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Engineering Hydrology
B.E. : Semester V
(Branch : Civil Engineering)

Unit I

INTRODUCTION

Syllabus : Definition and Scope, Hydrology in relation to water resources development, Hydrologic Cycle, The necessity for hydrologic data. The global water budget. Practical applications.
Hydrometeorology : Introduction, constituents of atmosphere, The weather and the atmosphere, The general circulation, Air masses and fronts. Climate and weather season in India.

Introduction : Hydrology means the science of water. It is the science that deals with the occurrence, circulation and distribution of water of the earth and earth's atmosphere. As a branch of earth science, it is concerned with the water in streams and lakes, rainfall and snowfall, snow and ice on the land and water occurring below the earth's surface in the pores of the soil and rocks. Hydrology is a very broad subject of an inter-disciplinary nature drawing support from allied sciences, such as meterology, geology, statistics, chemistry, physics and fluid mechanics.

Hydrology is basically an applied science. To further emphasise the degree of applicability, the subject is sometimes classified as :

1. **Scientific hydrology :** The study which is concerned chiefly with academic aspects.
2. **Engineering or applied hydrology :** A study concerned with engineering applications.

Q. 1. Define Hydrology ? **(C.S.V.T.U. Nov.-Dec., 2007; April-May, 2008, Nov.-Dec., 2009)**

Ans. The word hydrology is derived from the greek words hydor, which means water and logos, which means science. Hydrology is the science which is concerned with all waters on earth, its occurrence, distribution and circulation, its physical and chemical properties, its effects on the environment and on life of all forms.

"Hydrology as the science that deals with process governing the depletion and replenishment of water resources of the land areas of the earth."

Q. 2. Describe Hydrologic Cycle ?

(C.S.V.T.U. Nov.-Dec., 2007; Nov.-Dec. 2009; April-May, 2010)

Or

Discuss the Hydrology cycle and necessity of hydrology ? **(C.S.V.T.U. April-May, 2008)**

Or

Describe the hydrologic cycle. Explain briefly the man's interference in various parts of this cycle ? **(C.S.V.T.U. Nov.-Dec., 2008; April-May, 2009)**

Ans. Water exists on planet earth in its three forms gaseous, liquid and solid forms and is circulated mainly by solar and planetary forces. The sun provides the energy for the evaporation of sea water and earths gravitational field and coriolis force contributes to the circulation of water. The group of numerous arcs which represent the different paths through which the water in nature circulates and is transformed is what is known as hydrologic cycle. These arcs penetrate into the three parts of the total earth system, namely, atmosphere, hydrosphere and lithosphere. Hydrosphere is the bodies of water that cover the surface of the earth. Lithosphere is the solid rock below the hydrosphere.

The hydrologic cycle has no beginning or end as the water in nature is continuously kept in cyclic motion. For the purpose of description the cycle may be visualised to commence with the precipitation from the atmosphere. Precipitation may take place in liquid form as rain and also in solid form as hail, show, dew, frost etc. While precipitation is taking place, apart of it may evaporate and reach back the atmosphere. Some more precipitation is intercepted by the trees and vegetation and the rest of it only would reach the ground. The precipitation reaching the ground

surface is called the throughfall. Considerable portion of the throughfall gets infiltrated into the ground.

The precipitation falling directly over the streams is called the channel precipitation and it readily becomes runofff without any delay. The precipitation falling on the water bodies like ponds and lakes may be disposed of either as surface runoff to streams if the water bodies overflow. The evaporation would also be taking place from stream surfaces. The infiltrated water may percolate deep and become groundwater supply to surface streams known as the groundwater runoff. The groundwater runoff is sometimes referred to as the baseflow. The total streamflow which is the sum of the surface runoff.

The entire cycle repeats when the atmospheric moisture precipitates on to the ground after cloud formation.

Q. 3. What are the practical applications of hydrology ?

(C.S.V.T.U. Nov.-Dec., 2007; April-May, 2009; Nov. Dec., 2009; April May, 2010; April-May, 2011)

Ans. Some of the practical applications of hydrology are briefly discussed below :

Design of hydraulic structures : The design of any structure related to water such as spillway, dam, culvert, highway bridge, rail bridge etc., may be considered to consist of three parts, hydrologic design, hydraulic design and structural design. Hydrologic design deals with the estimation of the quantities of water to be handled at the site of the structure, their time distribution, time of occurrence and frequency of occurrence hydraulic design provides the best suitable shape and section of the structure to cope with the waters estimated and the structural design ensures the stability and safety of the chosen section against the water pressure and other pressure. So hydrology plays an important role in the design of any structure.

Municipal and industrial water supply : The availability of water is often the most important factor in locating the major industries and it has considerable effect on the growth of municipalities. Hydrologists would answer such questions as whether the flow in the nearby stream is sufficient to meet the needs of the municipal city.

Irrigation : Provision of adequate storage facilities at the irrigation and other multipurpose projects either to irrigate the ayacut under the project or to meet the demands of other purposes is the essential part of the design. In arriving at the storage capacity of the reservoir the evaporation, seepage and other losses must be properly accounted for. This requires the information on the hydrological variables such as runoff, infiltration and evaporation. A large river basin is taken as a system and all the projects in the system are together optionally designed and operated to achieve the stipulated objectives.

Hydropower : Hydrologic studies are essential for the planning of any water power development. To determine the feasibility of the run-of-river plant operating with pondage, a reliable prediction is needed of the absolute minimum daily flow that may be expected in the stream and of the percentages of time that various other flows may be expected to exist. For storage plants, however, low seasonal flows rather than low daily flows are important. After commissioning, the storage plant is continuously faced with problems in the economics of operation. Whether the reservoir can be emptied boldly permitting the shut down of the other thermal plants in the grid resulting in fuel saving.

Flood control : Reservoirs, levees, channel improvements and channel diversions or a combination of them are the most commonly used flood control structures. Flood control problems are complicated because any type of flood control project modifies the natural regime of the stream and thus in the process of protecting one area it may increase the flood damage in another. Hence the technique of flood routing is essential to the intelligent and economic planning of flood control projects. Flood control measures will really become very effective where they are associated with

flood forecasts. The forecasts which are the joint work of the hydrologists and the meteorologists could be profitably utilised in planning the advanced evacuation of the threatened areas, in organising the stand-by crews for the emergency works on rail roads.

Navigation : Hydrologic problems in navigation projects require answers to such questions as how much water will be required for lock gates and to maintain minimum draft, where from this water can be obtained.

Erosion and sediment control : Excessive erosion in the catchment feeds sediment into the runoff. This leads to many undesirable effects. The reservoirs may lose their capacity at a faster rate reducing their economic lift span drastically. Tons and tons of fertile top soil will be lost every year resulting in reduced crop yields. The problem of erosion control is mainly linked with the phenomena of overland flow and infiltration. Hydrology of the catchment alongwith the knowledge of the existing watershed management practices will help in finding out the effective erosion control measures suitable for the given soil conditions.

Pollution abatement : Indiscriminate disposal of sewage from cities and industries into the nearby streams, which has been general tendency, results in health hazards to the public and the destruction of the fish and other wild life. Complete prevention of river pollution is not economically feasible. As the stream is a natural water purification system, it is generally considered permissible to allow disposal of certain amount of sewage into streams. The purification in the stream is a result of bactrial action and aeration.

Q. 4. Write a note on climate and weather seasons in India ?

(C.S.V.T.U. Nov.-Dec., 2007; April-May, 2008; Nov.-Dec., 2008)

Ans. The state of the atmosphere with respect to the temperature, humidity, wind, cloudiness etc., at any given time is generally referred to as the weather. The climate of a region is the aggregate of the weather. The earth receives non-uniform solar radiation over its surface. This results in broadly three different climatic zones, namely the torrid zone, the temperate zone and the frigid zone. The region on either side of the equator between the tropics, that is between 23½° N and 23½° S latitudes is know as the torrid zone. The regions between 23½° and 66½° latitudes are the temperate zones while the remaining areas between 66½° N latitude and North pole and 66½° S latitude and south pole are called the frigid zones.

In India, the year may be divided into four weather seasons as given below :

(i) Cold weather season : December to February.

(ii) Hot weather sesson : March to May.

(iii) South west monsoon season : June to September.

(iv) Retreating south-west monsoon season : October to November.

Cold weather season : This is the season during which fine weather prevails over the entire country, through the southern parts along the east coast may be occasionally subjected to cyclones. The north will be in the grip of the cold wave. The day and night temperatures touch their lowest. The himalayas and Jammu and Kashmir will be experiencing moderate to heavy rainfall and snowfall.

Hot weather season : During this season the temperature is on the rise reaching the highest value in the second half of May at most of the places.

The highest temperature of about 38°C will be recorded in the Deccan Plateau in March. In April the highest temperature in the country will be observed in Gujarat and Madhya Pradesh with a value of about 43° C. The Bay of Bengal storms move northward first and then north-east and reach the Arakan and Chittogong coasts by the end of this season. The arabian sea storms move to the north-east arriving the west coast of Maharashtra and Kerala.

South-west monsoon season : The south-west monsoon consists of the two currents which originate in the south Bay of Bengal and the Arabian sea during the hot weather season.

The Bay currents move north or north east. They are deflected by Arakan hills and the hills of Assam and then by the eastern range of Himalayas. Owing to forced ascent over the hills they give very heavy rainfall, for example Chirrapunji in Assam. Monsoon depressions forming in the north or central bay and intensifying into cyclonic storms sometimes move to the west-north-west to merge with the seasonal law pressure regions formed in Rajasthan which are called the western disturbances.

Retreating south-west monsoon season : In the post-monsoon period as the south-west monsoon retreats, storms due to tropical cyclonic disturbances develop in the south. They are observed to move in any of the following paths :

(i) Though they are north-easterly to start with, they may recurve and strike the Arakan coast like the south-west monsoon storms developing in south bay have been observed to do.

(ii) Moving south-west they may strike the north Tamil Nadu and South Andhra Coast and weaken. Then moving through Andhra Pradesh and Orissa (Odisha) they may emerge into the north bay, intensify there and move to the north-east.

Q. 5. Write notes on the following :

(i) Hydrometeorology

(ii) Air Masses and Fronts.

(C.S.V.T.U. April-May, 2008; April-May, 2009, Nov.-Dec., 2009; April-May, 2010; April-May, 2011)

Ans. (i) Hydrometeorology : Meteorology deals with the atmospheric portion of the hydrologic cycle, that is with the transportation of water in the air. For this reason meteorology is often defined as the science of the atmospheric phenomena. The study of the atmospheric processes which affect the water resources of the earth and are of interest to the hydrologic engineers.

(ii) Air masses : A vast and deep body of the air in which the temperature and humidity characteristics are relatively homogeneous at any given elevation is called an air mass. Air mass is formed through the heat exchange when the air stagnates for a considerable time interval over a region where the earth's surface is homogeneous.

The continental air mass is usually dry and fluctuates widely in temperature from relatively cold in winter to hot in summer. The maritime air mass is nearly always moist with more uniform temperature.

Air front : The surface of contact between two adjacent air masses or between an air mass and the surrounding atmosphere is called a frontal surface or simply air front. The intersection of the frontal surface with the earth's surface is called a surface front. When two air masses come into contact, the colder air forms a wedge under the warm air and the frontal surface has a slope of 1 in 100 in normal cases.

The air fronts are classified according to their motion. When the cold air is moving into warm air forcing the warm air up over the surface front, then it is called a cold surface front.

Q. 6. Discuss the hydrological water budget with the aid of example ?

(C.S.V.T.U. Nov.-Dec., 2008; Nov.-Dec., 2010)

Ans. The basic source of water for India is the rainfall over the most part of the country and snowfall in the Northern region. The average annual rainfall for the country is about 119·4 cm and with the country's geographical area of $3{\cdot}28 \times 10^6$ km^2 it is equivalent to 3916 km^3 and together with snowfall which is not yet fully assessed the annual water resources may be approximated to 4000 km^3. Out of this 700 km^3 is lost to atmosphere, 2150 km^3 is soaked into the ground and the balance 1150 km^3 becomes the direct surface runoff to the streams. According to Irrigation Commission of India (1972) the total annual surface waterflow in the country is about 1800 km^3. This includes 200 km^3 of runoff brought in by the streams and rivers from the catchments lying

outside the country 450 km^3 of groundwater runoff carried by the streams during non-rainy periods and 1150 km^3 of direct surface runoff from precipitation. Out of the total surface water of 1800 km^3 about 150 km^3 is stored in various reservoirs and tanks, another 150 km^3 is utilised through diversion works and direct pumping and the remaining 1500 km^3 goes to the sea and some adjoining countries. The use of water through diversion and direct pumping is expected to increase to only 450 km^3 and the balance 1050 km^3 would continue to flow to the sea and outside the country. Out of 2150 km^3 of infiltrated water only 500 km^3 percolated deeply and becomes groundwater while the remaining 1650 km^3 is retained as soil moisture and goes back to the atmosphere as evaporation and transpiration.

Such contributions to groundwater during floods have been estimated to be of the order of 50 km^3. Similarly the additions from the irrigation system to the groundwater available comes to 670 km^3. This on full development of water reasources is likely to increase to 850 km^3.

Q. 7. What is meant by Probable Maximum Precipitation (PMP) over a basin ?

(C.S.V.T.U. April-May, 2010)

Ans. Determination of the probable maximum precipitation used in the spillway design, forecast of precipitation for reservoir operation and determination of probable maximum winds over water surfaces for evaluating the resulting waves in connection with the design of dams and levees are some of the hydrological problems in which meteorology plays an important role.

Q. 8. Determine the density in kilometers per cubic metre, of (a) dry air at 30°C and a pressure of 900 mb and (b) moist air with relative humidity of 70 per cent at the same temperature and pressure ?

Solution : (a)

$$P = 900 \text{ mb} = 900 \times 100 = 9 \times 10^4 \text{ N/m}^2$$
$$R = 287 \text{ N-m/kg-K}$$
$$T = 30°\text{C} = 30 + 273 = 303 \text{ K}$$
$$\rho = \frac{P}{RT} = \frac{9 \times 10^4}{287 \times 303}$$
$$= 1{\cdot}035 \text{ kg/m}^3$$

∴ Density of dry air = 1·035 kg/m^3

(b) Relative humidity h = 70%

$$h = \frac{100\,e}{e_s}$$
$$\therefore \quad e = \frac{h}{100} e_s = 0{\cdot}7\,e_s$$

Temperature of 30°C

$$e_s = 42{\cdot}43 \text{ mb}$$
$$\therefore \quad e = 0{\cdot}7 \times 42{\cdot}43$$
$$e = 29{\cdot}701 \text{ mb}$$

The density of moist air is given by

$$\rho = \frac{P}{RT}\left(1 - 0{\cdot}375\frac{e}{P}\right)$$
$$= 1{\cdot}035\left(1 - 0{\cdot}375 \times \frac{29{\cdot}701}{900}\right)$$
$$= 1{\cdot}0222 \text{ kg/m}^3$$

Ans.

Q. 9. Write short notes on the permanent and variable constituents of the atmosphere ?

Ans. The permanent constituents of the atmosphere, by volume are Nitrogen 78%, Oxygen 21% and the rest inert gases. The variable constituents may be in solid, liquid and gaseous forms. Water is the most important of these and can comprise as much as 4% of the atmosphere and exists in all the three forms. When water exists in the gaseous form as true vapour, it is invisible and is referred to as humidity. And when it is in the form of minute drops formed upon condensation, it is called fog. Ozone and carbon dioxide exist as gases in widely varying amounts. Solid components, besides water as snow and ice are particles of dust, smoke, salts and micro-organisms. They reflects, scatter and dissociate radiation and in particular light to produce various colours on the sky and sunset. They also play a role in the condensation of water vapour in the formation of clouds and also in the precipitation process.

Ozone : Most of the oxygen present in the atmosphere is diatomic (O_2). A small portion consists of triatomic oxygen (O_3) called ozone. The ozone is mainly found at large altitudes.

Carbon dioxide : The amount of carbon dioxide (CO_2) present air is a variable quantity. It is continuously by the vegetable world and it is produced by the animal world, by the burning of fuels, by volcanic actions and by various process of decay in the soil. The carbon dioxide in the air is important for the heat budget of the atmosphere because together with water vapour it causes part of the long wave radiation from the earth to be absorbed by the air.

Water vapour : For the view point of hydrologists the most important constituent of the atmosphere is the water vapour. The amount of water vapour present in the air is indirectly expressed through what is known as the vapour pressure. The partial pressure exerted by the water vapour is called the vapour pressure.

Q. 10. Describe the vertical structure of the atmosphere with respect to temperature ?

Ans. The features of the atmosphere wherein one may visualise some concentric shells with distinct temperature characteristics. These layers are given different names.

The lowest layer which contains about 75 per cent of the mass and almost all the moisture and dust of the atmosphere is called the troposphere. All the phenomena which are called weather are confined to the troposphere. The top of the troposphere is called the tropopause. The height of the tropopause varies from about 8 km over the poles to about 16 km near the equator.

Above the tropopause is the stratosphere. Stratosphere contains a major portion of the ozone. In the lower layers of the stratosphere the temperature is more or less constant with elevation. Stratosphere located at to 50 km above the earth's surface is the upper limit of the stratosphere. Above the stratosphere is a warm layer which is variously known as the mesopause. About 80 km from the earth's surface is the mesopause which is the upperlimit of the mesosphere. The fourth major layer above the mesopause is called the ionosphere. The pressures in the ionosphere are very low with about 0·01 mb at 90 km. The ionosphere merges gradually into the outermost shell called the exosphere. Hydrologists are mainly interested in the troposphere and the process that take place in it.

Q. 11. Write short notes on :

(i) Solar constant

(ii) Insolation.

Ans. (i) Solar constant : The average solar radiation received on plane unit area normal to the incident radiation at the outer limit of the atmosphere is called the solar constant. Whose value is generally accepted to be 2 ly/min.

(ii) Insolation : The solar radiation received by a unit area on a horizontal surface which is of primary concern to the hydrologists and meteorologists is called insolation.

Q. 12. Write short notes on cyclones and anticyclones ?

Ans. Cyclones : A cyclone is a more or less circular area of low atmospheric pressure in which winds blow spirally inward in counter clockwise direction in the Northern Hemisphere and in clockwise direction in southern Hemisphere. The pressure gradient exists towards the centre of the cyclone.

There are two types of cyclones. They are tropical cyclones and extratropical cyclones.

Anticyclones : These are the high pressure areas generally elliptical in shape covering very large areas. The wind is blow spirally outward in clockwise direction in the Northern Hemisphere and in counter clockwise direction in the Southern Hemisphere. The pressure gradient exists in outward direction away from the centre.

Q. 13. List out the essential requires for the formation of precipitation and discuss them to detail ?

Ans. There are four basic conditions which are to be satisfied for the precipitation to occur. They are :

(i) Accumulation of moisture of sufficient intensity to account for the observed rates of precipitation.

(ii) Cooling of air to the dew point temperature to produce saturation condition.

(iii) Condensation.

(iv) Growth of small water droplets to precipitable size.

It is common for the first three conditions to occur but not the fourth, in which case the clouds will gradually dissipate without producing any precipitation.

Accumulation of moisture : It is evaporation which feeds moisture to the atmosphere. The simple principle of conservation of mass requires that a balance must be maintained between the evaporation and precipitations.

Cooling : Cooling is of three types cyclonic cooling, orographic cooling and convective cooling.

The cyclonic cooling may be divided into two types as frontal cooling and non-frontal cooling. In the frontal type of cyclonic cooling, the circulation forces the air up over a frontal surface.

Orographic cooling occurs when the air is lifted up a slope to low pressures corresponding to higher elevations. Clouds first form and then precipitate if the dew point is reached.

Convective precipitations is of very short duration rarely exceeding 1h and covering limited areas of 20 to 50 km^2.

Condensation : Under certain controlled conditions in the laboratory, lowering of temperature of the air does not produce condensation. Investigations have shown that the air from which all the foreign particles have been removed, can be cooled until the relative humidity is as much as 1000 per cent before the droplets of the liquid water form.

Growth of droplets : The saturation vapour pressure over a curved surface is more than that over a horizontal surface. As the condensation nuclei attracts water, the size of the droplet increases making it less curved and further condensation therefore requires less super saturation.

Q. 14. Describe various types and forms of precipitation.

Ans. There are three types of precipitation.

(i) Cyclonic precipitation.

(ii) Convective Precipitation.

(iii) Orographic Precipitation.

Forms of Precipitation :

Drizzle : It is fine sprinkle of very small and rather uniform water drops with diameters between 0·1 and 0·5 mm. The drops are so small that they seem to float in air.

Rain : Rain is the precipitation of liquid water in which the drops are generally larger than 0·5 mm in size.

Glaze : The ice coating formed when rain or drizzle freezes as it comes in contact with cold objects at the ground is called the glaze.

Snow : Precipitation in the form of ice crystals is called snow. When the ice crystals fuse together, it is called snow flake.

Dew : Dew forms directly by condensation on the ground mainly during the night when the surface has been cooled by the outgoing radiation.

Q. 15. Assuming dry bulb and wet bulb temperatures of 27° C and 17° C respectively, and the atmospheric pressure as 995 mb; determine (a) actual vapour pressure (b) saturation vapour pressure (c) relative humidity (d) dew point temperature.

Ans. We have $T = 27°C$ and T_w 17°C

From table, the saturation vapour pressure $e_s = 35{\cdot}64$ – mb and e'_s which is the saturation pressure corresponding to 17°C = 19·367 mb.

$$P = 995 \text{ mb}$$

The actual vapour pressure e is given by

$$e = 19{\cdot}367 - 0{\cdot}0006606 \times 995 \times (27-17) \times \left(1+\frac{17}{872{\cdot}78}\right)$$
$$e = 19{\cdot}367 - 6{\cdot}701$$
$$e = 12{\cdot}666 \text{ mb}$$

$$\text{Relative humidity } h = \frac{100_e}{e_s} = \frac{100 \times 12{\cdot}666}{35{\cdot}649}$$
$$h = 35{\cdot}53 \text{ per cent.}$$

Q. 16. Determine (i) The saturation vapour pressure (ii) The actual vapour pressure (iii) Saturation deficit (iv) The dew point temperature of the atmosphere corresponding to a temperature of 30° and a relative humidity of 80%.

Sol. (i) The saturation vapour pressure at 30°C is obtained as 42·43 mb

$\therefore$ $e_s = 42{\cdot}43$ mb

(ii) $h = 80\%$

$\therefore$ $e = 0{\cdot}8e_s = 33{\cdot}994$ mb

$\therefore$ Actual vapour pressure = 33·944 mb

(iii) Saturation deficit $= (e_s - e)$

$= (42{\cdot}43 - 33{\cdot}944) = 8{\cdot}486$ mb

(iv) The temperature at which $e_s = e = 33{\cdot}944$ is obtained as 26·165°C

$\therefore$ The dew point temperature, $T_d = 26{\cdot}165°$ C. **Ans.**

Q. 17. If the atmospheric pressure, temperature and vapour pressure of the atmospheric are 1005 mb, 28°C and 19·873 mm of mercury. Determine the relative humidity, dew point temperature and the density of the atmosphere.

Sol. For 28°C $e_s = 37{\cdot}796$ mb

$e = 19{\cdot}873$ mm of mercury $= 19{\cdot}873 \times 1{\cdot}33$

$= 26{\cdot}43$ mb

$\therefore$ Relative humidity $h = \dfrac{100e}{e_s} = \dfrac{100 \times 26{\cdot}43}{37{\cdot}796}$

$= 69{\cdot}93\%$

$$\rho = \frac{P}{RT}\left(1 - 0{\cdot}375\frac{e}{P}\right)$$

Here,

$P = 1005 \text{ mb} = 1{\cdot}005 \times 10^5 \text{ N/m}^2$

$T = 28°C = 28 + 273 = 301 \text{ K}$

$R = 287 \text{ N-m/kg-k}$

$\therefore$ $\rho = \dfrac{1{\cdot}005 \times 10^5}{287 \times 301}\left(1 - \dfrac{0{\cdot}375 \times 26{\cdot}43}{1005}\right)$

$= 1{\cdot}152 \text{ kg/m}^3$. **Ans.**

Q. 18. What is the relative humidity if the air temperature and the dew point are 32°C and 18°C respectively ?

Sol. $T = 32°C$ and $e_s = 47{\cdot}551$ mb, $T_d = 18°C$ and $e = 20{\cdot}63$ mb

Relative humidity $h = \dfrac{100e}{e_s}$

$= \dfrac{100 \times 20{\cdot}63}{47{\cdot}551}$

$h = 43{\cdot}385\%$. **Ans.**

Q. 19. At a place the atmospheric pressure is recorded as 29·8 inches of mercury. Express the same in mb and in N/mm².

Sol. $P = 29{\cdot}8$ inches of mercury

$= 29{\cdot}8 \times 25{\cdot}4$ mm of mercury

$= 756{\cdot}92$ mm of mercury

Since 1 mm of mercury is equal to 1·33 mb,

$P = 756{\cdot}92 \times 1{\cdot}33$ mb

$= 1006{\cdot}7$ mb or 100670 N/m²

$= 0{\cdot}1007 \text{ N/mm}^2$. **Ans.**

Q. 20. An anemometer 10 m above the ground recorded a wind velocity of 5 m/s. What is the estimated wind velocity at 2 m above the surface ?

Sol. $Z_0 = 10$ m and $V_0 = 5$ m/s

$Z = 2$ m, $V = ?$

$$\frac{V}{5} = \left(\frac{2}{10}\right)^{0{\cdot}15} = 0{\cdot}7855$$

$\therefore$ $V = 0{\cdot}7855 \times 5$

$= 3{\cdot}93$ m/s. **Ans.**

Q. 21. Assuming dry bulb and wet bulb temperatures of 27°C and 17°C respectively and the atmospheric pressure as 995 mb; determine (a) Actual vapour pressure (b) Saturation vapour pressure (c) Relative humidity (d) Dew point temperature.

Sol. We have $T = 27°C$ and $T_w = 17°C$

The saturation vapour pressure $e_s = 35{\cdot}749$ mb and e'_s which is the saturation pressure corresponding to 17°C = 19·367 mb.

$$P = 995 \text{ mb}$$

The actual vapour pressure e is given by

$$e = 19{\cdot}367 - 0{\cdot}0006606 \times 995 + (27-17) \times \left(1+\frac{17}{872{\cdot}78}\right)$$
$$= 19{\cdot}367 - 6{\cdot}701$$
$$= 12{\cdot}666 \text{ mb}$$

$$\text{Relative humidity } h = \frac{100e}{e_s} = \frac{100 \times 12{\cdot}666}{35{\cdot}649}$$
$$= 35{\cdot}53 \text{ per cent.}$$

Temperature corresponding to e_s of 12·666 is read as 10·47°C, which is the dew point temperature.

Unit II

PRECIPITATION

Syllabus : Forms of precipitation, Measurement of precipitation, Recording and non-recording, Type of rain quage, Typical and record rainfall data, Errors in measurement of rainfall. Location of rain guage stations, Analysis and interpretation of rainfall data. Average depth of rainfall over area, Probable Maximum Precipitation (PMP).

Q. 1. Define Precipitation ? (C.S.V.T.U. April-May, 2008, 2009, 2010, 2011)

Ans. From the hydrological view point any form of moisture reaching the earth's surface from the atmosphere is called the precipitation. In a tropical country like India, major portion of the precipitation occurs in the form of rain only.

Precipitation data is of atmost importance to hydrologists as it forms the basis of many hydrological studies. It is the variations in the rainfall distribution over space and time which create serious hydrological problems such as floods and droughts.

Q. 2. What are the different forms of precipitation ? (C.S.V.T.U. Nov.-Dec., 2007)

Ans. Some of the common forms of precipitation are : rain, snow, drizzle, glaze, sleet and hail.

Rain : It is the principal form of precipitation in India. The term rainfall is used to describe precipitations in the form of water drops of sizes larger than 0·5 mm. The maximum size of a raindrop is about 6 mm. Any drop larger in size than this tends to break up into drops of smaller sizes during its fall from the clouds.

Snow : Snow is another important form of precipitation. Snow consists of ice crystals which usually combine to form flakes. When fresh, snow has an initial density varying from 0·06 to 0·15 g/cm³ and it is used to assume an average density of 0·1 g/cm³.

Drizzle : A fine sprinkle of numerous water droplets of size less than 0·5 mm and intensity less than 1mm/h is known as drizzle.

Glaze : When rain or drizzle comes in contact with cold ground at ground 0°C, the water drops freeze to form an ice coating called glaze.

Sleet : It is frozen raindrops of transparent grains which form when rain fall through air at sub freezing temperature.

Hail : It is a showery precipitation in the form of irregular pellets or lumps of ice of size more than 8 mm.

Q. 3. Describe different types of recording and non-recording rain-gauges ? (C.S.V.T.U. April-May 2008; Nov.-Dec., 2007; Nov.-Dec., 2010)

Ans. We have two types of rain-gauges given below :

(i) Recording rain-gauges : Non-recording rain-gauges give the amount of rainfall only. They cannot provide the information regarding when exactly the rain commenced, when the rain ended, what is the intensity of rainfall and how the intensity of rainfall varies within the duration of the storm. In order to record the beginning and end of the rain and to measure the intensity of rainfall, a continuous record of rainfall with time is required. For this purpose we have to use the recording rain-gauges. Recording rain-guages usually work by having a clock-driven drum carrying a graph on which open records the cumulative depth of rainfall continuously. There are different types of recording rain-gauges only three have grained widespread use. They are :

(a) Tipping bucket type,

(b) Weighing bucket type,

(c) Float type.

(a) Tipping bucket type rain-gauge : The principle involved in this type of gauge is very simple. A container is divided vertically into two compartments and is balanced in an unstable equilibrium about a horizontal axis. In its normal position it rests against one of the two stopper which prevent it from tipping over completely. The rain is led from a conventional collecting funnel into the uppermost compartment and after a predetermined rain has fallen the bucket becomes unstable in its present position and tips over its other position of rest. The compartments of the container are so shaped that water can now flow out of the lower one and leave it empty, meanwhile the rainfalls into the upper compartment again.

(b) Weighing-bucket rain-gauge : In this type of gauge the rain falling on the receiving area is collected by the funnel and is led into a storage bucket which rests on a weighing platform. The weight of the rainfall received since the recording began is recorded continuously by transmitting the movement of the platform through a system of links.

The main usefulness of this type of gauge is that it can record snow, hail and mixture of rain and snow.

(c) Float type rain-gauge : This type of rain-gauge is also known as the siphon type rain-gauge as it uses the siphon mechanism to empty the rainwater collected in the float chamber. Rain water entering the gauge at the top is led into the float chamber through a funnel and filter. The purpose of filter is to prevent dust and other particles from entering the float chamber which may hinder the siphon mechanism. The float chamber consists of a float with a vertical stem protruding outside, to the top of which a pen is mounted. This pen rests on a chart secured around a clock driven drum. There is a small compartment by the side of float chamber which is connected to the float chamber through a small opening at the bottom. This is called the siphon chamber which houses a small vertical pipe with bottom end open and the top end almost touching the top of the chamber.

(ii) Non-recording rain-gauges : The gauge consists of a funnel with a sharp edged rim of 127 mm diameter, a cylindrical body, a receiver with a narrow neck and handle and a splayed base which is fixed in the ground. The receiver should have a narrow neck and should be sufficiently protected from radiation to minimise the loss of water from the receiver by evaporation. To prevent rain from splashing in and out, the vertical wall of the sharp edged rim is made deep enough and the slope of the funnel steep enough. The rain falling into the funnel is collected in the receiver kept inside the body and is measured by measured by means of a special measure glass which is graduated in mm. The receiver has a capacity of 175 mm of rain. In regions of heavy rainfall, rain-gauges with receivers of 375 mm capacity may be used.

The measure glass has a capacity of 25 mm and can be read to nearest 0·1 mm. The gauge is fixed on a masonry or concrete foundation of size 60 cm × 60 cm × 60 cm which is sunk into the ground. The rim of the gauge is exactly 30 cm above the ground level. The top of the gauge should be perfectly horizontal.

The IMD has changed over to the use of fibreglass reinforced polyester rain-gauges which are an improved version of the symon's gauge. These gauges are available in different combinations of collector areas and receiver bottle capacities. They have the capacity to measure rainfall depths of 100 mm to 1000 mm.

At the routine time of observation the funnel is removed, the receiver is taken out and the rain water collected in the receiver is carefully poured into the measure glass and read without any parallax error. When the rainfall exceeds 25 mm the measure glass will be used as many times as required. The measured rainfall in the 24 hours ending with 8·30 am is recorded as the rainfall of the day on which 8·30 am observation is taken. The sum of all the readings taken in the last 24 hours is recorded as the rainfall of that day.

Q. 4. The annual rainfalls in mm recorded at a rainfall station for a period of 19 years from 1970 to 1988 are given below :

520, 615, 420, 270, 305, 380, 705, 600, 350, 550

560, 400, 520, 435, 395, 290, 430, 1020, 900.

(i) Find the average and standard deviation of the annual rainfall.

Solution :

$$\bar{x} = \frac{x_1 + x_2 + \dots\dots + x_n}{n}$$
$$= \frac{520 + 615 + \dots\dots + 1020 + 900}{19}$$
$$= \frac{9665}{19} = 508{\cdot}68 \text{ mm}$$

$$S_x^2 = \frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \dots\dots + (x_n - \bar{x})^2}{(n-1)}$$
$$= \frac{(520 - 508{\cdot}68)^2 + \dots\dots + (900 - 508{\cdot}68)^2}{(19-1)}$$
$$= \frac{709592{\cdot}11}{18} = 39421{\cdot}78$$
$$S_x = \sqrt{39421{\cdot}78}$$
$$= 198{\cdot}55 \text{ mm}$$

Q. 5. Rain-gauge station x did not function for a part of a month during which a storm occurred. The storm produced rainfalls of 84, 70 and 96 mm at the three surrounding stations A, B and C respectively. The normal annual rainfalls at the stations X, A, B and C are respectively 770, 882, 736 and 944 mm. Estimate the missing storm rainfall at station X. (C.S.V.T.U. Nov.-Dec., 2007)

Solution : The missing rainfall is given by

$$P_x = \frac{1}{3}\left[\frac{N_x}{N_a}P_a + \frac{N_x}{N_b}P_b + \frac{N_x}{N_c}P_c\right]$$

Here

$N_x = 770$ mm and $P_a = 84$ mm

$N_a = 882$ mm $P_b = 70$ mm

$N_b = 736$ mm $P_c = 96$ mm

$N_c = 944$ mm

$\therefore$
$$P_x = \frac{1}{3}\left[\frac{770}{882} \times 84 + \frac{770}{736} \times 70 + \frac{770}{944} \times 96\right]$$
$$= \frac{1}{3}[73{\cdot}33 + 73{\cdot}23 + 78{\cdot}305]$$
$$= 75 \text{ mm}$$

$\therefore$ The missing storm rainfall at rain-gauge station x may be taken as 75 mm.

Q. 6. A catchment has six rain-gauge stations. In a year, the annual rainfall recorded by the gauges are as follows :

Station	A	B	C	D	E	F
Rain fall (m)	82·6	102·9	180·3	110·3	98·8	136·7

For a 10% error in the estimation of the mean rainfall, calculate the optimum number of stations in the catchment. (C.S.V.T.U. Nov.-Dec., 2007; Nov.-Dec., 2008-April-May, 2009)

Solution : For this data,

$M = 6$, $\bar{P} = 118{\cdot}6$

$\sigma_{M-1} = 35{\cdot}04$

$\epsilon = 10$

$C_v = \dfrac{100 \times 35{\cdot}04}{118{\cdot}6}$

$= 29{\cdot}54$

$N = \left(\dfrac{29{\cdot}54}{10}\right)^2$

$N = 8{\cdot}7$, say 9 stations

The optimal number of stations for the catchment is 9. Hence three more additional stations are needed.

Q. 7. Define Probable Maximum precipitation (PMP) ? (C.S.V.T.U. Nov.-Dec., 2008, 2009; April-May, 2010, 2011)

Ans. The greatest depth of rainfall that can occur in a given duration at a given location is known as the possible maximum or the probable maximum precipitation abbreviated as PMP. It is the upper limit of the physically possible precipitation depth. It has been defined as the depth of precipitation which for a given area and duration can be reached but not exceeded under known meteorological conditions. If PMP for a given catchment is estimated, then it can be used to provide an estimate of the Probable Maximum Flood, abbreviated as PMF, after appropriate adjustments for infiltration losses etc. The PMF has virtually no risk of being exceeded. There are two approaches for estimating the PMP. The first approach uses the maximisation and transposition of real or model storms while the second approach utilises the statistical analysis of the extreme rainfall.

In the statistical approach the annual series of the observed maximum rainfall depths for given duration are analysed to yield the mean and standard deviation. PMP is there expressed as the mean of the series plus K times the standard deviation. That is

$$PMP = \bar{P} + K \cdot \sigma$$

The value of K is empirically determined.

Q. 8. Describe the different method of determining the average percipitate on a over a catchment due to a storm ? (C.S.V.T.U. Nov.-Dec., 2008, April-May 2009; April-2011)

Ans. There are three methods of treating the rain-gauge records to arrive at an approximate answer. They are :

(i) Arithmetic mean method

(ii) Thiessen polygon method

(iii) Isohyetal method.

The first two methods are purely mechanical processes requiring no special skill. On other hand, the results obtained by the third method, which perhaps should to be the most accurate, depend for their accuracy upon good judgement of the person making the computations.

(i) Arithmetic Mean Method : This is the simplest of the three methods. As the name implies the results is obtained by dividing the sum of the rainfall amounts recorded at all the rain-gauge stations which are located within the area under consideration by the number of stations. That is

$$P = \frac{P_1 + P_2 + \dots\dots P_n}{n}$$
$$= \frac{1}{n}\sum_{i=1}^{n} P_i$$

where P is the average depth of rainfall and $P_1, P_2, \dots\dots P_n$ are the rainfalls recorded at stations 1, 2...... etc. and n is the number of rain-gauge stations within the area. This method is also known as the unweighted mean method.

(ii) Thiessen Polygon Method : It attempts to make allowance for irregularities in gauge locations by weighing the record of each gauge in proportion to the area which is closer to that gauge than to any other gauge.

(a) The basin area is plotted to some scale and on the same Map the locations of the rain-gauge stations both within the area and also outside the area but nearby are indicated.

(b) The polygonal areas around each rain-gauge stations within the basin boundary are then measured.

(c) The average depth of rainfall P is computed as

$$P = \frac{A_1P_1 + A_2P_2 + \dots\dots + A_nP_n}{A_1 + A_2 + \dots\dots + A_n}$$

(iii) Isohyetal Method : Perhaps the most accurate method of computing the average depth of rainfall is the isohyetal method. An isohyet may be defined as a line joining points of equal rainfall. The rainfall amounts recorded by each station are indicated at the station locations. The volume of rainfall between any two successive isohyets is computed as the product of the area between those isohyets and the average of the two isohyetal values.

Q. 9. There are four rain-gauge stations existing in the catchment of a river. The average annual rainfall values at these stations are 800, 620, 400 and 540 mm respectively.

(i) Determine the optimum number of rain-gauges in catchment, if it is desired to limit the error in the mean value of rainfall in the catchment to 10%.

(ii) How many gauses will then be required to be installed ? (C.S.V.T.U. Nov.-Dec., 2008)

Solution : Mean of the rainfalls at the existing gauges is given by

$$\bar{x} = \frac{1}{M}\Sigma x_i = \frac{800 + 620 + 400 + 540}{4}$$
$$\bar{x} = \frac{2360}{4}$$
$$\bar{x} = 590 \text{ cm.}$$

The standard deviation of the rainfall is given by

$$S_x^2 = \frac{\Sigma(x_i - \bar{x})^2}{(m-i)}$$
$$S_x^2 = \frac{(800-590)^2 + (620+590)^2 + (400-590)^2 + (540-590)^2}{(4-1)}$$
$$= \frac{44100 + 900 + 36100 + 2500}{3}$$
$$S_x^2 = 27866{\cdot}66$$

Or
$$S_x = \sqrt{27866{\cdot}66}$$
$$S_x = 166{\cdot}93 \text{ cm}$$
$$C_v = \frac{S_x}{\bar{x}} \times 100$$
$$= \frac{166{\cdot}93}{590} \times 100$$
$$C_v = 28{\cdot}29$$

$$P = 10\%$$

$$\therefore \quad N = \left[\frac{C_v}{P}\right]^2 = \left(\frac{28.29}{10}\right)^2$$

$$N = 8.0032$$

$$\text{Additional gauges required} = (N - m) = (8.0032 - 4) = 4.0032 \text{ Say } 4$$

Q. 10. The normal annual precipitation of five rain-gauge station A, B, C, D and E respectively 125, 102, 76, 113 and 137 cm. during a particular storm the precipitation recorded by station A, B, C and D are 13.2, 9.2, 6.8 and 10.2 cm respectively. The instrument at station E was in operative during the storm.

Estimate the rainfall at station E during that storm ? **(C.S.V.T.U. Nov.-Dec., 2009)**

Solution : As the normal rainfall values vary more than 10% the normal ratio method is adopted.

$$P_E = \frac{137}{4}\times\left(\frac{13.2}{125}+\frac{9.2}{102}+\frac{6.8}{113}+\frac{10.2}{137}\right)$$

$$= 34.25\,(0.1056 + 0.090 + 0.060 + 0.074)$$

$$= 34.25 \times 0.3542$$

$$P_E = 12.13 \text{ cm.}$$

Q. 11. The average annual rainfall in cm at 4 existing rain-gauge stations in a basin at 105, 79, 70 and 66. If the average depth of rainfall over the basin is to be estimated within 10% error, determine the addition number of gauges needed. **(C.S.V.T.U. April-May, 2010)**

Solution : Mean of the rainfalls at the existing gauges is given by

$$\bar{x} = \frac{1}{m}\Sigma x_i = \frac{105+79+70+66}{4} = \frac{320}{4}$$

$$\bar{x} = 80 \text{ cm}$$

The standard deviation of the rainfalls is given by

$$S^2_x = \frac{\Sigma(x_i - \bar{x})^2}{(m-1)}$$

$$S^2_x = \frac{(105-80)^2+(79-80)^2+(70-80)^2+(66-80)^2}{(4-1)}$$

$$S^2_x = 307.33$$

Or

$$S_x = \sqrt{307.33}$$

$$S_x = 17.53 \text{ cm}$$

$$C_v = \frac{S_x}{\bar{x}}\times 100 = \frac{17.53}{80}\times 100$$

$$C_v = 21.91$$

$$P = 10\%$$

$$\therefore \quad N = \left[\frac{C_v}{P}\right]^2 = \left[\frac{21.91}{10}\right]^2$$

$$N = 4.80$$

$$\text{Additional gauges required} = (N - m) = (4.80 - 4) = 0.8 \text{ Say } 1$$

Q. 12. Rain-gauge station x was inoperative for part of a month during which a storm occurred. The respective storm totals at three surrounding station A, B and C were 107, 89 and 122 mm. The normal annual precipitation amounts at station S X, A, B and C are respectively 978, 1120, 935 and 1200 mm. Estimate the storm precipitation for station X ?

(C.S.V.T.U. April-May 2011)

Solution :

$$N_x = 978,\ N_a = 1120,\ N_b = 935,\ N_c = 1200$$

$$P_a = 107,\ P_b = 89,\ P_c = 122$$

$$\therefore \quad P_x = \frac{1}{3}\left[\frac{978}{1120}\times 107+\frac{978}{935}\times 89+\frac{978}{1200}\times 122\right]$$

$$= \frac{1}{3}\times 285.96$$

$$P_x = 95.31 \text{ mm}$$

Q. 13. What are the precautions to be taken selecting the site of the location of a rain-gauge ? **(C.S.V.T.U. April-May, 2010; April-May, 2011)**

Ans. According to Indian standards the following precautions must be strictly observed while selecting a site for a rain-gauge.

(i) The gauge shall be placed on a level ground, not upon a slope or a terrace and never on a wall or roof.

(ii) On no account the rain-gauge shall be placed on a slope such that the ground falls away steeply in the direction of prevailing wind.

(iii) The distance of the rain-gauge from any object shall not be less than twice the height of the object above the rim of the gauge.

(iv) In hills where it is difficult to find a level space, the site for the gauge shall be chosen where it is best shielded from high winds and where the wind does not cause eddies.

Q. 14. Explain the Intensity duration analysis ?

Ans. It can be generally observed that the most intense storms last for very short duration. As the duration of storm increases the maximum average intensity of the storm decreases. If the observed maximum rainfall intensities at a place for various durations such as 5 min, 10 min, 15 min.......... , 1*h*, 2*h*, 5*h*........etc., are plotted against the respective durations, a graph known as the intensity-duration graph is obtained.

The maximum intensity varies inversely with the duration and generally an equation of the form,

$$I = \frac{c}{(t+a)^b}$$

is assumed between I and t.

Taking logarithms on both sides transforms into a linear form.

$$\log I = \log c - b \log (t + a)$$

The best value of c, a and b are those for which the sum of the squared deviations is minimum. That is

$$S = \Sigma[\log I - \{\log c - b\log(t+a)\}]^2$$

$$\Sigma[\{\log I \log(t+a)\}] = \log c\,\Sigma \log (t + a) - b\,\Sigma\,[\{\log (t + a)]^2$$

Where n is the number of observations and all the summations are over all the observed values.

Q. 15. A storm commenced at 7 hours. The ordinates of the rainfall mass curve of this storm in mm as recorded by a recording rain-gauge at 15 min intervals are 0, 9.5, 17, 27, 40.5, 49, 63, 84, 95, 102, 110, 112 and 112 construct the hyetograph of this storm for a uniform interval of 15 min.

Solution :

Time	Rainfall in mm	Rainfall in Successive is min intervals	Rainfall intensity in mm/h
7	0	—	—
7.15	9.5	9.5	38
7.30	17	7.5	30
7.45	27	10	40
8	40.5	13.5	54
8.15	49	8.5	34
8.30	63	14	56
8.45	84	21	84
9	95	11	44
9.15	102	7	28
9.30	110	8	32
9.45	112	2	8
10	112	0	0

Q. 16. Thiessen polygons constructed for a network of 10 rain-gauges in a river basin yielded Thiessen weights of 0.10, 0.16, 0.12, 0.11, 0.09, 0.08, 0.07, 0.11, 0.06 and 0.10. If the rainfalls recorded at these gauges during a cyclonic storm are 132, 114, 162, 138, 207, 156, 135, 158, 168 and 150 mm respectively determine the average depth of rainfall by Thiessen mean and arithmetic mean methods. Also determine the volume of surface runoff at the basin outlet if 35% of the rainfall is lost as infiltration. Take the area of the basin as 5800 km² and express your answer in million cubic meters.

Solution : By arithmetic mean method, the average depth of rainfall is given by

$$P = \frac{132+114+162+138+207+156+135+158+168+150}{10} = \frac{1520}{10}$$

$$P = 152 \text{ mm}$$

By Thiessen polygon method, the average depth of rainfall is given by

$$P = \Sigma\, W_i\, P_i$$

Where W_i is the Thiessen weight of i the rain-gauge whose rainfall is P_i

$$P = [0.10 \times 132 + 0.16 \times 114 + 0.12 \times 162 + 0.11 \times 138 + 0.09 \times 207 + 0.08 \times 156 + 0.07 \times 135 + 0.11 \times 158 + 0.06 \times 168 + 0.10 \times 150]$$

$$P = 149.08 \text{ mm}$$

$$\text{Runoff depth} = \text{Rainfall} - \text{Loss} = 149.08 - 0.35 \times 149.08 = 96.9 \text{ mm}$$

$$\text{Volume of runoff} = \text{Area} \times \text{runoff depth} = 5800 \times 96.9 \text{ km}^2 - \text{mm} = 562020 \times 10^3 \text{ m}^3 = 562.02 \text{ million cubic metres.}$$

Q. 17. The analysis of a storm yielded the following information regarding isohyets. Calculate the average depth of rainfall.

Isohyet internal in mm	70–80	80–90	90–100	100–110	110–120	120–130
Area in km²	10	85	113	98	136	67

Solution :

Isohyetal interval mm	Area between isohyets km²	Average value of isohyets mm	Area × Average isohyetal value km² – mm
70–80	10	75	750
80–90	85	85	7225
90–100	113	95	10735
100–110	98	105	10290
110–120	136	115	15640
120–130	67	125	8375
Σ	509		53015

$$\text{Average depth of rainfall} = \frac{53015}{509} = 104.16 \text{ mm}$$

Q. 18. The isohyets due to a storm in a catchment and the area of the catchment bounded by isohyets were tabulated as below.

Isohyets (cm)	Area (km²)
Station-12	30
12 – 10	140
10 – 08	80
08 – 06	180
06 – 04	20

Estimate the mean precipitation due to the storm.

Solution : For the first area consisting of a station surrounded by a closed isohyet, a precipitation value of 12 cm is taken. For all other areas, the mean of two bounding isohyets are taken.

Isohyets	Area value of P (cm)	Area (km²)	Fraction of total area (Col. 3/450)	Weighted P (cm) (Col. 2× Col. 4)
1	2	3	4	5
12	12	30	0.0667	0.800
12–10	11	140	0.3111	3.422

10–8	9	80	0.1778	1.600
8–6	7	180	0.4000	2.800
6–4	5	20	0.0444	0.222
Total		450	1.0000	8.844

Mean precipitation $\bar{P} = 8.84$ cm.

Q. 19. Analysis of data on maximum one-day rainfall depth at Madras indicated that a depth of 280 mm had a return period of 50 years. Determine the probability of a one-day rainfall depth equal to or greater than 280 mm at Madras occurring (a) once in 20 successive years (b) two times in 15 successive years and (c) at least once in 20 successive years.

Solution : Here $P = \frac{1}{50} = 0.02$

$$P_{r,n} = {}^nC_r\,P^r\,q^{n-r} = \frac{n!}{(n-r)!\,r!}P^r q^{n-r}$$

(a) $n = 20,\ r = 1$

$$P_{1,20} = \frac{20!}{19!1!}\times 0.02\times(0.98)^{19} = 20\times 0.02\times 0.68123 = 0.272$$

(b) $n = 15,\ r = 2$

$$P_{2,15} = \frac{15!}{13!2!}\times(0.02)^2\times(0.98)^{13} = 15\times\frac{14}{2}\times 0.0004\times 0.769 = 0.323$$

(c)

$$P_1 = 1 - q^n = 1 - (1 - P)^n$$

$$P_1 = 1 - (1 - 0.02)^{20} = 0.332$$

Q. 20. Station X failed to report the rainfall recorded during a storm with respect to east-west and north-south axes set up at station X, the coordinates of 4 surrounding gauges, which are the nearest to station X in the respective quadrants are (10, 15), (– 8, 5), (– 12, – 9) and (5, – 15) km respectively. Determine the missing rainfall at X, if the storm rainfalls at the four surrounding gauges are 73, 89, 68 and 57 mm respectively.

Solution : $P_1 = 73$ mm, $P_2 = 89$ mm, $P_3 = 68$ mm, $P_4 = 57$ mm

Let r_1 be the distance between the station in the first quadrant and the station X. Then we have

$$r_1^2 = 10^2 + 15^2 = 225$$

The weightage factor for this station $= \frac{1}{r_1^2} = \frac{1}{325} = 0.00308$

Similarly, we obtain

$$r_2^2 = (-8)^2 + 5^2 = 89;\quad \frac{1}{r_2^2} = 0.01124$$

$$r_3^2 = (-12)^2 + (-9)^2 = 225;\quad \frac{1}{r_3^2} = 0.00444$$

$$r_4^2 = (5)^2 + (-15)^2 = 250;\quad \frac{1}{r_4^2} = 0.004$$

Substituting these value in eq.,

$$P_x = \frac{\left[\frac{1}{r_1^2}\times P_1+\frac{1}{r_2^2}P_2+\frac{1}{r_3^2}P_3+\frac{1}{r_4^2}P_4\right]}{\left[\frac{1}{r_1^2}+\frac{1}{r_2^2}+\frac{1}{r_3^2}+\frac{1}{r_4^2}\right]}$$

we get,

$$P_x = \frac{(0.00308\times 73+0.01124\times 89+0.00444\times 68+0.004\times 57)}{(0.00308+0.01124+0.00444+0.004)} = \frac{1.75512}{0.02276}$$

$$P_x = 77.11 \text{ mm}$$

∴ The missing rainfall at x may be taken as 77.11 mm.

Q. 21. Assuming that normal distribution is a good fit for the rainfall data of 19 years from 1970 to 1988 are given below :

520, 615, 420, 270, 305, 380, 705, 600, 350, 550

560, 400, 520, 435, 395, 280, 430, 1020, 900.

Determine the 50% and 75% dependable rainfalls. Also determine the probability for a rainfall of 800 mm or more to occur in any year.

Sol. The mean and standard deviation of the rainfall are already computed in as 508.68 mm and 198.55 mm respectively.

Determination of 50% dependable rainfall, the value of the standardised normal variable Z which satisfies the condition that

$$P[Z \ge z] = 0.5$$

is obtained as 0. But $z = \frac{x-\bar{x}}{S_x}$ or $x = \bar{x} = 508.68$ mm

∴ The 50% dependable rainfall is 508.68 mm.

Determination of 75% dependable rainfall, the value of z which satisfies the condition that

$$P[Z \ge z] = 0.75$$

is obtained as – 0.675

$$-0.675 = \frac{x-\bar{x}}{S_x}$$

or

$$x = \bar{x} - 0.675S_x = 508.68 - 0.675\times 198.55 = 374.66 \text{ mm.}$$

when $x = 800$ mm, $Z = \frac{800-508.68}{198.35} = 1.47$

$$P[z \ge 1.47] = 1 - P[z \le 1.47] = 1 - F(1.47) - 0.9288 = 0.0712$$

∴ The annual rainfall in any year exceeds 800 mm with a probability of 0.0712. Ans.

Q. 22. Describe the adequacy of rain gauge stations.

Ans. If there are already some rain gauge stations in a catchments, the optimal number of stations that should exist to have an assigned percentage of error in the estimation of mean rainfall is obtained by statistical analysis as

$$N = \left(\frac{C_v}{\varepsilon}\right)^2$$

where, N = Optimal number of stations, ε = Allowable degree of error in the estimate of the mean rainfall and C_v = Coefficient of variation of the rainfall values at the existing m stations.

$$C_v = \frac{100\times\sigma_{m-1}}{\bar{P}}$$

where,

$$\sigma_{m-1} = \sqrt{\left[\frac{\sum_1^m (P_i-\bar{P})^2}{m-1}\right]} = \text{Standard deviation}$$

$$\bar{P} = \frac{1}{m}\left(\sum_1^m P_i\right) = \text{Mean precipitation.}$$

Q. 23. Analysis of data on maximum one-day rainfall depth at Madras indicated that a depth of 280 mm had a return period of 50 years. Determine the probability of a one-day rainfall depth equal to or greater than 280 mm at Madras occurring (a) Once in 20 successive years (b) Two times in is successive years and (c) At least once in 20 successive years.

Sol. Here $P = \frac{1}{50} = 0.002$

(a) $n = 20,\ r = 1$

$$P_{1,20} = \frac{20!}{19!1!}\times 0.002\times(0.98)^{19} = 20\times 0.02\times 0.68123 = 0.272$$

(b) $n = 15,\ r = 2$

$$P_{2,15} = \frac{15!}{13!\,2!}\times(0.02)^2\times(0.98)^{13} = 0.323$$

(c)

$$P_1 = 1 - (1 - 0.02)^{20} = 0.332.$$

Ans.

Unit III

INFILTRATION AND RUNOFF

Syllabus : Introduction, Factors affecting infiltration, Measurement of infiltration, infiltrometers, infiltration equations, infiltration indices, Effect of infiltration on runoff and recharge of ground water, Runoff, Components of runoff, Estimation of runoff, Calculation by infiltration method, Rainfall-runoff relationship, Rational method of estimating runoff, Basin yield.

Introduction : As described in the hydrologic cycle, infiltration is one of the ways through which the precipitation reaching the earth's surface is disposed of. The other ways include evaporation and evapotranspiration, overland flow, and surface runoff. It is the only source for groundwater replenishment and thus forms an important arc of the hydrologic cycle.

Infiltration may be defined as the process by which water enters the surface strata of the earth.

A soil under given conditions has an upper limit on its absorbing capacity. The infiltration capacity of a soil under given condition is defined as the maximum rate at which it is capable of absorbing water and is denoted by f.

$$f_a = f, \text{ if } i \ge f \text{ and}$$

$$f_a = i, \text{ if } i < f.$$

Q. 1. Define Infiltration ?

(C.S.V.T.U. Nov.-Dec., 2007, Nov.-Dec., 2009, April-May, 2010)

Ans. Infiltration may be defined as the process by which water enters the surface strata of the earth. The infiltrated water first meets the soil moisture deficiency, and there after the excess water moves vertically downwards to reach the ground water table. This vertical movement is called percolation.

Q. 2. What are the factors affecting infiltration ?

Ans. The variations in the infiltration capacity are large. The filtration capacity is influenced by many factors. Some factors contribute to special variation while the others to temporal variation.

Depth of surface detention and thickness of saturated layer : Infiltration takes place due to combined influences of gravity and capillary forces. The infiltration of water through a soil surface may be visualised as a flow through a large number of tiny pipes. As the infiltration continues the wet front will be travelling downwards. At any instant of time the resistance to flow is proportional to time thickness of the saturated layer up to wet front L, while the driving head is proportional to $(L + d)$ d being the depth of detention.

Soil Moisture : If a soil is completely dry at the beginning of rain there is a capillary attraction for moisture in the subsurface layers that acts in the same direction as gravity and gives high initial value of infiltration.

Compaction : The clay surfaced soils are compacted even by the impact of rain drops which reduce f. This effect is negligible on sandy soils. Compaction not only reduces the porosity but also the pore sizes. When the compaction is artificial due to man-made effects the initial infiltration capacity is very low and it is further reduced during the storm. Overgrazed pastures, playgrounds and areas subjected to heavy vehicular traffic will have less infiltration capacities.

Surface cover conditions : The nature of surface cover has also an important influence on the infiltration. The presence of surface cover has also an important influence on the infiltration. The presence of a dense cover of vegetation on the surface increases f. The vegetative cover retards the movement of overland flow and causes high depths of detention. It reduces the effect of rain drop compaction.

Temperature : The effect of temperature on infiltration is explained through viscosity. The flow through soil pores is by and large laminar for which the resistance is directly proportional to viscosity. At high temperatures since viscosity of water is low, high infiltration capacities are expected.

Q. 3. A storm with 10 cm of precipitation produced a direct runoff 5·8 cm. The duration of rainfall was 16 hours and its time distribution is given below. Estimate the ϕ-index of the storm.

Time From Start (h)	0	2	4	6	8	10	12	14	16
Cumulative rainfall (cm)	0	0·4	1·3	2·8	5·1	6·9	8·5	9·5	10

(C.S.V.T.U. Nov.-Dec., 2007)

Sol : Pulses of uniform time duration $\Delta t = 2h$ are considered.

Pulse number (h)	1	2	3	4	5	6	7	8
Cumulative rainfall	0·4	1·3	2·8	5·1	6·9	8·5	9·5	10
Incremental rain (cm)	0·40	0·90	1·50	2·30	1·80	1·60	1	0·50
Intensity of rain (I_i) in cm/h	0·20	0·45	0·75	1·15	0·90	0·80	0·50	0·25

Hence duration of rainfall $D = 16$, $\Delta t = 2h$, $N = 8$

Assume $M = 8$, $\Delta t = 2h$

Hence $t_e = M \cdot \Delta t = 16$ hours

Since $M = N$, all the pules are included.

$$\text{Runoff } R_d = 5{\cdot}8 \text{ cm} = \sum_1^8 (I_i - \phi)\,\Delta t = \sum_1^8 I_i \times \Delta t - \phi(8 \times 2)$$

$$5{\cdot}8 = \{(0{\cdot}20 \times 2) + (0{\cdot}45 \times 2) + (0{\cdot}75 \times 2) + (1{\cdot}15 \times 2) + (0{\cdot}90 \times 2) + (0{\cdot}80 \times 2) + (0{\cdot}50 \times 2) + (0{\cdot}25 \times 2)\} - 16\,\phi = 10 - 14\,\phi$$

$$\phi = \frac{4{\cdot}2}{14} = 0{\cdot}263 \text{ cm/h}$$

Q. 4. Describe the different components of runoff ?

(C.S.V.T.U. Nov.-Dec., 2007, Nov.-Dec., 2009, April-May, 2010)

Ans. According to the source from which the flow is derived, the total runoff is visualised to consist of surface runoff, subsurface runoff and groundwater runoff. Before reaching the ground a small portion of precipitation evaporates and joins back the atmosphere while another small portion is intercepted which also eventually becomes atmospheric moisture through evaporation. This portion is usually small and insignificant in the runoff analysis. The remaining precipitation reaching the ground is called the through-fall.

It may fall either on land surface or directly on to the water surfaces of streams, lakes and reservoirs. The precipitation falling on water surfaces is called channel precipitation and it immediately becomes the stream-flow. A very small fraction of the precipitation. Falling on the land surface may be absorbed in the storage like small ponds, swamps etc., before it becomes evaporation and infiltration. This is called the depression storage. The rest of the precipitation falling on land surface, after satisfying the infiltration demand, is temporarily detained on the ground surface and when sufficient depth is built-up it travels over the ground surface towards the stream channels either as quasi-laminar sheet flow. This is called the overland flow. The overland flow ceases shortly after the rainfall stops.

Water which infiltrates the soil surface and then moves laterally through the upper soil horizons towards the stream channels above the main groundwater table is known as the inter flow. It is also known as subsurface runoff, subsurface storm flow, storm seepage and secondary base flow.

The infiltrated water which percolates deeply becomes groundwater and when groundwater table rises and intersects the stream channels of the basin it discharges into streams as the groundwater runoff.

For the practical purpose of analysis total runoff in stream channels is generally classified as direct runoff and base flow. The direct runoff is that part of runoff which enters the stream promptly and is equal to the sum of surface runoff and rapid inter flow.

The precipitation excess is that part of total precipitation which contributes directly to the surface runoff. When the precipitation is in the form of rainfall only it is known as rainfall excess.

Q. 5. Explain the different empirical equations for runoff calculation.

(C.S.V.T.U. Nov.-Dec., 2007)

Ans. With a keen sense of observation in the region of their activity many engineers of the past have developed empirical runoff estimation formulae. Some of the important formulae used in various parts of India are given below.

Binnie's Percentages : Sir Alexander Binnie measured the runoff from a small catchment near Nagpur during 1869 and 1872 and developed curves of cumulative runoff against cumulative rainfall. The two curves were found to be similar. From these he established the percentages of runoff from rainfall. These percentages have been used in Madhya Pradesh and Vidrabha region of Maharashtra for the estimation of yield.

Barlow's tables : Barlow, the first chief Engineer of the Hydro-Electric Survey of India (1915) on the basis of his study in small catchments (area ~ 130 km²) in Uttar Pradesh expressed runoff R as

$$R = K_b\, P$$

where K_b = runoff coefficient with depend upon the type of catchment and nature of monsoon rainfall.

Strange's table : The available rainfall and runoff in the border areas of present-day Maharashtra and Karnataka and has obtained yield ratios as functions of indicators representing catchment characteristics. Catchments are classified as good, average and bad according to the relative magnitudes of yield they give. For example, catchments with good forest and having soils of high permeability would be classified as bad, while catchments having soils of low permeability and having little or no vegetal cover is termed good.

Q. 6. Discuss the infiltration Indices ? (C.S.V.T.U. April-May 2008; Nov.-Dec., 2008)

Ans. The infiltration capacity curves which are developed either from infiltrometer tests or the hydrograph analyses methods can be used to estimate the runoff from a given storm. The infiltration rate curve existing at the time of occurrence of storm is superimposed on the rainfall hyetograph with base lines coincident. The area of the rainfall hyetograph above the infiltration curve would then represent the runoff volume whose time distribution may be obtained through the application of unit hydrograph principle. The rainfall volume below the infiltration curve represents the total depth of infiltration during the storm lies in selecting the appropriate infiltration curve representive of the conditions existing at the start of the storm.

Though this approach appears to be simple there are some difficulties. If the rainfall intensity is always more than the infiltration capacity the results are satisfactory. If the rainfall intensity fluctuates above and below the infiltration capacity rate curve the problem is complicated. The intensity of rainfall is rarely uniform both in time and space. If the rainfall is less than infiltration capacity the contribution to soil moisture is less than assumed and drop in infiltration curve is correspondingly less.

Q. 7. Discuss the rational method of estimating runoff ?

(C.S.V.T.U. April-May, 2008; Nov.-Dec., 2008)

Ans. Consider a rainfall of uniform intensity and very long duration occurring over a basin. The runoff rate gradually increases from zero to a constant value as indicated. The runoff increases as more and more flow from remote areas of the catchment reach the outlet. Designing the time taken for a drop of water from the farthest part of the catchment to reach the outlet as t_c = time of concentration, it is obvious that if the rainfall continues beyond t_c, the runoff will be constant and at the peak value. The peak value of the runoff is given by

$$Q_P = CA_i \text{ for } t \geq t_c$$

where C = coefficient of runoff,

A = Area of the catchment and i = intensity of rainfall. This is the basic equation of the rational method.

$$Q_P = \frac{1}{3{\cdot}6}\, C\,(i_{t_c,p})\, A$$

Q_P = peak discharge (m³/s)

C = coefficient of runoff

A = drainage area in km²

The use of this method to compute Q_P requires three parameters : t_c $(i_{t_c,p})$ and C.

Q. 8. A 6 h storm produced rainfall intensities of 7, 18, 25, 12, 10 and 3 mm/h in successive one hour intervals over a basin of 800 sq. km. The resulting runoff is observed to be 2640 hectare-metres. Determine ϕ-index for the basin. (C.S.V.T.U. Nov.-Dec., 2008)

Solution : Total Vol. of Runoff

$= 2640$ hectare-metres

$= 2640 \times 10000$

$= 264 \times 10^5 \text{ m}^3$

Area of the basin $= 800 \text{ km}^2 = 800 \times 10^6 \text{ M}^2$

$\therefore$ The depth of runoff $= \dfrac{264 \times 10^5}{800 \times 10^6} = 0{\cdot}033$ m

$= 33$ mm

By trial and error if ϕ-index is chosen to be 8 mm/h, the rainfall volume above the ϕ-index line to equal to

$0 + (18 - 8) + (25 - 8) + (12 - 8) + (10 - 8) - 0$

$= 0 + 10 + 17 + 4 + 2 + 0$

$= 33$ mm

This is exactly equal to the observed runoff. Therefore $\phi = 8$ mm/h.

Q. 9. What do you understand by Infiltration Capacity ?

(C.S.V.T.U. April-May, 2009; Nov.-Dec., 2010; April-May, 2011)

Ans. The maximum rate at which a given soil at a given time can absorb water is defined as the infiltration capacity. It is designated as f_p and is expressed in units of cm/h.

The actual rate of infiltration f can be expressed as :

$f = f_p$ when $i \geq f_p$

$f = i$ when $i < f_p$

where i = intensity of rainfall. The infiltration capacity of a soil is high at the beginning of a storm and has an exponential decay as the time elapses.

The infiltration capacity of an area is dependent on a large number of factors, chief of them are :

- Characteristics of soils
- Condition of the soil surface
- Current moisture content
- Vegetative cover
- Soil temperature.

Q. 10. Explain briefly :

(i) ϕ index

(ii) W index. (C.S.V.T.U. April-May, 2009; Nov.-Dec., 2010; April-May, 2011)

Ans. (i) ϕ index : The ϕ-index is an average rainfall intensity above which the rainfall volume equals the runoff volume. The rainfall hyetograph is plotted on a time base and a horizontal line is drawn such that the shaded area above the line exactly equals the measured runoff. Since the unshaded area below the line is also the line is also measured rainfall but did not appear as runoff it represents all the losses including depression storage, evaporation, interception as well as infiltration. Infiltration is the largest loss compared to the other losses. The ϕ-index can be determined for each flood event for which the runoff measurement are available. Then probably a relationship between the size of the flood, antecedent soil moisture and the ϕ-index could be developed. Since the data required to drive a precise infiltration rate curve for large watersheds is very large, the ϕ-index will be very useful in predicting the infiltration from a storm on large water-sheds. The ϕ-index is used in unit hydrograph studies to define the pattern of rainfall excess.

(ii) W-index : The W-index is a refined version of ϕ-index. It excludes the depression storage and interception from the total losses. It is the average infiltration rate during the time rainfall intensity exceeds the capacity rate.

That is
$$W = \frac{F}{t} = \frac{(P - Q - S)}{t}$$

where F is the total infiltration, t is time during which rainfall intensity exceeds infiltration capacity, P is total precipitation corresponding to t, Q is the total storm runoff and S is the volume of depression storage and interception. Thus W-index is essentially equal to ϕ-index minus the depression and interception storage.

Q. 11. What is the factor affecting runoff ? (C.S.V.T.U. April-May, 2008)

Ans. The runoff from a drainage basin is influenced by various factors which may be put under two groups, namely the climatic factors and the physiographic factors.

The climatic factors include :

(i) Type of precipitation.
(ii) Intensity of rainfall.
(iii) Duration of rainfall.
(iv) Areal distribution of rainfall.
(v) Direction of storm movement.
(vi) Antecedent precipitation.
(vii) Other climatic factors that affect evaporation and transpiration.

The physiographic factors are :

(i) Land use.
(ii) Type of soil.
(iii) Area of the basin.
(iv) Shape of the basin.
(v) Elevation.
(vi) Slope.

(vii) Orientation.
(viii) Type of drainage network.
(ix) Indirect drainage.
(x) Artificial drainage.

Type of Precipitation : If the precipitation falls in the form of rain its effect on runoff is almost immediately felt provided its intensity is sufficiently large. The resulting runoff, of course, will also depend upon the interaction of the other factors.

Intensity of precipitation : For rainfall intensities exceeding the infiltration capacity, the runoff increases with increase in intensity. Owing to the storage effects of the basin, the increase in the runoff rate is not same as the increase in rainfall intensity.

Duration of rainfall : If rainfall is of sufficiently prolonged duration, infiltration capacity rate is greatly reduced resulting in high runoff rates. Under favourable conditions the infiltrated water may even raise the watertable to the ground surface reducing the infiltration to zero leading to serious flood. As a consequence, rains of long duration may produce high rates of runoff even though the intensity is relatively mild. It is pertinent here to consider the duration of rainfall in conjunction with critical concentration time of the basin t_c, which is defined as the time taken by a rain drop falling on the remotest point of the basin to reach the basin outlet.

Antecedent precipitation : The soil moisture conditions of the basin existing at the time of occurrence of storm would greatly influence the runoff peak resulting from that storm. Even very intense rains falling in late summer, when the soil moisture is at its least, rarely produce high discharges because most of the water enters the soil moisture under the existing high infiltration capacity rates and is held there. In the winter and rainly seasons, since the precipitation occurred in the earlier periods would have raised the soil moisture to high level, one can expect very low infiltration capacity rates.

The Antecedent Precipitation Index (API) as given below

$$I_t = KI_{t-1}$$

If there is no rainfall in the previous t days then,

$$I_t = K^t\, I_0$$

where I_0 is the initial value of API.

Land use : Land use affects the runoff through its influence on interception, evapotranspiration and soil moisture movement. In urban areas there is little scope for infiltration and transpiration and all the rainfall immediately becomes direct runoff producing high discharges.

Type of Soil : The type of soil had direct influence on its infiltration capacity rate and consequently it also affects the runoff. Open textured sandy soils will tend to have higher infiltration rates and therefore tend to produce less peak discharges.

Elevation : The variation in elevation and also the mean elevation of a basin may influence runoff in as much as they decide the proportion of precipitation falling in the form of snow and the evaporation and transpiration losses. For large basins the mean elevation is determined by the intersections method.

Orientation : The orientation of the basin decides the amount of solar radiation received from the sun. Thus it may affect the runoff through its influence on evaporation, transpiration and snow melt processes.

Artificial drainage : Conditions of articifial drainage exist in areas provided with a system of open ditches or tile drains and also in urban areas provided with storm sewers and where considerable portions of the area are covered by buildings or paved surfaces. Runoff from such areas would naturally be accelerated, but the effect would be purely local and no significant increases in peak flow of large streams can result in general.

Q. 12. Explain the following :

(i) Infiltrometer

(ii) Basin yield. (C.S.V.T.U. Nov.-Dec., 2009, 2010; April-May, 2011)

Ans. (i) Infiltrometer : Infiltrometers are of two types. They are (i) Flooding type infiltrometers (ii) rainfall simulators. In the flooding type of infiltrometers water is applied in the form of a sheet usually with a constant depth of flooding. They may use a single ring or two rings to delineate the sample area. In former case it is known as a simple infiltrometer or a tube infiltrometer. In the latter case it is called a double ring infiltrometer. In the rainfall simulations water is applied by sprinkling at a uniform rate that is in excess of infiltration capacity.

(ii) Basin Yield : Yield refers to the quantity of any product resulting from the exploitation of natural resources basin yield refers to the quantity of water available from a stream at a given point over a specified duration of time. The duration of time in the definition of yield would normally be a month or longer. The emphasis is on water volumes rather than instantaneous discharges. Therefore yield from a basin is the summation of the continuous hydrograph of flow at its outlet over the specified time period. It is the consequence of all hydrologic events causing flow, including storms of all durations and intensities and the climatic, geologic and land use environment.

The hydrologic water balance equation for any basin under consideration may be written as

$$(S_1 + S_{s_1} + S_{g_1} + S_{sm_1} + P) = E + \int_{t_1}^{t_2} Q \cdot dt + (S_2 + S_{s_2} + S_{g_2} + S_{sm_2})$$

where S = volume of water in storage in channels and reservoirs of the basin.

Q. 13. The mean monthly temperatures over a basin for a 12 month period from June to May are 25·8, 24·4, 23·8, 23·5, 23·6, 20·2, 17·1, 16·6, 18·5, 23·3, 27·6 and 28·4° respectively. The observed rainfalls in mm in corresponding months are 86, 229, 208, 115, 15, 182, 10, 24, 24, 12, 0 and 0. Determine the annual runoff from the basin using Khosla's formula.

Solution : It may be noted that when L_m exceeds P_m resulting in a negative value for R_m, then R_m is set equal to zero.

Month	M	T_m	P_m (mm)	$L_m = 5\,T_m$	$R_m = P_m - L_m$ (mm)
June	1	25·8	86	129	0
July	2	24·4	229	122	107
August	3	23·8	208	119	89
September	4	23·5	115	117·5	0
October	5	23·6	15	118	0
November	6	20·2	182	101	81
December	7	17·1	10	85·5	0
January	8	16·6	24	83	0
February	9	18·5	24	92·5	0
March	10	23·3	12	116·5	0
April	11	27·6	0	138·0	0
May	12	28·4	0	142	0
					R_A = 277 mm

Q. 14. The cumulative depth of infiltration in an experiment on a tube infiltrometer is observed to follow the equation $F = 0{\cdot}165\, t^{0{\cdot}65}$, where F is in cm and t is in minutes. Determine the equation for infiltration rate and the average infiltration rate.

Solution :
$$F = 0{\cdot}165\, t^{0{\cdot}65}$$

$$f = \frac{dF}{dt} = 0{\cdot}165 \times 0{\cdot}65 \times t^{-0{\cdot}35}$$

$= 0{\cdot}10725\, t^{-0{\cdot}35}$ cm/minute

$f = 6{\cdot}435\, t^{-0{\cdot}35}$ cm/h, where t is in minutes.

$f = 1{\cdot}5353\, t^{-0{\cdot}35}$ cm/h, where t is in hours

$$f_{av} = \frac{F}{t} = 0{\cdot}165\, t^{-0{\cdot}35} \text{ cm/minute}$$

$= 9{\cdot}9\, t^{-0{\cdot}35}$ cm/h, where t is in min.

$= 2{\cdot}362\, t^{-0{\cdot}35}$ cm/h, where t is in hours.

Q. 15. The Horton's infiltration equation for a basin is given by $f = 6 + 16\,e^{-2t}$ where f is in mm/h t is in hours. What are the values of f_0, f_c and K ? If a storm occurs on this basin with an intensity of more than 22 mm/h determine the depth of infiltration for the first 45 minutes and the average infiltration rate for first 75 minutes.

Solution : On comparison with the Horton's equation in the standard form one can observe that $f_c = 6$ mm/h, $f_0 = 22$ mm/h and $k = 2$/h.

Since the rainfall intensity is more than f_0, the infiltration takes place at the capacity rate throughout the storm. Hence the cumulative depth of infiltration for the first 45 minutes is given by

$$F = \int_0^{3/4} f \cdot dt = \int_0^{0{\cdot}75} (6 + 16e^{-2t})\,dt$$

$$= \left[6_t - 8_e^{-2t}\right]_0^{0{\cdot}75}$$

$= [6 \times 0{\cdot}75 - 8 \times e^{-1{\cdot}5}] - [0 - 8]$

$= 12{\cdot}5 - 8e^{-1{\cdot}5} = 12{\cdot}5 - 1{\cdot}785$

$= 10{\cdot}715$ mm

The cumulative depth of infiltration for the first 75 minutes is given by

$$F = \int_0^{1{\cdot}25} f \cdot dt = \left[6t - 8_e^{-2t}\right]_0^{1{\cdot}25}$$

$= [6 \times 1{\cdot}25 - 8 \times e^{-2{\cdot}5}] - [0 - 8]$

$= 15{\cdot}5 - 0{\cdot}657 = 14{\cdot}843$ mm

The average infiltration rate for the first 75 minutes is given by

$$f_{av} = \frac{F}{t} = \frac{14{\cdot}843}{1{\cdot}25}$$

$$f_{av} = 11{\cdot}874$$

Q. 16. What are the initial losses ? How does the interception loss vary with the magnitude of storm rainfall ?

Ans. Much of the rain falling during the initial period of the storm is stored on the vegetal cover as interception. Some more precipitation is requiring to fill up all the depression before the overland flow commences. The interception and depression storage are together called the initial abstractions or the initial losses.

Interception : The amount of precipitation intercepted by the vegetal cover depends on factors such as density and compaction of vegetation, storm characteristics and prevailing

wind at the time of storm. It is very difficult to exactly measure the interception. It is estimated that the annual interception by a well-developed forest may be anything between 10 to 20% of the rainfall. If the area experiences a large number of small storms it can be even greater than 25%.

Depression storage : The water which goes to fill up the surface depressions is not available to runoff as it is eventually lost as either infiltration. Thus depression storage is considered as loss from rainfall. The depression storage depends again on many factors such as the type and the nature of catchment, slope of the catchment and the antecedent precipitation that reflects the soil moisture. It is observed that the depression storage for most basins lie between 10 and 50 mm.

Q. 17. A 500 sq. km watershed received a 8 h storm which produced hourly intensities of 6, 9, 20, 16, 4, 14, 12 and 2 mm/h. If the initial abstractions are estimated to be 15 mm and ϕ-index is 5 mm/h, what would be the runoff volume produced by the storm ?

(C.S.V.T.U. Nov.-Dec., 2008)

Solution : The rainfall occurring in the first two hours is 15 mm which is same as the initial abstractions. Therefore no runoff is produced in this period. In the remaining 6 h period the rainfall excess is given by

$(20-5) + (16-5) + 0\,(14-5) + (12-5) + 0 = 42$ mm

$\therefore$ The runoff volume = Area of the basin × Runoff depth

$$= 500 \times 10^6 \times \frac{42}{1000}$$

$$= 21 \times 10^6 \text{ m}^3$$

If the initial abstractions are neglected and ϕ-index is applied throughout the storm the runoff is over-estimated by 5 mm resulting in an error of about 12%. The basin produces surfaces runoff from the end of 2nd hour.

Q. 18. Rainfall of 12, 30, 40, 44 and 17 mm were recorded on 3rd, 9th, 10th, 16th and 17th days of a particular month. Compute the antecedent precipitation index for the first 20 days of the month and assume that API of the last day in the previous month is 85 mm and the value of the recession factor K is 0·90. (C.S.V.T.U. April-May, 2009)

Solution : The API of any day t, denoted by I_t is obtained from the equation.

$$I_t = K\, I_{t-1} + P_t$$

where P_t is the precipitation on t^{th} day. The computations to obtain the API for the first 20 days in the month are set out in Table, with $I_0 = 85$ and $K = 0{\cdot}90$

Day	Precipitation in (mm) P_t	I_{t-1}	$K \cdot I_{t-1}$	$I_t = KI_{t-1} + P_t$
1	0	85	76·50	76·50
2	0	76·50	68·85	68·85
3	12	68·85	61·97	73·97
4	0	73·97	66·57	66·57
5	0	66·57	59·91	59·91
6	0	59·91	53·92	53·92
7	0	53·92	48·53	48·53
8	0	48·53	43·68	69·31
9	30	43·68	39·31	102·38
10	40	69·31	62·38	92·14
11	0	102·38	92·14	82·93
12	0	92·14	82·93	74·64
13	0	82·93	74·64	67·18

14	0	74·64	67·18	60·46
15	0	67·18	60·46	98·41
16	44	60·46	54·41	105·57
17	17	98·41	88·57	95·01
18	0	105·57	95·01	85·51
19	0	95·01	85·51	76·96
20	0	85·51	76·96	76·96

Q. 19. The following table gives values of measured discharges at a stream gauging site in a year. Upstream of the gauging site a weir built across the stream diverts 3 Mm^3 and 0·50 Mm^3 of water per month for irrigation and for use in an industry respectively. The return flows from the irrigation is estimated as 0·8 Mm^3 and from the industry at 0·30 Mm^3 reaching the stream upstream of the gauging site. Estimate the natural flow. If the catchment area is 180 km^2 and the average annual rainfall is 185 cm. Determine the runoff-rainfall ratio.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Gauged flow	2	1·5	0·8	0·6	2·1	8	18	22	14	9	7	3

Solution : $R_N = (R_o - V_r) + V_d + E + E_x + \Delta S$

Here E, E_x and ΔS are assumed to be insignificant and of zero value.

V_r = Volume of return flow from irrigation, domestic water supply and industrial use = 0·80 + 0·30 = 1·10 Mm^3

V_d = Volume diverted out of the stream for irrigation, domestic water supply and industrial use = 3 + 0·5 = 3·5 Mm^3

Month	1	2	3	4	5	6	7	8	9	10	11	12
R_o (Mm^3)	2	1·5	0·8	0·6	2·1	8	18	22	14	9	7	3
V_d (Mm^3)	3·5	3·5	3·5	3·5	3·5	3·5	3·5	3·5	3·5	3·5	3·5	3·5
V_r (Mm^3)	1·1	1·1	1·1	1·1	1·1	1·1	1·1	1·1	1·1	1·1	1·1	1·1
R_N (Mm^3)	4·4	3·5	3·2	3	4·5	10·4	20·4	24·4	16·4	11·4	9·4	5·4

Total R_N = 116·8 Mm^3

Annual natural flow volume = Annual runoff volume = 116·8 Mm^3

$$\text{Annual natural flow volume} = \text{Annual runoff volume} = 116·8\ Mm^3$$

$$\text{Area of the catchment} = 180\ km^2 = 1·80 \times 10^8$$

$$\text{Annual runoff depth} = \frac{1·168\times10^8}{1·80\times10^8} = 0·649\ m = 64·9\ cm$$

$$\text{Annual rainfall} = 185\ cm$$

$$(\text{Runoff/Rainfall}) = 64·9/185 = 0·35$$

Q. 20. Monthly rainfall values of the 50% dependable year at a site selected for construction of an irrigation tank is given below. Estimate the monthly and annual runoff volume of this catchment of area 1500 ha.

Month	June	July	August	September	October
Monthly rainfall (mm) rainfall (mm)	90	160	145	22	240

Solution :

No.	Month	June	July	August	September	October
1.	Monthly rainfall (mm)	90	160	145	22	240
2.	Cumulative monthly rainfall (mm)	90	250	395	417	657
3.	Runoff/Rainfall as %	0·56	4·17	10·01	11·08	21·69
4.	Cumulative Runoff	0·50	10·43	39·54	46·20	142·50
5.	Monthly Runoff	0·50	9·92	29·11	6·66	96·30

Row 4 is obtained by using table. Note that cumulative monthly rainfall is used to get cumulative runoff-ratio percentage at any month

$$\text{Total monsoon runoff} = 142·50\ mm$$
$$= (142·5/1000) \times (1500 \times 10^4) / 16^6\ Mm^3$$
$$= 2·1375\ Mm^3$$

Annual Runoff is taken as equal to monsoon runoff.

Q. 21. The observed mean monthly flows of a stream for a one year period from June to May in m^3/s are 18, 20, 46, 42, 37, 30, 33, 23, 26, 21, 19 and 8.

(a) Determine the flow which can be expected 80 percent of time.

(b) What is the dependability of the flow of magnitude 40 m^3/s ?

Sol.

Month	Observed flow m^3/s	Flow arranged in descending order m^3/s	Rank m	Percent of time flow equalled or exceeded $= \frac{m}{n} \times 100(\%)$
June	18	46	1	8·33
July	20	42	2	16·67
Aug.	46	37	3	25
Sept.	42	33	4	33·33
Oct.	37	30	5	41·67
Nov.	30	26	6	50
Dec.	33	23	7	58·33
Jan.	23	21	8	66·67
Feb.	26	20	9	75
Mar.	21	19	10	83·33
Apr.	19	18	11	91·67
May	8	8	12	100

(a) Flow expected 80 percent of the time = 18·5 m^3/s

(b) Dependability of flow of magnitude 40 m^3/s = 18·4%. Ans.

Unit IV

HYDROGRAPH ANALYSIS

Syllabus : Introduction, Characteristics of the hydrograph, Effect of rainfall distribution on the shape of hydrograph, Hydrograph separation, Unit hydrograph, Deviation of the unit hydrograph, Unit hydrograph from the complex storms-hydrograph, Applications of unit hydrograph.

Introduction : The time distribution of runoff produced by a given precipitation on a basin is analysed. The runoff measured at the basin outlet, when plotted against time gives the hydrograph. As the runoff includes the contributions from surface runoff, interflow and groundwater runoff, the hydrograph can be regarded as an integral expression of the physiographic and climatic characteristics that govern the relations between rainfall and runoff. It shows the time distribution of runoff at the basin outlet defining the complexities of the basin characteristics by a single empirical curve. Thus it forms a basis to relate rainfall and the time distribution of runoff produced by it.

Q. 1. Define unit hydrograph ?

(C.S.V.T.U. Nov.-Dec., 2007; April-May, 2009; Nov.-Dec., 2009)

Ans. The Unit hydrograph of a drainage basin is defined as a hydrograph of direct runoff resulting from 1 cm of effective rainfall applied uniformly over the basin area at a uniform rate during a specified period of time.

Q. 2. Discuss the characteristics of the hydrograph. (C.S.V.T.U. April-May, 2008)

Ans. It has three characteristic regions :

(i) The rising limb AB, joining point A, the starting point of the rising curve and point B, the point of inflection.

(ii) The crest segment BC between the two points of inflection with a peak P in between.

(iii) The falling limb or depletion curve CD starting from the second point of inflection C.

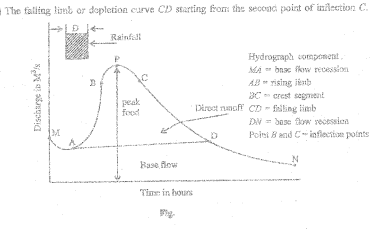

Fig.

Q. 3. Discuss the definition of a unit hydrograph implies ? (C.S.V.T.U. April-May, 2008)

Ans. (i) The unit hydrograph represents the lumped response of the catchment to a unit rainfall excess of D-h duration to produce a direct-runoff hydrograph. It relates only the direct runoff to the rainfall excess. A 1 cm depth of rainfall excess is considered the area of the unit hydrograph is equal to a volume given by 1 cm over the catchment.

(ii) The rainfall is considered to have an average intensity of excess rainfall (ER) of 1/D cm/h for the duration D-h of the storm.

(iii) The distribution of the storm is considered to be uniform all over the catchment.

Q. 4. Write limitation of unit hydrograph. (C.S.V.T.U. April-May, 2009)

Ans. Since uniform intensity over long duration is less likely the storms selected for unit hydrograph analysis should be of short duration. The uniform aerial distribution of rainfall over large areas is less likely, the unit hydrographs can be applied only to drainage basins with small areas. In case of large basins, the basin has to be divided into small sub-basins and each sub-basin is subjected to analysis for storms covering the whole sub-basin. The unit hydrograph is also not suitable for areas less than 200 hectares. Basins with odd shapes, particularly those which are long and narrow, will commonly have uneven rainfall distribution and hence unit hydrographs are not well adopted to such basins. The assumption of constant base period for storms of same duration may not produce excessive error since the recession curve approaches zero asymptotically. The unit hydrographs derived from two storms of same duration but with different runoff volumes will not be same. The peak discharge in the unit hydrograph derived from ordinary floods is often increased by 5 to 20 per cent before using it for predicting the extreme flood peaks with the belief that channel-flow time shortens as flood magnitude increases. If extreme floods overflow into flood plains, the opposite effect might result.

Q. 5. What are the assumptions of unit hydrograph theory ?(C.S.V.T.U. Nov.-Dec., 2009)

Ans. The following basic assumptions constitute the so-called unit hydrograph theory.

(a) The effective rainfall is uniformly distributed within its duration.

(b) The effective rainfall is uniformly distributed throughout the whole area of the basin.

(c) The base periods of the direct runoff hydrographs produced by effective rainfall of same duration are also same.

(d) The ordinates of the direct runoff hydrograph of a common base period are directly proportional to the total volume of direct runoff represented by the respective hydrographs.

(e) For a given drainage basin the hydrograph of runoff due to a given period of rainfall reflects the unchanging characteristics of the basin.

Q. 6. Explain briefly :

(i) Hydrograph Separation,

(ii) S-curve hydrograph. (C.S.V.T.U. April-May, 2009; April-May-2011)

Ans. (i) Hydrograph Separation : It is necessary to separate to observed hydrograph into its component parts namely the surface runoff, interflow and groundwater runoff for subsequent analysis. However, in many engineering applications it is the standard practice to separate the hydrograph into two parts only direct runoff and base flow.

If a continuous record of discharge in the stream over a period of few year is available a master depletion curve also called a type curve or a composite recession curve is constructed and used for separating the baseflow. The construction of the master depletion curve is as follows. Recession segments which represent only base flow contribution at their respective tails are selected. These segments should be selected at as many different stages in the river as possible.

They are then plotted on transparent papers with coincident time axis and are adjusted such that all of them will have a common overlapping portion.

While the procedure described above is perhaps the best available, it requires previously observed data on stream flow for a long period which may not be available in all cases. In such situations a point on the recession limb of the hydrograph to mark the end of direct runoff may be fixed N days after the peak of the hydrograph where N is calculated from the empirical equation.

$$N = 0·827\ A^{0·2} \quad ...(1)$$

in, A is the area of the drainage basin in km^2. N as given by eq. (1) may be taken as a rule of thumb and need not strictly adhered to, if it is giving either too long or too short base flow separation line.

(ii) S-curve hydrograph : A S-curve hydrograph may be defined as the hydrograph of direct runoff resulting from a continuous effective rainfall of uniform intensity $\frac{1}{D}$ cm/h. The S-curve is constructed by adding together a series of D h unit hydrographs, each lagged by D h with respect to the previous one. The S-curve hydrograph attains a constant ordinate called the equilibrium discharge denoted by Q_e, approximately at the end of the base period T of the unit hydrograph. Thus the number of unit hydrographs needed to produce the S-curve is $\frac{T}{D}$. The S-curve ordinates are sometimes found to oscillate in the top portion at and around the equilibrium discharge. This is called the hunting of S-curve.

Q. 7. Write a use and Applications of unit hydrograph ? (C.S.V.T.U. April-May, 2009)

Ans. The unit hydrographs are used in many hydrological problems such as :–

(i) In the development of flood hydrograph corresponding to design of hydraulic structures.

(ii) In the watershed simulation models.

(iii) In the studies of flood forecasting and flood warning systems, and

(v) In extending the flood flow records based on rainfall records.

Application of unit hydrograph :

(i) The rainfall hyetograph is constructed for the storm under consideration and the effective rainfall is determined by drawing an appropriate ϕ-index line.

(ii) The effective rainfall hyetograph is split into periods of approximately uniform intensity and durations that meet the requirements of the unit hydrograph available.

(iii) The direct runoff hydrograph resulting from each rainfall periods obtained by multiplying the ordinates of the appropriate U.H. by the depth of effective rainfall in that period.

(iv) These direct runoff hydrographs are plotted and graphically added with appropriate time lag to yield the composite direct runoff hydrograph.

(v) The estimated baseflow is then added to the composite direct runoff hydrograph to give the total runoff hydrograph.

Q. 8. Two storms each of 6 hours duration and having rainfall excess values of 3 and 2 cm respectively. The 2 cm ER rain follows the 3 cm rain. The 6 h unit hydrograph for the catchment is given, calculate the resulting DRH.

Time (h)	UH ordinates (m^3/s)
0	0
3	25
6	50
9	85

12	125
15	160
18	185
24	160
30	110
36	60
42	36
48	25
54	16
60	8
69	0

(C.S.V.T.U. Nov.-Dec., 2007)

Sol : First, the DRH_s due to 3 and 2 cm ER are calculated, by multiplying the ordinates of unit hydrograph by 3 and 2 respectively. Noting that the 2 cm DRH occurs after the 3 cm DRH, the ordinates of the 2 cm DRH are lagged by 6 hrs as shown column 4 of table. Column 3 and 4 give the proper sequence of the two DRH_s. Using the method of superposition, the ordinates of the resulting DRH are obtained by combining the ordinates of the 3 and 2 cm DRH_s at any instant. By this process the ordinates of the 5 cm DRH are obtained in column 5.

Time (h)	Ordinate of 6-h UH (m^3/s)	Ordinate of 3-cm DRH (col. 2) × 3	Ordinate of 2-cm DRH (col. 2 lagged by 6h) × 2	Ordinate of 5 cm DRH (col. 3 + col. 4) (m^3/s)	Remarks
1	2	3	4	5	6
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)	Interpolated value
24	160	480	370	850	
30	110	330	320	650	
36	60	180	220	400	
42	36	108	120	228	
48	25	75	72	147	
54	16	48	50	98	
60	8	24	32	56	
(66)	(2·7)	(8·1)	(16)	(24·1)	Interpolated value
69	0	0	(10·6)	(10·6)	Interpolated value
75	0	0	0	0	

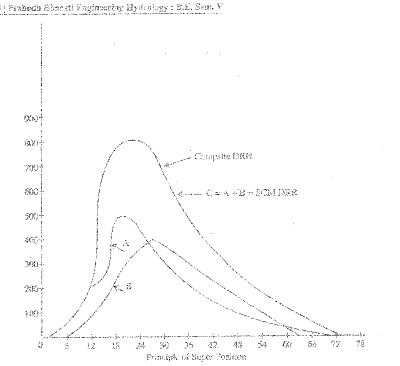

Fig.

Q. 9. Following are the ordinates of a storm hydrograph of a river during a catchment area of 423 km^2 due to a 6 h isolated storm. Derive the ordinates of 6 h unit hydrograph for the catchment.

Time from start of storm (h)	Discharge (m^3/s)
– 6	10
0	10
6	30
12	87·5
18	115·5
24	102·5
30	85
36	71
42	59
48	47·5
54	39
60	31·5
66	26

72	21·5
78	17·5
84	15
90	12·5
96	12
102	12

(C.S.V.T.U. Nov.-Dec., 2007)

Solution :

$$\text{Hence } N = (90 - 20) = 70\ h = 2·91 \text{ days}$$
$$N = 0·83\ (423)^{0·2}$$
$$= 2·78 \text{ days}$$

however, N = 2·91 days is adopted for convenience. A straight line joining A and B is taken as divide line for base flow separation. The ordinates of DRH are obtained by substracting the base flow from the ordinates of the storm hydrograph. The calculation are :

$$\text{Volume of } DRH = 60 \times 60 \times 6 \times (\text{sum of } DRH \text{ ordinates})$$
$$= 60 \times 60 \times 6 \times 587$$
$$= 12·68\ Mm^3$$
$$\text{Drainage area} = 423\ km^2 = 423\ Mm^2$$
$$\text{Runoff depth} = ER = \frac{12·68}{423}$$
$$= 0·03\ m = 3\ cm.$$

The ordinates of DRH (col. u) are divided by 3 to obtain the ordinates of the 6-h unit hydrograph.

Time from beginning of storm (h)	Ordinate of flood hydrograph (m^3/s)	Base flow (m^3/s)	Ordinate of DRH	Ordinate of 6 H unit hydrograph
1	2	3	4	5
– 6	10	10	0	0
0	10	10	0	0
6	30	10	20	6·7
12	87·5	10·5	77	25·7
18	111·5	10·5	101	33·7
24	102·5	10·5	101	33·7
30	85	11	74	24·7
36	71	11	60	20
42	59	11	48	16
48	47·5	11·5	36	12
54	39	11·5	27·5	9·2
60	31·5	11·5	20	
66	26	12	14	
72	21·5	12	9·5	

Time from beginning of storm (h)	Ordinate of flood hydrograph	Base flow	Ordinate of *DRH*	Ordinate of 6 *H* unit hydrograph
1	2	3	4	5
78	17·5	12	5·5	
84	15	12·5	2·5	
90	12·5	12·5	0	
96	12	12	0	
102	12	12	0	

Q. 10. The ordinates of a 4h U.H. of a basin of are 300 km² measured at 1h intervals are 6, 36, 66, 91, 106, 93, 79, 68, 58, 49, 41, 34, 27, 23, 17, 13, 9, 6, 3 and 1·5 m³/s respectively obtain the ordinates of 3h U.H for the basin using the S-curve technique.

(C.S.V.T.U. Nov., Dec., 2008)

Solution :
Column (1) = The time axis at a uniform interval of 1*h*.
Column (2) = The given ordinates of 4*h U.H*
Column (3) = The *S*-curve additions
Column (4) = Col. (2) + Col. (3) = The *S*-curve ordinates
Column (5) = S-curve lagged by 3 h (since D^1 = 3 h)
Column (6) = Col. (4) – Col. (5) = The difference graph.

$$\text{Column (7)} = \text{Col. (6)} \times \frac{4}{3}\left(\text{since } \frac{D}{D^1} = \frac{4}{3}\right)$$

= The ordinates of 3h U.H.

Time (t) hours	Ordinates of 4-h *UH* *U* (t) (m³/s)	S-curve additions *S* (t–4)	S-curve ordinates *S*(t)	S-curve lagged by 3h, *S*(t–3)	Difference graph	Ordinates of 3*h UH*
1	2	3	(4) = (2) + (3)	(5)	(6) = (4) – (5)	7 = (6) × (3)
0	0		0		0	0
1	6		6		6	8
2	36		36		36	48
3	66		66	0	66	88
4	91	0	91	6	85	113·3
5	106	6	112	36	76	101·3
6	93	36	129	66	63	84
7	79	66	145	91	54	72
8	68	91	159	112	47	62·7
9	58	112	170	129	41	54·7
10	49	129	178	145	33	44
11	41	145	186	159	27	36
12	34	159	193	170	23	30·7
13	27	170	197	178	19	25·3
14	23	178	201	186	15	20
15	17	186	203	193	10	13·3
16	13	193	206 *	197	9	12

17	9	197	206·5	201	5·5	7·3
18	6	201	207	203	4	5·3
19	3	203	207·5 *	206	1·5	2
20	1·5	206	208	206·5	0 **	0
21	0	206·5	208·5 *	207	0 **	

Q. 11. The effective rainfall hyetograph of a complex storm has a duration of 12*h*, with rainfall intensity of 2, 0·75 and 4 cm/h respectively in successive 4*h* periods. The ordinates of the corresponding direct runoff hydrograph read at 4*h* intervals are 160, 300, 570, 636, 404, 234, 105 and 48 m³/s respectively. Determine the ordinates of the 4*h* unit hydrograph using the deconvolution method. (C.S.V.T.U. Nov.-Dec., 2008; April-May, 2009)

Solution : From the given data, we have

$D = 4h$

$I_1 = 2{\cdot}0$ cm/h, $I_2 = 0{\cdot}75$ cm/h

$I_3 = 4$ cm/h

$P_1 = I_1 \cdot D = 2 \times 4 = 8$ cm

$P_2 = I_2 \cdot D = 0{\cdot}75 \times 4 = 3$ cm

$P_3 = I_3 \cdot D = 4 \times 4 = 16$ cm

$Q_1 = 160, Q_2 = 300 \ldots\ldots \text{and } Q_8 = 48$

Also $M = 3$, and $R = 8$. Therefore the 4*h* U.H. will have ($N = R + 1 - M = 8 + 1 - 3 = 6$) 6 ordinates which are computed as given below.

$$Q = P_1U_1 \text{ or } U_1 = \frac{Q_1}{P_1} = \frac{160}{8} = 20\,\text{m}^3/\text{s}$$

$$Q_2 = P_1U_2 \text{ or } P_2U_1 = 8U_2 + 3 \times 20 = 8U_2 + 60$$

$$U_2 = \frac{Q_2 - 60}{8} = \frac{300-60}{8} = 30\,\text{m}^3/\text{s}$$

$$Q_3 = P_1U_3 + P_2U_2 + P_3U_1 = 8U_3 + 3 \times 30 + 16 \times 20 = 8U_3 + 410$$

$$U_3 = \frac{Q_3 - 410}{8} = \frac{570-410}{8} = 20\,\text{m}^3/\text{s}$$

$$Q_4 = P_1U_4 + P_2U_3 + P_3U_2 = 8U_4 + 3 \times 20 + 16 \times 30 = 8U_4 + 540$$

$$U_4 = \frac{Q_4 - 540}{8} = \frac{636-540}{8} = 12\,\text{m}^3/\text{s}$$

$$Q_5 = P_1U_5 + P_2U_4 + P_3U_3 = 8U_5 + 3 \times 12 + 16 \times 20 = 8U_5 + 356$$

$$U_5 = \frac{Q_5 - 356}{8} = \frac{404-356}{8} = 6\,\text{m}^3/\text{s}$$

$$Q_6 = P_1U_6 + P_2U_5 + P_3U_4 = 8U_6 + 3 \times 6 + 16 \times 12 = 8U_6 + 210$$

$$U_6 = \frac{Q_6 - 210}{8} = \frac{234-210}{8} = 3\,\text{m}^3/\text{s}$$

Thus the ordinates of the 4 *h* unit hydrograph at 4 *h* intervals are 20, 30, 20, 12, 6 and 3 m³/s respectively.

Q. 12. The ordinates of 4 *h* unit hydrograph of a basin are tabulated below. Derive 2 *h* unit hydrograph ordinate from the 4 *h* unit hydrograph.

Time (h)	0	4	8	12	16	20	24	28	32	36	40	44
Ordinate or 4-*h* U.H.	0	20	80	130	150	130	90	52	27	15	5	0

(C.S.V.T.U. Nov.-Dec., 2009)

Solution : In this case the time interval of the ordinates of the given unit hydrograph should be at least 2 *h*. As the given ordinates are at 4 *h* intervals, the unit hydrograph is plotted and its ordinates at 2 *h* intervals determined. The ordinates are shown in column 2 of table. The *S*-curve additions and *S*-curve ordinates are shown in column 3 and 4 respectively. First, the *S*-curve ordinates corresponding to the time intervals equal to successive durations of the given unit hydrograph (in this case at 0, 4, 8, 12....*h*) are determined by following the method. Next the ordinates at intermediate intervals (at, *t* = 2, 6, 10, 14.....*h*) are determined by having another series of *S*-curve additions. To obtain a 2 *h* unit hydrograph the *S*-curve is lagged by 2 *h* (column 5) and this is subtracted from column 4 and the results listed in column 6. The ordinates in column 6 are now divided by *T/D* = 2/4 = 0·5, to obtain the required 2 *h* unit hydrograph ordinates, shown in column 7.

Time (h)	Ordinates of 4-*h UH* (m³/s)	S-curve additions (m³/s)	S-curve (Col. 2 + 3) (m³/s)	S-curve lagged by 2*h*	Col. 4 – Col. 5 *DRH* of $\left(\frac{2}{4}\right)$ = 0·5 cm	2 *h UH* ordinate Col. 6 (2/4)
1	2	3	4	5	6	7
0	0	—	0	—	0	0
2	8	—	8	0	8	16
4	20	0	20	8	12	24
6	43	8	51	20	31	62
8	80	20	100	51	49	98
10	110	51	161	100	61	122
12	130	100	230	161	69	138
14	146	161	307	230	77	154
16	150	230	380	307	73	146
18	142	307	449	380	69	138
20	130	380	510	449	61	122
22	112	449	561	510	51	102
24	90	510	600	561	39	78
26	70	561	631	600	31	62
28	52	600	652	631	21	42
30	38	631	669	652	17	34
32	27	652	679	669	10	20
34	20	669	689	679	10	(20) 15
36	15	679	694	689	5	(10) 10
38	10	689	699	694	5	(10) 6

40	5	694	699	699	(0)	(0) 3
42	2	699	701	699	(2)	(4) 0
44	0	699	699	701	(–2)	(–4) 0

Q. 13. The ordinates of 4 *h* unit hydrograph of a basin are tabulated below. Derives 8 *h* unit hydrograph from the 4 *h* unit hydrograph. Time (hour) 4 *h* UH ordinates m³/sec.

Time (h)	Ordinates
0	0
2	12·52
4	21·32
6	23·54
8	17·84
10	14·79
12	12·18
14	10·04
16	8·26
18	6·51
20	4·98
22	3·95
24	3·05
26	2·26
28	1·60
30	1·07
32	0·53

(C.S.V.T.U. April-May, 2010)

Solution : The necessary computations required to obtained the ordinates of 8 *h* unit hydrograph are given in Table :

Time (h)	Ordinates of without lage	4*h UH* in (m³/s) lagged by 4 *h*	Combined hydrograph m³/s	Ordinate of 8 *h U.H.* m³/s
(1)	(2)	(3)	(4) = (2) + (3)	(5) = (4)/2
0	0		0	0
2	12·52		12·52	6·26
4	21·32	0	21·32	10·66
6	23·54	12·52	36·06	18·03
8	17·84	21·32	39·16	19·58
10	14·79	23·54	38·33	19·17
12	12·18	17·84	30·02	15·01
14	10·04	14·79	24·83	12·42
16	8·26	12·18	20·44	10·22
18	6·51	10·04	16·59	8·30
20	4·98	8·26	13·24	6·62
22	3·95	6·51	10·46	5·23
24	3·05	4·98	8·03	4·02
26	2·26	3·95	6·21	3·11

28	1·60	3·05	4·65	2·33
30	1·07	2·26	3·33	1·67
32	0·53	1·60	2·13	1·07

Q. 14. Rainfall of magnitude 3·8 cm and 2·8 cm occurring on two consecutive 4-*h* durations on a catchment of area 27 km² produced the following hydrograph of flow at the outlet of the catchment. Estimate the rainfall excess and φ index.

Time from start of rainfall (h)	– 6	0	6	12	18	24	30	36	42	48	54	60	66
Observed flow (m³/s)	6	5	13	26	21	16	12	9	7	5	5	4·5	4·5

Solution : For using the simple straight line method of base flow separation by eqn.

$N = 0{\cdot}83 \times (27)^{0{\cdot}2} = 1{\cdot}6 \text{ days} = 38{\cdot}5\ h$

however, by inspection, DRH starts at *t* = 0, has the peak at *t* = 12 *h* and ends at *t* = 48 *h*. As *N* = 36 *h* appears to be more satisfactory than *N* = 38·5 *h*, in the present case *DRH* is assumed to exist from *t* = 0 to 48 *h*. A straight line base flow separation gives a constant value of 5 m³/s for the base flow.

$$\text{Area of } DRH = (6\times60\times60)\left[\frac{1}{2}(8)+\frac{1}{2}(8+21)+\frac{1}{2}(21+16)+\frac{1}{2}(16+11) + \frac{1}{2}(11+7)+\frac{1}{2}(7+4)+\frac{1}{2}(4+2)+\frac{1}{2}(2)\right]$$

$= 3600 \times 6\,(8 + 21 + 16 + 11 + 7 + 4 + 2)$

$= 1{\cdot}4904 \times 10^6\ \text{m}^3$

$$\text{Runoff depth} = \frac{\text{runoff volume}}{\text{catchment area}} = \frac{1{\cdot}4904\times10^6}{27\times10^6}$$

$= 0{\cdot}0552$ m

$= 5{\cdot}52$ cm = rainfall excess

Total rainfall $= 3{\cdot}8 + 2{\cdot}8 = 6{\cdot}6$ cm

Duration $= 8\ h$

$$\phi \text{ index} = \frac{6{\cdot}6 - 5{\cdot}52}{8} = 0{\cdot}135 \text{ cm/h}$$

Q. 15. Describe the analysis of the recession limb of a flood hydrograph ?

Ans. The recession limb, which extends from the point of inflection at the end of the crest segment to the commencement of the natural groundwater flow represents the withdrawal of water from the storage built up in the basin during the earlier phases of the hydrograph. The starting point of the recession limb, the point of inflection represents the condition of maximum storage. Since the depletion of storage takes place after the cessation of rainfall, the shape of this part of the hydrograph is independent of storm characteristics and depend entirely on the basin characteristics.

The storage of water in the basin exists as :

(i) surface storage, which includes both surface detention and channel storage.
(ii) interflow storage and,
(iii) groundwater storage, base-flow storage.

The recession of a storage can be expressed as :

$$Q_t = Q_0 K_r^t \quad \ldots(1)$$

in which Q_t is the discharge at a time *t* and Q_0 is the discharge at *t* = 0, K_r is a recession of value less than unity. Equation (1) can also be expressed in an alternative form of the exponential decay as

$$Q_t = Q_0 e^{-at} \quad \ldots(2)$$

where $a = -\ln K_r$

The recession constant K_r can be considered to be made up the three components to account for the three types of storages as

$$K_r = K_{rs} \cdot K_{ri} \cdot K_{rb}$$

where K_{rs} = recession constant for surface storage,
K_{ri} = recession constant for interflow and
K_{rb} = recession constant for base flow. Typically the value of these recession constants, when time *t* is in days, are

K_{rs} = 0·05 to 0·20 $\qquad$ K_{ri} = 0·50 to 0·85
K_{rb} = 0·85 to 0·99

when the interflow is not significant, K_{ri} can be assumed to be unity.

If suffixes 1 and 2 denote the conditions at two time instances t_1 and t_2.

$$\text{From eqn. (1)} \quad \frac{Q_1}{Q_2} = K_r^{(t_1-t_2)} \quad \ldots(3)$$

$$\text{or From eqn. (2)} \quad \frac{Q_1}{Q_2} = e^{-a(t_1-t_2)} \quad \ldots(4)$$

The storage S_t remaining at any time *t* is obtained as

$$S_t = \int_t^\infty Q_t\,dt = \int_t^\infty Q_0 e^{-at}\,dt = \frac{Q_t}{a} \quad \ldots(5)$$

Q. 16. Explain the term Rainfall Excess (*ER*). How is *ERH* of a storm obtained ?

Ans. Effective rainfall (also known as Excess Rainfall) (*ER*) is that part of the rainfall that becomes direct runoff at the outlet of the watershed. It is thus the total rainfall in a given duration from which abstractions such as infiltration and initial losses are subtracted. *ER* could be defined as that rainfall that is neither retained on the land surface nor infiltrated into the soil.

For purposes of correlating *DRH* with the rainfall which produced the flow, the hyetograph of the rainfall is also pruned by deducting the losses. The initial loss and infiltration losses are subtracted form it.

The resulting hyetograph is know as effective rainfall hyetograph (*ERH*). It is also known as excess rainfall hyetograph.

Both *DRH* and *ERH* represent the same total quantity but in different units. Since *ERH* is usually in cm/h plotted against time, the area of *ERH* multiplied by the catchment area gives the total volume of direct runoff which is the same as the area of *DRH*. The initial loss and infiltration losses are estimated based on the available data of the catchment.

Q. 17. Given below are the ordinates of a 6 *h* unit hydrograph for a catchment. Calculate the ordinates of the *DRH* due to a rainfall excess of 3·5 cm occurring in 6 *h*.

Time (h)	0	3	6	9	12	15	18	24	30	36	42	48	54	60	69
UH ordinate (m³/s)	0	25	50	85	125	160	185	160	110	60	36	25	16	8	0

Solution : The desired ordinates of the *DRH* are obtained by multiplying the ordinates of the unit hydrograph by a factor of 3·5 as in table. The resulting *DRH* are also the unit hydrograph. The intervals of coordinates of the unit hydrograph are not in any way related to the duration of the rainfall excess and can be any convenient value.

Time (h)	Ordinate of 6 h Unit hydrograph (m³/s)	Ordinate of 3·5 cm
(1)	(2)	(3) *DRH* (m³/s)
0	0	0
3	25	87·5
6	50	175
9	85	297·5
12	125	437·5
15	160	560
18	185	647·5
24	160	560
30	110	385
36	60	210
42	36	126
48	25	87·5
54	16	56
60	8	28
69	0	0

Q. 18. Derive the *S*-curve for the 4 *h* unit hydrograph given below :

Time (h)	0	4	8	12	16	20	24	28
Ordinate of 4-*h* UH (m³/s)	0	10	30	25	18	10	5	0

Solution : Computations are shown in table. In this table Col. 2 shows the ordinates of the 4-*h* unit hydrograph. Col. 3 gives the *S*-curve additions and Col. 4 gives the ordinates of the *S*-curve. The sequence of entry in Col. 3 is shown by arrows. Values of entries in Col. 4 is obtained by using eqn. *S* (*t*) = *U*(*t*) + *S*(*t*–*D*), by summing up of entries in Col. 2 and Col. 4 along each row.

Time in hours	Ordinate of 4-h	S-curve addition (m³/s)	Su-curve ordinate (m³/s) · (col. 2 + col. 3)
1	2	3	4
0	0		0
4	10	0	10
8	30	10	40
12	25	40	65
16	18	65	83
20	10	83	93
24	5	93	98
28	0	98	98

At *t* = 4 hours, ordinate of 4-*h UH* = 10 m³/s

S-curve addition = ordinate of 4-*h UH* @
(*t* = (4 – 4) = 0 hours) = 0
Hence *S*-curve ordinate Eqn.
S(*t*) = *U*(*t*) + *S*(*t*–*D*) = 10 + 0 = 10 m³/s
At *t* = 8 hours, ordinate of 4-*h UH* = 30 m³/s.
S-curve addition = ordinate of 4-*h UH* @
(*t* = (8 – 4) = 4 hours) = 10 m³/s
Hence S-curve ordinate eqn. = 30 + 10 = 40 m³/s
At *t* = 12 hours, ordinate of 4-*h UH* = 25 m³/s.
S-curve addition = ordinate of 4-*h UH* @
(*t* = (12 – 4) = 48 hours) = 40 m³/s
Hence *S*-curve ordinate eqn. = 25 + 40 = 65 m³/s.

This calculations is repeated for all time intervals till *t* = base with of *UH* = 28 hours.

Q. 19. A catchment of 200 hectares area has rainfalls of 7·5 cm, 2 cm and 5 cm in three consecutive days. The average φ index can be assumed to be 2·5 cm/day. Distribution-graph percentages of the surface runoff which extended over 6 days for every rainfall of 1-day duration are 5, 15, 40, 25, 10 and 5. Determine the ordinates of the discharge hydrograph by neglecting the base flow.

Solution :

Time interval (days)	Rainfall (cm)	Infiltration loss (cm)	Effective rainfall (cm)	Avg. distribution ratio (percent)	Distribution runoff for (rainfall excess) of 5 cm		0·25	Runoff cm	m³/s × 10²
0–1	7·5	2·5	5	5	0·250	0		0·250	5·75
1–2	2	2·5	0	15	0·750	0	0	0·75	17·3
2–3	5	2·5	2·5	40	2	0	0·125	2·125	49·1
3–4				25	1·250	0	0·375	1·625	37·62
4–5				10	0·500	0	1·00	1·50	34·7
5–6				5	0·250	0	0·625	0·875	20·2
6–7						0	0·250	0·250	5·79
7–8							0·125	0·125	2·89

[Runoff of 1 cm in 1 day = $\frac{200\times100\times100}{86400\times100}$ m³/s for 1 day = 0·23148 m³/s for 1 day.]

Q. 20. Explain a procedure of deriving a *D*-*h* unit hydrograph from the *IUH* of the catchment.

Ans. Consider an S-curve, designated as S_1, derived from a *D*-*h* unit hydrograph. In this the intensity of rainfall excess, *i* = 1/*D* cm/h. Let S_2 be another S-curve of intensity *i* cm/h. If S_1 is separated from S_2 by a time interval *dt* and the ordinates are subtracted, a *DRH* due to a rainfall excess of duration *dt* and magnitude *idt* = *dt*/*Dh* is obtained. A unit hydrograph of *dt* hours is obtained from this by dividing the above *DRH* by *idt*.

Thus the *dt*-*h* unit hydrograph will have ordinates equal to $\left(\frac{S_2 - S_1}{i\,dt}\right)$. As *dt* is made smaller, as $dt \to 0$, an *IUH* results. Thus for an *IUH*, the ordinate at any time *t* is

$$u(t) = \lim_{dt\to0}\left(\frac{S_2 - S_1}{i\,dt}\right) = \frac{1}{i}\frac{dS}{dt} \quad \ldots(1)$$

If *i* = 1, then $u(t) = dS/dt$. $\quad \ldots(2)$

where S' represents a S-curve of intensity 1 cm/h. Thus the ordinate of an IUH at any time t is the slope of the S-curve of intensity 1 cm/h at the corresponding time. Equation (1) can be used in deriving IUH approximately.

IUH_S can be derived in many other ways notably by (i) harmonic analysis (ii) Laplace transform (iii) Conceptual models.

Derivation of D-hour Unit hydrograph From IUH : For simple geometric forms of IUH, equation $Q(t) = \int_0^t u(t-\tau)\, I(\tau)\, d\tau$ can be used to derive a D-hour unit hydrograph.

From equation (2), $dS' = u(t)\, dt$

Integrating between two points 1 and 2

$$S'_2 - S'_1 = \int_{t_1}^{t_2} u(t)\, dt \quad ...(3)$$

If $u(t)$ is essentially linear within the range 1–2, then for small values of $\Delta t = (t_2 - t_1)$, by taking

$$u(t) = \bar{u}(t) = \frac{1}{2}[u(t_1) + u(t_2)]$$

$$S'_2 - S'_1 = \frac{1}{2}[u(t_1) + u(t_2)](t_2 - t_1) \quad ...(4)$$

But $(S'_2 - S'_1)/(t_2 - t_1)$ = ordinate of a unit hydrograph of duration $D_1 = (t_2 - t_1)$. Thus, in general terms, for small values of D_1, the ordinates of a D_1-hour unit hydrograph are obtained by the equation.

$$(D_1 - \text{hour } UH)_t = \frac{1}{2}[(IUH)_t + (IUH)_{t-D_1}] \quad ...(5)$$

Thus if two IUH_S are lagged by D_1-hour where D_1 is small and their corresponding ordinates are summed up and divided by two, the resulting hydrograph will be D_1-hour UH. After obtaining the ordinates of a D-hour unit hydrograph from eqn. (5), the ordinates of any D-hour UH can be obtained by the superposition method.

From accuracy considerations, unless the limbs of IUH can be approximated as linear, it is desirable to confine D_1 to a value of 1-hour or less.

Q. 21. In a stream the base flow is observed to be 30 m³/s on Feb. 1 and 23 m³s on Feb. 10. If there is no rain during February, estimate the base flow on Feb. 28 and the volume of water in groundwater storage on Feb. 1 and Feb. 28. Assume base flow recession curve of the stream can be described by eqn. $Q_t = Q_o K_r^{(t-t_o)}$.

Solution :

$$Q_o = 30 \text{ m}^3/\text{S} \qquad t_o = 1$$
$$Q_t = 23 \text{ m}^3/\text{S} \qquad t = 10$$
$$\frac{Q_t}{Q_o} = K_r^{(t-t_o)}$$
$$\frac{23}{30} = K_r^{(10-1)} = K_r^{9}$$
$$\therefore \quad K_r = 0.971$$
$$\text{when} \quad t = 28, \qquad Q_t = Q_o\,(0.971)^{(28-1)}$$
$$Q_t = 30 \times 0.971^{27} = 13.52 \text{ m}^3/\text{s}.$$

$\therefore$ The flow in the stream on Feb. 28 = 13·52 m³/s.

From eqn.

$$S_t = \frac{Q_t}{(-l_n K_r)} = \frac{Q_t}{-l n 0.971} = 33.98\, Q_t.$$

In the estimation of K_r a time unit of day has been used. Hence the storage computed from the above expression will be in cumec-days.

$$\text{Storage on Feb. 1} = 33.98 \times 30 = 1019.4 \text{ cumec–days}$$
$$= 88.08 \times 10^6 \text{ m}^3$$
$$= 88.08 \text{ Mm}^3$$
$$\text{Storage on Feb. 28} = 33.98 \times 13.52 = 459.41 \text{ cumec – days}$$
$$= 39.69 \times 10^6 \text{ m}^3$$
$$= 39.69 \text{ Mm}^3$$

Q. 22. The peak of flood hydrograph due to a 3-h duration isolated storm in a catchment is 270 m³/s. The total depth of rainfall is 5·9 cm. Assuming an average infiltration loss of 0·3 cm/h and a constant base flow of 20 m³/s, estimate the peak of the 3-h unit hydrograph (UH) of this catchment.

If the area of the catchment is 567 km² determine the base width of the 3-h unit hydrograph by assuming it to be triangular in shape. (C.S.V.T.U. April-May, 2011)

Solution :

Duration of rainfall excess = $3h$

Loss @ 0·3 cm/h for $3h$ = 0·9 cm

Total depth of rainfall = 5·9 cm

Rainfall excess = 5·9 – 0·9 = 5 cm.

Peak flow :

Peak of flood hydrograph = 270 m³/s

Base flow = 20 m³/s

Peak of DRH = 250 m³/s

$$\text{Peak of 3-}h \text{ unit hydrograph} = \frac{\text{Peak of } DRH}{\text{rainfall excess}} = \frac{250}{5} = 50 \text{ m}^3/\text{s}$$

Let B = base width of the 3-h UH in hours.

Volume represented by the area of UH = Volume of 1 cm depth over the catchment

Area of UH = (Area of catchment × 1 cm)

$$\frac{1}{2} \times B \times 60 \times 60 \times 50 = 567 \times 10^6 \times \frac{1}{100}$$
$$B = \frac{567 \times 10^4}{9 \times 10^4}$$
$$B = 63 \text{ hours.}$$

Q. 23. Derive a 3-h synthetic unit hydrograph of a basin with the following data : Basin area = 3000 km², Length of the main stream = 120 km; Distance from centroid of the basin to the outlet = 63 km. The synder's coefficients C_t and C_p may be assumed to be 1·60 and 0·64 respectively.

Solution :

$$t_p = C_t\,(LL_C)^{0.3}$$
$$= 1.6\,(120 \times 63)^{0.3}$$
$$t_p = 23.32\ h$$

$$D = t_p \times \frac{2}{11}$$
$$D = 4.24\ h$$
$$D' = 3h$$
$$t'_p = t_p + \frac{D'-D}{4} = 23.32 - 0.31 = 23.01\ h$$
$$q'_p = \frac{2.778\, C_p}{t'_p} = \frac{2.778 \times 0.64}{23.01} = 0.073 \text{ m}^3/\text{s/km}^2$$
$$Q'_p = A \cdot q'_p = 231.9 \text{ m}^3/\text{s}$$
$$T' = \frac{5.556}{q'_p} = \frac{5.556}{0.0773} = 71.87 \text{ h} \approx 72\,h$$
$$W_{50} = \frac{2.14}{(0.0773)^{1.08}} = 33.98 \text{ h} \approx 34h$$
$$W_{75} = \frac{1.22}{(0.0773)^{1.08}} = 19.37\,h$$

Q. 24. From the topographical map of a drainage basin the following quantities are measured: A = 3480 km², L = 148 km and L_C = 74 km. The 12 h unit hydrograph derived for the basin has a peak ordinate of 155 m³/s occurring at 40 h. Determine the coefficients C_t and C_p for the synthetic unit hydrograph of the basin.

Sol.

$$D' = 12h$$
$$t'_p = 40 - \frac{D'}{2} = 40 - 6 = 34h$$
$$t'_p = t_p + \frac{D'-D}{4}$$
$$D = \frac{2}{11} t_p$$
$$\therefore \quad 34 = t_p + \frac{12}{4} - \frac{1}{4}\left(\frac{2}{11} t_p\right)$$
$$t_p = 32.48h$$
$$C_t = \frac{t_p}{(LL_C)^{0.3}} = \frac{32.48}{(148 \times 74)^{0.3}} = 1.994$$
$$q'_p = \frac{Q'_p}{A} = \frac{155}{3480} = 0.04454$$
$$C_p = \frac{q'_p t'_p}{2.778}$$
$$C_p = \frac{0.04454 \times 34}{2.778}$$
$$= 0.545. \qquad \text{Ans.}$$

Q. 25. A basin having a drainage area of 2500 km² with L = 100 km and L_C = 50 km is a sub-basin of the catchment of 12 h unit hydrograph of 155 m³/s occurring at 40 h. Compute a 4 h synthetic unit hydrograph for this sub-basin.

Sol. The values of C_t = 1·994 and C_p = 0·545

$$t_p = C_t\left(LL_C\right)^{0.3}$$
$$= 1.994(100 \times 50)^{0.3}$$
$$= 25.67h$$
$$D = \frac{2}{11} t_p = \frac{2}{11} \times 25.67 = 4.67h$$
$$D' = 4h$$
$$t'_p = t_p + \frac{D'-D}{4} = 25.67 + \frac{4 - 4.67}{4} = 25.5h$$
$$q'_p = \frac{2.778\, C_p}{t'_p}$$
$$= \frac{2.778 \times 0.545}{25.5} = 0.0594 \text{ m}^3/\text{s}/\text{km}^2$$
$$Q_p = A \cdot q'_p = 2500 \times 0.0594$$
$$= 148.5 m^3/s$$
$$T' = \frac{5.556}{q'_p} = \frac{5.556}{0.0594}$$
$$= 93.5h$$
$$W_{50} = 2.14\left(q'_p\right)^{-1.08}$$
$$= \frac{2.14}{(0.0594)^{1.08}} = 45.2h$$
$$W_{75} = 1.22\left(q'_p\right)^{-1.08}$$
$$= \frac{1.22}{(0.0594)^{1.08}} = 25.7h. \qquad \text{Ans.}$$

Q. 26. Derive a 3h synthetic unit hydrograph of a basin with the following data : Basin area = 3000 km², Length of the main stream = 120 km, Distance from centroid of the basin to the outlet = 63 km. The snyder's coefficients C_t and C_p may be assumed to be 1·60 and 0·64 respectively.

Sol.

$$t_p = C_t(LL_C)^{0.3}$$
$$= 1.6(120 \times 63)^{0.3} = 23.32h$$
$$D = t_p \times \frac{2}{11} = 4.24h$$

$$D' = 3h$$
$$t'_p = t_p + \frac{D'-D}{4} = 23.32 - 0.31$$
$$= 23.01h$$
$$q'_p = \frac{2.778\, C_p}{t'_p}$$
$$= \frac{2.778 \times 0.64}{23.01} = 0.0773 \text{ m}^3/\text{s}/\text{km}^2$$
$$Q'_p = A \cdot q'_p = 231.9 \text{ m}^3/\text{s}.$$
$$T' = \frac{5.556}{q'_p}$$
$$= \frac{5.556}{0.0773} = 71.87h = 72h$$
$$W_{50} = \frac{2.14}{(0.0773)^{1.08}} = 33.98 \approx 34h$$
$$W_{75} = \frac{1.22}{(0.0773)^{1.08}} = 19.37h. \qquad \text{Ans.}$$

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Unit V

GROUND WATER

Syllabus : Introduction, Occurrence of ground water, Aquifer parameter, Ground water movement, Darcy's law, Permeability, steady and unsteady flow to wells in confined and unconfined aquifers, Ground-water exploration, Safe yield, Pumping test and recuperation test.

Introduction : Study of surface flow is equally important since about 30% of the world's fresh water resources exist in the form of groundwater. The surface water forms a critical input for the sustenance of life and vegetation in arid zones. Due to its important as a significant source of water supply, various aspects of groundwater dealing with the exploration, development and utilization have been extensively studied by workers from different disciplines, such as geology, geophysics, geochemistry, agricultural engineering, fluid mechanics and civil engineering and excellent treatises are available. This chapter confines itself to only an elementary treatment of the subject of groundwater as a part of engineering hydrology.

Q. 1. Define Aquifer ? (C.S.V.T.U. Nov.-Dec., 2007; Nov.-Dec., 2009)

Ans. Formations which contain groundwater and at the same time which are sufficiently permeable to transmit and yield water in usable quantities are called the aquifers. They may get recharged directly from above through the processes of precipitation and infiltration, or they may have the recharge area somewhere else on the earth's surface. The amount of water contained by the aquifer depends on the porosity of the aquifer formation while the amount of water that it can yield depends on its permeability.

Q. 2. Explain following terms :

(i) Porosity,

(ii) Specific yield. (C.S.V.T.U. Nov.-Dec., 2007; Nov.-Dec., 2009; April-May, 2010)

Ans. (i) Porosity : The ratio of volume of pore space, V_v to the volume of formation V is called the porosity, usually denoted by n.

Thus we have, $$n = \frac{V_v}{V}$$

In unconsolidated materials, the porosity depend on the shape and size distribution of the particles and their packing arrangement. The original porosity of a material is that which existed at the time the material was formed. Secondary porosity results from fractures and solution channels.

Original porosity can be measured in the laboratory using an undistributed sample. The sample is ovendried and its weight W_1 measured. It is then saturated with some liquid and its weight W_2 is again measured. Finally the saturated sample is immersed in a vessel containing the same liquid and the weight of the liquid displaced by the sample W_3 is noted. The weight of liquid required to saturate the sample, that is $(W_2 - W_1)$, divided by the weight of the liquid displaced by the saturated sample, that is W_3, is the porosity of the sample. Multiplication of this ratio with 100 gives the porosity by percentages. Secondary porosity cannot be measured without an impossibly large sample.

(ii) Specific yield : The specific yield of an aquifer is the ratio of the volume of water which will drain freely from the material to the volume of the formation. Therefore,

$$S_y = \frac{W_y}{V}$$

where W_y is the volume of water drained and S_y is the specific yield values of specific yield depend on grain size, shape and distribution of pores and compaction of the formation. Specific yield of fine-grained aquifers will be small, while coarse-grained material will have high specific yield. When material is drained, some water will always be retained in the small pore spaces under

capillary tension and therefore the volume of water drained will never be equal to the volume of pore spaces. That is $W_y < V_v$. Hence the specific yield is always less than porosity.

Q. 3. Explain following terms :

(i) Specific retention,

(ii) Storage coefficient. (C.S.V.T.U. Nov.-Dec., 2007; Nov.-Dec., 2009; April-May, 2010)

Ans. (i) Specific retention : The specific retention S_r is defined as the ratio of the volume of water retained W_r in the material to the total volume of the material, when a saturated material is dewatered. Thus :

$$S_r = \frac{W_r}{V}$$

Since W_r and W_y together constitute the total volume of water which is the total pore space, it is obvious that the specific retention and the specific yield are complimentary quantities whose sum represents the porosity of the aquifer. That means,

$$n = S_r + S_y$$

(ii) Storage Coefficient : The storage coefficient S is defined as the volume of water that an aquifer releases from or takes into 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 a confined aquifer. It is also known as storativity.

The storage coefficient of a confined of a confined aquifer will be very small in the range of 0·00005 to 0·005, indicating that large pressure changes over extensive areas are required to produce substantial water yields. The storage coefficient of unconfined aquifer on other hand is usually large and of the order 0·01 to 0·3.

Q. 4. Define the Permeability ? (C.S.V.T.U. Nov.-Dec., 2007)

Ans. The permeability of a material is a measure of its capacity to transmit water or any other fluid through its interstices. Groundwater is transmitted through aquifers at very small velocities ranging from 1 to 500 m/year. The laminar flow principles are shown to be applicable for the flow of groundwater in aquifers by Darcy. The Darcy's law states that the rate of flow per unit area of an aquifer is proportional to the gradient of the potential head measured in the direction of flow.

The Darcy's law may be written as :

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

where the constant of proportionality K is known as the hydraulic conductivity or the coefficient of permeability, V is the velocity of water through poreous medium and i or dh/dl is the hydraulic gradient.

Q. 5. Explain following terms :

(i) Transmissibility,

(ii) Aquitard. (C.S.V.T.U. Nov.-Dec., 2007; Nov.-Dec., 2009)

Ans. (i) Transmissibility : The transmissibility of an aquifer is 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 m²/day. If we consider a unit width of an aquifer of thickness b, the discharge through it is given by :

$$Q = \text{Area} \times \text{Velocity}$$
$$= (b \times 1) \times K\left(-\frac{dh}{dl}\right)$$
$$Q = Kb\left(-\frac{dh}{dl}\right) = T\left(-\frac{dh}{dl}\right)$$

Where $T = Kb$ is the transmissivity. When the hydraulic gradient equals unity, the discharge is equal to T itself. in other words, the transmissivity of an aquifer may be defined as the discharge through the aquifer of one metre width under a unit hydraulic gradient. The value of T ranges from

about 12 m²/day about 1200 m²/day depending on the type and thickness of the aquifer. It is usually evaluated from the pumping test.

(ii) Aquitard : It is a saturated geological formation which is poorly permeable and hence it does not yield water freely to wells. It may transmit vertically appreciable quantities of water to or from adjacent aquifers. Sandy clay is an example of a quitard.

Q. 6. A 30 cm well completely penetrates an unconfined aquifer of saturated depth 40 m. After a long period of pumping at a steady rate of 1500 lpm, the drawdown in two observation well 25 and 75 m from the pumping well were found to be 3·5 and 2m respectively. Determine the transmissivity of the aquifer. What is the drawdown at the pumping well ? (C.S.V.T.U. Nov.-Dec., 2007)

Solution :

(a)

$$Q = \frac{1500 \times 10^{-3}}{60}$$
$$Q = 0.025 \text{ m}^3/\text{s}$$
$$h_2 = 40 - 2 = 38 \qquad r_2 = 75 \text{ m}$$
$$h_1 = 40 - 3.5 = 36.5 \text{ m} \qquad r_1 = 25 \text{ m}$$
$$Q = \frac{\pi K(h_2^2 - h_1^2)}{\ln\frac{r_2}{r_1}}$$
$$0.025 = \frac{\pi K[(38)^2 - (36.5)^2]}{\ln\frac{75}{25}}$$
$$K = 7.823 \times 10^{-5} \text{ m/s}$$
$$T = KH$$
$$= 7.823 \times 10^{-5} \times 40$$
$$T = 3.13 \times 10^{-3} \text{ m}^2/\text{s}$$

(b) At the pumping well, r_w = 0·15 m

$$Q = \frac{\pi K(H_1^2 - h_w^2)}{\ln\frac{r_1}{r_w}}$$
$$0.025 = \frac{\pi \times 7.823 \times 10^{-5}[(36.5)^2 - h^2 w]}{\ln\frac{25}{0.15}}$$
$$h_w^2 = 811.84 \text{ and } h_w = 28.49 \text{ m}$$

drawdown at the well, S_w = 11·51 m

Q. 7. Discuss the method of ground water exploration ? (C.S.V.T.U. April-May, 2008; Nov.-Dec., 2008)

Ans. The occurrence and movement of groundwater are closely related to the geological formations. Therefore a through understanding of geological formations. Therefore a thorough understanding of geology of the area under investigation will be immence help to the hydrologists in search of groundwater. Apart from drilling, which is the direct method, there are some geophysical methods which can be used to detect the presence of groundwater. These include electrical resistivity method and seismic refraction method.

In the electrical resistivisty method, the resistivity of the formation is measured by sending electricity through it form the ground surface. In the seismic refraction method a seismic shock is produced by striking the ground with a heavy hammer and the velocity of travel of the shock wave is recorded. The resistivity measurements or the velocities of shock waves are then analysed and interpreted to know the characteristics of the formations and also the presence of water if any.

The technology of remote sensing has developed rapidly in the recent years. Photographs of earth taken from aircraft or satellite at various electromagnetic wavelength ranges can provide useful information regarding groundwater conditions.

Q. 8. What do you understand by confined and unconfined aquifers ? Explain with examples. **(C.S.V.T.U. April-May 2008; Nov.-Dec., 2008)**

Ans. **Unconfined Aquifers :** An aquifer having water table in it is called an unconfined aquifers. For this aquifer water table serves as the upper surface of zone of saturation while a less permeable or essentially impermeable layer defines its lower boundary. The impermeale layer underlying an unconfined aquifer may be made of clay, shale, solid limestone, igneous rock or bed rock. Unconfined aquifer is also known as a free aquifer, phreatic aquifer, watertable aquifer. The water table is an unconfined aquifer varies in undulating from and in slope, depending upon the areas of recharge and discharge, pumpage from wells and its permeability. A well driven into an unconfined aquifer will indicate a static water level corresponding to the water table level at that location.

Confined aquifer : When an aquifer is sandwiched between two layers of much less permeable material then it is called a confined aquifer. For example, a sandy layer between two clay layers, sandstone layer between two layers of shale etc. It is also known as a pressure aquifer or an artesian aquifer. Confined aquifers are completely filled with water and they do not have a free water table. They will have recharge area somewhere on the earth surface. The water in confined aquifers will be under pressure and the pressure condition in the aquifer is characterised by the piezometric. Surface, which is the surface obtained by connecting equilibrium water levels in the tubes. A horizontal surface in level with water table at the recharging area may be taken as the approximate piezometric surface of a confined aquifer. If the piezometric level at the place of the well is above the upper confining layer the static water level in the well will be above the aquifer. Such a well is called an artesian well. If the piezometric surface at the place of the well is above the ground level, the confined aquifer will yield a free-flowing well also known simply as a flowing well. A well penetrating into an unconfined aquifer, on the other hand, is called a water table well. The groundwater can also move to ground surface through natural passages like faults or sinkholes, where it then produces a spring.

Q. 9. Discuss the recuperation test in ground water. **(C.S.V.T.U. April-May, 2008; Nov.-Dec., 2008)**

Ans. This is not as accurate as the pumping test, but is resorted to when it is difficult to regulate the pump to maintain a constant level in the well. In this method, the water level in the well is depressed to some level below the normal water table level and the pumping is stopped. The water level in the well starts recuperating. The time taken by the water to rise to some other level is noted. From this data the specific yield of the well can be found out as explained below.

Let the water level be depressed by h_1 *m* through pumping. After a time of T hours let the depression head be h_2 *m*. Let h be the depression head in the well at a time t after the pumping stopped. Let dh be the change in depression head in a small time interval of dt.

Water flown into well = $Q \cdot dt = K \cdot h \cdot dt$

Volume change in water content of the well = $-A \cdot dh$

Equating these two,

$$K \cdot h \cdot dt = -A \cdot dh$$

Integrating the above equation between the limits :

$t = 0$ when $h = h_1$

$t = T$ when $h = h_2$

We obtain,
$$\frac{K}{A}\int_0^T dt = \int_{h_1}^{h_2} -\frac{dh}{h}$$

or
$$\frac{K}{A}[t]_0^T = [\ln h]_{h_1}^{h_2} = [\ln h]_{h_2}^{h_1}$$

$$\frac{K}{A} = \frac{1}{T}\ln\frac{h_1}{h_2}$$

or
$$C = \frac{2{\cdot}303}{T}\log\left(\frac{h_1}{h_2}\right) \quad ...(i)$$

The value of C obtained by substituting the recuperation test in eqn. (1) may now be used to estimate the safe yield of the open well for know working head from eqn. [$Q = C \cdot A \cdot H$].

Q. 10. A 30 cm diameter well completely penetrates a confined aquifer of permeability 45 m/day. The length of the strainer is 20 m. Under steady state of pumping the drawdown at the well was found to be 3 m and the radius of influence was 300 m. Calculate the discharge. **(C.S.V.T.U. April-May, 2009; Nov.-Dec., 2009)**

Solution :

$r_w = 0{\cdot}15$ m

$R = 300$ m

$S_w = 3$ m

$B = 20$ m

$$K = \frac{45}{60 \times 60 \times 24}$$

$K = 5{\cdot}208 \times 10^{-4}$ m/s

$T = KB = 10{\cdot}416 \times 10^{-3}$ m²/s

$$Q = \frac{2\pi T S_w}{\ln R/r_w}$$

$$= \frac{2\pi \times 10{\cdot}416 \times 10^{-3} \times 3}{\ln\frac{300}{0{\cdot}15}}$$

$= 0{\cdot}02583$ m³/s

$= 25{\cdot}83$ l ps

$Q = 1550$ l pm

Q. 11. The following data is obtained from a recuperation test on an open well of diameter 6·5 m.

(i) R.L. of water table = 237·8 *m*

(ii) R.L. water level in the well when the pumping is just stopped = 231·2 m

(iii) R.L. of water level in the well 2·5 hours after the pumping is stopped = 234·5 m.

Estimate the safe yield of the well, if the working head is 3m. **(C.S.V.T.U. April-May, 2009)**

Solution :

$h_1 = 237{\cdot}8 - 231{\cdot}2 = 6{\cdot}2$ m

$h_2 = 237{\cdot}8 - 234{\cdot}5 = 3{\cdot}3$ m

$T = 2{\cdot}5$ h

$$C = \frac{2{\cdot}303}{T}\log\left(\frac{h_1}{h_2}\right)$$

$$= \frac{2{\cdot}303}{2{\cdot}5}\log\left(\frac{6{\cdot}2}{3{\cdot}3}\right)$$

$C = 0{\cdot}2523\ h^{-1}$

$Q = CAH$

$$= 0{\cdot}2523 \times \left(\frac{\pi}{4} \times 6{\cdot}5 \times 6{\cdot}5\right) \times 3$$

$= 25.17$ m³/h

$Q = 6{\cdot}98$ lit/s

Q. 12. Derive an expression for the steady state discharge of well fully penetrating into a confined aquifer. **(C.S.V.T.U. Nov.-Dec., 2009; April-May, 2011)**

Ans. The flow around a well penetrating fully into a confined aquifer of thickness '*b*' under steady state conditions. In this case of the depth of flow remains constant everywhere. The discharge flowing into the well through a section which is situated at a radial distance r from the well becomes.

$$Q = 2\pi\ rbk \cdot \frac{dh}{dr}$$

$$dh = \frac{Q}{2\pi bK} \cdot \frac{dr}{r}$$

Integrating the above equation for the known boundary conditions at the two observation wells.

$$h_1 - h_2 = \frac{Q}{2\pi Kb}\ln\left(\frac{r_1}{r_2}\right)$$

$$Q = \frac{2\pi T(h_1 - h_2)}{\ln\left(\frac{r_1}{r_2}\right)}$$

where $T = Kb$ is the transmissivity of the aquifer.

In terms of drawdowns in the wells

$$Q = \frac{2\pi T(S_2 - S_1)}{\ln\left(\frac{r_1}{r_2}\right)}$$

In the absence of observation wells, utilising the boundary conditions at the well,

$$Q = \frac{2\pi T(H - h_w)}{\ln\left(\frac{R}{r_w}\right)}$$

where h_w and r_w are the height of water in the well and radius of the well respectively and R is the radius of influence. Since $(H - h_w)$ represents the drawdown in the well S_w, the discharge may also be written as :

$$Q = \frac{2\pi T S_w}{\ln\left(\frac{R}{r_w}\right)}$$

Q. 13. Short notes drawdown ? **(C.S.V.T.U. Nov.-Dec., 2009)**

Ans. The drop in the water table elevation at any point from its previous static level is called drawdown.

Q. 14. Derive an expression for the steady state of discharge condition from a well penetrating an unconfined aquifer. Also state the limitations of Deputies assumptions ? **(C.S.V.T.U. April-May, 2010)**

Ans. The thickness of aquifer is H and the well fully penetrates the aquifer. If water is pumped at a constant rate from the well, a gradient in the water table towards the well is created

which results in a depressing from of the water table. This is called the cone of depression. In practice this condition is rarely fulfilled and for the case of analysis a steady state flow is assumed if the changes in water table elevation have become negligible with time. The decrease in the water level at the well is called the drawdown. If the drawdown is small compared to the thickness of the aquifer, the streamlines of the flow to the well may be assumed to the horizontal.

In a steady state radial flow, the depth of flow at any radial distance r from the well is h and the area of flow at this section is $2\pi rh$. According to Darcy's law the velocity of flow V is given by $V = Ki$, where i is the hydraulic gradient. Since the tangement of the water table is taken as hydraulic gradient, the velocity at this section becomes $K \cdot \frac{dh}{dr}$ and the discharge is given by

$$Q = \text{Area} \times \text{Velocity}$$

$$= 2\pi rh \cdot K \cdot \frac{dh}{dr}$$

or
$$h \cdot dh = \frac{Q}{2\pi K} \cdot \frac{dr}{r}$$

Integration of the above equation with the known boundary conditions at the two observation bores yields.

$$\int_{h_1}^{h_2} h\ dh = \frac{Q}{2\pi K}\int_{r_1}^{r_2}\frac{dr}{r}$$

$$\frac{(h_1^2 - h_2^2)}{2} = \frac{Q}{2\pi K} \cdot \ln\frac{(r_1)}{(r_2)}$$

or
$$Q = \frac{\pi K(h_1^2 - h_2^2)}{\ln\left(\frac{r_1}{r_2}\right)}$$

Where h_1 and h_2 are the water levels in the two observation wells located at the radial distances r_1 and r_2 respectively from the main well. The radius at which the cone of depression just commences is known as the radius of influence denoted by R. If the radius of influence is known, the discharge can be computed, even in the absence of observation wells using the boundary condition at the well. That is

$$Q = \frac{\pi K(H^2 - h_w^2)}{\ln\left(\frac{R}{r_w}\right)}$$

where h_w and r_w are the water level in the well and radius of well, respectively.

But $K(H^2 - h_w^2) = \frac{2K(H + h_w)}{2} \cdot (H - h_w)$ and $(H - h_w)$ is nothing but the drawdown in the well whereas $\frac{(H + h_w)}{2}$ may be taken as the average thickness of the aquifer.

Therefore $K(H^2 - h_w^2) = 2T \cdot S_w$, where T is the average transmissivity of the aquifer and S_w is the drawdown in the well.

Now the discharge can also be expressed as :

$$Q = \frac{2\pi T S_w}{\ln\left(\frac{R}{r_w}\right)}$$

The following empirical equation may sometimes be useful to predict the radius of influence R.

$$R = 3000\ S_w\sqrt{K}$$

where S_w is in M and K is in m/s.

Dupuit-Assumption :

(1) The flow is horizontal and uniformly distributed in a vertical section.

(2) The velocity of flow is proportional to the tangent of the hydraulic gradient instead of sine of the hydraulic gradient.

Q. 15. When 3·68 million m³ of water was pumped out from an unconfined aquifer of 6·2 km² areal extent, the water table was observed to go down by 2·6 m. What is the specific yield of the aquifer ? During a monsoon season if the water table of the same aquifer goes up by 10·8 m what is the volume of recharge ?

Solution :

Water released from the aquifer = $(6{\cdot}2 \times 10^6) \times 2{\cdot}6 \times S_y$

Water pumped out = $3{\cdot}68 \times 10^6$ m³

Equating these two quantities $S_y = \frac{3{\cdot}68}{6{\cdot}2 \times 2{\cdot}6} = 0{\cdot}02283$

∴ Specific yield of the aquifer = 0·2283 or 22·83%

Volume of recharge $= 6{\cdot}2 \times 10^6 \times 10{\cdot}8 \times S_y$

$= 6{\cdot}2 \times 10^6 \times 10{\cdot}8 \times 0{\cdot}2283$

$= 15{\cdot}287$ million m³

Q. 16. An unconfined aquifer has a thickness of 30 m. A fully penetrating 20 cm diameter well in this aquifer is pumped at a rate of 35 lit/s. The drawdown measured in two observation well located at distance 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 :
$$Q = \frac{\pi K(h_1^2 - h_2^2)}{\ln\left(\frac{r_1}{r_2}\right)}$$

Or
$$K = \frac{Q \ln\left(\frac{r_1}{r_2}\right)}{\pi(h_1^2 - h_2^2)}$$

Here, $Q = 35$ lit/s $= 0{\cdot}035$ m³/s

$r_1 = 100$ m; $r_2 = 10$ m

$\ln\left(\frac{r_1}{r_2}\right) = 2{\cdot}302585$

$H = 30$ m

$S_1 = 0{\cdot}5$ m

$S_2 = 7{\cdot}5$ m

$h_1 = H - S_1$

$= 30 - 0{\cdot}5$

$h_1 = 29{\cdot}5$ m

$h_2 = H - S_2$

$= 30 - 7{\cdot}5$

$h_2 = 22{\cdot}5$ m

$$\therefore \quad K = \frac{0{\cdot}035 \times 2{\cdot}302585}{\pi(29{\cdot}5 + 22{\cdot}5)(29{\cdot}5 - 22{\cdot}5)}$$

$K = 7{\cdot}04745 \times 10^{-5}$ m/s

$K = 6{\cdot}089$ m/day

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

Then
$$Q = \frac{\pi K(H^2 - h_1^2)}{\ln\left(\frac{R}{r_1}\right)}$$

$$\ln\left(\frac{R}{r_1}\right) = \frac{\pi K(H^2 - h_1^2)}{Q}$$

$$= \frac{\pi \times 7{\cdot}04745 \times 10^{-5}(30^2 - 29{\cdot}5^2)}{0{\cdot}035}$$

$= 0{\cdot}1882$

$\frac{R}{r_1} = 1{\cdot}207$

$R = 1{\cdot}207 \times 100$

$R = 120{\cdot}7$ m

Q. 17. A well of 0·5 m diameter penetrates fully into a confined aquifer of thickness 20 m and hydraulic conductivity 8·2 × 10⁻⁴ m/s. What is the maximum yield expected from this well if the drawdown in the well is not to exceed 3 m. The radius of influence may be taken as 260 m.

Solution :
$$Q = \frac{2\pi T S_w}{\ln\left(\frac{R}{r_w}\right)}$$

$T = K \cdot b$

$= 8{\cdot}2 \times 10^{-4} \times 20$

$T = 0{\cdot}0164$ m²/s

$S_w = 3$ m;

$\frac{R}{r_w} = \frac{260}{0{\cdot}25}$

$\frac{R}{r_w} = 520$

$\ln\left(\frac{R}{r_w}\right) = 6{\cdot}25383$

$$\therefore \quad Q = \frac{2\pi \times 0{\cdot}0164 \times 3}{6{\cdot}25383}$$

$= 0{\cdot}04943$ m³/s

$Q = 49{\cdot}43$ lit/s

Q. 18. A pumping test was carried out on a new irrigation bore well penetrating fully into a confined aquifer at a rate of 22 lit/s. The drawdown measured in an observation well located at 45·7 m from the pumping well during the test is as given below. Determine T and S of the aquifer, using Cooper Jacob method.

Time t in hours	0·5	1·8	2·7	5·4	9	12	18	30	54
Drawdown S in m	0·091	0·294	0·382	0·55	0·701	0·785	0·911	1·06	1·24

Solution :

$Q = 22$ lit/S

$Q = 0{\cdot}022$ m³/S

$$T = \frac{2{\cdot}3026\,Q}{4\pi\Delta S}$$

$$T = \frac{2{\cdot}3026 \times 0{\cdot}022}{4\pi \times 0{\cdot}68}$$

$T = 5{\cdot}928 \times 10^{-3}$ m²/s

$T = 512{\cdot}2$ m²/day

$$S = \frac{2{\cdot}246\,T_{t_0}}{r^2}$$

$t_0 = 0{\cdot}8\ h = 2880$ seconds

$r = 45{\cdot}7$ m

$$\therefore \quad S = \frac{2{\cdot}246 \times 5{\cdot}928 \times 10^{-3} \times 2880}{45{\cdot}7 \times 45{\cdot}7}$$

$S = 0{\cdot}01836$

Q. 19. A 30 cm diameter well completly penetrates a confined aquifer of permeability 45 m/day. The length of the strainer is 20 m. Under steady state of pumping the drawdown at the well was found to be 3 m and the radius of influence was 300 m. Calculate the discharge.

Solution :

$r_w = 0{\cdot}15$ m

$R = 300$ m

$S_w = 3$ m

$B = 20$ m

$$K = \frac{45}{60 \times 60 \times 24}$$

$K = 5{\cdot}208 \times 10^{-4}$ m/s

$T = KB$

$T = 10{\cdot}416 \times 10^{-3}$ m²/s

$$Q = \frac{2\pi T S_w}{\ln R/r_w}$$

$$= \frac{2\pi \times 10{\cdot}416 \times 10^{-3} \times 3}{\ln\frac{300}{0{\cdot}15}}$$

$Q = 0{\cdot}02583$ m³/s

$Q = 25{\cdot}83$ lps

$Q = 1550$ *l* pm

Q. 20. A well is located in a 25 m confined aquifer of permeability 30 m/day and storage coefficient 0·005. If the well is being pumped at the rate of 1750, lpm, calculate the drawdown at a distance of (a) 100 m (b) 50 m from the well after 20 *h* of pumping.

Solution :

(a)
$$T = KB$$

$$= \frac{30}{86400} \times 25$$

$T = 8{\cdot}68 \times 10^{-3}$ m²/s

$$u = \frac{r^2 S}{4Tt} = \frac{(100)^2 \times (0{\cdot}005)}{4 \times (8{\cdot}68 \times 10^{-3}) \times (20 \times 60 \times 60)} = 0{\cdot}02$$

$$W(u) = -0{\cdot}5772 - \ln(0{\cdot}02) + 0{\cdot}02 - \frac{(0{\cdot}02)^2}{2{\cdot}2!} + \frac{(0{\cdot}02)^3}{3{\cdot}3!}$$

$W(u) = 3{\cdot}3547$

$$S_{100} = \frac{Q}{4\pi T}W(u)$$

$$= \left(\frac{1{\cdot}750}{60}\right) \times \frac{1}{4\pi(8{\cdot}68 \times 10^{-3})} \times 3{\cdot}3547$$

$= 0{\cdot}897\ m$

(b)
$$r = 50\ m,\ u = \frac{(50)^2 \times (0{\cdot}005)}{4 \times (8{\cdot}68 \times 10^{-3}) \times (20 \times 60 \times 60)}$$

$u = 0{\cdot}005$

$W(u) = -0{\cdot}5772 - \ln 0{\cdot}005$

$= 4{\cdot}726$

$$S_{50} = \left(\frac{1{\cdot}750}{60}\right) \times \frac{1}{4\pi(8{\cdot}68 \times 10^{-3})} \times 4{\cdot}726$$

$S_{50} = 1{\cdot}264\ m$

Q. 21. Describe the well loss ?

Ans. The total drawdown at the well S_w, can be considered to be made up of three parts :

(1) Head drop required to cause laminar porous media flow, called formation, loss, S_{wL}.

(2) Drop of piezometric head required to sustain turbulent flow in the region nearest to the well where the Reynolds number may be larger than unity S_{wt}.

(3) Head loss through the well screen and casing S_{wc} of these three,

$$S_{wL} \propto Q \text{ and } (S_{wt} \text{ and } S_{wc}) \propto Q^2$$

$$\text{thus } S_w = C_1Q + C_2 \propto Q^2$$

Ans.

Q. 22. During the recuperation test of a 4 m open wall a recuperation of the depression head from 2·5 m to 1·25 m was found to take place in 90 minutes. Determine the (i) specific capacity per unit well area, (ii) yield of the well for a safe drawdown of 2·5 m, (iii) what would be the yield from a well of 5 m diameter for a drawdown of 2·25 m ?

Solution : $A = \frac{\pi}{4} \times (4)^2$

$A = 12{\cdot}566\ m^2$

$\frac{K_o}{A} = \frac{1}{T_r} ln \frac{H_1}{H_2}$

Here $T_r = 90\ min = 1{\cdot}50\ h$

$H_1 = 2{\cdot}5\ m$

$H_2 = 1{\cdot}25\ m$

(i) $K_s = \frac{K_o}{A} = \frac{1}{1{\cdot}5} ln \frac{2{\cdot}5}{1{\cdot}25} = 0{\cdot}462\ h^{-1}$

(ii) $Q = K_s \cdot A \cdot H$

$= 0{\cdot}462 \times 12{\cdot}566 \times 2{\cdot}5$

$Q = 14{\cdot}52\ m^3/h$

(iii) $A_2 = \frac{\pi}{4}(5)^2$

$A_2 = 19{\cdot}635$

$Q = K_s \times A_2 \times H_2$

$Q = 0{\cdot}462 \times 19{\cdot}635 \times 2{\cdot}25$

$Q = 20{\cdot}415\ m^3/h$

Q. 23. A undisturbed rock sample has on over dry weight of 0·655 kg. After saturation with kerosene its weight is 0·732 kg. It is then immersed in kerosene and found to displace 0·301 kg. What is the porosity of the sample ?

Sol. Over-dry weight $W_1 = 0{\cdot}655$ kg.

Weight of saturated sample $W_2 = 0{\cdot}732$ kg.

Weight of kerosene required to saturate the sample $= (W_2 - W_1)$

$= 0{\cdot}732 - 0{\cdot}655 = 0{\cdot}077$ kg.

Weight of kerosene displaced by the saturated sample $W_3 = 0{\cdot}301$ kg.

Porosity of the sample $n = \frac{(W_2 - W_1)}{W_3}$

$= \frac{0{\cdot}077}{0{\cdot}301}$

$= 0{\cdot}2558$

$= 25{\cdot}58\%$. Ans.

Solved Question Paper

B.E. (5th Semester) Examination, Nov.-Dec., 2007

(Branch : Civil Engineering)

ENGINEERING HYDROLOGY

Time : Allowed 3 Hours *Maximum Marks : 80*

Minimum Pass Marks : 28

Note : Attempt all questions. Graph paper is required in this subject.

Q. 1. (a) **Define Hydrology.**

Ans. Refer to Q. No. 1 of Unit 1.

(b) **Describe Hydrologic cycle with neat sketch.**

Ans. Refer to Q. No. 2 of Unit 1.

(c) **What are the practical applications of hydrology ?**

Ans. Refer to Q. No. 3 of Unit 1.

(d) **Write a note on climate and weather seasons in India.**

Ans. Refer to Q. No. 4 of Unit 1.

Q. 2. (a) **What are the different forms of precipitation ?**

Ans. Refer to Q. No. 2 of Unit 2.

Attempt any two questions. (7 marks each)

(b) **Describe any one recoding type raingauge.**

Ans. Refer to Q. No. 3 of Unit 2.

(c) **Raingauge station *X* did not function for a part of a month during which a storm occurred. The storm produced rainfalls of 84, 70 and 96 mm at three surrounding stations *A*, *B* and *C* respectively. The normal annual rainfalls at the stations *X*, *A*, *B* and *C* are respectively 770, 882, 736 and 944 mm. Estimate the missing storm rainfall at station *X*.**

Ans. Refer to Q. No. 5 of Unit 2.

(d) **A catchment has six rain gauge stations. In a year, the annual rainfall recorded by the gauges are as follows :**

Stations	*A*	*B*	*C*	*D*	*E*	*F*
Rainfall (cm)	82·6	102·9	180·3	110·3	98·8	136·7

For a 10% error in the estimation of the mean rainfall, calculate the optimum number of stations in the catchment.

Ans. Refer to Q. No. 6 of Unit 2.

Q. 3. (a) **Define infiltration.**

Ans. Refer to Q. No. 1 of Unit 3.

Attempt any two questions. (7 marks each)

(b) **A storm with 10 cm precipitation produced a direct runoff of 5·8 cm. Given the time distribution of the storm as below, estimate the ϕ index of the storm :**

Time (*h*)	1	2	3	4	5	6	7	8
Incremental Rainfall	0·4	0·9	1·5	2·3	1·8	1·6	1·0	0·5

(c) **Describe the different components of runoff.**

Ans. Refer to Q. No. 4 of Unit 3.

(d) **Explain the different empirical equations for runoff calculation.**

Ans. Refer to Q. No. 5 of Unit 3.

Q. 4. (a) **Define unit hydrograph.**

Ans. Refer to Q. No. 1 of Unit 4.

Attempt any one question. (7 marks each)

(b) **Two storms each of 6 hours duration and having rainfall excess values of 3 and 2 cm respectively. The 2 cm ER rain follows the 3 cm rain. The 6*h* unit hydrograph for the catchment is given, calculate the resulting DRH.**

Time (*h*)	UH ordinate (m^3/s)
0	0
3	25
6	50
9	85
12	125
15	160
18	185
24	160
30	110
36	60
42	36
48	25
54	16
60	8
69	0

Ans. Refer to Q. No. 8 of Unit 4.

(c) **Following are the ordinates of a storm hydrograph of a river draining a catchment area of 423 km^2 due to 6*h* isolated storm. Derive the ordinates of 6*h* unit hydrograph for the catchment.**

Time form start of strom (*h*)	Discharge (m^3/s)
–6	10
0	10
6	30
12	87·5
18	115·5
24	102·5
30	85·0
36	71·0
42	59·0
48	47·5
54	39·0
60	31·5
66	26·0
72	21·5
78	17·5
84	15·0
90	12·5
96	12·0
102	12·0

Ans. Refer to Q. No. 9 of Unit 4.

Q. 5. (a) **Define Aquifer.**

Ans. Refer to Q. No. 1 of Unit 5.

Attempt any two questions. (14 marks each)

(b) **Explain following terms :**

Porosity, specific yield, specific retention, storage coefficient, permeability, transmissibility, aquitard.

Ans. Refer to Q. No. 2, 3, 4 and 5 of Unit 5.

(c) **A 30 cm well completely penetrates an unconfined aquifer of saturated depth 40 m. After a long period of pumping at a steady rate of 1500 1pm, the draw down in two observation wells 25 and 75 m from the pumping well were found to be 3·5 and 2 m respectively. Determine the transmissivity of the aquifer. What is the drawdown at the pumping well ?**

Ans. Refer to Q. No. 6 of Unit 5.

Solved Question Paper

B.E. (5th Semester) Examination, April-May, 2008

Note : All questions carry equal marks. Attempt three questions from each unit.

Q. 1. (a) **What is Hydrology ?**

Ans. Refer to Q. No. 1 of Unit 1.

(b) **Discuss the Hydrology Cycle and necessity of Hydrology data.**

Ans. Refer to Q. No. 2 of Unit 1.

(c) **Discuss the climate and weather seasons in India.**

Ans. Refer to Q. No. 4 of Unit 1.

(d) **Write short notes on the following :**

(i) Hydrometeorology.

(ii) Air masses and fronts.

Ans. Refer to Q. No. 5 of Unit 1.

Q. 2. (a) **What is precipitation ?**

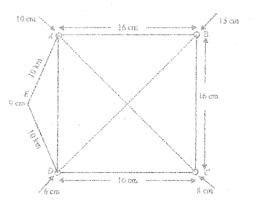
Ans. Refer to Q. No. 1 of Unit 2.

(b) **Describe different types of recording and Non-recording rain gauges. What is the difference between continuous and discoutinuous types gauges ?**

Ans. Refer to Q. No. 3 of Unit 2.

Or

(c) **The sketch below represents catchment area with the precipitations observed in a year. Calculate the mean precipitation by Thiessen method and check the result roughly by the arithmetic mean method.** 10



Q. 3. (a) **Discuss the infiltration indices :**

Ans. Refer to Q. No. 6 of Unit 3.

(b) **List the method of working out run off from a drainage area and describe any two methods in detail.**

Ans. Refer to Unit 3.

Or

(c) **The maximum values of 24 hr. rainfall at a rain gauge expressed in cm from 1930 to 1959 are given below :**

12·7	13·2	12·8	11·6	16·9	17·20	14·00	14·20	17·80	18·80
11·70	13·30	13·6	13·90	14·40	14·70	8·40	12·50	11·20	20·70
19·10	19·70	18·90	17·40	15·80	14·90	18·30	17·70	18·60	19·20

Estimate the maximum rainfall having a recurrent interval of (i) 10 years and (ii) 50 years.

Ans. Refer to Unit 3.

(d) **Discuss the rational method of estimating runoff.**

Ans. Refer to Q. No. 7 of Unit 3.

Q. 4. (a) **What is unit hydrograph ?**

Ans. Refer to Q. No. 1 of Unit 4.

(b) **Discuss the characteristics of the hydrograph.**

Ans. Refer to Q. No. 2 of Unit 4.

(c) **Find out the ordinates of a storm hydrograph resulting from a 3 hr. storm with rainfall of 2·0, 6·75 and 3·75 cm during subsequent 3 hr. intervals. The ordinates of unit hydrograph are :**

Hr.	OUH (cm^3)
3	0
6	110
9	365
12	500
15	390
18	310
21	250
24	235
3	175
6	130
9	95
12	65
15	40
18	22
21	10
24	0

Assume an initial loss of 5 mm, infiltration index of 2·5 mm/hr and base flow of cumecs. 10

Ans. Refer to Unit 4.

(d) **Discuss the applications of unit hydrograph.**

Ans. Refer to Unit 4.

Q. 5. (a) **Discuss Darcy's law and its use for ground water.**

Ans. Refer to Unit 5.

(b) **Discuss the method of ground water exploration.**

Ans. Refer to Q. No. 7 of Unit 5.

Or

(c) **What do you understand by confined and unconfined aquifers ? Explain with examples.** 10

Ans. Refer to Q. No. 8 of Unit 5.

(d) **Discuss the recuperation test in ground water.**

Ans. Refer to Q. No. 9 of Unit 5.

Solved Question Paper

B.E. (5th Semester) Examination, Nov.-Dec., 2008

Note : All questions carry equal marks. Attempt for 16 marks for each unit.

Q. 1. (a) **What do you understand by Hydrologic equation ?**

Ans. Refer to Q. Unit 1.

(b) **Describe the Hydrologic Cycle. Explain briefly the man's interference in various parts of this cycle.**

Ans. Refer to Q. No. 2 of Unit 1.

(c) **Discuss the hydrological water budget with the aid of example.**

Ans. Refer to Q. No. 6 of Unit 1.

(d) **Write a note on climate and weather seasons in India.**

Ans. Refer to Q. No. 4 of Unit 1.

Q. 2. (a) **Define probable maximum precipitation.**

Ans. Refer to Q. No. 7 of Unit 2.

(b) **Describe the different method of determining the average precipitate on over a catchment due to a storm.**

Ans. Refer to Q. No. 8 of Unit 2.

(c) **There are four rain gauge stations existing in the catchment of a river. The average annual rainfall values at these stations are 800, 620, 400 and 540 mm respectively.**

(i) Determine the optimum number of rain gauges in the catchment, if it is desired to limit the error in the mean value of rainfall in the catchment to 10%.

(ii) How many more gauges will then be required to be installed ?

Ans. Refer to Q. No. 9 of Unit 2.

(d) **A catchment has six rain gauge stations. In a year, the annual rainfalls recorded by the gauges are as follows :**

Station	A	B	C	D	E	F
Rainfall (cm)	82·6	102·9	180·3	110·3	98·8	136·7

For a 10% error in the estimation of the mean rainfall, calculate the optimum number of stations in the catchment.

Q. 3. (a) **Discuss the infiltration medics.**

Ans. Refer to Q. No. 6 of Unit 3.

(b) **List the methods of working out runoff from a drainage area and describe any two methods in details.**

Ans. Refer to Unit 3.

(c) **A 5*h* storm produced rainfall intensities of 7, 18, 25, 12, 10 and 3 mm/*h* in successive one hour intervals over a basin of 800 sq. km. The resulting runoff is observed to be 2640 hectare-metres. Determine ϕ-index for the basin.**

Ans. Refer to Q. No. 8 of Unit 3.

(d) **Discuss the rational method of estimating runoff.**

Ans. Refer to Q. No. 7 of Unit 3.

Q. 4. (a) **Define hydrograph.**

Ans. Refer to Unit 4.

(Attempt any one question)

(b) **The ordinates of a 4th hydrograph of a basin of area 300 km^2 measured at 1*h* intervals are 6, 36, 66, 91, 106, 93, 79, 68, 58, 49, 41, 34, 27, 23, 17, 13, 9, 6, 3 and 1·5 m^3/s respectively. Obtain the ordinates of a 3*h* unit hydrograph for the basin using the S-curve technique.**

Ans. Refer to Unit 4.

(c) **Write a use and limitation of unit Hydrograph. The effective rainfall hydrograph of a complex storm has a duration of 12 hr, with a rainfall intensity of 2·0, 0·75 and 4·0 cm/hr respectively in successive 4 hr periods. The ordinates of the corresponding direct runoff hydrograph read at 4 hr interval are 160, 300, 570, 636, 404, 234, 105 and 48 m^3s respectively. Determine the ordinates of the 4 hr unit Hydrograph using the de-convolution method.**

Ans. Refer to Q. No. 11 of Unit 4.

Q. 5. (a) **Discuss Darcy's law and its use for ground water.**

Ans. Refer to Unit 5.

(b) **Discuss the methods of ground water exploration.**

Ans. Refer to Unit 5.

(c) **What do you understand by confined and unconfined aquifers ? Explain with examples.** 10

Ans. Refer to Q. No. 8 of Unit 5.

(d) **Discuss the recuperation test in ground water.**

Ans. Refer to Q. No. 9 of Unit 5.

Solved Question Paper

B.E. (5th Semester) Examination, April-May, 2009

Note : Attempt 16 marks from each unit or each question.

Q. 1. (a) **What do you understaud by Hydrologic equations ?**

Ans. Refer to Unit 1.

(b) **Describe the Hydrologic Cycle. Explain briefly the man's interference in various parts of his cycles.**

Ans. Refer to Q. No. 2 of Unit 1.

(c) **Describe the practical application of Engineering Hydrology.**

Ans. Refer to Q. No. 3 of Unit 1.

(d) **Explain briefly :**

(i) Air Mass

(ii) Air front.

Ans. Refer to Q. No. 5 of Unit 1.

Q. 2. (a) **What is meant by PMP over a basin ?**

Ans. Refer to Q. No. 7 of Unit 2.

(b) **Explain the different method of determining the average rainfall over a catchment due to a storm.**

Ans. Refer to Q. No. 8 of Unit 2.

(c) **A catchment has six raingauge stations. In a year, the annual rainfall recorded by the gauge are as follows :**

Stations	Rainfall (cm)
A	82·6
B	102·9
C	180·3
D	110·3
E	98·8
F	136·7

For a 10% error in the estimation of the mean rainfall, calculate the optimum number of station in the catchment.

Ans. Refer to Q. No. 6 of Unit 2.

(d) **Describe the different method of recording of rainfall. Briefly explain float type rain gauge.**

Ans. Refer to Unit 2.

(Attempt any one question)

(b) The ordinates of a 4[th] hydrograph of a basin of area 300 km^2 measured at 1h intervals are 6, 36, 66, 91, 106, 93, 79, 68, 58, 49, 41, 34, 27, 23, 17, 13, 9, 6, 3 and 1·5 m^3/s respectively. Obtain the ordinates of a 3h unit hydrograph for the basin using the S-curve technique.

Ans. Refer to Unit 4.

(c) The ordinates of 4h unit hydrograph of a basin are tabulated below. Derives 8h unit hydrograph from the 4h unit hydrograph. Time (hour) 4h UH ordinates m^3/sec.

0	0
2	12·52
4	21·32
6	23·54
8	17·84
10	14·79
12	12·18
14	10·04
16	8·26
18	6·51
20	4·98
22	3·95
24	3·05
26	2·26
28	1·60
30	1·07
32	0·53

Ans. Refer to Q. No. 13 of Unit 4.

Q. 5. (a) Define confined Aquifer.

Ans. Refer to Unit 5.

(Attempt any one question)

(b) Derive an expression for the steady state of discharge condition from a well penetrating an unconfined aquifer. Also state the limitations of Deputies assumptions ?

Ans. Refer to Q. No. 14 of Unit 5.

(c) A well penetrates fully confined aquifer 10 m thick, having coefficient of permeability of 0·005 m/sec. The radius of well is 10 cm. What will be the percentage increase in the discharge if the radius of the well is doubled.

Ans. Refer to Unit 5.

(d) Explain following terms :

Aquiclude, aquitard, aquifuse, specific yield, specific retention.

Ans. Refer to Q. No. 2 and 3 of Unit 5.

Solved Question Paper

B.E. (5[th] Semester) Examination, Nov.-Dec., 2010

Note : Attempt any three parts from each questions, part 'a' is compulsory.

Q. 1. (a) Explain over land flow.

Ans. Refer to Unit 1.

(b) What are the basic data required for hydrological studies ? Name the agencies from which the data can be obtained.

Ans. Refer to Unit 1.

(c) Discuss the hydrological water budget with the aid of example.

Ans. Refer to Q. No. 6 of Unit 1.

(d) Discuss the role of weather and clouds in causing precipitation.

Ans. Refer to Unit 1.

Q. 2. (a) Differentiate between recording and non-recording types of rain gauges.

Ans. Refer to Q. No. 3 of Unit 2.

(b) The normal annual precipitation of five rain gauge stations P, Q, R, S and T are respectively 125, 102, 76, 113 and 137 cm. During a particular storm the precipitation by stations P, Q, R and S are 13·2, 9·2, 6·8 and 10·2 cm respectively. The instrument at station T was inoperative during that storm. Estimate the rainfall at station T during the storm.

Ans. Refer to Unit 2.

(c) The values of annual precipitations at a rain gauge station expressed in cm per year in chronological sequence from 1987 to 1996 are indicated below :

70·2, 31·7, 68·8, 50·9, 60·3, 58·7, 43·9, 50·3, 48·7, 67·5.

Estimate the value of precipitation, which has a recurrence interval of 5 year and year.

Ans. Refer to Unit 2.

(d) Explain the three different methods employed to determine the mean precipitation over a given area.

Ans. Refer to Q. No. 8 of Unit 2.

Q. 3. (a) Explain the term basin yield clearly.

Ans. Refer to Unit 3.

(b) The average rainfall over a basin of area of 50 during a storm was as follows :

Time (hr)	0	1	2	3	4	5	6	7
Rainfall (mm)	0·0	6·0	11·0	34·0	28·0	12·0	6·0	0·0

If the volume of runoff from this storm was measured as 25×10^3, determine the ϕ-index for the storm.

Ans. Refer to Unit 3.

(c) Explain with sketches if necessary, the following methods for calculating runoff.

(i) infiltration capacity method.

(ii) ϕ_{index} method.

Ans. Refer to Q. No. 9 and 10 of Unit 3.

Q. 3. (a) What do you understand by infiltration capacity ?

Ans. Refer to Q. No. 9 of Unit 3.

(b) Explain briefly :

(i) ϕ index

(ii) ω index.

Ans. Refer to Q. No. 10 of Unit 3.

(c) What is the factor affecting runoff ?

Ans. Refer to Q. No. 11 of Unit 3.

(d) The following are the rates of rainfall for successive 20 mm period of a 140 minutes storm. (2·5, 2·5, 10·0, 1·25, 0·25, 5·0) cm/hr. Taking the value of ϕ index as 3·2 cm/hr. Find out the runoff in cm.

Ans. Refer to Unit 3.

Q. 4. (a) What is a unit Hydrogaph ?

Ans. Refer to Q. No. 1 of Unit 4.

(b) Write a use and limitation of unit Hydrograph.

Ans. Refer to Q. No. 4 and 7 of Unit 4.

(c) Explain briefly :

(i) Hydrograph separation

(ii) S-curve hydrograph.

Ans. Refer to Q. No. 6 of Unit 4.

(d) The effective rainfall hydrograph of a complex storm has a duration of 12 hr. with rainfall intensity of 2·0, 0·75 and 4·0 cm/hr respectively in successive 4 hr periods. The ordinates of the corresponding direct runoff hydrograph read at 4 hr interval are 160, 300, 570, 636, 484, 234, 105 and 48 m^3/s respectively. Determine the ordinates of the 4 hr unit hydrograph using the deconvolution method.

Ans. Refer to Q. No. 11 of Unit 4.

Q. 5. (a) What is Darcy's law ?

Ans. Refer to Unit 5.

(b) A 30 cm diameter well completely penetrates a confined aquifer of permeability 45 m/day. The length of the strainer is 20 m. Under steady state of pumping the draw down at the well was found to be 3·0 m and the radius of influence was 300 m. Calculate the discharge.

Ans. Refer to Q. No. 10 of Unit 5.

(c) The following data is obtained from a recuperation test on an open well of diameter 6·5 m.

(i) R.L. of water table = 237·8 m.

(ii) R.L. of water level in the well when the pumping is just stopped = 231·2 m.

(iii) R.L. of water level in the well

2·5 hr after the pumping is stopped = 234·5 m

Estimate the safe yield of the well, if the working head 3 m.

Ans. Refer to Q. No. 11 of Unit 5.

Solved Question Paper

B.E. (5[th] Semester) Examination, Nov.-Dec., 2009

Note : All questions are compulsory. Each question have internal choice.

Q. 1. (a) Define hydrology.

Ans. Refer to Q. No. 1 of Unit 1.

Attempt any two questions.

(b) Explain the practical applications of hydrology.

Ans. Refer to Q. No. 3 of Unit 1.

(c) Describe hydrologic cycle with neat sketch.

Ans. Refer to Q. No. 2 of Unit 1.

(d) Explain the following :

Air mass and air front, Cyclone, Hydrometeorology.

Ans. Refer to Q. No. 5 of Unit 1.

Q. 2. (a) Define precipitation.

Ans. Refer to Q. No. 1 of Unit 2.

Attempt any two questions.

(b) The average annual rainfalls in cm at 6 existing rain gauge stations in a basin are 82·6, 102·9, 180·3, 110·3, 98·8 and 136·7. If the average depth of rainfall over the basin is to be measured within 10% error, determine the addition number of gauges needed.

Ans. Refer to Unit 2.

(c) (i) The normal annual precipitation of five rain gauge station A, B, C, D and E are respectively 125, 102, 76, 113 and 137 cm. during a particular storm the precipitation recorded by station A, B, C and D are 13·2, 9·2, 6·8 and 10·2 cm respectively. The instrument at station E was in operative during the storm. Estimate the rainfall at station E during the storm.

Ans. Refer to Q. No. 10 of Unit 2.

(ii) What are the precautions to be taken in selection a site for the location of a rain gauge ?

Ans. Refer to Unit 2.

(d) What are the different methods of measurement of rainfall ? Briefly explain the float type rain gauge.

Ans. Refer to Q. No. 8 of Unit 2.

Q. 3. (a) Define infiltration.

Ans. Refer to Q. No. 1 of Unit 3.

(b) A 7 hour storm produced the following rainfall intensities (in mm/h) at half an hour intervals over a basin of area 1830 km^2. 4, 9, 20, 18, 13, 11, 12, 2, 8, 16, 17, 13, 6 and 1.

If the corresponding observed runoff is 36·6 million m^3. Determine ϕ-index for the basin.

Ans. Refer to Unit 3.

(c) Describe the various components of runoff.

Ans. Refer to Q. No. 4 of Unit 3.

(d) What is meant by 'Runoff' and how it is produced ? Discuss very briefly the various factor on which it depends.

Q. 4. (a) List any four assumptions involved in the unit hydrograph theory.

Ans. Refer to Q. No. 5 of Unit 4.

(b) The following are the ordinates of the hydrograph of flow from a catchment area of 770 km^2 due to a 6-h rainfall. Derive the ordinates of a 6-h unit hydrograph. Make suitable assumptions regarding the base flow.

Time from beginning of storm (h)	0	6	12	18	24	30	36
Discharge (m^3/s)	40	65	215	360	400	350	270

Time from beginning	42	48	54	60	66	72
Discharge (m^3/s)	205	145	100	70	50	42

Ans. Refer to Unit 4.

(c) The ordinates of 2-h unit hydrograph are given :

Time (h)	0	2	4	6	8	10	12
2-h unit hydrograph	0	25	100	160	190	170	110
Time (h)	14	16	18	20	22		
2-h unit hydrograph ordinate (m^3/s)	70	30	20	6	0		

Determine and draw the ordinates of 4-h unit hydrograph.

Ans. Refer to Unit 4.

(d) Explain the use of the unit hydrograph in the construction of the flood hydrograph resulting from two or more periods of rainfall.

Ans. Refer to Unit 4.

Q. 5. (a) Explain the term specific capacity of a well.

Ans. Refer to Unit 5.

(b) A gravity well has a diameter of 60 cm. The depth of water in the well is 40 meters before pumping is started. When pumping is being done at the rate of 2000 litres/minutes the drawdown in a wait 10 meters away is 4 meters and in another well 20 meters away is 2 meters. Determine (i) Radius of zero drawdown. (ii) Coefficient of permeability and (iii) Drawdown in the well.

Ans. Refer to Unit 5.

(c) State Dupuit's assumption for obtaining general equations governing ground water flow. Derive an expression for the confined aquifer.

Ans. Refer to Unit 5.

(d) Write short notes on :

(i) Permeability and transmissibility and their relationship.

(ii) Recuperating test on open well.

Solved Question Paper

B.E. (5[th] Semester) Examination, April-May, 2011

Note : Attempt all questions. Part (a) of each question is compulsory. Answer any two parts from (b), (c) and (d).

Q. 1. (a) Define Hydrometeorology.

Ans. Refer to Q. No. 5 of Unit 1.

(b) Describe the Hydrologic cycle.

Ans. Refer to Q. No. 2 of Unit 1.

(c) Describe the practical application of Hydrology.

Ans. Refer to Q. No. 3 of Unit 1.

(d) Explain the following :

Global water budget, air mass and air front.

Ans. Refer to Q. No. 5 of Unit 1.

Q.2. (a) Define probable maximum precipitation.

Ans. Refer to Q. No. 6 of Unit 2.

(b) Describe the different method of determining the average precipitation over a catchment due to a storm.

Ans. Refer to Q. No. 8 of Unit 2.

(c) There are four rain gauge stations existing in the catchment of a river. The average annual rainfall values at these stations are 800, 620, 400 and 540 respectively.

(i) Determine the optimum number of rain gauges in the catchment, if it is desired to limit the error in the mean value of rainfall in the catchment to 10%

Ans. Refer to Unit 2.

(ii) How many more gauges will then be required to be installed ?

Ans. Refer to Unit 2.

(d) (i) Rain gauge station X was inoperative for part of a month during which a storm occurred. The respective storm totals at three surrounding stations A, B and C were 107, 89 and 122 mm. The normal annual precipitation amounts at stations X, A, B and C are respectively 978, 1120, 935 and 1200 mm. Estimate the storm precipitation for station X.

Ans. Refer to Unit 2.

(ii) What are the precaution to be taken in selecting a site for the location of a raingauge?

Ans. Refer to Q. No. 13 of Unit 2.

Q. 3. (a) Define basin yield.

Ans. Refer to Unit 3.

(b) A 7 hour storm produced the following rainfall intensities (in mm/h) at half an hour intervals over a basin of area 1830 km^2.

4, 9, 20, 18, 13, 11, 12, 2, 8, 16, 17, 13, 6 and 1

If the corresponding observed runoff is 36·6 million m^3. Determine ϕ-index for the basin.

Ans. Refer to Unit 3.

(d) Explain the following :

Infiltration capacity, infiltrometer, basin yield, infiltration indices.

Ans. Refer to Q. No. 12 of Unit 3.

Q. 4. (a) Define unit hydrograph.

Ans. Refer to Q. No. 1 of Unit 4.

(b) What are the assumptions of unit hydrograph theory ?

Ans. Refer to Q. No. 5 of Unit 4.

Attempt any one question.

(c) Following are the ordinates of a storm hydrograph of a river draining a catchment area of 423 km^2 due to a 6-h isolated storm. Derive the ordinates of a 6-h unit hydrograph for the catchment.

Time from start of storm (h)	–6	0	6	12	18	24	30	36	42	48	54
Discharge (m^3/s)	10	10	30	87·5	111·5	102·5	85	71	59	47·5	39

Time from start of storm (h)	60	66	72	78	84	90	96	102
Discharge	31·5	26	21·5	17·5	15	12·5	12	12

Ans. Refer to Unit 4.

(d) The ordinates of 4h unit hydrograph of a basin are tabulated below. Derive 2h unit hydrograph ordinate from the 4h unit hydrograph.

Time (h)	0	4	8	12	16	20	24	28	32	36	40	44
Ordinate of 4-h UH (m^3/s)	0	20	80	130	150	130	90	52	27	15	5	0

Ans. Refer to Q. No. 12 of Unit 4.

Q. 5. (a) Define Aquifer.

Ans. Refer to Q. No. 1 of Unit 5.

Attempt any two questions.

(b) Derive an expression for the steady state of discharge condition from a well penetrating.

Ans. Refer to Q. No. 12 of Unit 5.

(c) A well penetrates fully confined aquifer 20 m thick having coefficient of permeability of 45 m/day. The diameter of well is 30 cm. There is a drawdown of 3 m at the well face and its radius of influence is 300 m. Calculate the discharge which can be withdrawn from this well. What will be the percentage increase in the discharge if the diameter of the well is 45 cm.

Ans. Refer to Q. No. 10 of Unit 5.

(d) Explain the following terms :

Aquiclude, aquitard, aquifuse, specific yield, specific retention, drawdown, radius of influence.

Ans. Refer to Q. No. 2, 3 and 5 of Unit 5.

Solved Question Paper

B.E. (5[th] Semester) Examination, April-May, 2010

Note : All questions are compulsory.

Q. 1. (a) Define Hydrometeorology.

Ans. Refer to Q. No. 5 of Unit 1.

(b) Define Air masses and font.

Ans. Refer to Q. No. 5 of Unit 1.

(Attempt any one question)

(c) Explain the practical applications of hydrology.

Ans. Refer to Q. No. 3 of Unit 1.

(d) Describe hydrologic cycle with a net sketch.

Ans. Refer to Q. No. 2 of Unit 1.

Q. 2. (a) Define precipitation.

Ans. Refer to Q. No. 1 of Unit 2.

(b) What is meant by probable maximum precipitation (PMP) over a basin.

Ans. Refer to Q. No. 7 of Unit 2.

(Attempt any one question)

(c) The average annual rainfall in cm at 4 existing rain gauge stations in a basin at 105, 79, 70 and 66. If the average depth of rainfall over the basin is to be estimated within 10% error, determine the addition number of gauges needed.

Ans. Refer to Q. No. 11 of Unit 2.

(d) (i) The normal annual precipitation of five rain gauge station A, B, C, D and E are respectively 125, 102, 76, 113 and 137 cm during a particular storm the precipitation recorded by station A, B, C and D are 13·2, 9·2, 6·8 and 10·2 cm respectively. The instrument at station E was in operative during the storm. Estimate the rainfall at station E during the storm.

Ans. Refer to Q. No. 10 of Unit 2.

(ii) What are the precautions to be taken selecting the site of the location of a rain gauge ?

Ans. Refer to Q. No. 13 of Unit 2.

Q. 3. (a) Define infiltration.

Ans. Refer to Q. No. 1 of Unit 3.

(Attempt any one question)

(b) A 5h storm produced rainfall intensities of 7, 18, 25, 12, 10 and 3 mm/h in successive one hour intervals over a basin of 800 sq. km. The resulting runoff is observed to be 2640 hectare-meters. Determine ϕ-index for the basin.

Ans. Refer to Unit 3.

(c) Describe the various components of runoff.

Ans. Refer to Q. No. 4 of Unit 3.

(d) Describe the factors affecting infiltration.

Ans. Refer to Unit 3.

Q. 4. (a) Define hydrograph.

Ans. Refer to Unit 4.

(c) Describe the various factors affecting the infiltration.
Ans. Refer to Q. No. 11 of Unit 3.
(d) Explain the following :
Runoff, infiltration capacity, ϕ-index, infiltrometer.
Ans. Refer to Q. No. 9 and 10 of Unit 3.

Q. 4. (a) Define S-curve.
Ans. Refer to Q. No. 6 of Unit 4.
(b) The peak of flood hydrograph due to a 3-h duration isolated storm in a catchment is 270 m^3/s. The total depth of rainfall is 5·9 cm. Assuming an average infiltration loss of 0·3 cm/h and a constant base flow of 20 m^3/s estimate the peak of the 3h unit hydrograph of this catchment.
If the area of the catchment is 567 km^2 determine the base width of the 3h unit hydrograph by assuming it to be triangular in shape.
Ans. Refer to Q. No. 22 of Unit 4.
(c) The ordinates of a 2-h unit hydrograph are given :

Time (h)	2-h UH ordinate (m^3/s)
0	0
2	25
4	100
6	160
8	190
10	170
12	110
14	70
16	30
18	20
20	6
22	0

Determine the ordinates of S-curve hydrograph and using the determine the ordinates of a 4-h unit hydrograph.
Ans. Refer to Unit 4.
(d) Explain the following :
Base, flow separation, Unit hydrograph, Application of unit hydrograph.
Ans. Refer to Unit 4.

Q. 5. (a) Define ground water.
Ans. Refer to Unit 5.
(b) Derive an expression for the steady state discharge of well fully penetrating into a confined aquifer.
Ans. Refer to Q. No. 12 of Unit 5.
(c) A well penetrates into an unconfined aquifer having a saturated depth of 100 m. The discharge is 250 liters per minute at 12 m drawdown. Assuming equilibrium flow conditions and a homogeneous aquifer, estimate the discharge at 18 m drawdown. The distance from the well where the draw down influence are not appreciable may be taken to be equal for both the cases.
Ans. Refer to Unit 5.
(d) Define the following :
Aquifer, Aquiclude, Aquitard, aquifase.
Ans. Refer to Q. No. 2 and 3 of Unit 5.

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