NATIONAL OPEN UNIVERSITY OF NIGERIA

SCHOOL OF SCIENCE AND TECHNOLOGY

COURSE CODE: ESM 423

COURSE TITLE: HYDROLOGY AND WATER RESOURCES

ESM 423: HYDROLOGY AND WATER RESOURCES

MODULE I

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MODULE I

UNIT 1: DEFINITION AND SCOPE OF HYDROLOGY

Contents

1.0: Introduction

Hydrology is a scientific discipline, as it adopts the scientific method in its study. Hydrological studies involve the application of scientific knowledge and mathematical principles to solve water related problems. The focus of this unit is the introductory aspect of hydrology. Sub-topics such as: what is hydrology? Scope and major branches of hydrology will be highlighted.

2.0: Objectives

The learning objectives of this unit are as follows:

- To define hydrology
- To discuss the scope of hydrology
- To state the major branches of hydrology

3.0 Main Content

3.1 What is Hydrology?

Hydrology is the science dealing with the waters of the earth, their occurrence, distribution and circulation, their chemical and physical properties and their interaction with the environment (Ward and Robinson, 2000). Similarly, Universities Council on Water Resources (UCWR, 2011) defines hydrology as the science that encompasses the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle.

From the above definitions of hydrology, it can simply be summarized that hydrology is the detailed scientific study of water.

3.2 Scope of Hydrology

The study of hydrology is multi-disciplinary. That is, it incorporates professionals from various disciplines such as geography, chemistry, physics, biology, geology and engineering. The hydrologic cycle is the central theme of the study of hydrology; hence all of the physical, chemical and biological processes involving water as it travel its various paths in the atmosphere, over and beneath the earth's surface are of interest to the hydrologist (person that studied hydrology).

Although hydrology is concerned with the study of water, especially atmospheric and terrestrial fresh water, its emphases have changed from time to time and vary from one practitioner to another. Some have discerned in such changes identifiable historical patterns or 'eras' of hydrology, with a progression, for example, from physical hydrology, through engineering hydrology, to water resources hydrology (Ward and Robinson, 2000).

In spite of the changing emphases however, hydrological studies involve the application of scientific knowledge and mathematical principles to solve water related problems such as quantity, quality and availability in society. Hydrologists may be concerned with finding water supplies for cities or irrigated farms, or controlling river flooding or soil erosion.

The study of hydrology involves both laboratory analysis and direct field measurements of hydrological processes: rainfall, erosion, runoff, soil moisture etc. Measurement is fundamental for assessing water resources and understanding the processes involved in the hydrologic cycle. Because the hydrologic cycle is so diverse, hydrological measurement methods equally span many disciplines including soil, oceanography, atmospheric science, geology, geophysics amongst others. The data obtained through measurements of hydrological processes are analyzed and interpreted by the hydrologist for the purpose of predicting or solving water resources problems. Generally, each hydrologic problem is unique in that it deals with a distinct set of physical conditions within a specific river basin. Hence, quantitative conclusions of one analysis are often not directly transferable to another problem. However, the general solution for most problems can be developed from application of a few relatively basic concepts (Linsley, et al, 1982). It should be noted at this point that the modern day hydrologist relies on computers for organizing, summarizing and analyzing masses of data, and for modeling studies.

3.3 Major Branches of Hydrology

The continuous growth and development of hydrology, resulting to its several areas of application in society, has led to the evolvement of different areas of specialization. Each of these branches or areas of specialization is concerned with the study of an aspect of hydrology. The following are some of the major branches in hydrology.

Chemical Hydrology: This branch deals with the study of the chemical characteristics of water.

Ecohydrology: This branch is concerned with the study of interactions between organisms and the hydrologic cycle.

Surface Hydrology: This area focuses on the study of hydrologic processes that operate at or near Earth's surface.

Hydrogeology: This is the study of presence and movement of groundwater.

Hydrometeorology: This is the study of the transfer of water and energy between land and water body surfaces, and the lower atmosphere.

Engineering Hydrology: This area of hydrology is concerned mainly with estimating rates or volumes of flow or the changes in these values resulting from human activities.

Hydroinformatics: This is the study of the adaptation of information technology to hydrology and water resources applications.

Isotope Hydrology: This is the study of the isotopic signatures of water.

Self Assessment Exercise

Create a table showing the major branches in hydrology and state what each branch you mention focuses on in the study of hydrology.

4.0 Conclusion

Having gone through this unit, you should be well acquainted with the definition and scope of hydrology, its major branches and mode of study, which involve both laboratory analysis and field measurements of hydrological processes. To further appreciate the science of hydrology, unit 2 will discuss a brief history of the development of hydrology.

5.0 Summary

- Hydrology is the detailed scientific study of water.
- The study of hydrology is multi-disciplinary.
- The hydrological cycle is the central theme of the study of hydrology.
- Hydrological studies involve the application of scientific knowledge and mathematical principles to solve water related problems.
- The major branches of hydrology include: chemical hydrology, ecohydrology, surface hydrology, hydrogeology amongst others.

6.0 Tutor Marked Assignment

(1) The detailed scientific study of water is called________

(2) The branch of hydrology that deals with the study of the chemical characteristics of water is called_______

(3) The __________ is the central theme of the study of hydrology.

(4) A person that studied hydrology is called.

(a) hydrocomist (b) hydronomist

(c) hydrologist (d) hydronogist

(5) All except one are some of the hydrological processes measured in the study of hydrology.

(a) rainfall, (b) runoff (c) soil moisture (d) rock formation

(6) Which of the following is note a branch of hydrology?

(a) chemical hydrology (b) surf hydrology (c) hydrogeology

(d) isotope hydrology

7.0 References/Further Reading

Linsley, R.K. Jr, Kohler, M.A. and Paulhus J.L.H. (1982). *Hydrology for Engineers Third Edition.* McGraw-Hill International Book.

Universities Council on Water Resources (2011). *Hydrology: The Study of Water and Water Problems. A Challenge for Today and Tomorrow*.

Viessman, W and Lewis, G.L. (2003). *Introduction to Hydrology. Fifth Edition*, Pearson Education, Inc Upper Saddle River, NJ 07458.

Ward, R.C. and Robinson M. (2000). *Principles of Hydrology. Fourth Edition*, McGraw-Hill Publishing Company (UK).

UNIT 2: BRIEF HISTORY OF THE DEVELOPMENT OF HYDROLOGY

Contents

1.0 Introduction

Having been introduced to the definition and scope of hydrology in unit I, it is therefore important to have a peep into the historical development of hydrology. The historical aspect of the course is necessary because it provides a better understanding on how the course had faired through the various ages. The historical development of hydrology will be discussed under two broad subdivisions – early and modern stages of hydrology.

2.0 Objectives

The learning objectives are as follows:

- To state the development of hydrology during the early stage.
- To state the development of hydrology during the modern stage.
- To list the major contributors to the development of hydrology during both stages.

3.0 Main Content

3.1 Early Stage of Hydrology Development

Most of the early civilization in the world grew up along river courses, such as the Nile Valley in Egypt and the Hwang Ho River in China. These early civilizations developed along river courses because of the proximity to water supply.

In the times of this early civilization, dams and channels were dug to store, direct and conserve water. All the structures they built were mainly to control nature. The people who built these dams and channels did not really understand the hydrological implications of the structures they constructed. From the period of 3500-300 B.C, no efforts were really made to understand the structures built by early civilizations across river valleys to get water.

The Egyptians were at the forefront for knowledge in hydrological processes. For example, about 3500 BC the Nile was dammed to improve agricultural productivity of previously barren lands. In addition, they recorded the fluctuations in the level of water of the Nile using an instrument called the nilumeter. The information they obtained provided flood warning to inhabitants' resident at the lower basin of the Nile. In the field of groundwater, the Egyptians were also at the forefront. They constructed a lot of instruments used in determining the level of the water table and the likelihood of getting water from the place.

During the Roman Empire, there was substantial development in the field of hydrology. This was the era where the practical engineers really came to the forefront in hydrological study. They were more practical than their predecessors; they built sewers, fine harbours, roads and dams. In fact, the first water supply system was built in Rome. Their approach was mainly empirical. At this time, there were no established principles guiding the structures they built. The only area where the Romans discussed theory as a guiding principle in their engineering works was in the process of discharge, which they gave as:

$$D = V \times A \text{ --------- } (1)$$

Where:

D = discharge

V = velocity

A = cross sectional area.

One of the foremost contributors to hydrological development during the first century was Marcus Vitruvius. He described a philosophical theory of the hydrologic cycle, in which precipitation falling in the mountains infiltrated the Earth's surface and led to streams and springs in the lowlands.

In the 15th century upwards various exploration works began to surface. The Europeans exploration of the whole world at this period, led to the emergence of more philosophies about water in the landscape. For instance, with the adoption of a more scientific approach Leonardo da Vinci and Bernard Palissy independently reached an accurate representation of the hydrologic cycle.

Leonardo da Vinci made three major contributions to the development of hydrology.

(1) He stated clearly a hydrological cycle

(2) He made a clear understanding of the principle of flow of water in river channels.

(3) He used floats in determining water velocity, hence velocity distribution in the channel.

On the other hand, Bernard Palissy stated categorically that rivers and streams originate from rainfall. He expatiated on the principles guiding artesian wells, lag time in hydrograph and other related phenomena of water flow. He also thought about the need for aforestation in drainage basin to control erosion and conserve water in soils. It was not until the 17th century that hydrologic variables began to be quantified.

3.2 Modern Stage of Hydrology Development

The beginning of the modern stage of hydrology development could probably be traced to the 17th century when hydrological variables began to be quantified.

Pioneers of the modern science of hydrology include Pierre Perrault, Edmund Halley and Edme Mariotte. In France, Pierre Perrault proved that rainfall was sufficient to support the flow of streams and rivers throughout the year. He demonstrated this by demarcating the basin of River Seine and calculated the annual discharge, and rainfall of the basin and found out that the discharges of River Seine was only $^1/_6$ of the total discharge of the basin. Edmund Halley proved that enough water is evaporated from the ocean, stagnant water bodies to produce rainfall and replenish rivers. What he did was to calculated the total evaporation from the Mediterranean Sea and also determine the amount of water that enters it from the nine major rivers. He found that the amount of water entering the Mediterranean was a little over $^1/_3$ the amount of water lost through evaporation.

Edme Mariotte major contribution to hydrology was on his work on River Seine, where he combined velocity and river cross-section measurements to obtain discharge. Other major developments during this period were the development of the automatic rain gauge and the current meter, which was used to measure the velocity of water.

During the 18th century, the Pitot tube was developed and installed at various points along river channels in other to know at what point the velocity is highest along the cross sectional area of a river. It was found out that the river has its highest velocity at the centre of the cross-sectional area; and lowest on top and around the corners where it has frictional drags with the walls of the channel.

Anthony Chazy in the 18th century was the first to extend the characteristics of one stream to another. That is, he was the first to discuss the fact that most of the hydrological processes and principles of river systems are similar. He discovered this while he was working on the task to improve water supply to Paris.

In the 19th century like in other sciences, hydrology experienced rapid growth. This period saw the development in groundwater hydrology, including Darcy's law, the Dupuit-Thiem well formula, and Hagen-Poiseuille's capillary flow equation.

In the 20th century, rational analysis began to replace empiricism, while governmental agencies began their own hydrological research programmes. Of particular importance were Leroy Sherman's unit hydrograph, the infiltration theory of Robert E. Horton, and C.V. Theis's Aquifer test/equation describing well hydraulics. Since the 1950s however, hydrology has been approached with a more theoretical basis than in the past, facilitated by advances in the physical understanding of hydrological processes and by the advent of computers and especially Geographic Information Systems (GIS).

Self Assessment Exercise

Can you identify the major contributors and their contributions to the development of hydrology?

4.0 Conclusion

Having gone through the history of the development of hydrology, you should be well acquainted of its various developmental stages and major contributors to its development. From the history, it is evident that the early stage of hydrological study was unscientific, while the modern stage brought the study of hydrology to the full embrace of the scientific method.

5.0 Summary

- The history of the development of hydrology can be classified into early and modern stages.
- The Egyptians were at the forefront for knowledge in hydrological processes. For example, about 3500 B.C the Nile was dammed to improve agricultural productivity of previously barren lands.
- The early stage of hydrological development witnesses a philosophical and empirical approach.
- The 18th and 19th century witness significant growth in hydrology. This period saw the development of the pitot tube and ground water hydrology.
- The modern stage of hydrological development saw the embrace of the scientific methods.
- Some of the major contributors to the development of hydrology include: Marcus Vitruvius, Leonardo da Vinci, Bernard Palissy, Pierre Perrault, Edmund Halley and Edme Mariotte.

6.0 Tutor Marked Assignment

(1) The Egyptians recorded the fluctuations in the level of water of the Nile using an instrument called the _____________

(2) The approach to the study of hydrology during the early stage was ____________

(3) The beginning of the modern stage of hydrological development could probably be traced to what century.

(a) 15th century (b) 16th century (c) 17th century (d) 18th century

(4) Who described a philosophical theory of the hydrologic cycle, in which precipitation falling in the mountains infiltrated the Earth's surface and led to streams and springs in the lowlands.

(a) Marcus Vitruvius (b) Leonardo da Vinci (c) Bernard Palissy
(d) Edmund Halley.

(5) The beginning of the development of groundwater hydrology could be traced to what century.

(a) 15th century (b) 17th century (c) 18th century (d) 19th century

7.0 References/Further Reading

Ward, R.C. & Robinson, M. (2000). *Principles of Hydrology, Fourth Edition*, McGraw Hill Publishing U.K.

UNIT 3: BASIC PROPERTIES OF WATER

Contents

1.0 Introduction

Water, one of man most precious resources and an important component of the environment, is not well appreciated until reduced availability or quality or both threaten its use (Ohwo, 2010). Water is the most abundant compound in the biosphere. It has a volume of about 1½ billion cubic kilometers. Of this quantity 97% is salt water, which is a major disadvantage to man. Only 3% is fresh water, of which about three quarter is locked up in the poles as ice and of course on the top of high mountains. Less than one percent is left in lakes and rivers for human use.

In order to appreciate water as a resource, we will examine its basic properties, which include the states of water, water as a universal solvent, a source of energy, its effect on climate, and structure of its molecule.

2.0 Objectives

The learning objectives are as follows:

- To discuss the three states of water
- To state why water is referred to as universal solvent
- To discuss the moderating influence of water on climate
- To state how water is a source of energy.

3.0 Main Content

3.1 Structure of Water Molecule

The distance of Earth from the sun places it within a remarkable temperate zone compared with the other planets. This temperature location allows all states of water-ice, liquid and vapour, to occur naturally on earth. Two atoms of hydrogen and one of oxygen (H_2O), which readily bond, compose a water molecule. The resulting molecule exhibits a unique stability, as a versatile solvent, and possesses extraordinary heat characteristics (Christopherson, 2007). As the most common compound on Earth's surface, water exhibits uncommon properties. Because of the nature of the hydrogen-oxygen bond, the hydrogen side of the water molecule has a positive charge and the oxygen side a negative charge; hence it dissolves so many other molecules and elements. Thus, because of its solvent activity, pure water is rare in nature (Christopherson, 2007).

Water molecules are attracted to each other because of their polarity. The positive (hydrogen) side of one water molecule is attracted to the negative (oxygen) side of another. The bonding between water molecules is called hydrogen bonding, it is important to note that without hydrogen bonding, water would be a gas at normal surface temperatures.

3.2 Different States of Water

Water can exist in three states- Solid (ice), liquid (water), and gas (water vapour). A change of state from solid to liquid, liquid to gas or solid to gas requires the input of heat energy called latent heat, which is drawn in from the surroundings and stored within the water molecules. When the change goes the other way, from liquid to solid, gas to liquid, or gas to solid, this latent heat is released to the surroundings.

3.2.1 Water (Liquid Phase): As a liquid, water assumes the shape of its container and is a non compressible fluid, quite different from solid, rigid ice. For ice to melt, heat energy must increase the motion of the water molecules to break some of the hydrogen bonds. Despite the fact that there is no change in sensible temperature between ice at 0^0C and water at 0^0C, 80 calories of heat must be added for the phase change of 1 gram of ice to 1 gram of water. This heat is called latent heat because it is stored within the water and is liberated with a phase reversal when a gram of water freezes. These 80 calories are the latent heat of melting and of freezing. A calorie is the amount of energy required to raise the temperature of 1 gram of water (at 15^0C). To raise the temperature of 1 gram of water from freezing at 0^0C (32^0f) to boiling at 100^0C (212^0f), we must add 100 additional calories, gaining an increase of 1^0C (1.8^0f) for each calorie added (Christopherson, 2007).

3.2.2 Water Vapour (Gas Phase): Water vapour is an invisible and compressible gas in which each molecule moves independently. To accomplish the phase change from liquid to vapour at boiling temperature, under normal sea-level pressure, 540 calories must be added to 1 gram of boiling water. Those calories are the latent heat of vaporization. When water vapour condenses to a liquid, each gram gives up its hidden 540 calories as the latent heat of condensation.

In summary, taking 1g of ice at 0^0C and changing its phase to water, then to water vapour at 100^0C – from a solid to a liquid, to a gas – absorbs 720 calories (80 cal + 100 cal + 540 cal). Reversing the process, or changing the phase of 1g of water vapour at 100^0C to water, then to ice at 0^0C, liberates 720 calories into the surrounding environment.

3.2.3 Ice (Solid Phase): Among common compounds and molecules, water is the only one whose solid form is lighter than its liquid form (it expands by about 8% when it freezes, becoming less dense), which is why ice floats. If ice were heavier than liquid water, it would sink to the bottom of water bodies; the biosphere would be vastly different from what it is, and life, if it existed at all, would be greatly altered. If bodies of water froze from the bottom up, they would freeze solid, killing all life in the water. Cells of living organisms are mostly water. As water freezes and expands, cell membranes and walls rupture. Finally, water is transparent to sunlight, allowing photosynthetic organisms to live below the surface (Botkin and Keller, 1998). Figure 1.0 shows the three states of water and water's phase changes.

Figure 1.0 above shows the three physical states of water: (a) water vapour, (b) water, and (c) ice. Note the molecular arrangement in each state and the terms that describe the changes from one phase to another as energy is either absorbed or released. Also note how the polarity of water molecules bonds them to one another, loosely in the liquid state and firmly in the solid state. The plus and minus symbols on the phase changes denote whether heat energy is absorbed (+) or liberated (-) during the phase change.

3.3 Water as a Universal Solvent

Water is a universal solvent because it is needed by all biological lives. Water is a non-ionic polar molecule, which dissolve anything similar to it. As earlier stated, the molecule of water is made up of two atoms-hydrogen and oxygen. Out of these two, oxygen atom is negatively charged whereas the atom of hydrogen carries a positive charge. As both the charges are weak, it makes the molecule neutral in itself. It is because of the same reason that water is able to dissolve all those substances which are of the similar type. Thus, water dissolves more of the substances rather than the liquid in it.

When a substance dissolves, its molecules separate from one another and mingle with molecules of the solvent. Because water is electrically charged, it dissolves other charged molecules such as salts, but it does not dissolve uncharged molecules such as oil (Arms, 1994).

It should be noted that humans require more of water than any other substance. The food we eat and the air we breathe in contain a lot of chemicals and other toxins, which are only purified by our kidneys with the help of water.

3.4 Water as a Source of Energy

Water act as a source of energy in different ways, for example, the evaporation of water is one of the major sources through which the atmosphere gets its energy. Evaporated water on getting to the upper part of the atmosphere condenses and energy is liberated into the atmosphere.

Hydroelectric energy is produced through the force of falling water. The capacity to produce this energy is dependent on both the available flow and the height from which the water falls. Building up behind a dam, water accumulates potential energy. This is transformed into mechanical energy when the water rushes down the sluice and strikes the rotating blades of a turbine. The turbine's rotation spins electromagnets, which generate current in stationary coils of wire. Finally, the current is put through a transformer where the voltage is increased for long distance transmission over power lines.

3.5 Moderating Influence of Water on Climate

Bodies of water affect climate in many ways, but perhaps the most significant impact is based on the fact that large bodies of water act as heat sinks. In other words, large bodies of water tend to store heat in warm periods and release it in cold periods. This is because the thermal capacity of water is high, which means it takes a lot of energy to change the temperature of water. So, during the summer, land areas near a large body of water may not heat up as much as areas that are not close to water, because the water itself is absorbing much of the heat energy. This will cause the climate to be more moderate in summer near the coast. Likewise in winter, the water near the coast will slowly release this energy, causing coastal areas to be less cold, in general, than inland areas. So, in summary, large bodies of water tend to moderate temperatures in both summer and winter in nearby land areas, compared to areas that are further inland.

There are many other ways that bodies of water affect climate, such as warm or cold temperature currents. The Gulf stream, for example, a warm current, tends to keep the east coast of the US warmer than it otherwise would be, because it flows from the warm Gulf of Mexico past Florida and up along the east coast.

Self Assessment Exercise

What evidence do you have to support the assertion that the solid state (ice) of water is lighter than the liquid state?

4.0 Conclusion

In order to understand water as a resource, we must understand its basic properties and its role in the biosphere. As has been revealed from the above discussions, water is a unique liquid; without it, life as we know it is impossible. Compared with most other common liquids, water has a high capacity to absorb or store heat and it's a good liquid solvent. Because many natural waters are slightly acidic they can dissolve a great variety of compounds. In addition, water can exist in three different states – liquid, solid and gas; it also has a moderating effluence on climate and a good source of energy.

5.0 Summary

- Two atoms of hydrogen (positive) and one of oxygen (negative) which readily bond compose a water molecule. The molecules are attracted to each other because of their polarity. The bonding between water molecules is called hydrogen bonding.
- Water can exist in three states-solid, liquid and gas. A change of state from one form to another requires the input of heat energy called latent heat.

- Water is a universal solvent because it is needed by all biological lives. It is a non-ionic polar molecule, which dissolves anything similar to it.
- Evaporation of water is one of the major sources through which the atmosphere gets its energy. Water is also a source of hydroelectric energy.
- Water has a moderating influence on climate, as large bodies of water act as heat sinks (its ability to store heat in warm periods and release it in cold periods).

6.0 Tutor Marked Assignment

(1) The bonding between water molecules is called ______________

(2) Name the three states of water

(a) ___________________

(b) ___________________

(c) ___________________

(3) Water is referred to as a universal solvent because it is needed by all ______

(4) How many calories of heat must be added for the phase change of 1 gram of ice to 1 gram of water?

(a) 70 calories (b) 80 calories (c) 540 calories (d) 720 calories

(5) Which of the following is true about water?

(a) The solid form is heavier than the liquid form

(b) The solid form is lighter than the liquid form

(c) The solid form is equal to the liquid form

(d) None of the above

(6) What happens when water freezes?

(a) It contracts (b) it remains unchanged (c) It expands (d) None of the above

7.0 References/Further Reading

Arms, K. (1994). *Environmental Science. Second Edition,* Sanders College Publishing. U.S.A.

Botkin, D.B and Keller, E.A. (1998). *Environmental Science. Earth as a Living Planet. Second Edition,* John Wiley and Sons Inc. New York.

Christopherson, R.W. (2007). *Elemental Geosystems. Fifth Edition,* Pearson Prentice Hall Upper Saddle River, N.J. 07458.

http://wiki.answers.com/Q/How does large bodies of Water affect climate ll ix zz/ouqr6xud 4/6/11.

Ohwo, O. (2010). *The Spatial Patterns of Water Supply and Management in Warri Effurun Metropolis, Delta State, Nigeria. Unpublished Ph.D Thesis.* Delta State University, Abraka.

Strahler, A and Strahler, A (2006). *Introducing Physical Geography*, *Fourth Edition* John Wiley & Sons Inc.

UNIT 4: THE HYDROLOGIC CYCLE

Contents

1.0 Introduction

As noted in unit 1, the hydrologic cycle is the central theme of the study of hydrology. Hence, it is important to know what hydrologic cycle is all about, and the various processes involved in the hydrologic cycle. Understanding the hydrologic cycle therefore, is basic to understanding water supply and is a key to the proper management of water resources.

2.0 Objectives

The learning objectives are as follows:

- To define hydrologic cycle
- To identify and discuss the various processes in the hydrologic cycle.

3.0 Main Content

3.1 Definition of Hydrologic Cycle

The movement and endless recycling of water between the atmosphere, the land surface, and underground is called hydrologic cycle. This movement, driven by the energy of the sun and the force of gravity, supplies the water needed to supported life (http://www.cartage.org.ib/en/themes/sciences/Earthscience/Geology/water cycles/ Hydro, 2005).

Similarly, Viessman and Lewis (2003) defined hydrologic cycle as a global sun-driven process whereby water is transported from the oceans to the atmosphere to the land and back to the sea. The ocean is the earth's principal reservoir; it stores over 97 percent of the terrestrial water. Water is evaporated by the sun, incorporated into clouds as water vapour, falls to the land and sea as precipitation, and ultimately finds its way back to the atmosphere through a variety of hydrologic processes.

The hydrologic cycle can be considered a closed system for the earth because the total amount of water in the cycle is fixed even though its distribution in time and space varies. There are many sub-cycles within the worldwide system, which are generally open-ended. It is these subsystems that give rise to the many problems of water supply and allocation that confront hydrologists and water managers (Viessman and Lewis, 2003).

3.2 Processes in the Hydrologic Cycle

The entire process in the hydrologic cycle can be divided into five parts, which include: condensation, precipitation, infiltration, runoff and evaporation. The hydrologic cycle is very complex. This is because all biological lives depend on water. However, it is necessary, in spite of its complexities to look at the major path-ways or processes in the movement of water through the cycle.

Starting from the ocean, which is sometimes termed as the reservoir of water, evaporation takes place due to solar heating. The evaporated water moves into the upper atmosphere, where it condenses and may fall back as rain into the ocean bodies. However, where there is an onshore wind, the evaporated water could be blown to the land in form of moisture laden wind. Over the land, condensation can occur especially where the moisture laden wind is forced high up into the atmosphere due to topography. This may result in orographic rains. Even right on the land evaporation could take place from stagnant water body, the soil and vegetation-in a combined processes known as evapotranspiration. Rain that falls on land is used in very many processes. Plants and animals depend on it for survival. Some of it sinks into the soil through infiltration, flows underground into river systems. Where the soils are saturated, runoffs are generated. The runoffs could flow into river systems. Man can even tap water from the soils by sinking bore holes and wells. The rivers could be dammed for irrigation purposes, domestic and industrial processes.

Water could also be evaporated from dams and in other processes in which man uses it. The evaporated water moves up into the atmospheric system where it can also condense and fall as rain. The movement of water continues along the river systems. As the rivers move into the ocean, evaporation continues to take place; until it eventually empties into the ocean.

It is generally observed that evaporation is the driving force in the movement of water in the hydrologic cycle. The movement of water just discussed is a simplified model of the hydrologic cycle. In nature, the movement of water could be much more complex and complicated. The hydrologic cycle is so fundamental to sustainable water supply because it continues to move water and keep sources fresh. Without this process, life on Earth would be impossible (http://www.und. nodak.edu/instruct/eng/fkarner/pages/cycle.htm, 2006). Figure 1.1 shows a simplified diagram of the hydrologic cycle.

Self Assessment Exercises

(i) To better understand the concept of the hydrologic cycle, try and identify the major pathways of precipitation and the various uses of water on the earth surface.

(ii) Draw a simplified diagram of the hydrologic cycle.

4.0 Conclusion

From the above discussions, it is no longer in doubt that the hydrologic cycle is the major theme of the study of hydrology. Most of the basic concepts and processes studied in hydrology have their roots in the hydrologic cycle, as would soon be revealed in the following modules. It can safely be concluded that without the hydrologic cycle that continue to purify our water supply sources, life on Earth would have been greatly uttered.

5.0 Summary

- The hydrologic cycle is the endless movement of water between the atmosphere, land and underground, driven by the sun and force of gravity.

- The entire process in the hydrologic cycle can be divided into five parts- evaporation, condensation, precipitation, infiltration and runoff.
- Evaporation caused by the sun's energy is the driving force in the movement of water in the hydrologic cycle.
- The hydrologic cycle is so fundamental to sustainable water supply because it continues to move water and keep sources fresh.

6.0 Tutor Marked Assignment

(1) Evaporation takes place due to ________________

(2) When evaporated water moves into the upper atmosphere it __________

(3) The process of water sinking into the soil is called _________________

(4) The combined process of water loss from soil and vegetation is called what

(a) evaporation (b) infiltration (c) transpiration

(d) evapotranspiration

(5) The movement of water on the land surface is called what?

(a) runoff (b) hydrologic cycle (c) evaporation (d) precipitation

7.0: References/Further Reading

Aguado, E. and Burt, J.E. (2007) *Understanding Weather and Climate; Fourth Edition* Pearson Prentice Hall, Upper Saddle River, New Jersey, 07458,124.

Arms, K. (1974) *Environmental Science. Second Edition,* Sanders College Publishing U.S.A.

http://www.cartage.org.ib/en/themes/science/Earthscience/Geology/watercycles/hydo 30/10/2005

Viessman W.Jr. & Lewis, G.L. (2003). *Introduction to Hydrology, Fifth Edition*, Pearson Education Inc. Upper Saddle River N.J. 07458.

UNIT 5: APPLICATIONS OF HYDROLOGY

Content

1.0 Introduction

There must be justifiable reasons for the study of any discipline, and the study of hydrology is not an exception. The question now is why do we study hydrology? This question will be answer by taking a look at the various applications of hydrology in society.

2.0 Objective

The learning objective for this unit is as follows:

- To identify the various areas of application of hydrology in society.

3.0 Main Content

3.1 Applying Hydrology in Society

The application of hydrology in the society can be traced to any human endeavour that requires the use of water. Hydrologists apply scientific knowledge and mathematical principles to solve water-related problems in society: problems of quantity, quality and availability. They may be concerned with finding water supplies for cities or irrigated farms; or controlling river flooding or soil erosion. They may work in environmental protection: preventing or cleaning up pollution or locating sites for safe disposal of hazardous wastes.

Most cities meet their needs for water by withdrawing it from the nearest river, lake or reservoir. Hydrologists help cities by collecting and analyzing the data needed to predict how much water is available from local supplies and whether it will be sufficient to meet the city's projected future needs. To do this, hydrologist study records of rainfall, snowpack depths and river flows that are collected and compiled by hydrologists in various government agencies.

Managing reservoirs can be quite complex, because they generally serve many purposes. Reservoirs increase the reliability of local water supplies. Hydrologists use topographic maps and aerial photographs to determine where the reservoir shorelines will be and to calculate reservoir depths and storage capacity. This work ensures that, even at maximum capacity, no highways, railroads or homes would be flooded.

Deciding how much water to release and how much to store depends upon the time of year, flow predictions for next several months, and the needs of irrigation and cities, as well as downstream water-users that rely on the reservoir. If the reservoir also is used for recreation or for generation of hydroelectric power, those requirements must be considered. Decisions must be coordinated with other reservoir managers along the river. Hydrologists collect the necessary information, enter it into a computer, and run computer models to predict the results under various operating strategies. On the basis of these studies, reservoir managers can make the best decision for those involved.

The availability of surface water for swimming, drinking, industrial or other uses is sometimes restricted because of pollution. Pollution can be merely an unsightly and inconvenient nuisance, or it can be an invisible, but deadly threat to the health of people, plants and animals. In this regard, hydrologists assist public health officials in monitoring public water supplies to ensure that health standards are met. When pollution is discovered, environmental engineers work with hydrologists in devising the necessary sampling programme. Water quality in estuaries, streams, rivers and lakes must be monitored, and the health of fish, plants and wildlife along their stretches surveyed. Related work concerns acid rain and its effects on aquatic life, and the behaviour of toxic metals and organic chemicals in aquatic environments. Hydrologic and water quality mathematical models are developed and used by hydrologists for planning and management and predicting water quality effects of changed conditions.

Hydrologists help to protect groundwater supply by providing guidance in the location of monitoring wells around waste disposal sites and sample them at regular intervals to determine if undesirable leachate –contaminated water containing toxic or hazardous chemicals is reaching the ground water. Hydrologists are often consulted for the selection of proper sites for new waste disposal facilities.

Hydrology also finds its applications in the determination of water balance of a region; agricultural water balance, mitigating and predicting flood, landslide and drought risk. It is also relevant in designing dams for water supply or hydroelectric power generation, bridges, sewers and urban drainage system. Worthy of note is the relevance of hydrology in predicting geomorphological changes, such as erosion or sedimentation, and assessing the impacts of natural and anthropogenic environmental change on water resources.

Self Assessment Exercise

Examine the various use of water in the society and identify areas where hydrology can be applied.

4.0 Conclusion

From the discussions on the various possible applications of hydrology in society, it can however be concluded that the applications of hydrology is as varied as the uses of water and may range from planning multibillion naira interstate water projects to advising homeowners about backyard drainage problems.

5.0 Summary

- The application of hydrology can be traced to any human endeavour that requires the use of water.
- Hydrology can be applied in the provision of water for domestic, agricultural and industrial and other uses.
- Hydrology is also relevant in predicting geomorphogical changes, such as erosion or sedimentation, and assessing the impacts of natural and anthropogenic environmental change on water resources.

6.0 Tutor Marked Assignment

(1) The applications of hydrology in the society can be traced to any human endeavour that requires the use of ________________

(2) The availability of surface water for drinking, industrial or other uses is sometimes restricted because of ___________________

(3) Hydrology can be applied in which of the following areas?

(a) determination and monitoring of water quality

(b) determination of agricultural water balance

(c) designing dams for water supply

(d) all of the above

7.0 References/Further Reading

Universities Council on Water Resources (2011). Hydrology: *The Study of Water and Water Problems. A challenge for Today and Tomorrow*.

MODULE II

UNIT 1: CONCEPT OF THE DRAINAGE BASIN

Contents

1.0 Introduction

Having been introduced to the concept of the hydrologic cycle in Module I, unit 4, this unit will focus on the drainage basin. The drainage basin is fundamental to the understanding of the hydrologic cycle because each drainage basin acts as an individual hydrological system, receiving quantifiable inputs of precipitations, which are transformed into flows and storages and into output of evaporation and runoff. As a result, the drainage basin is the most commonly used unit for modeling hydrological processes, for water balance studies, for chemical budgets and for examining human impacts on hydrological systems (Ward and Robinson, 2000). This unit will however focus on the definition, features and patterns of drainage basin.

2.0 Objectives

The learning objectives for this unit are as follows:

- To define drainage basin
- To discuss the features of a drainage basin
- To discuss the various patterns in a drainage basin.

3.0 Main Content

3.1 Drainage Basin Defined

A drainage basin is the topographic region from which a stream receives runoff, through flow, and groundwater flow (Pidwimy, 2006).

Another definition of the drainage basin is by Gallagher (2011), who defined it as an area of the earth's surface occupied by a surface stream or other water body together with all of the tributary streams, surface, and subsurface water flows. Having defined a drainage basin, let us examine its basic features.

3.2 Features of Drainage Basin

A drainage basin consists of a branched network of stream channels and adjacent slopes that feed the channels. It is bounded by a drainage divide, which mark the boundary between slopes that contribute water to different streams or drainage systems.

According to Pidwimy (2006), drainage basins are divided from each other by topographic barriers called watershed. A watershed represents all of the stream tributaries that flow to some location along the stream channel. The number, size and shape of the drainage basins found in an area vary with the scale of examination. It should be noted that drainage basins are arbitrarily defined based on the topographic information available on a map. The quality of this information decreases as map scale becomes smaller.

Large-scale features of a drainage basin include the size, shape, and relief of the basin. Small-scale features include measurements of channel length and slope, storage capacity and drainage density of the stream network within the basin. Each of these geomorphic properties can be used to compare basins.

Drainage basins are open systems. Inputs to these systems include precipitation, snow melt, and sediment. Drainage basins lose water and sediment through evaporation, deposition, and stream flow. A number of factors influence input, output, and transport of sediment and water in a drainage basin. Such factor includes topography, soil type, bedrock, climate, and vegetation cover. These factors also influence the nature of the pattern of stream channels.

In a typical stream network within a drainage basin, each tributary receives runoff from a small area of land surface surrounding the channel. This runoff is carried downstream and merged with runoff from other small tributaries as they join the main stream. The drainage system thus provides a converging mechanism that funnels overland flow into streams and smaller streams into larger ones.

Drainage basins are important to understanding the characteristics of stream habitats. The boundaries of a drainage basin are used to explain biogeography distributions of fish species (Gallagher, 2011). Basin features are a factor in predicting flood patterns, estimating sediment yield, and predicting water availability and quality. The downstream transfer of water, sediment, nutrients, and organic material all influence the characteristics of stream habitat. It is therefore important to understand the geologic, hydrologic, morphologic, and vegetational setting of a stream in its basin. In addition, understanding drainage basin attributes aids habitat investigators when interpreting field data.

3.3 Drainage Basin Patterns

As earlier stated above, factors such as topography, soil types, bedrock type, climate, and vegetation cover influence input, output, and transport of sediment and water in a drainage basin. These factors also influence the nature of the pattern of stream channels. Consequently, five common drainage patterns can easily be identified. They include trellised, rectangular, parallel, dendritic and deranged. Fig 2.0 shows the common drainage patterns.

Trellised Drainage Pattern – It tends to develop where there is strong structural control upon streams because of geology. In such situations, channels align themselves parallel to structures in the bedrock with minor tributaries coming in at right angels.

Rectangular Drainage Pattern – This occurs in areas with tectonic faults or bedrock joints causing a stream to take on a grid-like or rectangular pattern.

Parallel Drainage Pattern – They are often found in areas with steep relief or where flow is over non-cohesive materials.

Dendritic Drainage Pattern – They are typical of adjusted systems on erodable sediments and uniformly dipping bedrock.

Deranged Drainage Pattern – It is found in areas recently disturbed by events like glacial activities or volcanic deposition. Over time, the stream will adjust the topography of such regions by transporting sediment to improve flow and channel pattern.

Self Assessment Exercise

Attempt a sketch of the five major drainage patterns and account for the influencing factors.

4.0 Conclusion

The discussions on the drainage basin have further supported the idea that drainage basin is the most commonly used unit for modeling hydrological processes. Therefore, the understanding of the concept of the drainage basin will foster a better understanding of the hydrologic cycle and the processes involved in it.

5.0 Summary

- A drainage basin is the topographic region from which a stream receives runoff, through flow, and groundwater flow.
- Drainage basin acts as an individual hydrological system, receiving quantifiable inputs of precipitations, which are transformed into flows and storages and into output of evaporation and runoff.

- A drainage basin is bounded by a drainage divide, which mark the boundary between slopes that contribute water to different streams or drainage systems.
- A drainage basin is an open system, with an input of precipitation, snow melt and sediment, and output of evaporation, deposition and streamflow.
- There are five major drainage patterns – trellised, rectangular, parallel, dendritic and deranged.

6.0 Tutor-Marked Assignments

(1) A _____________ represents all of stream tributaries that flow to some location along the stream channel.

(2) A _____________ drainage pattern are often found in areas with steep relief or where flow is over non-cohesive materials.

(1) Which of the following is not an input process to a drainage basin?

(a) deposition (b) precipitation (c) snow melt (d) sediment

(2) Which of the following is not a factor influencing input, output, and transport of sediment and water in a drainage basin.

(a) topography (b) soil colour (c) climate (d) vegetation

7.0 References / Further Reading

Pidwimy, M. (2006). "The Drainage Basin Concept" *Fundamentals of Physical Geography,2nd Edition*,http://www.physicalgeography.net/ fundamentals/10aa.html. 5/5/2011.

Strahler, A & Strahler A. (2006). *Introducing Physical Geography, Fourth Edition*, John Wiley and Sons Inc.

Ward, R.C. and Robinson, M. (2000). *Principles of Hydrology, Fourth Edition*, McGraw Hill Publishing, UK.

UNIT 2: GROUNDWATER RESOURCES

Content

1.0 Introduction

The two major sources of water supply on Earth are ground and surface water. Groundwater is a part of the hydrologic cycle that lies beneath the surface but is tied to surface supplies. Groundwater is the largest potential source of freshwater in the hydrologic cycle – larger than all surface lakes and streams combined (Christopherson, 2007). Despite this volume and its obvious importance, groundwater is widely abused. This unit will define and analyze the formation of groundwater resources. It will also discuss the problems of groundwater management.

2.0 Objectives

The learning objectives are as follows:

- To define groundwater.
- To discuss the formation of groundwater
- To identify the problems of groundwater management.

3.0 Main Content

3.1 Definition of Groundwater

Groundwater is the part of the sub-surface water that fully saturates the pore spaces in bedrock, regolith, or soil, and so occupies the saturated zone (Strahler and Strahler, 2006).

Arms (1994) simply defined groundwater, as water below Earth's surface. Of all the water that falls on land as rain or snow, about one third runs off the surface into streams and rivers, and another one third evaporates or is absorbed by plants. The rest drips or percolates down through soil and rocks and becomes part of the groundwater resources.

3.2 Formation of Groundwater Resources

Groundwater is fed by surplus water, which percolates downward from the zone of capillary water as gravitational water. This excess surface water moves through the zone of aeration, where soil and rocks are less than saturated (an unsaturated zone) and some pore spaces contain air. Eventually, water reaches an area of collected subsurface water known as the zone of saturation, where the pores contain only water. Like a sponge made of sand, gravel, and rock, this zone stores water within its structure, filling all available pores and voids.

The porosity of this layer is dependent on the arrangement, size, and shape of individual component particles; the cement between them; and their degree of composition. Subsurface structures are referred to as permeable or impermeable, depending on whether they permit or obstruct water flows.

An acquifer is a rock layer that is permeable to groundwater flow in usable amounts. An aquiclude is a body of rock that does not conduct water in usable amounts. The zone of saturation is an unconfined aquifer, a water-bearing layer that is not confined by an overlying impermeable layer. The upper limit of the water that collects in the zone of saturation is the water table; it is the contact surface between the zones of saturation and aeration.

The slope of the water table, which generally follows the contours of the land surface, controls groundwater movement. Water wells must penetrate the water table to optimize their potential flow. Where the water table intersects the surface, it creates springs or feeds lakes or riverbeds. Ultimately, groundwater may enter stream channels and flow as surface water. During dry periods the water table can act to sustain river flows.

3.3 Problems of Groundwater Management

The problems of groundwater management shall be examined from two perspectives – water table depletion and pollution.

The rapid withdrawal of ground water has seriously impacted the environment in many places. Increased urban populations and industrial developments require larger water supplies –needs that cannot always be met by constructing new surface water reservoirs. To fill these needs, vast number of wells using powerful pumps draws huge volumes of ground water to the surface, greatly altering nature's balance of groundwater discharge and recharge.

As water is pumped from a well, the level of water in the well drops, at the same time, the surrounding water is lowered in the shape of a downward-pointing cone, termed the cone of depression. The difference in height between the cone tip and the original water table is the drawdown. The cone of depression may extend out as far as 16km or more from a well where heavy pumping is continued. Where many wells are in operation, their intersecting cones will produce a general lowering of the water table. The depletion of the water table often greatly exceeds recharge-the rate at which infiltrating water moves downwards to the saturated zone.

Another byproduct of water table depletion is subsidence – a sinking of the land in response to the removal of water from underlying sediments. This problem has plagued a number of major cities that rely heavily on groundwater wells for their water supplies.

An interesting side effect of urban sprawl and paving land for parking lots, mall, office and industrial parks, and sub-divisions is that the process seals the land, rendering it impermeable to water. Paving and sealing urban surfaces deprives the groundwater system of adequate recharge water, thereby further reducing water table.

Another major environmental problem related to ground water withdrawal is contamination of wells by pollutants that infiltrate the ground and reach the water table. Both solid and liquid waste is responsible.

When surface water is polluted, groundwater also becomes contaminated because it is recharged from surface – water supplies. Groundwater migrates slowly compared to surface water. Surface water flows rapidly and flushes pollution downstream, but sluggish groundwater, once contaminated, remains polluted virtually forever (Christopherson, 2007).

Pollution can enter groundwater from industrial waste injection wells, septic tank outflows, seepages from hazardous waste disposal sites, industrial toxic-waste dumps, residues of agricultural pesticides, herbicides, fertilizers, and residential and urban wastes landfills.

Another source of contamination in coastal wells is saltwater intrusion. Since fresh water is less dense than salt water, coastal aquifer can be underlain by a layer of salt water from the ocean. When the aquifer is depleted, the level of saltwater rises and eventually reaches the well from below, rendering the well unusable.

Self Assessment Exercise

Account for the formation of groundwater resources, and state how the problem of groundwater can be effectively managed.

4.0 Conclusion

Groundwater is a rich source of fresh water supply for domestic, agricultural and industrial uses. However, there are some militating problems in its management, which include pollution and depletion of the water table. If the problem of overuse and pollution are controlled, groundwater will continue to be a reliable source of fresh water supply.

5.0 Summary

- Groundwater can be defined as water below the earth surface.
- Groundwater is the largest potential source of freshwater in the hydrological cycle.
- Groundwater is fed by surplus water, which percolates downward from the zone of capillary water as gravitational water.
- Water table depletion and contamination are some of the major challenges affecting the use of groundwater resources.

6.0 Tutor Marked Assignment

(1) The two major sources of water supply on earth are ____ and ____ water.

(2) __ is a rock layer that is permeable to groundwater flow in useable amounts.

(3) A sinking of the land in response to the removal of water from underlying sediment is called _________

(1) A body of rock that does not conduct water in usable amounts is called what?

(a) aquifers (b) cone of depression (c) aquiclude (d) gravel

(2) Which of the following is a problem of groundwater management?

(a) salt water intrusion (b) pollution (c) water table depletion (d) all of the above

(3) Pollution can enter groundwater through which of the following sources.

(a) industrial waste (b) injection wells (c) herbicides (d) all of the above

7.0 References / Further Reading

Arms, K. (1994) *Environmental Science. Second Edition,* Sanders College Publishing, U.S.A.

Christopherson, R.W. (2007) *Elemental Geosystem, Fifth Edition*, Pearson Prentice Hall Upper Saddle River N.J. 07458.

Strahler, A and Strahler A. (2006), *Introducing Physical Geography, Fourth Edition*, John Wiley and Sons Inc.

Ward, R.C. and Robinson, M. (2000) Principles of Hydrology, Fourth Edition MacGraw Hill Publishing UK.

UNIT 3: SURFACE WATER RESOURCES

Contents

1.0 Introduction

As earlier noted while discussing groundwater resources, surface water resources is one of the two major sources of water supply on earth. It is also a major component of the hydrological cycle.

So far, we have examined how water moves below the land surface. Now, we turn to tracing the flow paths of surplus water that runs off the land surface and ultimately reaches the sea. Here, we will be concerned primarily with rivers and streams. In general usage, we speak of "river" as large watercourses and "stream" as smaller ones. However, the word "stream" is also used as a scientific term designating the channeled flow of surface water of any amount. This unit will focus on the definition of surface water, overland and stream flows, and surface water pollution.

2.0 Objectives

The learning objectives are as follows:

- To define surface water
- To distinguish between overland flow and stream flow.
- To identify the various forms of surface water pollution.

3.0 Main Content

3.1 Definition of Surface Water

Surface water is water in a river, lake or fresh water wet land. Surface water is naturally replenished by precipitation and naturally lost through discharge to the oceans, evaporation and unrecovered infiltration (http://en.wikipedia.org/wiki/water_resources 2007).

Surface water can be withdrawn from the stream, lakes and reservoirs for human activities but only part of the total annual runoff is available for use. Some of it flows into the sea two rapidly to be captured and some must be left in the stream for wildlife. In some years the amount of runoff is reduced by below average precipitation (Miller, 1996). Although the only natural input to any surface water system is precipitation within its watershed, the total quantity of water in that system at any given time is also dependent on many other factors – landscape, temporal variation, geographic factors and human activities. Hence, surface water is non-uniformly distributed over the earth surface (Viessman and Hammer, 1998).

3.2 Overland Flow and Stream Flow

Runoff that flows down the slopes of the land in broadly distributed sheets is overland flow. We can distinguish overland flow from stream flow, in which the water occupies a narrow channel confined by lateral banks. Overland flow can take several forms. Where the soil or rock surface is smooth, the flow may be a continuous thin film, called sheet flow. Where the ground is rough or pitted, flow may take the form of a series of tiny rivulets connecting one water-filled hollow with another. On a grass-covered slope, overland flow is sub-divided into countless tiny threads of water, passing around the stems. Even in a heavy and prolonged rain, you might not notice overland flow in progress on a sloping lawn. On heavily forested slopes, overland flow may pass entirely concealed benefit a thick mat of decaying leaves.

Overland flow eventually contributes to a stream, which is a much deeper, more concentrated form of runoff. We can define a stream as a long, narrow body of flowing water occupying a trench like depression, or channel, and moving to lower levels under the force of gravity. The channel of a stream is a narrow trough. The forces of flowing water shape the trough to its most effective form for moving the quantities of water and sediment supplied to the stream.

As a stream flows under the influence of gravity, the water encounters resistance – a form of friction – with the channel walls. As a result, water close to the bed and banks moves slowly, while water in the central part of the flow moves faster. If the channel is straight and symmetrical, the single line of maximum velocity shifts toward the bank on the outside of the curve (Strahler and Strahler, 2006).

Streams may be classified as influent or influence. In an effluent stream, flow is maintained during the dry season by groundwater seepage into the stream channel from the subsurface. An influent stream is entirely above the groundwater table, and flows only on direct response to precipitation. Water from an influent stream seeps down into the subsurface.

3.3 Surface Water Pollution

Pollution of surface water occurs when too much of undesirable or harmful substance flows into a body of water exceeding the natural ability of that water body to remove the undesirable material, dilute it to a harmless concentration, or convert it to a harmless form.

Water pollutants, like pollutants in general are categorized as emitted from point or nonpoint sources. Point sources are distinct and confined, such as pipes from industrial or municipal sites that empty into streams or rivers. Nonpoint sources, such as runoff, are diffused and intermitted and are influenced by factors such as land use, climate, hydrology, topography, native vegetation, and geology. Common urban nonpoint sources include urban runoff from streets or fields; such runoff contains all sorts of pollutants, from heavy metals to chemicals and sediments. Rural sources of nonpoint pollution are generally associated with agriculture, mining, or forestry. Nonpoint sources are difficult to monitor and control (Botkin and Keller, 1998).

From an environmental view point, two approaches to deal with water pollution are-reduced the source or treat the water to remove or convert the pollutant to a harmless form. Which of the options is used depends on the specific circumstances of the pollution problem. However, reduction at the source is the most environmentally preferable way of dealing with pollutants.

Self Assessment Exercise

What do you think are the major limitations to the optimal use of surface water resources?

4.0 Conclusion

From the above discussions, it is evident that surface water constitutes an important source of water supply for our everyday usage. However, because of the peculiar nature of surface water, it is easily abused leading to pollution. The pollution problem has created a great burden for those who use this source of water supply. To enhance the quality of surface water supply, it has to be treated to remove the harmful substances in it.

5.0 Summary

- Surface water is one of the major sources of water supply; it is also an important component of the hydrological cycle.
- Surface water is water in a river, lake or fresh water wetland.
- Overland flow is runoff that flows down the slopes of the land in broadly distributed sheets; while stream flow is when the water occupies a narrow channel confined by lateral banks.
- Surface water pollution occurs when the water quality is degraded.
- Two of the approaches to dealing with water pollution are – reduce the source or treat the water to remove or convert the pollutant to a harmless form.

6.0 Tutor Marked Assignment

(1) Water in a river, lake or fresh water wetland is called ____________

(2) The only natural input to any surface water system within its watershed is _______

(3) When water occupies a narrow channel confined by lateral banks it is called_____

(4) Surface water is naturally lost through which of the following

(a) discharge to the ocean (b) evaporation (c) unrecovered infiltration

(d) All of the above

(5) Which of the following reasons accounts for the non uniform distribution of surface water over the earth surface?

(a) climatic factors (b) human activities (c) all of the above

(d) none of the above

(6) Which of the following is not a non point source of pollution of surface water?

(a) pipes from industrial sites that empty into rivers

(b) urban runoff from streets

(c) agricultural runoff

(d) runoff from fields

7.0 References/Further Reading

Botkin, D.B. and Keller, E.A. (1998). *Environmental Science: Earth as a Living Planet, Second Edition,* John Wiley and Sons Inc. New York.

http://en.wikipedia.org/wiki/water_resources 11/13/2007.

Miller, G.T. (1996). *Living in the Environment: Principles, Connections and Solutions, Nineth Edition*, Wadsworth Publishing Company Belomont, California.

Viessman, W. and Hammer, M.J. (1988). *Water Supply and Pollution Control, Sixth Edition,* California, Addison Wesley Longman Incorporated.

Strahler, A and Strahler, A. (2006). *Introducing Physical Geography, Fourth Edition,* John Wiley & Sons Inc.

UNIT 4: PRECIPITATION

Contents

1.0 Introduction

In our discussions on surface and groundwater resources, we did mention that precipitation is the primary input vector of the hydrologic cycle. It replenish both surface and groundwater sources. The major forms of precipitation are rain, snow and hail. Precipitation is derived from atmospheric water, its form and quantity thus being influenced by the action of other climatic factors such as wind, temperature, and atmospheric pressure. In this unit, we shall attempt a definition of precipitation, its formation, types and measurement.

2.0 Objectives

The learning objectives are as follows:

- To define precipitation.
- To discuss the formation of precipitation.
- To describe the types of precipitation.
- To illustrate the measurement of precipitation.

3.0 Main Content

3.1 What is Precipitation?

Precipitation can be defined as water falling in solid or liquid form e.g. rain, snow, and hail. Precipitation is the process that provides the fresh water essential for most forms of terrestrial life. Clouds are the source of precipitation; however, evaporation and condensation processes are the driving forces.

3.2 Formation of Precipitation

Precipitation can form in two ways. In warm clouds, fine water droplets condense, collide, and coalesce into larger and larger droplets that can fall as rain. In colder clouds, ice crystals form and grow in a cloud that contains a mixture of both ice crystals and water droplets. The first process occur when saturated air rises rapidly, and cooling forces additional condensation. Cloud droplets grow by added condensation and attain a diameter of 50 to 100mm. In collisions with one another; the droplets grow to about 500um in diameter. This is the size of water droplets in drizzle. Further collisions and coalescence increase drop size and yield rain. Average rain drops have diameters of about 1000 to 2000um, but they can reach a maximum diameter of about 7000um. Above this value they become unstable and break into smaller drops while falling. This type of precipitation occurs in warm clouds typical of the equatorial and tropical zones.

In cold clouds, a second process produces snow. Here, clouds contain a mixture of ice crystals and super cooled water droplets. As the ice crystals take up water vapour and grow by deposition, the super cooled water droplets lose water vapour by evaporation and shrink. When an ice crystal collides with a droplet of super cooled water, it induces freezing of the droplet. Ice crystals grow further, taking on shapes such as plates, columns, or needles. Under certain conditions, the ice crystals take the form of dendrites – delicate structure with six-sided symmetry.

When the underlying air layer is below freezing, snow reaches the ground as a solid form of precipitation. Otherwise, it melts and arrives as rain. A reverse process, the fall of raindrops through a cold air layer results in the freezing of rain and produces pellets or gains of ice; which are commonly referred to as a sleet in North America (Strahler and Strahler, 2006).

3.3 Types of Precipitation

Precipitation is often classified according to the factor mainly responsible for the lifting of the air mass (Linsley, et al, 1982). Accordingly, three major types of precipitation are identified. They include cyclonic, convectional and orographic precipitation.

3.3.1 Cyclonic Precipitation

Cyclonic precipitation results from the lifting of air converging into a low-pressure-area, or cyclone. Cyclonic precipitation may be either frontal or nonfrontal. Frontal precipitation results from the lifting of warm air on one side of a frontal surface over, cold denser air on the other side. Warm-front precipitation is formed when warm air advances upward over a colder air mass. The rate of ascent is relatively slow, since the average slope of the frontal surface is usually between $^1/_{100}$ and $^1/_{300.}$ Precipitation may extend 300 to 500km ahead of the surface front and is generally light to moderate and nearly continues until passage of the front. Cold front precipitation, on the other hand, is of showery nature and is formed when warm air is forced upward by an advancing mass of cold air, the leading edge of which is the surface cold front. Cold fronts move faster than warm fronts, and the frontal surfaces, with slopes usually averaging $^1/_{50}$ to $^1/_{150}$, is steeper. Consequently, the warm air is forced upward more rapidly than by the warm front, and precipitation rates generally much higher. Heaviest amounts and intensities occur near the surface front.

3.3.2 Convectional Precipitation

Convectional precipitation is caused by natural rising of warmer, lighter air in colder, denser surrounding. Generally, this kind of precipitation occurs in the topics, where on a hot day, the ground surface gets heated unequally, causing the warmer air to lift up as the colder air comes to take its place. The vertical air currents develop tremendous velocities. Convectional precipitation occurs in the form of showers of high intensity and of short duration.

3.3.3 Orographic Precipitation

Orographic precipitation is caused by air masses which strike some natural topographic barriers like mountains, and cannot move forward and hence rise up, causing condensation and precipitation. All the precipitation we have in Himalayan region is because of this nature. It is rich in moisture because of their long travel over oceans.

At this point, it should be noted that in nature, the effects of these various types of cooling discussed above, are often interrelated. Therefore, the resulting precipitation in most cases cannot be identified as being of any one type.

3.4 Measurement of Precipitation

A variety of instruments and techniques have been developed for gathering information on precipitation. Instruments for measuring amount and intensity of precipitation are the most important. All forms of precipitation are measured on the basis of the vertical depth of water that would accumulate in a level surface if the precipitation remained where it fell. In the metric system precipitation is measured in millimeters and tenths.

Precipitation is measured with a rain gauge. It consists of a collecting jar, a funnel and a container, which is dug on the ground, with 30cm of the instrument appearing above the ground. Rain gauge is usually sited is an open place, where there are no trees or tall buildings to obstruct the incoming precipitation. The diameter of the funnel is normally 13cm. The water that collects in the jar is then poured into a measurement cylinder from where the amount of precipitation that has fallen is read off. Figure 2.1 shows a diagrammatic representation of a rain gauge.

Self Assessment Exercise

Identify the three major types of precipitation and state their modes of formation

4.0 Conclusion

Precipitation is an important process of the hydrologic cycle, which helps to replenish both surface and groundwater sources. It also helps to sustain the available freshwater pool on earth. Having gone through this unit, you should appreciate the various dynamic processes that take place for us to receive precipitation on planet Earth. In addition, you should be well acquainted with the types of precipitation and mode of its measurement.

5.0 Summary

- Precipitation can be defined as water falling in solid or liquid form e.g. rain, snow, and hail.
- The formation of precipitation involves three basic processes-lifting and cooling of air mass, condensation and droplet formation.
- There are three types of precipitation – cyclonic, convectional and orographic.
- Rain gauge is an instrument used in measuring precipitation.

6.0 Tutor Marked Assignment

(1) The instrument used in measuring rainfall is ________

(2) The type of precipitation caused by air masses which strike some natural topographic barriers like mountain is called______

(3) Which of the following is not a type of precipitation?

(a) snow (b) cyclonic (c) convectional (d) orographic

(4) The formation of precipitation that involves the natural rising of warmer, lighter air in colder, denser surrounding is called what

(a) orographic (b) conventional (c) cyclonic (d) none of the above

(5) What type of precipitation is mainly associated with the tropics?

(a) cyclonic (b) orographic (c) conventional (d) all of the above

6.0 References / Further Reading

Linsley, R.K. Jr; Kohler M.A. and Paulhus, J.L.H. (1982). *Hydrology for Engineers, Third Edition,* MacGraw Hill, International Book Company.

Smithson, P; Addison, K and Atkinson, K (2002). *Fundamentals of the Physical Environment, Third Edition,* Rutledge, Tay and Frances Group, London.

Strahler, A and Strahler A. (2006). *Introducing Physical Geography, Fourth Edition*, John Wiley & Sons Inc.

UNIT 5: HUMIDITY

Contents

1.0 Introduction

Humidity is another subset of the hydrological cycle, and its knowledge is important to the study of hydrology. Humidity is concerned with the vapor state (gas) of water in the atmosphere. This unit will focus on the definition of humidity, specific and relative humidity, and its measurement.

2.0 Objectives

The learning objectives are as follows:

- To define humidity
- To distinguish between specific and relative humidity
- To state and describe the instruments used in measuring humidity.
- To calculate relative humidity

3.0 Main Contents

3.1 What is Humidity?

Humidity refers to the amount of water vapour present in the air. The amount of water vapour present in the air varies widely from place to place and time to time. It ranges from almost nothing in the cold, dry air of arctic regions in winter to as much as 4 or 5 percent of a given volume of air in the warm wet regions near the equator (Strahler and Strahler, 2006).

Understanding humidity and how the moisture content of air is measured involves an important principle, which states that the maximum quantity of moisture that can be held at any time in the air is dependent on air temperature. Warm air can hold more water vapour than cold air. For example, air at room temperature (20^0C) can hold about three times as much water vapour as air at freezing point (0^0C).

3.2 Specific Humidity

Specific humidity is the actual quantity of water vapour held by a parcel of air. This measure is important because it describes how much water vapour is available for precipitation. Specific humidity is stated as the mass of water vapour contained in a given mass of air and is expressed as grams of water vapour per kilogram of air (g/kg). Specific humidity is often used to describe the moisture characteristics of a large mass of air. For example, extremely cold dry air over arctic regions in winter may have a specific humidity as low as 0.2g/kg. In comparison, the extremely warm, moist air of equatorial regions often holds as much as 18g/kg. The total natural range on a worldwide basis is very wide. In fact, the largest values of specific humidity observed are from 100 to 200 times as great as the smallest (Strahler and Strahler, 2006).

Specific humidity is a yardstick for a basic natural resource – water. It is a measure of the quantity of water in the atmosphere that can be extracted as precipitation. Cold moist air can supply only a small quantity of rain or snow, but warm, moist air is capable of supplying large amounts.

Another way of describing the water vapour content of air is by its dew-point temperature. If air is slowly chilled, it eventually will reach saturation. At this temperature, the air holds the maximum amount of water vapour possible. If further cooling continues, condensation will begin and dew will form. The temperature at which saturation occurs is therefore known as the dew-point temperature. Moist air will have a higher dew-point temperature than drier air.

3.3 Relative Humidity

Relative humidity is a ratio (expressed as a percentage) of the amount of water vapour that is actually in the air compared to the maximum water vapour possible in the air at a given temperature. Warmer air increases the evaporation rate from water surfaces, whereas cooler air tends to increase the condensation rate of water vapour to water surfaces. Because there is a maximum amount of water vapour that can exist in a volume of air at a given temperature, the rates of evaporation and condensation can reach equilibrium at some point; the air is then saturated with humidity. Relative humidity varies because of evaporation, condensation; or temperature changes. All three affect both the moisture in the air (the numerator) and the water vapour possible (the denominator) in the air. The formula for calculating the relative humidity ratio and expressing it as a percentage is simply.

$$\text{Relative Humidity} = \frac{\text{Actual water vapour in the air} \times 100}{\text{Maximum water vapour possible in the air at that temperature}}$$

As earlier stated, air is saturated when the rate of evaporation and the rate of condensation reach equilibrium – that is 100% relative humidity. In saturated air, the net transfer of water molecules between a moisture surface and the air reaches equilibrium. Saturation indicates that any further addition of water vapour or any decrease in temperature that reduces the evaporation rate will result in active condensation (clouds, fog, or precipitation). Therefore, relative humidity indicates the nearness of air to a saturated condition and when active condensation will begin.

The temperature at which a given mass of air becomes saturated is the dew-point temperature. In other words, air is saturated when the dew-point temperature and the air temperature are the same. When temperatures are below freezing, the term frost point is sometimes used. A cold drink in a glass provides a common example of these conditions. The water droplets that form on the outside of the glass condense from the air because the air layer next to the glass is chilled to below its dew-point temperature and thus is saturated (Christopherson, 2007).

During a typical day, air temperature and relative humidity relate inversely – as temperature rises, relative humidity falls. Relative humidity is highest at dawn, when air temperature is lowest. If you park outdoors, you know about the wetness of the dew that condenses on the car overnight. Relative humidity is lowest in the late afternoon, when higher temperatures increase the rate of evaporation.

3.4 Measurement of Humidity

Relative humidity is measured with various instruments. The hair hygrometer is based on the fact that human hair changes as much as 4% in length between 0% and 100% relative humidity. The instrument connects a standardized bundle of human hair through a mechanism to a gauge. As the hair absorbs or loses water in the air, its change in length indicates relative humidity.

Another instrument used to measure relative humidity is a sling pyschrometer. This device has two thermometers mounted side by side on a metal holder. One is called the dry-bulb thermometer; it simply records the ambient (surrounding) air temperature. The other thermometer is called the wet-bulb thermometer, because it is moist. The psychrometer is then spun by its handle; after a minute or two, the temperature of each bulb is compared on a relative humidity (Psychrometric) chart, from which relative humidity can be determined. The rate at which water evaporates from the wick depends on the relative saturation of the surrounding air. If the air is dry, water evaporates quickly, absorbing the latent heat of evaporation from the wet bulb thermometer, causing the temperature to drop (wet-bulb depression). In an area of high humidity, much less water evaporates from the wick, resulting in a smaller temperature difference between the two thermometers.

Self Assessment Exercises

(i) Based on your understanding of the concepts of precipitation and humidity, do you think there is any relationship between both concepts?

(ii) What is the difference between specific humidity and relative humidity?

4.0 Conclusion

Having gone through this unit, you should by now be well informed of the close relationship that exists between humidity and precipitation – a significant component of the hydrologic cycle. Humidity is a measure of the quantity of water in the atmosphere that can be extracted as precipitation. In other words, the amount of precipitation received in a given area is dependent to a very large extent on the moisture characteristics of the air mass.

5.0 Summary

- Humidity refers to the amount of water vapour present in air.
- Warm air holds much more water vapour than cold air.
- The dew-point temperature of a mass of air is the temperature at which saturation will occur. The more water vapour in the air, the higher is the dew-point temperature.
- Relative humidity depends on both the water vapour content and the temperature of air. It compares the amount of water held by air to the maximum amount that can be held at that temperature.

6.0 Tutored-Marked Assignments

(1) The amount of water vapour present in the air is called _______

(2) The maximum quantity of moisture that can be held at any time in the air is dependent on __________

(3) The actual amount of water vapour held by a parcel of air is called ______

(4) Which of the following is an instrument used in measuring relative humidity?

(a) sling psychrometer (b) hair hygrometer (c) A & B (d) none of the above

(5) At what percentage is relative humidity said to be saturated

(a) 0% (b) 50% (c) 100% (d) 200%

(6) What factor influences the variation of relative humidity?

(a) evaporation (b) temperature (c) a and b (d) none of the above

7.0 References / Further Reading

Christopherson, R.W. (2007). *Elemental Geosystems, Fifth Edition*, Pearson Prentice Hall Upper Saddle River N.J. 07458.

Strahler, A and Strahler, A. (2006). *Introducing Physical Geography. Fourth Edition,* Wiley and Sons Inc.

MODULE III

UNIT 1: INTERCEPTION

Contents

1.0 Introduction

Interception is another important concept in the study of hydrology. On our study of precipitation in Module II, we did not expatiate on the intervening process that prevents precipitation from getting to the ground. Such intervening process is interception. This unit will attempt a definition of interception; analyze the factors affecting interception and measurement of interception.

2.0 Objectives

The learning objectives are as follows:

- To define interception
- To state the factors affecting interception
- To describe the measurement of interception

3.0 Main Content

3.1 Definition of Interception

The temporary storage and prevention of precipitation from reaching the ground surface by natural and artificial objects is called interception.

Ward et al (2000) defined interception as that segment of the gross precipitation input, which wets and adheres to above ground objects until it is returned to the atmosphere through evaporation.

When precipitation falls into a vegetated surface, only a part may actually reach the ground beneath. Depending upon the nature and density of the vegetation cover, a proportion of the rain may be intercepted by the leaves and stems of the vegetation canopy and temporarily stored on its surfaces. Some or all of this water may be evaporated back into the atmosphere, and so take no part in the land-bound portion of the hydrological cycle; this is termed the interception loss. The remaining water which reaches the ground constitutes the net rainfall. The bulk of this comprises throughfall consisting of raindrops that fall through spaces in the vegetation canopy and water which drips from wet leaves, twigs and stems to the ground surface; a generally much smaller amount of water trickles along twigs and branches to run down the main stem or trunk to the ground as stemflow.

Interception process is important because it can help to reduce runoff and erosion problems. Secondly, the net rainfall beneath a vegetation canopy is generally less than the gross rainfall falling onto the top of the vegetation canopy. In some cases the interception loss may be quite large and can have a significant impact on the water balance.

3.2 Factors Affecting Interception

Several factors affect the magnitude of interception. Some of these factors are: vegetation type and density, wind system, duration and nature of rain.

Very dense vegetation cover is known to intercept more water than a sparse one. In addition, the general canopy density affects the rate and magnitude of interception. Also, the dryness and wetness of the vegetation is very important. Dry vegetation has higher interception storage – the ability of the vegetation surfaces to collect and retain falling precipitation, than wet vegetation, because of the differences in their surface tension.

The wind system and the duration of the rain also affect interception. The winds affect the rate of water lost through evaporation. Apart from creating turbulence within the whole system, the duration is important because the longer the period of rainfall, the more water that is likely to be intercepted. The nature of the rainfall is also important because the ability of the vegetation to intercept water is higher during low intensity rainfall than during storms.

3.3 Measurement of Interception

The most common method of measuring interception loss (I) in the field is to compute the difference between the precipitation above the vegetation layer (P) and the net precipitation below the vegetation canopy, comprising the throughfall (T) and stemflow (S), thus:

$$I = P - T - S \text{ ------ } (2)$$

Due to the difficulties of installing equipment underneath a vegetation canopy, this method has been used more for forest vegetation than for lower-order covers.

Throughfall may be measured using funnel or trough gauges placed beneath the forest canopy, and stemflow may be collected by small gutters sealed around the circumference of the truck leading into a container.

Self Assessment Exercise

Of what importance is interception? Can you account for the factors that influence the rate of interception?

4.0 Conclusion

The journey of precipitation from the clouds to the ground is not a straight one as has been highlighted from the above discussions. Part of it is intercepted by both natural and artificial objects. Hence, the net rain that reaches the ground surface is less than the gross rainfall, which has implications on surface runoff and water balance.

5.0 Summary

- The temporary storage and prevention of precipitation from reaching the ground surface by natural and artificial objects is called interception.
- Interception accounts for the variation between the gross rainfall and the net rainfall that reaches the ground.
- Factors that influence the magnitude of interception include vegetation type and density, wind system, duration and nature of rain.

6.0 Tutor Marked Assignment

(1) The process that prevents precipitation from getting to the ground by natural and artificial objects is called __________

(2) The major natural objects of interception is ____________

(3) The ability of the vegetation surface to collect and retain falling precipitation is called ______________

(4) Which of the following factors do not affect interception?

(a) soil profile (b) wind system (c) duration of rain

(d) vegetation density

(5) Interception lost can be represented by which of the following equations:

(a) I=P-T+S (b) I=P-T-S (c) I=P+T+S (d) I=P+T-S

(6) Which of the following options is true of interception?

(a) vegetation intercept more during high storm

(b) vegetation intercept more during low intensity rainfall

(c) vegetation interception does not very at all

(d) all of the above.

7.0 References / Further Reading

Chorley R.J. (1969). *Water, Earth and Man. A Synthesis of Hydrology, Geomorphology and Socio-Economic Geography*, Methuen and Co Ltd, London.

Ward, R.C. & Robinson, M. (2000). *Principles of Hydrology, Fourth Edition*, McGraw-Hill Publishing, U.K.

UNIT 2: INFILTRATION

Contents

1.0 Introduction

In the preceding unit, we learnt that not all precipitation gets to the ground surface due to the process of interception. In this unit we are going to examine infiltration, one of the processes that precipitation which gets to the ground surface under goes. Here we shall attempt a definition of infiltration, examine the factors that influence infiltration and measurement of infiltration.

2.0 Objectives

The learning objectives are as follows:

- To define infiltration
- To list and discuss the factors that influence infiltration
- To discuss the commonly used methods in measuring infiltration.

3.0: Main Content

3.1: Definition of Infiltration

Infiltration is the process by which precipitation moves downward through the surface of the earth and replenishes soil moisture, recharges acquifers, and ultimately supports streamflows during dry periods. Along with interception, depression storage, and storm period evaporation, it determines the availability, if any, of the precipitation input for generating overland flows. Furthermore, infiltration rates influence the timing of overland flow inputs to channelized systems. Accordingly, infiltration is an important component of any hydrological model.

3.2 Factors Influencing Infiltration

The rate at which infiltration occurs is influenced by several factors such as, the type and extent of vegetal cover, the condition of the surface crust, temperature, rainfall intensity, and physical properties of the soil. Infiltration rates vary from one soil type to another. In very loose soil, e.g. sandy soils, the rate of infiltration is usually very high and lowest in clay soils because clay soils have very tiny particles, which make them compact. The pores are smaller in size and number when compared with sandy soils. Soils act as a kind of giant sponge containing passages and caverns of various sizes. The total space available for water and air in the soil is called porosity. Infiltration is a function of porosity. The passage of water from soil surface to stream banks or water conducting rocks (acquifers) takes place in a very tortuous way through small diameter passages. So, it is not surprising that water movement within the soil is slow.

Most soils are on sloping lands and so soil water movement takes place towards the slope base in a process called the through flow. The vertical movement of water in the soil is however called percolation. The degree of which is related to porosity of the soil.

The rate at which water is transmitted through the surface layer is highly dependent on the condition of the surface. For example, inwash of fine material may seal the surface so that infiltration rates are low even when the underlying soils are highly permeable. After water crosses the surface interface, its rate of downward movement is controlled by the transmission characteristics of the underlying soil profile. The volume of storage available below ground is also a factor affecting infiltration rates.

3.3 Measurement of Infiltration

Hydrograph analyses and infiltrometer studies are some of the commonly used methods for determining infiltration capacity. Hydrograph is a graph which represents the changes in the level of water with time. Estimates of infiltration based on hydrograph analyses have the advantage over infiltrometers of relating more directly to prevailing conditions of precipitation and field. They are however, not better than the precision with which rainfall and runoff are measured. Of special importance in such studies is the areal variability of rainfall.

Infiltrometers are usually classified as rainfall stimulators or flooding devices. In the former, artificial rainfall is simulated over a test plot and the infiltration is calculated from observations of rainfall and runoff, with consideration given to depression storage and surface detention. Flooding infiltrometers are usually rings or tubes inserted in the ground. Water is applied and maintained at a constant level and observations are made of the rate of replenishment required. It should be noted that several other methods for measuring infiltration have been developed and are currently in use.

Self Assessment Exercise

If you agree that infiltration is the downward movement of water through the surface of the earth, then state the factors that affect the rate of infiltration.

4.0 Conclusion

From the above discussions, it has been revealed that the study of infiltration is very vital in hydrologic studies. Its importance can be found in the determination of soil moisture, aquifer recharge, and support to stream flow during dry season. In addition, it can be use to determine runoff and erosion.

5.0 Summary

- Infiltration is the process by which precipitation moves downward through the surface of the earth.
- Some of the factors that influence infiltration are physical properties of the soil, vegetal cover, rainfall intensity, and nature of the surface crust.
- Infiltration capacity is commonly measured with the aid of hydrograph analyses and infiltrometer studies.

7.0 Tutor Marked Assignment

(1) The process by which precipitation moves downward through the surface of the earth is called _____________

(2) The total space available for water and air in the soil is called _____

(3) Which of the following options is incorrect about infiltration?

(a) it replenishes soil moisture (b) it affects the rate of interception
(c) it recharges aquifers (d) it supports stream flow.

(4) The rate of infiltration is highest in which of the following soil types
(a) clay soil (b) loamy soil (c) sandy soil (d) none of the above

7.0 References/Further Reading

Viessman, W. Jr. and Lewis, G.L. (2003). *Introduction to Hydrology, Fifth Edition,* Pearson Education Inc. Upper Saddle River, N.J. 07458.

Ward, R.C. and Robinson, M. (2000). *Principles of Hydrology, Fourth Edition,* McGraw Hill Publishing, UK.

UNIT 3: SOIL MOISTURE

Contents

1.0 Introduction

In the preceding unit we discussed the process of infiltration-downward movement of water from the surface. In this unit we are going to examine soil moisture, which is a direct consequence of infiltration process. The discussion will centre on the definition and importance of soil moisture, factors affecting soil moisture, and measurement of soil moisture.

2.0 Objectives

The learning objectives are as follows:

- To define soil moisture and state its importance
- To identify soil properties affecting soil moisture
- To describe the measurement process of soil moisture

3.0 Main Content

3.1 Definition and Importance of Soil Moisture

Soil moisture or soil water as it is referred to in some quarters, is normally considered to include both the water contained in the soil profile itself and the subsurface water in the unsaturated subsoil layers between the soil profile and the water table. Thus defined, soil moisture includes all the water in the zone of aeration which may extend tens or even hundreds of metres below the ground surface. However, the ability of the shallow soil profile proper to absorb and retain moisture is generally of great hydrological importance (Ward and Robinson 2000).

Water in the soil is a critical resource needed for plant growth. The amount of water available at any given time is determined by the soil water balance, which includes the gain, loss, and storage of soil water. Water held in storage in the soil water zone is increased by recharge during precipitation but decreased by use through evapotranspiration. Surplus water is disposed of by downward percolation to the ground water zone or by overland flow.

Soil moisture storage is a “savings account” of water that can receive deposits and allow withdrawals as conditions change in the water balance. Soil moisture storage refers to the amount of water that is stored in the soil and is accessible to plant roots. Moisture retained in the soil comprises two classes of water, only one of which is accessible to plants. The inaccessible class is hydroscopic water, the thin molecular layer that is tightly bound to each soil particle by the natural hydrogen bonding of water molecules. Such water exists even in the desert but is not available to meet moisture demands. Soil is said to be at the wilting point when all that is left in the soil is unextractable water; the plant wilt and eventually die after a prolonged period of such moisture stress.

The soil moisture that is generally accessible to plant roots is capillary water, held in the soil by surface tension and hydrogen bonding between the water and the soil. Most capillary water that remains in the soil is available water in soil-moisture storage and is removable to meet moisture demands through the action of plant roots and surface evaporation. After water drains from the larger pore spaces, the available water remaining for plants is termed field capacity, or soil-storage capacity. Generally, maintaining soil moisture close of field capacity is essential to plant growing success.

When soil becomes saturated after rainfall or snowmelt, some soil-water surplus becomes gravitational water. This excess water percolates downward under the influence of gravity from the shallower capillary zone to the deeper groundwater zone.

Plant roots exert a tensional force on soil moisture to absorb it. As water transpires through the leaves, a pressure gradient is established throughout the plant, thus "pulling" water into plant roots. When soil moisture is at field capacity, plants obtain water with less effort. As the soil water is reduced by soil-moisture utilization, the plants must exert greater effort to extract the same amount of moisture. As a result, even though a small amount of water may remain in the soil, plants may be unable to exert enough pressure to utilize it. The unsatisfied demand is a deficit (Christopherson, 2007). Rainwater, snowmelt, and irrigation water provide soil moisture recharge.

3.2 Factors Influencing Soil Moisture

The main forces responsible for holding water in the soil are those of capillarity, absorption and osmosis. Capillary forces result from surface tension at the interface between the soil air and soil water. Molecules in the liquid are attracted more to each other than to the water vapour molecules in the air, resulting in a tendency for the liquid surface to contract. If the pressure was exactly the same on either side, then the air-water interface would be flat, but pressure differences result in a curved interface, the pressure being greater on the inner, concave side by an amount that is related to the degree of curvature. At the interface in the soil pore space, the air will be at atmospheric pressure, but the water may be at a lower pressure.

In addition to capillary forces, soil water liquid or vapour can be absorbed upon the surfaces of soil particles mainly due to electrostatic forces in which the polar water molecules are attracted to the charge faces of the solids. Since the forces involved are only effective very close to the solid surface, only very thin films of water can be held in this way. Nevertheless, if the total surface area of the particles (i.e. the specific surface) is larger, and/or the charge per unit area is large, then the total amount of water absorbed in a volume of soil may be considerable.

A third force which acts to retain water in the soil results from osmotic pressure due to solutes in the soil water. Osmotic pressure is important when there is a difference in solute concentration across a permeable membrane. This may be at a plant root surface, making water less available to plants, especially in saline soils, or across a diffusion barrier such as an air-filled pore, by allowing the movement of water vapour, but not the solute, across the pore from the more dilute to the more concentrated solution (Hillel, 1982) quoted from (Ward and Robinson, 2000).

The amount of water that can be held in a given volume of soil and the rate of water movement through that soil depend upon both the texture, i.e. the size distribution of the mineral particles of the soil, and upon the soil structure, the aggregation of these particles. Water may occupy both inter structural voids and textural voids (between the particles). At high moisture contents water flow through the former may be dominant, but becomes rapidly less important as the soil becomes drier. In general, the coarser the particles, the larger will be the intervening voids and the easier it will for water movement to take place. Thus, sandy soils tend to be more freely draining and permeable than clay soils, which are both slower to absorb water and slower to drain water.

3.3 Measurement of Soil Moisture

Soil moisture measurements are made in a variety of ways but the principal method employed is the gravimetric method. In that procedure, a soil sample is weighed and placed in a container of known weight. The weight of the wet soil sample is thus known. The soil sample is sealed in its container and taken to a laboratory where it is removed and over dried at 105^0C, until all the water evaporates. The sample is then weighed again, and the loss in weight is equated to the weight, and thus the amount of soil moisture that the field sample contained.

A number of other methods for determining soil moisture include radiological, electric resistance, remote sensing amongst others. Details of these methods are available in literature.

Self Assessment Exercise

Make a case for the study of soil moisture in hydrology.

4.0 Conclusion

Soil moisture is a critical resource for plant growth as has been established from the above discussions. However, of more importance is capillary water, which is generally accessible to plant roots. The knowledge of soil moisture is therefore vital in planning for an effective and efficient irrigation system aimed at improving agricultural productivity.

5.0 Summary

- Soil moisture includes all the water in the zone of aeration, which may extend tens or even hundreds of metres below the ground surface.
- Soil moisture is critical for plant growth, and the water accessible to plant is called capillary water.
- The main forces responsible for holding soil moisture are capillarity, adsorption and osmosis.
- One of the most popular ways for measuring soil moisture is gravimetric method.

6.0 Tutor Marked Assignment

(1) Soil moisture that is accessible to plant roots is called __________

(2) Water held in storage in the soil water zone is increased by recharge during _______

(3) Soil moisture that is inaccessible to plant roots is called
(a) absorption (b) osmosis (c) capillary (d) hydroscopic

(4) Soil moisture is much more relevant to which of the following
(a) agriculture (b) stream flow (c) mining (d) none of the above

7.0 References / Further Reading

Christopherson, R.W. (2007). *Elemental Geosystems, Fifth Edition,* Pearson Prentice Hall Upper Saddle River, N.J. 07458.

Strahler, A and Strahler A. (2006). *Introducing Physical Geography, Fourth Edition,* John Wiley and Sons Inc.

Viessman, W. Jr and Lewis, G.L. (2003). *Introduction to Hydrology, Fifth Edition,* Pearson Education Inc. Upper Saddle River N.J. 07458.

Ward, R.C. and Robinson, M (2000). *Principles of Hydrology, Fourth Edition,* McGraw Hill Publishing, UK.

UNIT4: EVAPORATRION AND EVAPOTRANSPIRATION

Contents

1.0 Introduction

This unit focuses on that phase of the hydrologic cycle in which precipitation reaching the earth's surface is returned to the atmosphere as vapour. Of the precipitation falling earthward, a portion evaporates before reaching the ground. The discussions shall however centre on the definitions of evaporation and evapotranspiration, which include transpiration by plants and evaporation from soil, lakes, streams etc. Furthermore, the factors controlling the evaporation process and its measurement will also be highlighted.

2.0 Objectives

The learning objectives are as follows:

- To differentiate between evaporation and transpiration
- To identify the factors driving the evaporation process.

3.0 Main Content

3.1 Defining Evaporation and Evapotranspiration

Evaporation can be defined as the process by which a liquid is converted into gaseous state. It involves the net movement of individual water molecules from the surface of the earth into the atmosphere, a process occurring wherever there is a vapour pressure gradient from the surface to the air. The rate of evaporation depends on the balance between the vaporization of water molecules into the atmosphere and the condensation rate from the atmosphere. However, when the air reaches saturation (100 percent relative humidity) no net evaporation takes place. Wind is therefore required to remove the layer of air near the surface which would otherwise become saturated and stop net evaporation (Smithson, et al, 2002).

Transpiration is a related process involving water loss from plants. It occurs mainly by day when small pores called stomata, on leaves of the plants open up under the influence of sunlight. They expose the moisture in the leaves to the atmosphere and, if the vapour pressure of the air is less than that on the leaf cells, the water is transpired. As a result of this transpiration, the leaf becomes dry and a moisture gradient is set up between the leaf and the base of the plant. Moisture is drawn up through the plant and from the soil into the roots.

In reality it is often difficult to distinguish between evaporation and transpiration. Wherever vegetation is present, both processes tend to be operating together, so the two are normally combined to give the composite term evapotranspiration. This process is governed mainly by atmospheric conditions. Energy is needed to power the process, and wind is necessary to mix the water molecules with the air and transport them away from the surface.

In addition, the state of the surface plays an important part, for evaporation can continue only so long as there is a vapour pressure gradient between the ground and the air. Thus, as the soil dries out the rate of evapotransipiration declines. Lack of moisture at the surface often acts as a limiting factor on the process.

We can therefore distinguish between two aspects of evapotranspiration. Potential evapotranspiration (PE) is a measure of the ability of the atmosphere to remove water from the surface, assuming no limitation of water supply. Actual evapotranspiration (AE) is the amount of water that is actually removed. Except where the surface is continuously moist, AE is lower than PE.

3.2 Factors Controlling the Evaporation Process

Rates of evaporation vary, depending on meteorological factors and the nature of evaporating surface. If natural evaporation is viewed as an energy-exchange process, it can be demonstrated that radiation is by far the most important single factor and that the term solar evaporation is basically applicable. On the other hand, theory and wind-tunnel experiments have shown that the rate of evaporation from water of specific temperature is proportional to wind speed and is highly dependent on the vapour pressure of the overlying air (Linsley et al, 1982). How are these two conclusions to be reconciled? In essence, it can be said that water temperature is not independent of wind speed and vapour pressure. If radiation exchange and all other meteorological elements were to remain constant over a shallow lake for an appreciable time, the water temperature and the evaporation rate would become constant. If the wind speed were then suddenly doubled, the evaporation rate would also double momentarily. This increased rate of evaporation would immediately begin to extract heat from the water at a more rapid rate than what could be replaced by radiation and conduction. The water temperature would approach a new, lower equilibrium value, and evaporation would diminish accordingly (Linsley et al, 1982).

The nature of evaporating surface is another important factor in the evaporation process. All surfaces exposed to precipitation, such as vegetation, buildings, and paved streets, are potentially evaporation surfaces. The rate of evaporation from a saturated soil surface is approximately the same as that from an adjacent water surface of the same temperature; as the soil begins to dry, evaporation decreases and its temperature rises to maintain the energy balance. Eventually, evaporation virtually ceases, since there is no effective mechanism for transporting water from appreciable depths. Thus the rate of evaporation from soil surfaces is limited by the availability of water, or evaporation opportunity.

Evaporation from snow and ice constitute a special problem since the melting point lies within the range of temperatures normally experienced. Evaporation can occur only when the vapour pressure of the air is less than that of the snow surface i.e, only when the dewpoint is lower than temperature of the snow. It should be noted that only foreign material which tends to seal the water surface or change its vapour pressure or albedo will affect the evaporation.

3.3 Measurement of Evaporation and Evapotranspiration

Evaporation pans have been widely used for estimating the amount of evaporation from free water surfaces. The devices, depicted in figure.30 are easy to use, but relating measurements taken from them to actual field conditions is difficult and the data they produce are often of questionable value for making areal estimates. A variety of pan types have been developed but the U.S. Weather Bureau Class A pan is the standard in the United States (Viessman and Lewis, 2003). Pan evaporation observations have been used to estimate both free water (lake) evaporation and evapotransipiration from well-watered vegetation. Interestingly enough, field experiments have shown a high degree of correlation of pan data with evapotranspiration from surrounding vegetation when there is full cover and good water supply (Viessman and Lewis, 2003). As in the case of precipitation gauges, pan data can be continuously recorded and transmitted to a central receiving station.

Evapotranspiration measurements are often made using lysimeters. These devices are containers placed in the field and filled with soil, on which some type of vegetation growth is maintained. The object is to study soil-water-plant relationships in a natural surrounding. The main feature of a weighing lysimeter is a block of undisturbed soil, usually weighing about 50 tons, encased in a steel shell that is 10x10x8ft. The lysimeter is buried so that only a plastic border marks the top of the underground scale sensitive enough to record even the movement of rabbit over its surface (Viessman and Lewis, 2003). The soil is weighed at intervals, often every 30 minutes around the clock, to measure changes in soil water level. The scales are set to counterbalance most of the dead weight of the soil and measure only the active change in weight of water in the soil. The weight loss from the soil in the lysimeter represents water used by the vegetative cover, plus any soil evaporation. Added water is also weighed and thus an accounting of water content can be kept. Crops or cover are planted in the area surrounding the lysimeter to provide uniformity of conditions surrounding the instrument. Continuous records at the set weighing intervals provide almost continuous monitoring of conditions. The data obtained can be transmitted to any desired location for analysis and/or other use. Weighing lysimeters can produce accurate values of evapotranspiration over short periods of time, but they are expensive. Non-weighing types of lysimeters, which are less costly, have also been used, but unless the soil moisture content can be measured reliably by some independent method, the data obtained from them cannot be relied upon except for long-term measurements such as between precipitation events (Viessman and Lewis, 2003).

Self Assessment Exercise

Evaporation has been identified as one of the driving forces of the hydrologic cycle; in your opinion, what are the major controlling forces of the evaporation process.

4.0 Conclusion

The above discussions revealed that evaporation process is mainly dependent on an energy source (sun) and wind-which is necessary to mix the water molecules with the air and transport them away from the surface. Without evaporation, the hydrologic cycle processes will be incomplete, with serious implications on precipitation, which would have adverse effects on plants, animals and human lives.

5.0 Summary

- Evaporation is the process by which a liquid is converted into a gaseous state; while transpiration involves water lost from plants. The combine process is called evapotranspiration.
- Rates of evaporation vary, depending on meteorological factors and the nature of the evaporating surface.
- Evaporation pans and lysimeters are the common instruments used in measuring evaporation and evapotranpiration respectively.

6.0 Tutor Marked Assignment

(1) The process by which precipitation reaching the earth's surface is returned to the atmosphere as vapour is called _____________

(2) At what percentage is air said to be saturated _____________

(3) The process of water lost by plants through the stomata is called___

(4) Evapotranspiration involves the combined process of which of the following.

(a) evaporation and respiration (b) evaporation and Precipitation

(c) evaporation and transpiration (d) none of the above

(5) The rate of evaporation is mainly dependent on what factor.

(a) hydrological (b) meteorological (c) geological (d) biological

(6) A measure of the ability of the atmosphere to remove water from the surface assuming no limitation of water supply is called

(a) potential evapotranspiration (b) actual evapotranspiration

(c) equal evapotranspiration (d) a and b only.

7.0 References/Further Reading

Linsley, R.K. Jr; Kohler, M.A. and Paulhus J.L.H. (1982). *Hydrology for Engineers, Third Edition,* McGraw Hill International Book Company.

Smithson, P; Addison, K. and Atkinson, K. (2002). *Fundamental of the Physical Environment, Third Edition* Routledge, Tayor and Frances Group, London.

Viessman, W. Jr. and Lewis, G.L. (2003). *Introduction to Hydrology, Fifth Edition,* Pearson Education Inc. Upper Saddle River N.J. 07458.

Ward, R.C. and Robinson, M. (2000). *Principles of Hydrology, Fourth Edition*, McGraw Hill Publishing, UK.

UNIT 5: RUNOFF

Contents

1.0 Introduction

Two of the major pathways of precipitation received on the Earth's surface are infiltration and evaporation, as was discussed in the preceding units. The third major pathway is runoff, which shall be the focus of this unit. The discussions shall centre on sub topics such as definition of runoff, quickflow and delayed flow, sources and components of runoff.

2.0 Objectives

The learning objectives are as follows:

- To define runoff

- To distinguish between quick flow and delayed flow
- To identify sources and components of runoff.

3.0 Main Content

3.1 Definition of Runoff

Runoff or stream flow comprises gravitation movement of water in channels, varying in size from those containing the smallest ill defined trickles to those containing the largest rivers such as the Amazon or the Congo (Ward and Robinson, 2000).

Runoff, which is also known as stream flow, stream or river discharge, or catchment yield, can simply be referred to as the movement of water over the Earth's surface. The point to be stressed here is that they all mean the same because they tell us on how water moves from one place to the other on the Earth surface. The unit area over the earth surface which has been found to be most convenient for monitoring water flow is the river basin – the boundary of a river system.

Generally, water within the basin is separated into various components. There is the channel flow, which is common in rivers and streams. There is surface runoff, which is mostly experience on land after rain. It could be in form of sheet flow or channel flow. Runoff is important in hydrological study because they are the causes of major environmental problems experience on the landscape.

3.2 Quickflow and Delayed flow

The immediacy of streamflow response to a rainfall event indicates that part of the rainfall takes a rapid route to the stream channels (i.e. quickflow); equally, the subsequent continuity of flow through often prolonged dry weather period indicates that another part of the rainfall takes a much slower route as delayed flow, which is more usually referred to as baseflow. These two components of flow are apparent in rivers of all sizes. However, in large river systems lag effects, both within and outside channels, and the multiplicity of flow contributions to the main channel from numerous tributary streams complicate interpretation of the hydrograph response of major rivers to precipitation. It is estimated that globally an average of 36 percent of the total precipitation falling on the land areas reaches the oceans as runoff. Of this amount, quickflow accounts for about 11 percent and delayed flow accounts for the remaining 25 percent of precipitation (Ward and Robinson, 2000).

3.3 Sources and Components of Runoff

The variable response of streamflow to precipitation, both spatially and with time, reflects the contrasting flowpaths of precipitation towards the stream channels. Precipitation may arrive in the stream channel by a number of flowpaths: direct precipitation onto the watersurface, overland flow, shallow subsurface flow (throughflow); and deep subsurface flow (groundwater flow). The relative importance of these sources of runoff may vary spatially, depending upon drainage basin characteristics, such as soil type and the nature and density of the vegetation cover, and upon precipitation conditions. In addition, the importance of individual runoff sources may vary with time, for example over a period of years or seasonably, and may also change quite dramatically during an individual storm or sequence of rainfall events in response to variations of infiltration capacity, water table levels and surface water area.

3.3.1 Channel Precipitation

The contribution of precipitation falling directly on to water surfaces is normally small simply because the perennial channel system occupies only a small proportion (1-2 percent) of the area of most catchments. Even so, for small precipitation events channel precipitation may be the only component of the hydrograph. The channel system is more extensive where catchments contain a large area of lakes or swamps and in these circumstances; channel precipitation will tend to be a more dominant component of runoff. In addition, channel precipitation will increase significantly during a prolonged storm or sequence of precipitation events, as the channel network expands, and may temporarily account for 60 percent or more of total runoff in some small catchments.

3.3.2 Overland Flow

Overland flow comprises the water that flows over ground surface to stream channels either as quasi-laminar sheet flow or more usually, as flow anastomosing in small trickles and minor rivulets. One cause of overland flow is the inability of water to infiltrate the surface as a result of a high intensity of rainfall and/or a low value of infiltration capacity. Ideal conditions are found on moderate to steep slopes in arid and semi-arid areas. Here, vegetation cover may be sparse or non-existent, exposing the surface to raindrop impact and crusting processes. Other conditions in which overland flow assumes considerable importance involve the hydrophobic nature of some very dry and sodic soils, the deleterious effects of many agricultural practices on infiltration capacity, and freezing of the ground surface. In humid area, vegetation cover is thicker and more substantial and because of the high value of infiltration, which characterizes most vegetation – covered surfaces, overland flow is rarely observed, even in tropical rainforest (Anderson and Spencer, 1991), quoted from (Ward and Robinson 2000).

However, there are many areas, both humid and sub-humid, where the effects of topography or the nature of the soil profile facilitate the rise of shallow water tables to the ground surface during rainfall or throughflow events. In such conditions the infiltration capacity at the ground surface falls to zero and saturation overland flow result.

3.3.3 Thoughflow

Water that infiltrates the soil surface and then moves laterally through the upper soil horizon towards the stream channels, either as unsaturated flow or, more usually, as shallow perched saturated flow above the main groundwater level, is known as throughflow. Alternative terms found in the literature include interflow, subsurface stormflow, storm seepage and secondary baseflow. Throughflow is liable to occur when the lateral hydraulic conductivity of the surface soil horizons greatly exceeds the overall vertical hydraulic conductivity through the soil profile. Then, during prolonged or heavy rainfall on a hill slope, water will enter the upper part of the profile more rapidly than it can drain vertically through the lower part, thus accumulating and forming a perched saturated layer from which water will 'escape' laterally, i.e. in the direction of greater hydraulic conductivity.

3.3.4 Groundwater Flow

Most of the rainfall that infiltrates the catchment surface will percolate through the soil layer to the underlying groundwater and will eventually reach the main stream channels as groundwater flow through the zone of saturation. Since water at depth can move only very slowly through the ground, the outflow of groundwater into the stream channels may lag behind the occurrence of precipitation by several days, weeks or even years. Groundwater flow tends to be very regular, representing as it does the outflow from the slowly changing reservoir of moisture in the soil and rock layers. In general groundwater flow represents the main long-term component of total runoff and is particularly important during dry spells when surface runoff is absent. Figure 3.1 shows the diagrammatic representation of the runoff process.

Self Assessment Exercise

Identify the various sources of runoff to a stream channel.

4.0 Conclusion

The sources of runoff identified above include direct precipitation, overland flow, through flow and groundwater flow. These sources are however influenced by the characteristics of the drainage basin, such as soil type, nature and density of the vegetation cover, and upon precipitation conditions. In areas where the soils are compact or where the macro and micro pores of the soil has been sealed up due to trampling, vehicular movement and other human activities, runoff generation is usually high as a result of low infiltration. This explains why there is higher runoff in urban centres than in rural areas.

5.0 Summary

- Runoff comprises the gravitation movement of water in channel in varying sizes.
- Quickflow involves rapid flow of precipitation to stream channel, while delayed flow involves a much slower flow.
- The major sources of runoff include channel precipitation, overland flow, througflow and groundwater flow. These sources are influenced by the nature of the drainage basin characteristics, which include soil, precipitation and plant cover.

6.0 Tutor Marked Assignment

(1) Precipitation that gets to the ground surface follows three major pathways, which include evaporation, infiltration and ______________

(2) The movement of water over the land surface is called _____________

(3) Which of the following is a source of runoff?

(a) overland flow (b) groundwater flow (c) throughflow

(d) all of the above

(2) Which of the following options is not true of runoff?

(a) Runoff is high when infiltration is high

(b) Runoff is low when infiltration is high

(c) Runoff is affected by soil characteristics

(d) Runoff is high when infiltration is low.

7.0 References/Further Reading

Ward R.C. and Robinson M. (2000). Principles of Hydrology. 4th Edition, McGraw Hill Publishing , U.K.

Chorley R.J. (1969). *Water, Earth and Man. A Synthesis of Hydrology, Geomorphology and Socio-Economic Geography,* Methuen and Co Ltd, London.

MODULE IV

Contents

UNIT 1: EROSION

1.0 Introduction

In the preceding unit, we discussed the runoff process-which simply means the movement of water over the Earth surface. This process acting with other natural agents such as wind and ice leads to erosion. The question now is what is erosion? What are the agents of erosion, and how can the problem of erosion be controlled? Answers to these questions will be the focus of this unit.

2.0 Objectives

The learning objectives are as follows:

- To define erosion
- To list and discuss the agents of erosion
- To state how the problem of erosion can be controlled.

3.0 Main Content

3.1 Definition of Erosion

Erosion is the wearing away and removal of soil and rock fragments at the surface of the earth by wind, water, ice, or other natural agents. It is part of the process known as gradation, which besides the wearing away of rocks to form sediments also involves the transportation and eventual deposition of the sediments. Working together, the processes of erosion and deposition have done much to shape the earth's surface (Encyclopedia Americana, 1990).

The New Encyclopedia Britannica (2007) defines erosion as the removal of surface material from the Earth's crust, primarily soil and rock debris, and the transportation of the eroded materials by natural agencies from the point of removal.

Erosion will often occur after rock has been disintegrated or altered through weathering. Weathered rock material will be removed from its original site and transported away by a natural agent. With both processes often operating simultaneously, the best way to distinguish erosion from weathering is by observing the transportation of materials. Erosion is the part of a cycle of geological events that may be complemented by processes that originate beneath the earth's surface. For example, mountain ranges are first raised by great crustal movements and are then slowly worn away by the agents of erosion.

3.2 Agents of Erosion

Rocks are continually being worn away and land areas gradually lowered as agents of erosion attack the minerals of which the rocks are made. The fragments thus produced are carried elsewhere by wind, water, ice or other transporting agents. Most of the sediments eventually are deposited in the ocean, where they settle at the bottom to probably become the sedimentary rocks of the geological future. There are five principal agents of erosion-running water, wind, groundwater, glacier and marine.

3.2.1 Running Water

Streams have been recognized to cause more erosion than all other geological agents combined. The erosion starts when rain begins to runoff the earth's surface. The runoff at first is sometimes in the form of sheets of moving water, but such sheets usually are soon channeled into streams and rivers.

The ability of a stream to erode is governed by several factors. Thus an increase in the volume of water and in the velocity of stream flow greatly increases the rate of erosion. Streams running down steep slopes in areas that lack vegetation are especially effective erosional forces. Stream volume and velocity also determine the stream's sediment load at a given time.

Transported rock fragments become cutting tools that widen and deepen a channel by rubbing against the channel bed. The fragments also are eroded by knocking against each other, and some rocks are slowly dissolved by the stream water as well. In addition, turbulent water may remove materials from the stream channel by a "plucking" action caused by hydraulic pressure, or by cavitations, an erosive process caused by the sudden collapse of vapour bubbles against the channel wall.

3.2.2. Wind

Wind erosion is more likely to occur in dry areas where soil is loose and unprotected by vegetation. Winds of high velocity in these areas carry a load of rock fragments that cause wind abrasion. Evidence of such abrasion is seen on rock fragments with facets that have been cut and polished by the sandblasting action of windblown sediments, and in rocks undercut to form table rocks or pedestals. A form of erosion that occurs when loose rock particles are blown away by the wind is called deflation. Features produced by deflation include blowouts, and desert pavement.

3.2.3 Groundwater

Erosion by groundwater takes place just beneath the earth's surface. Carbon dioxide from the air and decaying organic matter from the soil may combine with groundwater to form carbonic acid. Groundwater containing carbonic acid and circulating through rocks commonly removes soluble minerals and carries them away in solution.

3.2.4 Glaciers

Glaciation is a powerful erosional agent. As a glacier advances, the moving ice quarries pieces of material from the bedrock over which it passes. The fragments become embedded in the ice and serve as abrasive tools that further scratch and gouge the bedrock.

3.2.5 Marine

The ocean acts as an erosional agent primarily through waves and the currents produced by waves. Most ocean waves are generated by wind currents that agitate the water's surface. Large waves may pound the shore with tremendous force, producing a hydraulic-lifting action that dislodges large masses of coastal rock. The blocks fall to the ocean bottom, where they undergo more erosion along with other wave-battered rock debris that has accumulated there. The sand and rock fragments grind against each other and scour the shore. In areas where the coast is formed of soluble rocks, the ocean may also erode the rocks by dissolving their minerals.

3.3 Erosion Control

Erosion can be controlled through various measures, which include reforestation, contour ploughing, strip cropping, crop rotation, control grazing and deforestation, avoidance of over cultivation amongst other measures.

Reforestation is the restocking of existing forests and woodlands which have been depleted. Trees can be used as windbreakers or shelterbelt – a plantation usually made up of one or more rows of trees or shrubs planted in such a manner as to provide shelter from the wind and to protect soil from erosion. They are commonly planted around the edges of fields or farms.

Contour ploughing or contour farming is the farming practice of ploughing across a slope following its elevation. The rows formed slow water runoff during rainstorms to prevent soil erosion and allows the water time to settle into the soil.

Strip cropping is a method of farming used when a slope is long and steep or when other types of farming may not prevent soil erosion. Strip cropping helps to stop soil erosion by creating natural dams for water, helping to preserve the strength of the soil. Certain layers of plants will absorb minerals and water from the soil more effectively than others. When water reaches the weaker soil that lacks the minerals needed to make it stronger, it normally washes it away. However, when strips of soil are strong enough to slow down water from moving through them, the weaker soil can't wash away like it normally would, thereby preventing erosion.

The carrying capacity of land for cattle varies with the rainfall and the fertility of the soil. However, when the carrying capacity is exceeded, the land is overgrazed. Overgrazing reduces the diversity of plant species, lead to reduction in the growth of vegetation and dominance of plant species that are relatively undesirable to the cattle, increases the loss of soil by erosion as the plant cover is reduced and results to damage from the cattle trampling on the land. For example, paths made as the cattle travel to the same water hole or stream develop into gullies, which erode rapidly in the rain. To control erosion caused by overgrazing, proper care should be taken to ensure that the carrying capacity of the land is not exceeded.

Another practice that encourages erosion is deforestation – harvesting trees for commercial and other uses and burning forest to convert lands to agricultural purposes. This practice exposes the land to the active agents of erosion. Deforestation has to be properly managed by ensuring that trees are replanted to replace fell ones, and the forest has to be given time to regenerate. This management method will help in achieving sustainability of the forest, and consequently reduce erosion.

Over cultivation of farmlands is another negative agricultural practice that promotes erosion. Over cultivation exposes the land for erosion. For example, when a particular farmland is tilled year in year out, the soil structure is affected, and the loose soil can easily be eroded away by rain or wind. The stoppage of over cultivation will help to maintain the soil structure, thereby enhancing its ability to withstand erosion.

Another effective way of preventing soil erosion is the practice of crop rotation. This practice can greatly affect the amount of soil lost from erosion by water. In areas that are highly susceptible to erosion, farm management practices such as zero and reduced tillage can be supplemented with specific crop rotation methods to reduce raindrop impact, sediment detachment, sediment transport, surface runoff, and soil loss. Protection against soil loss is maximized with rotation methods that leave the greatest mass of crop stubble (plant residue left after harvest) on top of the soil. Stubble cover in contact with the soil minimizes erosion from water by reducing overland flow velocity, stream power, and thus the ability of the water to detach and transport sediment. Crop rotation helps to prevent the disruption and detachment of soil aggregates that cause macrospores to block, infiltration to decline, and runoff to increase. This significantly improves the resilience of soils when subjected to periods of erosion and stress.

Self Assessment Exercise

Identify the agents of erosion, and propose how erosion menace can be ameliorated.

4.0 Conclusion

Even though most people see erosion as a negative process, it also has its benefits to man though they are usually not so striking. Erosion usually helps is breaking down bedrocks to form soil.

However, erosion unless kept in check, also destroys soils and removes them from the land. Urban development aggravates some erosional problems, as when housing projects are built on unstable soils that are subject to landslides. In addition, commercial operations such as strip mining, quarrying, and poor agricultural practices take their toll on precious soil. Consequently, soil-conservation practices are becoming increasingly important as population grows and land areas are abused on a wider scale.

5.0 Summary

- Erosion is the wearing away and removal of soil and rock fragments at the surface of the earth by wind, water, ice or other natural agents.
- There are five principal agents of erosion, which include running water, wind, groundwater, glacier and marine.
- Some measures of erosion control include reforestation, contour ploughing, strip cropping, crop rotation, control glazing and deforestation, and stoppage of over cultivation.

6.0 Tutor Marked Assignment

(1) ____________ erosion is more likely to occur in dry areas where soil is loose and unprotected by vegetation.

(2) A form of erosion that occurs when loose rock particles are blown away by wind is called ____________

(3) __________ erosion takes place just beneath the earth's surface

(4) Erosion control measures include all of the following except which

(a) deforestation (b) aforestation (c) strip cropping (d) contour ploughing

(5) Which of the following is not an agent of erosion?

(a) marine (b) groundwater (c) wind (d) evaporation

(6) Erosion rate may be increased through which of the following measures

(a) planting of cover crops (b) over cultivation (c) control grazing (d) crop rotation

7.0 References/Further Reading

Botkin, D.B. and Keller, E.A. (1998). *Environmental Science. Earth as a Living Planet, Second Edition.* John Wiley and Sons Inc. New York.

Encyclopedia Americana (1990) "Erosion" Vol.10, Encyclopaedia Americana Corporation.

The New Encyclopedia Britannica (2007). "Erosion" Encyclopaedia Britannica, Incorporated.

Carroll C; Halpin M; Burger P, Bell K; Sallaway M.M and Yule D.F. (1997). "The Effect of Crop Type, Crop Rotation, and Tillage Practice on Runoff and Soil Loss on Vertisol in Central Queensland". *Australian Journal of Soil Research.*

UNIT 2: FLOODING

Contents

1.0 Introduction

Flooding has been an environmental menace in most urban centres worldwide. In well planned urban centres however, the problem is minimized. It is more pronounced in urban centres of developing countries due to poor planning and negative human activities. This unit will attempt a definition of flooding; examine the causes, impacts and control of flooding.

2.0 Objectives

The learning objectives are as follows:

- To define flooding

- To list the causes of flooding
- To examine the impacts of flooding and control measures.

3.0 Main Content

3.1 What is flooding?

Flooding is the inundation of land beyond the normal confines of a channel or coastline, either by overflow of excess water or its influx via shallow subsurface or low-lying routes (Smithson et al, 2002). Flooding can also be defined as a process whereby a river outflows its natural channel or the artificial channel constructed for it.

Periodic floods occur on many rivers, forming a surrounding region known as the flood plain. During times of rain or snow, some of the water is retained in ponds or soil, some is absorbed by grass and vegetation, some evaporates, and the rest travels over the land as surface runoff. Floods occur when ponds, lakes, riverbeds, soil, and vegetation cannot absorb all the water. Water then runs off the land in quantities that cannot be carried within stream channels or retained in natural ponds, lakes, and man-made reservoirs.

3.2 Causes of Flooding

There are several causes of flooding, prominent amongst which are meteorological factors, poor development planning and poor maintenance. Flooding can however, be exacerbated by increased amounts of impervious surface or by other natural hazards such as wildfires, which reduce the supply of vegetation that can absorb rainfall.

Most floods are the result of severe meteorological or climatologically conditions. They may follow severe local thunderstorms or more widespread rain falling on a saturated landscape. Snowmelt, particularly when associated with further rain, can cause major flooding. Storm surges onto the coast as a result of tropical cyclones can cause even more damage when reaching delta where rivers are in flood.

Floods may also occur as a result of individual disasters such as landslides or dam bursts. Although these conditions may be very important, major floods are usually the result of flood-intensifying conditions which worsen the original meteorological problem. For example, the basin characteristics may aid the movement of rainwater by having unvegetated steep, impermeable slopes, variable altitude and a basin shape, which focuses the tributaries on to a particular part of the catchment. Floods often occur where there is a sudden change of channel gradient, causing the flow of water to decrease its velocity and perhaps spillover the flood banks.

Severe winds over water bodies can also result to flooding, even when rainfall is relatively light. For example, the shorelines of lakes and bays can be flooded by severe winds-such as during hurricanes-that low water into the shore areas. In addition, coastal areas are sometimes flooded by unusually high tides, such as spring tides, especially when steep compounded by high winds and storm surges. Tsunamis have also been identified as a trigger for flooding. Tsunamis are high large waves, typically caused by undersea earthquakes or massive explosions, such as the eruption of an undersea volcano. A recent example of a tsunami triggered flood happen in Japan some months ago, as a result of a massive earthquake, which claimed the lives of over 10,000 people, with property worth billions of US dollars destroyed.

Apart from meteorological factors, anthropogenic (human) factors are also very important in determining the severity of floods. Poor development planning and maintenance are responsible for some of the flooding episode so far recorded in the world. In the urban areas of most parts of the world, there are reported cases of inappropriate developments in flood plains due to pressure on available land. Inappropriate constructions of roads, car parks, buildings etc, in such a way that prevents rainfall from draining away naturally, can increase the risk of flooding from rainwater runoff. Furthermore, poor or insufficient drainage networks, inadequate maintenance of watercourses, faulty sewer networks, failure of dams, levees, retention ponds, or other structures that retain water, due to poor design, construction or maintenance all contribute to flooding.

3.3 Impacts of Flooding

Flooding has many impacts. It damages property and endangers the lives of humans and other species. Rapid water runoff causes soil erosion and concomitant sediment deposition elsewhere (such as further downstream or down a coast). The spawning grounds for fish and other wildlife habitats can become polluted or completely destroyed. Some prolonged high floods can delay traffic in areas which lack elevated roadways. Floods can interfere with drainage and economic use of lands, such as interfering with farming. Structural damage can occur in bridge abutments, bank lines, sewer lines, and other structures within floodways. Waterway navigation and hydroelectric power are often impaired. Financial looses due to floods are typically in millions of dollars each year. The impacts of flooding will be discussed further under three board sub-heading – health, economic and social impacts.

3.3.1 Health Impact

Specifically, health effects caused by a flood event may result from: the event itself; the disruption and problems arising from trying to recover; and from the worry or anxiety about the risk of flood re-occurring. The potential health effects can be considered at three time periods:

- **Immediate:** Death by drowning, injuries due to being knocked over by flood waters or struck by falling trees, over-exertion during the event, hypothermia, electrocution, exposure to contaminants, and the stress of the event itself.

- **Medium term:** Gastrointestinal illnesses, cardiovascular disease from over-exertion during recovery/clean-up processes, lacerations, sprains/strains, dermatitis, respiratory illnesses and carbon monoxide poisoning.
- **Longer term:** Longer term effects are mostly psychologically related. Sewer flooding and the health issues associated with it is a key issue for urban flooding, whereas concern is growing over the effects of diffuse pollution in rural flooding. In terms of density and sparsity issues, because of the close proximity of people to one another within the urban environment, there are more chances of an outbreak of epidemic, especially if sewer flooding is involved (Twigger-Ross, 2005).

3.3.2 Economic Impact

This includes the cost of damage done to a property by a flood, the cost of clean-up (eg paying for the house to be dried out), the costs of living in temporary accommodation, and possibly the costs of having a house that is harder to re-sell because it has been flooded or is in a defined flood plain. In rural areas where there are few facilities, the loss of services and shops could have a disproportionately large economic impact on small communities. There could also be a negative impact in deprived urban neighbourhoods where business confidence is vital to regeneration. If businesses fail because of the impacts of flooding this could damage the perception of the area as an attractive place for investment.

3.3.3 Social Impact

Social impact includes every other kinds of discomfort, which is not directly economic or health related. Social impacts may include household disruption, community and neighbourhood changes, and associated impacts of evacuation and temporary accommodation.

Household disruption, include the stress of cleaning up the house, dealing with builders, and dealing with living in a damp environment. These activities are rated as something that is very stressful for a lot of people (Defra, 2004) as quoted from (Twigger-Ross, 2005). In both rural and urban areas, there is likely to be pressure on services to aid the clean up of the flooding. In urban areas, if a large area has been flooded, then there may be difficulties in finding workmen to repair flood damage.

Impacts associated with evacuation and temporary accommodation include both the effects of having to leave home and those of having to live away from home. In urban areas, if there are large numbers of people to be relocated then this will put pressure on services, and may mean that people have to live in cramped and overcrowded conditions, or have to move a distance from their homes. For people in both rural and urban centres, difficulties will be experienced if they are relocated to areas, which is some distance from their homes. Specifically, it will be harder to keep in touch with repairs being carried out on their homes, and harder to maintain normal routines because of greater travelling distances and new routes to schools, work and services.

3.4 Flood Control

Flood control refers to all methods used to reduce or prevent the detrimental affects of flood waters. Some methods of flood control have been practiced since ancient times.

These methods include planting vegetation to retain extra water, terracing hillsides to slow flow downhill, and the construction of floodways (man-made channels to divert floodwater). Other techniques include the construction of levees, dikes, dam; reservoirs or retention ponds to hold extra water during times of flooding.

Many dams and their associated reservoirs are designed wholly or partially to aid in flood protection and control. In many countries, rivers prone to floods are often carefully managed. Defenses such as levees, bunds, reservoirs, and weirs are used to prevent rivers from overflowing their banks. When these defenses fail, emergency measures such as sandbags or portable inflatable tubes are used. A weir, also known as low head dam, is most often used to create millponds, but on the Humber River in Toronto, a weir was built near Raymore Drive to prevent a recurrence of the flood damage caused by Hurricane Hazael in 1954. Coastal flooding has been addressed in Europe and the Americans with coastal defenses, such as sea walls, beach nourishment, and barrier islands.

Other methods of flood control include the stoppage of further developments of flood plains; proper channelization of drainage systems; discourage indiscriminate to disposal of waste (especially rubber bags and cans), which are not biodegradable and have the capacity to block drainage systems, leading to flooding.

Self Assessment Exercise

Flooding is a global environmental menace especially in urban centres. In your own opinion what are the causes, impacts and controls of flooding?

4.0 Conclusion

Floods are the most common of all environmental hazards. Each year many thousands of people die as a result of flooding and millions are affected by indirect consequences such as damage to crops, housing, transport, etc. Most flood problems are found on riverine flood plains, in both developed and developing countries, though the impact is often greater in the latter, where high populations are to be found on extensive and often relatively fertile flood plains such as those of the ganges and the Yangtse.

Having gone through this unit, you should be well informed of the causes, impacts and control measures of flooding. This knowledge should therefore, be transform to positive actions in contributing to solving the flooding menace in our environment.

5.0: Summary

- Flooding is a process whereby a river outflows its natural channel or the artificial channel constructed for it.
- The major causes of floods are meteorological or climatological conditions. However, human activities tend to exacerbate its effects.
- Flooding has noticeable impacts on health, economic and social well being of the affected people.
- Flooding can be control by several coordinated measures which include planting vegetation, construction of dams, levees etc, and avoidance of areas prone to floods – such as flood plains.

6.0 Tutor Marked Assignments

(1) The process by which a river outflows its natural channel or the artificial channel constructed for it is called ____________

(2) The area of land surrounding a river whose floods occur periodically is called_____________

(3) The causes of flooding can broadly be classified into natural and ____ factors

(4) Which of the following conditions would favour the process of flooding?

(a) light rainfall (b) Heavy rainfall that is well infiltrated (c) Heavy rainfall on vegetated surface (d) Heavy rainfall on concrete surface

(5) Which of the following statements is true of the social impact of flooding?

(a) Cost and damage done to a property by a flood

(b) Inconveniences of relocating to a temporary accommodation

(c) Psychological problems

(d) Exposure to contamination

(6) One of the following is a measure for flood control.

(a) planting vegetation (b) building on floodplains

(c) deforestation (d) none of the above

7.0 References / Further Reading

Smithson P; Addison K. and Atkinson K (2002). *Fundamental of the Physical Environment, Third Edition,* Routledge, Tayor and Frances Group, London.

Twigger – Ross, C. (2005). *Impacts of Flooding on Urban and Rural Communities,* Environment Agency, Rio House, Waterside Drive Aztec West, Almondsbury, Bristol BS 324 UD.

UNIT 3: SEDIMENT

Contents

1.0 Introduction

Sediment and erosion are closely related concepts in hydrology. The erosion process produces sediment in form of both organic and inorganic materials, which are transported and eventually deposited. This unit will examine the sources, transportation process, deposition, impacts, and control measures of sediment.

2.0 Objectives

The leaving objectives are as follows:

- To define sediment
- To list the transport modes of sediment
- To identify the sources of sediment
- To state the preventive and control measures of sediment

3.0 Main Content

3.1 What is Sediment?

Sediment is naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, and by the force of gravity acting on the particle itself.

In the context of stream hydrology, sediment is inorganic and organic material that is transported by, suspended in, or deposited by streams. Sediment load, which is the quantity of sediment transported by a stream, is a function of stream discharge, soil and land-cover features, weather conditions, land-use activities, and many other factors. Sediment load carried by streams and rivers can be composed either of fine materials, mostly silts and clays, or larger materials such as sand.

3.2 Sources of Sediment

Sediment is a natural product of stream erosion: however, the sediment load may be increased by human activities. Such enhanced sources of sediment in a watershed include unvegetated stream banks and uncovered soil regions, including construction sites, deforested areas, and croplands.

When soils erode, sediments are washed into streams and rivers. Sediment in waterways are often high in areas where river banks are grazed by livestock, on farms with steep slopes cleared of trees, and where there is a lack of riparian vegetation.

Grazing along river banks removes or damages existing vegetation, increases compaction of the soil, and damages the banks of a waterway. With time, the area around a stream will become unstable, prone to slips, and vulnerable to erosion, especially during floods.

Deer can cause sediment loads into waterways because they have a tendency to walk along fenced lines. This activity causes soil compaction and erosion, which may lead to the formation of drainage channels that then transport water and sediment to the nearest stream.

Forest increases soil stability because their roots bind the soil together. When large areas of land are cleared and harvested of trees, the soil becomes vulnerable to erosion as tree roots die and as the land is exposed to direct rainfall. Trees increase the soil's ability to take up water, and as a result there is usually a significant increase in the amount of surface water runoff from the surrounding catchment when trees are felled. Removal of riparian vegetation directly next to a waterway is likely to cause banks to become unstable and prone to slips, thereby increasing erosion, especially during floods. Other impacts that can produce sediment include earthwork for roads and landing sites, and hauling logs across bare slopes.

When land is cleared for urban development, earthworks are required to establish roads and building sites. The exposed soils are prone to erosion and can cause large quantities of sediment to be washed into nearby waterways through surface runoff especially after heavy rain. Small streams and rivers may also be completely modified through channelization, construction of revetments (concrete structures), and instream barriers (e.g. culverts and dams), and removal of riparian vegetation.

Dams impact on the amount of sediment that moves downstream. Sediments are trapped behind a hydro-dam's reservoir (hydro-lake) and build up. This reduces the reservoir's storage capacity. The rate at which this happens varies greatly among hydro-dams. Dams also reduce the amount of sediment deposited downstream. This increases erosion and scouring and decreases the amount of sediment available to replenish downstream habitats.

The conversion of wetlands or wood lands to cropland can increased soil erosion and the associated sedimentation in streams, particularly when bare soil is exposed. Wind blown particles from bare soil also contribute to sedimentation problems. Activities such as dredging and channelization that increase stream slope and velocity can increase the streams erosive capacity and sediment-transport capability. Construction projects within or adjacent to stream can contribute to the sedimentation problems as they dislodge or expose soil and sediment.

3.3 Sediment Transport Process

Sediment is transported based on the strength of the flow that carries it and its own size, volume, density, and shape. Stronger flows will increase the lift and drag on the particle, causing it to rise, while larger or denser particles will be more likely to fall through the flow.

Sediment is most often transported by water (fluvial processes), wind (aeolian processes) and glaciers. Beach sands and river channel deposits are examples of fluvial transport and deposition, though sediment also often settles out of slow-moving or standing water in lakes and oceans. Deserts sand dunes and loess are examples of aeolian transport and deposition. Glacial moraine deposits and till are ice transported sediment.

Rivers and streams carry sediment in their flows. This sediment can be in a variety of locations within the flow, depending on the balance between the upwards velocity on the particle (drag and lift forces), and the settling velocity of the particle. These relationships are given in the following table for the Rouse number which is a ratio of sediment fall velocity to upwards velocity.

$$\text{Rouse} = \frac{\text{Setting Velocity}}{\text{Upwards velocity from lift and drag}} = \frac{Ws}{KU^*}$$

Where:

Ws is the fall velocity

K is the von Karman constant

U* is the shear velocity

Table: 4.0 Ration of Sediment Fall Velocity to Upwards Velocity.

Mode of Transport	**Rouse Number**
Bed load	> 2.5
Suspended load 50% suspended	>1.2, < 2.5
Suspended load 100% suspended	>0.8, < 1.2
Wash load	< 0.8

Source: Http://en.wikipedia.org/wiki/sediment, 23/5/11

If the upwards velocity approximately equal to the settling velocity, sediment will be transported downstream entirely as suspended load. If the upwards velocity is much less than the settling velocity, but still high enough for the sediment to move, it will move along the bed as bed load by rolling, sliding, and saltation (jumping up into the flow, being transported a short distance then settling again). If the upwards velocity is higher than the settling velocity, the sediment will be transported high in the flow as wash load. As there are generally a range of different particle sizes in the flow, it is common for material of different sizes to move through all areas of the flow for given stream conditions.

The overall balance between sediment in transport and sediment being deposited on the bed is given by the Exner equation. This expression states that the rate of increase in bed elevation due to deposition is proportional to the amount of sediment that falls out of the flow. This equation is important in that changes in the power of the flow changes the ability of the flow to carry sediment, and this is reflected in patterns of erosion and deposition observed throughout a stream. This can be localized, and simply due to small obstacles: examples are scour holes behind boulders, where flow accelerates, and deposition on the inside of meander bends. Erosion and deposition can also be regional: erosion can occur due to dam removal and base level fall. Deposition can occur due to dam emplacement that causes the river to pool, and deposit its entire load or due to base level rise.

Solid sediment load can be divided into two components on the basis of the mode of sediment transport, suspended sediment, and bedload sediment, each of which is produced by mechanical weathering processes is clearly visible, and is able to settle out of water. Suspended sediment consists of silt-sized and clay-sized particles held in suspension by turbulence in flowing water. Bedload sediment consists of larger particles which slide, roll, or bounce along the stream bed by the force of moving water. Dissolved load consists of inconspicuous material in solution moving downstream. It is produced by chemical weathering processes, and does not settle out of water.

Sediment yield is the total quantity of sediment transported from a watershed (drainage basin) at a given location in a given period of time. Low suspended sediment yields can be attributed to, among other factors, a region’s low erosion rate. Permeable soils and low topographic relief, in general, help limit the availability of eroded material from within a watershed. Conversely, relatively impermeable soils and steep topography can yield high erosion rates and therefore greater sediment yield.

3.4 Sediment Deposition

Deposition begins once the flow velocity falls below the settling velocity of a particle, which for a given particle size is less than that required for entrainment. Settling velocity is closely related to particle size, so that the coarsest fraction in motion should be deposited first with progressively finer grains settling out as the flow velocity continues to fall. The net effect is a vertical and horizontal (downstream and transverse) gradation of sediment sizes (Knighton, 1984).

The most common depositional feature is the flood-plain, formed from a combination of within-channel and overbank deposition, although many sedimentary forms are involved (Lewin, 1978), quoted from (Knighton, 1984). During lateral channel migration, erosion of one bank is approximately compensated by deposition against the other, principally but not exclusively in the form of point-bars. With continuing migration, a point-bar is built stream ward and also increases in height through the deposition of sediment carried onto the bar surface by inundating flows. The sediment deposited by overbank floodwaters comes from material carried in suspension, either as wash load (silts and clays) or the finer fractions of the bed-material load (fine and medium sand). Since the transportation ability of the flow tends to decrease away from the channel margins, both the amount and mean size of deposited sediment should similarly vary. Also, as the flood recedes and flow velocities over the flood-plain decline, an upward fining of sediment may develop.

Flood-plains provide storage space for sediment as it moves through a drainage basin, the potential for which increases as they become wider with distance downstream. The flood-plain is an integral part of the fluvial system, whose deposits influence channel form through the composition of the channel boundary and therefore the type of material supplied to a stream.

3.5 Impacts of sediment

One of the principal causes of degraded water quality and aquatic habitat is the depositing of eroded soil sediment in water bodies. Excessive amounts of sediment resulting from natural or human-induced causes can result in the destruction of aquatic habitat and a reduction in the diversity and abundance of aquatic life. Diversity and population size of fish species, mussels, and benthic (bottom-dwelling) macro invertebrates associated with course substrates can be greatly reduced if the substrates are covered with sand and silt. Where sand or silt substrates have historically predominated, however, increased deposition may have little detrimental impact on benthic aquatic life.

Suspended sediment causes the water to be cloudy (turbid). Increased turbidity reduces light transmission (and hence photosynthesis), thereby reducing the growth of algae and aquatic plants, which can adversely affect the entire aquatic ecosystem. Moreover, increased turbidity decreases the water's aesthetic appeal and the human enjoyment of recreational activities. If the river cross-section is sufficiently reduced by sediment build up, sedimentation can increase downstream flooding. In addition, some metal ions, pesticides and nutrients may adhere to sediment particles and be transported downstream.

Increased sediment in surface-water bodies (e.g. rivers, lakes, and reservoirs) may have an economic impact on public water systems that use them as a source of drinking water. High turbidity not only is aesthetically displeasing, but also interferes with disinfection of the water prior to it being pumped to customers. Communities whose water-supply source has been more turbid often invest millions of naira to upgrade their treatment faculties in order to remove the increased sediment load.

Excessive erosion can reduce the soil's inherent productivity, whereas the associated sedimentation can damage young plants and fill drainage ditches, lakes, and streams. Erosive processes can reduce farm income by decreasing crop yields and increasing maintenance costs for drainage systems. Additional erosion damages in both rural and urban areas include reduced ditches, and surface-water supplies.

Erosion is also an issue in areas of modern farming, where the removal of native vegetation for the cultivation and harvesting of a single type of a crop has left the soil unsupported. Many of these regions are near rivers and drainage. Loss of soil due to erosion removes useful farmland, adds to sediment loads, and can help transport anthropogenic fertilizers into the river system, which leads to eutrophication, with negative consequences on aquatic lives.

3.6 Sediment Control

Sediment control is a practice or device designed to keep eroded soil on a construction site or other places, so that it does not wash off and cause water pollution to a nearby stream, river, lake, or bay. Sediment controls are usually employed together with erosion controls, which are designed to prevent or minimize erosion and thus reduce the need for sediment controls.

Coordinated efforts by federal and state agricultural programmes can help reduce the amount of soil erosion and sedimentation. Farmers should be encouraged to utilize a variety of conservation practices to reduce erosion and limit sedimentation, such as conservation tillage methods, use of conservation buffers and riparian habitat, and establishment of conservation easements.

Water quality can be protected by controlling and minimizing erosion. Federal and state laws should provide some consideration for erosion and sedimentation control along streams and lakes during flood control, drainage, highway, bridge, and other stream-related construction projects. Both the public and private agencies should be engaged in a variety of programmes for erosion control. Such programmes should include research projects, education programmes, technical assistance, regulatory measures, and cost-share financial assistance.

In a nutshell, preventive measures for reducing excessive sediment load in streams include:

- Proper repair and maintenance of drainage ditches and levees.
- Minimal disturbance of the stream banks.
- Avoidance of structural disturbance of rivers.
- Reduction of sediment excesses arising from construction activities.
- Application of artificial and natural means for preventing erosion, and
- Use of proper land and water management practices on the water-shed.

These preventive measures are preferred over remedial measures, which include;

- Construction of detention reservoirs, sedimentation ponds, or settling basins.
- Development of side-channel flood-retention basin and
- Removal of deposited sediment by dredging.

Self Assessment Exercise

Examine the relationship between sediment and erosion processes, and account for the sources, transport mode, impacts and control measures of sediment.

4.0 Conclusion

Discussions in this unit have established the close relationship between erosion and sedimentation processes. Erosion process exacerbates sedimentation problems; therefore, in designing any control measures for sedimentation problems, accounts must be taken of erosion control.

5.0 Summary

- Sediment is naturally-occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, and by the force of gravity acting on the particle itself.
- There are several sources of sediment, which include eroded uncovered soils, construction sites, dredging and channelization of streams, grazing along river banks etc.
- Sediment is transported based on the strength of the flow that carries it and its own size, volume, density and shape. Sediment are most often transported by water, wind and glacier.
- Some of the major impacts of sediment are pollution – increase in water turbidity, eutrophication, and disruption of aquatic ecosystems.
- There are two broad categories of sediment control – preventive and remedial measures. Preventive measures are proactive, while remedial measures are reactionary.

6.0 Tutor Marked Assignments

(1) Sediment load may be increased by both natural and ____ activities.

(2) Sediment is most often transported by water, wind and ______

(3) Solid sediment load can be divided into two components on the basis of the mode of transportation; they are suspended and _____ sediment.

(4) Which of the following is not a means of sediment transport
(a) wind (b) ice (c) water (d) none of the above

(5) Which of the following activities is most likely to contribute less to sedimentation.
(a) riparian vegetation (b) grazing (c) deforestation (d) dredging

(6) The total quantity of sediment transported from a watershed at a given location in a given period of time is called.
(a) sediment transport (b) sediment load (c) sediment yield (d) sediment deposi

7.0 References/Further Reading

http://e.wikipedia.org/wiki/sediment, 23-6 -2011

Nicholas, G (1999), *Sedimentology and Stratigraphy*, Malden, MA: Wiley-Blackwell.

Prothero, D.R. and Schwab, F. (1998). *Sedimentary Geology: An Introduction to Sedimentary Rocks and Stratigraphy*, W.H. Freeman.

Tarbuck, E.J. and Frederick, K.L. (1998). *The Earth: An Introduction to Physical Geology, 6th Edition*, Prentice Hall, New York.

Troeh, F.R; Ray, L.D. and Arthur H. (2000), *Soil and Water Conservation.* Prentice Hall, New York.

UNIT 4: PROBLEMS OF WATER RESOURCES DEVELOPMENT

Contents

1.0 Introduction

Several problems militating against water resources development have been identified in literature. Some of the identified problems include precipitation pattern, population growth, pollution, increase affluence, economic growth and development, corruption in the water sector, energy, finance, technology, political will and management. These problems are not limited to certain regions but extend throughout the world.

2.0 Objectives

The learning objectives are as follows:

- To list the major problems of water resources development.
- To discuss how these problems militate against water resources development.

3.0 Main Content

3.1 Precipitation Patterns

Precipitation patterns have been identified as one of the primary problems militating against water resources development, since precipitation is the primary source of replenishment of both surface and groundwater sources (Miller, 1996). In areas where there is lower than normal precipitation, there is usually water stress, which may result to a drought situation. Drought is usually triggered by reduced average annual precipitation, higher than normal temperatures, or both. Such situations do not favour adequate water resources development.

3.2 Population Growth

Population growth has been identified as a major factor in water resources development. At the most fundamental level, water is needed to supply people's basic domestic needs, in quantities directly proportional to the number of people. For instance, the National Research Council (1999) stated that with population growth; demand for the world's finite supply of fresh water is rising, putting strains even on the industrialized countries. Global population projections suggest that the world population of over 6 billion people in 2000 will increase by 20% to over 7 billion by 2015, and to 7.8 billion by 2025, a 30% rise. Enormous strains will be put on existing services, and substantial increases in the provision of water and sanitation will be needed to meet the needs of the ever-growing population. As populations grow and demands for water and other services expand, pollution levels will raise, which will then reduce the availability of water for human consumption.

3.3 Pollution

Pollution is another major problem in the development of water resources. Water pollution according to Botkin and Keller (1998) refers to degradation of water quality. In defining pollution, we generally look at the intended use of the water, how far it departs from the norm, its effects on public health, or its ecological impacts. From a public heath or ecological view, a pollutant is any biological, physical or chemical substance that in identifiable excess is known to be harmful to other desirable living organisms. Water pollutants include excessive amounts of heavy metals, certain radioactive isotopes, *faecal coliform* bacteria, phosphorus, nitrogen, sodium, and other useful (even necessary) elements, as well as certain pathogenic bacteria and viruses (Botkin and Keller, 1998).

The primary causes of deterioration of surface water quality are municipal and domestic waste water, industrial and agricultural wastes (organic, inorganic, heat) and solid and semi-solid refuse. Groundwater quality is influenced by the quality of its source. Changes in source water or degraded quality of source supplies may seriously impair the quality of the groundwater supply. Municipal and industrial wastes entering an aquifer are major sources of organic and inorganic pollution. A municipality obtaining its water supply from a surface body may find its source so fouled by wastes and toxic chemicals that it is unsuitable or too costly to treat for use as a water supply (Viessman and Hammer, 1998).

Another form of pollution that has impacted negatively on water resources development, especially in the coastal regions of the world is salt water intrusion. According to Oteri and Atolagbe (2003), potable water supply to inhabitants in some of the communities in the coastal belt of Nigeria has been a major problem due to salt water intrusion. They stated that communities such as Burutu in Delta State and Aiyetoro in Ondo State have no potable water source as the surface water is salty, while all the boreholes drilled so far have yield saline water. The inhabitants therefore depend on rain water harvesting (in the midst of numerous gas flares from oil production platforms) and purchasing water from merchants coming from the hinterland in boats. They noted that the high degree of restiveness and agitations against oil companies and installations is partly due to the lack of basic infrastructure in their areas especially potable water.

3.4 Corruption

Corruption has also been identified as a major problem of water resources development worldwide. For instance, Stalgen (2007) in his analysis of corruption in the water sector observed that the main reason behind the inadequate water supply is not the lack of a natural supply of water nor is it primarily an engineering problem, i.e. stemming from the lack of technical solutions. Instead, the global water crisis is primarily a crisis of governance. As a group of experts working under the UN Millennium Project puts it, the problem is "the lack of appropriate institutions at all levels and the chronic dysfunction of existing institutional arrangements". Stalgren affirms that corruption is at the core of the governance crisis in the water sector. Whereas the scope of corruption varies substantially across the sector and between different countries and governance systems, estimates by the World Bank suggest that 20% to 40% of water sector finances are being lost to dishonest and corrupt practices. The magnitude of this figure is distressing, especially, if one considers current efforts to aggregate the $6.7 billion needed annually to meet the Millennium Development Goals (MDGs) for water and sanitation in sub-Saharan Africa. An average level of corruption of 30% represents a leakage of $20 billion over the next decade. This situation is not healthy for water resources development.

3.5 Energy

Inadequate energy supply has also been identified as a factor in water resources development, most especially in developing economies. For instant, Onyekakeyah (2007) in his analysis of national power blackout and water supply, noted that Nigerians lives in cities without water, and that the absence of power to pump water further compound the problem. He stated that water supply is directly tied to regular supply of electricity. Without electricity, there can be no potable water supply. Pipe water flows when power is energized. But in a situation where the entire nation is in blackout, water supply is drastically reduced and becomes critical.

3.6 Other Factors

Apart from the problems discussed above, other factors that affect the development of water resources include poor maintenance culture (evidence abounds of pipe leakages, rusted pipes, unlocked taps, broken valve etc); high cost of facilities, economic growth and development (putting pressure on existing water infrastructure) and increasing affluence (increase in demand for water, through the use of washing machines, dishes, and the watering of lawns). All these factors act in one way or the other to militate against water resources development.

Self Assessment Exercise

What are the factors you can identify as militating agent water resources development in your locality?

4.0 Conclusion

The discussions above have made it very clear that there are several problems militating against adequate water resources development world wide. Apart from precipitation pattern, which is an obvious natural factor, the others are human factors that can be surmounted. With adequate planning and management, change of negative habits (pollution, corruption, poor maintenance and wastages) the task of water resources development, can be made easier, more effective and efficient.

5.0 Summary

- Problems militating against water resources development over the world are similar; though vary in severity from one region or country to another.
- The problems can be classified into human and natural. Precipitation seems to be the only major natural factor.
- The human factors include pollution, energy, corruption, population growth etc.
- With adequate planning and management, and change of negative habits, the task of water resources development could be simplified.

6.0 Tutor Marked Assignments

(1) The problems of water resources development can be classified into human and ______________

(2) The act of degradation of water resources is called __________

(3) Which of the following is a problem affecting water resources development?

(a) population growth (b) high precipitation (c) adequate power supply

(d) none of the above

7.0 References/Further Reading

Botkin, D.B and Keller, E.A. (1998). *Environmental Science: Earth as a Living Planet, Second Edition*, New York, John Wiley and Sons Inc.

Miller, G.T. (1996). *Living in the Environment: Principles, Connections and Solutions, Nineth Edition,* Wadsworth Publishing Company, Belomont, California.

National Research Council (1999) “Water for the Future: The West Bank and Gaza strip, Israel and Jordan”, *US National Academy of Science, http/books.nap.edu/openbook.nap.edu/openbook.php?record_id:6031*

Oteri, A.U. and Atolagbe, F.P. (2003). “Salt-Water Intrusion into Coastal Aquifers in Nigeria, *The Second International Conference on Intrusion Saltwater and Coastal Aquifers-Monitoring Modeling and Management, Merida, Tucatan, Mexico, March 30 – April 2, 2003.*

Onyekakeyah, L. (2007). “National Power Blackout and Water Supply” *The Guardian, Tuesday, March 27, 2007.*

Stalgren, P. (2007), “Corruption in the Water Sector” *The Punch, Wednesday, March 7, 2007.*

Viessman, W. and Hammer, M.J. (1998). *Water Supply and Pollution Control, Sixth Edition,* California, Addison Wesley Longman Incorporated.

UNIT 5: DEVELOPMENT AND MANAGEMENT OF WATER RESOURCES

Contents

1.0 Introduction

One of the most fundamental objects of hydrological studies is to provide adequate water supply for domestic, industrial and agricultural uses. In spite of this however, the problem of inadequate water supply is still prevalent in most parts of the world including Nigeria. The question now is how can we develop and manage water resources to meet our current and future forecasted needs? This question will form the central theme of discussions in this unit.

2.0 Objectives

The learning objectives are as follows

- To define water resources development
- To list and discuss the key dimensions in the development and management of water resources.

3.0 Main Contents

3.1 Defining Water Resources Development

Water resources development is the process by which the world's water sources are engineered to deliver adequate quantities of high-quality water to serve the forecasted need of society (Botkin and Keller, 1998). Management of water resources for water supply is a complex issue that will become more difficult as demand for water increases in the coming years. This difficulty will be especially apparent in the semiarid and arid parts of the world where water is or soon will be in short supply. Options for minimizing potential water supply problems include locating alternative water supplies and managing existing supplies better (Botkin and Keller, 1998). These options were also advocated by Miller (1999) where the stated that the two general approaches to water resources management are to increase the unstable supply and to decrease unnecessary loss of waste. Most water resource experts believe that any effective plan for water management should combine these approaches.

3.2 Key Dimensions in Water Resources Development and Management

According to Mcdonald and Kay (1988), water management is multidimensional. It embraces planning, design, construction, operation and maintenance. It must be conducted within the constraints of technology, social goals, laws and regulations, political viewpoints, environmental concerns, and economic realities. To be effective, water management must recognize and take advantage of interconnections between surface and groundwater bodies, exploit the potential for coordinated use of existing facilities, acknowledge that water quantity and quality are a single issue, devise new ways to operate old systems, blend structural and non structural approaches, accept that the expansiveness of water resources systems may require regional rather than local solutions to problems. In concept, water management is simple; the trouble is that the boundaries of the physical systems that must be dealt with often differ markedly from the political boundaries that affect how water is used and developed.

According to Wurbs (2003), the development and management of water resources include the following key dimensions.

- Facilities Provision
- Demand Management
- Desalination
- Water Allocation
- Integrated Water Management.

3.2.1 Facilities Provision

Water supply facilities include wells, dams and storage reservoirs, pipelines and pump station, water treatment plants, municipal distribution pipe network, wastewater collection and treatment systems, and irrigation equipment. Dams, reservoirs, and associated structures play a key role in water supply and multipurpose water management. Most of the world's rivers are characterized by highly variable flows, with seasonal fluctuations aggravated by severe droughts and extreme floods. Reservoir storage is therefore necessary to regulate stream flow fluctuations and develop reliable water supplies (Wurbs, 2003). Also highlighting the role of dams in water resources management, Miller (1996) stated that rainwater and water from melting snow that would otherwise be lost can be captured and stored in large reservoirs behind dams built across rivers. He further noted that damming increases the annual supply by collecting fresh surface water during wet periods and storing it for use during dry periods.

3.2.2 Demand Management

Hydrologic, environmental, and economic conditions have led to heightened constraints on developing additional water supplies. Consequently, demand management in the form of reducing waste and increasing efficiency of use has become a major focus in the development of water resources in some parts of the world.

Demand management is concerned with the prevention of water wastages in any form – domestic, industry or agriculture. Water wastages through undetected pipeline leaks in aging water-distribution systems, agricultural losses through seepage and evaporation, and other forms of looses are involved in demand management.

3.2.3 Desalination

Removing dissolved salts from ocean water or brackish (slightly salty) groundwater is an appealing way to increase freshwater supplies because of the huge volume of, seawater adjacent to coastal cities (Miller, 1996). Until recently, the high salt content of the oceans, inland seas, and certain segment of rivers and groundwater has severely restricted our ability to use their waters. Now, however, desalination technology is well established and readily available.

The primary limiting factor of desalination is other cost relative to the water-supply options. However, due to over drafting of the groundwater system, large areas of wetlands are being permanently damaged, lakes are drying up, and domestic wells for hundreds of families are being lost. This type of scenario will lead to increased use of desalination technology, but the challenge for future research and development is to continue to minimize cost.

2.2.4 Water Allocation

Water rights systems and interstate and international agreements allocating water resources are becoming increasingly important. Around the world, 261 river basins are shared by two or more countries, often leading to disputes and conflicts related to water supply. As a result, methods of cooperation and conflict mitigation need to be brought into play (Wurb, 2003).

3.2.5 Integrated Water Management

Water resources are tapped by multiple users for a variety of purpose. Therefore, effective water management requires a systems approach, with comprehensive integration of a number of factors. In particular, attention must be given to both water quality and quantity. Conjunctive management of groundwater and surface water resources is required and the water needs to be appropriately allocated to the various users. Human needs must be balanced with ecosystem needs, economic development with environmental protection. Efforts have to be made toward optimizing the mix of demand management programmes, new facilities construction, and improved operations and maintenance of existing facilities. Water-management approaches need to incorporate ongoing advances in water supply technologies such as desalination processes and efficient irrigation techniques – and the technology chosen have to be appropriate for the particular country, region, and local culture. In addition, computer technology can be used to assist in data collection, analysis, systems modeling and management.

Self Assessment Exercise

As a newly appointed minister of water resources, what are the measures you will put in place to ensure effective and efficient development and management of water resources in Nigeria?

4.0 Conclusion

As we look to the future, we can expect that the planning and management of water resources will move toward a holistic systems approach, which will coordinate and integrate various aspects, including water supply (for domestic, industrial, and agricultural needs), hydroelectric power, flood control, and ecosystem conservation. The reduction of waste and enhancement of efficiency will be increasingly stressed. And the decision making process will have to consider the views of various people, including scientists, engineers, political officials, interest groups, and the public at large. The success of this approach will depend on how well the diverse factors are blended to make up the larger picture.

5.0 Summary

- Water resource development is the process by which the world's water sources are engineered to deliver adequate quantities of high-quality water to serve the forecasted need of society.
- The key dimensions in water resources development and management include facilities provision, demand management, water allocation, desalination and integrated water management.

6.0 Tutor Marked Assignments

(1) The process of removing dissolved salts from ocean water or brackish groundwater is called ____________

(2) Which of the following options is not a key dimension in water resources development?

(a) Desalination (b) facilities provision (c) demand management

(d) none of the above

7.0 References / Further Reading

Botkin, D.B and Keller, E.A. (1998). *Environmental Science: Earth as a Living Planet, Second Edition,* New York, John Wiley and Sons Inc.

McDonald, A.T and Kay, D. (1988). *Water Resources Issues and Strategies, Longman Scientific and Technical*, Longman Group UK Ltd.

Miller, G.T. (1996), *Living in the Environment: Principles, Connections and Solutions, Nineth Edition*, Wadsworth Publishing Company, Belomont, California.

Onyekakeyah, L. (2007). "National Power Blackout and Water Supply" *The Guardian, Tuesday, March 27, 2007.*

World Water Council (2005). *Water Supply and Sanitation, http//www.worldwater council.org/index.php?id 10/7/2005.*

Wurbs, A.R. (2003). *Managing our Water Resources, The World and Online Magazine http://www/worldandi.com/public/2000/october/waters.html. 1/5/2007.*

Answers to Tutor Marked Assignments

Module I

Unit 1: Definition and Scope of Hydrology

1. Hydrology
2. Chemical hydrology
3. Hydrologic cycle
4. (c) Hydrologist
5. (d) Rock formation
6. (b) Surf hydrology

Unit 2: Brief History of the Development of Hydrology

1. Nilumeter
2. Philosophical or Unscientific
3. (c) 17^{th} Century
4. (a) Marcus Vitruvius
5. (d) 19^{th} Century

Unit 3: Basic Properties of Water

1. Hydrogen bonding
2. (a) Liquid, (b) solid (c) gas
3. Biological lives
4. (b) 80 calories
5. (b) The solid form is lighter than the liquid form.
6. (c) It expands

Unit 4: The Hydrologic Cycle

1. Solar heating
2. Condenses

3. Infiltration

4. (d) Evapotranspiration

5. (a) Runoff

Unit 5: Application of Hydrology

1. Water

2. Pollution

3. (d) All of the above

MODULE 2

Unit 1: Concept of the Drainage Basin

1. Watershed

2. Parallel

3. (a) Deposition

4. (b) Soil colour

Unit 2: Groundwater Resources

1. Ground and surface water

2. Aquifers

3. Subsidence

4. (c) Aquiclude

5. (a) All of the above

6. (d) All of the above

Unit 3: Surface Water Resources

1. Surface water

2. Precipitation

3. Stream flow

4. (d) All of the above

5. (a) Climatic factors

6. (a) Pipes from industrial sites that empty into rivers.

Unit 4: Precipitation

1. Rain gauge

2. Orographic

3. (a) Snow

4. (b) Convectional

5. (c) Conventional

Unit 5: Humidity

1. Humidity

2. Air temperature

3. Specific humidity

4. (c) A & B

5. (c) 100%

6. (c) A & B

MODULE 3

Unit 1: Interception

(1) Interception

(2) Vegetation

(3) Interception storage

(4) (a) Soil profile

(5) (b) I=P-T-S

(6) (b) Vegetation intercept more during low intensity rainfall

Unit 2: Infiltration

(1) Infiltration

(2) Porosity

(3) (b) It affects the rate of interception

(4) (c) Sandy soil

Unit 3: Soil Moisture

(1) Capillary water

(2) Precipitation

(3) (d) Hydroscopic

(4) (a) Agriculture

Unit 4: Evaporation and Evapotranspiration

1. Evaporation
2. 100%
3. Transpiration
4. (c) Evaporation and transpiration
5. (b) Meteorological
6. (a) Potential evapotranspiration

Unit 5: Runoff

1. Runoff
2. Runoff
3. (d) All of the above
4. (a) Runoff is high when infiltration is high

MODULE IV

Unit 1: Erosion

1. Wind
2. Deflation
3. Groundwater

4. (a) Deforestation

5. (d) Evaporation

6. (b) Over cultivation

Unit 2: Flooding

(1) Flooding

(2) Flood plain

(3) Human or Anthropogenic

(4) (d) Heavy rainfall on concrete surface

(5) (b) Inconveniences of relocating to a temporary accommodation

(6) (a) Planting vegetation

Unit 3: Sediment

(1) Human

(2) Glacier

(3) Bed load

(4) (d) None of the above

(5) (a) Riparian vegetation

(6) (c) Sediment yield

Unit 4: Problems of Water Resources Development

(1) Natural

(2) Pollution

(3) (a) Population growth

Unit 5: Development and Management of Water Resources

(1) Desalination

(2) (d) None of the above