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WATER RESOURCES PLANNING AND THE HYDROLOGIC CYCLE

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Abstract - *Water is an essential ingredient for sustenance of life. The total quantity of water available on earth is estimated to be about 1400 million cubic kilometer, which is enough to cover the earth with a layer 3 km deep. However, 97.3% of this is saltwater in oceans, thereby leaving only 2.7% freshwater. Again, about 75% of the freshwater lies frozen in the Polar Regions and about 22.6% is groundwater- some of it very deep to be economically extractable. The surface freshwater is thus only about 0.007% of the total water occurring on earth. With increasing population, while the demand for water increases, anthropogenic pressures are rendering many water sources unfit for use because of the high level of pollution. Development and management of water resources is thus one of the important aspects of development at the present time.*

Key Words: Water Management, Hydrology, Water resources, Global

1. INTRODUCTION

As a starting point for the study of hydrology it is useful to consider the hydrological cycle. This is a conceptual model of how water moves around between the earth and atmosphere in different states as a gas, liquid or solid. As with any conceptual model it contains many gross simplifications; these are discussed in this section. There are different scales that the hydrological cycle can be viewed at, but it is helpful to start at the large global scale and then move to the smaller hydrological unit of a river basin or catchment. Hydrologic cycle, availability of water on earth, importance of hydrology and its applications in engineering, Precipitation: Forms & types, measurement of rainfall, optimum number of rain guage stations, consistency of rainfall data, presentation of precipitation data, mean aerial rainfall, depth – area duration curve, design storm, losses from precipitation, evaporation, and infiltration.

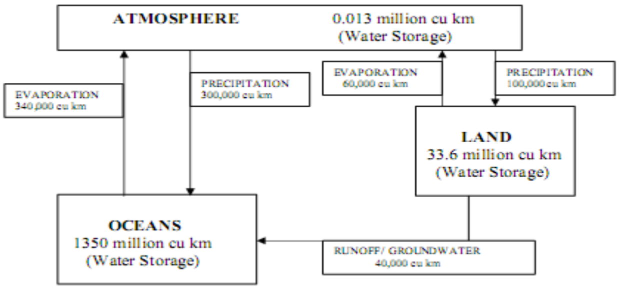
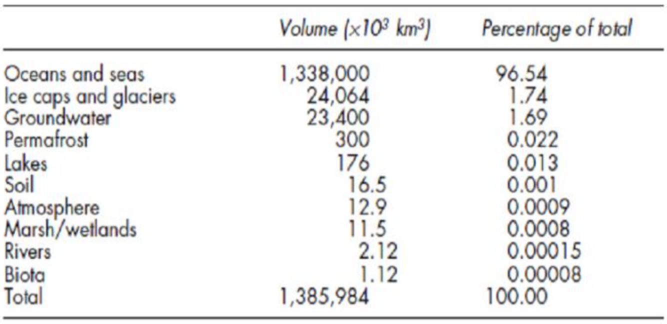


Fig 1 Importance of water management

Table 1 sets out an estimate for the amount of water held on the earth at a single time. These figures are extremely hard to estimate accurately. Estimates cited in Gleick (1993) show a range in total from 1.36 to 1.45 thousand million (or US billion) cubic kilometres of water. The vast majority of this is contained in the oceans and seas. If you were to count groundwater less than 1 km in depth as „available" and discount snow and ice, then the total percentage of water available for human consumption is around 0.27 per cent. Although this sounds very little it works out at about 146 million litres of water per person per day (assuming a world population of 7 billion); hence the ease with which Stumm (1986) was able to state that there is enough to satisfy all human needs.



	Volume ($\times 10^3$ km^3)	Percentage of total
Oceans and seas	1,338,000	96.54
Ice caps and glaciers	24,064	1.74
Groundwater	23,400	1.69
Permafrost	300	0.022
Lakes	176	0.013
Soil	16.5	0.001
Atmosphere	12.9	0.0009
Marsh/wetlands	11.5	0.0008
Rivers	2.12	0.00015
Biota	1.12	0.00008
Total	1,385,984	100.00

Table 1 Estimated volumes of water held at the earth's surface

2. THE HYDROLOGICAL CYCLE

Figure 1 shows the movement of water around the earth–atmosphere system and is a representation of the global hydrological cycle. The cycle consists of evaporation of liquid water into water vapour that is moved around the atmosphere. At some stage the water vapour condenses into a liquid (or solid) again and falls to the surface as precipitation. The oceans evaporate more water than they receive as precipitation, while the opposite is true over the continents. The difference between precipitation and evaporation in the terrestrial zone is runoff, water moving over or under the surface towards the oceans, which completes the hydrologicalcycle.

As can be seen in Figure 1 the vast majority of evaporation and precipitation occurs over the oceans. Ironically this means that the terrestrial zone, which is of greatest concern to hydrologists, is actually rather insignificant in global terms. The three parts shown in Figure 2 (evaporation, precipitation and runoff) are the fundamental processes of concern in hydrology. The figures given in the diagram are global totals but they vary enormously around the globe. This is illustrated in Figure 3 which shows how total precipitation is partitioned towards different hydrological processes in differing amounts depending on climate. In temperate climates (i.e. non tropical or polar) around one third of precipitation becomes evaporation, one third surface runoff and the final third as groundwater recharge. In arid and semi-arid regions the proportion of evaporation is much greater, at the expense of groundwater recharge. With the advent of satellite monitoring of the earth‟s surface in the past thirty years it is now possible to gather information on the global distribution of these three processes and hence view how the hydrological cycle varies around the world.

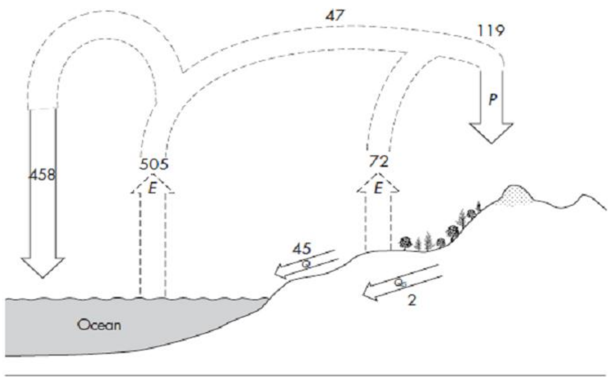


Fig 2 Global hydrological cycle.

The figure given above of 146 million litres of fresh water per person per year is extremely misleading, as the distribution of available water around the globe varies enormously. The concept of available water considers not only the distribution of rainfall but also population. Even this is misleading as a country such as Australia is so large that the high rainfall received in the tropical north-west compensates for the extreme lack of rainfall elsewhere; hence it is considered water rich. The use of rainfall alone is also misleading as it does not consider the importation of water passing across borders, through rivers and groundwater movement.

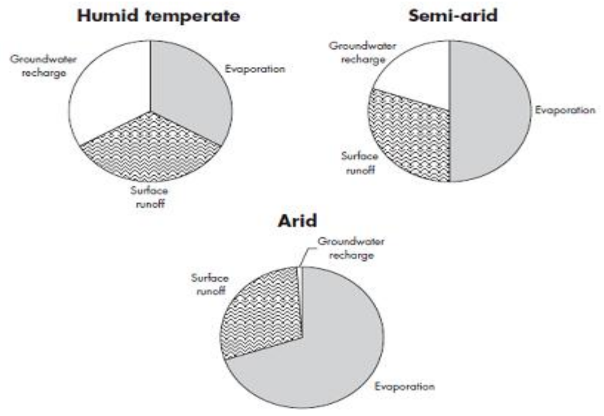


Fig 3 Proportion of total precipitation that returns to evaporation, surface runoff or groundwater recharge in three different climate zones.

3. The catchment or river basin

In studying hydrology the most common spatial unit of consideration is the catchment or river basin. This can be defined as the area of land from which water flows owards a river and then in that river to the sea. The terminology suggests that the area is analogous to a basin where all water moves towards a central point (i.e. the plug hole, or in this case, the river mouth). The common denominator of any point in a catchment is that wherever rain falls, it will end up in the same place: where the river meets the sea (unless lost through evaporation). A catchment may range in size from a matter of hectares to millions of square kilometres.

A river basin can be defined in terms of its topography through the assumption that all water falling on the surface flows downhill. In this way a catchment boundary can be drawn (as in Figures 2 and 3) which defines the actual catchment area for a river basin. The assumption that all water flows downhill to the river is not always correct, especially where the underlying geology of a catchment is complicated. It is possible for water to flow as groundwater into another catchment area, creating a problem for the definition of „catchment area‟. These problems aside, the catchment does provide an important spatial unit for hydrologists to consider how water is moving about and is distributed at a certain time.

4. THE CATCHMENT HYDROLOGICAL CYCLE

At a smaller scale it is possible to view the catchment hydrological cycle as a more in-depth conceptual model of the hydrological processes operating. Figure 4 shows an adaptation of the global hydrological cycle to show the processes operating within a catchment. In Figure 4 there are still essentially three processes operating (evaporation, precipitation and runoff), but it is possible to subdivide each into different subprocesses. Evaporation is a mixture of open water evaporation (i.e. from rivers and lakes); evaporation from the soil; evaporation from plant surfaces; interception; and transpiration from plants. Precipitation can be in the form of snowfall, hail, rainfall or some mixture of the three (sleet). Interception of precipitation by plants makes the water available for evaporation again before it even reaches the soil surface. The broad term „runoff‟ incorporates the movement of liquid water above and below the surface of the earth. The movement of water below the surface necessitates an understanding of infiltration into the soil and how the water moves in the unsaturated zone (throughflow) and in the saturated zone (groundwater flow). All of these processes and subprocesses are dealt with in detail in later chapters; what is important to realise at this stage is that it is part of one continuous cycle that moves water around the globe and that they may all be operating at different times within a river basin.

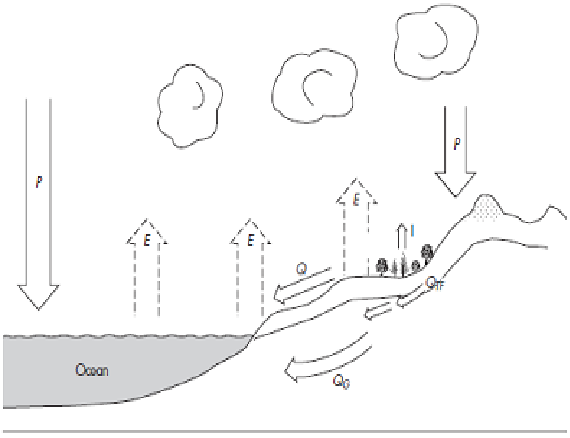


Fig 4 Process in the hydrological cycle operating at the basin or catchment basin

5. THE WATER BALANCE EQUATION

In the previous section it was stated that the hydrological cycle is a conceptual model representing our understanding of which processes are operating within an overall earth– atmosphere system. It is also possible to represent this in the form of an equation, which is normally termed the water balance equation. The water balance equation is a mathematical description of the hydrological processes operating within a given timeframe and incorporates principles of mass and energy continuity. In this way the hydrological cycle is defined as a closed system whereby there is no mass or energy created or lost within it. The mass of concern in this case is water. There are numerous ways of representing the water balance equation but equation 1 shows it in its most fundamental form.

$P \pm E \pm \_S \pm Q = 0$ .... eqn 1

where P is precipitation; E is evaporation; _S is the change in storage and Q is runoff. Runoff is normally given the notation of Q to distinguish it from rainfall which is often given the symbol R and frequently forms the major component of precipitation. The ± terminology in equation 1 represents the fact that each term can be either positive or negative depending on which way you view it – for example, precipitation is a gain (positive) to the earth but a loss (negative) to the atmosphere. As most hydrology is concerned with water on or about the earth‟s surface it is customary to consider the terms as positive when they represent a gain to the earth. Two of the more common ways of expressing the water balance are shown in equations 2

$P - Q - E - \_S = 0$ (1.2) $Q = P - E - \_S$ .... eqn 2

In equations 1 and 2 the change in storage term can be either positive or negative, as water can be released from storage (negative) or absorbed into storage (positive). The terms in the water balance equation can be recognised as a series of fluxes and stores. A flux is a rate of flow of some quantity in the case of hydrology the quantity is water. The water balance equation assesses the relative flux of water to and from the surface with a storage term also incorporated. A large part of hydrology is involved in measuring or estimating the amount of water involved in this flux transfer and storage of water. Precipitation in the water balance equation represents the main input of water to a surface (e.g. a catchment).

Precipitation is a flux of both rainfall and snowfall. Evaporation as a flux includes that from open water bodies (lakes, ponds, rivers), the soil surface and vegetation (including both interception and transpiration from plants). The storage term includes soil moisture, deep groundwater, water in lakes, glaciers, seasonal snow cover. The runoff flux is also explaine. In essence it is the movement of liquid water above and below the surface of the earth. The water balance equation is probably the closest that hydrology comes to having a fundamental theory underlying it as a science, and hence almost all hydrological study is based around it. Field catchment studies are frequently trying to measure the different components of the equation in order to assess others. Nearly all hydrological models attempt to solve the equation for a given time span – for example, by knowing the amount of rainfall for a given area and estimating the amount of evaporation and change in storage it is possible to calculate the amount of runoff that might be expected. Despite its position as a fundamental hydrological theory there is still considerable uncertainty about the application of the water balance equation. It is not an uncertainty about the equation itself but rather about how it may be applied. The problem is that all of the processes occur at a spatial and temporal scale (i.e. they operate over a period of time and within a certain area) that may not coincide with the scale at which we make our measurement or estimation.

6. PRECIPITATION

Precipitation is the release of water from the atmosphere to reach the surface of the earth. The term „precipitation‟ covers all forms of water being released by the atmosphere, including snow, hail, sleet and rainfall. It is the major input of water to a river catchment area and as such needs careful assessment in any hydrological study. Although rainfall is relatively straightforward to measure (other forms of precipitation are more difficult) it is notoriously difficult to measure accurately and, to compound the problem, is also extremely variable within a catchment area.

The ability of air to hold water vapour is temperature dependent: the cooler the air the less water vapour is retained. If a body of warm, moist air is cooled then it will become saturated with water vapour and eventually the water vapour will condense into liquid or solid water (i.e. water or ice droplets). The water will not condense spontaneously however; there need to be minute particles present in the atmosphere, called condensation nuclei, upon which the water or ice droplets form. The water or ice droplets that form on condensation nuclei are normally too small to fall to the surface as precipitation; they need to grow in order to have enough mass to overcome uplifting forces within a cloud. So there are three conditions that need to be met prior to precipitation forming:

Cooling of the atmosphere, • Condensation onto nucle

i• Growth of the water/ice droplets.

Atmospheric cooling Cooling of the atmosphere may take place through several different mechanisms occurring independently or simultaneously. The most common form of cooling is from the uplift of air through the atmosphere. As air rises the pressure decreases; Boyle‟s Law states that this will lead to a corresponding cooling in temperature. The cooler temperature leads to less water vapour being retained by the air and conditions becoming favourable for condensation.

The actual uplift of air may be caused by heating from the earth‟s surface (leading to convective precipitation), an air mass being forced to rise over an obstruction such as a mountain range (this leads to orographic precipitation), or from a low pressure weather system where the air is constantly being forced upwards (this leads to cyclonic precipitation). Other mechanisms whereby the atmosphere cools include a warm air mass meeting a cooler air mass, and the warm air meeting a cooler object such as the sea or land. Condensation nuclei Condensation nuclei are minute particles floating in the atmosphere which provide a surface for the water vapour to condense into liquid water upon. They are commonly less than a micron (i.e. one millionth of a metre) in diameter. There are many different substances that make condensation nuclei, including small dust particles, sea salts and smoke particles. Research into generating artificial rainfall has concentrated on the provision of condensation nuclei into clouds, a technique called cloud seeding.

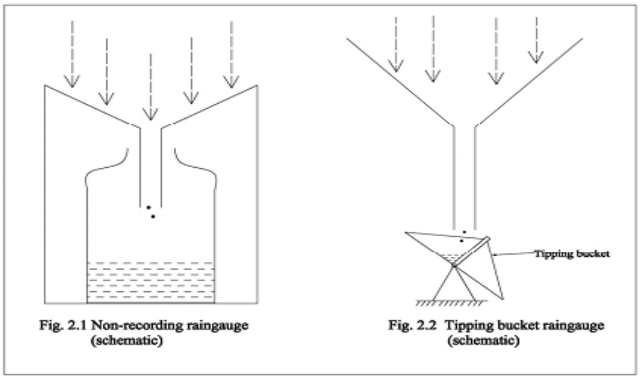


Fig. 2.1 Non-recording raingauge (schematic)

Fig. 2.2 Tipping bucket raingauge (schematic)

Fig 5 Non- Recording Raingauges

7. INFILTRATION AND PERCOLATION

When rain falls on the ground, it first wets the vegetation or the bare soil. If the soil is porous, the water moves through the surface into the soil and this is known as infiltration. Once water has infiltrated, it moves through the soil till it reaches the zone of saturation at the phreatic surface. This is termed as percolation. The maximum rate at which water can enter the soil at a particular point under a given set of conditions is called the infiltration capacity and denoted by fc, while the actual rate of infiltration is denoted by f and is less than or equal to fc. There is a progressive reduction in the infiltration with time as the capillary pores of the soil get filled and almost steady conditions are attained with infiltration equaling percolation. Besides the soil characteristics and its surface conditions, infiltration is also affected by the rainfall intensity, initial moisture content of the soil and the ground slope.

Infiltration can be measured using an infiltrometer, which is a wide diameter tube surrounding an area of soil (Fig.2.3). It is generally provided with an outer ring also. The rings are filled to a certain depth and continually refilled to maintain the depth and the inflow measured, which gives the infiltration. The purpose of the outer ring is to eliminate to some extent the edge effect of the surrounding dryer soil. Another way to measure infiltration is to simulate rainfall by a sprinkler and collect the runoff from the plot. The difference between the water supplied to the sprinkler and the runoff collected is assumed to have infiltrated. In practice, approximation of infiltration losses can be made using infiltration indices. Of the various indices, the Φ-index is the simplest to use. The Φ-index is defined as the average rainfall intensity above which the volume of rainfall equals the volume of runoff 6. Although the Φ-index does not account for the change in infiltration rate with time

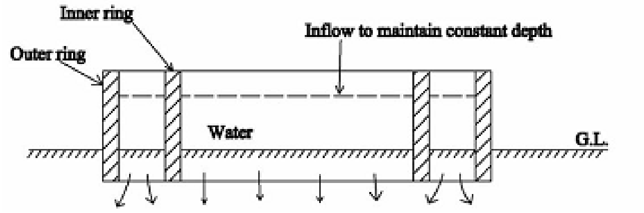


Fig 6 i=Infiltrometer,

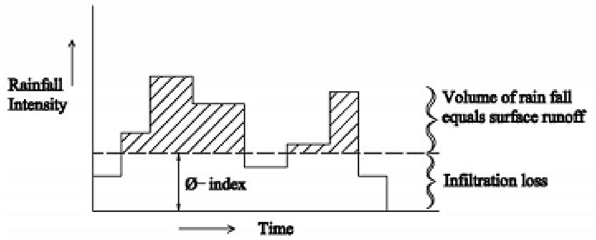


Fig 7 The Φ-index

8. HYDROGRAPH

The Unit Hydrograph Theory was propounded first by Sherman in 1932 and is a mathematical concept. A unit hydrograph is defined as the hydrograph of surface runoff (storm flow) that results from a unit (1" or 1cm in SI units) of excess precipitation spread uniformly in space and time over a watershed for a given duration. There are a few points worth emphasising in the above. First, the theory talks of excess precipitation i.e. precipitation after removing the infiltration. The duration considered in the theory is the duration of excess precipitation and the unit hydrograph duration is the same. Thus one may have a 1hr, 2hr or 6hr unit hydrograph depending on whether the duration of excess precipitation is 1hr, 2hr or 6hr respectively. Also the excess precipitation is assumed spread evenly over the watershed and constant over the time interval. The hydrograph is for surface runoff only and thus does not include base flow. The area under the hydrograph will therefore represent only the direct runoff and be equal to the product of the watershed area and the excess precipitation.

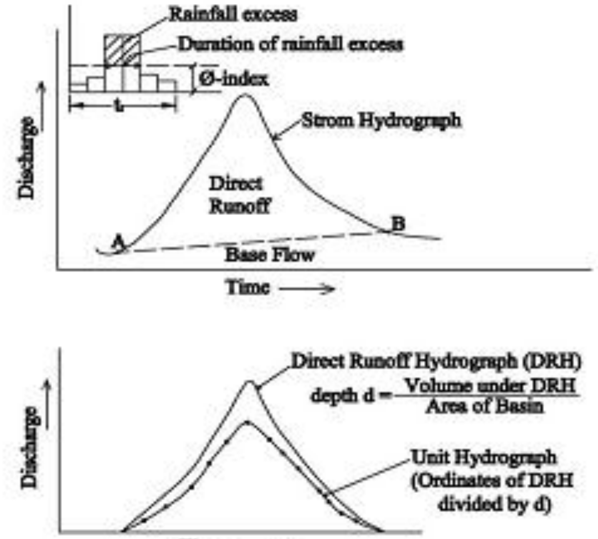


Fig 4.3 Derivation of a unit hydrograph

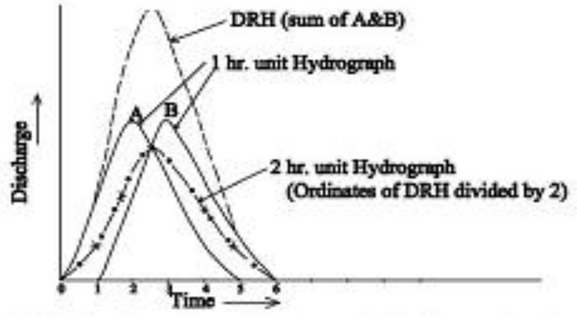


Fig 5 Hydrograph

9. CONCLUSIONS

In conclusion, As result of ever increasing anthropogenic influences, enormous amount of nitrogen containing wastewater has been discharged into different water bodies with little or no treatments throughout the world. Due to significant pollution concerns related to this waste stream, the need for effective and efficient mitigation measures to the adverse consequence of water pollution is evident.

This resulted to an increased attention for nitrogen pollution concerns. Finally, to mitigate nitrogen pollution impact, my recommendation summarized in to the following major points: Pollution sources should be managed to reduce waste generation. Enhancing effective and efficient mechanism of Nutrient usage. .

With increasing population, while the demand for water increases, anthropogenic pressures are rendering many water sources unfit for use because of the high level of pollution. Development and management of water resources is thus one of the important aspects of development at the present time.

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