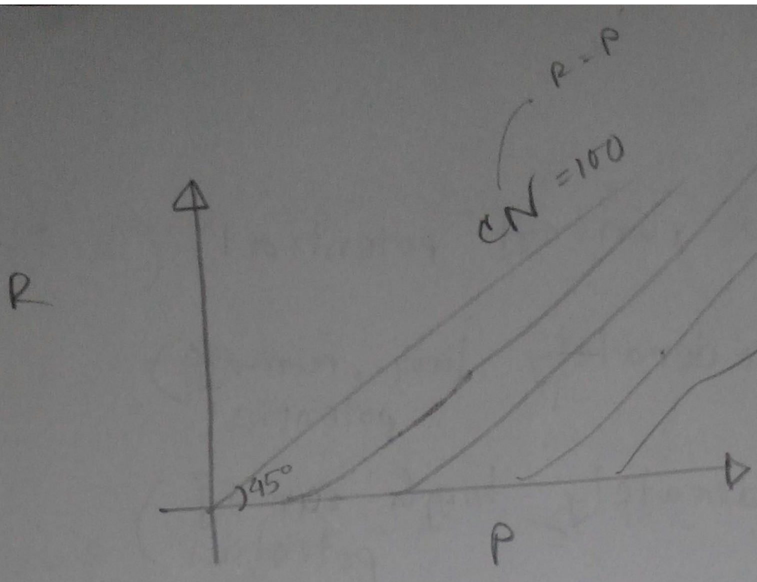
Hw → প্রতিপাদন,

$$R = \frac{(P - I_a)^2}{P - I_a + S}$$

Again, $I_a = 0.2S$. [SCS no. of catchment area ও study করে পেয়েছেন]

$$\therefore R = \frac{(P - 0.2S)^2}{P + 0.8S}$$

$$R = f(P, S)$$



curve number = $\frac{R}{P}$

$S = \frac{1000}{CN} - 10$ .... S is in inch

$S = \frac{25400}{CN} - 254$ ..... S is in mm

CN বের করতে হবে, CN জানলে S জানব,

Then P, S জানলে R জানা যাবে।

CN depends on
1. soil type (sandy, clay diff)
2. Antecedent moisture condition. (AMC)
   already wet থাকলে যে runoff < dry runoff
3. Land use
   (urband, forest, road, wheatcrop rice crop etc)

① soil type:

Group A (Low run-off potential) (sandy type soil)

Group B (moderately low run-off potential)

Group C (Moderately high run-off potential)

Group D (High value potential) (plastic clay)

এই এ table আছে show differ.

② Antecedent moisture condition (AMC):

AMC group	Total 5 day antecedent rainfall (mm)	
	Dormant season	Growing season
I (dry)	<13	< 36
II (avg)	13 - 28	36 - 53
III (wet)	> 28	> 53

এই (SSC এর table এ value দেওয়া $\boxed{\text{avg}}$ condition এ)

CN_{II}

⊗ dry season এর জন্য করতে হবে ??

= empirical eqⁿ আছে betⁿ CN_{II}, CN_{I}, CN_{III}

⊗ Table 5.6(a) → page 188 (CN for AMC II এর জন্য read করা যায়)

⊗ weighted avg CN = ? (method আছে) (যত জায়গায় condition same না)

$$\boxed{CN_{I}} = \frac{CN_{II}}{2.281 - 0.01281\, CN_{II}}$$ (দেওয়া থাকবে)

(dry)

and

$$CN_{III} = \frac{CN_{II}}{0.427 + 0.00573\, CN_{II}}$$

(wet)

⊗ যদি থাকে, → % soil A, % B, → soil type

→ % road, % residence → land use

= CN_{II} পাব

→ Then conversion CN_{I}

→ S = $\boxed{}$ → R = $\boxed{}$

Lec 9 01/04/17

[*] India modified for black soil.

[*] Problem 5.13 (page 235)

(a) Urban land

avg anticident moisture condition [মত]

from Table 5.6(c)

Land use	Total %	Soil group B (35%)			Soil group C (40%)		
		%	CN	Product	%	CN	product
Residential	80	28%	85	2380	32%	90	2880
Paved road	20	7%	98	686	8%	98	784
				3066			3664

$$\text{average } CN_{II} = \frac{3066 + 3664 + 2330}{100} = 90.6$$

as percent এ নিয়েছি

$$R_{unoff} = \frac{[\overset{P}{150\,mm} - 0.2 \times \overset{26.35}{S}]^2}{150 + 0.8 \times \underset{26.35}{S}}$$

$= 122.44$ mm

Runoff 122.44 mm হবে

$$S = \frac{25400}{90.6} - 254 \text{ (mm)}$$

$= 26.35$ mm

Soil group D (25%)

%	CN	product
20%	92	1840
5%	98	490
		2330

vol^m চাইলে,

vol^m = R × area

=

vegetation
agricultural land

(b) Pasture Land (CN diff, run-off diff)
(poor)

Land use	Total%	Soil group B (35%)			Soil group C (40%)		
		%	CN	product	%	CN	product
Pasture, poor	100%	35	79	2765	40	86	3440

P [illegible] %

Run-off বেশি

$$\boxed{CN_{II}} = \frac{2765+3440+2225}{100} = 84.3$$

max

$$S = \frac{25400}{84.3} - 254 = 47.3 \text{ mm}$$

$$R = \frac{(150-0.2\times 47.3)^2}{150+0.8\times 47.3}$$

$= 105.2$ mm.

আগের 105.2 mm, urban = 122.44.

% increase of $\frac{122.44-105.2}{105.2}$

$= 16.3\%$.

Soil group D (25%)		
%	CN	product
25	89	2225

$\boxed{*}$ v. Rational method :

~~quick~~ peak runoff value দিয়ে design.

Peak runoff এর জন্য peak Q দরকার,

$$Q_p = CiA$$

A → Area of the catchment

i → rainfall intensity = $\frac{\text{magnitude}}{\text{time}}$ = rate of P

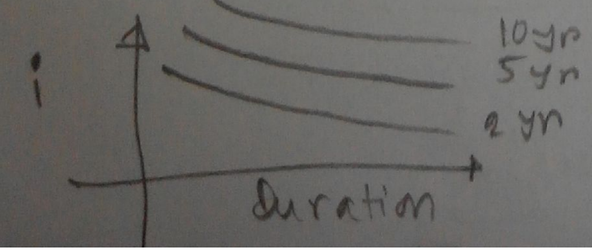
C = runoff co-efficient

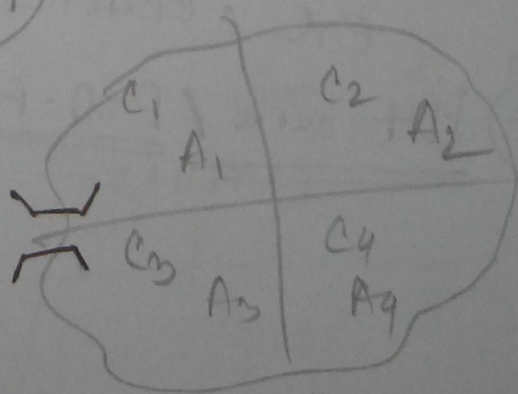
↳ depends on land use, soil type [page 299 7.1(a) table]

(*) : কোনটি নিব??

time কম নিলে intesity বেশী

period " বেশী " " কম





$$C = \frac{\sum C_i A_i}{A_i}$$

[*] Short duration(3hr) এর diff yr এর data থাকলে,

diff year এর diff max^m value নিব।

20yr এর 20 টি random value পাব।

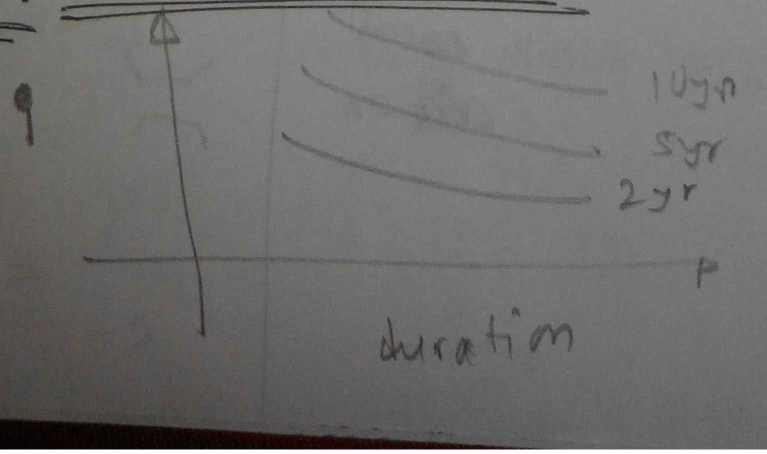
[*] regulator design করতে গেলে কোন value টি নিব

→ max নিলে $\frac{1}{20} = 5\%$ probability of occurance (T=20yr) (প্রতি 20 yr এ ১ বার)

→ avg " $\frac{1}{5} = 20\%$ " " " (T=2yr) (প্রতি 2 yr এ ১ বার)

So, it is called return period / (how frequently it will come) frequency, T or Probability of exceedence, P.

(*) I-D-F curve / I-D-F relationship:



IDF is represted by an equ^n.

$$\boxed{i = \frac{KT^x}{(D+a)^n}}$$

frequency (yr)

Duration (hr).

$\boxed{cm/hr}$ (x)

K, x, a, n = const (depends on catchment + P of catchment)

emperical formula

Here, $\boxed{D = t_c \text{ (time of concentration) at least or বড়}}$

- time of concentration = time taken for a drop of water from farthest part of the catchment to reach the outlet

$\boxed{x}$ i = mean intensity of precipitation for a duration equal to time of concentration and desired frequency

$\boxed{\text{প্রত্যেক বছর} = 5 \text{ year হলেই হবে}}$

Kirpitch formula,

$$t_c = 0.01947 \, L^{0.77} \, S^{-0.385}$$

min

slope

max^m length of travel (in meter)

depends on catchment shape
(shape লম্বা হলে বেশি,)

(x) comparision bet^n CN_{II} & C (02)

Ex 7.2 : $A = 500\,ha$, $L = 3000\,m.$, $T = 25\,yrs.$

elev. diff, $\Delta H = 25m$

$A_1 = 250\,ha$, $c_1 = 0.10$

$A_2 = 50\,ha$, $c_2 = 0.11$

$A_3 = 200\,ha$, $c_3 = 0.3$

$$i = \frac{6.311\,T^{0.1523}}{(D+0.5)^{0.945}}$$

Soln: $$C_{avg} = \frac{250\times0.1 + 50\times0.11 + 200\times0.3}{500}$$

$$= 0.181$$

i calc করতে হলে tc লাগবে।

$$\underset{(min)}{t_c} = 0.01947 \times L^{0.77}_{\text{in m}}\ S^{-0.385}$$

$$= 0.01947 \times (3000)^{0.77} (0.0083)^{-0.385}$$

$$S = \frac{\Delta H}{L} = \frac{25}{3000} = 0.008$$

$$= 58.3\ min.$$

$$t_c = \frac{58.3}{60} = 0.98\ hrs$$

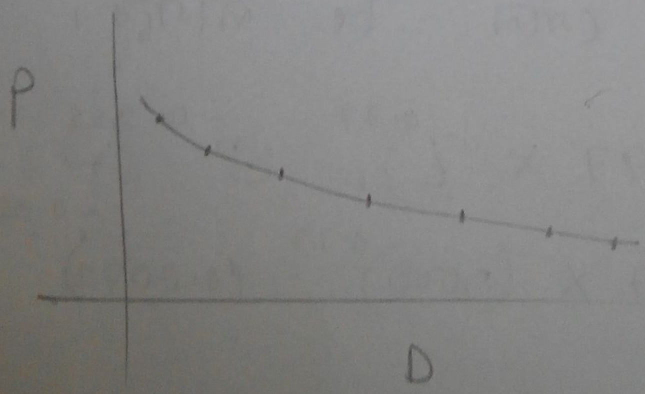
$$i = \frac{6.311 \times (25)^{0.1523}}{(0.98 + 0.5)^{0.945}}$$

$= 7.11$ cm/hr.

$$Q_p = \frac{0.181 \times (7.1 \times 10^{-2})^{m/hr} \times (500 \times 10^{4})^{m}}{(60 \times 60)^{sec}} \qquad \left[Q_p = \frac{C_e i A}{3.6} \right]$$

$= 17.84 \ m^3/s$.

ex 7.1 : for diff points (Duration, depth) নেয়া (not in equ^n)



D (min) 20		30
P (m) 40		50

27.4 min

(linear interpolation)

te = 27.4 min এর জন্য, P = 47.4 mm

$$i = \frac{47.4 \text{ mm}}{27.4 \text{ (min)}} = 103.8 \text{ mm/hr}$$

te = 27.4 min

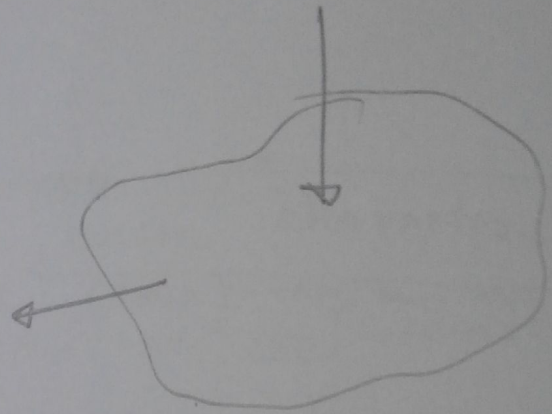
exercise: 7.2, 7.6, 7.7

Chap 6

Hydrograph

→ plot of Q vs time (t)

→ particular river / storm এর জন্য দেখতে পারি।



~~আগে~~ নয়?

annual hydrograph

প্রতি 365 দিনের Q ~~cat~~ plot করি

1. $\boxed{\text{Storm hydrograph}}$

$\boxed{\text{hydrograph}}$

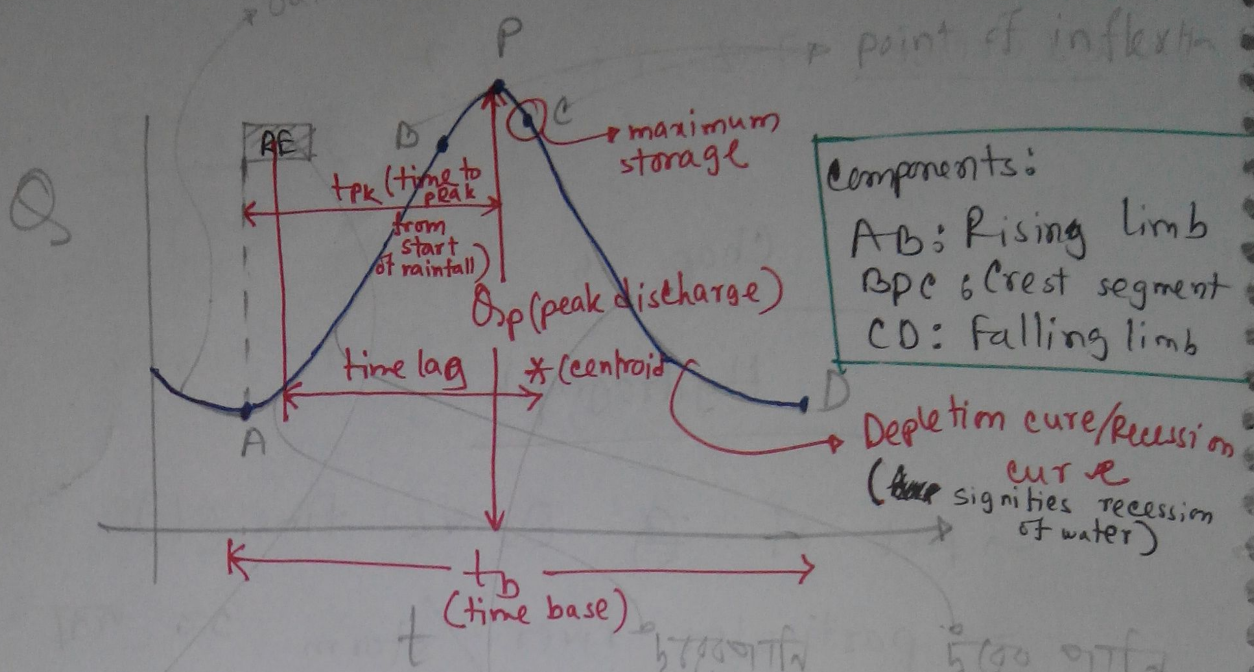
[how a catchment respons to a storm]

2. can be W.L vs time

It's called $\boxed{\text{water level}}$ $\boxed{\text{hydrograph}}$

3. GW এর সাথে হতে পারে

$\boxed{\text{GWT hydrograph}}$



Components:

AB: Rising limb
BPC: Crest segment
CD: Falling limb

rainfall excess

(*) Rainfall − $\boxed{\text{Loss}}$ = Run-off

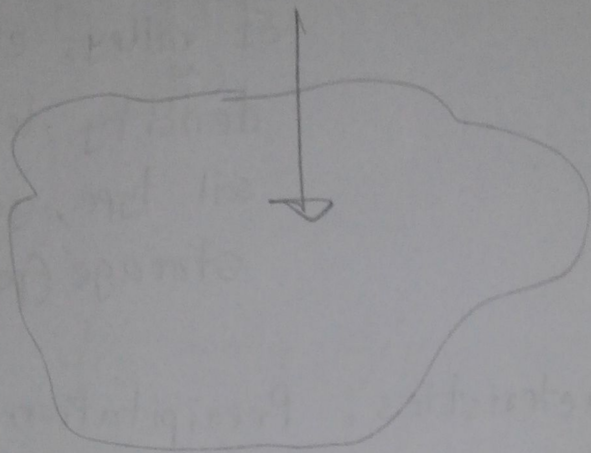
mainly infiltration

(*) $RE = P - \phi \Delta t$

RE: effective rainfall

Rainfall এর যে অংশ run-off generate করে that's effective rainfall or RE or rainfall excess.

(x) surface storage [e represents max^m storage]
interflow "
GW/base "



(x) Recession depends on basin characteristics.
(doesn't vary much with time)

Elements:

Q_p = peak discharge

t_{pk} = time to peak from rainfall start.

t_b = time base

T_L = Lag time

[*] Factors effecting flood hydrograph :

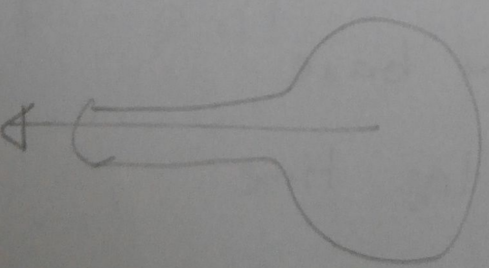
1. Basin characteristics : size, shape, slope, nature of valley, elevation, drainage density, land use and cover, soil type, geological condition, storage (pond, lake)

2. Storm characteristics : Precipitation, intensity, duration, magnitude, and movement

3. Climatic ~~the~~ factor : initial loss, evapotrans-piration (ET).

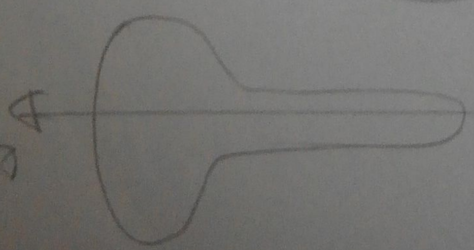
Shape :

কম আসবে



most of the land outlet হতে দূরে (travel time, tc বেশী)

বেশী আসবে



most of the land outlet এর কাছে।

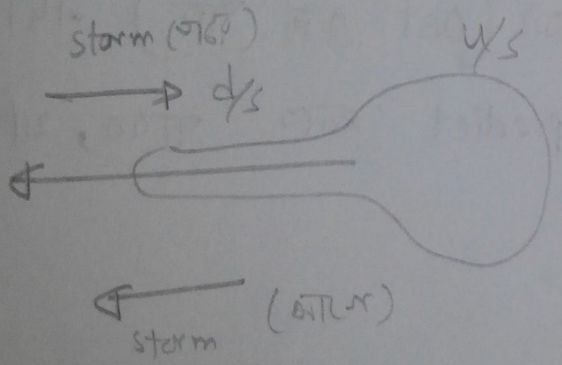
Drainage density:

Overland ~~fall~~ flow এ friction কম। তাই OCF পানি quick আসে।
এ OL flow এ
(density ↑↑)

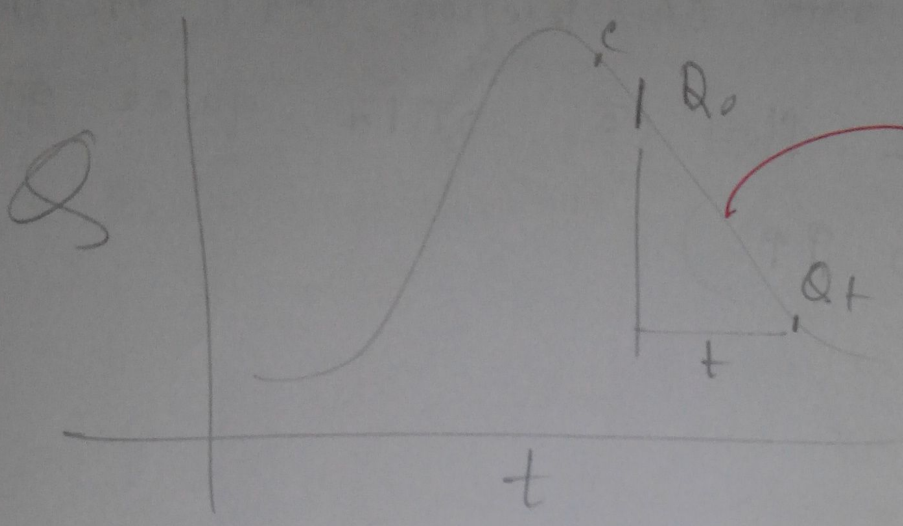
movement:

U/S → d/S [আগে হবে]

d/S → U/S [পরে হবে]



✱ Recession curve এর shape use করে low flow model prediction করতে পারি।



$Q_t = Q_0 K_r^t$

Recession const

→ Q_0, t জানা থাকলে Q_t বলতে পারব

→ Dry season এ (oct এর পর) নদীর পানির Q predict করতে পারব, যদি k_r জানি।

→ We call it low flow model as it is for dry season.

→ Deplition curve develop করতে পারি বাকি মাসের avg নিয়ে।

$$\frac{Q_t}{Q_0} = k_r^t$$

$$\Rightarrow \log\left(\frac{Q_t}{Q_0}\right) = t \log(k_r)$$

$$\Rightarrow \log(K_r) = \frac{1}{t} \log\left(\frac{Q_t}{Q_0}\right).$$

(*) K_r consists of K_{rs} (surface storage)

" " K_{ri} (interflow ")

" " K_{rb} (base flow ")

$$K_r = K_{rs} . \boxed{\cancel{K_{ri}}} . K_{rb} .$$

এটি কম (negligible)

value = 1 হবে

$$= K_{rs} . K_{rb}$$

08/04/17

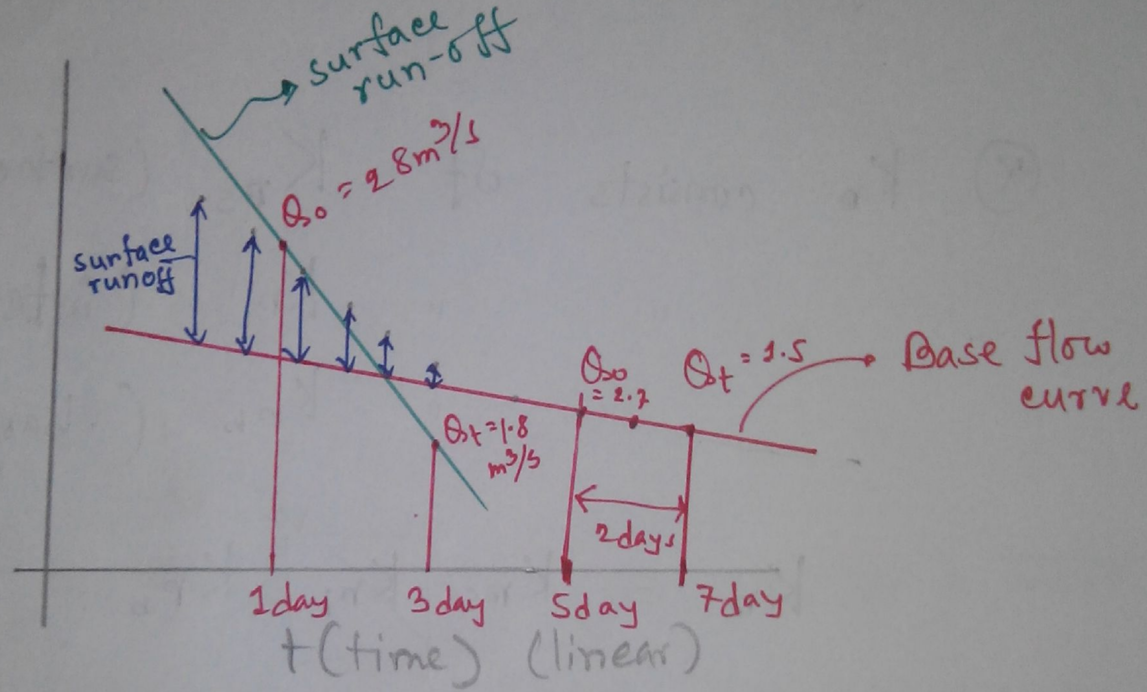
Lec 11

Ex 6.1

Fig 6.4

page 247

semi-log (ঘুরিয়ে নিতে হবে)



last 3 point ধরে straight line.

Base flow curve/ equ^n, $\frac{Q_t}{Q_o} = k_r b^t$

$\Rightarrow \log(k_{rb}) = \frac{1}{t} \log\left(\frac{Q_t}{Q_o}\right)$

$\Rightarrow \log(k_{rb}) = \frac{1}{2} \log\left(\frac{1.5}{2.7}\right)$

Scanned by CamScanner

$\Rightarrow K_{rb} = 0.75$

(x) hydrograph analysis = K_r বের করা যাবে

$K_{ri} = 1.$ [negligible]

Surface run-off. $\frac{Q_t}{Q_0} = K_{rs}^t$

$\Rightarrow \log(K_{rs}) = \frac{1}{t}\log\left(\frac{Q_t}{Q_0}\right)$

$\Rightarrow \log(K_{rs}) = \frac{1}{2}\log\left(\frac{1.8}{28}\right)$

$\Rightarrow K_{rs} = 0.25$

practise: graph এ করব [problem 6.1]
(semi log) page 287

(*) dry season এর discharge জানলে এর বিদুৎ পরের discharge predict করতে পারব,

problem 6.2

June 1 $Q = 80 \ m^3/s$

June 21 $Q = 40 \ m^3/s$

এর মাঝে কোন বৃষ্টি নেই।

$K_r = ?$ July 10 , $Q = ?$

Soln:

$t = 20$ days.

$Q_t = 40$

$Q_0 = 80$

$$\frac{Q_t}{Q_0} = K_r b^t$$

$$\Rightarrow \log\left(\frac{Q_t}{Q_0}\right) = \frac{1}{t}\log(k_r [illegible])$$

$$\Rightarrow \log\left(\frac{40}{80}\right) = \frac{1}{20}\log(k_r [illegible])$$

$$\Rightarrow K_r = 0.96$$

June 1, July 1 , $Q_t = Q_0 k_r^t$

$$= 80 \times 0.96^{30}$$

$$= 28.39$$

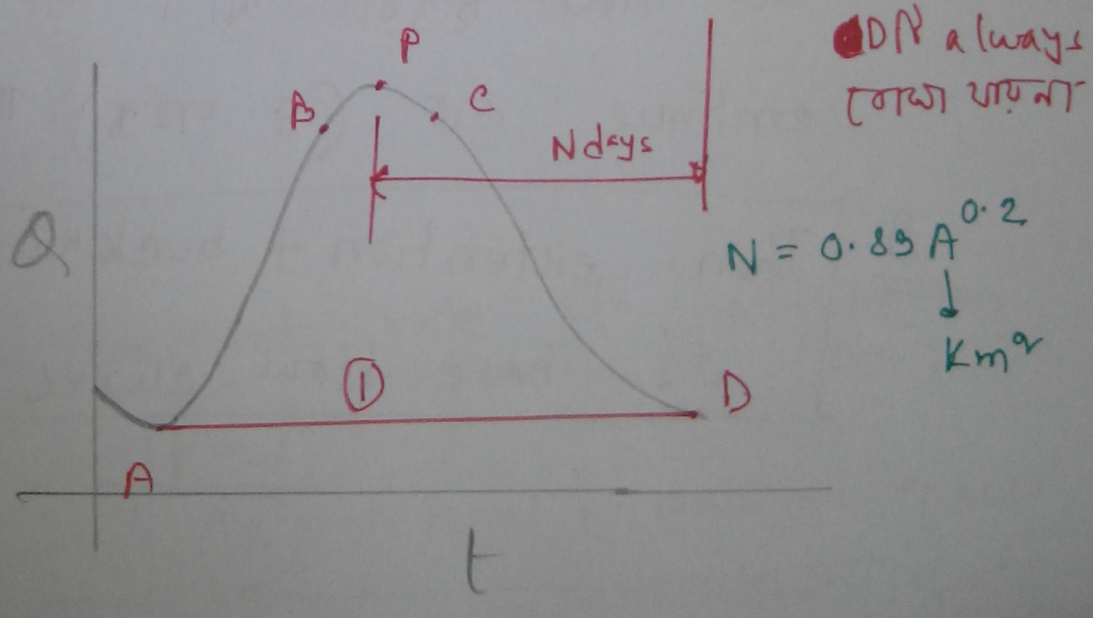
→ direct/surface run-off : আমাদের বেশী প্রয়োজন বৃষ্টির যাতে যাতে কত পানি আসছে।

→ rainfall hydrograph এ base flow বের করছি আগের math এ.

→ তাই, Base flow separate করে actual run-off টি বের করতে হবে।

$\boxed{\text{3 methods of separate base flow:}}$

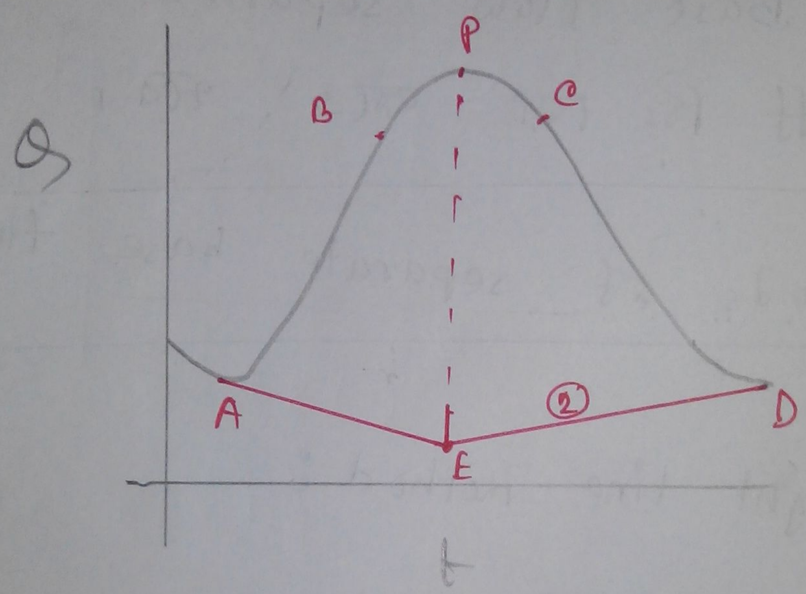
1. Straight line method :



Disadv:

এর কোন rationality নেই।

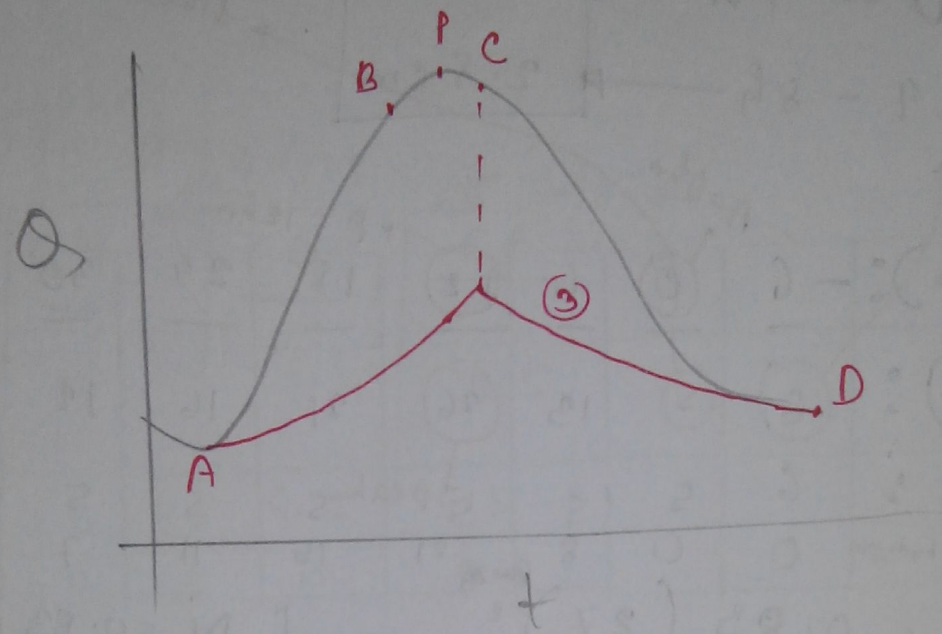
2. Extention of previous base flow curve



Peak flow হওয়া আগে পর্যন্ত base flow continue করে (E পর্যন্ত). Then connect to D.

3. Then extention + backward extention of base flow curve.

3. Backward extension of base flow curve



no such authenticity.

method ① is widely used.

(*)

ϕ_{index} = constant rate of infiltration (loss)

$$\phi = \frac{P - R}{t_e}$$

P → Precipitation (time 1)

R → " (time 2)

t_e → Period of rainfall excess

যদি hm | rainfall intensity = capacity of infiltration | of soil then | no run-off |

" " | " > " " " | = | run off | [illegible]

Example 6.2 [page 250] Estimate RF & ϕ_{index}.

$A = 27\ km^2$

0 – 4h → 3.8 cm

4 – 8h → 2.8 cm.

magnitude high, তাহলে runoff হবে

direct run-off start

base flow থাকে

A = 0hr

হতে শুরু হওয়ার 6 ঘন্টা আগের discharge

P = 12hr

T(hr) :	−6	0	6	12	18	24	30	36	42
Q (m^3/s) :	6	5	13	26	21	16	12	9	7
Base flow (m^3/s) :	6	5	5	5 peak	5	5	5	5	5
Direct runoff hydrograph (DRH) (m^3/s)	0	0	8	21	16	11	7	4	2

ordinates of DRH

$\Sigma O_i = 69$

$N = 0.83\,(27)^{0.2}$ $\quad [N = 0.83\,(A)^{0.2}]$

$= 1.6$ days

$= 38.5$ hr from peak

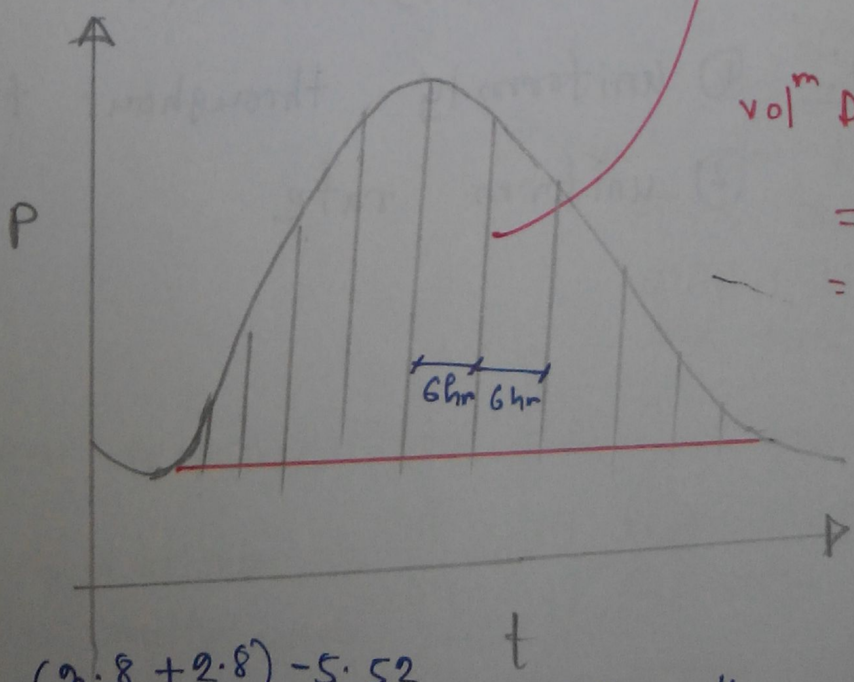
$(38.5 + 12)$ hr $= \boxed{50.5\text{hr}}$ from start of P.

D=48 hr

48	54	60	66
5	5	4.5	4.5
5	5	4.5	4.5
0	0	0	0

50.5 hr
এর মানে
(48 আছে)
তাই D=48

vol^m DF = $\boxed{\text{primoidal rule দিয়ে বের করা}}$



$$vol^m\ DF = \Sigma O_i\ \delta t$$

$$= 69 \times (6 \times 60 \times 60)$$

$$= 1.49 \times 10^6\ m^3$$

$$RE = \frac{1.49 \times 10^6}{27 \times 10^6}\ m$$

$$= 0.0552\ m$$

$$= 5.52\ cm$$

$$\phi_{index} = \frac{(3.8 + 2.8) - 5.52}{8} = 0.135\ cm/hr$$

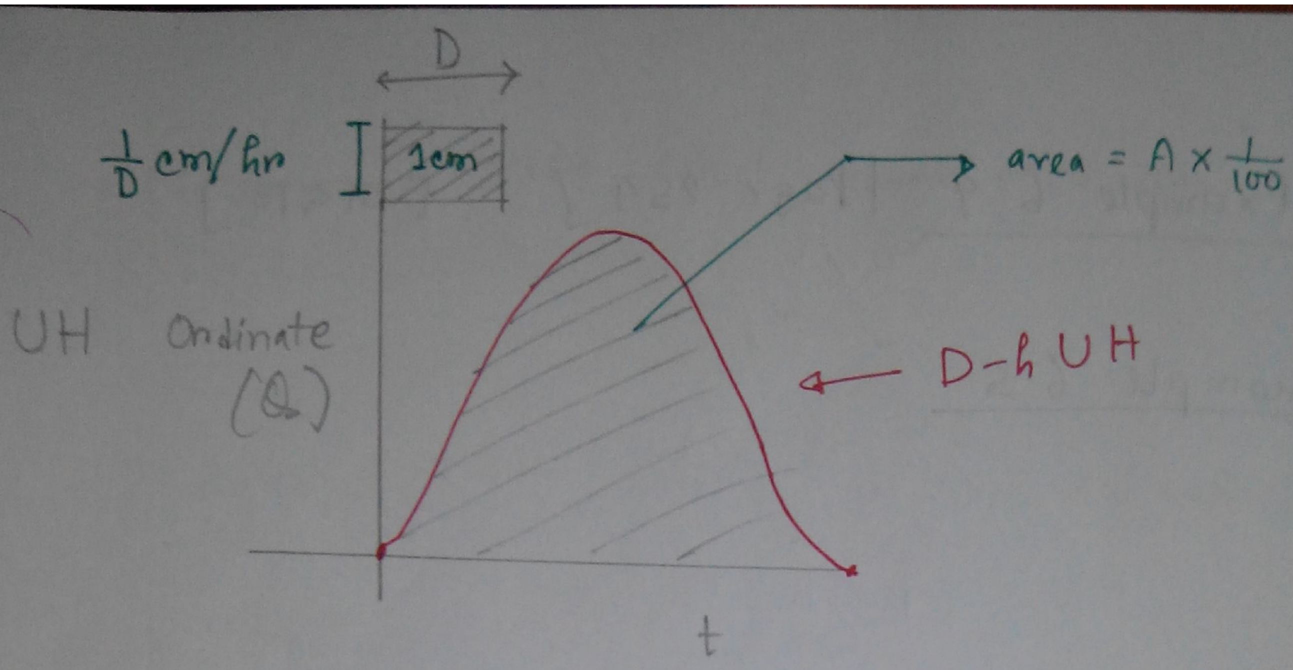
Lect 2 10/04/17

Unit hydrograph

→ Catchment এর Q unit hydrograph দ্বারা করা যায় ।

Defⁿ: hydrograph of direct run-off (R − Infiltration) resulting from an unit $\boxed{(1\text{ cm})}$ depth rainfall excess occuring $\boxed{\text{uniformly}}$ over the basin and at $\boxed{\text{uniform rate}}$ for a $\boxed{\text{specified duration (D)}}$.

assumption:



Assumptions:

1) RE is uniformly distributed over the catchment.

2) Rate of RE is const.

3) Time invariente [যদি 6 hr hydrograph হয়, its hydrograph of Q = 6 hr.
But 6hr - 12hr এর মাঝে হলেও ordinate change হবেনা। অর্থাৎ, ordinates are time invarience]

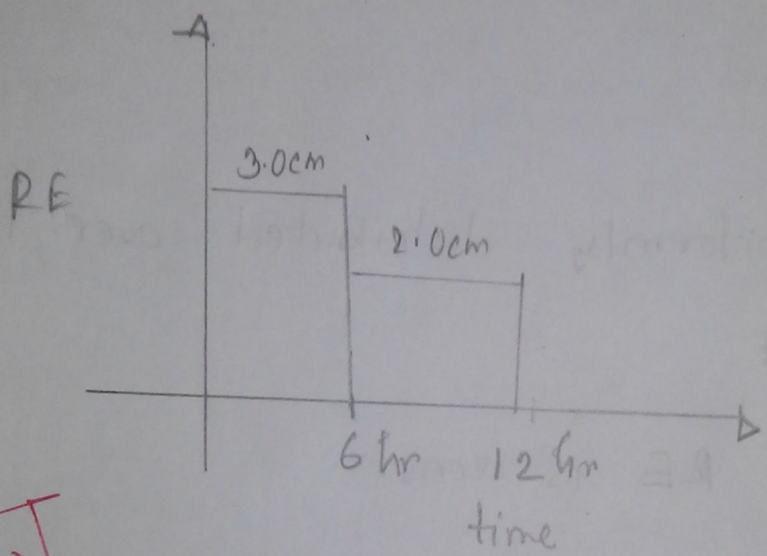
4) Linear response [কোনো func linear হলে (+), (x) করতে পারি। UH represent DR of 1cm depth। 3 cm এর জন্য চাইলে ওর ordinate কেও 3 দিয়ে গুণ হবে। আবার যোগ করতে চাইলে 6 hr এর corresponding ordinate এর সাথে যোগ করব]

principle of addition
" " multiplication

Example 6.4 [Page 254] [বাদ্যাও]

Example 6.5

Rainfall Intensity & time → hytograph.



Time equal interval এ নেই

It's rainfall excess (RE) hydrograph.

(6-12)hr এ হয়েছে [তাই 6hr আগের value নিয়ে] (0-6hr) হয়েছে। OK.

Time (hr)	0	3	6	9	12	15	18	24	30	36
Ordinate of 6h UH	0	25	50	85	125	160	185	160	110	60
DRH 1 (3cm)	0	75	150	255	375	480	555	480	330	180
DRH 2 (2cm)	-	-	0	25x2 = 50	50x2 = 100	170	250	370	320	220
DRH ord (m^3/s)	0	75	150	305	475	650	805	850	650	400

18 $\xleftrightarrow{6hr}$ 24

[illegible] storm ৬০, [illegible] effect count করতে হবে।

3.5 DRH 2.35 [illegible]
63 SF value [illegible]

42	48	54	60	(63)	(66)	(69)	(75)
36	25	16	8	(5.3)	(2.7)	0	0
108	75	48	24	(8.1)		0	
140	72	50	32	(22.8)		10.6	
283	197	98	56			10.6	

* t vs cummilative raintall দেয়া থাকলে

or t vs infiltration " " ।

$$RE = RF - \text{infiltration}.$$

এভাবে UH পাব

যদি ২'টি / ৩টি storm এর data দেয়া

থাকে যোগ করব।

Q_{total} of catchment পাব।

Data:

→ Raintall pattern

→ Loss

→ UH

$\boxed{\text{hytograph}}$ + Base flow = Q_{total}

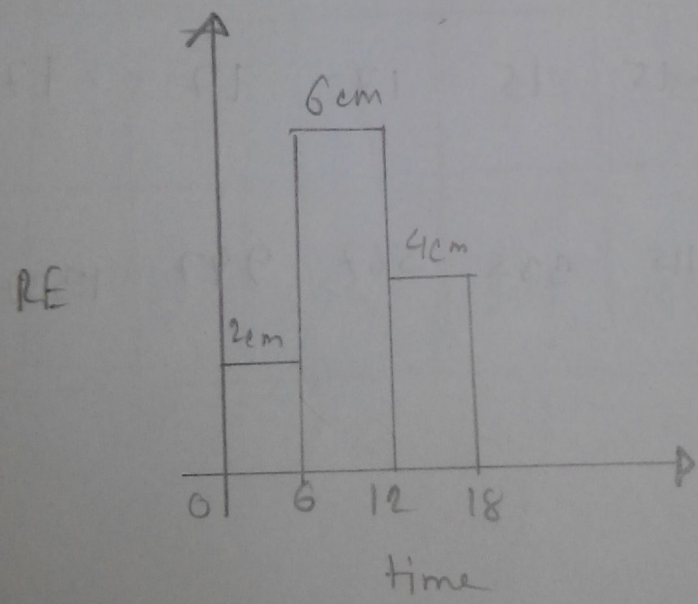
থেকে Q

Run-off

Example 6.6

Time(hr)	0	6	12	18
ΣP	0	3.5	11	16.5

time	P(cm)		$\phi \Delta t$	RE (cm)
0 - 6hr	3.5	$\boxed{(11-3.5) = 7.5}$	1.5	3.5 - 1.5 = 2
6 - 12hr	7.5cm		1.5	7.5 - 1.5 = 6
12 - 18hr	5.5cm		1.5	5.5 - 1.5 = 4



base flow = $15 m^3/s$ beginning, increasing $2 m^3$/every 12hr

T(hr)	0	3	6	9	12	15	18
Ordinate	~~25~~0	~~50~~ 25	~~85~~ 50	~~125~~ 85	~~160~~ 125	~~185~~ 160	~~160~~ 185
DRH 1 (2cm)	0	50 (25X2)	100	170	250	320	370
DRH 2 (6cm)	. .	.	0	(25X6) =150	300	510	750
DRH 3 (4cm)	.	.	.	.	0	150 (25X4) =100	240
DRH	0	50	100	320	550	930	1320

Le 13

29/04/17

30	36	42	48	54 57	60	63 69
~~60~~ 110	~~36~~ 60	~~25~~ 36	~~16~~ 25	16 ~~8~~ 12	8	5.30
220	120	72	50	32	16	0
960	660	360	216	150	96	31.8 ≈ 32
740	640	440	240	144	100	48
1920	1420	872	506	326	212	80
19	21	21	23	23	25	25
1939	1441	893	529	349	237	105

(5.3×6) =31.8

(12×4) =48

Next example

→ ±10% allow করে isolated flow hytograph নিতে হবে।

→ BF estimate করতে হবে।

BF Beginning

BF end ($0.83 A^{0.2}$) point কে করলাম

মাঝের value straigh line থেকে পাব।

→ BF subtrat করব।

$$\text{RE পাব} = \frac{\text{DRH ordinate sum}}{\text{area}} = Rf\ (x)$$

x cm এর জন্য hytograph

→ ~~RE/area~~ = x দিয়ে ভাগ করে দিব

exam এ const দিতে পারে (সব same থাকবে)

Example 6.7 $A = 423\ km^2$

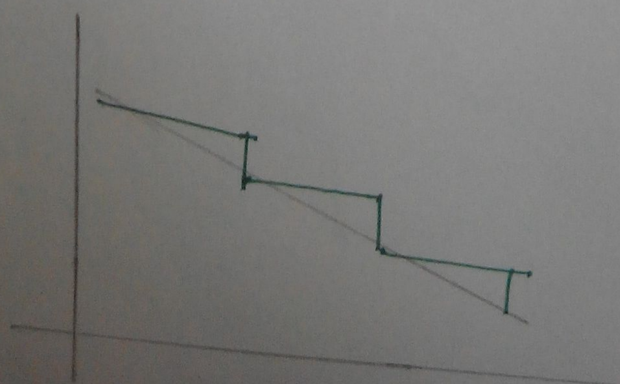
Arbitrily (প্রতি বার 0.5 বাড়িয়েছি)
90hr → 2.5 বাড়ে
18hr → 0.5 বাড়ে

peak

highest discharge

T (hr)	-6	0	6	12	18	24	30	36	42
Q (m^3/s)	10	10	30	87.5	$\boxed{115.5}$	102.5	85	71	59
BF	10	10	10	10.5	10.5	10.5	11	11	11
DRH ordinate (m^3/s) (Q − BF)	0	0	20	77.5	105	92	74	60	48
UH ordinate (DRH/3)	0	0	6.7	25.7	35	30.7	24.7	20	16

$N = 0.83(423)^{0.2} = 2.78$ days $= 66.76$ hours.
$= 66.8$ hr.
$+\ 18$ (Peak)
84.8



$\boxed{\text{Stepping}}$

BF

End

48	54	60	66	72	78	84	90	96	102	
47.5	39	31.5	26	21.5	17.5	15	12.5	12	12	
11.5	11.5	11.5	12	12	12	12.5	12.5	12	12	
36	27.5	20	14	9.5	5.5	2.5	0	0	0	
12	9.2	6.7	4.7	3.2	1.8	0.8	0	0	0	

1st DR = $\boxed{591} \times 6 \times 60 \times 60 = 12.76\ Mm^3$.

Q ordinate sum

vol^m of DRH = 591×6×60×60
= 12.76 Mm³

RE = $\frac{vol^m}{area} = \frac{12.76 \times 10^6}{423 \times 10^6} = 0.03\ m = 3\ cm$

ex : 6.8 (catchment area, time base = ??)

peak = given

P = "

BF = " (const)

$Q - BF = DR$

(a) Depth of RF $= 5.9$, loss $= 0.3\,cm/h \times 3h = 0.9\,cm$

$\therefore RF = 5.9 - 0.9 = 5\,cm$

Peak of 3h Flood hydrograph $= 270\,m^3/s$

BF $= 20\,m^3/s$

Peak of 3h DRH $= 250\,m^3/s$

$\therefore$ " " " UH $= \frac{250}{5} = 50\,m^3/s$.

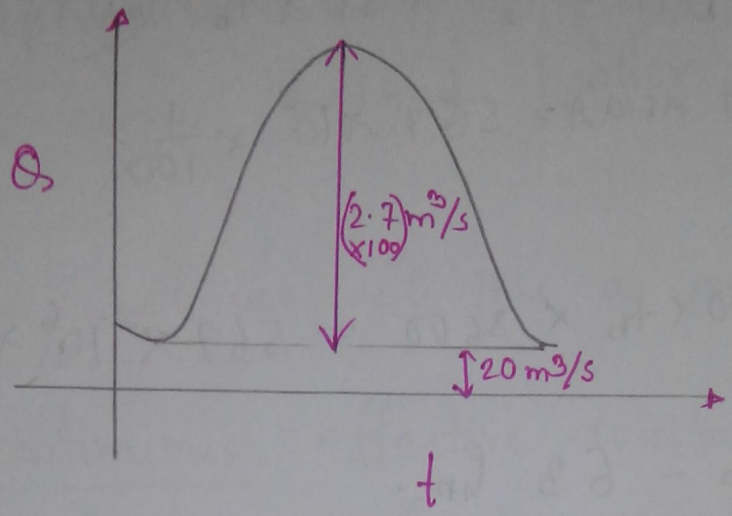
(b) vol^m of catchment = area of UH = area of triangle

$\Rightarrow (567\,km^2 \times 1\,cm) = \frac{1}{2} \times (t_b \times 60 \times 60)\,s \times 50\,\frac{m^3}{s}$

$\Rightarrow \left(567 \times 10^6 \times \frac{1}{100}\right) m^3 = \frac{1}{2} \times t_b \times 60 \times 60 \times 50$

$\Rightarrow t_b = 63\,hr.$

Lec 14



$P = 5.9\,cm$

ϕ index $= 0.3\,cm/hr$

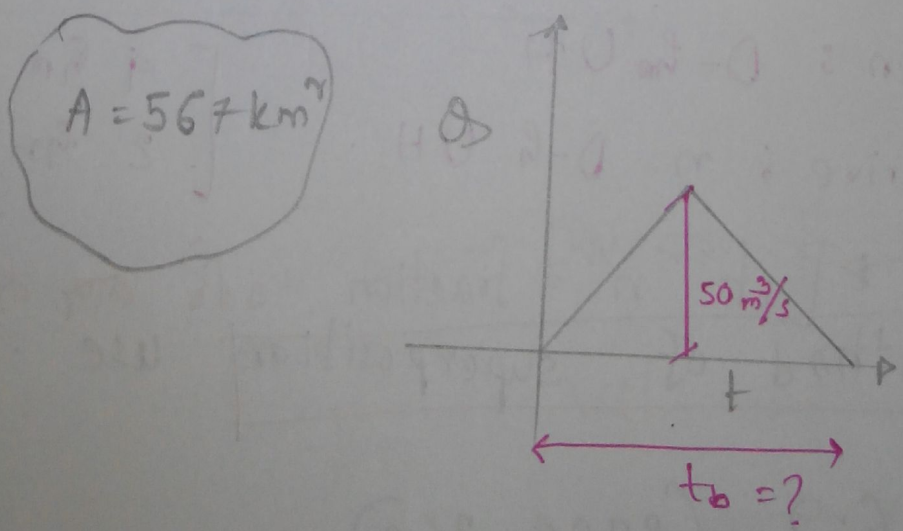
$\therefore RE = 5.9 - 3 \times 0.3$

$= 5\,cm$

(a) Peak of DRH $= 270 - 20 = 250\ m^3/s$.

" " UH $= \frac{250}{5} = \boxed{50\ m^3/s}$.

(b)



catchment area × 1 cm = triangle 𝑎𝑟 area
(area of UH)

hr→s conversion

$$\text{vol}^m \text{ of } DH = \frac{1}{2} \times 50 \times t_b \times (60 \times 60)$$

$$\text{catchment area}, A = 567 \times 10^6 \times \frac{1}{100}$$

$$\therefore \frac{1}{2} \times 50 \times t_b \times 3600 = 567 \times 10^6 \times \frac{1}{100}$$

$$\Rightarrow t_b = 63 \text{ hr.}$$

change:

$t_b = 60$ hr হলে catchment area = ?

Given: D-hr UH

Derive 6 hr D-h UH.

[4 hr UH দেয়া
2 hr বের করো
$\therefore n = \frac{1}{2}$]

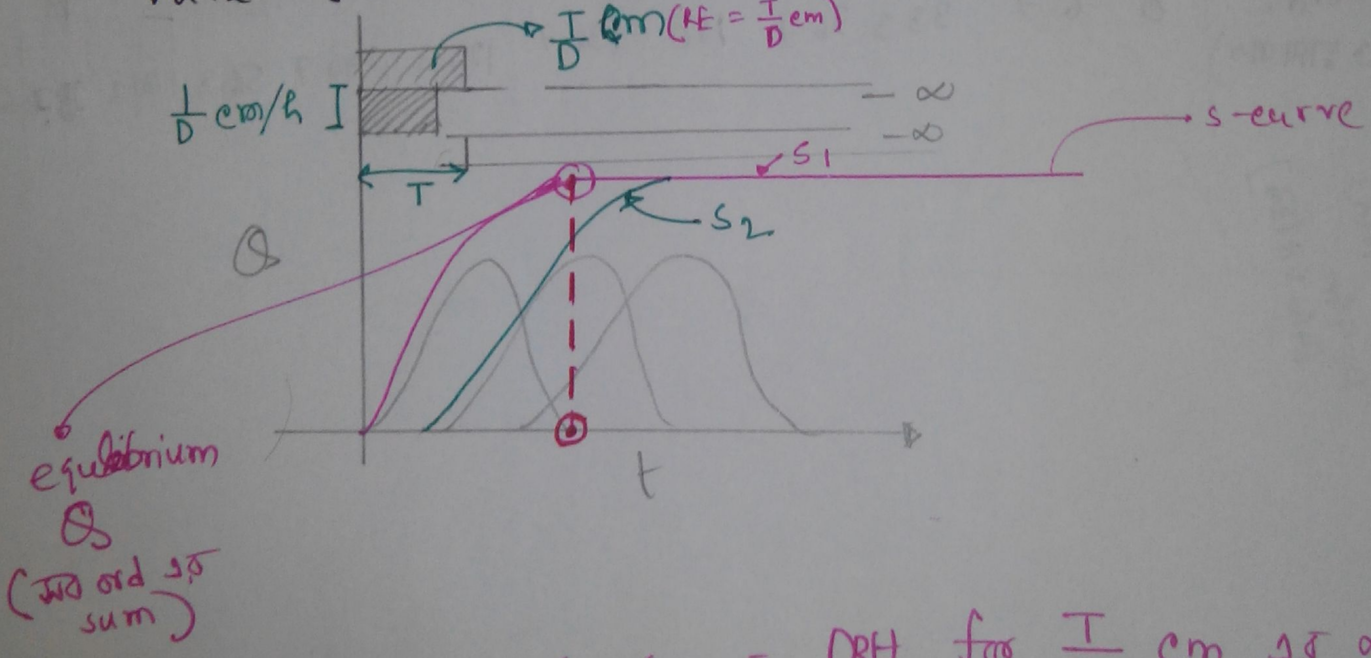
[[if 'n' = fraction হলে তখন হবেনা]
Method of superposition use করো।]

Ex: 6.9 (page 263)

methods

1. superposition [n = integer]
2. S-curve method [when n = fraction ~~both~~ + integer]

S-curve / S-hydrograph: It is a hydrograph produced by continuous effective rainfall at a constant rate for an infinite period.



$$S_1 - S_2 = \text{DRH for } \frac{I}{D} \text{ cm এর জন্য}$$

$$\therefore \frac{S_1 - S_2}{\frac{I}{D}} = \text{UH ord.}$$

(*) যদি 4 hr UH এ 4 hr পর পর থাকলে সব sum (0+4+8+...) hr যোগ করব,

প্রত্যেকটা (*) " " " " 2 hr " "

hr এ তে conversion

vol^m of DH $= \frac{1}{2} \times 50 \times t_b \times (60 \times 60)$

catchment area, $A = 567 \times 10^6 \times \frac{1}{100}$

$\therefore \frac{1}{2} \times 50 \times t_b \times 3600 = 567 \times 10^6 \times \frac{1}{100}$

$\Rightarrow t_b = 63$ hr.

change:

$t_b = 60$ hr হলে catchment area = ?

(*) Given: D-hr UH

Derive 6 h D-h UH.

[4 hr UH দেওয়া
2 hr বের করো
$\therefore n = \frac{1}{2}$]

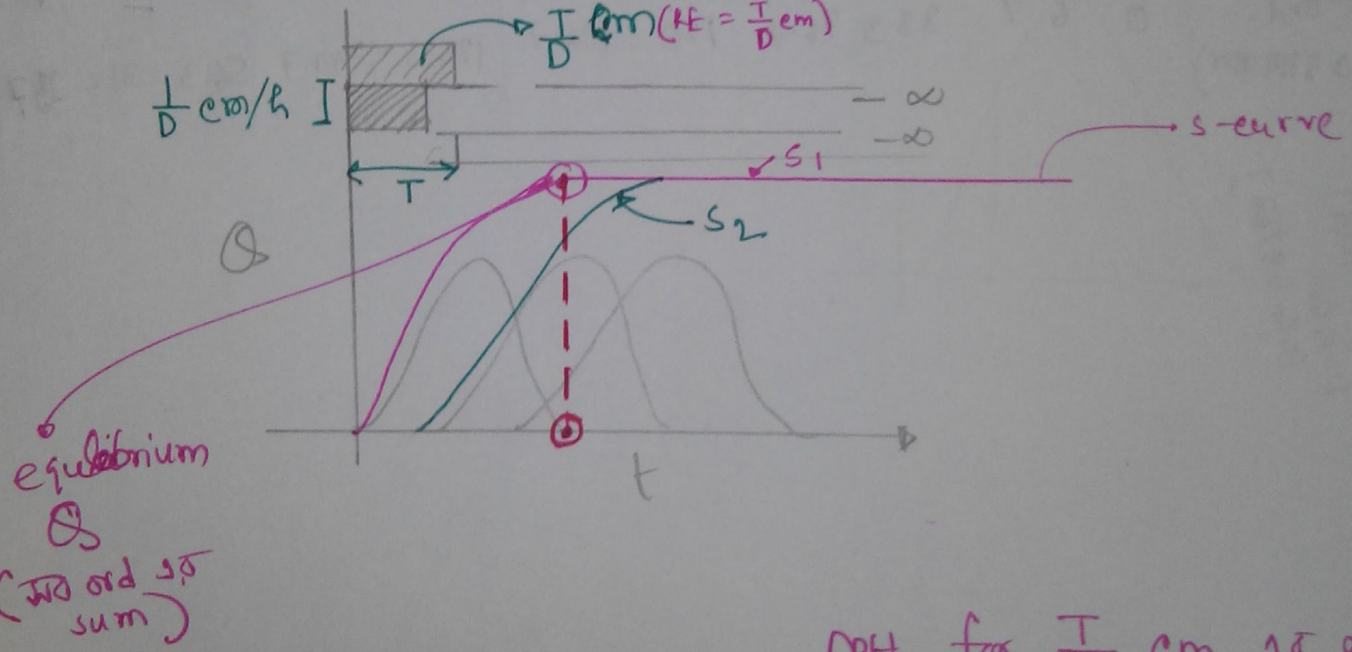
[if 'n' = fraction হয় তবে সেক্ষেত্রে]

[Method of superposition use করো।]

methods

1. superposition [n = integer]
2. S-curve method [when n = fraction ~~both~~ + integer]

S-curve / S-hydrograph: It is a hydrograph produced by continuous effective rainfall at a constant rate for an infinite period.



$$S_1 - S_2 = \text{DRH for } \frac{I}{D} \text{ cm এর জন্য}$$

$$\therefore \frac{S_1 - S_2}{\frac{I}{D}} = \text{UH ord.}$$

(*) যদি 4 hr UH এ 4 hr পরপর থাকলে সব sum (0+4+8+... hr) যোগ হবে,
সতর্কতা (*) " " " " 2 hr " "

example 6.11

$T = 12\ hr,\ D = 4\ hr \quad \therefore \frac{T}{D} = 3$

UH starts with 0 & ends up with 0

Time(hr)	0	4	8	12	16	20	24	28	32	36	40	44
Ordinate of 4 h UH	0	20	80	130	150	130	90	52	27	15	5	0
S_1 curve	0	20	100	230	380	510	600	652	679	694	699	699
S_2 curve	—	—	—	0	20	100	230	380	510	600	652	679
$S_1 - S_2$	0	20	100	230	360	410	370	272	169	94	47	20
UH ord. ($\frac{T}{D} = 3$ দ্বারা ভাগ)	0	6.7	33.3	76.7	120	136.7	123.3	90.7	56.3	31.3	15.7	6.7

T=12 hr
(12 hr দিয়েছে)
D=4 hr
[4 hr UH ছিল]

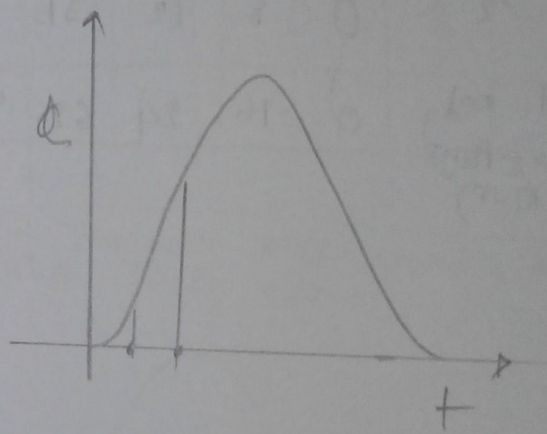
(এই math এ 4 hr UH, and 4hr দরকার ছিল। তাই S-curve easily লাগেনি)

48	52
0	0
699	699
694	699
5	0
1.7	0

[আমার 2hr UH থাকে, But value 4hr UH দেয়া, তখন কী করব?]

$\boxed{\text{ex: 6.12}}$ graph এঁকে দিতেনা করতে

= graph এঁকে interpolate করতে হয়, (not linear interpolate)



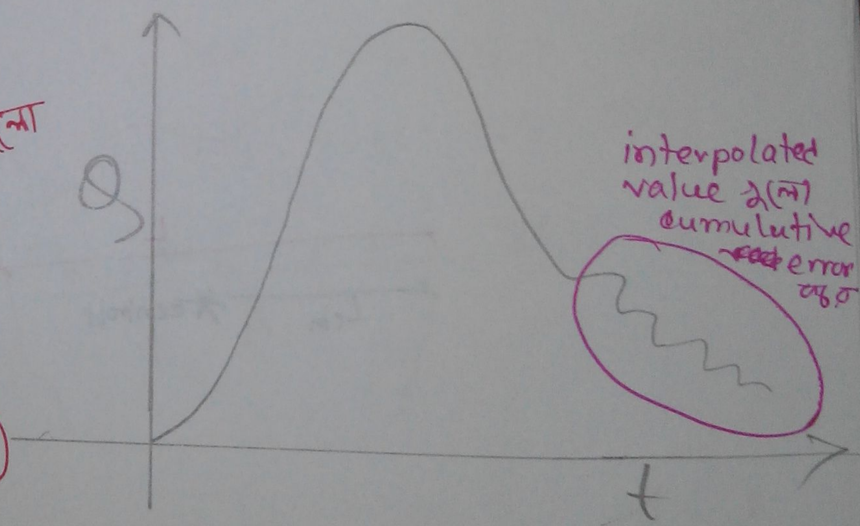
ex: 6.12 interpolated value (2hr পর পর নিয়ে নিছি)

T(hr)	0	2	4	6	8	10	12	14	16	18	20	22
UH ord.	0	8	20	43	80	110	130	146	150	142	130	112
S_1 curve (4hr পরপর যোগ করছি)	0	8	20	51	100	161	230	307	380	449	510	561
S_2 curve (2hr shift)	0	0	8	20	51	100	161	230	307	380	449	510
$S_1 - S_2$	0	8	12	31	49	61	69	77	73	69	61	51
UH ord ($\frac{T}{D} = \frac{1}{2}$ দিয়ে গুণ)	0	16	24	62	98	122	138	154	146	138	122	102

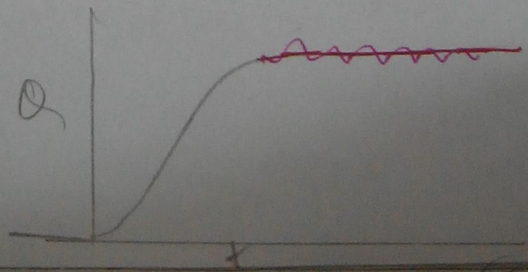
24	26	28	30	32	34	36	38	40	42	44
90	70	52	38	27	20	15	10	5	2	0
600	631	652	669	679	689	694	699	699	701	699
561	600	631	652	669	679	689	694	699	699	701
39	31	21	17	10	10	5	5	0	2	−2
76	62	42	34	20	20	10	10	0	4	−4

এখানে flaccuate করছে। smooth করে value নিতে হবে।

needs adjustment (exam এ value গুলো ঠিক না করলেও চলবে, কারণ value ঠিক করতে graph আঁকা লাগে)



এখন smooth করা হয়



L 15

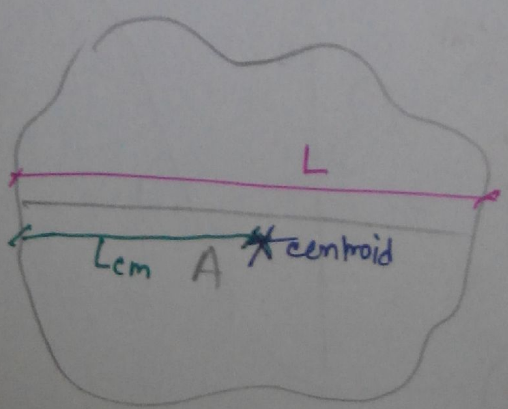
13/05/17

Synthetic unit hydrograph :

→ Artifically developed

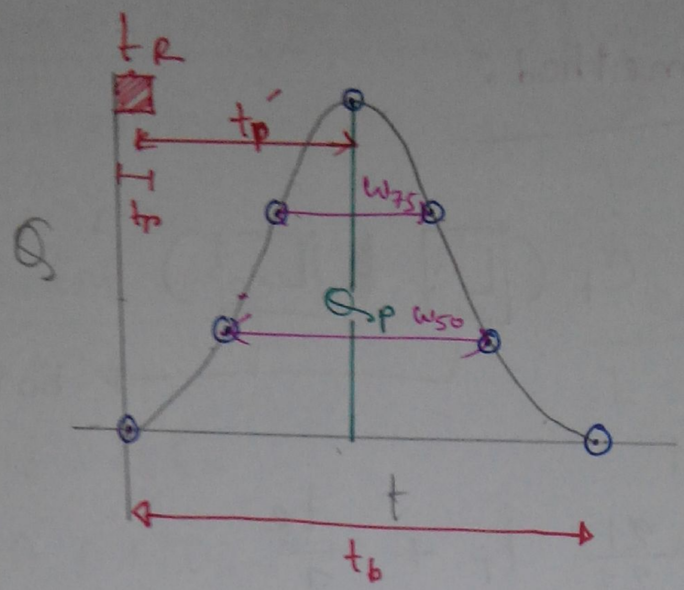
→ empirical equ^n দ্বারা basin characteristic use করে prepare করা।

Def^n: Unit hydrograph derived using empirical equ^n which relate unit hydrograph with basin characteristics.



1. area
2. furthest point to outlet (L)
3. centroid (*)
4. centroid → point to outlet (Lcm)

$\boxed{*}$



t_r = standard unit hydrograph

t_R = non " "

→ অনেক shape এর UH হতে পারে। But আমরা unit hydrograph correctly point out করতে চাই। তাই W_{75}, W_{50} point গুলো def^n করি।

* Snyder's method :

$$\boxed{t_p} = C_t\left(\boxed{L}\,\boxed{L_{ca}}\right)^{0.3}$$

in hr — both in km

$$t_p' = \frac{21}{22}\,t_p + \frac{t_R}{4}$$

$$Q_p = \frac{2.78\,C_p \cdot A}{t_p'}$$

m^3/s — in km^2

$$t_b = 72 + 3\,t_p'$$ [দেখা নেই ৩০ area পর্যন্ত এটি valid]

$$= 5\left[t_p' + \frac{t_R}{2}\right]$$

$$W_{50} = \frac{5.87}{\left(\frac{Q_p}{A}\right)^{1.08}}$$

$$W_{75} = \frac{W_{50}}{1.75}$$

Scanned by CamScanner

Example 6.14 (page 274)

meterologically equ^n = C_p, C_t সমান।

Catchment A.

$L = 30\ km$

$L_{ca} = 15\ km$

$A = 250\ km^2$

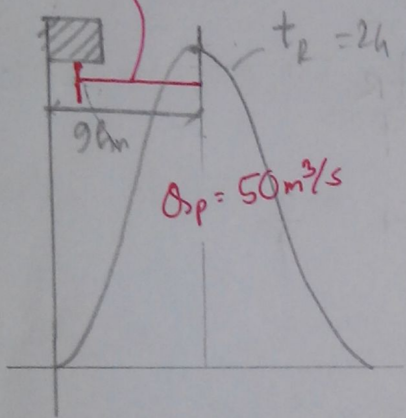
Catchment B.

$L = 45\ km$

$L_{ca} = 25\ km$

$A = 400\ km^2$.

$t_p' = 9 - \frac{2}{2} = 8\ hr$



$$t_p' = \frac{21}{22} t_p + \frac{2}{4}$$

$$\Rightarrow 8 = \frac{21}{22} t_p + \frac{2}{4}$$

$$\Rightarrow t_p = 7.86\ hr$$

now, $t_p = C_t (30 \times 15)^{0.3} = 7.86$

$\Rightarrow \boxed{C_t = 1.26} \rightarrow$ same for A, B

$$Q_p = \frac{2.78 C_p \, 250}{8} = 50$$

$\Rightarrow \boxed{C_p = 0.58} \rightarrow$ for A, B same

<u>Catchment B</u>

$$t_p = C_t (L \cdot L_{ca})^{0.3} = 1.26 \times (45 \times 25)^{0.3}$$

$$= 10.37 \text{ hr}$$

$$t_p' = \frac{21}{22} t_p + \frac{t_R}{4}$$

assume করে B এর ক্ষেত্রে 2 hr UH

$$= \frac{21}{22} \times 10.37 + \frac{2}{4}$$

$$= 10.4 \text{ hr}$$

$$Q_p = \frac{2.78 \times C_p \times A}{t_p'} = \frac{2.78 \times 0.58 \times 400}{10.4}$$

$$= 62 \text{ m}^3/\text{s}$$

$$t_b = 72 + 3 t_p' = 72 + 3 \times 10.4 = \boxed{103.2 \text{ hr}}$$

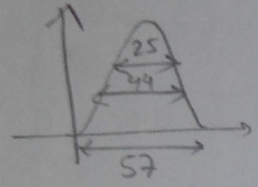
$$\text{and } t_b' = 5\left[t_p' + \frac{t_R}{2}\right] = 5 \times \left(10.4 + \frac{2}{2}\right)$$

$$\boxed{= 57 \text{ hr}}$$

কোনটি more acceptable?? W_{75}, W_{50} কেও দেখব

$$\omega_{50} = \frac{5.87}{\left(\frac{Q_p}{A}\right)^{1.08}} = \frac{5.87}{\left(\frac{62}{400}\right)^{1.08}} = \boxed{44\ hr}$$

$$\omega_{75} = \frac{\omega_{50}}{1.75} = \frac{44}{1.75} = \boxed{25\ hr}$$



এই দুটি থেকে বুঝলাম $t_b = 57$ hr

(*) Flood discharge estimate করতে very imp tool.

But there is limitations of UH.

[*] Limitation of using UH:

1. Assumptions of uniform distribution of RF both in $\boxed{\text{time}}$ and $\boxed{\text{space}}$ are rarely meet [catchment বড় হলে storm এর centre এ তৈরি হয়, ছোট হলে, uniform নয়] [আবার অবশ্যই একসাথে বৃষ্টি হয় না। beginning থেকে শেষ, মানে ↑ intensity]

2. Applicable to catchment area from 200 ha to 5000 km².

3. Applicable for precipitation from rainfall only. [snowfall হলে হবেনা]

4. catchment area should have large storage.

exercise বই দেখানো]

CT → Unit hydrograph [12th week শনিবার]

theory → Def^n + assumption + limition + s-curve + UH Def^n

Math → preparet Derive + apply + convert duration + (S-curve) + synthetic UH + (c.8)

→ base flow (const থাকবে) [beginning + end]

exercise 6.17 + triangl

or অন্য math

Lec

20/05/17

[✗] Statistical methods in hydrology:

Max^m 24 hr RF → এই data গুলো আমরা design এর জন্য

" 3 day "

" Flood discharge

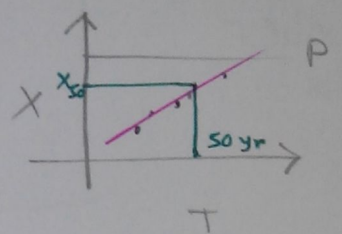
" " WL

(random; 3 day (running) নিলে 1 yr এর সাথে অন্য year match করবে না)

→ Diff year এর জন্য diff (random variable)

বের করতে হব:
- X_T → return period
- X_P → probability of occurrence

→ এগুলো বের করতে frequency analysis করা লাগে।



→ frequency analysis

frequency analysis can be carried out in 2 ways.

1. emperical method (Weibel's formula) $T = \frac{N+1}{m}$

[প্রতি yr এর data কে descending order এ সাজালাম,

20 yr data	rank (m)	$T = \frac{N+1}{m}$
X (highest)	1	plotting position
X_1	2	
⋮	⋮	
X_{20} (lowest)	20	

disadv: we can't extrapolate it beyond and upto a limit.

যত year data তার 2.5 গুণ limit করা যায়।

But important structure এর জন্য আমরা এটি use করতে পারি না

2. Analytical method

$$X_T = \bar{X} + k\,\sigma_{n-1}$$

$\bar{X}$ → avg

k → frequency factor (কোন distribution use করছি সেটির উপর depend করবে)

σ → standard deviation

σ_{n-1} → for sample

1. Gumbel's extreme value distribution (widely used)
2. Log - Pearson type III "
3. Log- normal distribution

Gumbel's:

$$P(x \geq x_0) = 1 - e^{-e^{-y}}$$

[y = dimensionless variable]

Here, $y = \frac{1.2825\,(x - \bar{x})}{\sigma_x} + 0.577$

If we have finite number of data

$$\Rightarrow y_T = \frac{1.2825\,(x_T - \bar{x})}{\sigma_x} + 0.577$$

$$x_T = \bar{x} + k\sigma_x \quad \text{where } k = \frac{y_T - 0.577}{1.2825}$$

$$y_T = -\ln\ln\left(\frac{T}{T-1}\right)$$