CE 3203
Hydrology

Prepared By-

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Hydrology

COURSE CODE: CE 3203 **CREDIT: 03**

MID EXAMINATION: 2 HOURS **CIE MARKS: 90**

SEMESTER END EXAMINATION: 3 HOURS **SEE MARKS: 60**

Course Learning Outcomes (CLOs): After completing this course, students will be able to-

CLO 01 Understand general terms related to ground water.

CLO 02 Explain concepts of weather, hydrologic cycle and hydrologic losses, uncertainty and reliability.

CLO 03 Design water well.

CLO 04 Estimate mean precipitation, infiltration, evaporation, evapotranspiration.

Sl.	Course Contents	Hours	CLOs
1	Definitions, sources of groundwater, advantages, aquifer, flow, mathematical problems.	6	CLO 1
2	Hydrologic cycle, precipitations, rain gauges, differences, rainfall measurement by Radar, mean precipitation over an area, mathematical problems.	8	CLO 2, CLO 4
3	Introduction, well diameter & depth, design of well screen, open well, tubewell, rotary well construction, well grouting materials.	8	CLO 3
4	Interception, depression, infiltration, horton's formula, mathematical problems. Evaporation & it's types, measurement of evaporation, mayer's formula, water budget method, mathematical problems. Evapotranspiration, mathematical problems.	8	CLO 4
5	Probabilistic approaches, analysis methods, uncertainties in design, Techniques for analysis.	2	CLO 2

References

1. Engineering Hydrology- K Subramanya
2. Engineering Hydrology- Linsley
3. Handbook of Engineering Hydrology- Saeid Eslamian

Week	Topic	Teaching Learning Strategy	Assessment Strategy	CLOs	Page No.
1-2	Ground water	Lecture, Presentation, Video Clip	Mid, Final	CLO 1	06-17
3-4	Ground water condition of Barishal division.	Presentation	Assignment, Mid, Final	CLO 1	18-19
5	Weather and hydrologic cycle.	Lecture, Presentation	Mid, Final	CLO 2, CLO 4	20-25
6-7	Precipitation.	Lecture, Presentation	Class Test, Mid, Final	CLO 2, CLO 4	26-42
8-9	Design of water well.	Lecture, Presentation	Mid, Final	CLO 3	43-58
10-11	Water well drilling and construction.	Lecture, Discussion	Assignment, Mid, Final	CLO 3	59-79
12	Hydrologic losses (1).	Lecture, Discussion	Class Test, Assignment, Final	CLO 4	80-89
13-14	Hydrologic losses (2).	Lecture, Discussion	Assignment, Final	CLO 4	90-104
15-16	Hydrologic reliability and uncertainty.	Lecture, Presentation	Final	CLO 2	105-109

ASSESSMENT PATTERN

CIE-Continuous Internal Evaluation (90 Marks)

Bloom's Category Marks (out of 90)	**Tests (45)**	**Assignments (15)**	**Quizzes (15)**	**External Participation in Curricular/Co-Curricular Activities (15)**
Remember	10		10	Attendance 15
Understand	5		5	
Apply	10			
Analyze	10			
Evaluate	5			
Create	5	15		

SEE- Semester End Examination (60 Marks)

Bloom's Category	**Tests**
Remember	10
Understand	10
Apply	10
Analyze	15
Evaluate	10
Create	5

Ground Water

(Week 1-2)

What is Hydrology?

"Hydrology" (**Hydro + Logos**) is the study of water.

It is the science that deals with the study of water on the earth's surface, under the surface of earth, the properties and movement of water and so on.

What is Ground Water?

In general, “Ground water” or “Surface water” refers to the water that occurs below the surface of the earth.

Ground water is being continuously utilized and re-used in many ways in our daily life.

Sources of Ground Water

The following are the major sources of groundwater:

i. Meteoric water,

ii. Connate water and

iii. Juvenile water.

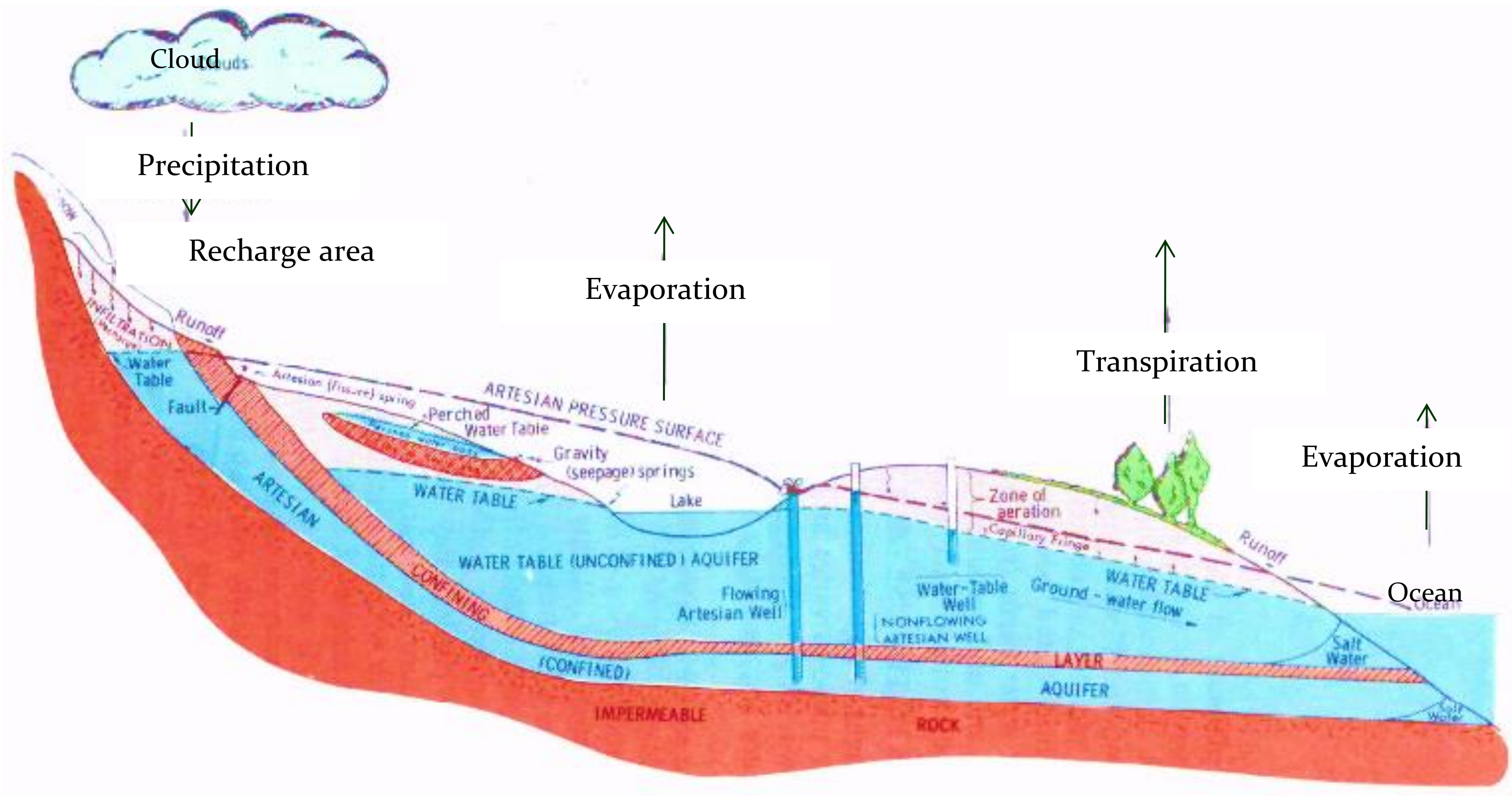
Meteoric water: This includes rain, sleet, snow, hail and other forms of precipitation. It is this water which fills the soil and upper crust of the earth. It is the most important source of water used by human.

Sources of Ground Water

Connate water: This is the seawater or fresh water trapped in sediments when they are deposited on sea bottoms or lakes. It is usually salty. Connate water is often found in rock units with oil. This oil floats on it and rises upward until it is trapped.

Juvenile water (Magmatic water): This water is produced from volcanic and magmatic activity and during the process of crystallization of rock molecules. It is hard to determine how much of this water is coming to the surface of the earth at present.

Sources of Ground Water

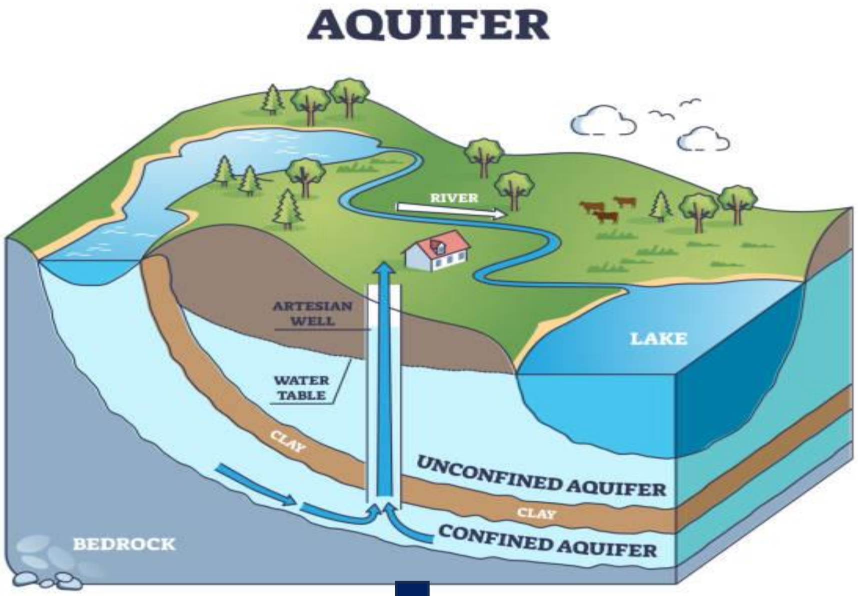


Advantages of Ground Water

- ❖ Free from pollutants.
- ❖ Free from pathogenic organism.
- ❖ Very useful for domestic use.
- ❖ It is rich in several minerals.
- ❖ It can be made available with small capital cost.
- ❖ Has been an important water source from ages.

Aquifer

- It is observed that the surface of earth consists of alternate courses of pervious and impervious strata.
- The pervious layers are those through which water can easily pass while it is not possible for water to go through an impervious layer.
- The pervious layers are known as the “Aquifers” or water-bearing strata.



Aquifer

Aquifers are mainly two types:

- ***Unconfined aquifer*** or ***water table aquifer*** is the one in which a water table serves as the upper surface of zone of saturation. It is also sometimes known as *free*, *phreatic* or *non-artesian* aquifer.
- ***Confined aquifer*** or ***artesian aquifer*** is the one in which groundwater is confined under pressure greater than atmospheric. In a well penetration such an aquifer, the water level will rise to the level of the local static pressure or *artesian head*.

Permeability & Laminar Flow

❑ Permeability

It is the measure of the capacity to transmit water or any other fluid through the intersection of a material.

❑ Laminar Flow

The flow in which streamlines are parallel and water flow at low velocity is termed as laminar flow.

Laminar flow principles are applicable for the flow of ground water in aquifer.

Mathematical Problems

Example 1: An undisturbed soil sample has an oven dry weight of 0.655 kg. After saturation with kerosene its weight is 0.732 kg. It is then immersed in kerosene and found to displace 0.301 kg. What is the porosity of the sample?

Solution. Oven-dry weight $w_1 = 0.655$ kg

Weight of saturated sample $w_2 = 0.732$ kg

Weight of kerosene required to saturate the sample

$$= (w_2 - w_1)$$

$$= 0.732 - 0.655 = 0.077 \text{ kg}$$

Weight of kerosene displaced by the saturated sample

$$w_3 = 0.301 \text{ kg}$$

Porosity of the sample n

$$n = \frac{(w_2 - w_1)}{w_3}$$

$$= \frac{0.077}{0.301} = 0.2558$$

$$= 25.58\%$$

Mathematical Problems

Example 2: The water table levels in two observation wells 350 m apart are 210.5 m and 206.25 m. If hydraulic conductivity and porosity of the aquifer are 12.5 m/day and 15%, determine the actual flow velocity in the aquifer.

Solution. $v = K\left(-\frac{dh}{dl}\right)$

$$v = 12.5 \times \left[-\frac{(206.25-210.5)}{350}\right]$$

$$= 0.1518 \text{ m/day}$$

$$v_a = \frac{v}{n} = \frac{0.1518}{0.15} = 1.012 \text{ m/day}$$

$\therefore$ The actual velocity in the aquifer = 1.012 m/day.

dh = Lower level-Higher level
dl = Distance between wells

Ground Water Condition of Barishal Division

(Week 3-4)

Ground Water Condition of Barishal Division

Assignment: Prepare a Presentation on-

"Ground Water Condition of Barishal Division"

Hints:

- Groundwater quality assessment
- Reason of water level degradation
- Water pollution
- Arising problems
- Possible measures to preserve water
- Water quality etc.

N.B.: Each group may consist of 6 members.

No. of slides (30-35), Slide size (standard 4:3)

Weather & Hydrologic Cycle

(Week 5)

Weather & Climate

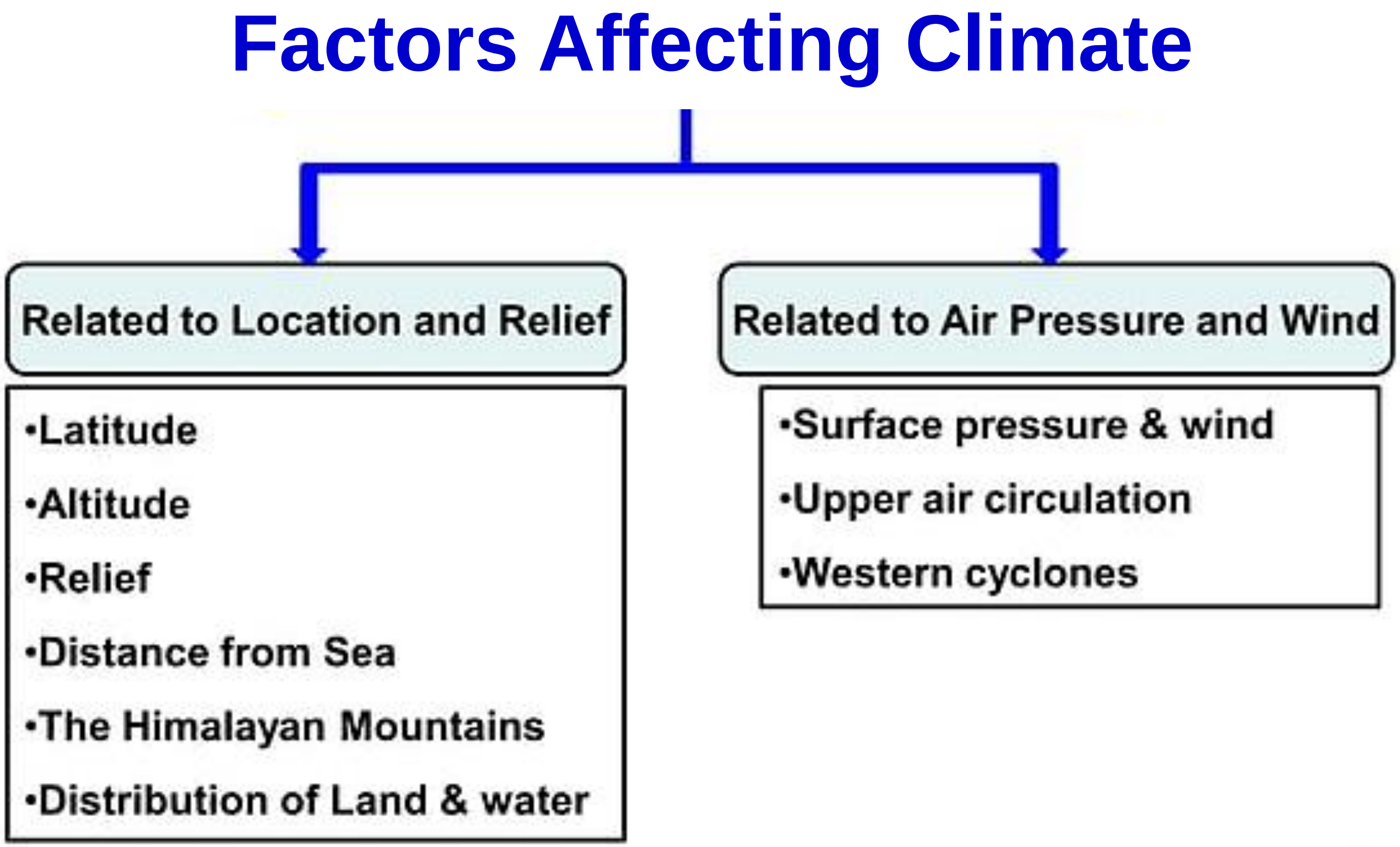
- **Weather-** "the state of the atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness".

- **Climate –** "the average course or condition of the weather at a place usually over a period of years as exhibited by temperature, wind velocity, and precipitation".

Weather refers, generally, to day-to-day temperature and precipitation activity, whereas climate is the term for the average atmospheric conditions over longer periods of time.

(Wikipedia)

Factors Affecting Climate



Hydrology

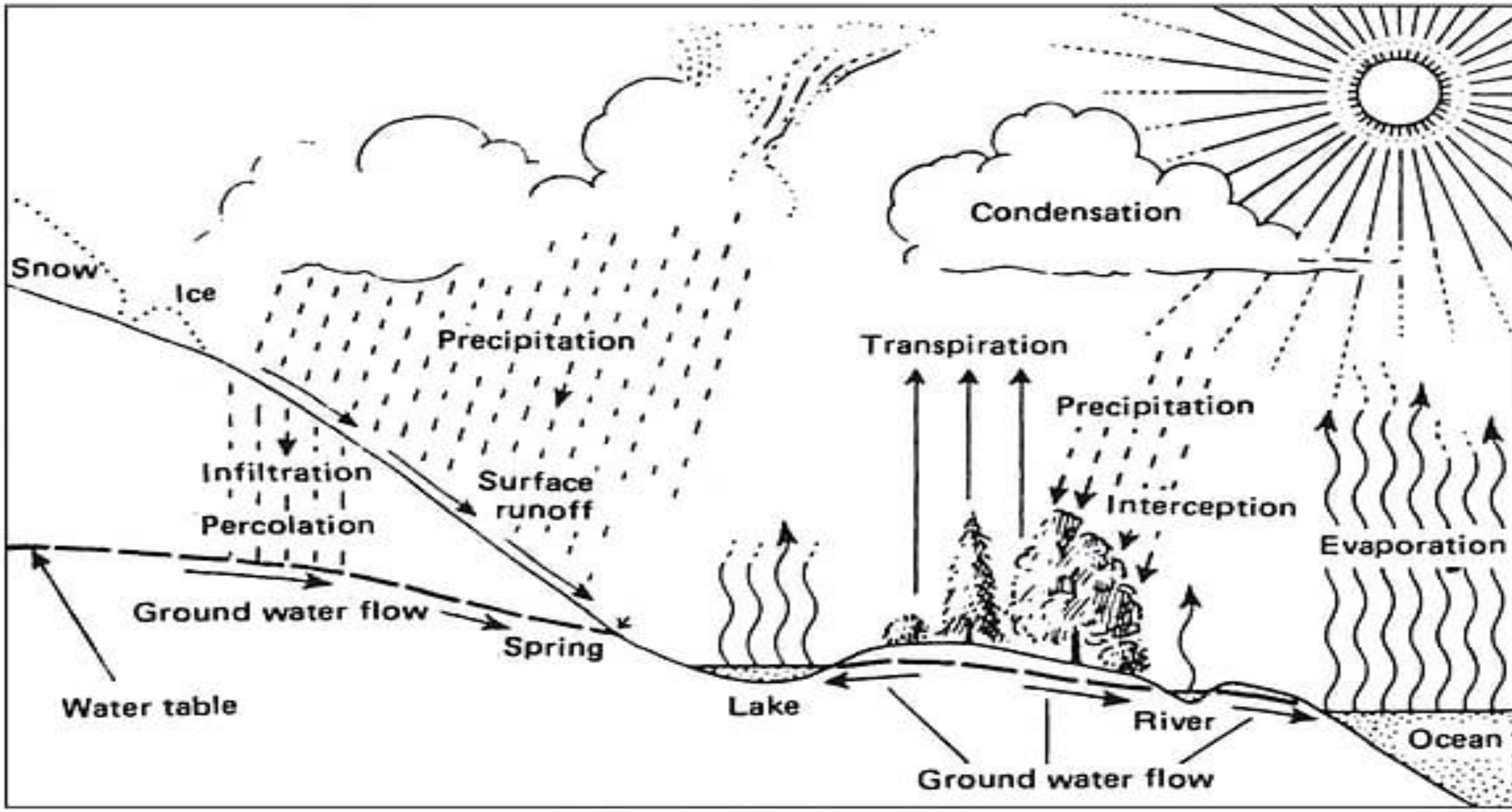
Hydro (Greek) and logos (Greek)

Hydro means water and logos means study

Hydrology is a science which deals with the occurrence, circulation and distribution of water of the earth and earth's atmosphere.

Hydrological Cycle: It is also known as water cycle. The hydrologic cycle is a continuous process in which water is evaporated from water surfaces and the oceans, moves inland as moist air masses, and produces precipitation, if the correct vertical lifting conditions exist.

Hydrologic Cycle



Stages of the Hydrologic cycle

- Precipitation
- Infiltration
- Interception
- Depression storage
- Run-off
- Evaporation
- Transpiration
- Groundwater

Precipitation

(Week 6-7)

Forms of precipitation

- **Rain**

Water drops that have a diameter of at least 0.5 mm. It can be classified based on intensity as,

Light rain → up to 2.5 mm/h

Moderate rain → 2.5 mm/h to 7.5 mm/h

Heavy rain → > 7.5 mm/h

- **Snow**

Precipitation in the form of ice crystals which usually combine to form flakes, with an average density of 0.1 g/cm^3.

- **Drizzle**

Rain-droplets of size less than 0.5 mm and rain intensity of less than 1mm/h is known as drizzle.

Forms of precipitation Contd…

- **Glaze**

When rain or drizzle touches ground at 0°C, glaze or freezing rain is formed.

- **Sleet**

It is frozen raindrops of transparent grains which form when rain falls through air at subfreezing temperature.

- **Hail**

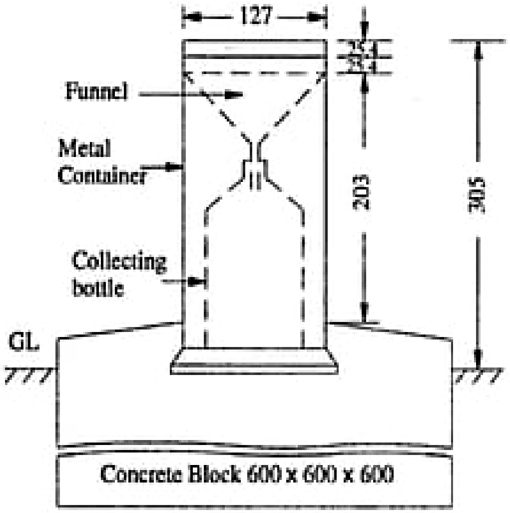
It is a showery precipitation in the form of irregular pellets or lumps of ice of size more than 8 mm.

Rainfall measurement

The instrument used to collect and measure the precipitation is called raingauge.

Types of raingauges:

1) Non-recording : Symon's gauge
2) Recording
   - Tipping-bucket type
   - Weighing-bucket type
   - Natural-syphon type



Symon's gauge

Instrumental Operation: Self Study

Precipitation

Recording raingauges

❖The instrument records the graphical variation of the rainfall, the total collected quantity in a certain time interval and the intensity of the rainfall (mm/hour).

❖It allows continuous measurement of the rainfall.

1. Tipping-bucket type

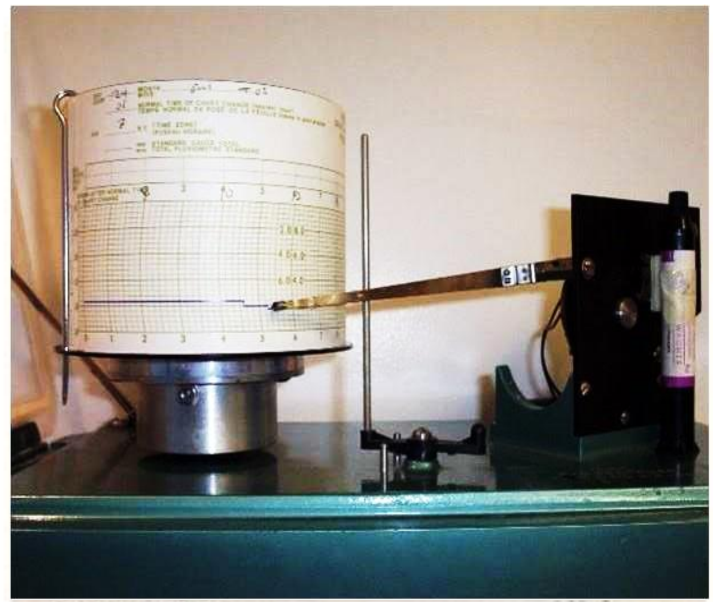
These buckets are so balanced that when 0.25mm of rain falls into one bucket, it tips bringing the other bucket in position.

Tipping-bucket type raingauge

Instrumental Operation: Self Study

2. Weighing-bucket type

- The catch empties into a bucket mounted on a weighing scale.
- The weight of the bucket and its contents are recorded on a clock work driven chart.
- The instrument gives a plot of cumulative rainfall against time (mass curve of rainfall).

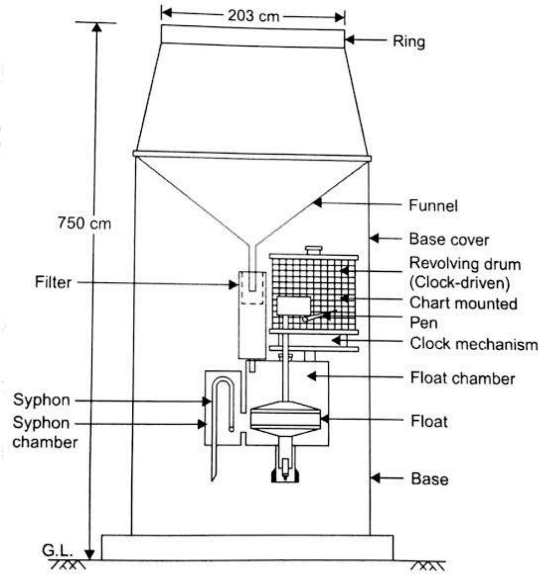


Weighing-bucket type raingauge

Instrumental Operation: Self Study

3. Natural Syphon Type (Float Type)

- The rainfall collected in the funnel shaped collector is led into a float chamber, causing the float to rise.
- As the float rises, a pen attached to the float through a lever system records the rainfall on a rotating drum driven by a clockwork mechanism.
- A syphon arrangement empties the float chamber when the float has reached a preset maximum level.



Float-type raingauge

Instrumental Operation: Self Study

Differences Between Recording and Non-Recording Gauge

Recording Gauge	Non-Recording Gauge
Records amount and duration of rainfall simultaneously.	Records rainfall depth only.
Initial cost is more.	Initial cost is comparatively less.
Measuring capacity is better.	Lower capacity.
Maintenance cost is more.	Maintenance cost is comparatively low.
Rainfall in hilly area can be measured accurately.	Rainfall in hilly area can not be measured.
Ex: Weighing type, tipping bucket, float.	Ex: Symon's rain gauge.

Installation of Rain Gauge

- Ground surface must be level.
- Slopping wall, terrace wall or roof must be avoided.
- Site should represent entire area.
- Wind affected areas should be avoided.
- Site should be open.
- Rain gauge must be shielded by fencing around 5.5 x 5.5 sqm area at least, in hilly areas.
- Rain gauge should be installed in vertical position.
- Installation should be preferred in easily accessible areas.

Rainfall Measurement by Radar

Rainfall measurement by radar, also called "weather radar," involves sending out radio waves that bounce off raindrops in the atmosphere, allowing the radar to detect the location and intensity of precipitation by analyzing the strength and timing of the reflected signal.
Essentially, the stronger the echo, the heavier the rainfall in that area.

Factors Affecting Accuracy:

Raindrop size and distribution:
The size and distribution of raindrops significantly affect the radar signal, making it challenging to accurately measure rainfall in situations with uneven drop sizes.

Attenuation:
Radar signals can be weakened by heavy rain, leading to underestimation of precipitation intensity in very heavy storms.

Ground clutter:
Reflections from buildings and terrain can interfere with the radar signal, causing inaccuracies near the radar site.

Rainfall Measurement by Radar

Applications of Radar Rainfall Measurement:

Weather forecasting: Providing real-time information about rainfall intensity and movement to improve weather predictions.

Flood warning systems: Identifying areas at risk of flooding by monitoring heavy rainfall patterns.

Hydrological studies: Estimating total rainfall over large areas for water resource management.

Rainfall Measurement by Radar

<u>Advantages of Radar Rainfall Measurement:</u>

- Provides 24 hr rainfall intensity.
- Adopted for large areas.
- Provides instant precipitation map.
- Gives space wise and time wise measurement.
- Data are more precise.

<u>Disadvantages of Radar Rainfall Measurement:</u>

- Costly set up.
- Several radars can not be installed at the same time.
- Well trained people are required to operate.
- Maintenance cost is higher than conventional instruments.

Precipitation

Presentation of rainfall data

- **Hyetograph**

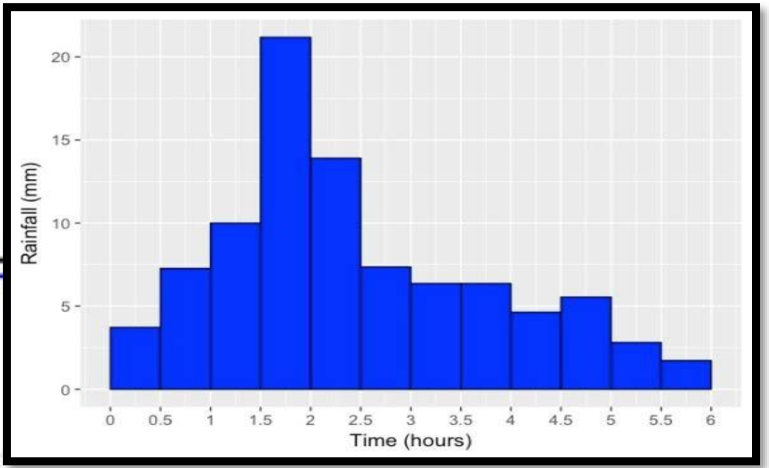
  Plot of rainfall intensity against time, where rainfall intensity is depth of rainfall per unit time

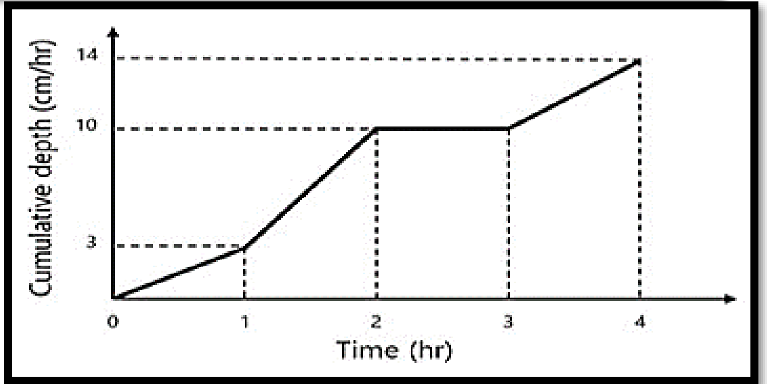
- **Mass curve of rainfall**

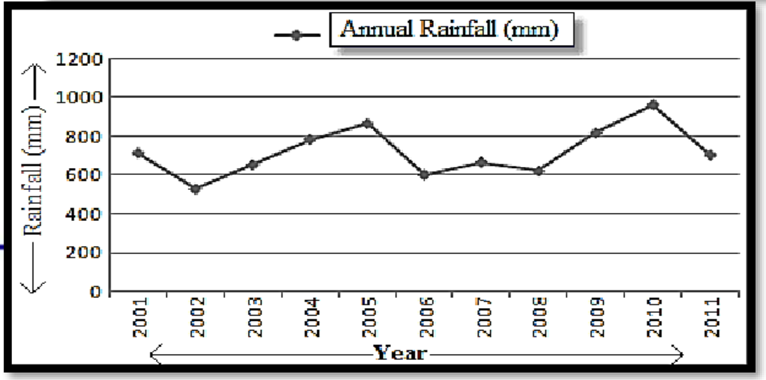
  Plot of accumulated precipitation against time, plotted in chronological order.

- **Point rainfall**

  It is also known as station rainfall . It refers to the rainfall data of a station







Mean precipitation over an area

The following methods are used to measure the average precipitation over an area:

1. Arithmetic Mean Method
2. Thiessen polygon method
3. Isohyetal method
4. Inverse distance weighting

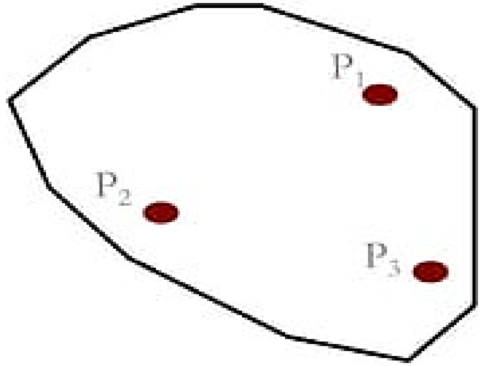
1. Arithmetic Mean Method

Simplest method for determining areal average

$$\overline{P} = \frac{1}{N}\sum_{i=1}^{N} P_i$$

where, P_i : rainfall at the i^{th} raingauge station

N : total no: of raingauge stations



Mean precipitation over an area

Contd…

2. Thiessen polygon method

This method assumes that any point in the watershed receives the same amount of rainfall as that measured at the nearest raingauge station. Here, rainfall recorded at a gage can be applied to any point at a distance halfway to the next station in any direction.

Steps:

a) Draw lines joining adjacent gages

b) Draw perpendicular bisectors to the lines created in step a)

c) Extend the lines created in step b) in both directions to form representative areas for gages

d) Compute representative area for each gage

e) Compute the areal average using the following:

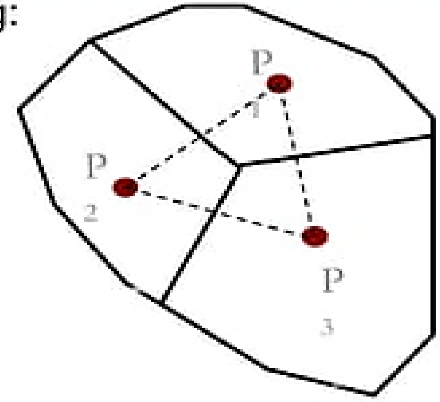
$$\overline{P} = \frac{1}{A}\sum_{i=1}^{N} A_i P_i$$

$P_1 = 10$ mm, $A_1 = 12$ Km^2

$P_2 = 20$ mm, $A_2 = 15$ Km^2

$P_3 = 30$ mm, $A_3 = 20$ km^2

$$\overline{P} = \frac{12\times10+15\times20+20\times30}{47} = 20.7\ mm$$



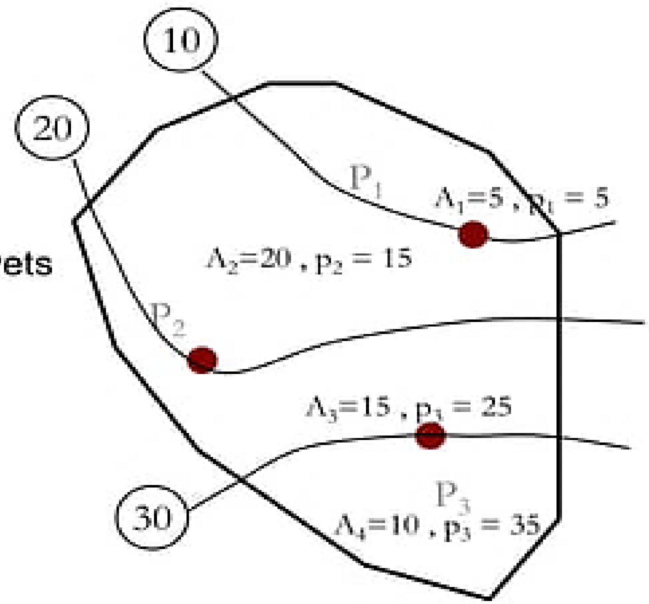
3. Isohyetal method

$$\overline{P} = \frac{1}{A}\sum_{i=1}^{N} A_i P_i$$

where, A_i : Area between each pair of adjacent isohyets

P_i : Average precipitation for each pair of adjacent isohyets

$$\overline{P} = \frac{5\times5+20\times15+15\times25+10\times35}{50} = 21mm$$



4. Inverse distance weighting (IDW) method

Prediction at a point is more influenced by nearby measurements than that by distant measurements. The prediction at an ungauged point is inversely proportional to the distance to the measurement points.

Steps:

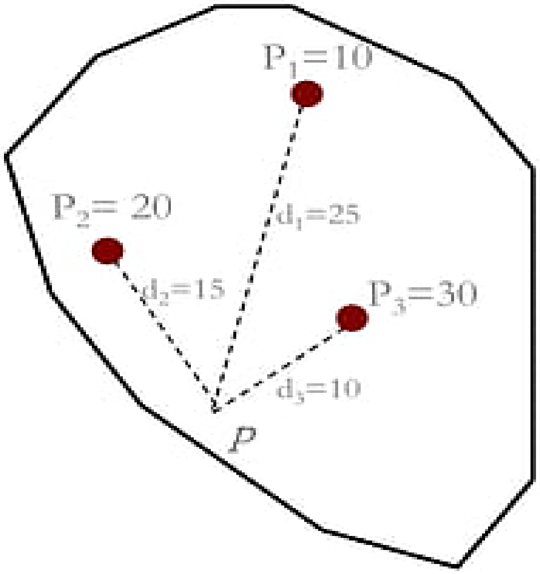
a) Compute distance (di) from ungauged point to all measurement points.

$$d_{12} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

b) Compute the precipitation at the ungauged point using the following formula:

$$\hat{P} = \frac{\sum_{i=1}^{N} \left(\frac{P_i}{d_i^2} \right)}{\sum_{i=1}^{N} \left[\frac{1}{d_i^2} \right]} \qquad \hat{P} = \frac{\frac{10}{25^2} + \frac{20}{15^2} + \frac{30}{10^2}}{\frac{1}{25^2} + \frac{1}{15^2} + \frac{1}{10^2}} = 25.24 \ mm$$

N = No: of gauged points



Design of Water Wells

(Week 8-9)

Introduction:

A water well has to be designed to get the optimum quantity of water economically from a given geological formation

- ❑ The water requirements for the particular schemes –rural water supply , agricultural and industrial needs, has to be carefully determined

- ❑ The choice of open wells or bore wells (tube wells) and the method of well design depends upon-

-**Topography**

-Geological conditions of the underlying strata

-Depth of GW table

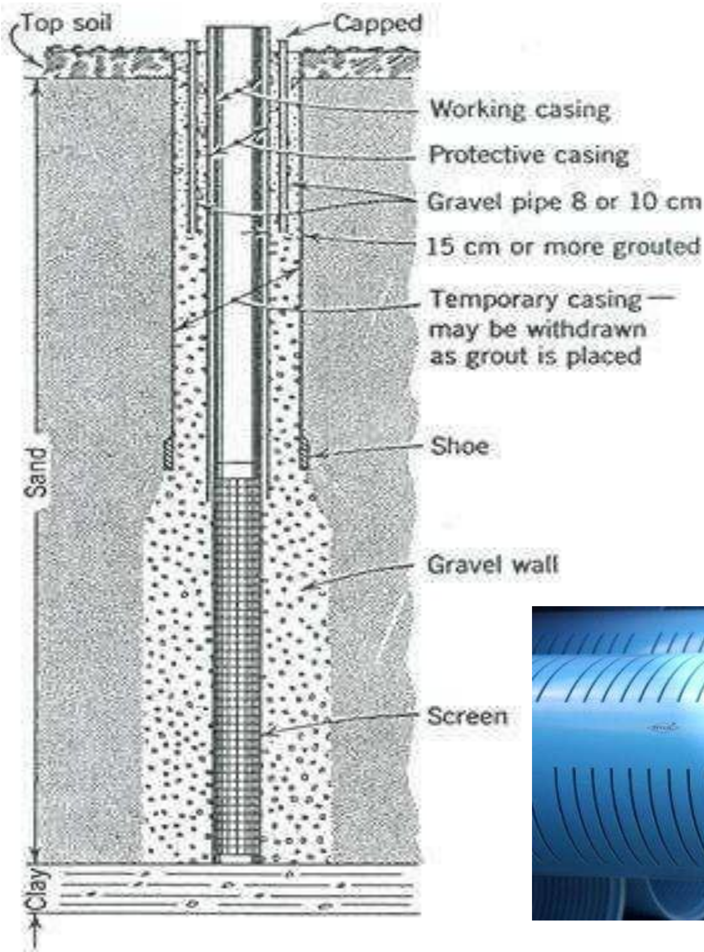
-Rainfall

-Climate

-The quantity of water required

Introduction Cont…

- A water well design involves selection of proper dimensions like the diameter of the well and that of the casing, length and the location of the screen including slot size, shape and percentage of opening area


Top soil
Capped
Working casing
Protective casing
Gravel pipe 8 or 10 cm
15 cm or more grouted
Temporary casing —
may be withdrawn
as grout is placed
Shoe
Gravel wall
Screen
Sand
Clay


ATUL 150 ND uPVC CASING PIPE (CM) WITH

Well Diameter

The Size of the well diameter should be properly chosen since it significantly affects the cost of well construction.

The diameter must be chosen to give the desired percentage of open area in the screen (15 to 18%), so that the entrance velocities near the screen do not exceed 3 to 6 cm/sec, so as to reduce the well losses and hence the drawdown, to exclude the finest particles of sand from migrating near the slots and prevent incrustation and corrosion at the strainer slots.

Well Diameter, Discharge

Equation of Dupuit →

$$Q = \frac{\pi K\left[{h_e}^2 - {h_w}^2\right]}{ln\left[\frac{r_0}{r_w}\right]}$$

A well with a radius of 0.3 m, including gravel envelope and developed zone, completely penetrates an unconfined aquifer with K = 25 m/day and initial water table at 30 m above the bottom of the aquifer. The well is pumped so that the water level in the well remains at 22 m above the bottom of the aquifer. Assuming that pumping has essentially no effect on water table height at 300 m from the well, determine the steady-state well discharge. Neglect well losses.

Solution:

From Eq.[4]

$$Q = \frac{\pi K\left[{h_e}^2 - {h_w}^2\right]}{ln\left[\frac{r_0}{r_w}\right]}$$

$$Q = \frac{3.14 \times 25 \times [30^2 - 22^2]}{\ln\left[\frac{300}{0.3}\right]} = 4729.84\ \text{m}^3/\text{day}$$

Well Depth

- The depth of a well and the number of aquifers it has to penetrate is usually determined from the lithological log of the area.
- An experienced driller can decide the depth at which drilling can be stopped after being advised by the hydrologist who analyses the samples collected during the drilling.
- The well is usually drilled up to bottom of the aquifer so that the full aquifer thickness is available, permitting greater well yield.

Design of well Screen

- Screen Length: In homogeneous artesian aquifer about 70 to 80% (3/4)of the aquifer thickness is screened.

- In case the non-homogeneous artesian aquifer, it is best to screen the most Permeable strata.

- Theory and experience have shown that screening the bottom one- third of the aquifer provides the optimum design.

Screen Diameter

After the length of the screen (depending upon the aquifer thickness) and the slot size (based on the size and gradation of the aquifer materials) have been selected , the screen diameter is determined so that the **entrance velocities near the Screen will not exceed 3 to 6 cm/sec to prevent incrustation and corrosion and to minimize friction losses**

Selection of Screen

Selection of screen material depends on-
-mineral content of water
-presence of bacterial slimes
-strength requirements

Selection of Screen

The Screen material should be resistant to incrustation and corrosion and should have strength to withstand the column load and collapse pressure.

The **principle** indicators of corrosive ground water are

-low pH

-Presence of dissolved oxygen

-CO_2> 50ppm (parts per million or mg/l)

-CL> 500ppm

The **principal indicators of incrustating ground water** are

-total Hardness> 330 ppm

-total alkalinity> 300ppm

-iron content> 2 ppm

-pH> 8

Open wells Versus Borewells

In choosing the type of well the following factors have to be considered

1. Availability of space
2. **Hydrological characteristics** of the subsurface strata
3. Seasonal **fluctuation** of water levels
4. **Cost** of well construction including provision of water lifting appliances
5. **Economics and ease** of water lifting operation

Open wells -Advantages

1.**Storage capacity** of water is available in the well itself

2.Do not require sophisticated equipment and skilled personnel for construction

3.**Can be easily operated** by installing a centrifugal pump at different Settings for low and high water levels

Open wells -Disadvantages

1.Large space is required for the well and for excavated material lying on the surface like a big mound
2.Construction is slow and laborious
3.Subject to high fluctuations of water table during different seasons
4. Susceptibility to dry up in years of drought
5. High cost of construction as the depth increases in hard rock areas
6. Deep seated aquifer cannot be economically tapped
7. Uncertainty of tapping water of good quality
8. **Susceptibility for contamination or pollution** unless sealed from surface water ingress

Tube (bore) wells -Advantages

1.Do not require much space
2.Can be constructed quickly
3.Fairly sustained yield of water can be obtained even in years of scanty rainfall
4. Economic when deep –seated aquifers are encountered
5. Generally good quality of water is tapped

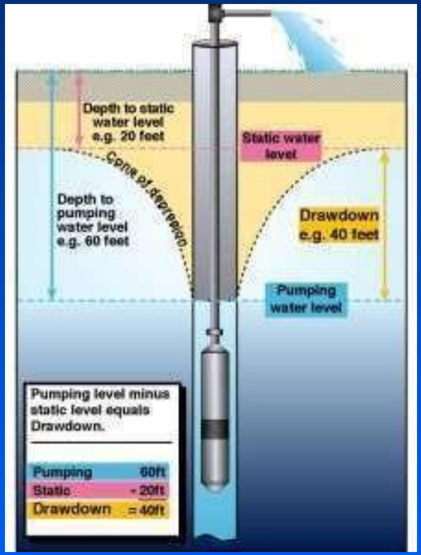
Tube (bore) wells -Disadvantages

1.Require costly and complicated drilling equipment and machinery
2.Required skilled workers and great care to drill and complete the tube wells
3.Installation of costly turbine or submersible pumps is required
4. Possibility of missing the fracture , fissures and joints in hard rock areas resulting in many dry holes

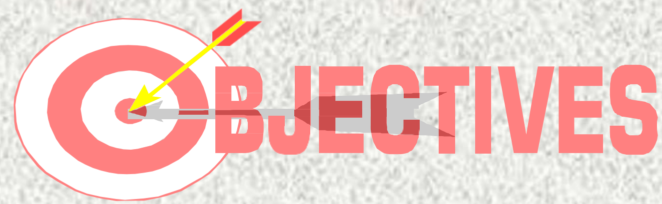
Water Well Drilling and Construction

(Week 10-11)

WATER WELL
Drilling & Construction



WATER WELL DESIGN



- ❖ Provide well that meets needs of owner
- ❖ Provide suitable quality water (potable and turbidity-free for drinking water wells)
- ❖ Provide long service life (25+ years)

Types of Water Wells

- DRILLED
- DRIVEN
- DUG

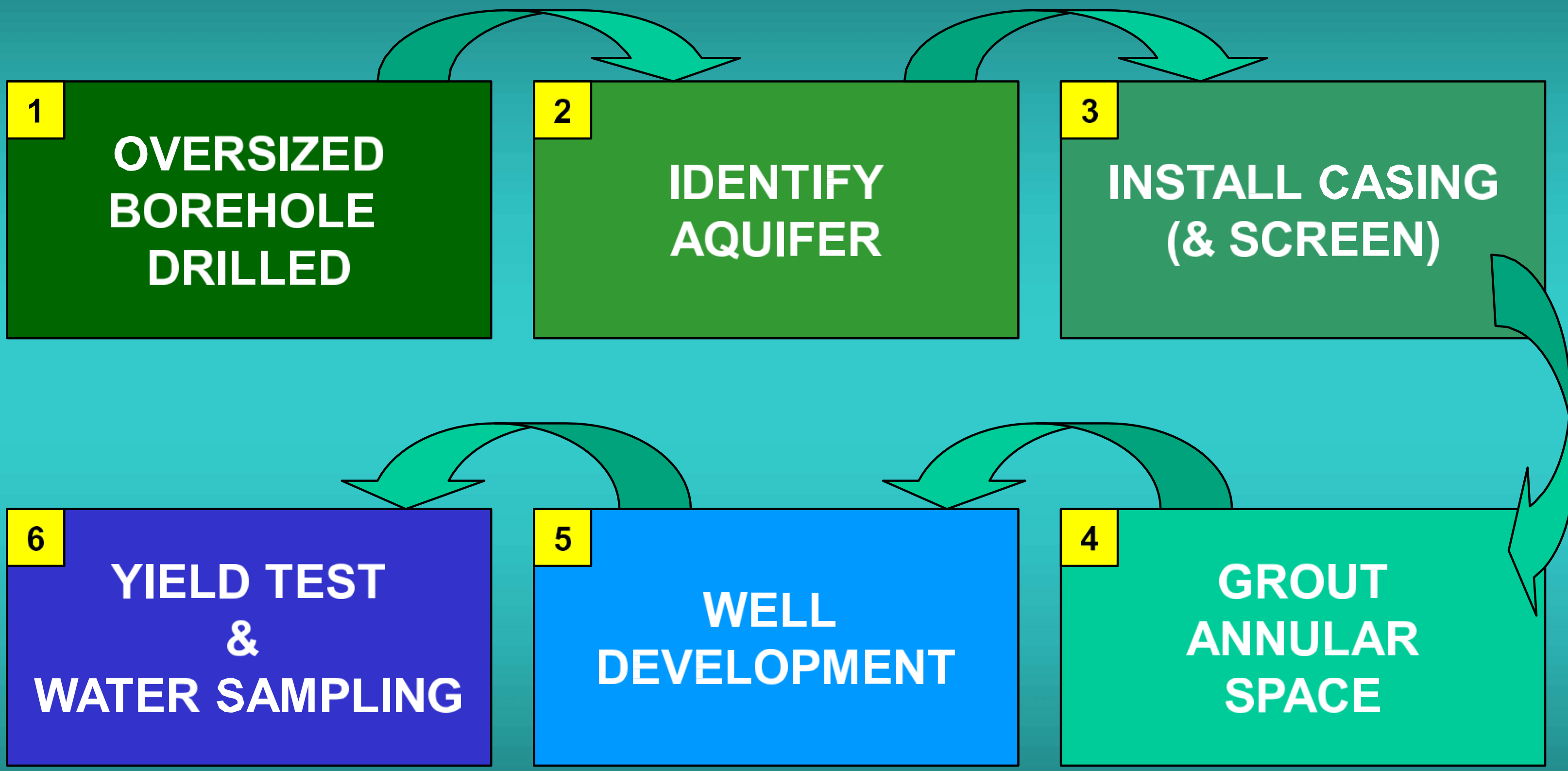
DRILLED WELLS

- ➔ Terminated in glacial drift (sand, gravel) or bedrock
- ➔ Constructed with rotary, cable tool, jetting, hollow rod or auger drilling methods


Rotary

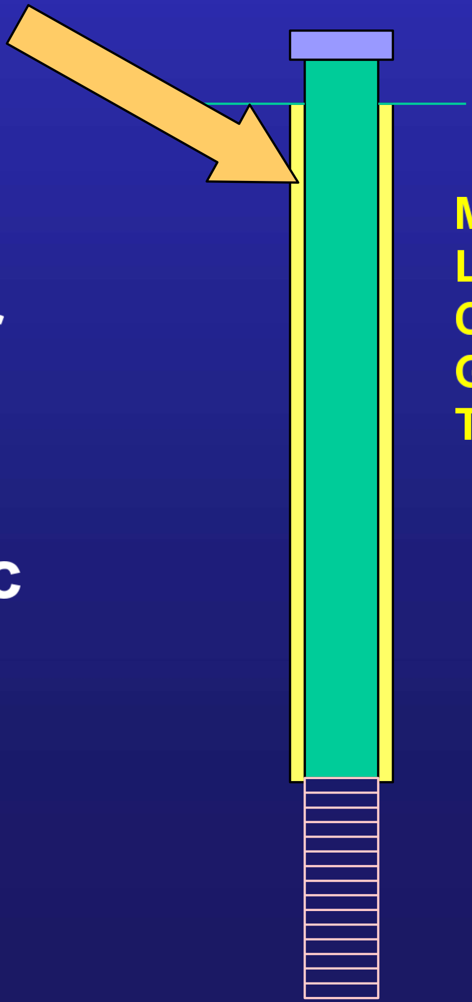

Cable Tool

TYPICAL ROTARY WELL CONSTRUCTION SEQUENCE

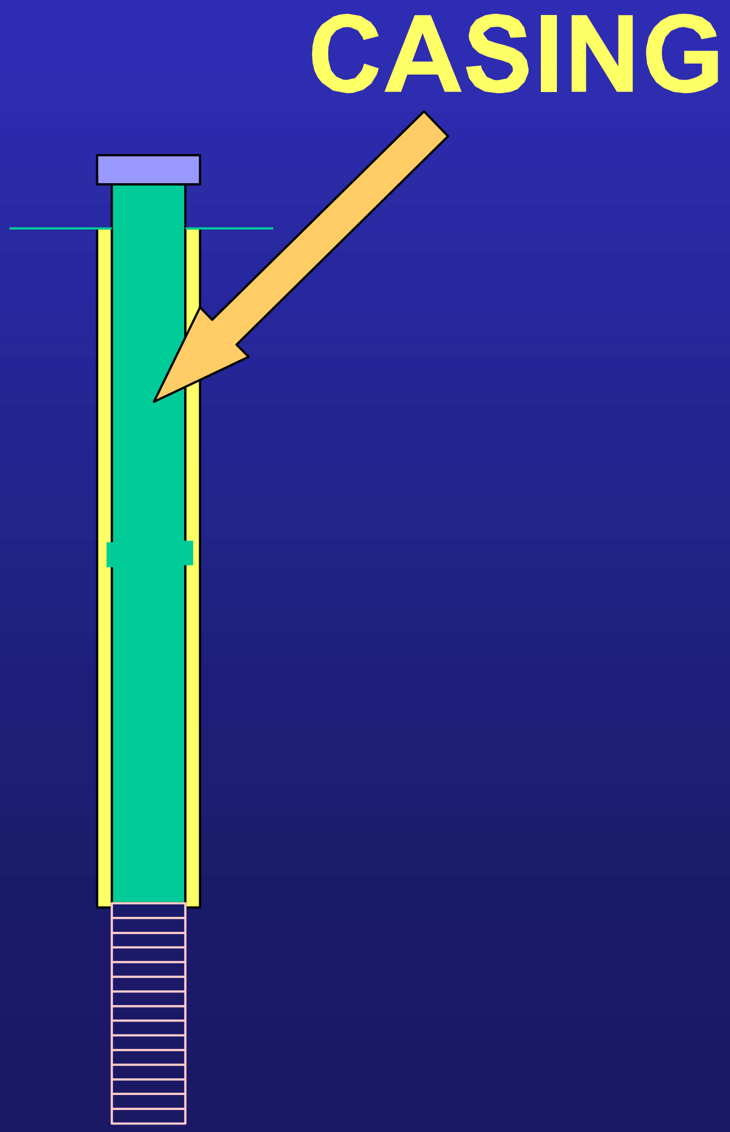


BOREHOLE

Vertical circular boring to reach aquifer (water bearing geologic material)



Steel or plastic pipe installed to keep borehole wall from collapsing

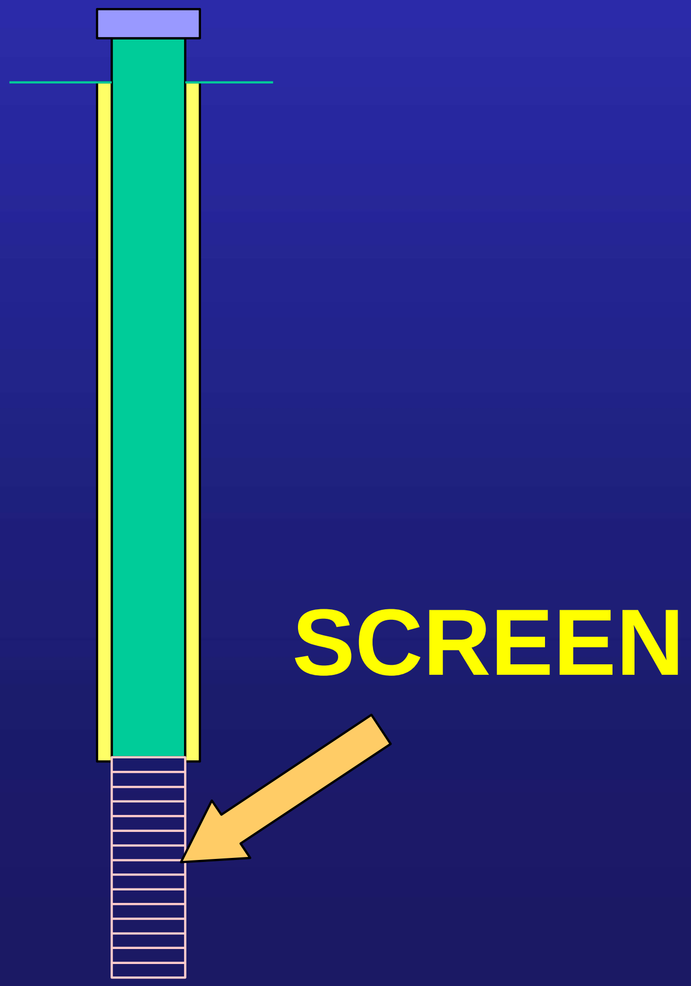


WELL CAP or SEAL

Mechanical device to prevent contaminants (including insects) from entering well casing

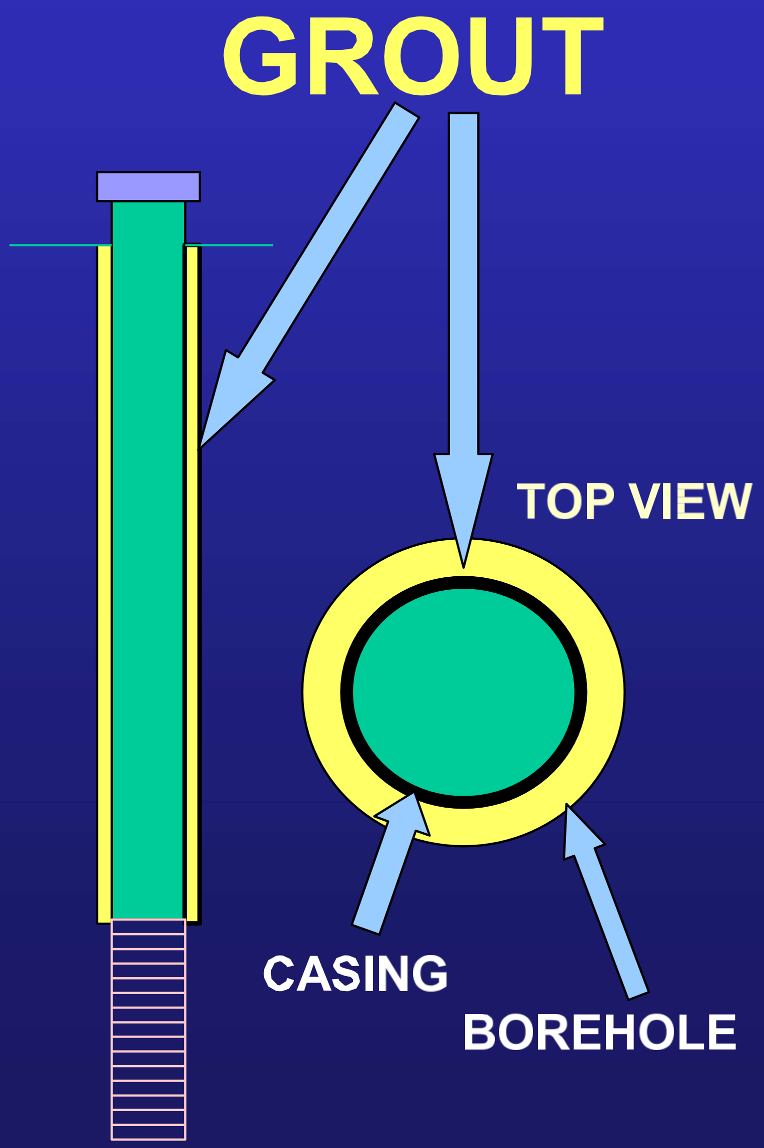
Intake device to allow water to enter well and keep sand out

Wire-wrapped screen most common



Impermeable cement or bentonite clay slurry placed in annular space between borehole and casing to:

- prevent well contamination



WELL GROUTING MATERIALS

TYPE	*COMPOSITION*	*CHARACTERISTICS*
BENTONITE SLURRY	POWDERED BENTONITE & WATER GRANULAR BENTONITE, POLYMER & WATER	▪FLEXIBLE LOWER STRENGTH SEAL ▪MOST POPULAR DUE TO LOWER COST AND TARGETED MARKETING ▪WASH-OUT UNDER ARTESIAN PRESSURE ▪NO HEAT OF HYDRATION
NEAT CEMENT	PORTLAND CEMENT & WATER	▪MORE WIDELY USED IN OIL FIELD THAN WATER WELLS ▪HIGHER STRENGTH RIGID SEAL ▪BEST CHOICE FOR BEDROCK WELLS & FLOWING WELLS ▪HEAT OF HYDRATION & MICROANNULUS CONCERNS
CONCRETE GROUT	PORTLAND CEMENT, SAND & WATER	▪MORE PERMEABLE THAN NEAT CEMENT GROUT ▪MORE DIFFICULT TO PUMP (ABRASIVE) ▪GOOD CHOICE FOR LARGE DIAMETER WELLS

CASING MATERIALS COMPARISON

PVC PLASTIC	VS.	STEEL
Non-corroding		Corrodes
Lower strength		Higher strength
Fewer water quality complaints		Rusty water
Rotary construction only		Suitable for any drilling method
1/3 cost of steel		

DRIVEN WELLS

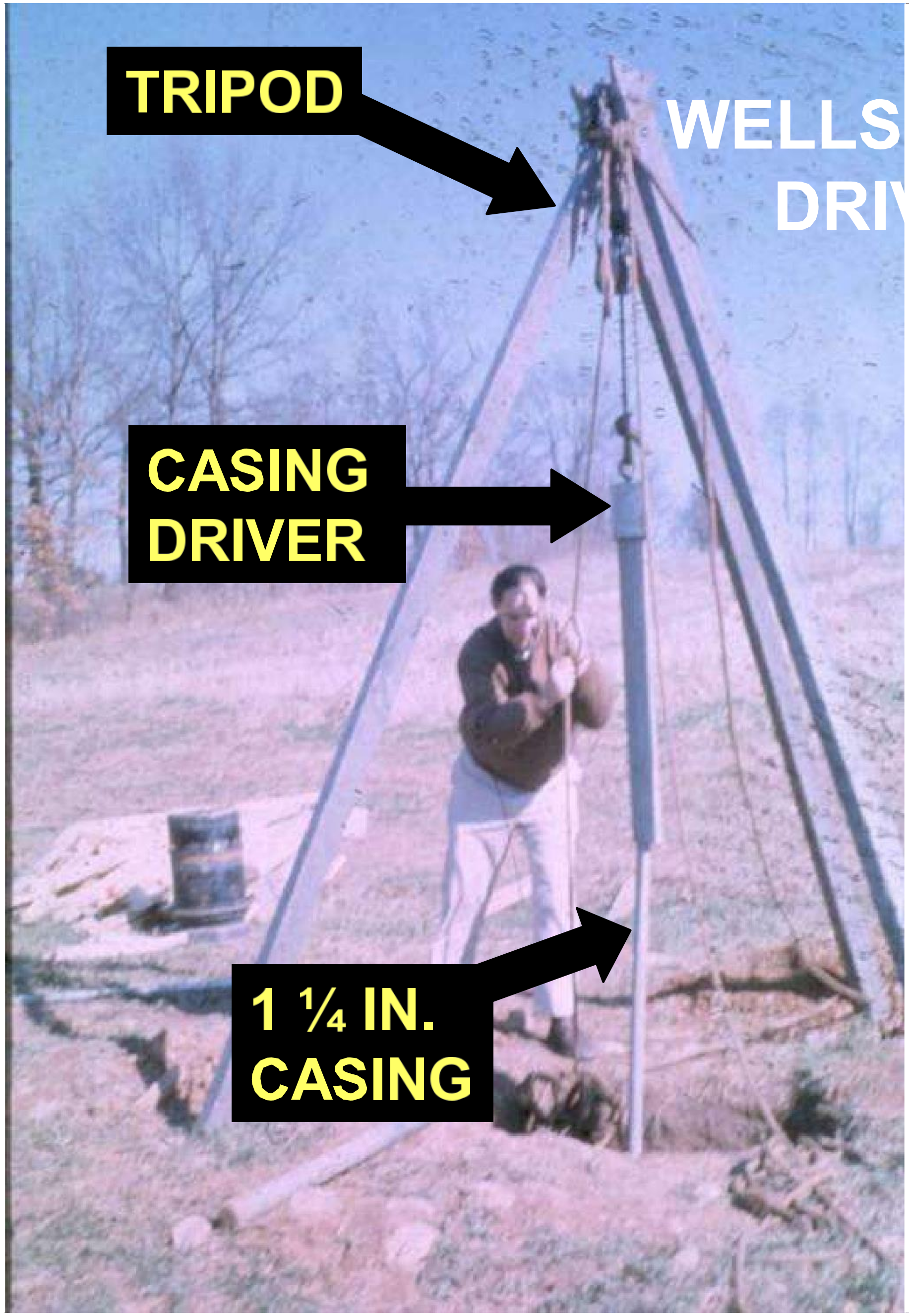
- ❒ Installed in glacial drift only - CANNOT be driven through boulders or into bedrock
- ❒ Well point driven into ground with post-driver, tripod w/ weight or sledge hammer
- ❒ 1 1/4 in. to 2 in. diameter

DRIVEN WELLS

- ❒ Installed by property owners
- ❒ Common around lakes and high water table areas
- ❒ Most <35 ft. deep, limited yield (7 gpm or less)

MORE SUSCEPTIBLE TO SURFACE CONTAMINATION THAN DRILLED WELLS

WELLS BEING DRIVEN



DUG WELLS

- Large diameter (18-48 in.)
- Found in low yield areas
- Casing material - concrete crocks w/ loose joints

  Older wells: stones, brick-lined
- Water enters well through loose casing joints

DUG WELLS

- Older wells - hand dug
- Low well yield - storage in casing (100's of gallons)
- HIGHLY VULNERABLE TO CONTAMINATION


SHALLOW UNSANITARY DUG WELL


OLD HAND-DUG WELL
LINED WITH FIELD STONE

Hydrologic Losses (1)

(Week 12)

Hydrologic losses

- In engineering hydrology, runoff is the main area of interest. So, evaporation and transpiration phases are treated as “losses”.

- If precipitation not available for surface runoff is considered as “loss”, then the following processes are also “losses”:
    - Interception
    - Depression storage
    - Infiltration

- In terms of groundwater, infiltration process is a “gain”.

Interception

- Interception is the part of the rainfall that is intercepted by the earth's surface and which subsequently evaporates.

- The interception can take place by vegetal cover or depression storage in puddles and in land formations such as rills and furrows.

- Interception can amount up to 15-50% of precipitation, which is a significant part of the water balance.

Depression storage

❖ Depression storage is the natural depressions within a catchment area which store runoff. Generally, after the depression storage is filled, runoff starts.

❖ A paved surface will not detain as much water as a recently furrowed field.

❖ The relative importance of depression storage in determining the runoff from a given storm depends on the amount and intensity of precipitation in the storm.

Infiltration

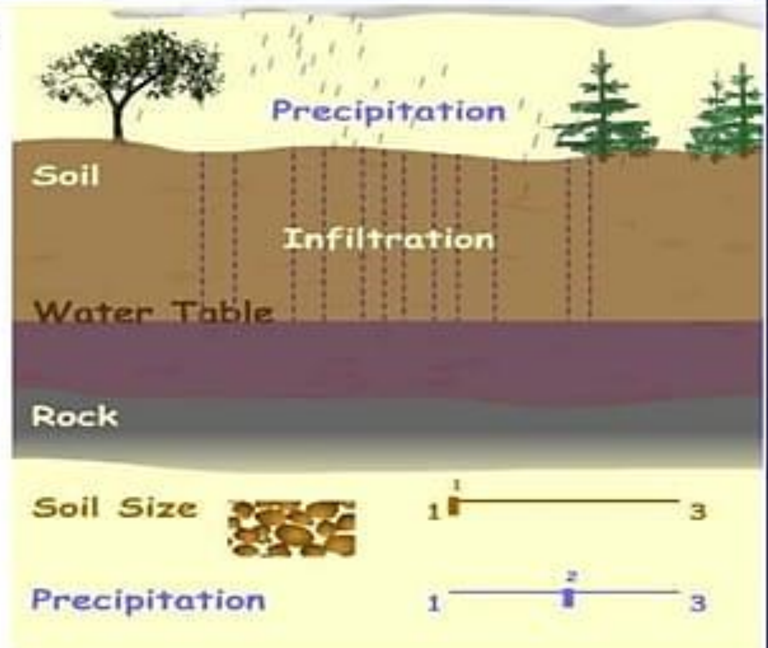
The process by which water on the ground surface enters the soil. The rate of infiltration is affected by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil.

The soil texture and structure, vegetation types and cover, water content of the soli, soil temperature, and rainfall intensity all play a role in controlling infiltration rate and capacity.

Factors affecting infiltration

Infiltration capacity or amount of infiltration depends on :

- Soil type
- Surface of entry
- Fluid characteristics.



http://techalive.mtu.edu/meec/module01/images/Infiltration.jpg

Factors affecting infiltration Contd…

Soil Type : Sand with high porosity will have greater infiltration than clay soil with low porosity.

Surface of Entry : If soil pores are already filled with water, capacity of the soil to infiltrate will greatly reduce. Also, if the surface is covered by leaves or impervious materials like plastic, cement then seepage of water will be blocked.

Fluid Characteristics : Water with high turbidity or suspended solids will face resistance during infiltration as the pores of the soil may be blocked by the dissolved solids. Increase in temperature can influence viscosity of water which will again impact on the movement of water through the surface.

Infiltration rate

Infiltration capacity :

The maximum rate at which, soil at a given time can absorb water.

$$f = f_c \text{ when } i \geq f_c$$

$$f = \text{ when } i < f_c$$

where f_c = infiltration capacity (cm/hr)

i = intensity of rainfall (cm/hr)

f = rate of infiltration (cm/hr)

Infiltration rate Contd…

Horton's Formula: This equation assumes an infinite water supply at the surface i.e., it assumes saturation conditions at the soil surface.

For measuring the infiltration capacity the following expression are used:

$$f(t) = f_c + (f_0 - f_c)\, e^{-kt} \quad \text{for } 0 \le t \le t_d$$

where k = decay constant ~ T^{-1}

f_c = final equilibrium infiltration capacity

f_0 = initial infiltration capacity when $t = 0$

$f(t)$ = infiltration capacity at any time t from start of the rainfall

t_d = duration of rainfall

Infiltration rate **Contd…**

Example Problem: Applying Horton's Formula, calculate infiltration capacity at any time from the start of rainfall. Given, fo = 0.5 mm, fc = 30 mm, t = 7 hour, k = 0.35.

Hydrologic Losses (2)

(Week 13-14)

Evaporation

- In this process, water changes from its liquid state to gaseous state.
- Water is transferred from the surface to the atmosphere

through evaporation

Evaporation is directly proportional to :

- Vapor pressure (e_w),
- Atmospheric temperature (T),
- Wind speed (W) and
- Heat storage in the water body (A)

Evaluation

Factors affecting evaporation

Vapour pressure: The rate of evaporation is proportional to the difference between the saturation vapour pressure at the water temperature, e_w and the actual vapour pressure in the air ea.

$$E_L = C\,(e_w - e_a)$$

E_L = rate of evaporation (mm/day); C = a constant ; e_w and e_a are in mm of mercury;

The above equation is known as Dalton's law of evaporation. Evaporation takes place till $e_w > e_a$, condensation happen if $e_w < e_a$

Example Problem: Find out the rate of evaporation, where ew = 27 mm/hr, ea = 10 mm/hr, C = 0.75.

Factors affecting evaporation Contd…

Temperature: The rate of evaporation increase if the water temperature is increased. The rate of evaporation also increase with the air temperature.

Heat Storage in water body: Deep bodies can store more heat energy than shallow water bodies. Which causes more evaporation in winter than summer for deep lakes.

Types of Evaporation

- **Soil evaporation:** Evaporation from water stored in the pores of the soil i.e., soil moisture.

- **Canopy evaporation:** Evaporation from tree canopy.

→ **Total evaporation** from a catchment or an area is the summation of both soil and canopy evaporation.

Measurement of evaporation

The amount of water evaporated from a water surface is estimated by the following methods:

1. Using evaporimeter data
2. Empirical equations
3. Analytical methods

1. **Evaporimeters :** Water containing pans which are exposed to the atmosphere and loss of water by evaporation measured in them in the regular intervals.
   a) Class A Evaporation Pan
   b) ISI Standard pan
   c) Colorado sunken pan
   d) USGS Floating pan

Measurement of evaporation Contd…

1. Evaporimeters

Demerits of Evaporation pan:

1. Pan differs in the heat-storing capacity and heat transfer from the sides and bottom.
   Result: reduces the efficiency (sunken pan and floating pan eliminates this problem)
2. The height of the rim in an evaporation pan affects the wind action over the surface.
3. The heat-transfer characteristics of the pan material is different from that of the reservoir.

Measurement of evaporation Contd…

Pan Coefficient (Cp)

For accurate measurements from evaporation pan a coefficient is introduce, known as pan coefficient (**Cp**). Lake evaporation = **Cp** x pan evaporation

Type of pan	Range of **Cp**	Average value **Cp**
Class A land pan	0.60-0.80	0.70
ISI pan	0.65-1.10	0.80
Colorado sunken pan	0.75-0.86	0.78
USGS Floating pan	0.70-0.82	0.80

Source: Subramanya, 1994

Measurement of evaporation Contd…

2. Empirical equation

Mayer's Formula (1915)

$$E_L = K_m (e_w - e_a) (1 + (u_9/16))$$

where E_L = Lake evaporation in mm/day;

e_w = saturated vapour pressure at the water surface temperature;

e_a = actual vapour pressure of over lying air at a specified height;

u_9 = monthly mean wind velocity in km/hr at about 9 m above the ground;

K_m= coefficient, 0.36 for large deep waters and 0.50 for small shallow waters.

Example Problem

A reservoir with a surface area of 250 ha had the following parameters: water temp. 22.5°C, RH = 40%, wind velocity at 9.0 m above the ground = 20 km/hr. Estimate the volume of the water evaporated from the lake in a week.

Given e_w = 20.44, Km =0.36.

Solution:

e_a = 0.40 x 20.44 = 8.176 mm Hg; U_9 = 20 km/hr;

Substitute the values in Mayer's Equation .

Now, E_L = 9.93 mm/day

For a week it will be **173775 m³**.

Volume of Water =

= (9.93x7x250x10000)/1000

= **173775** Cubic meter

[1 hectare (ha) = 10000 Square metre]

Measurement of evaporation **Contd…**

3. Analytical method

Water Budget method: This is the simplest analytical method.

$$P + V_{is} + V_{ig} = V_{os} + E_L + ds + T_L$$

P= daily precipitation;

V_{is} = daily surface inflow into the lake;

V_{ig} = daily groundwater flow ;

V_{os}= daily surface outflow from the lake;

V_{og}= daily seepage outflow;

E_L= daily lake evaporation;

ds= increase the lake storage in a day;

T_L= daily transportation loss

Measurement of evaporation Contd…

Example Problem: Applying Water Budget Method. Find out the increase in lake storage in a day. Given, P = 70 mm, Vis = 16 mm, Vig = 12 mm, Vos = 27 mm, EL = 14 mm, TL = 23 mm.

Evapotranspiration

Transpiration + Evaporation

This phenomenon describes transport of water into the atmosphere from surfaces, including soil (soil evaporation), and vegetation (transpiration).

Hydrologic Budget equation for Evapotranspiration:

$$P - Rs - Go - Eact = \text{del } S$$

P= precipitation; Rs= Surface runoff; Go= Subsurface outflow; Eact = Actual evapotranspiration; del S = change in the moisture storage.

Evapotranspiration

Example Problem: Estimate the change in moisture storage in an area, where P = 57 mm/day, Rs = 26 mm/day, G0 = 3 mm/day, Eact = 7 mm/day.

Hydrologic Reliability and Uncertainty

(Week 15-16)

Probabilistic Approaches to Reliability

- **Statistical analysis** of data of past failure records for similar systems

- **Reliability analysis**, which considers and combines the contribution of each factor potentially influencing the failure with the steps as

  (1) to identify and analyze the uncertainties of each contributing factor; and

  (2) to combine the uncertainties of the stochastic factors to determine the overall reliability of the structure.

Uncertainties in Hydraulic Engineering Design

Hydrologic uncertainty
(Inherent, parameter, or model uncertainties)

Hydraulic uncertainty
(Uncertainty in the design and analysis of hydraulic structures)

Structural uncertainty
(Failure from structural weaknesses)

Economic uncertainty
(Uncertainties in various cost items, inflation, project life, and other intangible factors)

Techniques for Uncertainty Analysis

- **Analytical Technique**
  - Fourier and Exponential Transforms
  - Mellin Transform
- **Approximate Technique**
  - First-Order Variance Estimation (FOVE) Method
  - Rosenblueth's Probabilistic Point Estimation (PE) Method
  - Harr's Probabilistic Point Estimation (PE) Method
- **Reliability Analysis Methods**

Reliability Analysis Methods

1. **Performance Function and Reliability Index**
2. **Direct Integration Method**
3. **Mean-Value First-Order Second-Moment (MFOSM) Method**
4. **Advanced First-Order Second-Moment (AFOSM) Method**
   a) First-order approximation of performance function at design point.
   b) Algorithms of AFOSM for independent normal parameters.
   c) Treatment of correlated normal random variables.
   d) Treatment of non-normal random variables.
   e) AFOSM reliability analysis for non-normal, correlated random variables.
5. **Monte Carlo Simulation Methods**

Thanks for Your Attention!!!