COURSE CODE: WMA 301

COURSE TITLE: Surface Hydrology I

NUMBER OF UNITS: 2 Units

COURSE DURATION: Two hours per week

COURSE DETAILS:

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Other Lecturers: Dr. Idowu and Dr. Grace Oluwasunya

COURSE CONTENT:

Precipitation: Analysis.
- Thiessen, Isohyetal and Arithmetical method of computations.
- Detection of missing data, Double mass curve, Intensity-Depth-Duration-frequency analysis.

Evapo-transpiration:
- Water budget and energy budget methods of determination of reservoir evaporation
- Evapo-transpiration from climatological data
- Penman method

Stream flow:
- Discharge volume and depth of runoff
- Average annual runoff
- Seasonal runoff
- Relationship between water levels and discharges
    - Rating curves
    - Stream flow hydrograph
    - Overflow

Unit hydrograph:
- Derivation of unit hydrograph
- Synthetic unit hydrographs
- Application of unit hydrographs

Sediment transport:

  Erosive action of rivers
  Suspended load and bed load

Lake and reservoirs:

  Hydrology of lakes and reservoirs
  Inflow-outflow balance of lakes.
  Heat and temperature balance of lakes
  Rivers, estuaries, salinity, waves and current.

COURSE REQUIREMENTS:

This is a compulsory course for all students of the department of water resources management and Agrometeorology and elective course for students from other departments of the College of Environmental Resources Management in the University. In view of this, students are expected to participate in all course activities and have minimum of 75% attendance to be able to write the final examination.

READING LIST:

1. Ayoade, J.O. Tropical hydrology and water resources
2. Duru, L .1984. Climate, Water and Agriculture in the tropics. Longman publishers. London, UK
3. Shaw, M. 1994. Hydrology in practice. Van Nostrand Reinhold. Berkshire, UK.

LECTURE NOTES

PRECIPITATION

The term precipitation includes all forms of water deposited in the earth surface derived from atmospheric vapor. Precipitation is considered meteorological concept when it has not reached the ground. when it reaches the ground it becomes an hydrological concept. The principal forms of precipitation are rain, mist, snow and hail.

Measurement of precipitation

All forms of precipitation are measured by the vertical depth of water that will accumulate if the precipitation remains on the ground without flowing. The most common device for measuring precipitation is the standard rain gauge. Precipitation measurement at present is described as a point sampling procedure. Hence, rainfall over an area has to be estimated from these point measurement. The total quantity over a catchment area or drainage basin is evaluated from thepoint measurement expressed in depth (mm, cm) or sometimes in volume (m^3) for a specific time period. This total quantity over a catchment area or drainage basin is now increasingly referred to as ***areal rainfall*** **or** ***areal precipitation*** and the term average rainfall is restricted to long term average value.

There are many ways of deriving the areal precipitation over a catchment from rainfall gauge measurements. This includes the following:

Arithmetic mean method

This involves the simultaneous measurement for a selected duration at all gauges summed together and total divided by number of gauges (number of stations) in the basin.

$$\text{Pavg} = \sum_{i=1}^{n} \frac{Pi}{N}$$

Where P_{avg} = average precipitation

Pi = total number of stations

N = precipitation depth

The rainfall stations used in the calculation are usually those inside the catchment area, but neighboring gauges outside the boundary may be included if it is considered that the measurements are representative of the nearby parts of the catchment.

The arithmetic mean method gives a very satisfactory measure of the areal rainfall under the following conditions

(1) That catchment area is sampled by many uniform spaced rain gauges
(2) The area has no marked diversity in topography.

Limitation

The method assigns the same weight to each station regardless to location and other conditions

Thiessen polygon method

The rainfall measurements at individual gauges are first weighed by fractions of the catchment area represented by the gauges, and then summed. On the map of the catchment with the rain gauges stations plotted, the catchment area is divided into polygons by lines that are equidistant between pairs of adjacent stations.

<u>Steps in applications</u>

(1) The stations are plotted on a map and joined by straight lines.
(2) Perpendicular bisectors of the lines forms a polygon around each of the stations

(3) The polygon around each station is the limit of the effect of rainfall recorded at that station
(4) The area of each polygon is obtained with a planimeter
(5) The Thiessen formula is then used to obtain the average precipitation.

$$P_{avg} = \frac{\sum_{i=1}^{n} AiPi}{A}$$

$$P_{avg} = \frac{A_1 P_1 + A_2 P_2 + A_3 P_3 + \text{--------} A_n P_n}{A}$$

Where P_{avg} = average precipitation

Pi = Precipitation at individual station

Ai = area of polygon around each of the stations

A = area of catchment

Limitations

(1) Inflexibility because a new Thiessen diagram has to be constructed any time there is a change in rainfall network.
(2) It does not account for the influence of relief where the area is not mountainous

Isohyetal method

This method is considered one of the most accurate methods, but it is subjective and dependent on skilled experienced analyst having a good knowledge of the rainfall characteristics of the region containing the catchment area. The method provides the means of considering orographic or other effects in our computation of average precipitation.

Procedure for applications

(1) Plot on the map the location of the stations and amount of precipitation in each area.
(2) Draw contours of equal precipitation known as Isohyet.
(3) Find area between isohyet (measure using planimeter)
(4) The Isohyetal formula is then used to obtain the average precipitation.

$$P_{avg} = \frac{\sum_{i=1}^{n} airi}{A}$$

Where P_{avg} = average precipitation

ri = mean rainfall between isohyets

ai = inter- isohyetal area

A = Area of catchment

DETECTION OF MISSING DATA

Hydrologist are encountering problem in their use of precipitation data, accuracy of measurement, short duration of data, missing data and lack of homogeneity of records.

Adjustment of data

We make a various type of measurement in hydrology (rainfall, evaporation etc). The measurement varies, we have to make adjustments. The adjustments are made without violating the integrity of measurements.

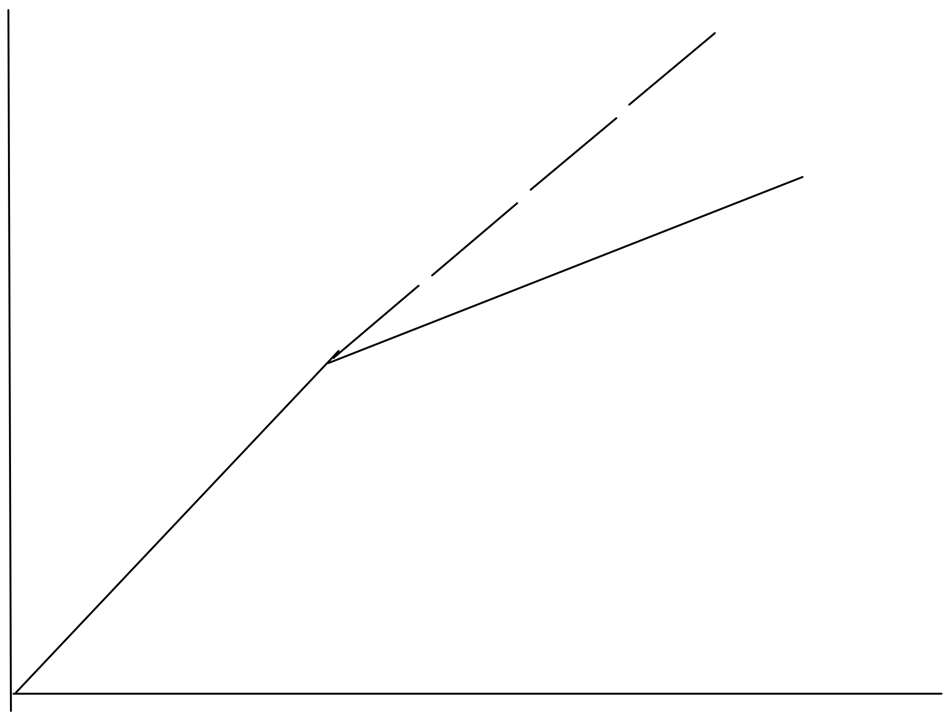
Purpose for making adjustment of data

There are 3 main purposes for making adjustments

(1) To make the record homogeneous with a given environment e.g fitting a uniform period of record for which a mean or normal is to be computed or the conversion of measurement to a standard and height of instrument.
(2) To eliminate or reduce the effect of extraneous influence e.g application of the double mass analysis which tends to correct for changes in gauge location or exposure.
(3) Abstracting or summarizing data for presentation or examination e.g A smoothed isohyetal map on a regression line which shows an average relationship instead of the complexity of a scattered diagram.

Double mass analysis

We use the double analyses to establish the consistency or the lack of consistency of records and to interpolate for the missing data. To do this, the cumulative values at the station in question is plotted against the combined cumulative values of a nearby reliable station or group of stations. After plotting, if the record is consistent, the graph should be a straight line graph, if not it will exhibit a change in slope and this change in slope may be caused by change in exposure or location of gauge or changing in procedure of collecting or processing data. Lack of consistency can be rectified by graphically straightening this break.



Accumulate mean precipitation at a
number of surrounding stations

Alternatively, to synthesis a continuous record, the observation data are adjusted by multiply them by ratio of the slopes of the two line segment.

$$P_a = \frac{S_a}{S_o} \times P_o$$

Where P_a = adjusted precipitation , P_o = observed precipitation,

S_a = slope of line to which records are adjusted.

S_o = slope of line at P_o

We have to exercise a lot of caution in applying double mass techniques. The plotted points always deviate about the mean line and changes in slope should be accepted only when marked or substantiated by other evidence. Double mass is not suitable for adjusting daily or storm precipitation. The effectiveness of method in detecting inconsistency in records and correcting for this depends on the correlation between the station whose records are being texted at the base station or stations. The base stations must be as close as possible in the same climatic type as the station whose record is being tested.

Estimation of missing data.

We often found that many meteorological states have a short break in their records. And this may be due to absence of observer to work. If other gauges exist in the same geological location with concurrent records, it is possible to estimate the missing records. The method that can be used includes.

(1) Arithmetic mean method

Application of the normal annual precipitation of missing station "X" is within 10% of the normal annual rainfall at the adjourning three station a,b,c.

The missing data at X is estimated as

$P_x = 1/3\ (P_a + P_b + P_c)$

Where P_x = precipitation at missing station X

P_a = precipitation at adjoining station a

P_b = precipitation at adjoining station b

Pc = precipitation at adjoining station c

(2) Normal ratio method

Application of the normal annual precipitation at any precipitation of the surrounding station i.e at A,B,C differs from that at the station in question by more than 10%.

(1) Find the cross correlation of each station with station X.

(2) Those that shows reasonable correlation i.e those that have correlation of less than 10 (correlation co-efficient is 0.8 for 10 years data concurrent) are selected for infilling station X.

Assume that a,b and c good correlations for X, then we can estimate the missing data by using

$$Px = \frac{Nx}{Na}Pa + \frac{Nx}{Nb}Pb + \frac{Nx}{Nc}Pc$$

Where Nx, Na, Nb and Nc are normal annual precipitation at the stations. If on the other hand, assuming it is only station ‘a’ that shows good correlation. Then we have

$$Px = \frac{Pa}{Na} Nx$$

Where Nx = mean annual precipitation for station X for common period of record

Na = mean annual precipitation for station ‘a’ for common period of record

Pa = annual precipitation for station ‘a’

(3) Graphical method

Applicable only when are have two stations that are meteorologically homogeneous. In this method graphical comparison of the two rainfall data are plotted and a straight line passing approximately through the middle of all point is drawn. An ordinate is drawn against known value of the station so as to cut the straight line through which another straight line is drawn horizontally to read the correspond rainfall for the missing station.

DEPTH-AREA-ANALYSIS.

In the design of hydraulic structure to control river flow, an Engineer needs to know the areal rainfall of the area drained to the control point. While it is the average river flow that is being considered in some cases, more often the works are intended to control flood flow and therefore knowledge of heavy rainfall is required.

The technique of relating areal rainfall depth to area by analyzing several storms gives depth areal relationship for different specific durations. Hence in a region where particular types of storms are experienced the areal rainfall expected from a given catchment area for a duration to suit the catchment response can be taken for those depth area relationship for that region.

Method or procedure drawing depth area relationship

(1) It is advisable to draw a single cell storm patterns for the analysis.

(2) Isohyet are drawn from the measurement made at all the rain gauge at the area.

(3) The areas enclosed by the isohyet are measured by planimeter.

(4) The area between each enclosing isohyets is estimated.

(5) Average rain between isohyets is taken as the arithmetic mean, the average rain enclosed by the top isohyets is estimated.

(6) The area rain for each enclosing isohyets is plotted against the logrithmns of each area and the depth area relationship for the area for the duration of selected storm is thus obtained.

EVAPORATION AND EVAPOTRANSPIRATION

Evaporation is the term used to describe water loss from water and bare ground surfaces. It is a process by which moisture is converted into water vapour and removed and transported upward into the atmosphere. On vegetated surface where transpiration is an important component of water loss the term evapotranspiration is used. Evapotranspiration is thus the combined process of evaporation and transpiration.

<u>Process of evapotranspiration</u>

(1) Movement of water within the soil towards the ground surface or zone of adsorption around the roots of plants.
(2) Transpiration
(3) Vaporization of the water at soil or plant surface (intercepted water) or the stomata of leaves (transpired water).
(4) Removal and transport of evaporated water, now in gaseous formal into the atmosphere.

<u>Factors influencing the process evaporation-evapotrnapiration.</u>

(1) Availability of moisture at given surface.
(2) Ability of the atmosphere to vaporize the water and remove and transport the vapour upwards.

If moisture is always available in sufficient qualities at the evaporating (non limiting water), then evaporation or evapotranspiration wills occur at the maximum rate possible for that environment. The concept of maximum water availability in an evaporating surface is called **Potential evapotranspiration**.

Potential evapotranspiration is the water loss that would occur from a permanently moist surface.

<u>Factors controlling rate of evaportranspiration</u>

(1) Climatic factors (**Major)**

- (a) Amount of energy available (solar radaition).
- (b) Atmosphere (air) humidity
- (c) Wind speed.

  others are derived from the major component
- (d) Sunshine duration
- (e) Temperature

(2) Non climatic factor

- (a) Characteristics of evaporating surface
- (b) Whether it is water or soil.
- (c) If soil whether vegetated or not.
- (d) Type of soil and land management
- (e) Moisture content of soil profile,

  If water surface:
- (f) Turbidity of water
- (g) Depth of water
- (h) Surface area of water body.

<u>Methods of estimating evaporatranspiration</u>

(1) Water budget or the water balance method.

(2) Empirical formulae method

(3) Mass transfer method

(4) Energy balance method

(5) Penman's theory approach.

Water budget

The water budget approach is a measurement of the continuity of flow of water and it holds for any time interval and applies to a drainage basin.

In the approach, the emphasis is on the total amount of water gained by drainage basin and total amount lost by the drainage basin.

i.e Input – output = storage.

Requirement

(1) Systematic rainfall records

(2) Regular stream gauging

(3) Storage condition (surface & ground water condition)

Putting all this into consideration we can deduce evaporation to be total input minus total losses. i.e

$E_t = P - R \pm G \pm S \rightarrow P - R - \Delta S \ (\Delta S = G + S)$

Where E_t = Evapotranspiration

E = Evaporation

P = total precipitation

R = surface runoff (surface outflow)

G= underground out flow or inflow (ground storage).

ΔS = Change in storage both surface and subsurface.

Looking at the terms in the equation. There is problem of accuracy since most of the terms are difficult to measure in our locality. Hence, there are sparse records. Also the evapotranspiration so obtained is more of potential than actual and the potential evapotranspiration figure are higher than the actual evapotranspiration figure because it presupposes that the total area for which the figure is applicable is covered by water.

STREAM FLOW

The hydrologist is interested in flow rate or discharge of a river in terms of cubic metres per second (m^3/s). stream flow data are gathered primarily for hydrologic study and to engineering hydrologist, stream flow is the depending variable in most of our studies because in engineering hydrology we are concern with estimating of rate or volume of flow or the change in those values resulting from human activities.

In practice, it is always difficult to make direct measurement and continuous measurement of stream flow in a stream but, it is easier to obtain a continuous record of stage. Stage is the primarily field data at most stream flow measurement station.

River stage

It is the water level at a gauging station. It is measured with respect to a datum either to a local bench mark or to the crest level of the control which in turn should be leveled into the geodetic survey datum of the country. All continuous estimates of the discharge derived from a continuous stage record depend on the accuracy of the stage values.

Stage measurements

Stage measurement instrument are grouped into

(i) Recording
(ii) Non recording.

The staff gauge

This is a permanent graduated staff generally fixed vertically to the river bank at a stable point in the river unaffected by turbulence or wave action. The gauge may be conveniently attached to the upstream side of a bridge piles firmly or other structures that extends into the lower channels of the river. The gauge should extend from the datum or lowest stage to the highest stage expected. Where there is a large range in the stage with a shelving river bank, sectional staff gauge can be used with appropriate overlaps to give continuity.

All staff should be made of durable materials insensitive to temperature changes and they should be kept clean especially in the range of average level.

Crest gauges

These are used for minor gauging stations where flood records are particularly important. it consist of 50 mm diameter steel tube perforated near the bottom and closed at the top with one or two holes under a lid to allow air to escape. Inside the tube is a removable rod that retains the highest water mark from floating granular cork supplied near the base. The crest gauge is leveled into a measured staff gauge or bench mark on the bank. The rod is clean and the crest gauge reset after each reading.

Disadvantages

They must be read frequently

Autographic recorders

The most reliable means of recording water level is provided by a floating operated chant recorder. To ensure accurate sensing of small changes in water level, the float must be installed in a stilling well to exclude waves and turbulence from the main flow.

Mechanisms used for the operation

(1) The moving float looped over a geared pulley with a counter weight activates a pen marking the level on a chat driver round on a vertical clock work drum. The level calibration of the chart should accommodate the whole range of water levels but extreme peaks are sometimes lost. The timescale of the chart is usually designed to serve is week but the trace continuous round the drum until the chart is charged or the clock stops.

(2) The float with its geared pulley and counterweight turns the charted drum set horizontal and the pen arm is moved across the chart by clockwork. With this instrument all levels are recorded, but the time scale is limited.

Acoustic gauges

Here ultrasound transducers are often used to determine water depth. The pulse of ultrasound from the subsurface transducers is reflected normally from the water surface and the travel time to and from the transducers determines water depth and hence water level.

DISCHARGE (RUN-OFF)

The most direct method of obtaining a value of discharge to correspond with a stage measurement is by the velocity- area method in which the flow velocities are measured at selected verticals of known depth across a measured section of the river. Around 90% of the world's river discharges depends on this method.

At a river gauging station, the cross section of the channel is surveyed and considered constant unless major modifications during flood flows are suspected, after which it must be re-surveyed.

Measurement of velocity

Float method: the simplest method for determining a velocity is by timing the movement of a float over a know distance. Surface floats comprising any available floating object are often used in range preliminary surveys, these measurements give only the surface velocity and a correction factor must be applied to give the average velocity over a depth. A factor of 0.7 is recommended for a river of 1m depth with a factor of 0.8 for 6m or greater.

Types of floats

(1) Surface float
(2) Canister float
(3) Rod float

Current meter

This is reasonably precise instrument that can give a nearly instantaneous and consistent response to velocity changes. It is of simple construction and big enough to withstand rough treatment in debris laden flood flows.

Types

Cup types – this has an assembly of six cups revolving round a vertical axis, it is more robust but has a high drag. It registers the actual velocity whatever its direction, rather than the required velocity component normal to the measuring section.

Propeller type

This has a single propeller rotating on a horizontal axis. It is more sensitive and easily damaged but has a low drag and records the true normal velocity component with actual velocities up to 15^0 from the normal direction.

Both types of instrument used to be calibrated to obtain the relationship between the rate of revolutions of the cups or propeller and the water velocity. Each individual instrument generally has its own calibration curve or rating table and if in regular use, it should have a calibration check every year. The sampling of the velocities across a gauging section depend on the size of the river and its accessibility sampling can be done by wading bridge (reel carried on a trolley), Boat cable way.

Gauging procedure

At the gauging station or selected river cross section, the mean velocities for small sub-area of the cross- section (Vi) obtained from point velocity measurement at selected sampling vertical across the river are multiplied by the corresponding sub-area (ai) and the products summed to give the total discharge.

$$Q = \sum_{i=1}^{n} Viai$$

When n = the number of sub-areas

(a) The estimate Q is the discharge related to the stage at the time of gauging; therefore before beginning a series of current – meter measurement the stage must be read and recorded.

(b) The width of the river is divided into about 20 sub-sections so that no sub-section has more than 10% of the flow

(c) At each of the selected sub-section points, the water depth is measured by sounding and the current meter operated at selected points in the vertical to find the mean velocity in the vertical, e.g at 0.6 depth (one point method) or at 0.2 and 0.8 depth (two point method). At a new gauging station where the vertical velocity distribution is at first unknown, more reading should be taken to establish that the best sampling points 1- give the mean are those of the usual one or two point methods.

(d) For each velocity measurement, the number of complete revolutions of the meter over a measured time period (about 60s) is recorded using a stop watch. If pulsations are noticed, then a mean of three such counts should be taken.

(e) When velocities at all the sub-division points across the river have been measured, the stage is read again should there be difference in stage readings over the period of the gauging, a mean of the two stages is taken to relate to the calculated discharge. Once gaugers have gained experience of a river section at various river stages, the procedure can be speeded up and one velocity reaching only at 0.6 depth taken quickly at each point across the stream, with the depths relating to the stage already known.

Relationship between stage & discharge (rating curve)

When continuous flow data are required from the continuous stage records at a river gauging station. It is essential to establish a reliable relationship between the monitored variable stage and the corresponding discharge.

However, conditions in a natural river are rarely stable for any length of natural river are rarely stable for any length of time and thus the stage-discharge relation must be checked regularly and certainly after flood flows, new discharge measurement should be made throughout range of stages. The stage – discharge relationship can be represented in three ways.

(1) Graphical plot of stage versus discharge
(2) Tabular form (rating table)
(3) Rating equation

SEDIMENTATION

Includes all processes in the denudation (weather process) of land surface where by the rock waste or mantle is removed and deposited by surface agents. The hydrologic definition of sedimentation restricts the definition to the action of running water and excludes other surface agents such as wind and ice.

Erosion

The wearing away of earth surface by surface agents. The major part of which is accomplished by running water through the removal of rock and soil by sheet flow without the formation of significant channel (sheet erosion). Also progressive enlargement by concentrative runoff called gully. There is also the bank cutting and also stream bed erosion. In between the erosion and deposits is transportation, then deposit is the final stage. The deposition of eroded particles transported by stream which occurs in river channel flood plain, lakes, reservoir, canal harbor whenever the velocity of the sediment carrying stream is checked resulting in a reduction of transportation power (carrying capacity) and consequent deposition of sediment.

Sediment problems

In the design of engineering works many problems are encountered where the nature of work demand storage or diversion of sediment laden water. some of the serious problems includes.

(1) Reservoir sedimentation.

(2) Scour and deposition in irrigation canal

(3) Degradation of the stream bed below a dam.

(4) Problem of sediment entering the penstocks.

Sediment transportation theory

Sediment moved by flowing water may be divided into three classes according to the physical process by which it is moved.

(1) Bed load(contact load)

(2) Suspended load (also dissolved load)

(3) Saltation load

The physical process involving the movement of sedimentary are related to water flow and to the force exerted by the water on the sediment particles. The motion of stream water is turbulent and the degree of turbulence depends on the degree of roughness of the bank and the bed and the velocity to which the water moves.

Bed load

Relatively coarse particles (sands, gravel, silts) moves with water on the bed down stream. Materials rolls or slides along the bed in substantially continuous contact with the bed due to the turbulence of the velocity is of a magnitude for a sufficient period to exert a force on the particle overcoming it's mential motion is produced thus the sedimentary will roll or slide along the stream propelled by the require velocity and force. It usually forms a very small percentage between 0 to 20% of total load carried by the river.

Suspended load: is moving in suspension and which is maintained in these portion by component of upward current of turbulent water tending to force the particles upwards uphold the force of gravity tending to pull the particles downwards. The particles are retained in suspension for a time interval depending on the settling rate of particles (Stoke's law).

Total sediment load = bed load + suspended load

Saltation: is the material bouncing along the bed or moved directly or indirectly by the impact of the bouncing particles as more amount of material in the form of particles travelling near the stream bed may intermittently strike the bed and bounce upward and as a result of impact many force other particle upwards into the flowing water for a temporary period except in very high velocities or very turbulent water.

Agents of transportation

(1) Runoff

(2) Splash of raindrops

Dissolved load

Consist of materials capable of forming solution in which state they are transported. They are made up of anions and cations as well as dissolved colloids

Anions → Cl^-, SO_4^{2-}, CO_3^2 , HCO_3^- NO_3^- , Po_4^3

Cation → Ca^{2+} , Na^+ , K^+ and Mg^{2+}

Dissolved colloids → SiO_2(dissolved silica)

LAKES AND RESERVOIRS

A lake is generally described as a partially enclosed body of fresh water surrounded by land. It origin may be natural or artificial. A lake is characterized by hydrological chemical, biological and sedimentological parameters depending on its age, its history, the prevailing climate and its water budget. Lakes commonly pass through an organic cycle which is divided into four stages.

(1) Oligotrophic stage; this is the initial stage in which nutrient are present in small concentration thereby limiting the production of living organism matter balances its production.

(2) Mesotrophic stage : which represent a stage when supply of nutrient is increased and there is a corresponding increase in community of living organism thereby leading to the accumulate of organic matter.

(3) Eutrophic stage: here the lake becomes very rich in nutrients, living organisms flourishes and organic matter accumulates at a high rate. Such organic matter is present largely as bottom deposits.

(4) Dystrophic stage: there is excessive accumulation of both organic and holmic materials and this limit the biological activities within the lake. At this stage the lake is in the process of becoming marsh.

Classification (different types) of lakes

(1) Tectonic lakes from tectonic mechanism

(2) Volcanic lakes.

(3) Solution lakes

(4) Lake basin formed by

- (i) Fluvial process
- (ii) Wind action
- (iii) Shoreline process
- (iv) Organic accumulation
- (v) Activity of man → man – made lakes (reservoir) for water supply, hydro-power, irrigation.
- (vi) Impact of meteorites'.

Tectonic: mechanism have been responsible fir very large scale movement which caused the formation of vast lake in places like south eastern Europe southern Asia and east Africa. Particularly in east Africa small crustal movement vertically downward formed the lake Victoria, lake Nyasa and

L.Tanjeyica. Also, submarine tectonic depression which have been caused by differential marine sedimentation may become lake when uplifted above sea level.

Volcanic lake: lake of volcanic origin are often very deep and usually smaller than those of tectonic formation. They may be formed by

(1) Lava- damming (lava is the product of volcanic erosion) e.g L. kivu in east Africa and sea of galilee.

(2) Crater explosion e.g carter lake of origin (usa)

(3) Collapse of solidified lava crust.

Solution lakes

Are common in areas underline by carbonate, evaporation or evaporitic rocks are very often reliable to solution by ground water thereby leading to the formation of sinks. Such lakes usually exhibit annual flunctuation in water level and some may drain away suddenly through subsurface conduits when a natural underground siphon is operated by very high water levels. Carbonate is accomplished by care or cavern formation.

$$CaCo_3 + H_2 O + CO_2 \rightarrow 2HCO_3 + Ca^{2+}$$

Lake basin formed by fluvial processes

Fluvial action may produce ox-bow lakes and these results from the shifting of the channel or by deposition of sediment barriers.

Those formal by wind action or eolian

Wind is also capable of producing closed depression by erosive process of deflation and by deposition of wind burned sediments most of such lakes are rather shallow and some may contain water only seasonally.

Those formal by shore line process

In marine areas accumulation of beach sands formed by waves and currents may close valleys and thereby form hostile lagoons. The Lagos lagoon may have been formed by such a process.

Those formed by organic accumulation

This set of lakes includes those formed when large masses of plant dam a stream as well as those formed by accumulation of oral fragment in tropical and subtropical oceanic region, the latter are also called Oral lakes. Some of such lakes many retain subsurface connection with the sea and therefore the water level will rise and fall with the tide.

Man made lake

These are lakes that have been artificially constructed across drainage system to serve definite purposes they are mostly deeper at the dam and than farther upstream soon after the dam have been filled by water, wind action by way of waves and currents modify the shore line through erosion and sedimentation. Large man made lakes includes the lake Kariba (Zambia, L. kanji (Nigeria) and the volta lake (Ghana).

Those formed by impact of meteorites

The surface of the earth is sometimes bounded by cosmic bodies which are generally called meteoroties. There is a stone and iron meteorite. The impact of such a body which very often produces an explosion creates circular crater.

Inflow-outflow balance in lake

There may be more than one inflow & outflow in lake. The inflow, outflow balance or water budget.

$E_T = P\text{-}R \pm G \pm S = P\text{-}R\text{-}\ \Delta S.$

The water budget method is used as the quantitative expression of water cycle in the lake. The stream flow in discharge into or out of the reservoir must be measured in well defined channel and measurement must be continuous. There is need for a rating curve for easy measurement of discharge which is frequent (annually). The volume of precipitation of the lake surface must be accurately determined through precipitation gauges which are located at the shore of the lake. In very large lakes, more precipitation gauges may be required. The net seepage or bank storage cannot be measured directly, particularly bank storage is evaluated by a study of the ground water elevations in well around the lake.(note ; observation wells (boreholes) are located around lakes (dams) so as to determine the amount of losses (seepage) through the lake. However, in most cases, seepage and bank storage values are usually small. The change in reservoir storage could be determined by use of water storage records.

Temperature variation in lakes

Lakes exhibit variation in temperature as a function of depth from one part of the year to the other.

Shortly after the raining season the water in a lake is isothermal from the surface to the end (same temperature). Gradual warming at the surface later occurs by solar radiation. The warm surface water is mixed downwards by wind and wave action, thus, the in-coming heat is distributed uniformly throughout the lake except in very deep ones. As surface heating continuous, the warmer water near the surface becomes sufficiently light resist complete vertical mixing. The action of wind continues however and under the combined effect of heating & mixing a relatively shallow layer of isothermal water develop. Below this layer a vertical temperature gradient is much increased. Thus stable layer of isothermal water is called the thermocline. The thermocline therefore separates the warmer water mixed layer which is called the EPILIMNION from the deeper cooler water called Hypolimnion.

Shortly after its formation the thermocline is shallow often forming under 2-3m below the surface. Period of strong wind result in deeper mixing and the thermocline descend. Lighter wind continued heating may then form a new warm layer and thermocline will be formed at a deeper level. This process often repeats itself and it is usual to have several thermocline existing simultaneously during a hot part of the year. The whole process of thermocline formation is called thermal stratification.

STREAM FLOW HYDROGRAPH

This is the graphical representation of stream flows fluctuation arranged in chronological order. The discharge hydrograph is obtained from continuously recorded river stages and the stage-discharge relationship appropriate to the gauging station. What do we do to plot discharge hydrograph.

We plot Q against time, Q in curves and time in his , days or months. We can obtain discharge by measuring with level of the river.

In plotting hydrograph, we plot stage against time. Now when rainfalls, part of it will go as infiltration into the ground and when they get into the ground they get to the stream due to ground water movement. Part of will flow over the surface and gets to the streams. The water which moves much slowly than surface run off and this is what artributes to the sustained flow of stream during period of pry weather.

Hydrograph has two main components :

(1) Surface runoff- produced by a volume of water derived from the storm amount.

(2) Baseflow- which is contributed from the ground water, if we plot.

So far, we see the parts of the hydrograph. the

At the beginning of rainfall, the river level is low, there is a time lapse before the river begins to rise, during this period, the rainfall is intercepted by vegetation or infiltrates the earth and contribute to the soil moisture deficits. The length of the delay before the river rises will depend on the wetness of the catchment/ basin before the storm and also on the intensity rainfall.

After rainfall has made up catchment deficit and when the surface and the soil are saturated, surface runoff begins. The proportion and portion of rainfall that find its way into river is known as effective rainfall.

Apart from this effective rainfall, there are physical phenomena like evaporation detention on the surface or retention in the soil will account from remaining losses.

The limb rises to a peak and even after the rainfall has stopped, it rises and fall until it parts to the inflection point. The recession is known as the falling limb at the recession were the water flow/ base flow continues to provide the flow until the water from the whole of the effective rainfall is completely depleted.

The slope of the rising limb is influenced by the character of the storm which caused the rise. The recession curve depend on the character of the storm causing the rise.

It should be noted that on large basins subject to runoff producing rainfall ever early a part of the basin, the recession may very from storm to storm depending on the particular area of runoff generation. If there should be rainfall whole the recession of a recent storm is in progress, the recession will naturally be distorted. The recession curve is a useful tool is hydrology.

Equation for recession curve and/ or depletion curve

$Q_1 = q_0kr$--------------(1)

Where q_0 = flow at any time.

Q_1 = flow one time unit later

$K_{r\,=}$ recession constant which is less than unity

Rewriting (1)

$$Q_t = q_0 kr^t = q_e e^{-\Box t}$$

Where q_t is the flow at the end of time t and

Q_o is the flow at the start of period.

E is the raperian base and $\Box$ = -tlog Kr

This equation resemble equation of a straight line.

$$Y = mx + c$$

$$\text{Log}q_t = \log q_o - t \log kr$$

The value of kr can be determined by plotting the value of recession data that is value of q_t versus t on a semi log paper.

The lag is the measure of the catchment response time. The hydrograph consist of two components.

(1) Surface runoff and (2) baseflow. The problem arises therefore of separation of baseflow and runoff.

Determining the boundary between surface runoff and base flow.

The boundary between the surface runoff and baseflow is difficult to define and will depend largely on the geological structure and composition of the catchment. If we have permeable aquifers like limestone or sandstone strata, there aquifers will sustain high baseflow contributions but strata like impervious clay and built-up area provides little or no baseflow to a river.

The baseflow is also affected by the general climatic state of the area and hence baseflow tend to be high after wet weather and very low after prolonged drought.

When rainfalls, the baseflow component of the hydrograph continues to fall ever after the river levels have begin to rise and only when the storm rainfall has had time to percolate down to the water table thus, the baseflow division curve begin to rise. It is usual for the baseflow component to finish at a high level at the end if the storm surface runoff than at the rise of the hydrograph. There is thus, an enhanced river flow from the ground water storage after a significant rainfall event. Ground water provides the total flow of the general recession curve until the next period of wet weather.

Factors affecting the shape of a hydrograph

(1) Shape of the catchment
(2) Size of catchment
(3) Rainfall duration;
(4) Rain distribution;
(5) Rainfall variation
(6) Storage characteristics of the basin

UNIT HYDROGRAPH CONCEPT

After hydrograph of surface runoff has being derived, the problem that follow is how the hydrograph can be correlated with the rainfall which cause it.

The quantity and intensity of rain both have a direct effect on the hydrograph though, we don't know how this two does so. The concept of unit hydrograph sort to correlate the hydrograph with the rainfall. (another name for unit hydrograph is unit graph).

UNIT HYDROGRAPH: the unit hydrograph for a catchment is definition as the discharge hydrograph resulting from a unit of direct runoff generated uniformly over the catchment at a uniform rate during a specified period of time.

The correlation to be made is between the net or effective rain (i.e what remains as runoff after all the losses by evaporation, interception and infiltration have being allowed for) and surface runoff (i.e hydrograph of runoff minus base flow).

There are 3 basic assumption involved in the unit hydrograph concept.

(1) With uniform intensity nett rainfall on a particular catchment different intensity of rain of the same duration produce runoff for the same period of time although of drift quantities.
(2) With uniform intensity net rain on a particular catchment, different intensities of rain of the same duration produce hydrograph of runoff, the ordinates of which at any given time are in the same proportion to each other as the rainfall intensities.
(3) The principle of super position : the hydrograph of runoff due to (e.g 3 separate storms is the sum of the 3 separate hydrographs).

A unit rain may be any specified amount of rain measured as depth on the catchment. The unit rain must then appear as run-off in the unit hydrograph.

The area under the curve of the hydrograph has the dimension of instantaneous discharge multiply by time i.e.

$$\frac{L^3}{T} \times T = L^3$$

L^3 = volume of runoff.

Though unit rain is measure in cm but volume = m^3

If we have a unit hydrograph for a particular catchment and a particular duration of rain is known, then the runoff for other rain of the same duration may be predicted. But if however the rainfall is of different duration from that of the unit graph then the unit graph must be altered before it can be used.

DERIVATION OF THE UNIT HYDROGRAPH

Steps

(i) Search rainfall records to the finds storms of the derived duration.

(ii) Locate the associated discharge hydrograph from the stream flow records.

(iii) Separate the base flow from surface runoff.

(iv) Calculate the volume of surface runoff. This is obtained by measuring the area above the base flow separate line and enclosed by the hydrograph (by planimeter)

(v) Calculate total storm flow expressed in mm

(vi) Determine that part of the measured total storm flow that constitute the effective rainfall. The unit hydrograph is then constructed by

(a) Maintaining the same time ordinate as the measured hydrograph

(b) Dividing each of the runoff ordinate by the average dept of effective rainfall to find the ordinate of the unit hydrograph

(vii) The result is the unit hydrograph.

P_{nett} = P – losses------------ (i)

Or

$P_{nett} = \frac{\sum Qdt}{A}$

TRO = total runoff ordinate

BFO= Base flow ordinate.

TRO – BFO = DRO ---------------- (Ib)

Now,

$\frac{DRO}{Pnet}$ = UGO = Unit hydrograph ordinate ---------------(ic)

Where P is the total rainfall

P_{nett} is the nett precitipation (from the hydrograph or direct runoff as equivalent depth over the basin) losses-------------- due to infiltration (FP)

A = Area of drainage basin

T= time interval between successive direct runoff ordinate.