NATIONAL OPEN UNIVERSITY OF NIGERIA

COURSE CODE :ESM 223

COURSE TITLE:
WATER RESOURCES EVALUATION

COURSE GUIDE

ESM 223
WATER RESOURCES EVALUATION

Course Developer/Writer	Eludoyin A.O. Department of Geography Obafemi Awolowo University Ile-Ife, Nigeria
Programme Leader	Dr. Temi Ologunorisa School of Science & Technology National Open University of Nigeria

NATIONAL OPEN UNIVERSITY OF NIGERIA

National Open University of Nigeria
Headquarters
14/16 Ahmadu Bello Way
Victoria Island
Lagos

Abuja Office:
No.5 Dar-es-Salaam Street
Off Aminu Kano Crescent
Wuse II, Abuja

e-mail: centralinfo@nou.edu.ng
URL: www.nou.edu.ng

First Printed 2009

ISBN:

Printed by ……………..
For
National Open University of Nigeria

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Introduction

Water is used for a variety of purposes, and these have very different quantity, quality, and timing characteristics. It is a fundamental natural resource that influences human health, ecology and economic development. Man requires it for his cooking, washing, sanitation, drinking and for growing his crops and running his factories. Man has used water to generate hydropower or regulate river flow; extensive groundwater schemes have also been linked to complex multi-source centralised public water supply systems in some countries. Water has also been used for waste disposal and irrigated agriculture. Demands for water, has however fluctuated from year to year depending on the weather patterns. It is therefore important to discuss how this delicate resource is studied, managed and evaluated to sustain its usefulness.

Water Science, hydrology or in general terms, water study is an applied science, borrowing from engineering, pure and physical science, social sciences and management. Its study therefore requires a sound, broad based education in these areas. The present course structure however employs a beginner's approach to the study of water resource management and evaluation. There are two Modules (2) in this course, each with six units (6). The approach is the system form that makes use of the variables in water cycle for its explanations, in order to lead you through a clearly defined pathway of the water cycle system, and the way each is evaluated.

Unit 1 introduces you to the nature and distribution of water on the earth.

Unit 2 explains the concepts of hydrological or water cycle. It provides information about how water cycling occurs through the processes of evaporation, condensation, precipitation, runoff, to groundwater flow and the processes involved.

Units 3 to 5 describe the processes involved in water cycle to some level of details, the reservoirs; particularly the surface and subsurface sources. The concept of the unit of hydrological measurements, drainage basin is discussed in unit 6.

The Units 1 to 5 of Module 2 focused on the discussion of the precipitation, evaporation, runoff and stream flow, in that order. Techniques for obtaining information about these variables were also highlighted.

Finally, water quality in the surface and subsurface basins forms the basis of discussion in Unit 6. Pollution and the regulating framework for water management in some parts of the world, including Nigeria are also discussed here.

The Course

This Course Guide tells you briefly what to expect from this material. The study of Water is not only an academic endeavour, it is a lifelong determining process. Where is Earth's water located and in what forms does it exist? Is it safe for drinking? Can fish and other aquatic life thrive in streams and lakes that are affected by human activities? What is the water quality? All these are questions that are relevant to human survival on earth.

Hydrology is the science that studies the Earth's water molecules and their movement through the hydrologic cycle. The Earth and its various abiotic and biotic systems are greatly influence by water. Water is essential for life and plays an important role in atmospheric and lithospheric processes.

The hydrologic cycle is used to model the storage and movement of water molecules between the biosphere, atmosphere, lithosphere and hydrosphere. Water is stored in the following reservoirs: atmosphere, oceans, lakes, rivers, glaciers, soils, snowfields, and groundwater. It moves from one reservoir to another by processes like: evaporation, condensation, precipitation, deposition, runoff, infiltration, sublimation, transpiration, and groundwater flow.

Precipitation can be defined as any aqueous deposit, in liquid or solid form, that develops in a saturated atmospheric environment and generally falls from clouds. A number of different precipitation types have been classified by meteorologists including rain, freezing rain, snow, ice pellets, snow pellets, and hail. Fog represents the saturation of air near the ground surface. Classification of fog types is accomplished by the identification of the mechanism that caused the air to become saturated.

The distribution of precipitation on the Earth's surface is generally controlled by the absence or presence of mechanisms that lift air masses to cause saturation. It is also controlled by the amount of water vapor held in the air, which is a function of air temperature. A figure is presented that illustrates global precipitation patterns.

Evaporation and transpiration are the two processes that move water from the Earth’s surface to its atmosphere. Evaporation is movement of free water to the atmosphere as a gas. It requires large amounts of energy. Transpiration is the movement of water through a plant to the atmosphere. Scientists use the term evapotranspiration to describe both processes. In general, the following four factors control the amount of water entering the atmosphere via these two processes: energy availability; the humidity gradient away from the evaporating surface; the wind speed immediately above the surface; and water availability. Agricultural scientists sometimes refer to two types of evapotranspiration: Actual Evapotranspiration and Potential Evapotranspiration. The growth of crops is a function of water supply. If crops experience drought, yields are reduced. Irrigation can supply crops with supplemental water. By determining both actual evapotranspiration and potential evapotranspiration a farmer can calculate the irrigation water needs of their crops.

The distribution of precipitation falling on the ground surface can be modified by the presence of vegetation. Vegetation in general, changes this distribution because of the fact that it intercepts some the falling rain. How much is intercepted is a function of the branching structure and leaf density of the vegetation. Some of the water that is intercepted never makes it to the ground surface. Instead, it evaporates from the vegetation surface directly back to the atmosphere. A portion of the intercepted water can travel from the leaves to the branches and then flow down to the ground via the plant's stem. This phenomenon is called stemflow. Another portion of the precipitation may flow along the edge of the plant canopy to cause canopy drip. Both of the processes described above can increase the concentration of the water added to the soil at the base of the stem and around the edge of the plant's canopy. Rain that falls through the vegetation, without being intercepted, is called throughfall.

Infiltration is the movement of water from precipitation into the soil layer. Infiltration varies both spatially and temporally due to a number of environmental factors. After a rain, infiltration can create a condition where the soil is completely full of water. This condition is, however, only short-lived as a portion of this water quickly drains (gravitational water) via the force exerted on the water by gravity. The portion that remains is called the field capacity. In the soil, field capacity represents a film of water coating all individual soil particles to a thickness of 0.06 mm. The soil water from 0.0002 to 0.06 mm (known as capillary water) can be removed from the soil through the processes of evaporation and transpiration. Both of these processes operate at the surface. Capillary action moves water from one area in the soil to replace losses in another area (biggest losses tend to be at the surface because of plant consumption and evaporation). This movement of water by capillary action generally creates a homogeneous concentration of water throughout the soil profile. Losses of water stop when the film of water around soil particles reaches 0.0002 mm. Water held from the surface of the soil particles to 0.0002 mm is essentially immobile and can only be completely removed with high temperatures (greater than 100 degrees Celsius). Within the soil system, several different forces influence the storage of water.

Runoff is the surface flow of water to areas of lower elevation. On the microscale, runoff can be seen as a series of related events. At the global scale runoff flows from the landmasses to the oceans, the Earth's continents experience runoff because of the imbalance between precipitation and evaporation.

Throughflow is the horizontal subsurface movement of water on continents. Rates of throughflow vary with soil type, slope gradient, and the concentration of water in the soil. Groundwater is the zone in the ground that is permanently saturated with water. The top of groundwater is known as the water table. Groundwater also flows because of gravity to surface basins of water (oceans) located at lower elevations.

The flow of water through a stream channel is commonly called streamflow or stream discharge. On many streams humans gauge streamflow because of the hazards that can result from too little or too much flow. Mechanical gauging devices record this information on a graph known as a hydrograph. In the online notes there is a representation of a hydrograph showing some of its typical features.

Course Aim

The aim of this study is to provide an understanding and appreciation of water resources

Course Objectives

Sequel to the aim above, this course sets to achieve some objectives. After reading this course, you should be able to:

- discuss the nature of water and its distribution on earth
- describe the hydrological cycle
- describe the processes of water transfer in the hydrological cycle
- enumerate surface water resources
- enumerate the various forms of groundwater sources
- describe the drainage basin
- enumerate precipitation forms and describe ways of measuring rainfall
- describe the processes of evaporation and highlight how they could be measured

- describe discharge measurement in a stream
- define water quality and enumerate the source of pollutants into water sources.

Working through the Course

You are advised to study this course material very well. The course may not be that simple but you may be assured that great efforts have been put into its development in the attempt to make it very readable and comprehensible. Nevertheless, you must study it very well. I would advise that you avail yourself the opportunity of attending tutorial sessions where you would have the opportunity of comparing knowledge with your peers.

The Course Material

You will be provided with the following materials;

Course Guide and Study Units

In addition, the course comes with a list of recommended textbooks which though are not compulsory for you to acquire or indeed read, are necessary complements to the course material.

Study Units

This course is made up of two Modules (2) each with six units (6)

Module 1

Unit 1	Nature and Distribution of Water on the Earth
Unit 2	Water (Hydrological) Cycle
Unit 3	Processes of Water Transfer
Unit 4	Surface Water Sources
Unit 5	Groundwater Sources
Unit 6	The Concept of Drainage Basin

Module 2

Unit 1	Precipitation Forms and Rainfall Measurements
Unit 2	Evaporation and Evapotranspiration
Unit 3	Runoff
Unit 4	Streamflow
Unit 5	Streamflow Measurements
Unit 6	Water Quality Assessment

References/Further Reading

Bras, R.L. *Hydrology: An Introduction to Hydrologic Science,* Massachusetts: Addison-Wesley, 1990.

Christopherson, R. W. *Geosystems: An Introduction to Physical Geography.* 5th Edition New Jersey, Prentice Hall, 2005.

Davie, T. *Fundamentals of Hydrology*, Routledge Publishing, 2002.

Singh, V.P. Elementary Hydrology, Pearson Education, 1997.

Alan H. and Arthur Strahler, *Physical Geography: Science and Systems of the Human Environment*. 2nd Edition, New York: John Wiley and Sons, 2003.

Viessman, W. and G.L. Lewis. *Introduction to Hydrology*, 5th edition. New Jersey: Prentice Hall, 2003.

Assessment

There are two components of assessment for this course. The Tutor-Marked Assignment (TMA), and the end of course examination

Tutor-Marked Assignment

The TMA is the continuous assessment component of your course. It accounts for 30% of the total score. You will be given TMAs to answer. You must answer all these before you are allowed to write the end of course examination. The TMAs would be given to you by your facilitator and returned after you have done them.

End of Course Examination

This examination concludes the assessment component for the course. It constitutes 70% of the whole course. You will be informed of the time for the examination. It may or not coincide with the University semester's examination

Summary

This course intends to provide you with some underlying knowledge of water resources and the way they are assessed. By the time you complete studying this course, you will be able to answer the following questions:

- What is streamflow? Describe the effect of an intense storm on streamflow using a hydrograph.

- Distinguish between evaporation and evapotranspiration. What factors control the rate of evapotranspiration?

- Discuss the movement of water into soils. How and why does infiltration vary with time?

- Why does runoff occur?

- What is potential evapotranspiration and how does it differ from actual evapotranspiration. What factors control the rate at which water leaves the Earth's surface by way of evaporation and transpiration?

- Explain the global distribution patterns of precipitation.

- What is the importance of water cycle

I wish you success in this course. In particular, I hope you will be able to appreciate the importance of water as common, valuable but endangered resource.

Best wishes.

MAIN COURSE

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Course Developer/Writer	Eludoyin A.O. Department of Geography Obafemi Awolowo University Ile-Ife, Nigeria
Programme Leader	Dr. Temi Ologunorisa School of Science & Technology National Open University of Nigeria Victoria Island, Lagos

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National Open University of Nigeria 2009

First Printed 2009

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Printed by ……………..
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MODULE 1

UNIT 1 NATURE AND DISTRIBUTION OF WATER ON THE EARTH

CONTENTS

1.0 INTRODUCTION

It is assumed that you have read the summary of the contents of the Course Guide that has been prepared alongside this material. If you have done this, you would have gotten an overview of what this unit contains. In this unit, you are introduced to water and its properties, and how it is distributed over the earth.

Before we discuss this, it is good that you know your learning expectations for the unit. These are included in the learning objectives stated below.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- mention the physical and chemical properties of water
- differentiate between polluted and normal water
- describe the distribution of water over the earth surface.

3.0 MAIN CONTENT

3.1 Properties of Water

What are the physical and chemical properties of water that make it so unique and necessary for living things? When you look at water, taste and smell it. Pure water is virtually colourless and has no taste or smell. But the hidden qualities of water make it a most interesting subject. Thus, water is known to possess two main categories of properties, namely; chemical and physical properties.

3.1.1 Chemical Properties

You probably know that water's chemical formula is H_2O. One atom of oxygen bound to two atoms of hydrogen. The hydrogen atoms are "attached" to one side of the oxygen atom, resulting in a water molecule having a positive charge on the side where the hydrogen atoms are and a negative charge on the other side, where the oxygen atom is. Since opposite electrical charges attract, water molecules tend to attract each other, making water kind of "sticky." The side with the hydrogen atoms (positive charge) attracts the oxygen side (negative charge) of a different water molecule.

All these water molecules attracting each other mean they tend to clump together. This is why water drops are, in fact, drops! If it was not for some of Earth's forces, such as gravity, a drop of water would be ball shaped - a perfect sphere.

Water is called the "universal solvent" because it dissolves more substances than any other liquid. This means that wherever water goes, either through the ground or through our bodies, it takes along valuable chemicals, minerals, and nutrients. Pure water has a neutral pH of 7, which is neither acidic nor basic.

3.1.2 Physical Properties

Water is unique in that it is the only natural substance that is found in all three states -- liquid, solid (ice), and gas (steam) - at the temperatures normally found on Earth. Earth's water is constantly interacting, changing, and in movement.

Water freezes at 0^o Celsius (C) and boils at 100^o C at sea level. In fact, water's freezing and boiling points are the baseline with which temperature is measured: 0^o on the Celsius scale is water's freezing point, and 100^o is water's boiling point. Water is unusual in that the solid form, ice, is less dense than the liquid form, which is why ice floats.

Water has a high specific heat index. This means that water can absorb a lot of heat before it begins to get hot. This is why water is valuable to industries and in your car's radiator as a coolant. The high specific heat index of water also helps regulate the rate at which air changes temperature, which is why the temperature change between seasons is gradual rather than sudden, especially near the oceans.

Water has a very high surface tension. In other words, water is sticky and elastic, and tends to clump together in drops rather than spread out in a thin film. Surface tension is responsible for capillary action, which allows water (and its dissolved substances) to move through the roots of plants and through the tiny blood vessels in our bodies.

3.2 Distribution of Water

Where is Earth's water located and in what forms does it exist? You can see how water is distributed by viewing the bar charts below. The left-side bar shows where the water on Earth exists; about 97 percent of all water is in the oceans. The middle bar shows the distribution of that three percent of all Earth's water that is freshwater. The majority, about 69 percent, is locked up in glaciers and icecaps, mainly in Greenland and Antarctica. You might be surprised that of the remaining freshwater, almost all of it is below your feet, as ground water. No matter where on Earth you are standing, chances are that, at some depth, the ground below you is saturated with water. Of all the freshwater on Earth, only about 0.3 percent is contained in rivers and lakes—yet rivers and lakes are not only the water we are most familiar with, it is also where most of the water we use in our everyday lives exists.

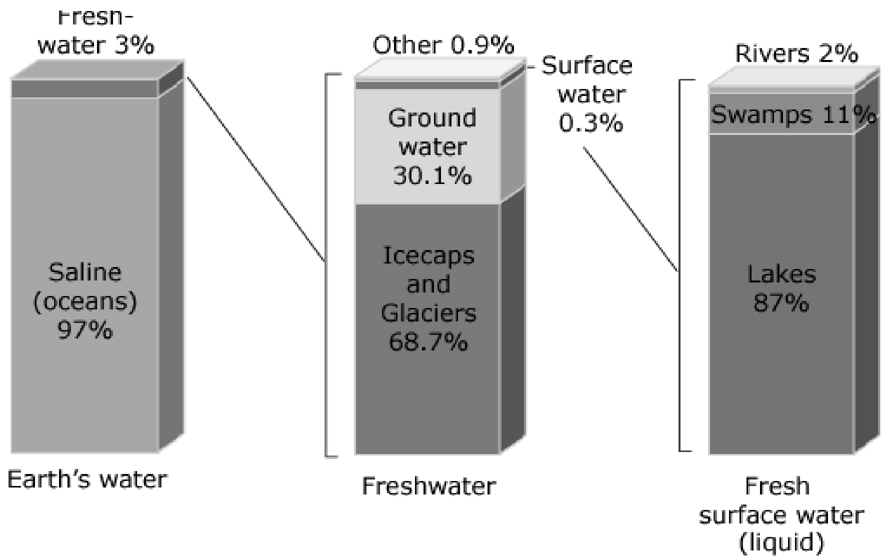


Figure 1.1: Distribution of water on the earth

3.2.1 Water Supply

How much of this water is available for our uses ... and in what forms does it exist? You can best see how water is distributed by viewing these pie charts (Figure 1.2). The top pie chart shows that over 99 percent of all water (oceans, seas, ice, most saline water, and atmospheric water) is not available for our uses. And even of the remaining fraction of one percent, much of that is out of reach. Considering that most of the water we use in everyday life comes from rivers, you will see that we generally only make use of a tiny portion of the available water supplies. The bottom pie shows that the vast majority of the fresh water available for our uses is stored in the ground. For a detailed explanation of how water is distributed, look at the data table below. Notice how of the world's total water supply of about 1,386 million cubic kilometres of water, over 96 percent is saline.

And, of the total freshwater, over 68 percent is locked up in ice and glaciers. Another 30 percent of freshwater is in the ground. Thus, surface-water sources (such as rivers) only constitute about 93,100 cubic kilometres, which is about 0.0067 percent of total water, yet rivers are the source of most of the water people use.

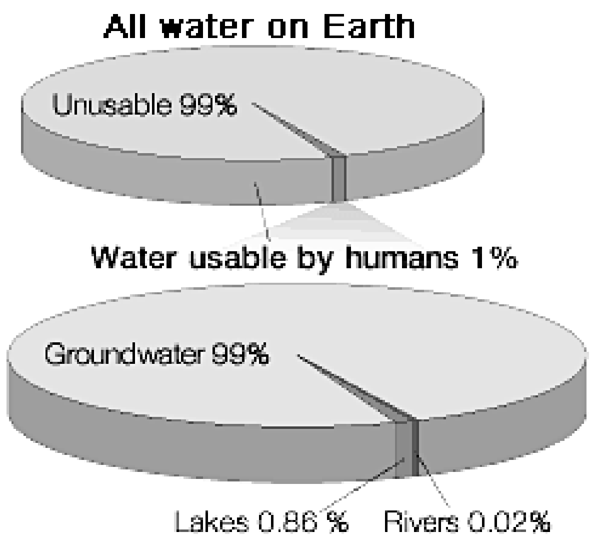


Figure 1.2: Global water availability and use

Table 1.1: Distribution of water in volume and percentages of freshwater available for use.

Water source	Water volume (km^3)	% of fresh water	% of total water
Oceans, Seas, & Bays	1,338,000,000	0	96.5
Ice caps, Glaciers, & Permanent Snow	24,064,000	68.7	1.74
Groundwater	23,400,000	--	1.7
Fresh	10,530,000	30.1	0.76
Saline	12,870,000	--	0.94
Soil Moisture	16,500	0.05	0.001
Ground Ice & Permafrost	300,000	0.86	0.022
Lakes	176,400	--	0.013
Fresh	91,000	0.26	0.007
Saline	85,400	--	0.006
Atmosphere	12,900	0.04	0.001
Swamp Water	11,470	0.03	0.0008
Rivers	2,120	0.006	0.0002
Biological Water	1,120	0.003	0.0001
Total	**1,386,000,000**	**100.04g**	**100**

Source: www.ga.water.usgs.gov/edu.html

4.0 CONCLUSION

In this unit, you have learnt about the constituents of water, and how it is distributed across the earth. You have also realised that a tangible proportion of water available on the earth is not useful, and although we use water everyday, the amount available for use is just 1%.

You should at this point attempt to identify the need to conserve the little water that you have and think of possible ways to correct your previous believe that water is abundance. Can you identify some possible sources of water in the arid region and deserts? What will happen if the little available water in the region is wasted?

5.0 SUMMARY

This unit has focused on the characteristics of water, its distribution and availability for use. Good water should be tasteless, neither acidic nor basic. It should also be odourless, etc. it should be free from pollutants. The unit also showed that of the total water available on the earth surface, only 1% is available for use. Others are either hidden somewhere or are not in desired form for use. Unit 2 will discuss the process with which this water gets to us in the earth system.

6.0 TUTOR-MARKED ASSIGNMENTS

i. Highlight three, each of the chemical and physical properties of water.

ii. Differentiate between a polluted and good (pure) water.

iii. Describe in your own words, how water is distributed over the earth.

7.0. REFERENCES/FURTHER READING

Singh, V.P. *Elementary Hydrology*. Pearson, 1997.

Strahler, Alan H. and Arthur Strahler. *Physical Geography: Science and Systems of the Human Environment*. 2nd Edition John Wiley and Sons, New York, 2003.

www.ga.water.usgs.gov/edu.html

UNIT 2 WATER (HYDROLOGICAL) CYCLE

CONTENTS

1.0 INTRODUCTION

Unit 1 elucidates the properties and distribution of water on the earth surface. This Unit explains further the way this water is transferred from one form to another, and how and where they are stored.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- define the water (hydrological) cycle
- identify the components of water cycle
- describe the processes of water cycle
- discuss the importance of the cycle.

3.0 MAIN CONTENT

3.1 What is Water Cycle?

Earth's water is always in movement. The water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above, and below the surface of the Earth. It is a unified system which describes the way the hydrosphere (earth's water bodies). Since the water cycle is truly a "cycle," there is no beginning or end. Water can change states among liquid, vapour, and ice at various places in the water cycle, with these processes happening in the blink of an eye and over millions of years. Although the balance of water on Earth remains fairly constant over time, individual water molecules can come and go in a hurry. The primary source of water into the earth is the precipitation, in form of snow or rain.

3.2 Elements of the Water Cycle

The key elements of the water (hydrological) cycle are atmospheric water, surface water, soil water and ground water. The atmospheric water is made up of water vapour and clouds. Water vapour exist in the gaseous state, clouds are tiny droplets of water in the atmosphere. In order to have rain there must be a cloud. A cloud is made up of water in the air (water vapour). Along with this water are tiny particles called condensation nuclei. For instance, the little pieces of salt leftover after sea water evaporates, or a particle of dust or smoke. Condensation occurs when the water vapour wraps itself around the tiny particles. Each particle (surrounded by water) becomes a tiny droplet between 0.0001 and 0.005 centimetre in diameter. (The particles range in size, therefore, the droplets range in size). However, these droplets are too light to fall out of the sky.

The surface water is either flowing exposed, such as in rivers, streams or pond on land, such as in lakes, ponds, lagoons, seas and oceans. Subsurface water is that which occupies opening in the soil or rock. When it is held in the soil within a few meters of the surface, it is known as soil water. However, when held in the openings of the bedrock, it is referred to as groundwater. Subsurface water is therefore made up of two components; soil water and groundwater.

3.3 The Water Cycle Process

Picture a huge room full of tiny droplets milling around. If one droplet bumps into another droplet, the bigger droplet will "eat" the smaller droplet. This new bigger droplet will bump into other smaller droplets and become even bigger – this is called coalescence. Soon the droplet is so heavy that the cloud (or the room) can no longer hold it up and it starts falling. As it falls it eats up even more droplets. We can call the growing droplet a raindrop as soon as it reaches the size of 0.5mm in diameter or bigger. If it gets any larger than 4 mm, however, it will usually split into two separate drops.

The raindrop will continue falling until it reaches the ground. As it falls, sometimes a gust of wind (updraft) will force the drop back up into the cloud where it continues eating other droplets and getting bigger. When the drops finally reach the ground, the biggest drops will be the ones that bumped into and coalesced with the most droplets. The smaller drops are the ones that didn't run into as many droplets. Raindrops are of different sizes for two primary reasons; initial differences in particle (condensation nuclei) size and different rates of coalescence.

The resulting precipitation falls to the earth, and thereby adds to the surface water (lakes, rivers, oceans, etc). Some of the precipitation will percolate the soil to contribute to soil water or groundwater. Through the subsurface flow, the soil water and groundwater will reach streams and rivers. The falling rain drops may on account of either its intensity or soil moisture condition; contribute to surface runoff, which eventually empties into streams and rivers. The rivers will eventually discharge their waters into the sea.

The cycle is completed by the return of water to the atmosphere in form of vapour through evaporation from the surface waters or through the process of evapotranspiration from vegetated surface. The cyclic movement of water is illustrated in Fig. 2.1.

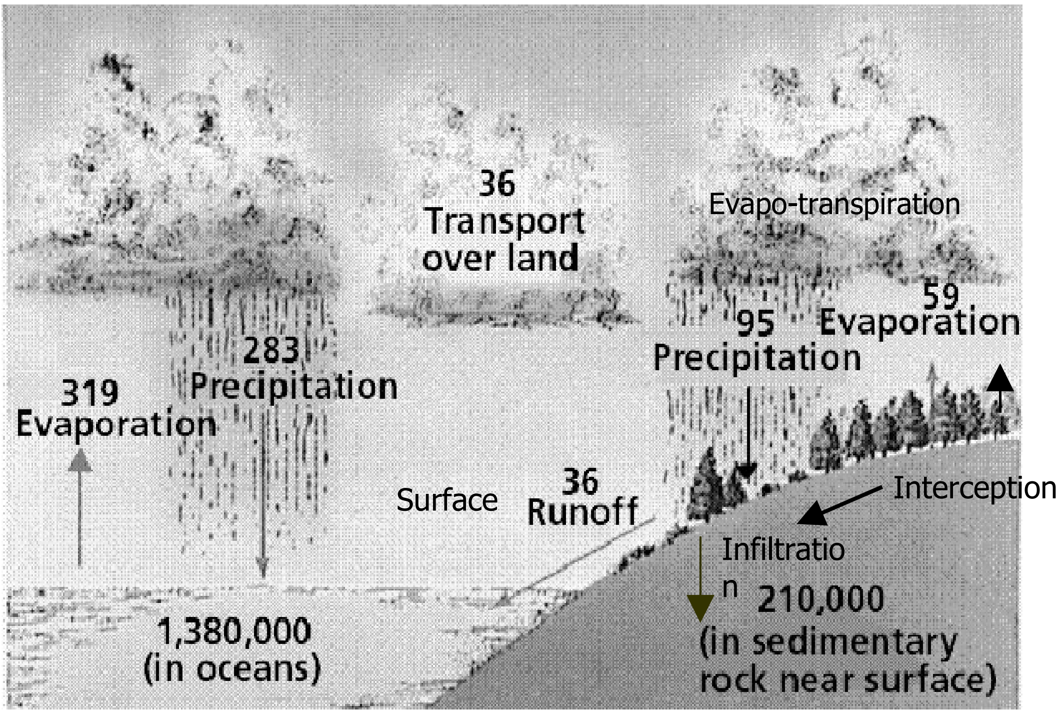


Figure 2.1: The Water Cycle (the digits are available water volume in km^3)

3.4 Importance of hydrological cycle

The hydrological cycle is very vital to life sustenance on earth. The followings are some of the specific importance:

1. The circulation of water from the oceans and land surfaces into the atmosphere and back again creates a resource, which is unlimited in global terms.

2. It is the largest circulation of matter within the earth-atmosphere system. As the ultimate recycling process, it washes away waste products in rainfall and purifies supplies by evaporation.

3. The supply of freshwater on earth is entirely due to hydrological cycle.

4. The solar energy and the gradients in water concentration between surface and atmosphere that drive evaporation also drive transpiration, the process that causes the sap to rise in most terrestrial plants. In this sense, the hydrological cycle shares with solar radiation the role of driving force behind primary biological production, basic food production on land.

5. By maintaining vapour in the atmosphere, the water cycle creates climate for life. Water vapour creates a 'green house effect' by absorbing heat loss from the surface of the earth.

4.0 CONCLUSION

In this unit, you have learnt about the water cycle, and how water from rains gets to the earth surface. Some of the components and processes were also discussed. You should at this point be able to describe, in simple terms, the principle of water cycle, and briefly explain the components and processes involved.

5.0 SUMMARY

You have learnt in this unit that the primary source of water to the earth is rainfall. The rainfalls, and the water undergoes a continuous cycle, that the water fall passes through some stages and later go back to the atmosphere, for the cycle to continue. The importance of this was highlighted, part of which include the ability to circulate the global energy resource. The importance of this cycle is enormous and all other activities on the earth are dictated by it, and its component

6.0. TUTOR-MARKED ASSIGNMENTS

i. Sketch and explain the hydrologic cycle.

ii. Mention 3 reasons why water cycle is an important phenomenon.

7.0 REFERENCES/FURTHER READING

http://ga.water.usgs.gov/edu/watercycle.html

Jeje, L.K. and Adesina, F. A . *Man and Environment – an introductory note*, Lecture note, Obafemi Awolowo University, Ile-Ife, 2002.

UNIT 3 PROCESSES OF WATER TRANSFER

CONTENTS

1.0 INTRODUCTION

You have learnt that water is transferred during the hydrological cycle. Water changes from one state to the other, and also moves from one medium to the other. As you have learnt in the earlier Unit, this is true. You will learn more about the mechanisms through which this is done and the terms given to them by hydrologist. You will also begin to see these terms being frequently used in subsequent Units. The first process is of course rainfall, which has been introduced to you in Unit 2, and with more details in Module 2 Unit 1.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- Interception
- Stemflow
- Infiltration
- Throughfall, etc.

3.0 MAIN CONTENT

3.1 Interception, Stemflow, Canopy Drip, and Throughfall

Vegetation often modifies the intensity and distribution of precipitation falling on it through its leaves and woody structures. The most obvious effect plants have on falling precipitation is interception.

3.1.1 Interception

This can be technically defined as the capture of precipitation by the plant canopy and its subsequent return to the atmosphere through evaporation or sublimation. The amount of precipitation intercepted by plants varies with leaf type, canopy architecture, wind speed, available radiation, temperature, and the humidity of the atmosphere.

Vegetation can intercept up to 50% of the rain that falls on its leaves. The leaves of deciduous trees commonly intercept anywhere from 20 to 30% of the falling rain. Water dripping off leaves to the ground surface is technically called leaf drip.

Precipitation that is not intercepted can be influenced by the following processes:

3.1.2 Stemflow

is the process that directs precipitation down plant branches and stems. The redirection of water by this process causes the ground area around the plant's stem to receive additional moisture. The amount of stemflow is determined by leaf shape, stem and branch architecture. In general, deciduous trees have more stemflow than coniferous vegetation.

3.1.3. Canopy drip

Some plants have an architecture that directs rainfall or snowfall along the edge of the plant canopy. This is especially true of coniferous vegetation. On the ground, canopy drip creates areas with higher moisture content that are located in a narrow band at the edge of the plant canopy.

3.1.4. Throughfall

This is used to describe the process of precipitation passing through the plant canopy. This process is controlled by factors like: plant leaf and stem density, type of the precipitation, intensity of the precipitation, and duration of the precipitation event. The amount of precipitation passing through varies greatly with vegetation type.

When the water gets to the ground in any of these flow processes, some will infiltrate the soil. It is therefore necessary to look at this process and its implications.

3.2 Infiltration and Soil Water Storage

3.2.1 Infiltration

Infiltration refers to the movement of water into the soil layer. The rate of this movement is called the infiltration rate. If rainfall intensity is greater than the infiltration rate, water will accumulate on the surface and runoff will begin.

Movement of water into the soil is controlled by gravity, capillary action, and soil porosity. Of these factors soil porosity is most important. A soil's porosity is controlled by its texture, structure, and organic content. Coarse textured soils have larger pores and fissures than fine-grained soils and therefore allow for more water flow. Pores and fissures found in soils can be made larger through a number of factors that enhance internal soil structure. For example, the burrowing of worms and other organisms and penetration of plant roots can increase the size and number of macro and micro-channels within the soil. The amount of decayed organic matter found at the soil surface can also enhance infiltration. Organic matter is generally more porous than mineral soil particles and can hold much greater quantities of water.

The rate of infiltration normally declines rapidly during the early part of a rainstorm event and reaches a constant value after several hours of rainfall. A number of factors are responsible for this phenomenon, including:

(1) The filling of small pores on the soil surface with water reduces the ability of capillary forces to actively move water into the soil.

(2) As the soil moistens, the micelle structure of the clay particles absorbs water causing them to expand. This expansion reduces the size of soil pores.

(3) Raindrop impact breaks large soil clumps into smaller particles. These particles then clog the soil surface pores and reduce the movement of water into the soil.

3.2.2 Soil Water Storage

Within the soil system, the storage of water is influenced by several different forces. The strongest force is the molecular force of elements and compounds found on the surface of soil minerals. The water retained by this force is called hygroscopic water and it consists of the water held within 0.0002 millimetres of the surface of soil particles.

The maximum limit of this water around a soil particle is known as the hygroscopic coefficient**.** Hygroscopic water is essentially non-mobile and can only be removed from the soil through heating.

Matric force holds soil water from 0.0002 to 0.06 millimetres from the surface of soil particles.

This force is due to two processes: soil particle surface molecular attraction (adhesion and absorption) to water and the cohesion that water molecules have to each other. This force declines in strength with distance from the soil particle. The force becomes nonexistent past 0.06 millimetres. Capillary action moves this water from areas where the matric force is low to areas where it is high. Because this water is primarily moved by capillary action, scientists commonly refer to it as capillary water. Plants can use most of this water by way of capillary action until the soil wilting point is reached. Water in excess of capillary and hygroscopic water is called gravitational water. Gravitational water is found beyond 0.06 millimetres from the surface of soil particles and it moves freely under the effect of gravity. When gravitational water has drained away the amount of water that remains is called the soil's field capacity.

Figure 3.1 describes the relationship between the thickness of water film around soil particles and the strength of the force that holds this water. Force is measured in units called bars. One bar is equal to 1000 millibars. The graph also displays the location of hygroscopic water, the hygroscopic coefficient, the wilting point, capillary water, field capacity, and gravitational water along this line.

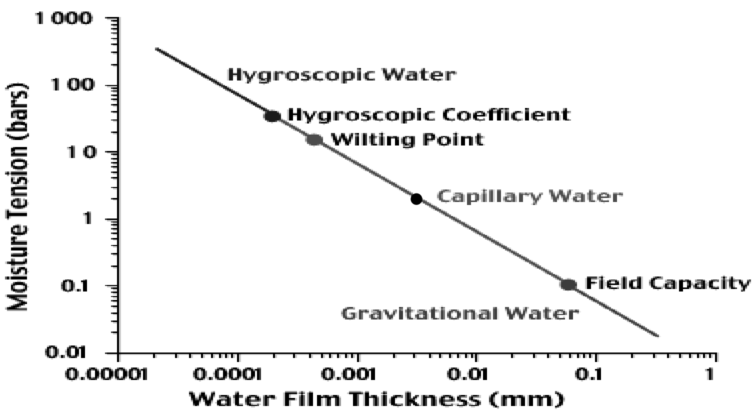


Figure 3.1: shows relationship between soil water film thickness and moisture tension

3.3 Throughflow and Groundwater Storage

3.3.1 Throughflow

Throughflow is the sporadic horizontal flow of water within the soil layer (Figure 3.2). It normally takes place when the soil is completely saturated with water. This water then flows underground until it reaches a river, lake, or ocean. Rates of water movement via throughflow are usually low. Rates of maximum flow occur on steep slopes and in pervious sediments. The lowest rates of flow occur in soils composed of heavy clays. Rates of throughflow in these sediments can be less than 1 millimetre per day.

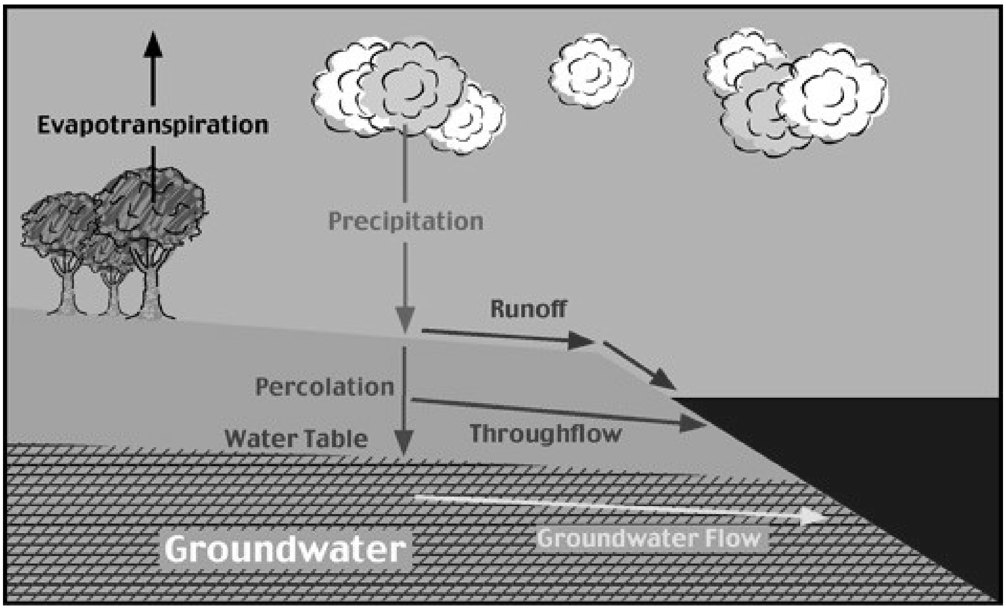


Figure 3.1: Hydrologic movement of water beneath the Earth's surface. Water usually enters the surface sediments as precipitation. This water then percolates into the soil layer. Some of this water flows horizontally as throughflow. Water continuing to flow downward eventually reaches a permanent store of water known as the groundwater. The movement of groundwater horizontally is called groundwater flow.

3.3.2 Groundwater flow

Precipitation that succeeds in moving from the soil layer down into the underlying bedrock will at some point reach an area of permanent saturation that is known as the groundwater zone (Figure 3.1). The top of this zone is called the water table. Approximately 22% of the fresh water found at the Earth's terrestrial surface is stored as groundwater. Groundwater tends to flow by way of gravity to the point of lowest elevation. Often groundwater flow discharges into a surface body of water like a river channel, lake, or ocean. Typical groundwater flow velocities lie in the range of 250 to 0.001 meters per day. Highest groundwater flow velocities are commonly found in sedimentary deposits (like gravel, conglomerate, or sandstone) because of their very high permeability. The least permeable ground type occurs in dense igneous rock materials like granite. Rock formations that store groundwater water are known as aquifers. Rock formations that cannot store groundwater are called aquicludes.

4.0 CONCLUSION

You will be exposed to more terms as you continue with this module, please try to use them to be able to remember them adequately. You have so far learnt the processes involved in water transfer to and from the main earth reservoirs; the atmosphere (precipitation), oceans and the groundwater. What names are given to the process by which they are distributed? Subsequent Units (4 and 5) inform you about the sources, and the approach is to divide them into surface and groundwater sources for apt understanding.

In this Unit, you should have learnt the meaning of terms like interception, infiltration, throughfall, etc and explain them in your own words.

5.0 SUMMARY

This unit has taught you the many terms we use in hydrology and their meanings. Interception refers to the process by which some portions of the rains are obstructed from reaching the earth surface. Some got to the surfaces through stemflow, canopy drip, etc. at the surface; some infiltrate and mix with the groundwater as throughflow etc. in other words this unit has taught you the right word for some hydrological occurrences.

6.0 TUTOR-MARKED ASSIGNMENT

i. Distinguish between throughfall and throughflow.

ii. Describe the process of infiltration.

7.0 REFERENCES/FURTHER READING

http://www.waterencyclopedia.com/St-Ts/Stream-Hydrology.html

Dingman, S. L. *Physical Hydrology,* Upper Saddle River, NJ: Prentice Hall, 1994.

UNIT 4 SURFACE WATER SOURCES

CONTENTS

1.0 INTRODUCTION

You would have learnt from Unit 2 that the water that drops as rainfall is either collected as pond or lakes infiltrates to seep into nearby surface water or infiltrates deep into the ground to mix with the groundwater. The importance of this unit is to teach you about the surface waters, part of the water from the atmosphere that collects somewhere in the surface of the earth, where they can be seen, and groundwater, the hidden part. Their importance for man in shaping the earth surface is also noted.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

1. mention some examples of surface waters
2. compare the surface waters described in 1 above
3. identify different uses to which these water sources are put, and their limitations.

3.0 MAIN CONTENT

3.1 Surface Waters

Oceans, seas rivers, streams, creeks, etc. are all names for water flowing on the Earth's surface. As far as many literatures on water resources are concerned, they are pretty much interchangeable. I tend to think of creeks as the smallest of the three, with streams being in the middle, and rivers being the largest. The water in the rivers, streams, creeks, lakes, and reservoirs are vitally important to our everyday life. The main uses of surface water include drinking-water and other public uses, irrigation uses, and for use by the thermoelectric-power industry to cool electricity-generating equipment. The majority of water used for thermoelectric power, public supply, irrigation, mining, and industrial purposes came from surface-water sources.

3.1.1 Rivers and Streams

Rivers and streams begin their lives as smaller creeks, often called "the headwaters". These small tributaries run downhill until they merge to form bigger tributaries, which continue merging to form larger rivers. Rivers keep flowing to lower altitudes, towards the oceans. River systems are similar to the blood vessels in your body. Tiny capillaries that carry blood keep merging together until all of the blood empties into large veins, which deliver the blood to your heart.

All rivers are surrounded by a certain amount of land that is higher in altitude than the actual river. Precipitation that falls in this area eventually flows downhill towards the river. At any particular point on a river, the land upstream is the river's watershed, or drainage basin. This example of a drainage basin gives a rough idea of how precipitation flows downhill into rivers (and lakes). The concept of drainage basin is the focus of the Unit 5 of this module.

3.1.2 Lakes and Reservoirs

If people had to pick their favourite water body, they would probably choose a crystal-clear lake nestled in the mountains. Not all lakes are clear or are near mountains, though. The world is full of lakes of all types and sizes.

A lake really is just another component of Earth's surface water. A lake is where surface-water runoff (and maybe some groundwater seepage) has accumulated in a low spot, relative to the surrounding countryside. It is not that the water that forms lakes get trapped, but that the water entering a lake comes in faster than it can escape, either via outflow in a river, seepage into the ground, or by evaporation.

A reservoir is the same thing as a lake in many peoples' minds. But, in fact, a reservoir is a manmade lake that is created when a dam is built on a river. River water backs up behind the dam creating a reservoir.

The Earth has a tremendous variety of freshwater lakes, from fishing ponds to Lake Superior (the world's largest), to many reservoirs. Most lakes contain fresh water, but some, especially those where water cannot escape via a river, can be salty. In fact, some lakes, such as the Great Salt Lake, are saltier than the oceans. Most lakes support a lot of aquatic life, but the Dead Sea is not called "Dead" for nothing -- it is too salty for aquatic life! Lakes formed by the erosive force of ancient glaciers, such as the Great Lakes, can be thousands of meters deep. Some very large lakes may be only a few dozen meters deep.

3.1.3 Seas and Lagoons

The word ‘Sea’ has through usage been restricted to smaller water bodies to differentiate them from the oceans, which are extensive water bodies. The main difference between the sea and ocean is therefore in size. Lagoons, on the other hand are large sheets of water separated from the open sea by means of sand bars. They are often connected with the open seas by means of channels known as creeks. Examples of lagoons are found around Lagos in Nigeria, and around coastal areas in many parts of the world.

3.1.4 Oceans

The world’s oceans comprise a system of interconnected water bodies. It is however, a common practice to recognise four or five oceans. Oceanographers distinguish these oceans into the Atlantic, the Pacific, the India, the Arctic and the Southern oceans based on their circulations. These are as discussed below.

3.1.4.1 The Atlantic Ocean

This ocean separates the continents of Africa and Europe to the east from the North and South Americas to the west. Its natural boundaries include the Arctic Ocean and part of the southern Atlantic Ocean. The Atlantic Ocean has some tributary seas, including the Caribbean seas, Gulf of Mexico, the Mediterranean Sea, and the Black sea. Many rivers including the Amazon, Congo and Niger, Panama, Mississippi, St. Lawrence and River Rhine, also flow into the Atlantic Ocean.

The Atlantic Ocean is of great commercial value to mankind. It is the oldest and most important seaway between Europe and many other parts of the world. The ocean navigation and ocean cable networks on the Atlantic Ocean are among the densest in the world.

3.1.4.2 The Pacific Ocean

This is the largest of all the oceans. It covers about one third of the earth’s surface, and represents nearly half the water surface of the earth.

It is larger than all the continents, put together. Its total area is 180 million square kilometres! The pacific, like the Atlantic Ocean is connected with other water bodies. Some large rivers, e.g. Yangtze Kiang and Hwang Ho in China and Colorado in the USA discharge into the Pacific. The Ocean is also a major highway for both commerce and passengers, and many important shipping routes cross it.

3.1.4.3 The Indian Ocean

This important water body is about 40 million square kilometres in size. Unlike the Pacific and Atlantic, it does not extend into the northern hemisphere beyond the Tropic of Cancer, except through the Persian Gulf and the Red Sea. It however has no physical boundary to the South. Seas that drain into the Indian Ocean include the Red Sea and the Persian Gulf, and rivers, which drain into it, include the Ganges and Brahmaputra in India. The monsoon winds initially hampered navigation on the Indian Ocean but by the 19th century, this problem has been overcome.

3.1.4.4 The Arctic Ocean

This is also called the North Polar Sea. It lies around the North Pole. It is about 14 million square kilometres in area. Many great rivers from the Asia and North America empty into it. Sea ice forms throughout the Arctic basin in most months of the year, thereby preventing access into the depth beyond the surface. Since 1945 however, several airlines have been making regular flights over the Arctic region

3.1.4.5 The Southern or Antarctic Ocean

This Ocean surrounds the continent of the Antarctic. It is separated from the other oceans by the line of latitude 40ºS. For most part of the year, pack of icebergs covers most of the water, moving with winds and currents.

3.2 Importance of Surface Water Sources to Mankind

1. Rivers and streams have a great impact on both the local landscape and our own lives. Flowing water continually erodes the land it runs through, and over millions of years the topography of the land can be greatly changed.

2. River water is used by humans for irrigation; rivers deposit mineral-rich soil in their flood plains where man can grow crops; rivers are used to transport people and their manufactured products; rivers can produce hydroelectric power; and, if you

notice where towns and cities are located, people build their communities next to rivers.

3. Rivers also transport soil and sediment from one place to another, which has a great impact on the landscape. This is important to our stomachs, as silt that is deposited in flood plains of rivers makes excellent farmland (just ask the ancient Egyptians who lived along the Nile River and depended on the annual flooding of the river for their livelihood).

4. Oceans and seas constitute the world's best transport route, and the greatest machinery for commerce and trade.

5. Oceans, Seas and Lagoons are the main sources of some useful chemically formed sedimentary rocks, such as rock salt (gypsum) and potash which are of great industrial and domestic uses

4.0 CONCLUSION

You have learnt in this Unit some of the many examples of the surface water bodies. The features of these water bodies have also been highlighted. The problems facing their use have also been highlighted. I advise that you go through Unit 1 again and see why we illustrated that most of the water bodies covering the earth surface are not accessible. Imagine the water held in the Arctic and the Antarctic Oceans! Again, please note that the waters contained in the ocean and seas are of great salt content (i.e. saline). They can therefore not be consumed.

5.0 SUMMARY

This unit has discussed the sources of surface water to include rivers, lakes, reservoirs and oceans. The importance of the water sources to human kind was also highlighted. You should be able to note these, especially since some of them are obvious things within the environment

6.0 TUTOR-MARKED ASSIGNMENTS

Make an inventory of water bodies around you, and classify them according to the different examples we have discussed.

7.0 REFERENCES/FURTHER READING

Lecture notes from 16/9-03, Joakim Malm

http://www.colostate.edu/Depts/SoilCrop/extension/Newsletters/1999/gujune99.htm#Focus, 2003-10-02

http://www-cger.nies.go.jp/grid-e/gridtxt/tateishi.html, 2003-10-02

UNIT 5 GROUNDWATER SOURCES

CONTENTS

1.0 INTRODUCTION

Figure 5.1 shows an example of groundwater exploitation. There is an immense amount of water in aquifers (when a water-bearing rock readily transmits water to wells and springs, it is called an aquifer) below the earth's surface. In fact, there is a hundred times more water in the ground than is in all the world's rivers and lakes.

Figure 5.1: A form of groundwater exploitation

This unit will essentially discuss this, and different forms of groundwater will be exposed to you to know. It is better that you read this section carefully because you may not have been used to some terms used therein.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

1. describe the groundwater
2. discuss the occurrence of groundwater
3. mention some sources of groundwater
4. define water dowsing.

3.0 MAIN CONTENT

3.1 What is Groundwater?

Groundwater occurs only close to the Earth's surface. There must be space between the rock particles for groundwater to occur, and the Earth's material becomes denser with more depth. Essentially, the weight of the rocks above condenses the rocks below and squeeze out the open pore spaces deeper in the Earth. That is why groundwater can only be found within a few metres of the Earth's surface.

Groundwater is an important part of the water cycle. It is the part of precipitation that seeps down through the soil until it reaches rock material that is saturated with water. Water in the ground is stored in the spaces between rock particles as groundwater (there are no underground rivers or lakes). Groundwater slowly moves underground, generally at a downward angle (because of gravity), and may eventually seep into streams, lakes, and oceans.

Fig. 5.2 is a simplified diagram showing how the ground is saturated below the water table. The ground above the water table may be wet to a certain degree, but it does not stay saturated. The dirt and rock in this unsaturated zone contain air and some water and support the vegetation on the Earth. The saturated zone below the water table has water that fills the tiny spaces (pores) between rock particles and the cracks (fractures) of the rocks.

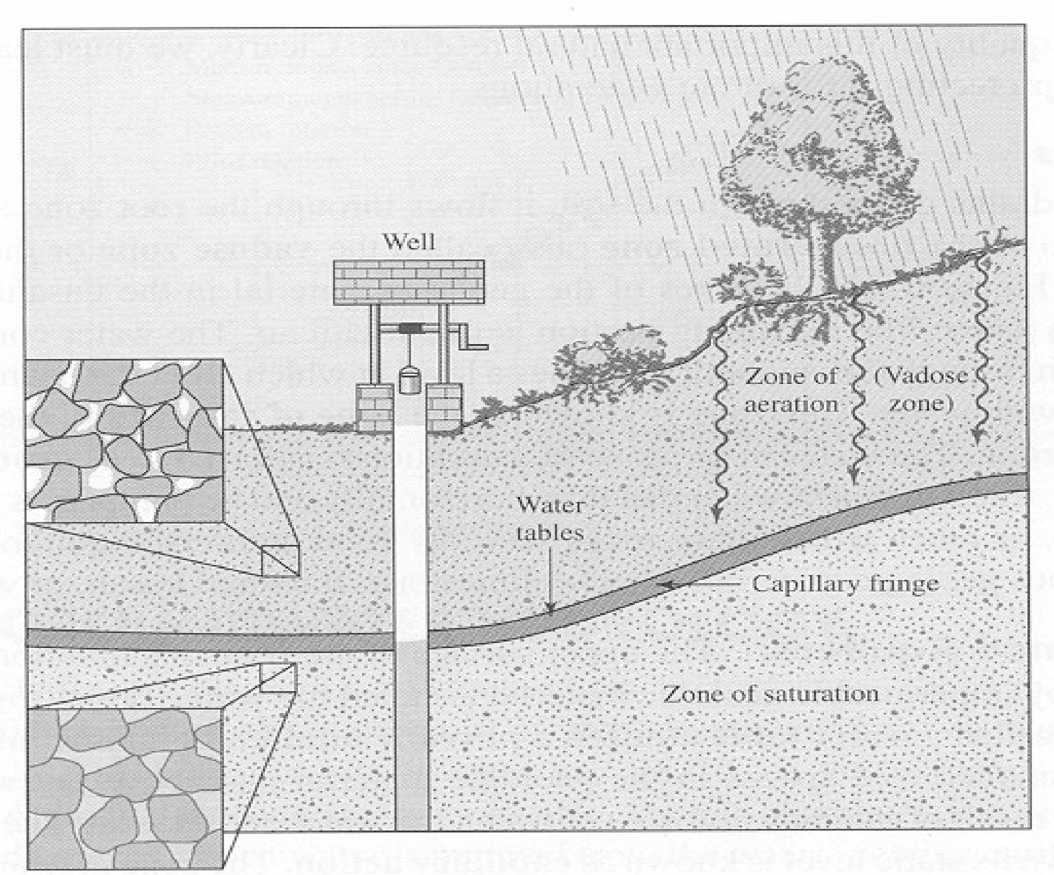


Figure 5.2: A simplified form of the occurrence of groundwater

3.1.1 Forms of Groundwater

Groundwater occurs in two main forms.

1. Unconfined groundwater

2. Confined

Unconfined groundwater occurs when the flow of subterranean water is not confined by the presence of relatively impermeable layers (Figure 5.3). The presence of an impermeable layer beneath this type of groundwater can cause the formation of a perched water table. These features are elevated some distance above the surface's main water table. A perched water table that intersects the surface will often result in the formation of spring.

In some cases, groundwater can become confined between two impermeable layers. This type of enclosed water is sometimes called artesian. If conditions are right, a confined aquifer can produce a pressurized ground to surface flow of water known as an artesian well. In an artesian well, water flows against gravity to the earth's surface because of hydrostatic pressure. Hydrostatic pressure is created from the fact that most of the aquifer's water resides at an elevation greater than the well opening. The overlying weight of this water creates the hydrostatic pressure.

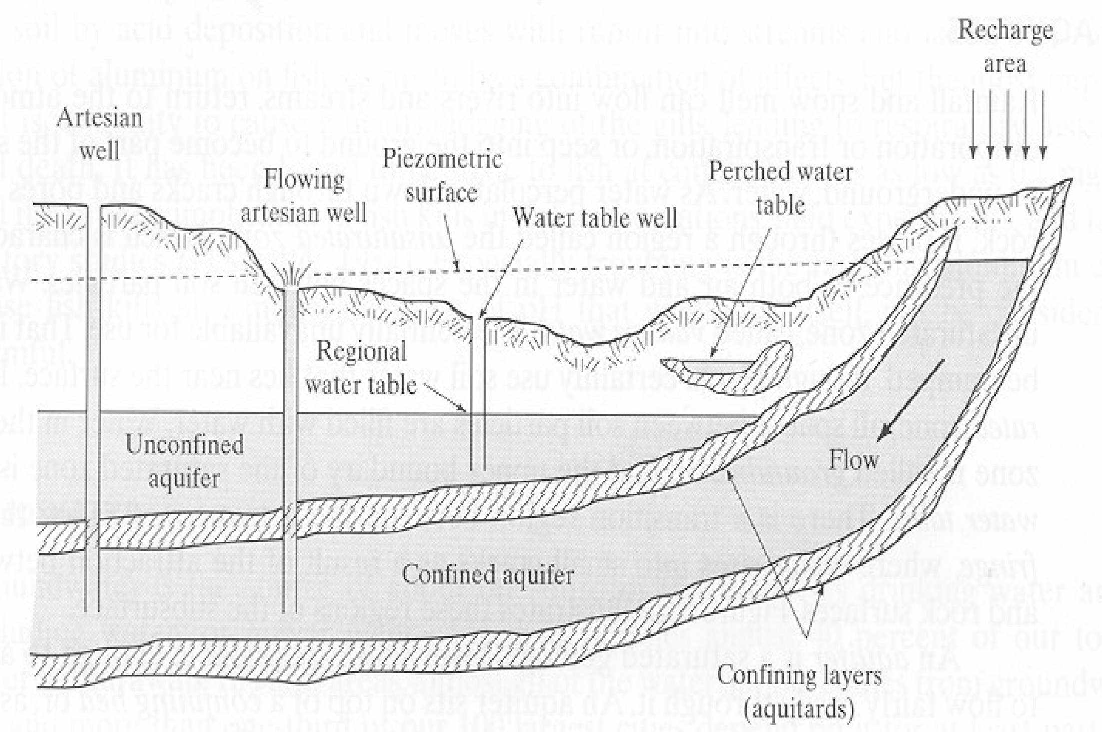


Figure 5.3: Sources of groundwater

When saturated conditions are found with impermeable material between the aquifer and ground surface, we term this an unconfined aquifer, water table aquifer, or a phreatic aquifer. If a well is drilled into this aquifer, the water level in the well defines the water table, phreatic surface or the piezometric surface.

The piezometric surface moves up and down depending on the amount of water in the aquifer. The addition of water to the aquifer is termed recharge. The elevation (above sea level) of the surface of the aquifer is termed the head. The change in head, or head loss, with distance is termed the hydraulic gradient. Groundwater flows down the hydraulic gradient.

3.2 Why is there Groundwater?

A couple of important factors are responsible for the existence of ground water:

3.2.1 The effect of gravitational force

The force of gravity pulls water toward the centre of the Earth. That means that water on the surface will try to seep into the ground below it. The possibility of the percolation however will depend on the underlain rock type.

Try as it might, gravity does not pull water all the way to the centre of the Earth. Deep in the bedrock there are rock layers made of dense material, such as granite, or material that water has a hard time penetrating, such as clay. These layers may be underneath the porous rock layers and, thus, act as a confining layer to retard the vertical movement of water. Since it is more difficult for the water to go any deeper, it tends to pool in the porous layers and flow in a more horizontal direction across the aquifer toward an exposed surface-water body, like a river.

3.2.2 The underlain rock type

The rock below the Earth's surface is the bedrock. If all bedrock consisted of a dense material like solid granite, then even gravity would have a hard time pulling water downward. But Earth's bedrock consists of many types of rock, such as sandstone, granite, and limestone. Bedrocks have varying amounts of void spaces in them where ground water accumulates. Bedrock can also become broken and fractured; creating spaces that can fill with water. And some bedrock, such as limestone, is dissolved by water - which results in large cavities that fill with water.

In many places, if you looked at a vertical cross-section of the earth you would see that rock is laid down in layers, especially in areas of sedimentary rocks. Some layers have rocks that are more porous than others, and here water moves more freely (in a horizontal manner) through the earth. Sometimes when building a road, the layers are revealed by road cuts, and water can be seen seeping out through the exposed layers.

3.2.3 Groundwater Sources

Many sources of groundwater exist. They are discussed below:

3.2.3.1 Groundwater wells

Wells are extremely important to all societies. In many places wells provide a reliable and ample supply of water for home uses, irrigation, and industries. Where surface water is scarce, such as in deserts; people could not survive and thrive without ground water of wells. Modern wells are more often drilled by a truck-mounted drill rig. Still, there are many ways to put in a well. Below are some of the common methods.

3.2.1.2 Dug wells

Hacking at the ground with a pick and shovel is one way to dig a well. If the ground is soft and the water table is shallow, then dug wells can work. They are often lined with stones to prevent them from collapsing. They cannot be dug much deeper than the water table - just as you cannot dig a hole very deep when you are at the beach... it keeps filling up with water!

3.2.1.3 Driven wells

Driven wells are still common today. They are built by driving a small-diameter pipe into soft earth, such as sand or gravel. A screen is usually attached to the bottom of the pipe to filter out sand and other particles. They however, can only tap shallow water, and because the source of the water is so close to the surface, contamination from surface pollutants can occur.

3.2.1.4 Drilled wells

Most modern wells are drilled, which requires a fairly complicated and expensive drill rig. Drill rigs are often mounted on big trucks. They use rotary drill bits that chew away at the rock, percussion bits that smash the rock, or, if the ground is soft, large auger bits. Drilled wells can be drilled more than 300 metres deep. Often a pump is placed at the bottom to push water up to the surface.

Groundwater users would find life easier if the water level in the aquifer that supplied their well always stayed the same. Seasonal variations in rainfall and the occasional drought affect the "height" of the underground water level. If a well is pumped at a faster rate than the aquifer around it is recharged by precipitation or other underground flow, then water levels around the well can be lowered. The water level in a well can also be lowered if other wells near it are withdrawing too much water. When water levels drop below the levels of the pump intakes, then wells will begin to pump air - they will "go dry."

4.2.1.5 A flowing (artesian) well

This has been described under 3.1.

3.3 Methods of groundwater location

There are many methods of locating the position of potential high quantity of groundwater. These methods have been generally classified into two here; water dowsing and the scientific methods. They are discussed below:

3.3.1 Water dowsing

Water dowsing refers in general to the practice of using a forked stick, rod, pendulum, or similar device to locate underground water, minerals, or other hidden or lost substances. This has been a subject of discussion and controversy for hundreds, if not thousands, of years.

Although tools and methods vary widely, most dowsers (also called diviners or water witches) probably still use the traditional forked stick, which may come from a variety of trees, including the willow, peach, and witch-hazel. Other dowsers may use keys, wire coat hangers, pliers, wire rods, pendulums, or various kinds of elaborate boxes and electrical instruments. In the classic method of using a forked stick, one fork is held in each hand with the palms upward. The bottom or butt end of the "Y" is pointed skyward at an angle of about 45 degrees. The dowser then walks back and forth over the area to be tested. When he passes over a source of water, the butt end of the stick is supposed to rotate or be attracted downward.

Water dowsing seems to be a mainly European cultural phenomenon; it was carried across the Atlantic to America by some of the earliest settlers from England and Germany. Case histories and demonstrations of dowsers may seem convincing, but when dowsing is exposed to scientific examination, it presents a very different picture. The natural explanation of "successful" water dowsing is that in many are as water would be hard to miss. In a region of adequate rainfall and favourable geology, it is difficult not to drill and find water!

Some water exists under the Earth's surface almost everywhere. This explains why many dowsers appear to be successful. To locate ground water accurately, however, as to depth, quantity, and quality, a number of techniques must be used. Hydrologic, geologic, and geophysical knowledge is needed to determine the depths and extent of the different water-bearing strata and the quantity and quality of water found in each. The area must be thoroughly tested and studied to determine these facts.

3.3.2 Scientific method of locating the groundwater

To locate ground water accurately and to determine the depth, quantity, and quality of the water, several techniques must be used, and a target area must be thoroughly tested and studied to identify hydrologic and geologic features important to the planning and management of the resource. The landscape may offer clues to the hydrologist about the occurrence of shallow groundwater. Conditions for large quantities of shallow ground water are more favourable under valleys than under hills. In some regions – in parts of the arid region, for example- the presence of "water-loving" plants, such as cottonwoods or willows, indicates ground water at shallow to moderate depth. Areas where water is at the surface as springs, seeps, swamps, or lakes reflect the presence of ground water, although not necessarily in large quantities or of usable quality.

Rocks are the most valuable clues of all. As a first step in locating favourable conditions for ground-water development, the hydrologist prepares geologic maps and cross sections showing the distribution and positions of the different kinds of rocks, both on the surface and underground. Some sedimentary rocks may extend many miles as aquifers of fairly uniform permeability. Other types of rocks may be cracked and broken and contain openings large enough to carry water. Types and orientation of joints or other fractures may be clues to obtaining useful amounts of ground water. Some rocks may be so folded and displaced that it is difficult to trace them underground.

Next, a hydrologist obtains information on the wells in the target area. The locations, depth to water, amount of water pumped, and types of rocks penetrated by wells also provide information on ground water. Wells are tested to determine the amount of water moving through the aquifer, the volume of water that can enter a well, and the effects of pumping on water levels in the area. Chemical analysis of water from wells provides information on quality of water in the aquifer.

3.4 Uses of Groundwater

The main uses of ground water include irrigation uses, drinking-water and other public uses, and for supplying domestic water to people who do not receive public water supply. The majority of water used for self-supplied domestic and livestock purposes came from groundwater sources

4.0 CONCLUSION

In this unit you have learnt about another main source of water; the groundwater. You should be able to cite some sources of this, and explain them. Some importance of these water sources has also been highlighted. You should have also learnt about water dowsing, and the scientific ways of locating the groundwater. You at this point should be able to describe these sources, and identify them within your immediate environments.

5.0 SUMMARY

You have leant about the groundwater sources; the form in which it exists and the various ways in which it is tapped. The concept of groundwater location; dowsing and the modern techniques were also identifies. Some of the uses of the groundwater were also highlighted with some of the associated landforms, particularly, the artesian well.

6.0 TUTOR-MARKED ASSIGNMENTS

i. Describe various groundwater sources

ii. Mention FOUR types of groundwater wells

iii. Compare the water dowsing approach with the scientific way of groundwater location.

7.0 REFERENCES /FURTHER READING

Viessman, W. and G.L. Lewis. *Introduction to Hydrology*. 5th edition. Prentice Hall, Upper Saddle River, New Jersey, 2003.

Price, M. Water from the ground. Inside Science 42. *New Scientist* Feb. 16., 1991.

UNIT 6 THE CONCEPT OF DRAINAGE BASIN

CONTENTS

1.0 INTRODUCTION

When looking at the location of rivers and the amount of streamflow in rivers, the key concept is the river's drainage basin (also called catchment or watershed). What is a drainage basin? Easy, if you are standing on ground right now, just look down. You are standing, and everone is standing, in a atershed. A drainage basin is the area of land where all of the water that falls in it and drains off of it goes into the same place. Basins can be as small as a footprint or large enough to encompass all the land that drains water into rivers that drain into River Niger, where it enters the Atlantic Ocean.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- defien a drainage absin, and dscuss its role
- account for the different types of drainage basins
- disucss the impact of uirbanisation fo drainage basins.

3.0 MAIN CONTENT

3.1 What is a Drainage Basin?

A drainage basin is the topographic region from which a stream receives runoff, throughflow, and groundwater flow. Sometimes called a watershed, drainage basins are surrou7nded by drainage divides, or topographic high points in the landscpae that funnel water downward into a stream valley (Figure 6.1). The number, size, and shape of the drainage basins found in an area vary with the scale of examination. Drainage basins are arbitrarily defined based on the topographic information available on a map.

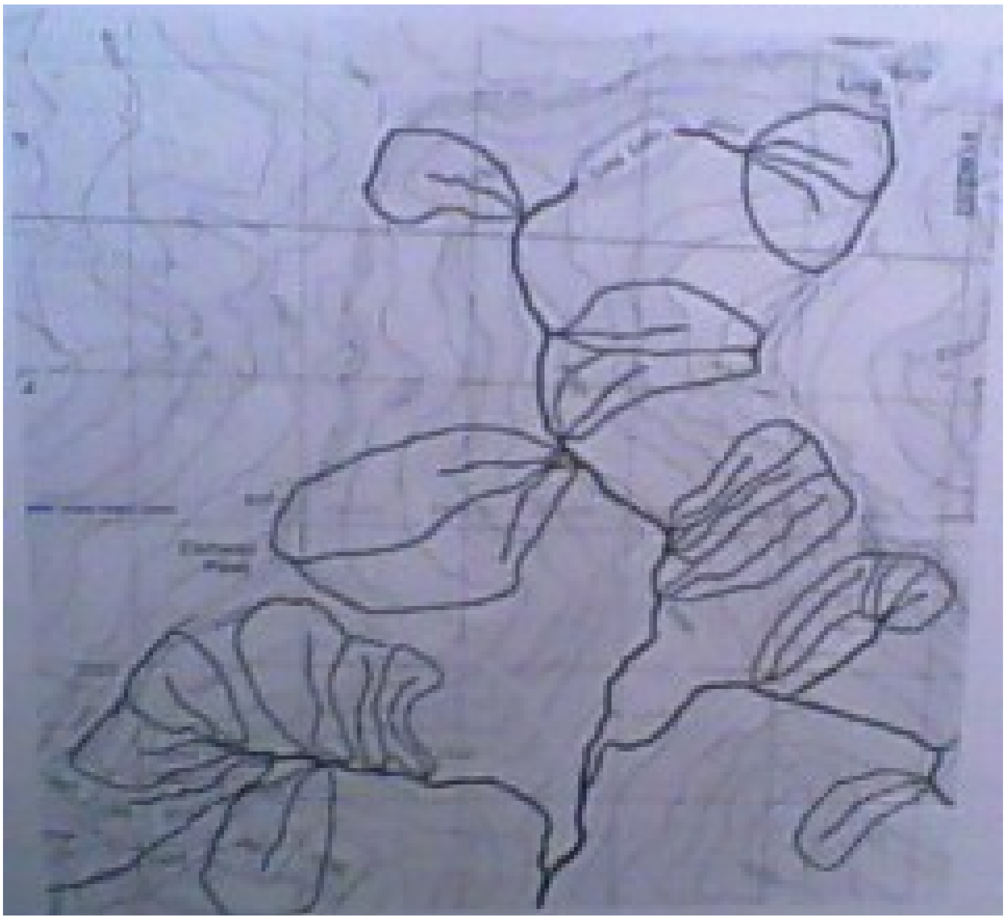


Figure 6.1 shows the nested nature of drainage basins as determined from a topographic map sheet. The lines describe the catchment for the drainage basins.

Drains basins are commonly viewed by scientists as being ipen systems. Inputs to these systems include precipitation, snow melt, and sediment. Drainage basins lose water and sediment through evaporation, deposition, and streamflow. A number of factors influence input, output, and transport of sediment and water in a drainage basin. Such factors include topography, soil type, bedrock type, climate, and vegetation cover. These factors also influence the nature of the pattern of stream channels.

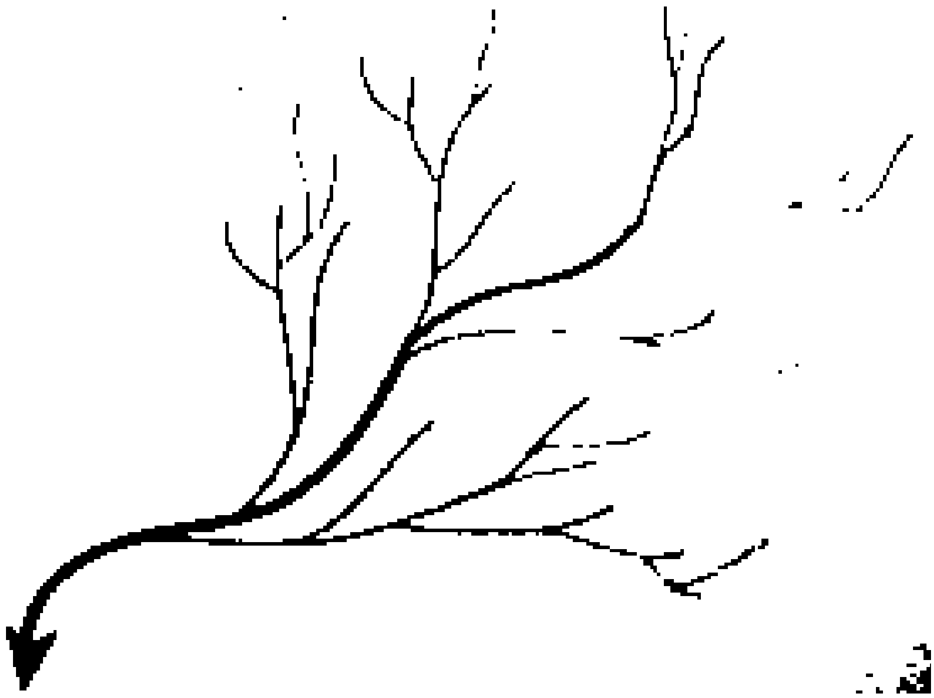
3.2 Types of Drainage Systems

Drainage systems fall into one of several categories, depending on the topography and geology of the land:

1. Dendritic drainage systems

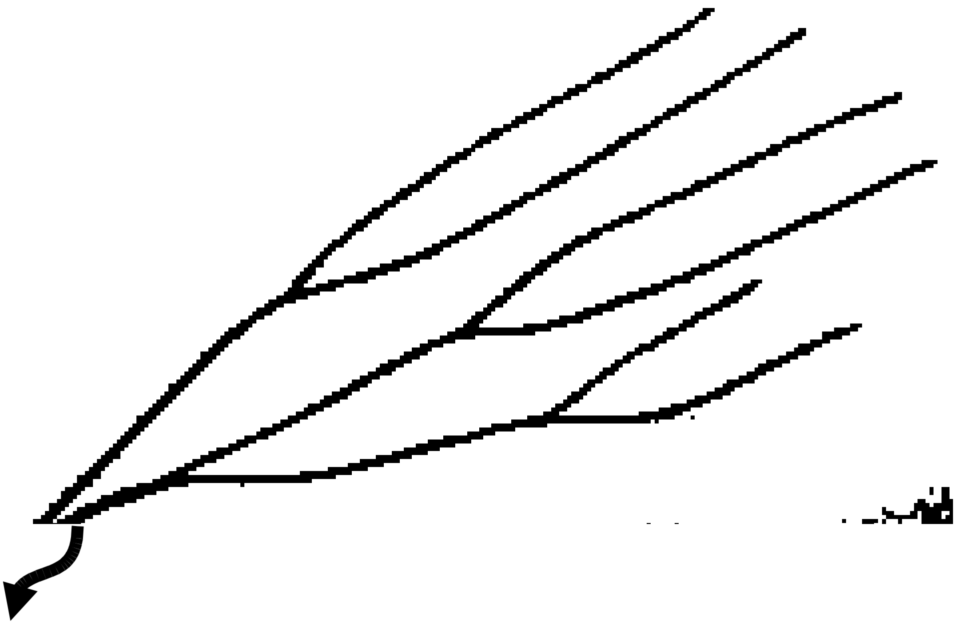
Are the most common form of drainage system. The term dendritic comes from the Greek word "dendron", meaning tree, due to the resemblance of the system to a tree. In a dendritic system there is one main river (like the trunk of a tree), which is joinmed and formed by many smaller tributary rivers. They develop where the river channel follows the slope of the terrain.

Dendritic systems form in V-shaped valleys; as a result, the rock types must be impervious and on-porous arrangemenet of tributaries and main rivers like the branches on a tree.



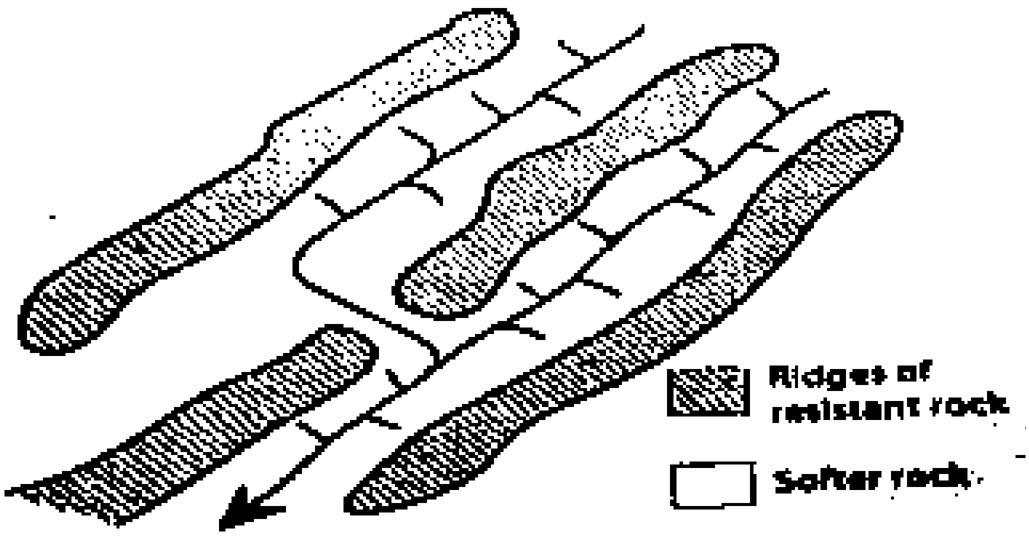
2. Parallel drainage system

A parallel drainage system is a pattern of rivers caused by steep slopes with some relief. Because of the steep slopes, the streams are swift and straight, with very few tributaries, and all flow in th esame direction. This system forms on uniformly sloping surfaces, for example, rivers flowing southeast from the Aberdare mountains in Kenya.



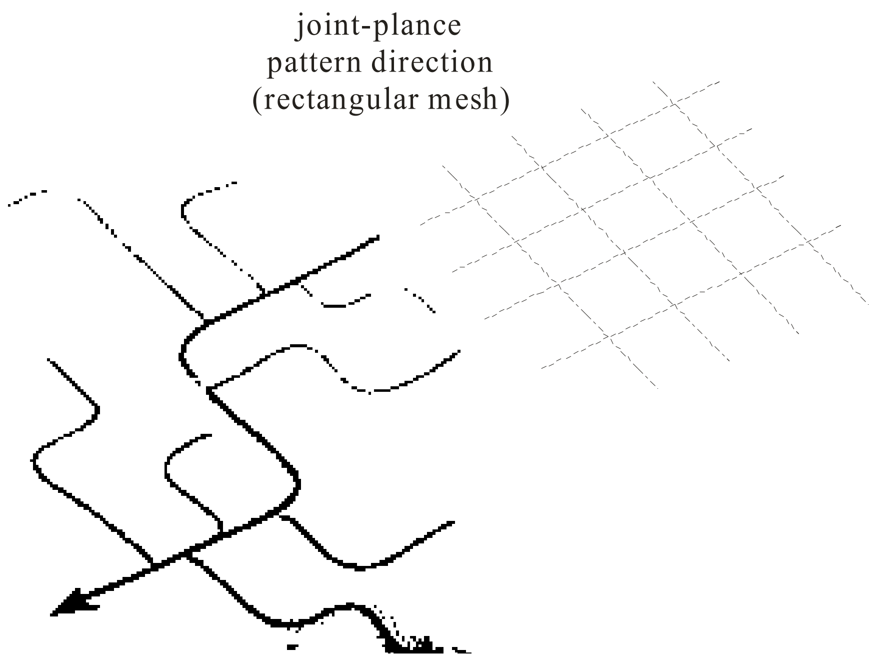
3. Trellis drainage system

Form in areas of alternating geology, particularly chalk and clay. The main river (the consequent) flows straight down hill. Subsequent streams develop perpendicular to the consequent along softer rocj adn erode it away, froming vales. The consequent river thenc uts through the escarpments of harder rock. Obsequent streams flow down the dip slope of the escarpments to join the subsequent streams.



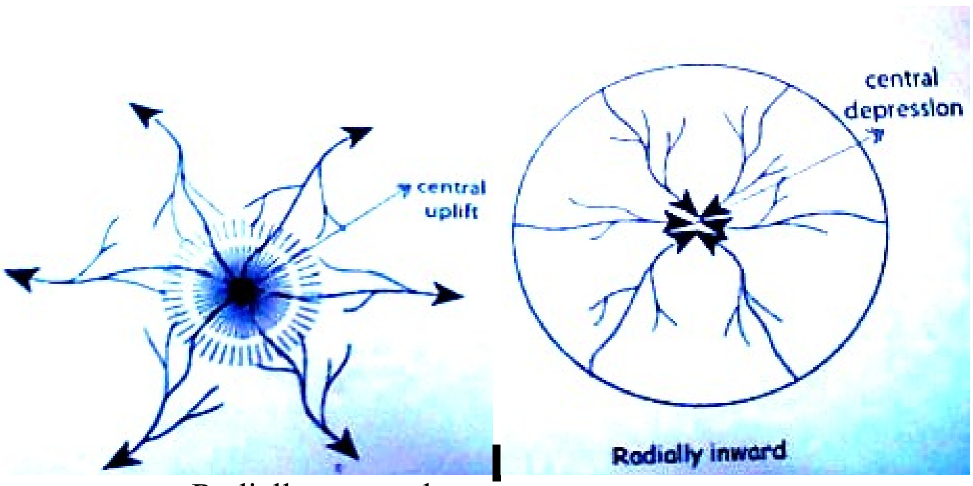
4. Rectangular drainage system

Develops on a strongly jointed rocky terrain. The rectangular drainage pattern is found in regions that have udnergone faulting. Streams follow the path fo least resistance and thus are cocnentrated in places where exposed rock is the weakest. Movement of the surface duw to faulting offsets the direction of the stream. As a result, the tributary streams make shape bends and enter the main stream at high angles.



5. **Radial drainage system**

Rivers radiate outwards from a central point, e.g. a volcanic cone or from a moutnain range batholith.



Radially outward

6. **Deranged drainage system**

Is a drainage system in watersheds where there is no coherent pattenr tyo the rivers and lakes. It happens in areas where there has been much geological disrption. The classic example is the Canadian Shield. During the last ice age, the topsoil was scraped off, leaving mostly bare rock.

The melting of the glaciers left land with many irregulaties of elevation, and a great deal of water to collect in the low points, explaining the large number of lakes which are found in Canada. The watersheds are young and are still “sorting themselves out”. Eventually the system will stabilize.

3.3 Factors that can Alter Drainage Pattern

Many factors are capable of altering the shape of a drainage patten. Most important ones include:

a. Time

If the drainage basin is young (like after a glacier has ploughed over and obliterated the former topography), a deranged drainage pattern will appear. The topography is young, not yet eroded and developed into an efficient drainage network. Characterized by lost of scattered lakes, wetlands, bogs, and wandering stream channels.

b. Steep slope

If slopes are steep, gravity will sculpt drainage networks that run linearly downhill. This can produce parallel drainage (a steep inclined plane e.g. western Great Plains) or a radial drainage (a steep cone, like a mountain).

c. Differential rock resistance

If alternating weak and resustant rocks are exposed at the surface, drainage networks will preferentially erode into weaker materials.

This can produce a grid-like or rectangular drainage (following the geometry of jointing patterns), or trellis drainage (in regions of folded strata).

3.4 Importance of Drainage Basins

Drainage basisn are very important to mankind. Some areas of their vitality are explained below:

1. In hydrology, the drainage basin is a logical unit of focus for studying the movementn of water within the hydrological cycle, becayse the majority of water that discharges from the basin outlet originated as precipitation falling ont he basin (see Unit 2). Measurement of the discharge of water from a basin may be made by a stream garge located at the basin's outlet.

2. Drainge basins are important elements to consider also in ecology. As water flows over the ground and along rivers it can pick up nutrients, sediment, and pollutants. Like the water, they get transported towards the outlet of the basin, and can affect the ecological processes along the way as well as in the receiving water source. Modern usage of artificial fertilizers, containing nitrogen, phosphorus, and potassium, has affected the mouths of watersheds. The minerals will be carried by the watershed to the mouth and accumulate there, disturbing the natural mineral balance.

3. Becuase drainage basins are coherent entities in a hydrological sense, it has become common to manage water resources on the basis of individual basins. In the Nigeria, governmental entities that perform this fucntion are called River Basins Development Authorities. In New Zealand, they are called Catchment Boards. In Brazil, the National Policy of Water Resources, regulated by Act no 9.433 of 1997, establishes the drainage basin as territorial division of Brazilian water management.

3.5 Effect of Urbanisation on Drainage Basin

As urbanisation continues and more development occurs, the natural landscape is replaced by roads, buildings, housing developments, and parking lots. Impervious surfaces can have an effect on local streams, both in water quality and streamflow and flooding charactersitics. Fig. 6.3a illustrates how water-quality problems can occur from development. Sediment-laden water from a tributary where construction is tyaking place is shown entering the river.

Furthermore, a significant portion of rainfall in forested watersheds is absorbed into soils (infiltration), is stored as ground water, and is slowly discharged to streams through seeps and springs. Flooding is less significant in these conditions because some of the runoff during a storm is absorbed into the groun, thus lessenign the amount of runoff into a stream during the storm.

Figure 6.3a, b: show effect of urbanisation on drainage systems

As drainage basins are urbanized, much of the vegetation is replaced by impervious surfaces, thus reducing the area where infiltration to ground water can occur. More stormwater runoff occurs – runoff that must be collected by extensive drainage systems that combine curbs, storm sewers, and ditches to carry stormwater runoff directly to streams. More simply, in a developed basin, much more water arrives into a stream much more quickly, resulting in an increased likelihood of more frequent and more severe flooding. As fig. 6.3b shows, frequent flooding causes problems for residents and also the local government which has to clean up the sand deposited on the road, and also had to install the drainage pipe to move water off the roadway back into the stream.

4.0 CONCLUSION

You have now gotten an idea of what a drainage basin, catchment or watershed is. The knowledge of this is essential in water resoruces. It is the basic unit of study in water resources evaluation as you will eventually see in the following Units. You will remember that Unit 2 informed us about how water reaches the ground, and later collected in the stream (drainage basin). Unit 4 informed you that even the groundwater is later collected in a drainage basin.

5.0 SUMMARY

This unit has emphasised the use of drainage basin as hydrologic unit of study. Its characteristics and operational processes have been spelt out. Different patterne xists, including dendritic, trellised, etc. The importance of the drainage basin was also stressed.

6.0 TUTOR-MARKED ASSIGNMENT

i. What is a drainage basin?

ii. Enumerate three types of drainage system .

7.0 REFERENCES/FURTHER READING

Christopherson, R. W. *Geosystems: An Introduction to Physical Geography*. (5th Edition). Prentice Hall, Upper Saddle River, New Jersey, 2005.

http://en.wikipedia.org/wiki/Drainage_basin.

MODULE 2

UNIT 1 PRECIPITATION FORMS AND RAINFALL MEASUREMENTS

CONTENTS

1.0 INTRODUCTION

You have been introduced to the concept of precipitation in Unit 2 as all forms of drops of water from the atmosphere unto the earth surface. You were probably did not know that rainfall is a form of precipitation. Yes it is. But there are other forms. These include drizzle, snow, showers and hail. Of most important significance is of course rainfall. It determines how much water enters into the streams, soils and groundwater. In other words, it determines how much water is available for crops, and of course our survival on the earth. Therefore it is expected that you should learn about it and understand how it could be quantified.

You will therefore be guided by the following learning objectives.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define precipitation and describe its development
- mention at least four forms of precipitation and distinguish among them
- describe a rain gauge
- describe when and how you will measure rainfall with the rain gauge.

3.0 MAIN CONTENT

3.1 Definition of Precipitation

We can define precipitation as any liquid or solid aqueous deposit that forms in a saturated atmosphere (relative humidity equals 100%) and falls from clouds to the ground surface. It is important to recognize that most clouds do not produce precipitation. In many clouds, water droplets and ice crystals are just too small to overcome the natural updrafts found in the lower atmosphere. As a result, the tiny water droplets and ice crystals remain suspended in the atmosphere until they are converted back into vapour

3.2 Mechanism of Precipitation Development

Water droplets and ice crystals can only fall to the Earth's surface if they grow to a size that can overcome updrafts. Conditions for growth can develop in clouds via two different processes. In clouds with temperatures above freezing, turbulent atmospheric mixing can cause droplets to grow through the processes of collision and coalescence. One initial condition, however, must be met for this process to begin: droplet size in the cloud must be variable. This initial condition allows larger and heavier droplets to collide and coalesce with lighter smaller droplets during downdraft periods. If enough atmospheric mixing occurs the larger droplets can expand by up to 250 times and can become heavy enough to fall to the Earth's surface.

The other mechanism of precipitation development involves clouds whose temperature is below freezing. In these clouds, large ice crystals grow due to the differences in vapour pressure between ice crystals and supercooled water droplets. Vapour pressure differences between ice and supercooled water cause a net migration of water vapour from water droplets to ice crystals. The ice crystal then absorbs the water vapour, depositing it on their surface. At the same time, the loss of vapour from the water droplets causes them to shrink in size. A necessary initial requirement for this process is the presence of both condensation nuclei and deposition nuclei. While deposition nuclei form ice crystals at temperatures just below zero degrees Celsius, condensation nuclei can remain liquid (supercooled) to temperatures as low as -40°Celsius depending on size. Because of this phenomenon, cold clouds can contain both ice crystals and supercooled water droplets. The relative proportion of these two types of particles determines whether snow crystals grow to a size to overcome atmospheric updrafts.

3.3 Forms of Precipitation

Many forms of precipitation exist. They are usually distinguished by their sizes. These include:

Rain: any liquid deposit that falls from the atmosphere to the surface and has a diameter greater than 0.5 millimetres. The maximum size of a rain drop is about 5 millimetres. Beyond this size inter-molecular cohesive forces become too weak to hold the mass of water together as a single drop.

Freezing rain takes place when falling liquid water droplets encounter a surface with a temperature below 0° Celsius. Upon contact with this surface, the rain quickly turns into ice. Another important condition required for freezing rain is that the atmosphere where rain develops must be above freezing.

Ice pellets or sleet: are transparent or translucent spheres of frozen water. They have a diameter smaller than 5 millimetres. This form of precipitation develops first as raindrops in a relatively warm atmosphere where the temperature is above freezing. These raindrops then descend into a colder lower layer of the atmosphere where freezing temperatures occur. In this layer, the cold temperatures cause the raindrops to freeze into ice pellets during their transit to the ground surface. Similar to freezing rain, an air temperature inversion is required for the formation of ice pellets.

Snow is a type of precipitation common to the mid and high latitudes. Snow develops when water vapour deposits itself (skipping the liquid phase) directly on six-sided (hexagon) deposition nuclei as solid crystals, at temperatures below freezing. The unique form of snowflakes occurs because ice crystal growth is most rapid at the six points associated with geometric shape of the deposition nuclei. These points are more directly exposed to the atmosphere and consequently convert more water vapour into ice. Snow is usually generated by frontal lifting associated with mid-latitude cyclones. Snowfall can occur in the fall, winter, and spring months when atmospheric temperatures can drop below freezing. Much of the ground surface of North America can be covered with snow for several months during a typical year

Hail is a type of frozen precipitation that is more than 5 millimetres in diameter Hailstones often have concentric shells of ice alternating between those with a white cloudy appearance and those that are clear. The cloudy white shells contain partially melted snowflakes that freeze onto the surface of the growing hailstone. The clear shells develop when liquid water freezes to the hailstone surface. Strong updrafts in mature thunderstorm clouds provide the mechanism for hail formation. These updrafts move hailstone embryos (often large frozen raindrops) upward through the storm cloud where they encounter layers of ice crystals, snow, and supercooled rain. Each encounter causes the hailstone to grow larger in size as ice, snow, and rain accretes to the surface. Hailstones can grow very large in size when they are carried upward by more than one updraft. When the hailstone becomes too heavy to be supported by updrafts, it begins falling under the influence of gravity. Descending hailstones can lose a significant amount of their mass because of melting as they encounter the warm air found in between the cloud base and the Earth's surface. Small hailstones often melt completely before they reach the ground.

Fog is simply a cloud of minute water droplets that exists at ground level. Fog develops when the air at ground level is cooled enough to cause saturation (relative humidity equals 100%). Meteorologists have a very specific definition to determine if fog exists. This definition suggests that fog is occurring when the visibility of the atmosphere, near the Earth's surface, becomes less than 1 kilometre. Fog can be created by a variety of processes:

Radiation fog or ground fog, is produced by near surface cooling of the atmosphere due to longwave radiation emission. This particular type of fog is normally quite shallow and develops during the evening hours. Shortly after sunrise the radiation fog disappears because of surface heating due to the absorption of solar radiation.

Upslope fog is created when air flows over higher topography. When the air is forced to rise in altitude because of the topographic barrier, it is cooled by adiabatic expansion. This type of fog is often found forming on the windward slopes of hills or mountains.

Advection fog is generated when air flows over a surface with a different temperature. Warm air advection can produce fog if it flows over a cold surface. The contact cooling associated with this process causes saturation to occur in a relatively thin layer of air immediately above the ground surface.

Evaporation fog is a specific type of advection fog. It occurs when you get cold air advancing over warm water or warm, moist land surfaces. In this situation, fog forms as water from the surface evaporates into the cold air and then saturates (Figure 8f-6). This type of fog can also be called steam fog or sea smoke.

Frontal fog is a type of fog that is associated with weather fronts, particularly warm fronts. In this situation, rain descending into the colder air ahead of the warm front can increase the quantity of water vapour in this atmosphere through evaporation. Fog then forms when the quantity of water in the atmosphere ahead of the front reaches saturation (relative humidity equals 100%).

3.4 How and why is Rainfall Observed?

Rainfall is an important natural resource which provides us with the water we drink and wash with, and which is widely used in industry and for leisure activities. It is therefore important that the rain which falls is measured so that water supplies can be managed and conserved.

Observations of rainfall amount, for instance, are easy to make. This explains why they are carried out at so many locations, by both amateur and professional observers. This also explains the popularity with schools of the simple rainfall measurements which satisfy the National Curriculum requirements for the study of weather, climate and the environment. Mathematics and Information Technology can be used to manipulate the data for a variety of applications. You too could be involved in this, i.e. to measure the rainfall in your environment. Rainfall data are kept throughout Nigeria by the Ministry of Aviation, some agricultural research institutes, Agricultural Development Programme's extension services, etc.

3.5 What Aspect of Rain do we Measure?

A particular place can experience long or short periods of heavy or light rain, or no rain at all. The basic measurement of rainfall is that of how much rain falls in a specified period of time. By how much, we mean the depth of rain accumulating on a level surface without soaking in, running away or evaporating. The depth is usually measured in millimetres. The standard periods are the hour, the day, the month and the year. Measurements of rainfall depth over a period of an hour or less are usually only required for specialised purposes, and have to be made using automatic instruments.

The most common measurement of rainfall is the amount falling in a day. Meteorologists use a standardised day which runs from 9 O'clock GMT each morning to 9 O'clock GMT the next morning (10 O'clock Nigerian Standard Time). This period originates from the 19th century when it was fashionable for amateurs, particularly doctors and vicars, to make rainfall measurements at a time which conveniently fitted in with their professional activities. Daily rainfall amounts measured routinely can be added together to provide monthly and annual totals.

Since the required observation is that of the amount of rainfall, then the simplest way of obtaining this is to accumulate the rainfall in a container and measure the amount at the end of each day. The combination of a storage container and a device for measuring the amount of rain collected is usually called a storage gauge. Most storage gauges for professional use are intended for measuring daily rainfall amounts, although larger versions are made for measuring monthly totals at inaccessible locations.

3.6 Why do we use a Rain Gauge?

In answering this question we can partly explain why storage gauges are designed and operated the way they are. Suppose on a particular day some rain falls on the ground; why do we not just go out and measure the depth of the rain somewhere with, say, a ruler?

Consider what happens to rainwater when it falls on the ground. It collects in puddles, drains into gutters and streams, soaks into the ground and evaporates. It is quite possible for a puddle in a car park, which collects water from a large surrounding area, to have a depth ten times the depth of rain that fell. The area which drains into the puddle may be dry soon after the rain stops falling. Rain soaks into porous ground, such as fields, very quickly and leaves no accumulation to measure.

Obviously then, it is difficult to find a 'natural' place where an accurate representative measurement of depth of accumulated rainfall can be made with confidence. We use a gauge to overcome these problems.

3.7 Structure of a Rain Gauge

Many models of rain gauges exist, ranging from German to British models. The British model for example uses the copper 5" standard gauge. It consists of a 5" diameter funnel with a sharp rim, the spout of the funnel being inserted into a glass collecting jar. The jar is in an inner copper can and the two are contained in the main body of the gauge, the lower part of which is sunk into the ground (Figure 6.1).

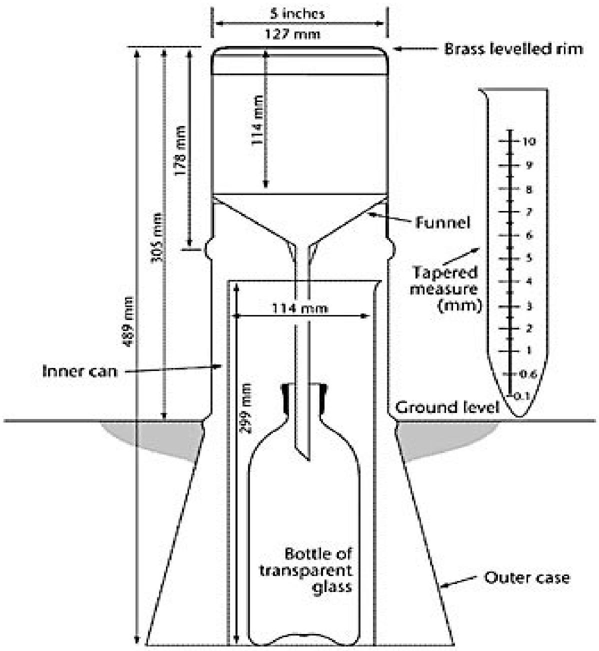


Figure 6.1: shows the skeletal system of a typical British manual rain gauge

The main features of the gauge are:

i) The sharp inner edge of the funnel which allows it to have an accurate 5" internal diameter;

ii) the whole gauge is set into the ground to keep it secure and upright with the rim 12" above the surrounding short grass or gravel, this height being chosen so that no rain splashes from the surroundings into the funnel;

- The gauge is set vertical so that the rim of the funnel is horizontal;

iv) The inner can is provided so that the glass jar can be lowered gently into the gauge and can also hold the water if the jar overflows or cracks in cold weather;

v) The funnel has a narrow spout so that there is little exposure of the water in the jar to the air, to reduce evaporation.

4.0 CONCLUSION

This Unit has taken you through what precipitation is, and the mechanisms of its evolution. You have also been made to read the various forms of precipitation and how the most important to us, rainfall, could be measured through a rain gauge. You have also been taught the configurations of a British model rain gauge.

4.0 SUMMARY

This unit has taught you what precipitation is, and how to read the various forms of precipitation. You also learnt how the most important to us, rainfall, could be measured through a rain gauge.

6.0 TUTOR-MARKED ASSIGNMENTS

i. In your own words, define precipitation

ii. Highlight the distinguishing differences in any four forms of precipitation

iii. Describe briefly the components of a rain gauge

7.0 REFERENCES/FURTHER READING

http://www.physicalgeography.net/fundamentals/8b.html

Davie, T. *Fundamentals of Hydrology,* Routledge Publishing, 2002.

Singh, V.P. *Elementary Hydrology,* Pearson Education, 1997.

UNIT 2 EVAPORATION AND EVAPOTRANSPIRATION

CONTENTS

1.0 INTRODUCTION

Evaporation is the primary process of water transfer in the hydrological cycle. The water is transformed into vapour and transported of to the sky. The evaporation plus transpiration from a vegetated surface with unlimited water supply is known as *potential evaporation* or *potential evapotranspiration* (PE) and it constitutes the maximum possible rate due to the prevailing meteorological conditions. Thus PE is the maximum value of the actual evaporation (E_t): PE = E_t when water supply is unlimited.

Actual evaporation is the amount of water which is evaporated a normal day which means that if for instance the soil runs out of water, the actual evaporation is the amount of water which has been evaporated, and not the amount of water which could have been evaporated if the soil had had an infinite amount of water to evaporate. Because of the variability of region and seasons, water managers who are responsible for planning and adjudicating the distribution of water resources need to have a thorough understanding of the evapotranspiration process and knowledge about the spatial and temporal rates of evapotranspiration.

2.0 OBJECTIVES

With the background and what you learnt in Unit 1, you are expected to be able to do the following by the end of this lecture:

a. define and compare evaporation and transpiration, potential evaporation and actual evaporation;
b. describe TWO methods of measuring potential evaporation
c. describe TWO methods of measuring actual evaporation.

3.0 MAIN CONTENT

3.1 Definitions

Evaporation can be defined as the process where liquid water is transformed into a gaseous state. Evaporation can only occur when water is available. It also requires that the humidity of the atmosphere be less than the evaporating surface (at 100% relative humidity there is no more evaporation). The evaporation process requires large amounts of energy. For example, the evaporation of one gram of water requires 600 calories of heat energy.

Transpiration is the process of water loss from plants through stomata. Stomata are small openings found on the underside of leaves that are connected to vascular plant tissues. In most plants, transpiration is a passive process largely controlled by the humidity of the atmospheric and the moisture content of the soil. Of the transpired water passing through a plant only 1% is used in the growth process. Transpiration also transports nutrients from the soil into the roots and carries them to the various cells of the plant and is used to keep tissues from becoming overheated. Some dry environment plants do have the ability to open and close their stomata. This adaptation is necessary to limit the loss of water from plant tissues. Without this adaptation these plants would not be able to survive under conditions of severe drought.

It is often difficult to distinguish between evaporation and transpiration. So we use a composite term evapotranspiration.

3.2 Factors Affecting Evapotranspiration

The rate of evapotranspiration at any instant from the Earth's surface is controlled by four factors:

1. **Energy availability**

The more energy available; the greater the rate of evapotranspiration. It takes about 600 calories of heat energy to change 1 gram of liquid water into a gas.

2. **The humidity gradient away from the surface**

The rate and quantity of water vapour entering into the atmosphere both become higher in drier air.

3. **The wind speed immediately above the surface**

Many of us have observed that our gardens need more watering on windy days compared to calm days when temperatures are similar. This fact occurs because wind increases the potential for evapotranspiration. The process of evapotranspiration moves water vapour from ground or water surfaces to an adjacent shallow layer that is only a few centimetres thick. When this layer becomes saturated evapotranspiration stops. However, wind can remove this layer replacing it with drier air which increases the potential for evapotranspiration.

4. **Water availability**

Evapotranspiration cannot occur if water is not available.

3.3 Measurement of Potential Evaporation

There are many different ways of measuring evaporation. One of the most common methods is to use the lysimeter. Other ones are the use of an atmometer and the standardised Class A pan.

3.4 Lysimeter

Potential Evapotranspiration (PE) is what would be evaporated from a surface if water was never a limiting factor. PE can be calculated using empirical formulae, from the simple needing only temperature, to complicated ones requiring several observations (e.g. that of Penman or Thornthwaite were among the first). Alternatively PE may be calculated as the difference between two easily measurable quantities. These quantities are the input and output of water in a system, which may be anything from a large water catchment area to a small container.

Among the earliest attempts to measure evaporation were those of Dr Dobson in Liverpool between 1772 and 1775. Dr Dobson used two well-tarnished tin vessels of 12 in (30 cm) diameter; one of which was to serve the purposes of a raingauge and the other an evaporating vessel. Mr J Dalton and his friend Thomas Hoyle made observations, from 1795 to the turn of the century, of the water balance of England and Wales. They used an apparatus resembling a transpirometer, for measuring evaporation (transpiration) of plants. These methods all involve measurement of evaporation by difference, the subtraction of one quantity from another.

Early observations were somewhat inaccurate and difficult to interpret, but in the 1960's, the late Frank Green did much to standardise the method and set up a national network of stations measuring PE. Green's lysimeter was made from two 40 gallon oil drums, 30 cm diameter. One drum cut in half was the tank the other, full size, the receiving vessel. The metal drums, although painted with bitumastic paint, tended to rust and eventually leaked if the soil was acidic particularly in peaty sites in mountain areas.

The measurement of PE (Fig. 7.1) includes that moisture evaporated to the atmosphere from plants and soil. If the soil is kept moist (at or near field capacity so that water is not limiting) by the addition of water, and well covered by vegetation (a grass sward is ideal), evapotranspiration is controlled by the weather and is largely independent of the amount (biomass) of the vegetation. If the soil and vegetation is confined within a small tank (the lysimeter) and measurements are made of the water **input** (Rainfall **R** and Additional water **A**) and **output** (Percolated water P) collected in the receiver (Fig. 7.2), then PE can be estimated from the equation:

PE = R + A - P

A criticism of this is that the result is dependant on the catch of rainfall by the raingauge which, usually at standard height above ground, may not be that received by the lysimeter at ground level. PE may therefore be inaccurate by the same amount as the rainfall is inaccurate. If both apparatus are similarly exposed, and particularly not overexposed, then reasonable results can be expected. (A ground level gauge could be used to try and obviate this criticism, but there are problems with these gauges as well).

The difference between the water percolated and the water added (**P - A**) is the *Potential Water Balance* (**PWB**). Both **P** and **A** are accurate measurements which are independent of the rainfall measurement. *Potential Water Surplus* (**PWS**) and *Potential Water Deficit* (**PWD**) can be estimated from the same difference sum. If the answer is positive it is **PWS** and if negative it is **PWD**. The *Potential Water Balance* (**PWB**) is the arithmetic sum of **PWS** and **PWD** or, more simply, **P - A**.

These values are useful in their own right for correlating with plant growth and calculating runoff. Depositions of water as dew or frost although not measured are effectively incorporated in the overall result. During extremely dry weather when the ground surrounding the lysimeter is dried out, values of PE will be abnormally high. This is known as the 'oasis effect'.

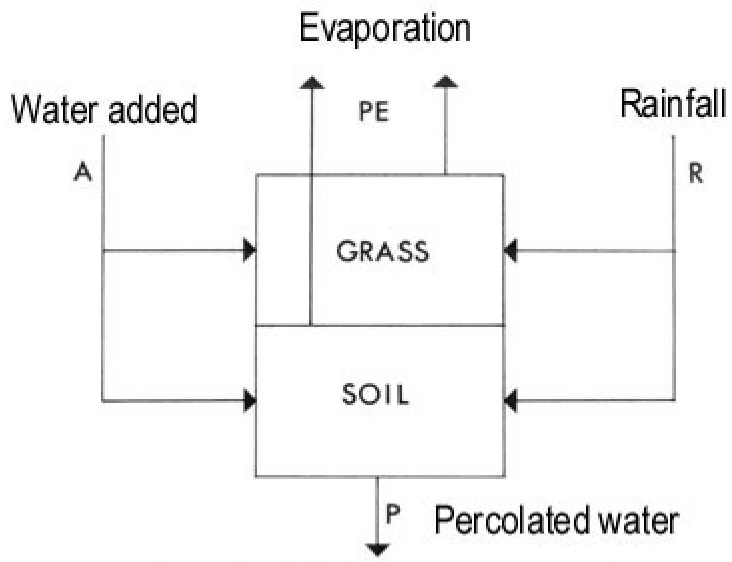


Fig. 7.1: A simplified pathway of water in an evapotranspiration measuring apparatus.

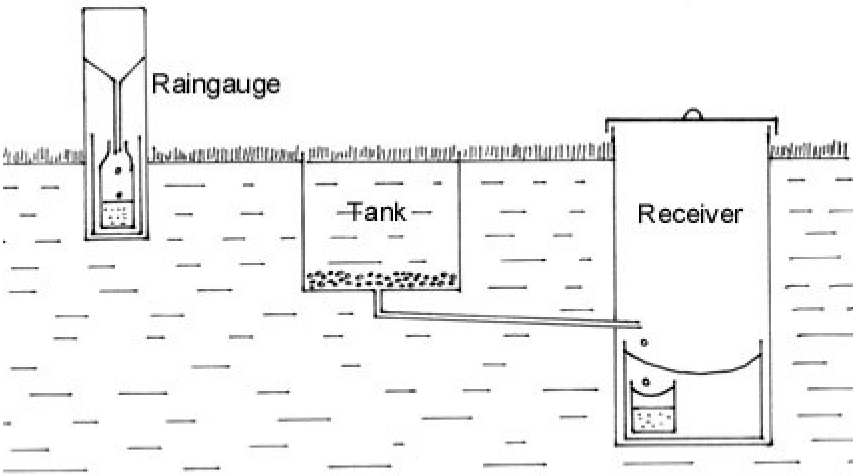


Figure 7.2: An image of a lysimeter apparatus for measuring potential evaporation

4.5 'Class A' Pan

There are a lot of standardized pans for measuring evaporation and the US Class A pan is probably the most used. The pan is circular with a diameter of 1.21 m and depth of 255 mm which gives it a volume of about 0.3 m^3. The basin is put on a 150 mm high wooden frame due to air circulation around the basin (Figure 7.2).

The water level is kept about 50 mm below the rim, due to allowance of percolation and the need of water. The water level is measured every day, either you measure the difference between the present and the origin water level or if you have chosen to obtain the water level in the pan, you measure the amount of water you have put into the pan.

Due to that the sun hits the sides of the pan; the temperature gets higher which means that the evaporation gets higher than the actual evaporation. To correct this value you multiply your evaporation value from the pan with a coefficient, called pan coefficient and its value depends on what climate region your test have been taken.

Another kind of pan is the UK British Standard tank which is a bit larger than the American pan and put on the same level as the ground. The principle is almost the same as with the American pan.

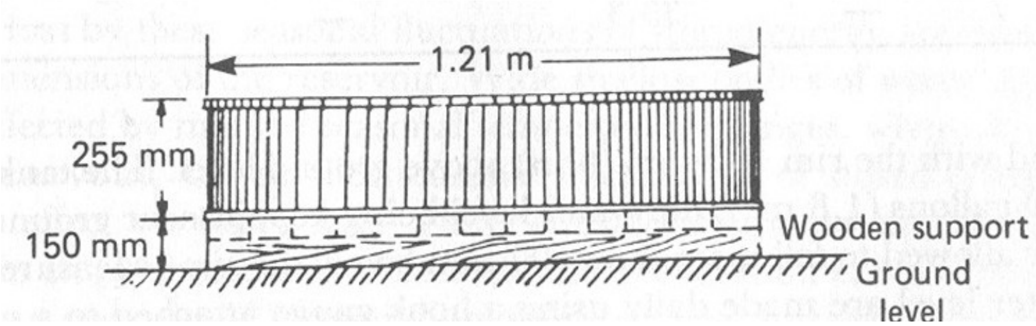


Figure 7.3: An image of a US Class A pan

3.6 Atmometer

This is a device that can give direct measurement of evaporation. Atmometers basically consist of a wet, porous ceramic cup mounted on top of a cylindrical water reservoir. The ceramic cup is covered with a green fabric that simulates the canopy of a crop. The reservoir is filled with distilled water that evaporates out of the ceramic cup and is pulled through a suction tube that extends to the bottom of the reservoir. Underneath the fabric, the ceramic cup is covered by a special membrane that keeps rain water from seeping into the ceramic cup. A rigid wire extending from the top keeps birds from perching on top of the gauge (Figure 7.3).

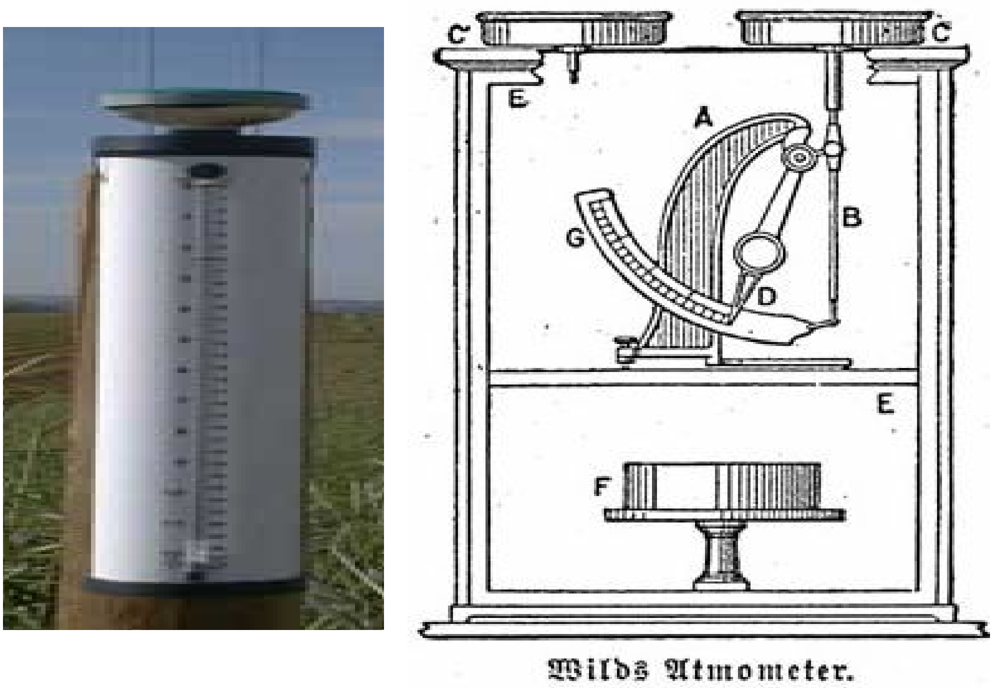


Figure 7.4: Image of an atmometer for obtaining direct measurement of evaporation

3.7 Methods for Measuring Actual Evaporation

3.7.1 Use of Percolation gauge

Measuring actual evaporation is probably not as common as measuring potential. The most common method is the percolation gauge (see Figure 7.4).

The percolation gauge is actually regarded as a research tool and not a standard instrument for measuring evaporation and transpiration. There are many different designs of the gauge but Figure 7.4. is the recommended. On the left side can we see a 1 meter deep hole filled up with soil, rock and gravel and a pipe from the bottom to the collection pit. The top of the hole should be indistinguishable from the surrounding vegetation.

When you measure evaporation with a percolation gauge, you take no consideration to changes in soil water storage. That means that the measurements should be made over a time period when the gauge is saturated.

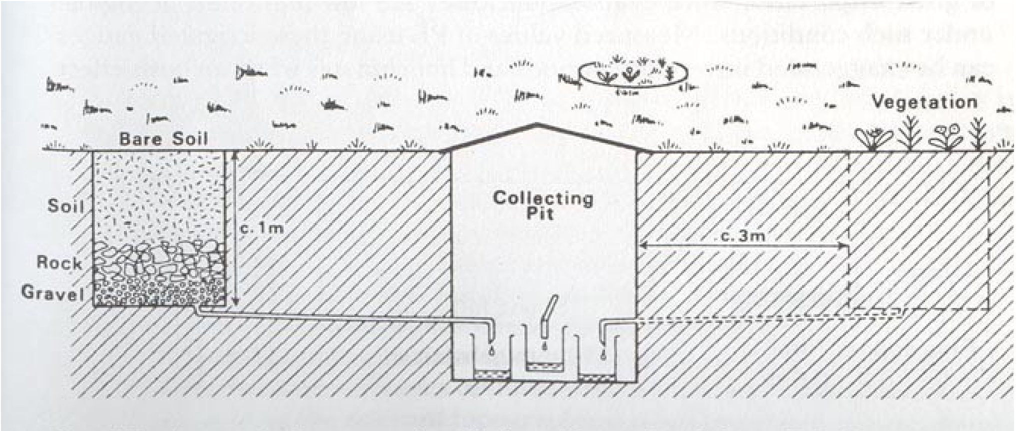


Figure 7.5: An image of percolation gauge for measuring actual evaporation.

Another method to measure evapotranspiration is with a lysimeter which takes consideration to how much water is stored in the soil. The lysimeter weigths the soil and gives a value on how much water is stored. This method is more complex, expensive and harder to maintain than percolation gauges.

3.7.2 Estimating Evapotranspiration from Satellite Data

When a surface evaporates, it looses energy and cools itself. It is that cooling that can be observed from space. Satellites can map the infrared heat radiated from Earth, thus enabling to distinguish the cool surfaces from the warm surfaces. Very dry and desert-like surfaces show easily as they get hotter than their surroundings. From this qualitative reasoning, the scientific objective is to determine quantitatively the amount of evapotranspiration that occurs at given locations. In practice, it consists in entering various types of satellite observations (not just infrared) into mathematical models of the atmosphere. The models, of various complexities, are run in algorithmic form on computers.

4.0 CONCLUSION

It is expected that you have noted the distinguishing characteristics of the potential and actual evaporation, as well as the relationship between evaporation and evapotranspiration. You have also learnt the various methods for determining them. You should now be set to answer the questions in the next line.

5.0 SUMMARY

In this unit, you have learnt the distinguishing characteristics of potential and actual evaporation, as well as the relationship between evaporation and evapotranspiration. You have also learnt the various methods for determining them. You should now be set to answer the questions in the next line.

6.0 TUTOR-MARKED ASSIGNMENTS

i. Define the following terms:

   a) respiration.

   b) evaporation.

   c) actual evapotranspiration.

   d) potential evapotranspiration.

ii. Mention TWO methods, each for measuring potential and actual evapotranspiration

7.0 REFERENCES/FURTHER READING

Whitlow, J.B. ***The Penguin Dictionary of Physical Geography,*** Second Edition. Penguin, 2001.

http://www.physicalgeography.net/fundamentals/8i.html

UNIT 3 RUNOFF

CONTENTS

1.0 INTRODUCTION

In Unit 3, you learnt about some hydrological processes, including infiltration. Here, you will need to remember what you learnt in that Unit to understand this Unit. In other words, the understanding of the previous Units is a prerequisite to the understanding of this Unit. you are therefore employ to concentrate in other to understand this section, so as to be able to answer the questions in the next section, without flaws;

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define runoff
- itemise the types of runoff
- discuss the effects of runoff on the receiving environment.

3.0 MAIN CONTENT

3.1 What is Runoff?

If the amount of water falling on the ground is greater than the infiltration rate of the surface, runoff or overland flow will occur. Runoff specifically refers to the water leaving an area of drainage and flowing across the land surface to points of lower elevation. It is the combination of surface runoff and interflow. It is also equivalent to quick flow.

3.2 Types of Runoff

3.2.1 Surface Runoff

It is also a term used to describe the flow of ***water***, from precipitation, over the land, and is a major component of the ***water cycle***. *It is not the water flowing beneath the surface of the ground*. It has the following forms of generation

3.2.1.1 Infiltration excess overland flow

This occurs when the rate of rainfall on a surface exceeds the rate at which water can infiltrate the ground, and any depression storage has already been filled. This is called infiltration excess overland flow, Hortonian overland flow (after Robert E. Horton), or unsaturated overland flow. This more commonly occurs in arid and semi-arid regions, where rainfall intensities are high and the soil infiltration capacity is reduced because of surface sealing, or in paved areas.

3.2.1.2. Saturation excess overland flow

When the *soil* is saturated and the depression storage filled, and rain continues to fall, the rainfall will immediately produce surface runoff. The level of *antecedent soil moisture* is one factor affecting the time until soil becomes saturated. This runoff is **saturation excess overland flow** or saturated overland flow.

3.2.1.3 Subsurface return flow

After water infiltrates the soil on an up-slope portion of a hill, the water may flow laterally through the soil, and exfiltrate (flow out of the soil) closer to a channel. This is called **subsurface return flow** or interflow.
As it flows, the amount of runoff may be reduced in a number of possible ways: a small portion of it may evaporate; water may become temporarily stored in microtopographic depressions; and a portion of it may become run-on, which is the infiltration of runoff as it flows overland. Surface runoff that remains eventually flows into a receiving water body such as a river, lake, estuary or ocean.

3.2.1.3 Interflow

Interflow is the name given to the lateral movement of water in the vadose zone, the name given to the area between the soil water which is above and the ground water underneath.

Interflow could be described as a 'semi-deep' flow as it is above the regions where baseflow takes place. Interflow is slower than throughflow but faster than groundwater flow.

3.2.1.4 Streamflow or channel runoff

This is the flow of water in streams, rivers, and other channels, and is a major element of the water cycle. It is one component of the runoff of water from the land to waterbodies, the other component being surface runoff.

3.3 Global runoff

Oceans make up 71% of the Earth's surface and the solar radiation received here powers the global evaporation process. In fact, 86% of the Earth's evaporation occurs over the oceans, while only 14% occurs over land. Of the total amount of water evaporated into the atmosphere, precipitation returns only 79% to the oceans, and 21% to the land. Surface runoff sends 7% of the land based precipitation back to the ocean to balance the processes of evaporation and precipitation.
The distribution of runoff per continent shows some interesting patterns (see Table 9.1). Areas having the most runoff are those with high rates of precipitation and low rates of evaporation

Table 9.3: Continental runoff values

Continent	**Runoff Per Unit Area (mm/yr.)**
Europe	300
Asia	286
Africa	139
North and Central America	265
South America	445
Australia, New Zealand and New Guinea	218
Antarctica and Greenland	164

Source: Lvovitch, M.L. 1972. World water balance, in: *Symposium of World Water Balance,* IASH-UNESCO. Report Number 92.

3.4 Effects of Runoff

A significant portion of rainfall in forested basins is absorbed into soils (infiltration), stored as ground water, and /or is slowly discharged to streams through seeps and springs. Flooding is less significant in these conditions because some of the runoff during a storm is absorbed into the ground, thus lessening the amount of runoff into a stream during the storm.

As drainage basins are urbanized, much of the vegetation is replaced by impervious surfaces, thus reducing the area where infiltration to ground water can occur. Thus, more stormwater runoff occurs - runoff that must be collected by extensive drainage systems that combine curbs, storm sewers, and ditches to carry stormwater runoff directly to streams. More simply, in a developed drainage basin, much more water arrives into a stream much more quickly, resulting in an increased likelihood of more frequent and more severe flooding.

Drainage ditches to carry stormwater runoff to storage ponds are often built to hold runoff and collect excess sediment in order to keep it out of streams.

Runoff from agricultural land (and even our own yards) can carry excess nutrients, such as nitrogen and phosphorus into streams, lakes, and ground-water supplies. These excess nutrients have the potential to degrade water quality.

Surface runoff is also one of the causes of ***erosion*** of the earth's surface**.**

4.0 CONCLUSIONS

This unit is expected to have equipped you with knowledge about runoffs, and their types. Two basic types have been noted; the surface runoff and the subsurface- the interflow runoff. These, when they reach the lowest part of elevation within the drainage basin are joined with the contribution of the groundwater to make the streamflow, measurements of the stream flow are very important, as will be seen in the next unit.

In addition, runoff was also shown to impact human activities. Your ability to understand this unit will be tested with the questions in the Tutor Marked Assignment.

5.0 SUMMARY

This unit has equipped you with knowledge about runoffs, and their types. Two basic types have been noted; the surface runoff and the subsurface- the interflow runoff.

6.0. TUTOR-MARKED ASSIGNMENT

i. Distinguish between Hortonian overland flow and saturation excess overland flow.

ii. Highlight THREE effects of runoff on man's activities.

7.0 REFERENCES/FURTHER READING

Allaby, A. and M. Allaby (eds]. ***Dictionary of Earth Sciences***, 2nd Edition. Oxford University press, London, 1999.

Strahler, Alan H. and Arthur Strahler. *Physical Geography: Science and Systems of the Human Environment*. 2nd Edition John Wiley and Sons, New York, 2003.

UNIT 4 STREAMFLOW

CONTENTS

1.0 INTRODUCTION

You should well be aware now that all the runoffs that escaped infiltration into the groundwater will likely end in a stream, hence the importance attached to streams. I believe that you have read and assimilated the content of Unit 4 before reaching this stage. That will introduce you to different categories of streams, and perhaps streamflow. Streamflow is the term that is used to describe the process of water flowing in the organized channels of a stream or river.

Water flowing in channels comes from surface runoff from adjacent hillslopes, from groundwater flow out of the ground, and from water discharged from pipes. The record of flow over time is called a hydrograph. Flooding occurs when the volume of water exceeds the capacity of the channel. Once rain falls, the streams respond appropriately, once it receives through any of the flow paths. Such reaction forms the basis for this unit.

2.0 OBJECTIVES

The main objective of this unit is therefore to describe and discuss the concept of hydrograph – a graph which plots the response of stream to the part of precipitation that it receives. By the end of this unit, you should be able to:

- define a hydrograph
- explain its structure
- mention the factors that will affect the structure.

3.0 MAIN CONTENT

3.1 Concept of Hydrograph

A **unit hydrograph** is used to more easily represent the effect rainfall has on a particular basin. It is a hypothetical unit response of the watershed to a unit input of rainfall. This allows easy calculation of the response to any arbitrary input, by simply performing a convolution between the rain input and the unit hydrograph output.

An **instantaneous unit hydrograph** is a further refinement of the concept; for an IUH, the input rainfall is assumed to all take place at a discrete point in time (obviously, this is not the case for actual rainstorms). Making this assumption can greatly simplify the analysis involved in constructing a unit hydrograph, and it is necessary for the creation of a geomorphologic instantaneous unit **hydrograph** (GIUH).

The creation of a GIUH is possible given nothing more than topologic data for a particular drainage basin. In fact, only the number of streams of a given order, the mean length of streams of a given order, and the mean land area draining directly to streams of a given order are absolutely required (and can be estimated rather than explicitly calculated if necessary). It is therefore possible to calculate a GIUH for a basin without any data about stream height or flow, which may not always be available.

3.2 Structure and Composition of a Hydrograph

There are two meanings for hydrographs both coming from *hydro-* meaning water, and *-graph* meaning chart. A hydrograph plots the discharge of a river as a function of time. This activity can be in response to episodal event such as a flood.

In surface water hydrology, a hydrograph is a time record of the discharge of a stream, river or watershed outlet. Rainfall is typically the main input to a watershed and the streamflow is often considered the output of the watershed; a hydrograph is a representation of how a watershed responds to rainfall. They are used in hydrology and water resources planning. The graph (Figure 10.1) below illustrates a typical hydrograph and its measurement of discharge over time.

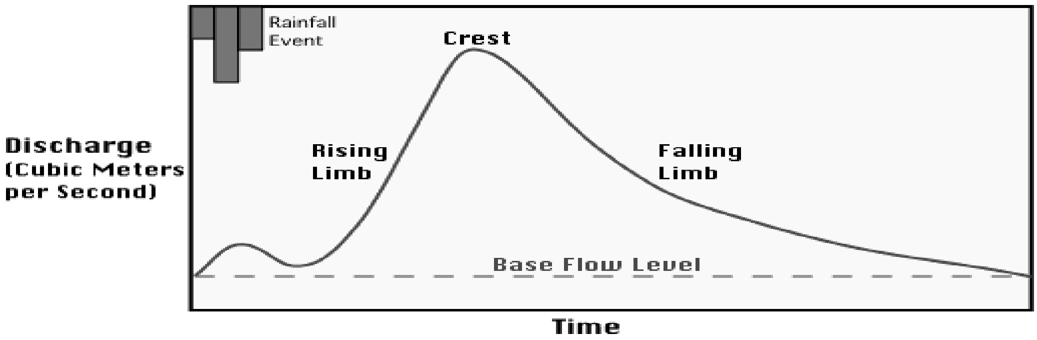


Figure 10.1: Stream hydrograph.

From this graph we can observe the following things:

A small blip caused by rain falling directly into the channel is the first evidence that stream discharge is changing because of the rainfall.

A significant time interval occurs between the start of rain and the beginning of the main rise in discharge on the hydrograph. This lag occurs because of the time required for the precipitation that falls in the stream's basin to eventually reach the recording station. Usually, the larger the basin the greater the time lag.

The rapid movement of surface runoff into the stream's channels and subsequent flow causes the discharge to rise quickly.

The falling limb of the hydrograph tends to be less steep that the rise. This flow represents the water added from distant tributaries and from throughflow that occurs in surface soils and sediments.

After some time the hydrograph settles at a constant level known as base flow stage; most of the base flow comes from groundwater flow which moves water into the stream channel very slowly.

3.3 Factors Affecting the Shape of Hydrograph

There are multiple factors affecting the discharge and discharge rate of a river, particularly after a high amount of rainfall.

Relief **or** ***gradient*** ***of the area:*** The steeper the slopes, the lower the rate of infiltration and faster the rate of runoff when the soil is saturated (saturated overland flow) or when rainfall intensity (rate per unit of time) is high (infiltration excess over land flow).

Geology, rock type and soil type: Runoff will occur quickly where impermeable rocks are exposed at the surface or quickly when the impermeable rocks underlay soils (limited amount of infiltration). Soils with large amounts of clay do absorb moisture but only very slowly - therefore their permeability is low. The deeper the soil the more water can be absorbed. Soils which have larger particle sizes (e.g those derived from the weathering of sandstones) have larger infiltration capacities.

Presence of vegetation: Dense vegetation canopies intercept rainfall. In particular, the significant volume of water held in fine spaces between pine needles evaporates before reaching ground. Between rain events evapotranspiration from soil, leaves and branches removes water. Drier soil infiltrates and retains more of the initial water. Finally plant root systems facilitate infiltration of the precipitation, rather than generating more surface runoff. All this delays the onset of runoff, and reduces the initial runoff flow.

Evergreen plants are able to transpire throughout the year (assuming temperatures are high enough and moisture is available - not frozen). Deciduous trees have a much greater leaf area/biomass than evergreen conifers and generally transpire more moisture over the year (even though they lose their leaves in winter) than evergreen conifers.

Dense underbrush and grasses increase surface roughness which slows overland flows that are insufficient to flatten the vegetation.

Urbanisation: Impermeable road surfaces, sloping roofs, guttering, and underground sewer and drainage systems help transfer water in an urban area to rivers quickly. The increase of house building in towns and villages as people have opted to move from large settlements (counter-urbanisation) especially on river flood-plains has contributed to the increase responsiveness of river systems.

Agriculture: Irrigation and drainage ditches will increase the speed of water transfer (also occurs in fields where farmers plough up and downslope). One solution to this problem is contour ploughing. Ploughing on wet land compresses the subsoil - creating a "plough pan" that can lead to decreased water holding, infiltration and increased runoff/erosion. The afforestation of the areas upriver can increase the interception and infiltration in the area, reducing discharge.

Water use: Dams and reservoirs slow down the rate of discharge at peak times as water is held back, possibly to protect the low-lying land downstream. Water extracted for industry, irrigation, and domestic use, also reduces discharge.

Drainage density: This ratio is the length of river course per area of land. The larger the amount of streams and rivers per area the shorter distance water has to flow and the faster the rate of response.
Precipitation: The rate and intensity of the rainfall will directly affect the amount and rate of overland flow. Snowfall results in less runoff initially, but a sharp rise in temperature may result in a quick thaw and a sharp increase in overland flow, especially if the ground underneath the snow is still frozen, and the melted snow will flow rapidly on ice, into the river, increasing discharge.

Time of year/season: In the dry season, when evapotranspiration rates are higher, reducing the amount of surface runoff. As well, photosynthesis in plants will be at a maximum - longer spells of sunlight and higher temperatures will create more opportunities for root systems to absorb water, and leaf systems to transpire water.

4.0 CONCLUSION

This unit focused the explanation and usefulness of a hydrograph. A number of factors that will affect the shape of a hydrograph have also been highlighted. You are therefore requested to test the level of your understanding of the concept after the reading with the questions in the tutor marked assignments.

5.0 SUMMARY

In this unit, the emphasis was on the usefulness of a hydrograph. A number of factors that will affect the shape of a hydrograph have also been highlighted.

6.0 TUTOR-MARKED ASSIGNMENTS

i. What is a hydrograph?

ii. Mention three components of information that a hydrograph will contain

iii. Highlight five factors that could affect the shape of a hydrograph

7.0 REFERENCES/FURTHER READING

Watson, I, A.D. Burnett and A.D. Watson. *Hydrology: An Environmental Approach***,** Lewis Publishers**,** 1999.

http://www.physicalgeography.net/fundamentals/8n.html

UNIT 5 STREAMFLOW MEASUREMENTS

CONTENTS

1.0 INTRODUCTION

Now let us imagine that one of your favourite activities is to sit with on a quiet river bank, drink your glass of lemonade, and ponder the complexities of life. Probably the question you are asked is "How much water is flowing in this river?" This section will definitely guide you through the discovery of the right answer. It is a process involving two concepts; measurements of Stream stage and the stream discharge.

2.0 OBJECTIVES

The main objective of this unit is therefore to describe and discuss how stage and flow of a stream are measured. You should be able to:

- measure the stage of a river or stream
- explain river discharge
- discuss stage to stream discharge.

3.0 MAIN CONTENT

3.1 Stream stage

Often during a large rainstorm, one can hear an announcement on the radio like 'River Niger is expected to crest later today at 30 cm'. The 30 cm the announcer is referring to is the stream stage. A number of methods are used to measure the stream height, or stage, including the use of a staff gauge. The theory behind this is not that much different from just bolting a measuring rod to a bridge and reading how high the water level is. But determining the amount of water flowing at various stream heights is not so simple.

Stream stage (also called stage or gage height) is the height of the water surface, above an established datum plane where the stage is zero.

The zero level is arbitrary, but is often close to the stream bed. You can get an idea of what stream stage is by looking at this picture of a common staff gage, which is used to make a visual reading of stream stage. The gage is marked in centimetres intervals (Figure 11.1).

Figure 11.1: A staff gauge (a graduated ruler firmly fixed in a river channel)

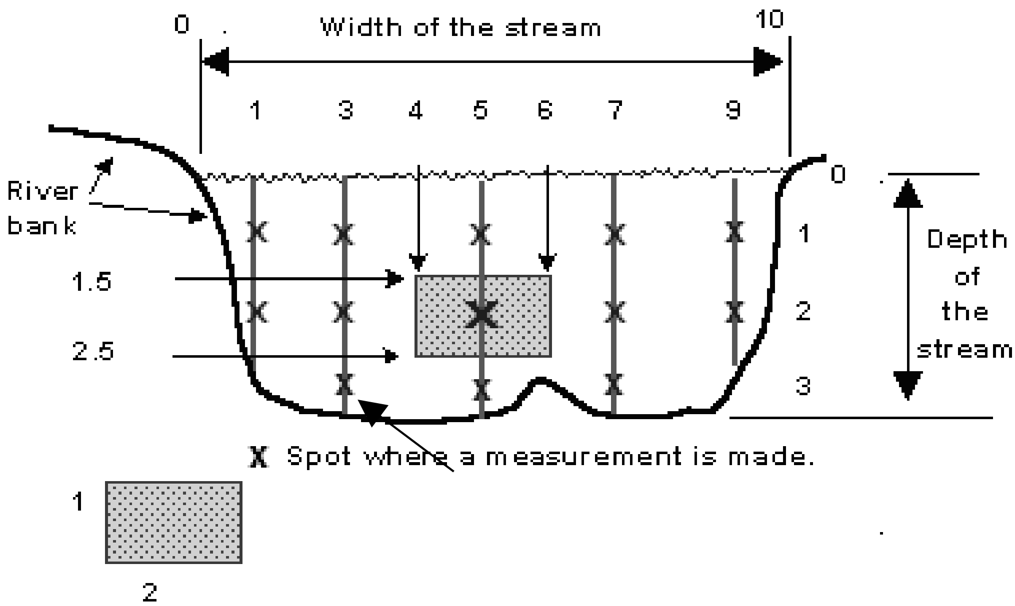
3.2 Stream Discharge

Stream discharge, is the volume of water flowing past a fixed point in a fixed unit of time. For water flow in streams, the value could be expressed in cubic meter per second (m^3/s).

In order to accurately determine stream discharge, measurements must be made of its width, depth, and speed (velocity) of the water at many horizontal and vertical points across the stream. To develop a stream-stage/stream discharge relation (rating curve), streamflow must be measured at many different stages. The well-developed rating curve allows for estimation of streamflows at virtually any stream stage. More simply, if a stream is measured at stages of 3.5, 6, 7.1, 9, and 10.2 m, then an estimate can be made for a streamflow at 8 m - that is the goal.

For example, let us say we need a measurement of River Example, when it is at a stream stage of approximately 3 m. First, someone has to go out to the stream when the stage is near 3 m. Figure 10.2 shows a cross-section of River Example at a 3 m stage. Note that the stream stage does not necessarily correlate to the actual depth of the stream. Example River is about 10 m wide. The stream-measurement procedure is to go across the stream at selected intervals and measure the total depth and the velocity of the water at selected depths at each interval across the stream.

Fig. 11.3: Shows a current meter (attached above the torpedo-looking weight), which is lowered into the stream and measures water velocity. The spinning cups on the current meter measure velocity.



so this area is 1 by 2 (m) or 2 sq. m.

Fig. 11.2: Variables involved in the measurement water velocity, and consequent determination of stream discharge

Fig. 11.3: A current meter inserted into the stream

In the Figure 11.2, the hydrologist would take a measurement of how fast the water is moving at every green 'X', and would then determine the areas between all of the measured intervals, such as the one shown by the box.

Subsequently, water depth/velocity measurements are obtained horizontally across the stream at 1, 3, 5, 7, and 9 m (the vertical lines in the diagram). At each location, measurements of velocity and total depth are obtained. Depending on the depth and flow conditions, one or more velocity reading(s) are obtained in each vertical.

For our example, a water depth/velocity measurement is obtained at a point 5 m from the edge of the stream. The total depth is slightly more than 3 m and velocity readings are obtained at depths of 1, 2, and 3 m (the 'X's on the 5 m vertical line). The box represents an area that is midway between this measurement point and the measurement points on either side. The box area is 2 m across and one 1 high, or 2 sq. m. The measured velocity at the big X in the purple box is 2 m per second.

To compute the amount of water flowing in that box area each second, multiply the area of the purple box times the velocity of the water:

(1) 2 m wide x 1 m high = 2 square meter

(2) 2 square meter x 2 meter per second = 4 cubic meter per second.

To compute the total stream discharge, the hydrologist has to create imaginary boxes between all of the 'X's and, using the velocity of the water in every box, compute the streamflow for each box area. Summing the streamflows for all the box areas will give the total stream discharge. Actually, the example above is a simplified explanation of how streamflow is measured. When an actual measurement is made, the hydrologist takes measurements at about 20 points across the stream. The goal is to have no one vertical cross-section contain more than 5 percent of the total stream discharge.

3.3 How Stream Height Relates to Streamflow?

4.3.1 How does the height of water in a stream relate to the amount of water flowing? As Figure 10.3 shows, river banks are irregular and tend to be flat at the bottom, have a steeply rising bank near the bottom, and then have flatter banks as they near the surrounding land surface. Since the river banks are irregular, the relation between stream height and stream discharge (flow) is not linear. In other words, when a stream's height doubles from 10 m to 20 m, the flow can more than just a double.

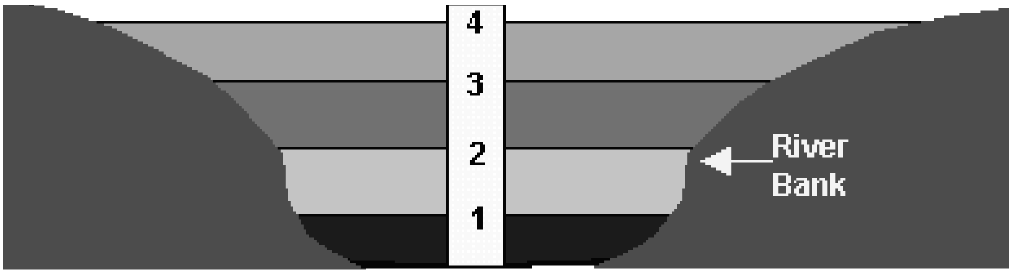


Figure 11.4

The diagram shows this better than I can explain it. At a gage height of 1 m, our stream has the amount of water (flow) represented by the first layer. Let's say it rains and the water rises to 2 m. The additional flow is represented by the next layer. Though the gage height doubled from 1 to 2 m, the total flow, represented by adding the first and second layers, is more than double the flow at 1 m (first layer). This is because the river bank has flattened out as it went up from the bottom of the river bed. Since the river bank continues to flatten, by the time the river's gage height goes to 4 m, the flow, represented by all the layers combined, is many times more than it was at 1 m. Also, as you can imagine, the speed of the water flowing during a storm is much faster than during low flow - thus, more flow at high water.

3.3.2 The use of a Rating Curve

The rating curve (Figure 11.4) shows the relationship between stream stage and streamflow. The stage-streamflow relation is used to relate water level to an associated streamflow. The rating curve for a specific stream location is developed by making successive steamflow measurements at many different stream stages to define and maintain a stage-streamflow relation. These steamflow measurements and their corresponding stages are then plotted on a graph. Continuous streamflow throughout the year can be determined from the rating curve and the record of river stage. The rating curve is crucial because it allows the use of stream stage, which is usually easily determined, to estimate the corresponding streamflow at virtually any stream stage.

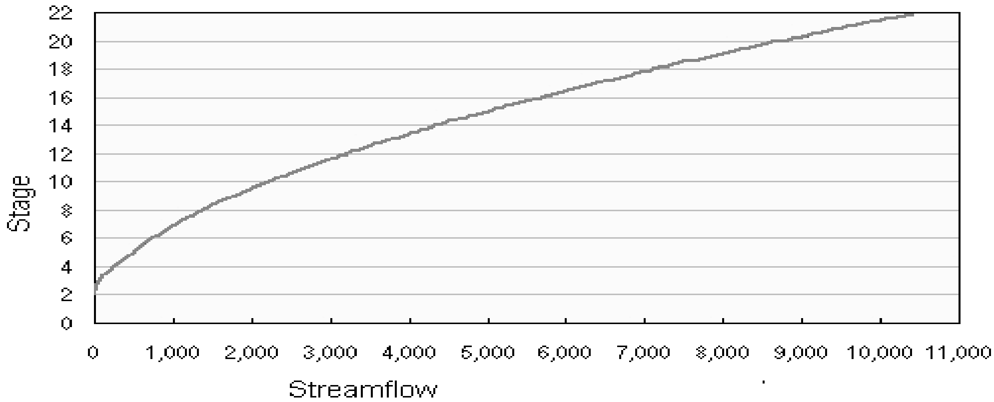


Figure 11.4: Rating curve defines stage/streamflow relation

3.4 Factors that Could Change the Shape of a Rating Curve

Rating curves are not static - they occasionally must be recalculated. Rating curves frequently shift due to changes in the factors that determine the relation between stream stage and streamflow. These factors are:

a Slope of the stream (affects velocity)
b. Roughness of the channel
c. Area of the channel at each stream stage
d. Backwater effects (when a tributary enters a larger river)
e. Filling in, scouring out, channel changes of river banks

Consider what can happen to a stream channel during a large flood. Figure 11.5 shows a streambed before and after a flood, thus changing the relation between the stream stage, and the amount of water flowing at that stage. The dark area represents how much water is flowing. Both diagrams show the same stage, but more water is flowing after the flood because the streambed profile has changed and now there is more area for water to flow. Scouring occurs more often on the outside edge of a curve in a stream, whereas sand build up occurs on the inside edge.

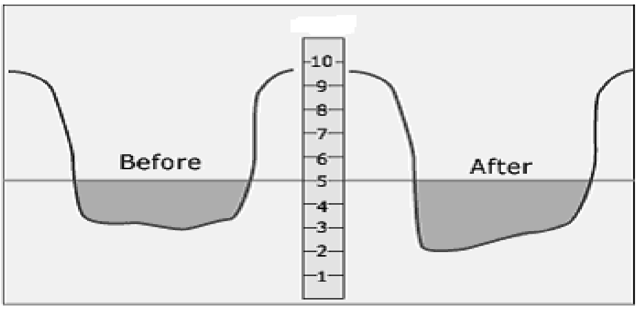


Figure 11.5

3.5 Other Devises to Determine Water Level

Sometimes a simple information as a "seed line" can help determine how high the water was (and the subsequent stream stage) during a flood. Instruments that read stream stage can indicate how high the stream stage was during a storm, but cannot show how high water got in the surrounding land and how much land will flood when the stream overflows its banks (unless detailed surveys are conducted). One way to determine this is to use high-water marks that occur during floods. If hydrologists can find a high-water mark on a tree or mailbox after a storm, then that information combined with the stream-stage data (from stream-stage records) can be used to estimate how much flooding will occur at different stream stages.

Here are a couple of pictures taken on a river bank a few days after high water occurred during a storm. Hydrologists often visit streams after a large storm to check for high-water marks. If, for example, records show that stream stage reached 17 m during a storm, a high-water mark will show the hydrologist what a stage of 17 m means in terms of how high the water was on the riverbanks and surrounding land, which helps to estimate how much land alongside a stream will be inundated at that stream stage. This kind of information is valuable in developing maps and information concerning the impact of floods on the adjacent landscape, structures, and people living there.

4.0 CONCLUSIONS

It is good that you have gone through this unit. You have learnt that staff gauge is the name of the instrument that we use to determine the water level. The discharge at different cross-section within the river could be determined by the use of Current meter. Both the water level (stage) and stream discharge (flow rate) are related but such relationship is affected by certain characteristics of the drainage basins and other surrounding forces of humans, and time. Now I ask you the following questions to assess your understanding of what you have read.

5.0 SUMMARY

In this unit, you have learnt that staff gauge is the name of the instrument that we use to determine the water level. The discharge at different cross-section within the river could be determined by the use of Current meter.

6.0 TUTOR-MARKED ASSIGNMENTS

i. Mention 2 instruments that we use in streamflow measurement

ii. Describe how water level (height or stage) relates to stream discharge

iii. Compare the use of 'seed line' over the staff gauge in determining stream level

7.0 REFERENCES/FURTHER READING

http://en.wikipedia.org/wiki/Water

http://ww2010.atmos.uiuc.edu (Gh)/guides/mtr/hyd/home.rxml

Viessman, W. and G.L. Lewis**.** *Introduction to Hydrology***.** 5th edition. Prentice Hall, Upper Saddle River, New Jersey, 2003.

UNIT 6 WATER QUALITY

CONTENTS

1.0 INTRODUCTION

All that you have learnt so far are processes which produce water on the earth surface, and the many pathways it takes to get to the streams, groundwater supplies, etc. Wait a minute; have you at any period taken time to ponder that the chemical characteristics of the water may be altered as it passes through many of its pathways? If this so, do you think that the quality may become undesirable for some uses by the time it gets to the sources? Yes it will, but people do not care about this, probably because situations have left them with no choice of theirs. Others do simply not care. But the implications are over the places, water related diseases, water poisoning etc. based on this I have desired that you learn some principles of water quality

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- define water quality
- Justify the need for quality water
- mention some sources of pollution or contamination of earth waters
- assess the responsiveness of the stakeholders to the problem of water pollution.

3.0 MAIN CONTENT

3.1 What is Water Quality?

This is the physical, chemical and biological characteristics of water in relationship to a set of standards. Water quality standards are created for different types of water bodies and water body locations per desired uses. The primary uses considered for such characterization are parameters which relate to drinking water, safety of human contact, and for health of ecosystems. The main classes of infectious diseases that are related to water are shown in Table 12.1. Surface water sources are more prone to contamination than the subsurface sources.

Table 12.1: Classification of Infectious Diseases Associated with Water

Transmission mechanism	Description	Examples of diseases
Waterborne	Oral ingestion of pathogens in water contaminated by urine or feces	Cholera, typhoid, bacillary dysentery, infectious hepatitis
Water-washed	Disease spread enhanced by scarcity of water making cleanliness difficult	Trachoma, scabia, dysentery, louseborne fever
Water-based	Water provides the habitat for intermediate host organisms, transmission to humans through water contact	Schistosomiasis (bilharziasis), dracunculiasis (guinea worm)
Water-related	Insect vectors (e.g., mosquitoes) rely on water for habitat, but human water contact not needed	Malaria, filariasis, yellow fever onchocerciasis (river blindness), dengue

3.1.1 Sources of pollutants into water bodies

Figure 12.1 shows diagrammatically some sources of pollutants in water

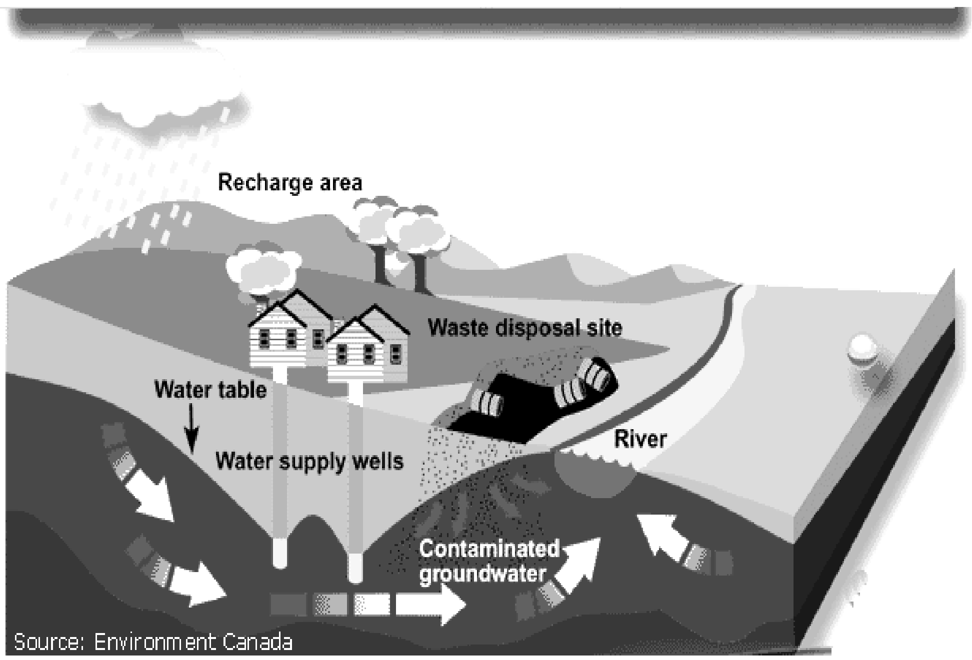


Figure 12.1: Pollutant sources and pathways into water supplies

The contaminants can be natural or human-induced. Naturally occurring contaminants are present in the rocks and sediments. As water flows through sediments, metals such as iron and manganese are dissolved and may later be found in high concentrations in the water. Industrial discharges, urban activities, agriculture, and disposal of waste all can affect water quality. Contaminants from leaking fuel tanks or fuel or toxic chemical spills may enter the groundwater and contaminate the aquifer.

Pesticides and fertilizers applied to lawns and crops can accumulate and migrate to the streams and water table

3.2 Concept of Water Pollution

Water pollution is the contamination of water bodies such as lakes, rivers, oceans, and groundwater caused by human activities, which can be harmful to organisms and plants which live in these water bodies. Although natural phenomena such as volcanoes, algae blooms, storms, and earthquakes also cause major changes in water quality and the ecological status of water, water is only called polluted when it is not able to be used for what one wants it to be used for.

3.2.1. Causes of water pollution

Water pollution has many causes and characteristics. Increases in nutrient loading may lead to eutrophication.

Organic wastes such as sewage impose high oxygen demands on the receiving water leading to oxygen depletion with potentially severe impacts on the whole ecosystem.

Industries discharge a variety of pollutants in their wastewater including heavy metals, resin pellets, organic toxins, oils, nutrients, and solids.

Discharges can also have thermal effects, especially those from power stations, and these too reduce the available oxygen.

Silt-bearing runoff from many activities including construction sites, deforestation and agriculture can inhibit the penetration of sunlight through the water column, restricting photosynthesis and causing blanketing of the lake or river bed, in turn damaging ecological systems

3.2.2 Effects of Pollution

Pollutants in water include a wide spectrum of chemicals, pathogens, and physical chemistry or sensory changes. Many of the chemical substances are toxic.

Pathogens can produce waterborne diseases in either human or animal hosts. Alteration of water's physical chemistry includes acidity, electrical conductivity, temperature, and eutrophication. Eutrophication is the fertilisation of surface water by nutrients that were previously scarce. Even many of the municipal water supplies in developed countries can present health risks.

Water pollution is a major problem in the global context. It has been suggested that it is the leading worldwide cause of deaths and diseases, and that it accounts for the deaths of more than 14,000 people daily.

Table 12.2: Selected Examples of Global Mortality and Populations at Risk, for Infectious Diseases Associated Water

Disease	Vector	Morbidity	Mortality	Population at risk
Diarrheal diseases	Microorganisms	> 1.5 billion	4 million	> 2 billion
Schistosomiasis	Water snails	200 million	200,000	500–600 million
Malaria	Mosquitoes	267 million	1–2 million	2.1 billion
Onchocerciasis	Blackflies	18 million	20 to 50,000	90 million

Source: UNEP (1993).

3.3 Regulating Framework

In Nigeria, the Ministry of Environment in the National Policy on Environment has set a guideline for water use in the country. This was acting upon the earlier stand of the defunct Federal Environmental Protection Authority Act 56 of 1987. Although the strictness of the implementation is another topic for discussion, the role of the National Agency for Food and Drug Administration and Control (NAFDAC) should be commended.

In the UK there are common law rights (civil rights) to protect the passage of water across land unfettered in either quality of quantity. Criminal laws dating back to the 16th century exercised some control over water pollution but it was not until the *River (Prevention of pollution) Acts 1951 - 1961* were enacted that any systematic control over water pollution was established. These laws were strengthened and extended in the *Control of Pollution Act 1984* which has since been updated and modified by a series of further acts. It is a criminal offence to either pollute a lake, river, groundwater or the sea or to discharge any liquid into such water bodies without proper authority. In England and Wales such permission can only be issued by the Environment Agency and in Scotland by SEPA.

In the USA, concern over water pollution resulted in the enactment of state anti-pollution laws in the latter half of the 19th century, and federal legislation enacted in 1899. The Refuse Act of the federal Rivers and Harbours Act of 1899 prohibits the disposal of any refuse matter form into either the nation's navigable rivers, lakes, streams, and other navigable bodies of water, or any tributary to such waters, unless one has first obtained a permit. The Water Pollution Control Act, passed in 1948, gave authority to the Surgeon General to reduce water pollution.

In 2004, the United States Environmental Protection Agency tested drinking water quality on commercial airline's aircraft and found that 15 percent of tested aircraft tested positive for total coliform bacteria, according to a press release issued on Friday March 28, 2008.

4.0 CONCLUSION

Here concludes the unit 12 lecture on water quality. It is also the conclusion of the module on water resources evaluation. In this unit, issues relating to the quality assessment of the water have been taught. These include water pollution. In fact, it is human desire that water is available in abundant quantity and in good quality for the desired use. Abundance water but at undesirable quality is not useful, hence the need to remind you of one of the old rhymes which says ‘water, water everywhere, but there is none for us to drink.

6.0 SUMMARY

Ii this unit, you have been taught some of the issues relating to the quality assessment of water. One of them is include water pollution.

6.0 TUTOR-MARKED ASSIGNMENTS

If you have indeed studied this unit, you will be assessed by the following questions:

i. What is water quality?

ii. Mention THREE effects of water pollution.

iii. Mention THREE sources of pollutant in the environment.

7.0 REFERENCES/FURTHER READING

http://www.environmentagency.gov.uk/subjects/waterquality/?version=1&lang=_e

http://www.physicalgeography.net/fundamentals/8n.html