



CE 472
Water Resources Engineering Lab II
(Lab Manual)



Department of Civil Engineering
Ahsanullah University of Science and Technology
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Preface

Water Resources Engineering is an important field of Civil Engineering. Water is the most precious natural resource but it can cause severe problems if it is not properly used. So proper utilization and management of water is necessary especially in the field of irrigation. Knowledge about Soil properties in an irrigation field, Irrigation Scheduling, Design of Canal and Analysis of Hydrological data are significant both in Agricultural and Civil Engineering Field. To meet this purpose, Water Resources Engineering Sessional-II was introduced. This Lab manual mainly deals with soil properties influencing irrigation such as- bulk density, soil suction, intake characteristics, coefficient of permeability; canal seepage loss; abstraction from a single well; irrigation scheduling; design of a branch canal; frequency analysis of hydrologic data and hydrograph analysis.

This Lab manual was prepared with the help of 'Irrigation Engineering and Hydraulic Structures' by S. K. Garg, and the lab manual 'Irrigation and Drainage Sessional' of Bangladesh University of Engineering and Technology (BUET). The authors highly indebted to Dr. M. Mirjahan Miah, Professor, Department of Civil Engineering, Ahsanullah University of Science and Technology for reviewing this manual and giving valuable comments to improve this manual.

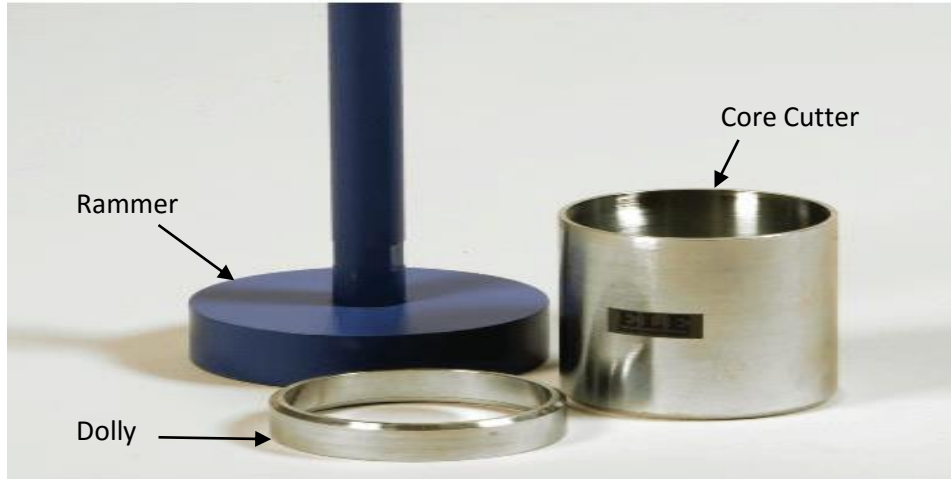
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Experiment 1

Determination of Soil Bulk Density by Field Method



Experiment No. 1

DETERMINATION OF SOIL BULK DENSITY BY FIELD METHOD

1.1 General

Knowledge of soil and water relationship is valuable to improve irrigation practices and to make the best use of water. Soil bulk density is an important parameter, which influences the soil-water relationship. It is very useful in irrigated regions as it influences the capacities of well drained soils in the field to retain water available for plants, and the flow, or movement of water in soils.

1.2 Theory

1.2.1 Bulk density

The bulk density of a soil is defined as the ratio of the mass of dried soil to the total volume of soil. In other words, it is the mass of a dry soil per unit bulk volume, the latter being determined before drying. It is expressed as

$$\rho_b = \frac{M_s}{V_t} = \frac{M_s}{V_s + V_a + V_w} \quad (1)$$

Here,

ρ_b = bulk density; gm/cc

M_s = Mass of solid; gm

V_t = Total soil volume; cc

V_s = Volume of solid; cc

V_a = Volume of air; cc

V_w = Volume of water; cc

The term bulk density and apparent specific gravity are often used synonymously. Apparent specific gravity is the ratio of the weight of a unit bulk volume of soil to the weight of an equal

volume of water. However, since, 1gm of water fills a volume of 1 cc at normal temperatures; the two terms have equal numerical value.

1.3 Scope of the Test

Bulk density is an important soil physical property considering its influence on the water holding capacity and hydraulic conductivity of soil. It is influenced by the structure, texture and compactness of the soil. The bulk density of uncultivated soils usually varies between 1.0 and 1.6; however compact layers may have a bulk density of 1.7 to 1.8. When working with the irrigated soils, it is necessary to know their bulk density in order to account for the water applied in irrigation, since it is impractical to measure, by direct means, the volume of water, which exists in the form of soil moisture in a given volume of soil. It is necessary to measure the weight of water in a given weight of soil by observing the loss of weight in drying and then convert the weight percentage so obtained to a volume percentage by use of the bulk density; thus, the volume of water in a given volume of soil may be determined. From this data the additional requirement of water in volumetric basis may also be calculated.

1.4 Objective

- 1) To determine the bulk density of soil.
- 2) To plot moisture content by weight and moisture content by volume and then determine the soil bulk density from the graph.

1.5 Procedure

- 1) The usual method of determining the bulk density or apparent specific gravity of a soil is to obtain an uncompacted soil sample of known volume. Core samplers are commonly used for this purpose. The sampler that has a cutting core is driven into the soil and an uncompacted core obtained within the tube.
- 2) The samples are carefully trimmed at both ends of the cylinder.

- 3) They are dried in an oven at 105°C-110°C for about 24 hours until the moisture is driven off and the sample is then weighted. The volume of a soil core is the same as the inside volume of the core cylinder.
- 4) The weight of the soil in grams divided by the volume of soil core in cc is the bulk density of soil.
- 5) From the data, calculate moisture content by weight.
- 6) Find moisture content by volume by multiplying the m/c by weight with bulk density.

1.6 Qualitative Curve

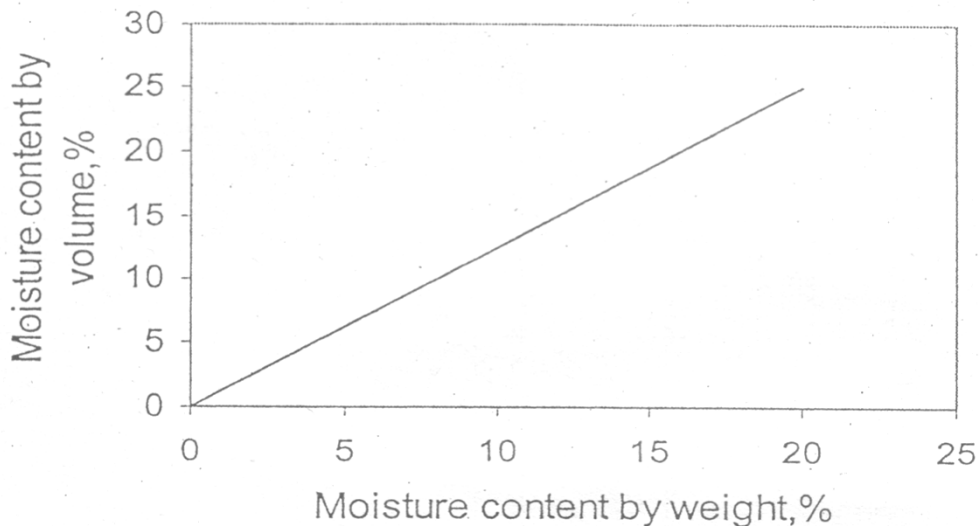


Figure.1: Moisture content by volume Vs moisture content by weight

1.7 Assignment

- 1) Prove that $\rho_b = \rho_s (1 - n/100)$

$$\rho_b = \rho_s (1 + e)$$

Where, ρ_s = density of soil, n = porosity, e = void ratio

- 2) Prove that moisture content by volume is the product of moisture content by weight and bulk density.
- 3) “Soil with high bulk density will have low hydraulic conductivity”—explain.

STUDENT ID:

DATE:

1.7 Data Sheet

DETERMINATION OF SOIL BULK DENSITY BY FIELD METHOD

Group No.	Volume of Cylinder (c.c)	Weight of beaker (gm)	Weight of beaker+wet soil (gm)	Weight of Wet soil (gm)	Weight of beaker+dry soil (gm)	Weight of dry soil (gm)	Moisture content by weight (%) (θ_m)	Bulk Density ρ_b	Moisture content by volume (%)

SIGNATURE OF THE TEACHER

Experiment 2

Soil Suction Measurement with Tensiometer



Experiment No: 2

SOIL SUCTION MEASUREMENT WITH TENSIOMETER

2.1 General

The functions of soil moisture in plant growth are very important. Particularly in irrigated regions the soil moisture condition is of special interest and importance, because the depth of water to apply in irrigation and the interval between irrigations are both influenced by present moisture condition and use rate of applied water. Soil suction measurement with tensiometer at various time intervals is an indirect mean of measuring soil moisture in the soil.

2.2 Theory

2.2.1 Soil Suction

In unsaturated soils, water is held in the soil matrix under negative pressure due to attraction of the soil matrix for water. Instead of referring to this negative pressure the water is said to be subjected to a tension exerted by the soil matrix. The tension with which the water is held in unsaturated soil is termed as soil-moisture suction or soil-moisture tension.

2.2.2 Tensiometer

The tensiometer is a mechanical device for measuring soil- water tension in the field. The essential parts of a tensiometer consist of the porous cup with a reservoir of water inside, the connecting tube, and the sensing element of a vacuum gauge or a mercury manometer.

The figure 1 below shows the essential parts of a tensiometer. A porous ceramic cup is positioned in the soil where information regarding soil water is desired. The cup, the connecting tube, and the sensing element of a vacuum indicator are all filled with water. Water in the soil near the cup is in hydraulic contact with bulk water inside the cup through pores in the cup wall. Flow, in or out through the cup wall, tends to bring the cup water into hydraulic equilibrium with the soil water. As water moves out of the cup because of the suction in the

soil water, the vacuum created in the cup is registered on the gauge. Conversely an increase of water will lower the tension, water will move into the cup, and the gauge will read less tension. Fluctuations of soil moisture are registered by the tensiometer, as long as tension does not exceed 0.8 atm. As soil water is depleted by root extraction, or replenished by rainfall or irrigation, corresponding changes in readings on the tensiometer gauges occur.

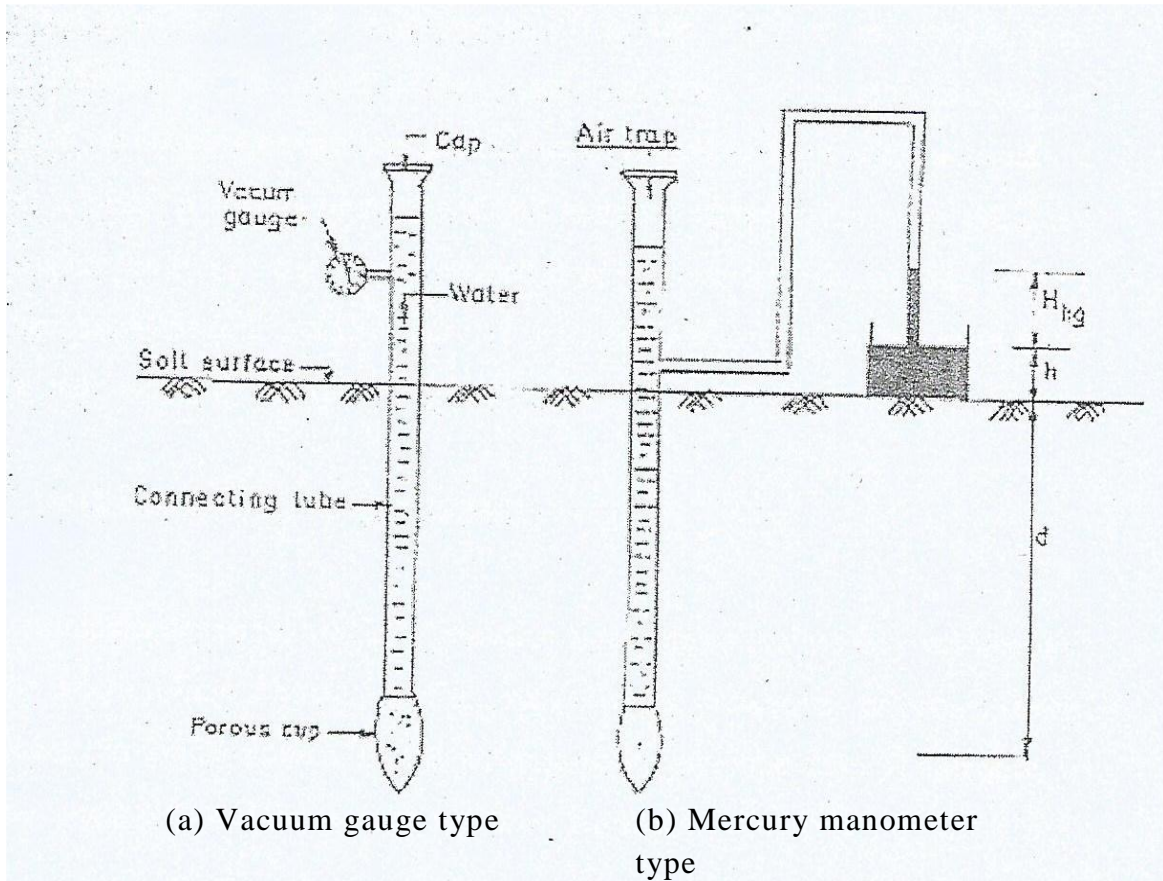


Figure.1: Tensiometer

2.3 Scope of the test

Tensiometer readings plotted as a function of time provide a useful record of soil water conditions in the neighborhood of the cup. They do not provide direct information on the amount of water held in the soil. Tension measurements are useful in deciding when to irrigate, but they do not indicate how much water should be applied. A special curve named soil moisture characteristic curve (Moisture Content Vs. soil suction curve), plotted from tensiometer readings is an indirect measure of soil moisture content. The tensiometer readings are also very useful in determining the use rate of applied water.

2.4. Limitation of Tensiometer

Tensiometer does have a definite limitation in the range of values they can measure. The practical limit is about 0.8 atm. At this pressure air enters the closed system through the pores of the cup and makes the unit inoperative. The air entry or bubbling pressure of the ceramic cup limits this range.

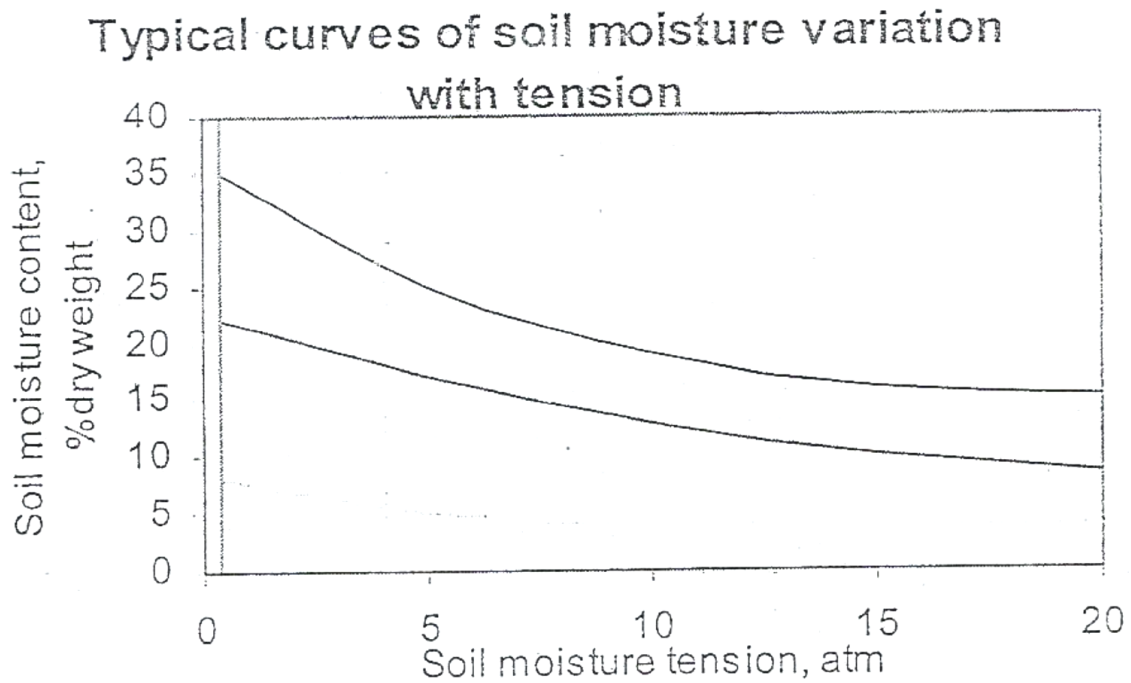
2.5 Objective

- 1) Use of tensiometer to measure soil moisture tension.
- 2) Measure the moisture content of the soil by weight.
- 3) Plot the soil moisture characteristic curve (moisture content vs. suction).

2.6 Procedure

- 1) For field installation, a hole is made in the soil using an auger of diameter larger than the porous ceramic tube. Insert the porous ceramic tube part in the hole and refill the hole with the material excavated. The soil surrounding the tensiometer ceramic tube should be refilled and compacted well to ensure good contact.
- 2) When suction equilibrium has been reached, take the necessary measurements. For the laboratory set-up, take tensiometer reading 1 day after installation.
- 3) Take soil samples from the depth where tensiometer was installed. Determine the weight of the soil.
- 4) Put the soil sample in an oven at about 110°C and allow the water to evaporate. The evaporation process at least takes 24 hours. Determine the weight of the dry soil and the weight of water.

2.7 Qualitative Curves



2.8 Assignment

- 1) For which type of soil tensiometer is most suitable? Explain.
- 2) Would you expect the suction in the soil to be zero at any time?
- 3) How tensiometer can be used to predict the frequency of irrigation?

STUDENT ID:

DATE:

2.9 Data Sheet

Group No.	Weight of can (gm)	Weight of wet soil + can (gm)	Weight of dry soil+can (gm)	Moisture content (%)	Soil suction (cm of Hg)	Soil Suction (atm)	Soil Suction (centibar)

SIGNATURE OF THE TEACHER

Experiment 3

Determination of Soil Intake Characteristics using Cylinder Infiltrometer



Experiment No. 3
DETERMINATION OF SOIL INTAKE CHARACTERISTICS USING
CYLINDER INFMTROMETER

3.1 General

Knowledge of the rate of entry of water into soil is of fundamental importance for efficient irrigation. Soil intake characteristic gives us information about the rate of entry of water into soil to avoid excess irrigation or shortage of irrigation.

3.2 Theory

3.2.1 Intake rate

The rate of entry of water into soil under field conditions is called intake rate. Whenever the configuration of soil surface influences the rate of water entry, the term intake rate should be used rather than the term infiltration rate to refer to the rate of entry of water into soil. Intake rate is therefore influenced by furrow size, shape as this term indicates infiltration under a particular soil surface configuration. On the other hand the term "infiltration" applies to a level surface covered with water.

3.2.2 Scope of the test

In all irrigation methods, except sub-surface irrigation, water is applied to the surface of land where it subsequently enters the soil and is stored for later use by plants. The object of irrigation is to get water into the soil where it can be stored. The intake rates obtained from the tests are indicative of the rates to be expected during irrigation provided, the surface condition is same. If intake rate is greater than irrigation rate sufficient water will neither enter the soil nor be stored therein and crop growth is significantly reduced. Again, if irrigation rate is greater than intake rate, runoff loss will occur. One of the major problems of irrigated farms is the low intake rate of fine textured soil, which is often reduced further by excessive working of soil and by salinity. Thus the determination of soil intake characteristic is of fundamental importance in irrigation practice.

3.2.3 Factors affecting Intake Rate

- Intake rate varies with many factors, including depth of water on the surface, temperature of water and soil, soil structure and texture, moisture content and salinity of the soil.
- Retarding layers of soil will greatly influence the rate.
- Configuration of the surface such as furrow shape and size, as well as the method of application, will be influencing factor also. Hence intake rate varies from place to place on a field and it also varies with time.

3.3 Method of determining Intake Rate

The best method of determining intake rate is to obtain direct measurements by recording the water applied less the water flowing from the field. When direct measurements are not feasible, cylinder infiltrometers can be used with reasonable accuracy.

3.3.1 Cylinder Infiltrometer

Cylinder infiltrometers have been found suitable for use in determining intake characteristics of irrigated soil. The cylinders should be at least 25 cm in diameter and 30 cm long. The cylinder should be carefully driven into the soil to a depth of about 15 cm. To begin a test, about 10 to 12 cm of water is quickly poured into the cylinder and timing of infiltration is recorded. The water surface readings are made from a datum with the help of a ruler. To represent the soil intake characteristics it is necessary to plot the accumulated intake vs. time. The equation for accumulated intake is

$$D = CT^n \quad (1)$$

Where D = accumulated intake, mm

T = time, min

C and n = constants

Average intake rate is given by

$$I_{ave} = \frac{D}{T} = \frac{CTn}{T} = CT^{n-1} \quad (2)$$

Instantaneous intake rate is given by

$$I_{ins} = \frac{dD}{dT} = CnT^{n-1} \quad (3)$$

3.3.2 Double Ring Infiltrometer (Buffer ponds)

After water penetrates to the bottom of the cylinder, it will begin to spread radially and the rate of intake will change accordingly. When a principal-restricting layer does not lie within the depth of penetration of the cylinder, the radial flow will cause considerable change in the intake rate. Buffer ponds surrounding the cylinder are used to minimize this effect. Buffer ponds can be constructed by forming an earth dike around the cylinder or by driving a larger diameter cylinder concentric with the intake cylinder into the soil. The water level in both the cylinders should be equal and approximately the depth to be expected during the irrigation. Care should be taken not to puddle the soil when water is added to the cylinder or the buffer pond.

3.4 Objective

- 1) To familiarize with the field testing procedure.
- 2) To plot accumulated depth Vs. time in a log-log paper and to find (a) the constant C, and (b) the exponent, n.
- 3) To develop the equations for accumulated intake, average and instantaneous intake rates from the test data.
- 4) To plot accumulated depth, average and instantaneous intake rate Vs. time in one plain graph paper.

3.5 Procedure

- 1) Note the soil profile and surface condition.
- 2) The cylinder should be carefully driven into the soil to a depth of about 15 cm

- 3) To begin a test, about 10 to 12 cm of water is quickly poured into the cylinder and timing of infiltration is recorded.
- 4) At various time intervals, measure the water level.
- 5) Calculate the time difference and water level difference.
- 6) The ratio of water level difference and time difference gives the instantaneous intake rate at different times.
- 7) The ratio of cumulative depth and cumulative time gives average intake rate.

3.6 Typical Intake Curves

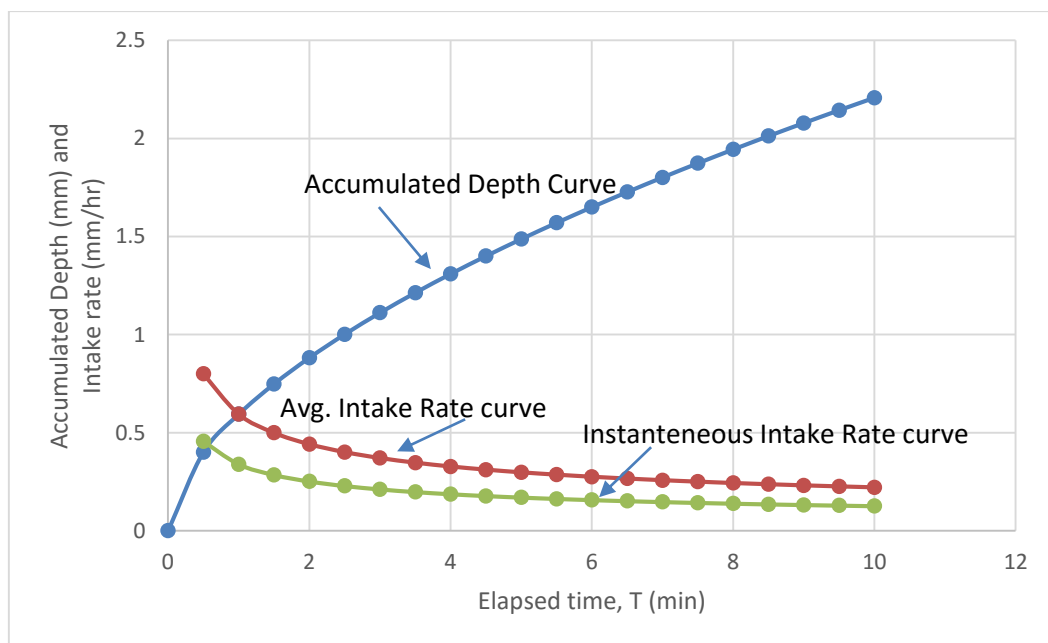


Figure. 1: Typical Intake Curves

3.7 Assignment

- 1) Why double ring infiltrometer is more preferable than single ring infiltrometer?
- 2) Intake data obtained by using cylinders and buffers will most closely approximate the actual intake from what method of irrigation?
- 3) Discuss the use of soil intake characteristics in the design and operation of irrigation systems.

Experiment 4

Measurement of Canal Seepage Loss by Ponding Method



Experiment No. 4

MEASUREMENT OF CANAL SEEPAGE LOSS BY PONDING METHOD

4.1 General

Determination of canal seepage loss is of very importance to make a provision for water loss in irrigation canal and to consider the other phenomena associated with canal seepage.

4.2 Theory

4.2.1 Canal Seepage Loss

During the passage of water from the main canal to the outlet at the head of the watercourse, water may be lost either by evaporation from the surface or by seepage through the peripheries of the channels. These losses are sometimes very high of the order of 25% to 50% of the water diverted. Evaporation losses are generally of the order of 2 to 3 percent of the total loss and may be more but seldom exceed 7%. So the major portion of the total loss is seepage loss and a minor portion is evaporation loss.

4.3 Scope of the test

In determining the channel capacity a provision, for water loss must be made. In this regard measurement of seepage loss is very important. Moreover seepage of water from irrigation canals is a serious problem. Not only is water lost, but also drainage problems are often aggravated on adjacent or lower lands. Occasionally water that seeps out of canal re-enters the river valley where it can be rediverted, or enters in an aquifer where it can be reused. It is a more serious economic loss when the seepage losses are not recoverable. Also economic and legal problems may result from water seepage from canals causing drainage problems on the lower lying lands. So determination of canal seepage loss is of very importance to visualize the total loss as well as the other effects.

4.4 Factors affecting Canal Seepage Loss

- Type of seepage, i.e. whether "percolation" or absorption.
- Soil permeability.
- The condition of the canal. The seepage through a silted canal is less than that from a new canal.
- Amount of silt carried by the canal; the more the silt, the lesser are the losses.
- Velocity of canal water; the more the velocity, the lesser will be the losses.
- Cross-section of the canal and its wetted perimeter.

4.5 Methods of determining Canal Seepage Loss

Several methods used to measure seepage from canals are inflow-outflow, ponding method, seepage meters, laboratory tests of permeability of soil etc.

4.5.1 Ponding methods

The ponding measurements are well adapted to estimate the seepage loss in short canal sections. The measurement can be made by installing a check or a dam at both ends of a canal section, filling the section with water and observing the rate at which the water level recedes with time. The recession rate can be determined by plotting the water level against time and noting the slope of the resulting curve at the operating level. The seepage rate is computed as

$$S = \frac{RWL}{PL} \quad (1)$$

Where, S= seepage rate, m/day

R = Rate of recession or slope of water level versus elapsed time curve at operating level, m/day

W = Average top width of the water surface, m

P = Average wetted perimeter of the test section, m

L = Length of the test section, m

4.6 Objective

- 1) To get acquainted with the field testing procedure
- 2) To estimate the seepage loss in the test canal section
- 3) Interpretation of the test results.

4.7 Procedure

- 1) At first construct a dam or check at the both ends of a short reach of the canal.
- 2) Fill the section with water
- 3) Observe the rate at which the water level recedes with time.
- 4) Plot the water level against time
- 5) Find the slope of resulting curve at operating level. The value of the slope is called recession constant.
- 6) Determine channel seepage loss using equation (1).

4.8 Assignment

- 1) What are the advantages and disadvantages of ponding method?
- 2) What is the difference between canal seepage loss and canal conveyance loss? How can you reduce the canal seepage loss?

Experiment 5

Abstraction from a Single Well in an Unconfined Aquifer



Experiment No. 5

ABSTRACTION FROM A SINGLE WELL IN AN UNCONFINED AQUIFER

5.1 General

Efficient and economical utilization of ground water through wells depends on the design of wells to best suit the characteristics of the water bearing formation. Flow of ground water into wells is influenced by the physical characteristics of the water bearing formations, the number and extent of these formations, the elements of well design and the methods used for constructing and developing the wells.

5.2 Theory

5.2.1. Aquifer

An aquifer is a water bearing formation in which flow of water is possible through the interconnected void structure of the formation. An unconfined aquifer is one in which water table serves as the upper surface of the zone of saturation of the formation.

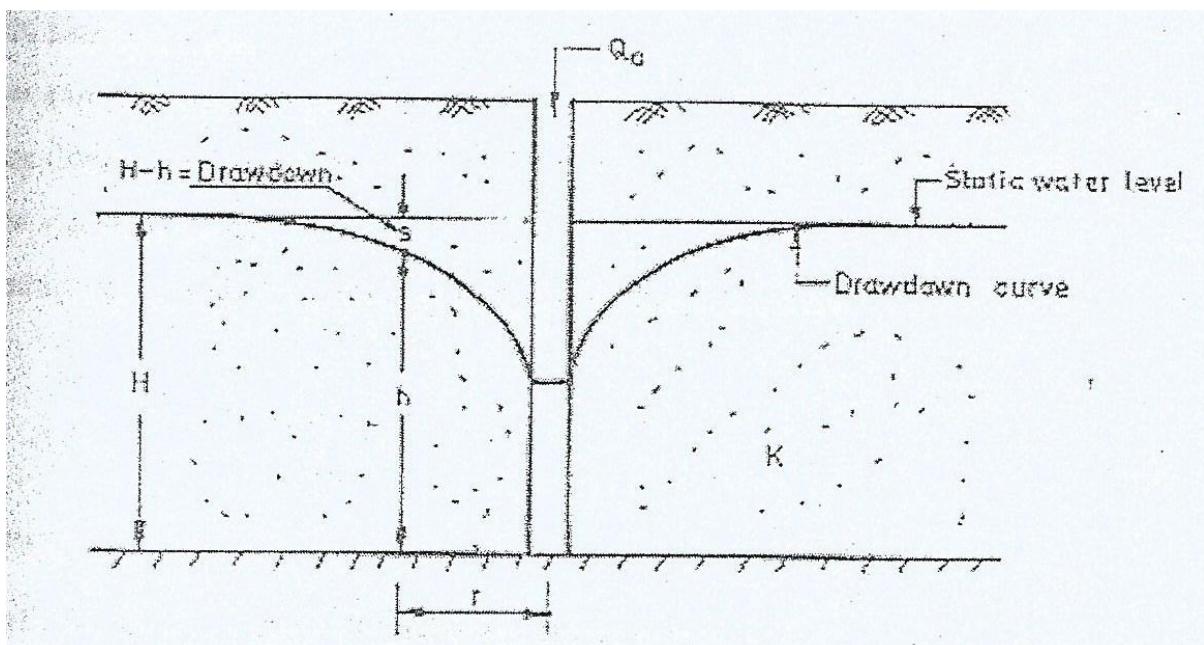


Figure.1: Abstraction from a single well in an unconfined aquifer

Fig.(1) shows an unconfined aquifer situated above an impervious base. There is neither

recharge by rainfall, nor loss of water due to evapotranspiration. Initially, the water table is horizontal. Abstraction of water from a well results in lowering of water table around the well, and then there is a reduction of the saturated thickness of the well.

5.2.2 Prediction of well yield

Irrigation wells operate according to certain fundamental hydraulic principles. Water flows into the well from the surrounding aquifer because the pumping of the well creates a difference in pressure. Darcy's theory established the fundamentals of ground water movement. Dupuit, a French hydraulic engineer established the analysis of seepage phenomenon and derived the well equations based on the following assumptions:

- i) The hydraulic gradient is the same at all points in a vertical section of an aquifer.
- ii) The hydraulic gradient at the water table (or at the piezometric surface in artesian flow) is equal to the slope of the surface at that point.

The equation of flow, for unconfined aquifer becomes:

From Darcy's Law:

$$Q = kiA = 2\pi rh K \frac{dh}{dr} \quad (1)$$

From Continuity Principle:

$$Q = \text{Constant} = Q_0 \quad (2)$$

Combining (1) and (2) and integrating gives Dupuit formula

$$H^2 - h^2 = \frac{Q_0}{\pi K} \ln \frac{R_0}{r} \quad (3)$$

Where,

H = depth of saturated thickness before pumping

h = depth of saturated zone at a distance 'r'

Q₀ = well discharge

R₀ = radius of influence

K = coefficient of permeability

H-h = s

= drawdown

If $s \ll H$, then $H+h \sim 2H$ and equation 3 can be written as

$$s = \frac{Q_0}{2\pi T} \ln \frac{R_0}{r} \quad (4)$$

Where, $T = KH$, the coefficient of transmissibility. Changing the base of logarithm, we get Thiems equation

$$s = \frac{2.303Q_0}{2\pi T} \ln \frac{R_0}{r} \quad (5)$$

5.3 Scope of the test

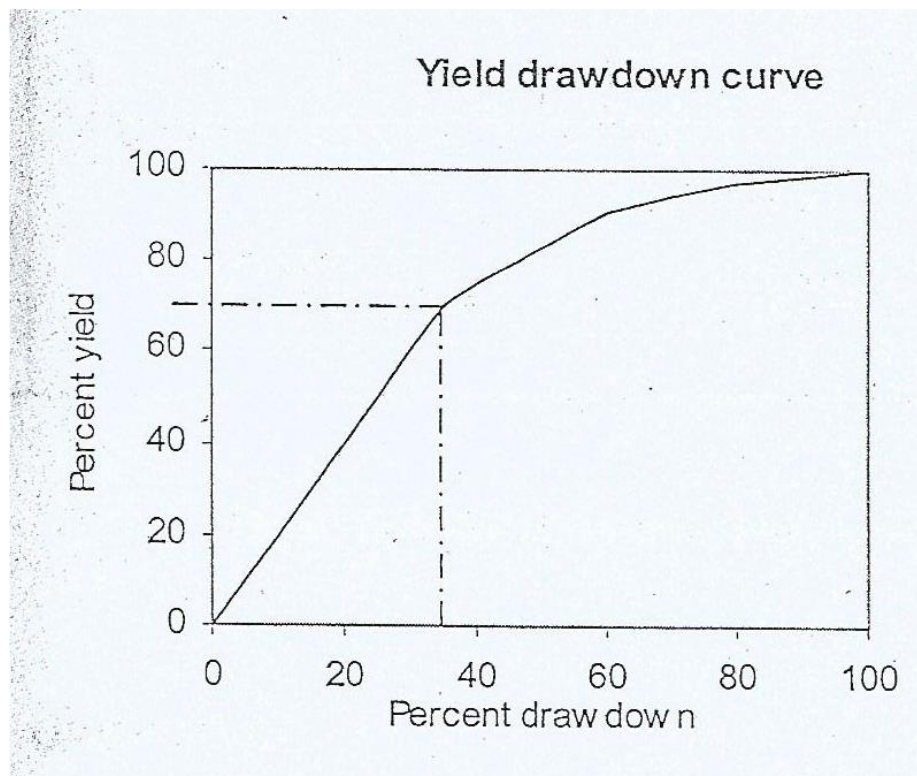
Irrigation wells are usually designed to obtain the highest yield available from the aquifer, and the highest efficiency in terms of specific capacity. The yield potential of a well is evaluated on the basis of hydrological conditions of the area- rainfall, runoff and recharge. When the yield potential of an area is not a limiting factor a properly designed irrigation well should provide the required quantity of water to irrigate the entire area owned by the farmer. So determination of yield potential of a well is very useful.

The topography of the farm, current water table condition, recharge possibilities etc are important factors in deciding the location of a well. The draw down curves and the water table contour can be helpful in this regard.

Whenever a well is pumped, the greatest amount of lowering of the water table occurs within the well and the immediately adjacent areas are lowered almost as much. But as pumping continues, a equilibrium gradient is established and the quantity of water entering the well from the surrounding zone will be approximately the same as that being pumped. The amount of lowering diminishes as the distance from the well increases, until a point is reached where pumping does not affect the level of the overall water table. If wells are spaced too closely together, the pumping of one may interfere with the yield of others. In other words, the yield of a well is decreased if its cone of depression is overlapped by the cone of an adjacent well. To select the suitable spacing we may take the help of the value of radius of influence. Experience and tests have shown that, in most cases, grouping of well should not be made at interval less than 70 meters.

5.4 Efficiency of a Well

The discharge from well is approximately proportional to the drawdown s . The discharge per unit drawdown is called the specific capacity of the well. This specific capacity will be different for different well designs. For determining the best draw down-discharge conditions for a well, the well may be operated under varying drawdown conditions, and then a graph may be plotted between discharge and drawdown (called yield-draw down curve).



The curve obtained is a straight line up to a certain stage of drawdown, beyond which the drawdown increases disproportionately with yield. This places an optimum and efficient limit to be created in a well. This is generally found to be 70% of maximum drawdown, which can be created in a well.

5.5 Description of the Apparatus

The experiment will be carried out in the 'Basic Hydrology System', which consists of a catchment basin, represented by a shallow tank filled with sand. At the two longitudinal ends of the catchment there are two submergence tanks, each connected by a water inlet pipe and

outlet pipes. The height of inlet pipe can be adjusted to maintain fixed water level in the tank.

At the base of the catchment there are two rows of manometer tapping points, which are mutually perpendicular to each other. The base also contains two wells situated on the longitudinal row of manometer tappings. The manometer tappings are connected to manometers on a manometer board by flexible tubes. The well points can discharge water to sump tank through a control valve. The locations of the manometer tapping and the wells 'A' are shown in the figure.

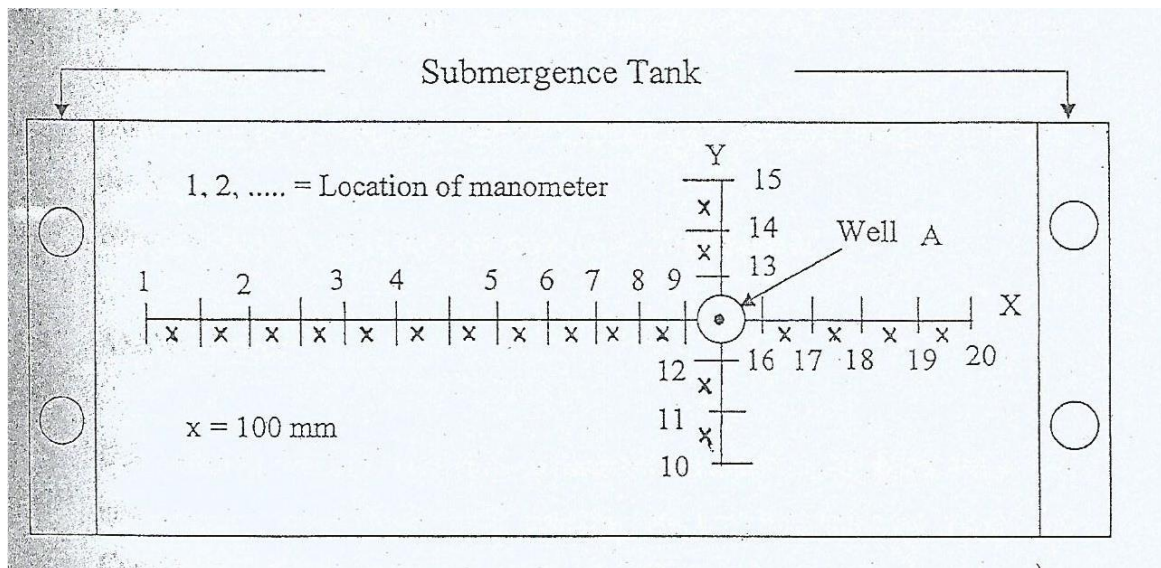


Figure.2: Locations of manometer tapping and wells

5.6 Objective

- 1) To draw the drawdown curve on a plain graph paper for the experimental data.
- 2) To draw water table contours around a well.
- 3) To draw the drawdown curve on a semi-log paper and determine the transmissibility and permeability of the aquifer.
- 4) To draw theoretical drawdown curve using Thiem's formula and compare with the actual curve.

5.7 Procedure of Experiment

- 1) Keeping the well discharge valve closed, flood the catchment to make the sand completely saturated.
- 2) Adjust the two groundwater inlet pipes to the same level, to maintain fixed water levels in the submergence tank.
- 3) Adjust the discharge to a valve suitable for the experiment and wait till water levels in all the manometers stand at the same height, and note the water levels in manometer.
- 4) Open the well discharge valve, and wait until water levels in all the manometers become stable.
- 5) Connect the well discharge pipe to a measuring tank and measure the well discharge.
- 6) Note the water levels in the manometers no. 5 through 20.

5.8 Assignment

- 1) Distinguish between (i) confined and unconfined aquifers; (ii) static water level and pumping water level; (iii) specific capacity and specific yield; (iv) co-efficients of permeability and transmissibility.
- 2) Discuss the effect of partial penetration of well. (Hints: Irrigation theory and practice by A M Michael)
- 3) What are the effects of well size and radius of influence on well yield in context to environmental considerations and economy? (Hints: Irrigation theory and practice by A M Michael)

Experiment No. 6

IRRIGATION SCHEDULING BY BOOK KEEPING METHOD



Experiment No. 6

IRRIGATION SCHEDULING BY BOOK KEEPING METHOD

6.1 General

The knowledge of irrigation scheduling, total water requirement and irrigation requirement is fundamental in the design of irrigation scheme and water supply system and in irrigated crop production.

6.2 Theory

6.2.1. Irrigation Scheduling

Irrigation scheduling is a decision making process involving when to irrigate, how much water to apply each time and how to apply. In other words scheduling of irrigation refers to application of water at the right time in the right amount by the right method.

6.2.2. Necessity of Irrigation Scheduling

The main objective of irrigation scheduling is management of water so that it is applied at right time and in the amount needed. In water short areas this can result in increased yields through an extension of cropped areas. In water surplus areas it can help to alleviate problems which may result from excess water applications. It can also reduce loss of nutrients through deep percolation.

6.2.3. Dependable Factors

An efficient and accurate irrigation-scheduling program depends on the following information of that area:

- Soil information
- Crop information
- Meteorological information
- Water supply information
- Methods of irrigation
- Social & economic factors

Two basic information that must be known before irrigation scheduling are:

- Soil moisture available for crop
- Rate of daily water use by the crop

6.2.4. Irrigation Scheduling by Book Keeping Method

In this method a worksheet for "Moisture balance for scheduling irrigation" is used for weekly or daily basis. Before starting this scheduling three major items should be known:

- Water holding capacity (WHC) of soil in the root depth
- Estimated E_t of the crop to be grown
- Soil moisture balance at the beginning of the scheduling period

By entering all these in the appropriate column of the worksheet the moisture balance at the end of the week is determined.

6.2.5 Field Capacity (FC)

Yield capacity is the moisture content of the soil when rapid drainage has essentially ceased and any farther drainage occurs at a very slow rate. The FC corresponds to a soil moisture tension of about 1/10 to 1/3 atmosphere.

6.2.6. Permanent Wilting Point (PWP)

The Soil moisture content at which the plant wilts permanently or dies is known as permanent wilting point. The soil still contains some water but it is too difficult for the roots to extract it from the soil as it is held with a suction force of about 15 atm. Typically for medium soils the moisture content at PWP is about one-half the FC.

6.2.7. Gravitational Water

The water in the large pores that moves downward freely under the influence of gravity is known as the gravitational water. This is the water between the saturated point and FC.

6.2.8. Available Water

The water contained in the soil between FC and PWP is known as the available water.

6.2.9. Total Available Water (TAW)

The amount of water, which will be available for plants in the root zone, is known as the total available water. It is the difference in volumetric moisture content at FC and at PWP; multiplied-by root zone depth.

6.2.10. Management Allowable Depletion (MAD)

MAD is the degree, to which the water in the soil is allowed to be depleted by management decision.

6.2.11. Reference Crop Evapotranspiration (ET_o)

The rate of evapotranspiration from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and of not short of water is known as the reference crop evapotranspiration.

6.2.12. Crop Evapotranspiration (ET_c)

The depth of water needed to meet the water loss through evapotranspiration of a disease-free crop, growing in large fields under non-restricting soil conditions including water and fertility and achieving full production potential under-the given growing environment.

6.2.13. Crop Coefficient (K_c)

The ratio of ET_c / ET_o is termed as crop coefficient.

6.2.14. Effective Rainfall (R_e)

Rain that is retained in the root zone and used by plants is considered as effective rainfall.

Effective Rainfall (R_e) = Total rainfall(R) - Runoff (R_0) - Evaporation (E) - Deep percolation (P)

6.3 Procedure

- 1) To calculate the WHC of soil in the root zone depth the m/c at PWP is subtracted from m/c at FC then multiplied by root zone depth

$$\frac{(FC - PWP)}{100} * A_s * RD$$

- 2) This available water is multiplied by an allowable depletion factor to determine the allowable depletion.
- 3) To calculate the current depletion (CD) the actual evapotranspiration and previous depletion is added and actual rainfall & irrigation (if any applied in the previous week) is subtracted from the previous sum.

$$CD = (ET_a + \text{previous depletion}) - (\text{actual rainfall} + \text{irrigation})$$

- 4) To calculate the predicted evapotranspiration K_c is multiplied by reference crop evapotranspiration.
- 5) The predicted depletion is calculated by adding the predicted evapotranspiration and current depletion and then subtract the rainfall from it. This predicted depletion is the amount for irrigation.
- 6) The irrigation frequency is calculated by using the following expression

$$\text{Irrigation frequency} = 7 * (\text{Allowable depletion} - CD + R) / E_{tc}$$

6.4 Problem

Irrigation scheduling for the period of July 1 to August 4.

The following information is given:

$$\text{Water holding capacity of soil} = \frac{(FC - PWP)}{100} * A_s \text{ (mm/m)}$$

- (i) Roll No + 50
(For Roll Nos. 1 - 100)
- (ii) Roll No. - 50
(For Roll Nos. 101 - 200)

Allowable Depletion, AD = 50%

Depletion at the end of the June 30 was 16.5 mm.

Week ending	Actual		Predicted			RD (cm)
	E_t (mm)	R_e (mm)	E_{tc} (mm)	R_e (mm)	K_c (mm)	
July 7	61.46	15	-	0	-	-
July 14	67.31	6.85	50.55	0	0.95	83.82
July 21	71.37	0	50.55	0	0.96	101.60
July 28	73.66	0	50.04	.0	0.99	101.60
August 4	67.56	2.03	49.28	0	0.98	101.60
August 11	-	-	48.26	0	0.94	101.60

6.5 Assignment

- 1) Explain why soil, climate and crop factors are considered while designing irrigation frequency.
- 2) "Shallow rooted crops will require more frequent irrigation than deep rooted crops" --
- explain.
- 3) How can you apply this method in improving the water management practice?
- 4) What modifications do you need to. apply this method for scheduling irrigation of rice?

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Data Sheet

IRRIGATION SCHEDULING BY HAND CALCULATOR METHOD

Calculation Sheet

PREVIOUS WEEK SOIL WATER BUDGET					IRRIGATION PREDICTION NEXT 7 DAYS									
Week Ending	E_{tc} Actual mm	Previous Depletion+ E_{tc} mm	Rain Actual + Irrigation mm	Current Depletion CD mm	Next 7 Days $E_{tc}=E_{tr} \times K_c$ mm	Root Depth RD mm	Water Holding Capacity HC mm/m	Available Water AW = RDxHC mm	Allowable Depletion AD %	Allowable Depletion ADI= AWx AD mm	Expected Effective Rainfall R_e mm	Predicted Depletion $E_{tc}+CD-R_e$ mm	Days to Next Irrigation = $7(ADI-CD+R_e)/E_{te}$	Comment

SIGNATURE OF THE TEACHER

Experiment No. 7

DESIGN OF A BRANCH CANAL IN AN IRRIGATION PROJECT



Experiment No. 7

DESIGN OF A BRANCH CANAL IN AN IRRIGATION PROJECT

7.1 General

In irrigation project a branch canal is needed to convey water from main canal to the tertiary canal.

7.2 Theory

7.2.1. Regime Channels

A channel is said to be in a state of regime if there is neither silting nor scouring in the channel. The shape, longitudinal slope, cross sectional dimension of a regime channel depends on the discharge, the sediment size, and sediment load. Two approaches of regime channel design are:

1. Kennedy's approach
2. Lacey's approach

In Kennedy and Lacey's approach the channel should be trapezoidal with side slope $\frac{1}{2}H:1V$

7.2.2. Kennedy's Approach

If the velocity in channel is sufficient to keep the sediment in suspension then silting in the channel will be avoided. Kennedy defined the critical velocity (V_0) as the mean velocity in a channel, which will just keep the channel free from silting & scouring.

7.2.3. Lacey's Approach

Lacey found many drawbacks in Kennedy's theory & put forward his new theory. Kennedy stated that a channel is said to be in a regime state if there is no silting & no scouring. Lacey stated that a channel showing no silting & non-scouring might not be in regime. According to Lacey a channel is in true regime only if the following conditions are satisfied.

- Discharge is constant
- Flow is uniform
- Silt charge is constant; *i.e.* the amount of silt is constant
- Silt grade is constant; *i.e.* the type & size of silt is always same

- Channel is flowing through a material which can be scoured as easily as it can be deposited (such soil is known as incoherent alluvium) & is of the same grade as is transported.

7.2.4. Design procedure for Lacey's approach

- 1) Calculate the silt factor f_s from the average particle size d

$$f_s = 1.76\sqrt{(d)} \text{ here, } d \text{ in mm} \quad (1)$$

- 2) Calculate the hydraulic radius R

$$R = 0.47 (Q/f_s)^{1/3} \quad (2)$$

Here R in m and Q in cumec

- 3) Calculate perimeter P

$$P = 4.75\sqrt{Q} \quad (3)$$

Here, P in m & Q in cumec

- 4) From P & R calculate sectional dimensions of trapezoidal section using the formulae of trapezoidal section i.e.

$$A = (b + 0.5y)y$$

$$P = b + 2y\sqrt{1 + 0.5^2}$$

- 5) Calculate the longitudinal slope S

$$S = \left[\frac{f_s^{5/3}}{3340Q^{1/6}} \right] (4)$$

7.2.5. Free Board

- The vertical distance between the top of the channel & the water surface at design condition
- Reason for providing FB:
 - i) Prevent water level from overtopping the sides of the channel as a result of fluctuation caused by wind, tide, super elevation, hydraulic jump
 - ii) The interception of storm runoff by the channel
 - iii) Occurrence of greater depth of flow due to sedimentation
- Normally 5%-30% of the depth of flow are used in design
- According to USBR

$$FB = \sqrt{(c * y)}$$

Here, c=coefficient

=1.5 for discharge $Q < 20$ cfs

=2.5 for discharge $Q > 300$ cfs

7.3 Problem

Design a branch canal of an irrigation system with the following data using the Lacey's regime equations for stable earthen channels in alluvium.

Design discharge = $(2500 + \text{Roll No.} * 20)$ cusec

Average particle size, $d = 0.16$ mm

Freeboard = 0.10 to 0.25 y (y = depth of flow)

Table: Design of a branch canal (Lacey's regime equation)

SL No.	Distance (miles)	S_w	Diversion	Losses(cusec)
1	0.00	0.417	-	-
2	0.70	0.417	22	4.5
3	1.59	0.417	61	5.8
4	2.00	0.417	-	2.6
5	5.30	0.423	13	21
6	6.20	0.423	30	6
7	6.50	0.423	178	3
8	6.85	0.423	44	1.8
9	7.15	0.423	32	2
10	8.25	0.423	-	7
11	10.71	0.430	21	16
12	10.88	0.430	19.6	1.1
13	12.55	0.430	13.1	10.6
14	13.72	0.430	-	7.5
15	14.20	0.44	407	3.1
16	15.43	0.44	18	7.8
17	15.89	0.44	98	2.9
18	17.95	0.44	21.1	13.1
19	17.99	0.44	-	-
20	22.50	0.44	-	29.5

The sections are to be chosen so that the distance L between the two consecutive sections is not greater than 5 miles and the slope of the water surface (S_w) within a chosen section remains same over the distance L .

Plot the longitudinal profile of the canal and draw all the cross-sections.

7.4 Procedure

To determine the section dimensions of a channel using the Lacey's regime equations, the following steps are involved.

- 1) Compute the silt factor f using Eq. (1)
- 2) Compute the longitudinal slope S using Eq. (4) based on Q_{avg} .
- 3) Compute the wetted perimeter P using Eq. (3) based on Q_{max} .
- 4) Compute the hydraulic radius R using Eq. (2) based on Q_{max} .
- 5) Compute the cross-sectional area $A=P*R$ based on Q_{max} .
- 6) Express A and P in terms of bottom width b and depth of flow y for trapezoidal section.
- 7) Solve the two equations for A and P simultaneously to obtain b and y .
- 8) Add a proper freeboard using the equations for freeboard.

7.5 Assignment

- 1) What are the general limitations of the regime equations?
- 2) Why the provision of freeboard is necessary for a designed channel section?
- 3) Draw a sketch to illustrate the effect of silt size upon the shape of regime channels.
- 4) When does a channel, according to Lacey, attain a regime condition?

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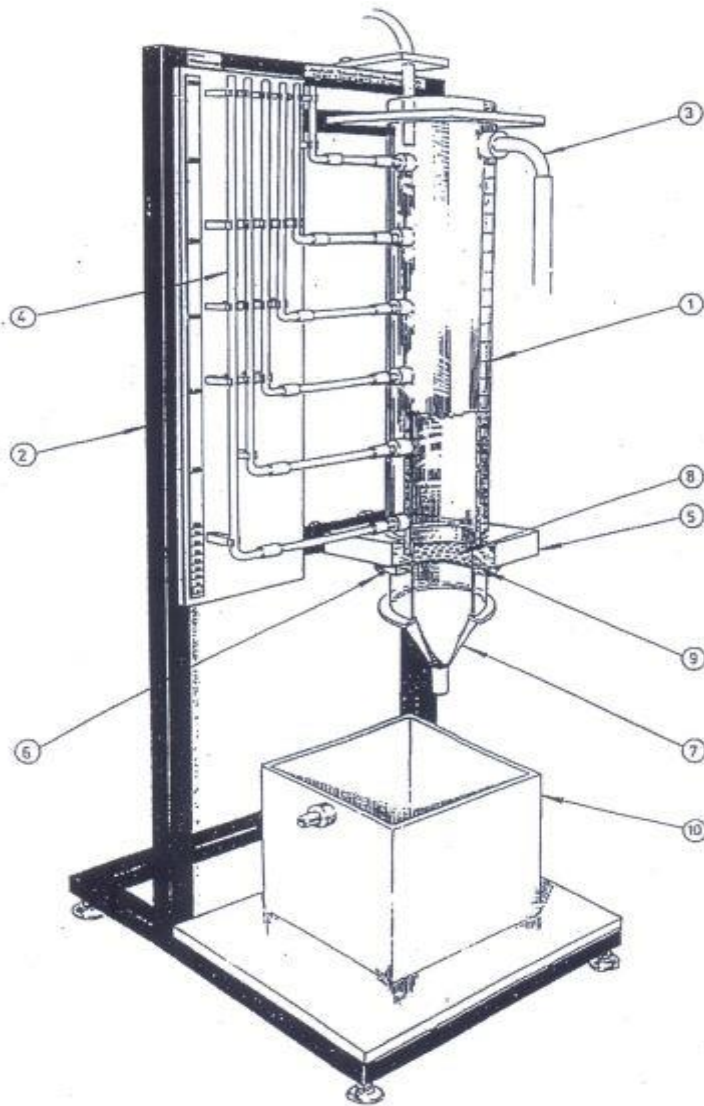
Data Sheet
DETERMINATION OF DESIGN PARAMETERS OF A BRANCH CANAL IN IRRIGATION PROJECT

Segment	Station	Distance (mile)	S_w	Diversion loss	Q u/s cumec	Q d/s cusec	P m	R m	A m ²	y m	b m	F. B. m	S

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Experiment No. 8

DETERMINATION OF COEFFICIENT OF PERMEABILITY OF SOIL USING DRAIN PERMEATOR



Drain Permeator

Experiment No. 8

DETERMINATION OF COEFFICIENT OF PERMEABILITY OF SOIL USING DRAIN PERMEATOR

8.1 General

Coefficient of permeability of soil indicates the drainage rate of that particular soil. This information is useful in determining the amount the flow through the soil. By knowing the drainage rate of a particular soil, the amount of water that is drained through that soil type for that crop is known. And this information gives the idea of the time of irrigation.

8.2 Theory

Darcy showed experimentally that, the rate of water Q flowing through soil of cross-sectional area A is proportional to the hydraulic gradient, i or

$$Q/A \propto i \quad \text{or} \quad Q = KiA$$

The coefficient of permeability K has been called “Darcy’s coefficient of permeability” or “Coefficient of permeability” or “hydraulic conductivity”. The coefficient is not dimensionless but has the units of velocity. Permeability is a soil property, which indicates the ease with which water will flow through the soil. Permeability enters all problems involving flow of water through soils, such as seepage under dams, the squeezing out of water from a soil by the application of a load and drainage of dams and backfills.

Permeability depends on a number of factors. The main ones are:

- (a) The size of soil grains: Permeability appears to be proportional to the square of an effective grain size. This proportionality is due to the fact that the pore size, which is the primary variable, is related to particle size.
- (b) The properties of pore fluid: Permeability is dependent on fluid viscosity, which in turn is sensitive to changes in temperature. The following equation expresses the relationship between viscosity and permeability.

$$K_{20^\circ\text{C}} = K_T \mu_T / \mu_{20^\circ\text{C}}$$

in which $K_{20^\circ\text{C}}$ = Permeability at temperature 20°C

$$K_T = \text{Permeability at temperature } T^\circ\text{C}$$

μ_T = Viscosity of water at temperature $T^\circ\text{C}$

$\mu_{20^\circ\text{C}}$ = Viscosity of water at temperature 20°C

- (c) The void ratio of soil: The more the void ratio, the more will be the permeability of soil. A permeability of 10^{-4} cm/sec is frequently used as the borderline between pervious (permeability $> 10^{-4}$ cm/sec) and impervious (permeability $< 10^{-4}$ cm/sec) soils.
- (d) The shape and arrangement of pores: Although permeability depends on the shapes and arrangement of pores, this dependence is difficult to express mathematically.
- (e) The degree of saturation: An increase in the degree of saturation of a soil causes an increase in permeability.

8.3 Description of the Equipment

All numerical references relate to diagram 1. The equipment consists of a vertical perspex cylinder (1) of 10.8 cm internal diameter and 65 cm long, mounted on a lightweight steel stand (2). The cylinder has an overflow outlet (3) and six piezometer tappings (4). The bottom support bracket (5) has four vertical studs (6) protruding from its base, these are used to secure the drain pipe (7), filters (8) and gaskets (9) to the bracket. The equipment includes two 14 cm by 14 cm gaskets which are used to prevent lateral leakage from the slotted drains and filters, and two sample drain materials of different slot shapes and sizes. The drain sample consists of 12 cm diameter discs of drain pipe. A variety of filter materials are also provided in 13 cm discs. A 20 cm by 20 cm by 20 cm collecting tank (10) with overflow is also provided to collect drainage water. Two lengths of plastic hose are provided. One for overflow (3) to drain and one to allow water to be admitted from laboratory supply to top of cylinder.

8.4 Objective

- 1) To measure the coefficient of permeability of soil.
- 2) To plot a graph, height of soil column Vs coefficient of permeability of soil.

8.5 Procedure

- 1) Assemble the apparatus with a slotted drain sample, filter and 10 cm of a sandy soil.
- 2) Introduce a steady stream of water into the cylinder.

- 3) Measure the drainage rate by collecting drained water in a measuring beaker over a measured period of time.
- 4) When a steady state drainage rate has been achieved. Record the following parameters:
 - (a) Drainage rate (m^3/day) D .
 - (b) Height of soil column (m) H_s .
 - (c) Height of water surface above base of soil column (m) H_w .
- 5) Turn of the water supply.
- 6) Empty the cylinder of water by using the supply tube as a siphon.
- 7) Add another 10 cm of soil and repeat steps (i) to (vi) until 4 trials have been run.
- 8) Record the results in the units indicated on the data sheet.
- 9) For each trial, calculate the hydraulic conductivity of the soil using the following equation:

$$K = D \times H_s / (\pi R^2 \times H_w)$$

Where,

K = Hydraulic Conductivity (m/d)

R = Radius of the soil column

8.6 Assignments

- 1) State Darcy's law. What are the limitations of Darcy's law?
- 2) Show mathematically how coefficients of permeability can be calculated for flow –a) Parallel to the bedding plane and b) Normal to the bedding plane.
- 3) Show graphically and then explain the relationship between the degree of saturation and coefficient of permeability.

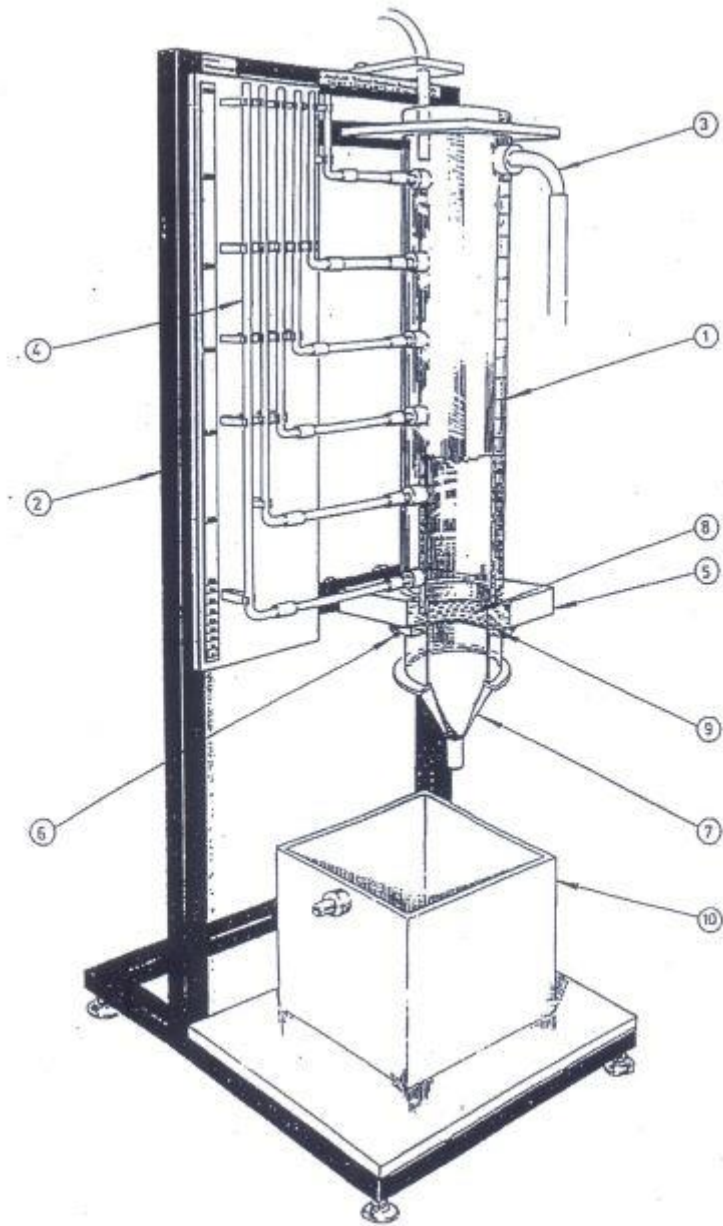


Figure: Drain Permeator

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Data sheet

DETERMINATION OF COEFFICIENT OF PERMEABILITY OF SOIL USING DRAIN PERMEATOR

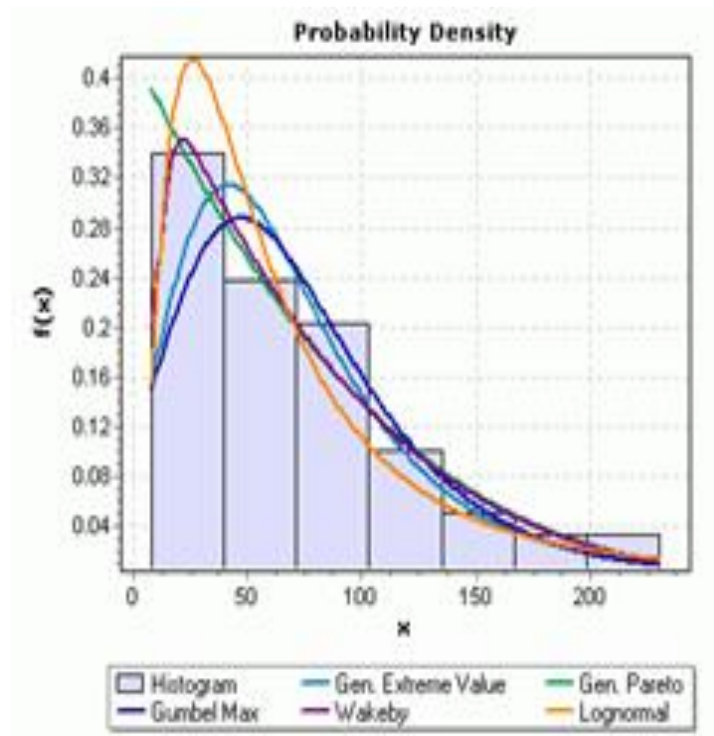
Radius of soil column, R =

Trial	Drain Rate (m ³ /day) D	Height of Soil (m) H _s	Height of Water (m) H _w	Area (m ²) πR ²	Hydraulic Conductivity (m/d) K
1.					
2.					
3.					
4.					
5.					

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Experiment No. 9

FREQUENCY ANALYSIS OF HYDROLOGIC DATA BY GUMBEL'S METHOD



Experiment No. 9

FREQUENCY ANALYSIS OF HYDROLOGIC DATA BY GUMBEL'S METHOD

9.1 General

Frequency analysis is very important in the design of practically all hydraulic structures. The peak flow that can be expected with an assigned frequency is of primary importance to adequately proportion the hydraulic structure to accommodate its effect. Flood peak values are required in the design of bridges, culvert, waterways and spillways for dams and also estimation of scour at a hydraulic structure.

9.2 Theory

9.2.1. Flood Frequency Analysis

Flood frequency analysis is a statistical approach to predict flood flows and estimate the magnitude of flood peak.

9.2.2. Annual Series

The values of the annual maximum flood from a given catchment area for a large number of successive years constitute a hydrologic data series called the annual series.

9.2.3. Mean Annual Flood

The value of a flood with a return period $T = 2.33$ years is called the mean annual flood. When the sample size is very large Gumble distribution has this property.

9.2.4. Gumble's Method

The "Extreme value distribution method" was introduced by Gumble in 1941 and is commonly known as Gumble's distribution. It is one of the most widely used probability distribution function for extreme values in hydrologic and meteorological studies for prediction of flood peaks, maximum rainfall, maximum wind speed, etc.

Gumble's equation for practical use (when sample size is finite) is given by,

$$x_T = \bar{x} + k \sigma_{n-1} \quad (1)$$

Where,

x_T = value of the variable x of a hydrologic series with a return period T

\bar{x} = mean of the variate

$$k = \text{frequency factor} = \frac{y_T - \bar{y}_n}{S_n} \quad (2)$$

$$\sigma_{n-1} = \text{standard deviation of the sample} = \sqrt{\frac{\sum(x - \bar{x})^2}{N-1}} \quad (3)$$

$$y_T = \text{reduced variate} = -\left(0.834 + 2.303 \log \log \frac{T}{T-1}\right) \quad (4)$$

\bar{y}_n = reduced mean, given in Table 2

S_n = reduced standard deviation of the sample, given in Table 3

The recurrence interval T for each discharge is given by,

$$T = \frac{N+1}{m} \quad (5)$$

Where, m = order number

N = sample size

9.2.5. Gumble Probability Paper

Gumble probability paper is an aid for convenient graphical representation of Gumble's distribution. It consists of an abscissa specially marked for various convenient values of return period. The magnitude of the flood or any hydrologic event or the value of the variate is plotted in the ordinate, which has an arithmetic scale. Since by equation (1) & (2) x_T varies linearly with y_T , Gumble distribution will plot as a straight line on a probability paper. This property can be used advantageously for graphical extrapolation.

9.3 Objectives

- 1) Prepare a Gumble probability paper.
- 2) Plot the Gumble distribution (x versus T) on a Gumble probability paper.
- 3) Estimate the flood discharge with recurrence interval of
 - (i) 100 years by graphical extrapolation
 - (ii) Roll No. + 20 (For Roll No. 1-50)
Roll No. – 20 (For Roll No. 51-100)
Roll No. – 60 (For Roll No. 101-150)

9.4 Procedure

9.4.1. Procedure for Gumble Distribution

- 1) Assemble the discharge data in decreasing order of magnitude. Find the value of T for each discharge. Here the annual flood value is the variate x.
- 2) Find \bar{x} and σ_{n-1} for the given data.
- 3) Use Tables 2 and 3 to determine \bar{y}_n and S_n appropriate to the given N.
- 4) Find y_T for a given T using Eq. (3).
- 5) Find K using Eq. (2).
- 6) Determine the required x_T by Eq. (1).

9.4.2. Procedure for Preparation of Gumble Probability Paper

- 1) To construct the T scale on the abscissa, first construct an arithmetic scale of y_T values from -2 to $+7$.
- 2) For selected values of T, say 1.01, 1.1, 1.2, 1.5, 2, 3, 4, 5, 7, 10, 15, 20, 30, 40, 50, 100, 200, 500 and 1000, find the values of y_T from eqn. (3) and mark off those positions on the abscissa. The T scale is now ready.
- 3) Now plot the x_T - T points in the probability paper.
- 4) The plotted points will follow a straight line.
- 5) By extending the straight line extrapolation is done.

9.5 Given Data

Maximum recorded floods in the river Brahmaputra-Jamuna at Bahdurabad station is given the following table from year 1957-1987.

Table 1. Maximum Annual Flood

Year	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Max Flood (m ³ /s)	62500	71300	68500	64800	64700	69400	56400	63100	64200	68900
Year	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Max Flood (m ³ /s)	69600	62300	56000	75000	66600	67300	91100	52200	65600	66600
Year	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Max Flood (m ³ /s)	56600	66100	61200	66500	55900	56500	77000	63800	43100	74000

Table 2. Reduced mean \bar{y}_n in Gumbel's extreme value distribution ($N =$ sample size)

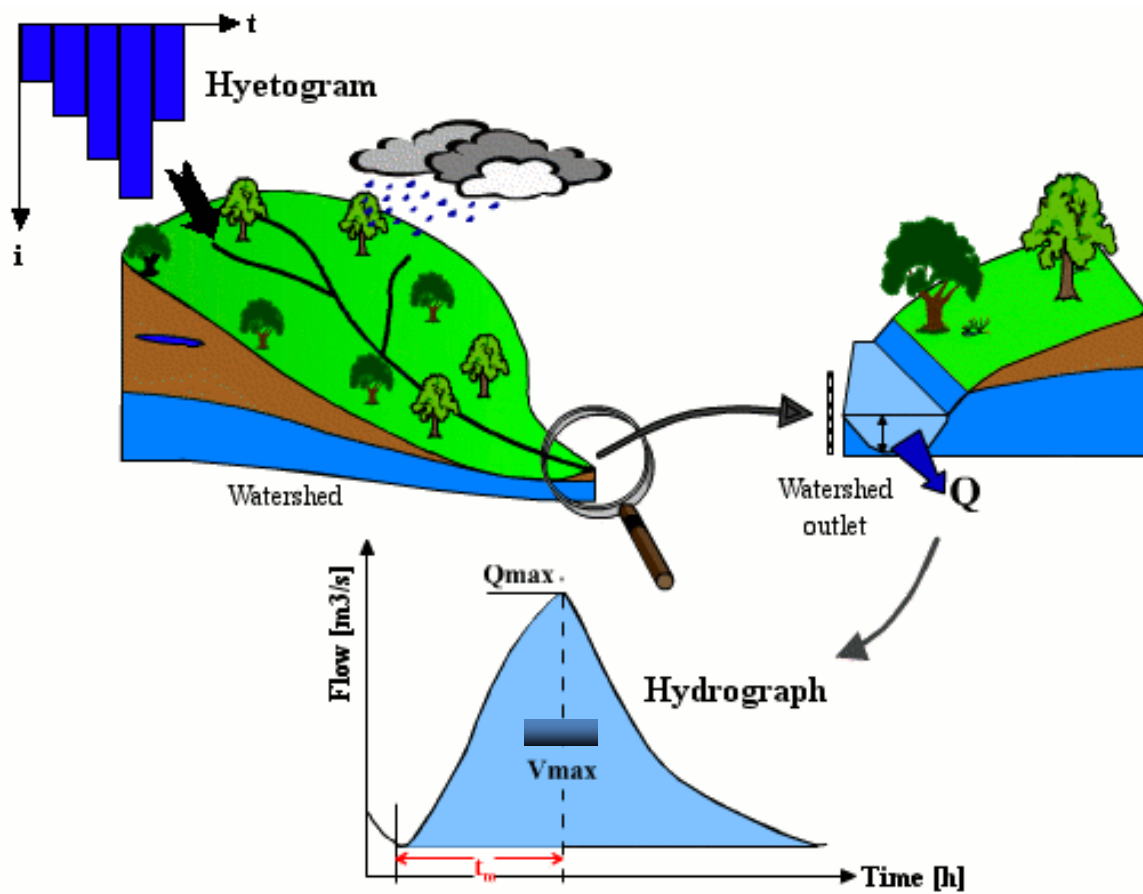
N	0	1	2	3	4	5	6	7	8	9
10	0.4952	0.4996	0.5035	0.5070	0.5100	0.5128	0.5157	0.5181	0.5202	0.5220
20	0.5236	0.5252	0.5268	0.5283	0.5296	0.5309	0.5320	0.5332	0.5343	0.5353
30	0.5362	0.5371	0.5380	0.5388	0.5396	0.5402	0.5410	0.5418	0.5424	0.5430
40	0.5436	0.5442	0.5448	0.5453	0.5458	0.5463	0.5468	0.5473	0.5477	0.5481
50	0.5485	0.5489	0.5493	0.5497	0.5501	0.5504	0.5508	0.5511	0.5515	0.5518
60	0.5521	0.5524	0.5527	0.5530	0.5533	0.5535	0.5538	0.5540	0.5543	0.5545
70	0.5548	0.5550	0.5552	0.5555	0.5557	0.5559	0.5561	0.5563	0.5565	0.5567
80	0.5569	0.5570	0.5572	0.5574	0.5576	0.5578	0.5580	0.5581	0.5583	0.5585
90	0.5586	0.5587	0.5589	0.5591	0.5592	0.5593	0.5595	0.5596	0.5598	0.5599
100	0.5600									

Table 3. Reduced standard deviation S_n in Gumbel's extreme value distribution ($N = \text{sample size}$)

N	0	1	2	3	4	5	6	7	8	9
10	0.9496	0.9676	0.9833	0.9971	1.0095	1.0206	1.0316	1.0411	1.0493	1.0565
20	1.0628	1.0696	1.0754	1.0811	1.0864	1.0915	1.0961	1.1004	1.1047	1.1086
30	1.1124	1.1159	1.1193	1.1226	1.1255	1.1285	1.1313	1.1339	1.1363	1.1388
40	1.1413	1.1436	1.1458	1.1480	1.1499	1.1519	1.1538	1.1557	1.1574	1.1590
50	1.1607	1.1623	1.1638	1.1658	1.1667	1.1681	1.1696	1.1708	1.1721	1.1734
60	1.1747	1.1759	1.1770	1.1782	1.1793	1.1803	1.1814	1.1824	1.1834	1.1844
70	1.1854	1.1863	1.1873	1.1881	1.1890	1.1898	1.1906	1.1915	1.1923	1.1930
80	1.1938	1.1945	1.1953	1.1959	1.1967	1.1973	1.1980	1.1987	1.1994	1.2001
90	1.2007	1.2013	1.2020	1.2026	1.2032	1.2038	1.2049	1.2049	1.2055	1.2060
100	1.2065									

Experiment No. 10

HYDROGRAPH ANALYSIS



Experiment No. 10

HYDROGRAPH ANALYSIS

10.1 General

Hydrograph analysis is used for flood routing, flood forecasting and determining design discharge for any hydraulic structure.

10.2 Theory

Rain falling on a catchment area will make its way to the point of concentration where it will leave the catchment. In a gravity flow situation, this will be the lowest point in the catchment if the discharge is through surface stream. On the other hand, if the catchment discharge is solely by means of ground water movement, the situation is more complex and the flow can be distributed over a wide front. But in the laboratory the flow is constrained to leave the model catchment at a single point, we shall not consider this case here.

In practice, a catchment area is defined only once when the point of concentration has been fixed and as streamflow data are needed here, the site of a new or pre-existing flow measurement structure is usually chosen. When rain falls on the catchment the time taken for the water to reach the point of concentration will depend on the horizontal distance it has to travel and also on the velocity.

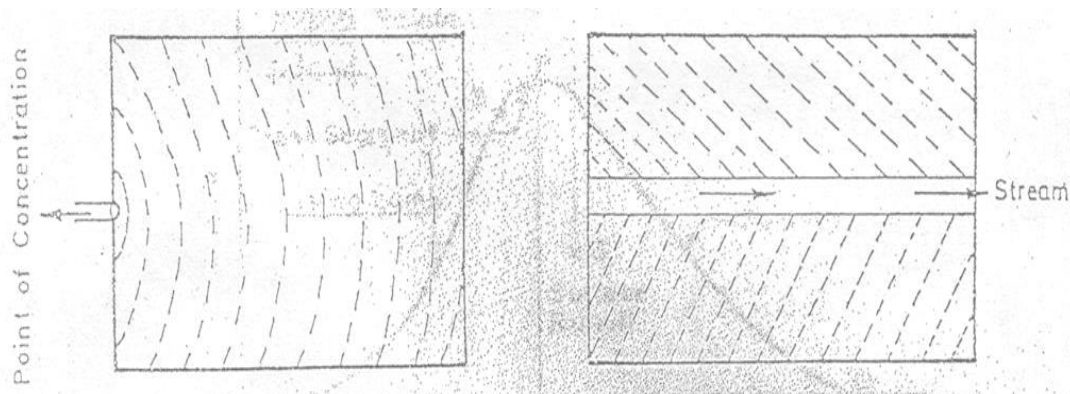


Fig.1: Lines of equal flow time for a catchment

Fig.2: A Valley catchment

Fig. 1 shows lines of equal flow time for a catchment of similar proportions to the model in which the flow velocity is everywhere the same. Fig.2 illustrates a valley catchment in which the flow velocity is assumed to increase once the water has entered the stream channel. Flow outside the stream could be either surface or ground water flow or both.

10.2.1. Time of concentration:

The time required for water to travel from the most remote portion of the basin to the outlet is called the time of concentration.

10.2.2. Hydrograph:

A graphical representation of discharge in a stream plotted against time chronologically is called a hydrograph. Depending upon the units of time involved, hydrographs are,

- i. Annual Hydrograph
- ii. Monthly Hydrograph
- iii. Seasonal Hydrograph
- iv. Flood Hydrograph

i. Annual Hydrograph:

Showing variation of daily or weekly or 10 daily mean flows over a year.

ii. Monthly Hydrograph

Showing variation of daily mean flow over a month.

iii. Seasonal Hydrograph

Showing variations of the discharge in a particular season such as the monsoon season or dry season.

iv. Flood Hydrograph

Hydrographs due to a storm representing stream flow over a catchments.

Flood hydrographs result due to an isolated storm is typically a single-peaked skew distribution of discharge. Fig. 3 shows a typical hydrograph resulting from a single rain storm. The duration and

intensity of the rainfall is shown by the block in the upper part of this figure and if the rainfall persists for longer than the time of concentration of the catchment, the run-off hydrograph will level off at the peak value on the catchment. Under these circumstances, the recession curve part of the hydrograph is delayed until the rain stops.

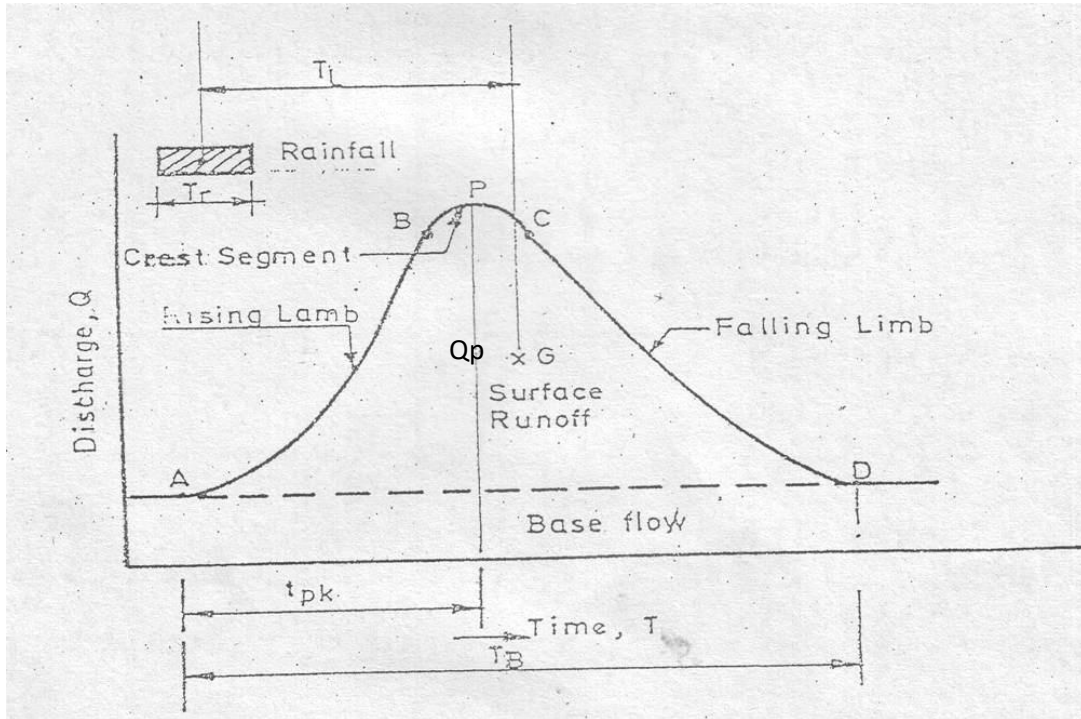


Fig.3: A typical hydrograph resulting from a single rain storm

During the early stages of the storm, so long as no recent rain has fallen, the ground will be able to absorb the water falling on it and add it to the ground water already present. When all the voids are filled, the excess must flow over the surface and enter the stream directly as surface flow. When the surface flow first reaches the point of concentration it produces a sharp rise in the hydrograph and this hydrograph discontinuity can be used to separate the ground water contribution from the direct run-off, as indicated in the figure. The hydrograph shown in Fig.3 is typical for storms of duration shorter than the time of concentration of the catchment.

The streamflow which is measured during a flood is the result of several watershed functions. Obviously, a major part of the flood is the result of direct run-off. Surface run-off is the streamflow which results when the overland flow arrives at a channel. The overland flow regime appears to

follow a laminar or a distributed laminar type of resistance law. In contrast, the channel flow is always turbulent.

It is convenient to define the following three parts of a flood hydrograph:

1. Concentration curve or rising limb
2. Crest segment
3. Recession curve or depletion curve or falling limb

The concentration curve exists between the point of rise at the beginning of the flood and the peak (if it can be recognized) or the point of inflection of the curve on the rising limb just prior to the peak. The crest segment exists between the point of inflection on the rising side and the point of inflection on the recession side of the peak. The shape of the rising limb is influenced mainly by the character of the storm which caused the rise. The point of inflection on the falling side of the hydrograph is commonly assumed to mark the time at which surface inflow to the channel system ceases.

10.2.3. Recession Limb:

The recession limb extends from the point of inflection at the end of the crest segment to the commencement of natural ground water flow. It represents the withdrawal of water from storage within the basin. The starting point of the recession limb shows the maximum storage. The shape of the recession is largely independent of the characteristics of the storm causing the rise. However, the recession curve for a basin is a useful tool in hydrology.

Barnes showed that the following equation could be used to define the recession curve.

$$Q_t = Q_o K_{rec}^t = Q_o e^{-\alpha t} \quad (1)$$

Where,

Q_t = flow t time units after Q_o

Q_o = flow measured t time earlier

K_{rec} = recession constant

t = time in between Q_o & Q_t

e = napierian base

$\alpha = -\ln K_{rec}$

Eq. (1) will plot as a straight line on semi-logarithmic graph paper provided K_{rec} for groundwater (K_{rb}) since, presumably, both interflow and surface runoff have ceased. By projecting this slope

backward in time and replotting the difference between the projected line and the total hydrograph, a recession which for a time consists largely of interflow is obtained. With the slope applicable to interflow thus determined, the process can be repeated to establish the recession characteristics of surface runoff.

10.2.4. Base flow separation:

Base flow may be separated by any of the following three methods.

a. Straight line separation

In this method the separation of the base flow is achieved by joining with a straight line the beginning of the surface runoff to a point on the recession limb representing the end of the direct runoff. In Fig. 4 point A represents the beginning of the direct runoff and it is usually easy to identify in view of the sharp change in the runoff rate at that point.

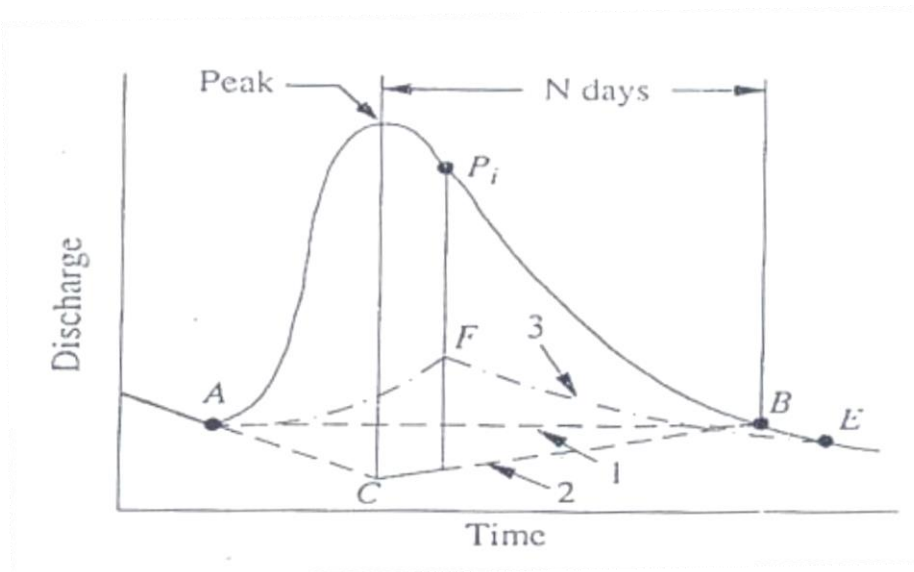


Fig.4: Base flow separation methods

Point B, marking the end of the direct runoff is rather difficult to locate exactly. An empirical equation for the time interval N (days) from the peak to the point B is

$$N = 0.83A^{0.2}$$

Where A = drainage area in km² and N is in days. Points A and B are joined by a straight line to demarcate to the base flow and surface runoff. It should be realized that the value of N obtained as above is only approximate and the position of B should be decided by considering a number of

hydrographs for the catchment. This method of base flow separation is the simplest of all three methods.

b. Fixed base length separation

In this method the base flow curve existing prior to the commencement of the surface runoff is extended till it intersects the ordinate drawn at the peak (point C in Fig. 4). This point joined to point B by a straight line. Segment AC and CB demarcate the base flow and surface runoff. This is probably the most widely used base flow separation procedure.

c. Variable slope separation

In this method the base flow recession curve after the depletion of the flood water is extended backwards till it intersects the ordinate at the point of inflection (line EF in Fig. 4). Points A and F are joined by an arbitrary smooth curve. This method of base-flow separation is realistic in situations where the groundwater contributions are significant and reach the stream quickly.

It is seen that all the three methods of base-flow separation are rather arbitrary. The selection of any one of them depends upon the local practice and successful predictions achieved in the past. The surface runoff hydrograph obtained after the base-flow separation is also known as direct runoff hydrograph (DRH).

10.2.5. Unit Hydrograph

A unit hydrograph is defined as the hydrograph of direct runoff resulting from one unit depth (1 cm) of rainfall excess occurring uniformly over the catchment and at a uniform rate for a specified duration (D-h). This will be known as D-h unit hydrograph. If an appropriate unit hydrograph is available, one can easily calculate the Direct Runoff Hydrograph (DRH) in a catchment due to a given storm.

10.2.6. S-curve

The S-curve, also known as S-hydrograph, is a hydrograph produced by a continuous effective rainfall at a constant rate for an infinite period. It is a curve obtained by summation of an infinite series of D-h unit hydrographs spaced D-h apart. S-curve is used to develop a unit hydrograph of duration mD , where m is a fraction.

10.2.7. Instantaneous Unit Hydrograph

The limiting case of a unit hydrograph of zero duration is known as instantaneous unit hydrograph (IUH). Thus IUH is a fictitious, conceptual unit hydrograph which represents the surface runoff from the catchment due to an instantaneous precipitation of the rainfall excess of 1 cm. For a given catchment IUH, being independent of the rainfall characteristics, is indicative of the basin storage characteristics.

10.2.8. Synthetic Unit Hydrograph

Unit hydrographs can be derived only if records of rainfall and the resulting flood hydrograph are available. Since only a relatively small portion of catchments are gaged, some means of deriving unit hydrographs for ungaged catchments is necessary. In order to construct unit hydrographs for such areas, empirical equations of regional validity which relate the salient hydrograph characteristics to the basin characteristics are needed. Unit hydrographs derived from such relationships are known as synthetic unit hydrographs.

10.3 Procedure

- 1) This experiment is done in the basic hydrologic system.
- 2) There is a artificial sand bed in the setup.
- 3) First artificial rainfall is created.
- 4) Reading of runoff starts at the beginning of rainfall.
- 5) Reading is recorded at every 10 second interval.
- 6) The rainfall will be stopped after 100 sec.
- 7) Reading is continued up to two consecutive readings become same.
- 8) The total hydrograph is then plotted in a plain graph paper.
- 9) The recession limb will be plotted on semi log paper.
- 10) A tangent is drawn at the constant value of the recession limb.
- 11) The slope of this tangent gives the recession constant for base flow (K_{rb}).
- 12) The ordinates of the tangent give the value of the base flow.
- 13) Now by subtracting the ordinates of this tangent from the total runoff we get the hydrograph for interflow and surface runoff.
- 14) If interflow is neglected i.e. taking the recession constant for interflow 1, then the surface runoff is calculated by subtracting the ordinate of base flow from the total hydrograph.

Surface runoff = Total runoff – base flow

10.4 Objective

- 1) To draw the recession limb of hydrograph on a semi-log paper.
- 2) To find the recession constant for base flow.
- 3) To find the recession constant for interflow.
- 4) To find the recession constant for surface run-off.
- 5) To find the surface run-off.

10.5 Assignment

- 1) What is surface run-off?
- 2) What is the time of concentration?
- 3) What is a synthetic unit hydrograph?
- 4) What is an S-curve?
- 5) Distinguish between lag time and time to peak.
- 6) Draw a neat figure of a hydrologic cycle and show the following in it:
 - a. Surface run-off
 - b. Ground water flow
 - c. Evaporation
 - d. Transpiration

STUDENT ID:

DATE:

Data Sheet
HYDROGRAPH ANALYSIS

Area of watershed =

Duration of rainfall =

Time	Discharge	Time	Discharge	Time	Discharge

SIGNATURE OF THE TEACHER

REFERENCES

1. Garg, S.K., *Irrigation Engineering and Hydraulic Structures*, Khanna Publishers, Delhi-21st Edition (April, 2007).
2. Daugherty, R.L., Franzini, J.B. and Finnemore, E.J., *Fluid Mechanics with Engineering Applications*, McGraw-Hill Book Co, Singapore-1989.
3. Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, *Irrigation and Drainage Sessional* (August-2015).

Appendix Lab Report Format

1. All students must have a same colored printed **cover page**. The design of cover page is provided with the lab manual. Students have to compose only the course teacher's name and designation and their information.
2. An **index** is provided. It should be printed and set after the cover page. Table may be filled up by pen during each submission after test.
3. Each report must have a common printed **top page**. Only the experiment name and no. and the date may be filled up by pen. A top page design is provided.
4. **A4 papers** have to be used for preparing the lab report. Writing should be done with **pen**. Pencil may be used for any kind of sketch.
5. In each experiment of the lab report the following points must have to be present: **Objective, Equipment, Procedure, Data Table (signed), Sample Calculation, Result, Discussion and Assignment.**



CE 472

Water Resources Engineering Sessional-II

(Lab Report)



Prepared For
Name of Course Teacher
Designation of Course Teacher
&
Name of Course Teacher
Designation of Course Teacher

Prepared By
Name of Student
Student's ID
Year/ Semester
Group



CE 472

Water Resources Engineering Sessional-II

(Lab Report)

Experiment No. :
Experiment Name:

Date of Performance:
Date of Submission:

Prepared For
Name of Course Teacher
Designation of Course Teacher
&
Name of Course Teacher
Designation of Course Teacher

Prepared By
Name of Student
Student's ID
Year/ Semester
Group

Appendix 3

Lab Instructions

1. All students must have to be present at the class just in time.
2. All students must have to submit the lab report just after the entrance and before the class start.
3. Lab reports have to be submitted serially according to Student's ID.
4. Students have to complete the data sheet in class and complete sample calculations and graphs in class and take sign from the course teacher. (In some experiment which require more times, data sheet should be completed as possible in class time.)