COURSE GUIDE

AFM 305
LIMNOLOGY

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WHAT YOU WILL LEARN IN THIS COURSE

Welcome to AFM 305 Limnology Course! Limnology is the study of inland bodies of water lakes, ponds, reservoirs, streams, rivers, wetlands, estuaries and their related ecosystems. Limnology deals with freshwaters within continental boundaries. Today, limnology plays a major role in water use and distribution as well as in wildlife habitat protection. Limnologists work on lake and reservoir management, water pollution control, stream and river protection, artificial wetland construction, fish and wildlife enhancement.

An important goal of education in limnology is to increase the number of people who, although not full-time limnologists, can understand and apply its general concepts to a broad range of related disciplines. It covers the biological, chemical, physical, geological and other attributes of all inland waters –running (lotic) and standing (lentic) waters; fresh and saline; natural or man-made.

Limnology evolved into a distinct science only in the past century, integrating physical, chemical and biological disciplines in order to describe and manage freshwaters ecosystems. Although inland water bodies are well below the oceans size, they are complex systems and they can't be fully understood if studied without taking into account the complex interrelations between physical, chemical and biological aspects. This course offers an overview of the basic principles of limnology. Particular attention has been devoted to the integration of physical, chemical and biological information, highlighting how abiotic and biotic compartments deeply interact to determine lakes and rivers evolution. Thus this course has the ambition to improve the understanding between the different disciplines dealing with the specific compartments of freshwater ecosystems. The term limnology was firstly proposed by François-Alphonse Forel (1841–1912).

The course is made up of 6 modules and 18 units. Your study time for each unit will vary from one to four weeks. You will find more detailed information about the contents of each unit in the section of this Course Guide entitled "Course Description". Each study unit contains a number of self-assessment. These allow you to check your progress as you work through each topic. At the end of each self-assessment is a question about your own experience. It is advisable that you think very well about these questions. You are requested to apply the material you have just read to your experience in your local government area or the country. All the questions are discussed in the final unit and tutorials. Some of your recommended textbooks are written by non- Nigerians. You will therefore, judge whether all or some of the materials contained in them apply in the Nigerian environment. Your opinion here therefore, matters

a lot, as there are various answers to these questions. You will learn some new terms and expressions during the course of the study. You will also come into contact with new ideas, which may make you look at the concept of iinnovations from an entirely different perspective.
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The study units, textbooks and exercises will help you master the topics over a period of about 18 weeks. Before looking at study units or your textbooks, you should read this Course Guide thoroughly. It tells you:

i. The aims and objectives of the course.
ii. What the course covers.
iii. The components of the course.
iv. The amount of study time you need to cover the course successfully.
v. How your performance in assignments and the examination will be assessed.
vi. How the tutorial system works.

You will probably need to refer to this course guide throughout the course to clarify important points about studying with the National Open University (NOU) of Nigeria.

COURSE AIMS

Limnology aims to provide you with the basic introduction to the workings of the freshwater system. It also intends to identify characteristics of natural and man-made lakes, aquatic chemistry, major water compartments, flowing water and thermal stratification. At the end of the course we shall be able to explain the characteristics of different freshwater environments contained within continental areas. A multi-disciplinary approach is used in the study of Limnology.

COURSE OBJECTIVES

After the course has been completed, you should be able to:

1. Distinguish between natural and man-made lakes.
2. Explain the different characteristics of freshwater, brackish water and marine water.
3. Explain the major water compartments and the hydrological cycle.
4. Discuss the transport and exchange processes that occur naturally.
5. Define the term thermal stratification and give its importance.

COURSE DESCRIPTION

One of the most important functions of Limnology is to bridge the gap between different disciplines involved in the management of the freshwater ecosystems.

There are 6 modules and18 study units in this course:

Module 1

Unit 1 Properties of Natural Lakes
Unit 2 Properties of Man-Made Lakes
Unit 3 Aquatic Chemistry

Module 2

Unit 1 Physicochemical Properties of Freshwater
Unit 2 Physicochemical Properties of Brackish Water
Unit 3 Physicochemical Properties of Marine (Sea) Water

Module 3

Unit 1 Major Water Compartments
Unit 2 Hydrology and Water Cycle
Unit 3 Transport and Exchange Processes

Module 4

Unit 1 Ground Water
Unit 2 The Flowing Waters: Rivers
Unit 3 Lake Food Chain

Module 5

Unit 1 Estimation of Algal Population and Measurement of Primary Productivity
Unit 2 Thermal Stratification
Unit 3 The Role of Soils

Module 6

Unit 1 Paleolimnology and Sediments
Unit 2 Other Sediment Depositional Environments
Unit 3 Littoral, Pelagic Zones and their Dynamics

The units build on each other to work from explaining what natural and man-made lakes are and how the water cycle operates and how you can learn to understand the freshwater environment by applying all that you have learnt in this course. If you have completed the pre-requisite courses, you will find certain concepts in some familiar units. But if you have not completed the pre-requisite courses, you may need to spend a little extra time familiarising yourself with some of the ideas.

There are adequate tutorial hours designed to assist you, try to take full advantage of the tutorials you need to be up to date with your study. Tutorials are not lectures but are designed to allow group discussion and input. You get the most from a tutorial session, if you contribute your ideas and opinions. Tutorials do not assist learners when they make no input. Your tutor will lead discussions and needs your help to make sessions successful.

The **Course Calendar** provides an overview of the course. It suggests the amount of time you should use to complete the units and helps you to plan your study schedule. It can be adjusted to fit your personal needs more closely.

The time needed to complete the study units, work through the practice exercises and assignments, and complete the other work involved in this course depends on your analytical ability and background. You need to plan your own study schedule carefully. The estimated time you need to spend on this course is about 10 hours per week. This estimate includes time for reading the study units and studying the textbooks, completing self-tests and practice exercises, completing your assignments, undertaking the suggested reviews, attending tutorials and preparing for your final examination.

You must complete and hand in your written assignments on time. Therefore, you need to plan and distribute your study time accordingly. There are assignments known as Tutor-Marked Assignment (TMAs) altogether to be marked by your tutor. One of these TMAs is required (i.e. you must hand your assignment to gain the specific amount of Overall Continuous Assessment Scores (OCAS) that is assigned to this TMAs). Other than this, the best three will be counted towards your usual OCAS. You can find more information on assignments in a later section of this course guide.

COURSE MATERIAL

In addition to this course guide, there are the following important components of the course. At this time, please ensure that you have all of these materials available and can identify the various components in the course if you do not have the NOUN- produced materials, you should contact the NOUN immediately. The textbooks, however, are your own responsibility. These can be obtained from academic and professional book centers. The addresses for the branches are in the book list that is sent to you.

STUDY UNITS

Although we have recommended the amount of time you should spend on each study unit, you may prefer to study material in a slightly different way. There is provision to detour from the pattern of the course, but you must complete the practice exercises, assignments and examination successfully. The course is structured so that each unit builds upon previous knowledge.

Each unit includes at least seven different ways to help you study Limnology.

These are:

1. Reading the study unit
2. Reading the textbooks
3. Testing your comprehension and analytical skills by working through the self-assessment exercises which appear throughout the units.
4. Undertaking the activities that appear throughout the units. These activities will ask you to think, observe, or under take some activities designed to help you apply your knowledge to your own experience.
5. Completing the practice exercises in each unit.
6. Preparing and writing problem-solving assignment
7. Asking you questions about your own experiences. Your answers help you link your experience to the course material and to Nigerian culture.

You must read each unit carefully. It provides a commentary on the textbooks and introduces you to additional material. Each unit also tells you how and when to complete your assignments. If you don't read the study units carefully, you may miss important information. Your study notes are designed to guide you through your textbooks.

You must read both the study notes and the texts. They are not alternatives to each other.

It is also helpful to read as widely as possible. Try to read articles in newspapers and journals, other books on the topic, and related cases.

The more you read, the better your appreciation and understanding of the subject will be.

Each unit directs you to read specific pages from chapters in the textbook. You are expected to study and understand the principles and concepts involved. Each unit contains self-test question, usually short ones, providing a duck on your understanding of a technique or principle you have just read about. By attempting these short questions, you will have instant feedback on your progress. You should attempt to answer all the self-text questions before looking at the answers. This will help you to prepare for your assignments and examination. After each self-test there is a question on your own experience!

At the end of each unit there is one practice exercise, which covers all areas you have studied in that unit. It is important to complete all the practice exercises. This will expose you to the types of questions you will be required to answer in assignments and in your final examination and also introduce you to some problems encountered in business, organizations and real life-situations. The questions reflect the demands of the unit objectives; they are designed to help you understand and apply those principles covered in the unit.

SET TEXT BOOKS

There are no compulsory textbooks for Limnology. Read as many textbooks or journal articles on the subject as possible.

ASSIGNMENT FILE

Assignment questions for the units of this course are contained in the section of the course materials entitled assignment file. You are required to complete your assignments and mail them together with a tutor-marked assignment (TMA) form to your tutor.

COURSE ASSESSMENT

Your assessment for this course is made up of two components:

- tutor-marked assignments (TMAs)
- a final examination.

The practice exercise is not part of your assessment but it is important to complete all of them.

TUTOR-MARKED ASSIGNMENT

This course has tutor-marked assignment at the end of each unit, which you will find in your Assessment File with detailed instructions on how to complete them. Your tutor will mark and comment on them. Pay attention to the feedback and use it to improve your other assignments.
You will see from the course time table the dates to submit in your assignments. The marks for the required TMAs and the best three out of four will be recorded and count towards your final mark for the credit for this course. Presently, the university has adopted electronic e-TMA which comprises eighty multiple or objective questions since 2009/2010 session.

You can write the assignments using the materials from your study units and textbooks. But it is preferable in all degree level education to demonstrate that you have read and researched more widely than the required minimum. Using other references will give you a different viewpoint and a deeper understanding of the subject. **But do remember that copying from any sources without acknowledgement is plagiarism and is not acceptable.** You must make reference when you refer to or quote from others' work. The minimum information needed is: author's name, date of publication, title, edition, publisher and place of publication.

The nature of the assignments varies, but they normally consist of either case **studies or questions** relating to the cases, short essays or short answer questions. It is useful to illustrate any theoretical points with examples from your own experience. This allows you to demonstrate your understanding of the application of theory to real life situations. Below are the total marks allocated to the assignments and to your final examination.

Title	**Value**
TMA	30%
Exam	70%
	100%

FINAL EXAMINATION AND GRADING

There is three-hour examination at the end of this course. After reading the last unit, ensure you review the whole course before the final examination. Also review your practice exercises, assignments and your tutor's comments on them before sitting for the examination. You will be advised of examination arrangements after you send in your examination registration card.

The final examination for AFM 305 covers information from all parts of the course and has the same format as the specimen examination paper, which will be discussed in the half-day school. The examination will not contain "trick" questions or questions that try to confuse you. That is, not consistent with the open approach, the NOUN approach is difference. To earn a passing grade for the course you must submit at least three TMAs including the required TMA, and attain a passing grade (i.e. at least score 40) on these **and** on your final examination.

TUTOR AND TUTORIALS

Your tutor marks and comments on your assignments, keep close watch on your progress and on any difficulties you encounter, and provide you with assistance.

Assignments should be mailed in accordance with the **course calendar**. They will be marked by your tutor and returned to you as soon as possible.

It is a good idea to keep a copy of all the assignments you send to your tutor for marking. The copies will prove useful, should you wish to make reference to them during telephone conversations, or if they are lost in the mail.

Do not hesitate to contact your tutor by telephone if you need help. Here are typical circumstances in which help is necessary. Contact your tutor if you:

- do not understand any part of the study units or the assigned readings
- have any difficulty with self-assessments or practices exercises
- have questions or problem with assignments, with your tutor's comments, or grading on an assignment.

Tutors have complete authority on two points. First, they are responsible for the grade you receive on assignments. If you disagree with a mark, discuss it with your tutor.

Second, they alone decide if you may or may not rewrite an assignment. To assist you in this course, regular tutorials are organised with your assigned tutor.

Very interesting activities are designed for the tutorials. They also give you an opportunity to sort out any problems. You will be notified of their dates, times, and location, together with the name and phone number of your tutor, as soon as you are allocated a tutorial group. We

strongly recommend that you attend these tutorials and the half-day school. They provide considerable assistance in your study of this course and improve your chances of gaining high marks. They also let you meet other learners studying through the NOU.
Tutors are required to start tutorial day school sessions on time. If a tutor fails to turn up30 minutes after the scheduled starting time, students may assume that the session is cancelled and they should report the case to the course coordinator so that a make-up session can be arranged.

TMA Extension Policy

The assignment policy of the university as stated in the student Handbook should be observed. Applications for extension of up to seven days should be submitted to the tutor. For extensions of over seven days, students should note the following:

1. Assignment extensions may be granted in extenuating circumstances, which should be interpreted as circumstances that are unexpected. Work commitments and traveling are not regarded as extenuating circumstances unless they are unexpected.
2. Supporting documents must be submitted along with the application for extension of over seven days to justify the claim. Applications without supporting documents will not be considered.
3. Applications for extension should be submitted either before or on the due date.
4. The decision to grant or refuse an extension is made by the:
   - Course Coordinator for extensions of up to 21 days.
   - Dean for extensions of over 21 days.

If the assignment is posted to the tutor, it is the responsibility of the student to check with their tutor that the assignment has successfully arrived. Extension applications without supporting documents on the ground of postal loss will not be accepted. The University cannot accept any responsibility for assignments that are not received by your tutor due to problems with the post. As a precaution, you are advised to keep a copy of each assignment you submit and obtain a certificate of posting from the post office when you post your assignment.

CONCLUSION

AFM 305 Limnology is a subject that should interest anybody who is concerned about the quality of life the freshwater environment either in Nigeria or any Third world Country of Africa and Asia. The course has therefore, been designed to help you understand the most complex problems of managing both the lotic and lentic water systems. You must apply concepts to understand limnology.

Hopefully, you will find it fun, interesting and useful as an administrator or a policymaker (or potential ones) interested in the development of your country. Good luck, and enjoy the course.

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MODULE 1

Unit 1	Properties of Natural Lakes
Unit 2	Properties of Man-Made Lakes
Unit 3	Aquatic Chemistry

UNIT 1 PROPERTIES OF NATURAL LAKES

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1.0 INTRODUCTION

Lakes are depressions surrounded by land and hold standing fresh or saline water all year round. Some lakes are however seasonal.In this unit, you will get to know the classification and characteristics of lakes including lake zonation.

2.0 OBJECTIVES

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

- give the definition of lakes
- enumerate the types of lakes and their characteristics
- highlight the classification of lakes according to origin
- list the classification of lakes according to their richness
- state the classification of lakes according to mixing or stratification features
- explain lake zonation.

3.0 MAIN CONTENT

3.1 Definition of Lakes

Lakes are inland depressions that hold standing fresh or saline water all year round though some lakes especially in the tropics may be seasonal. Lakes are also described as water bodies that are larger than ponds, have wave action on the shoreline, or where wind-induced turbulence plays a major role in mixing the water column. Lakes are bodies of water enclosed by land.

Lakes are created by natural or human–initiated processes. They are chemically and physically stable environments on yearly basis but may undergo considerable seasonal changes within the year. They are relatively closed systems, though some have substantial in flowing and out flowing rivers. They range in size from the Caspian Sea (371,795 km^2), to small ponds of a few hectares and depth from 1742 m in Lake Baikal in Siberia (contains 20% of global fresh water) to less than 1m.

3.2 Types of Lakes and their Characteristics

3.2.1 Seepage Lakes

This is a natural lake. These lakes have no stream inlet or outlet and overflow occasionally. They are land-locked water bodies with precipitation, groundwater and runoff as the sources of fresh water supply. Their levels may fluctuate seasonally and have a limited fishery because they are not influenced by streams. Seepage lakes have a small drainage area which may account for lower nutrient content. Seepage lakes may be more susceptible to acidification because of their low buffering capacity.

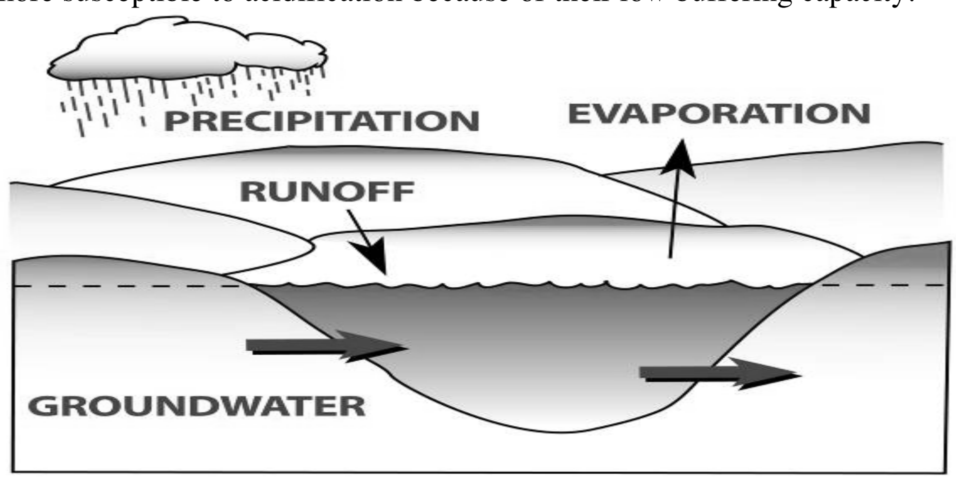

Fig.1: Schematic Illustration Showing the Sources of Entry and Loss of Water in a Seepage lake
(Source: Limnology 101: Wisconsin Department of Natural Resources, Wisconsin Association of Lakes and University of Wisconsin Extension)

3.2.2 Groundwater Drainage

This type of lake is also a natural lake with no inlets but has an outlet. The sources of water include groundwater flowing into bottom of the lake from inside and outside the immediate surface drainage area. Other sources include precipitation and runoff. These lakes are the head waters of many streams.

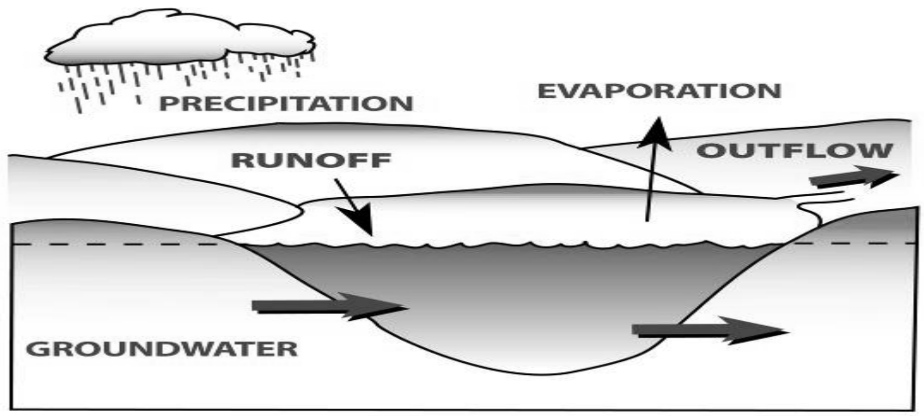

Fig 2: Schematic Illustration Showing a Groundwater Drainage Lake (Source: Limnology 101: Wisconsin Department of Natural Resources, Wisconsin Association of Lakes and University of Wisconsin Extension)

3.2.3 Drainage or Drained Lakes

They are natural lakes with both inlets and outlets.Their main water sources are stream, precipitation, runoff and groundwater.They support fish which are not necessarily identical to the streams connected to them.They have higher nutrient levels than many natural seepage or spring lakes. Water levels may fluctuate depending on supply .

3.2.4 Coastal Lagoons

Coastal lagoons are natural lakes separated from the sea by sandbars and are often associated with estuaries. They show large seasonal variations in salinity, since water flows into them from rivers (freshwater) for part of the year and from the sea for the remainder.

3.2.5 Impoundments / Reservoirs

These are man-made bodies of water usually created when a dam or other water control structure is constructed across a river and the water backs up to form the lake.The cavity hosting the lake could also have been dug for some mining operations (quarry lakes). Impoundments are created for agriculture, flood control, power generation and drinking water supply.

They are considered as drainage lakes since they have inlets and outlets with major water source from stream drainage. Many impoundments support fish populations which may differ from those in the streams connected to them. They have higher nutrient levels than many natural seepage or spring lakes.Water transit time is generally short.Example Kainji Lake (Nigeria).

3.3 Classification of Lakes According to Origin

3.3.1 Glacial Lakes

These lakes are formed by the scouring of large shallow basins from rocks through the activities of ice. The downhill flow of glaciers transformed V-shaped valleys into U-shaped valleys through the glacial erosion processes. The moraine material deposited on the floor and at the edge of the valley originated the basins hosting a moraine-dammed lake (glacial lakes). When retreating, glaciers left behind underground or surface chunks of ice that later melted leaving a depression containing water (North American cattle lakes). When the depression is filled with water a cirque lake is formed.

3.3.2 Rift Valley/Tectonic Lakes

Rift valley or tectonic lakes are formed by faults lines in the earth. They include Lake Baikal Siberia), Balkhash (Russia), East African Great Lakes e.g. Nyasa, Tangayika. They are deep lakes with the deepest lake in the world being Baikal.In Tectonic lakes, the movements and fractures of the deeper layers of the Earth's crust determined the opening of basins where water is collected.**Landslide lakes** are formed from catastrophic events that cause deposition at the bottom of a valley of debris from a collapsed valley wall.

3.3.3 Depression Lakes

Depression lakes are small and shallow, but may cover great areas. They include Lakes Chad and Victoria in Africa. The origins of depression lakes differ. Some are remnants of larger bodies of water partly filled by siltation e.g. Lake Chad. They may originate from uplifting of the Earth’s crust e.g. Lake Victoria. Depression lakes often have drainage basins that do not discharge to the sea (endorhoeic) and may become very saline over time.

3.3.4 Volcanic Lakes

Volcanic lakes are of volcanic origin and form in calderas or depressions formed by the subsidence of the magma chambers of inactive volcanoes (caldera lakes) and craters of extinct volcanoes (crater lakes). They are usually relatively small and isolated.

3.3.5 River Lakes

River lakes result from the erosive force of rivers. They are located on floodplains, where they form integral parts of the river system and are usually small. As riverine erosion occurs, sediments are resuspended and deposited downstream in the process. Large rivers can deposit sediments that dam tributary streams forming new lakes (lateral lakes). At river bends, turbulence and sediment deposition can build up, cause the river path to divide and dam a river meander separating it from the main river. The resulting water body is called an **oxbow lake** whichare small, crescent-shaped lakes which form in river valleys(New World Encyclopedia, 2008).

3.3.6 Salt Lakes (Saline Lakes)

Salt lakes or saline lakes form where there are no natural outlets, or where the water evaporates rapidly. The drainage surface of the water table has a higher-than-normal salt content. Examples include the Great Salt Lake, the Caspian Sea, the Aral Sea, and the Dead Sea.

3.3.7 Coastal Lakes

Coastal lakes are formed along irregularities in the shoreline of the sea by deposition of sediments in bars protruding above the mean sea level. This process is promoted by currents and eventually produces a fresh or brackish water lake.

3.3.8 Karstic Lakes

These lakes form in regions of calcareous ground. The running-over waters dissolve the carbonate constituting the rocks. The cracks in limestone rocks are attacked and widened by the waters dissolving the carbonate. In this way funnel-shaped cavities are formed (sinkholes) that are gradually widened and often end in a cave. The eroding water flow can weaken the ceiling of the cave till it breaks. The cavity formed can accumulate waters originating a sinkhole lake.

3.4 Lake Classification According to their Richness

Oligotrophic lakes are nutrient-poor lakes of glacial origins with underlying rocks made up mainly of granite.

Mesotrophic lakes have balanced nutrient status but their depths usually allow thermal stratification most times of the year causing differences in abundance of nutrients, phytoplankton and zooplankton e.g. Rift valley Lakes.

Eutrophic lakes are nutrient-enriched e.g. depression lakes. They usually have intensive agricultural activities around them. They are shallow and cover large areas so that evaporation causes a rapid build-up of nutrients and salts in the water.

Dystrophic lakes are formed in bogs and marshes and have water which may be poor in nutrients but with high concentrations of tannic acids from decaying vegetation.

Hypertrophic lakes have excessive concentrations of nutrients, very low transparency and contain devastating algal blooms due to excessive nutrients or fertilisers in the catchment areas. They have poor ecosystems and low dissolved oxygen.

3.5 Classification of Lakes According to Mixing or Stratification Features

According to their mixing features lakes can be classified as:

1. **Holomictic** lakes are those completely mix because they reach uniform temperature and density from top to bottom. Full circulation or mixing can occur once or twice a year.
2. **Monomictic** lakes mix from top to the bottom during one mixing period each year. There are two types of monomictic lakes namely cold and warm. Cold monomictic lakes are covered by ice for most parts of the year which prevents mixing in winter. Warm monomictic lakes never freeze and are thermally stratified throughout out much of the year. Mixing is prevented by density differences. In winter, the water cools and there is mixing. Monomictic lakes are isothermal once a year and then have one full circulation (monomictic lakes).
3. **Dimictic lakes** mix from top to bottom during two mixing periods in the year-spring and autumn.

4. **Polymictic lakes** are also holomictic lakes that mix several times a year. They are too shallow to develop thermal stratification and their waters mix from top to bottom throughout the year. Polymictic lakes can be cold polymictic lakes (i.e., ice-covered in winter), and warm polymictic lakes (i.e., without winter ice-cover).
5. **Oligomictic** lakes have irregular mixing, which may not occur every year.
6. **Amictic lakes** are lakes that never circulate or mix. Amictic lakes are usually ice covered throughout the year. Water temperature in the lake increase with depth (inverse cold water stratification). Below the ice surface, up to 4˚C where density of water is highest. Examples include lakes close to the North and South Poles, Alpine regions under ice cover.
7. **Meromictic** lakes are those in which bottom water never mixes with surface water. In these lakes, dissolved substances accumulate at the bottom, increasing the water density above the value attributable to temperature alone. The more superficial layers, where mixing is possible, constitute the **mixolimnion** while the deep layers that never mix, are the **monimolimnion**. The intermediate layer, where there is a sudden change in density at the upper edge of bottom layer accumulating salts or dissolved organic matter, is called **chemocline (or pycnocline).** Meromixis can be:

   - **ectogenic** when external events transport salt water into a freshwater lake or vice versa
   - **crenogenic,** when a saline spring at the bottom of the lake introduces in it water rich in salts
   - **biogenic,** when salts from organic matter decomposition in sediments or from carbonates precipitation due to pH changes promoted by photosynthesis accumulate in the deeper layers.

In meromictic lakes, lower compartments contain accumulations of dissolved CO_2 and other gases which are dangerous to living organisms when exposed. Examples occur in the Baltic Sea, Caspian Sea, Lake Nyos, Monoun, Kivu, Tanganyika. If stratification of water lasts for long periods the lake is described as meromictic.

3.6 Lake Zonation

According to light and temperature distribution in a lake, there are zones with different characteristics in lakes. These are commonly used in limnological context.

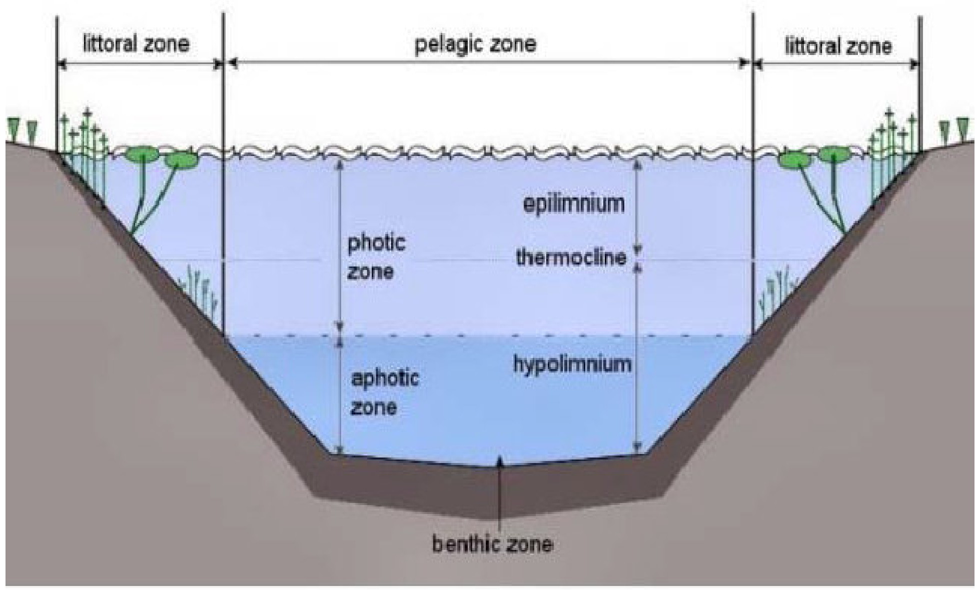

Fig. 3: A Schematic Diagram Showing the Zones of a Lake (Source: Bertoni, 2011)

The zones of a Lake are:

- **Littoral Zone:** Is the portion of the lake horizontally extending from the shore to the point impending the bottom area where submerged macrophytes and bentic algae can live. This is the part of the lake bottom reached by solar radiation, included in the photic zone.
- **Pelagic Zone:** Is the portion of the lake above the depths not reached by solar radiation.
- **Photic or Euphotic Zone:** Is the layer of water vertically extending from the surface to the depth reached by 1% of surface solar radiation.
- **Aphotic Zone:** Is the part of the water column not reached by solar radiation.
- **Epilimnion/Hypolimnion:** water layers overlying or underlying the thermocline.
- **Thermocline or Metalimnion:** Is the layer of water where the temperature changes of 1°C per meter.
- **Benthic Zone:** Is the portion of the lake located at the water-sediment interface. In the aphotic zone it is often called profound benthic zone.

4.0 CONCLUSION

There are several types of lakes which can be classified based on origin, richness and mixing or stratification characteristics. Lake zones include littoral, pelagic, photic and others -which are useful for limnological purposes.

5.0 SUMMARY

In this unit, we discussed the different types of lake classification and gave brief descriptions of each type of lake. We also described using a diagram the different zones of a lake.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is a lake?
2. List types of lakes and their characteristics.
3. Highlight the classification of lakes according to origin and richness.
4. Explain the classification of lakes according to mixing or stratification features
5. What is lake zonation?

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UNIT 2 PROPERTIES OF MAN-MADE LAKES (RESERVOIRS)

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1.0 INTRODUCTION

Man- made lakes are water bodies created by man to supply some basic needs. Man-made lakes in Africa include Kariba, Kainji, Volta, Lake Nasser and Nubia. The creation of man-made lakes has some beneficial effects such as contribution to water supply, recreational value, prevention of floods and electricity supply through hydropower. The main disadvantages are concerned with public health and resettlement.

Reservoirs are water bodies formed or modified by human activity for specific purposes, in order to provide a reliable and controllable resource.

Reservoirs are man-made water bodies usually formed by constructing a dam across a flowing river. Their main uses include:

- drinking and municipal water supply
- industrial and cooling water supply
- power generation
- agricultural irrigation
- river regulation and flood control
- commercial and recreational fisheries
- body contact recreation, boating, and other aesthetic recreational uses
- navigation
- canalisation
- waste disposal.

Reservoirs are constructed in areas of water scarcity (to conserve available water for when it is most needed) or excess (for flood control in downstream areas), or where there are agricultural or technological needs to have controlled water facilities. Power generation, fish-farming, paddy-field management or general wet-land formation, also require reservoirs.

Reservoirs are subject to significant human control and are very variable (UNEP, 1991). They differ in size, morphology, water quality and behavior is different from natural lakes. Reservoirs share a number of attributes with natural lakes. All reservoirs are subject to water quality requirements in relation to a variety of human uses. The variation in design and operation of control structures in reservoirs allow greater flexibility and potential for human intervention than in natural lakes.

2.0 OBJECTIVES

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

- state the definition of reservoirs and impoundments
- describe impoundments, off-river reservoirs and inter-basin transfers
- discuss the characteristics of reservoirs
- discuss water quality issues in reservoirs
- distinguish between natural and man-made lakes.

3.0 MAIN CONTENT

3.1 Definitions

A **reservoir** is a water body contained by embankments or a dam, and subsequently managed in response to specific community needs; or any natural waters modified or managed to provide water for developing human activities and demands.

Reservoirs formed by a dam across the course of a river, with inundation of the upstream land surfaces are called **impoundments**. Water bodies not constructed within the course of the river and formed by partially or completely enclosed water-proof banks are called **off-river or bounded reservoirs**.

3.2 Impoundments, Off–River Reservoirs and Inter-Basin Transfers

Impoundments and off-river reservoirs are the two main artificially created water bodies in which differing amounts of human control are possible. Impoundments tend to be larger than off-river reservoirs. They are both controlled by outlets and inlets. Off-river reservoirs may be isolated from the local terrain by enclosing and water-proofed embankments, whereas impoundments are subject to considerable interaction with the flood plain within which they were formed.

Impoundments tend to have higher watershed area to water surface area ratios than similar natural lakes. They also have a tendency to a sinuous form and a convoluted shoreline as a result of the artificial inundation of a terrain which would not otherwise contain a similar sized natural lake. Impoundments formed by dams are the most common forms of large reservoirs (Veltrop, 1993). They can occur singly or in series on a water course as cascades, where water passing through or released from one impounded section flows into another etc. The creation of cascades yield water quality benefits to the impounded sections downstream by retaining contaminants in the upstream impoundment or pre impoundment. Chemical and biological variables can be affected in lakes and reservoirs downstream of a major impoundment.

Off-river storage is achieved by constructing reservoirs with embankments of the main course but close to the river. These reservoirs are used for water supply purposes, acting as a means of controlling and modifying water quality and quantity transferred from the river to the treatment plant; fish-farming or agricultural purposes. Off-river storage reservoirs are usually filled and emptied by pumping, but some are designed to capture flood flows.

Inter-basin transfer schemes occur in water-poor regions, where water resources engineering efforts have been traditionally directed towards providing water from a variety of sources to centres of human settlement (Petitjean and Davies, 1988). This requires the transfer of water from one watershed to another by pumping, network of canals, balancing reservoirs and storages which make optimum use of gravity flows.

3.3 Characteristics of Reservoirs

Reservoirs in densely populated or agricultural areas, with little management control can be highly enriched although some also have a more rapid flushing regime than natural lakes. There is a high dependence of productive capacity on management regime, source water qualities, and internal chemical and biological process rates.

Reservoirs show many similar hydrodynamic, chemical and biological characteristics as the natural lakes but the operating regime determined by the purpose for which the reservoirs were created may significantly alter their physic-chemical character and biological responses. The peculiar form of a reservoir, its mode of operation, and unnatural location and shape may cause significant variation of the basic limnological behaviour (Straskrabá *et al*., 1993). Reservoirs formed by river impoundments undergo great changes in water quality during the early stages of their formation whilst a new ecological balance is being established.

3.3.1 Thermal Characteristics of Reservoirs

Most reservoirs have the same thermal structure development as natural lakes. If sufficiently deep, reservoirs become dimictic in temperate areas, or monomictic in polar and tropical areas, during their annual cycle. Many reservoirs are polymictic due to their relatively shallow depths or the effects of enhanced flow induced turbulence. Reservoirs constructed on broad flood plains are shallow and more susceptible to multiple mixing than those constructed in confined river channels, canyons or ravines. Large variations in water quality may be induced by internal waves (seiches) at fixed level off-takes at the reservoir shores.

In tropical reservoirs, as with lakes, the onset of stratification occurs over a smaller temperature range as a result of the higher ambient temperatures in these systems (Serruya and Pollingher, 1983). Impoundments can also show a range of thermal patterns at different times of the year because of fluctuating water levels due to their operating regimes. They may be deep enough to stratify while at maximum capacity but shallow enough to mix repeatedly or constantly at lower stage levels. For instance, the use of multi-level off-takes which remove water from the bottom of the reservoir can modify the thermal structure and chemical gradients of reservoirs by selectively removing surface, mid-depth or bottom waters thereby modifying the downstream flow regimes.

Some reservoirs have facilities provided to modify or eliminate thermal stratification. The removal of thermal stratification in a deep reservoir (e.g. mean depth 20 m), gives the sediments abnormal conditions of temperature and oxygenation. Relative to a natural lake, a completely a typical thermal and hydrodynamic regime can be established for reservoirs. Stratification control facilities enhance the natural turbulence in reservoirs, causing considerable modification of the vertical and horizontal distributions of chemical variables, together with biological organisms and their production dynamics.

3.3.2 Chemical Characteristics of Reservoirs

Chemical events in reservoirs are similar to natural lakes but their timing and intensity may differ. Inflow-outflow velocities and water body morphometry affect the characteristics of the reservoir. In reservoirs subject to thermal stratification, the suppression of vertical transport processes at the thermocline allows an oxygen gradient to occur which can cause anoxic conditions in the hypolimnion. The rich sediments of most reservoirs would then ensure the movement of large quantities of iron and manganese into the water column, with the production of hydrogen sulphide.

Hypolimnetic Deoxygenation is more common in tropical and sub-tropical reservoirs because of the higher rates of decomposition of organic materials at ambient temperatures. De-oxygenation is a major problem at the first inundation of tropical impoundments due to the oxygen demand of the decaying, submerged carbonaceous materials exceeding the available oxygen supply until a more stable aquatic regime is established.

In some reservoirs, denitrification can cause a substantial reduction in the inorganic nitrate-nitrogen concentrations compared with the concentrations of the source waters. In deeper, more oxygenated reservoirs, denitrification is a less effective process particularly if the sediments have been exposed and dry out, as may occur in drought years (Whitehead, 1992).

3.3.3 Biological Characteristics

Biological characteristics of reservoirs are similar to natural lakes, but the peculiar physico-chemical conditions, which occur in managed reservoirs, can produce biological production and ecological successions different in degree and timing from an equivalent natural lake. The biology of reservoirs is influenced by:

1. The effects of greater flow-through and turbulence.
2. The nutrient loading they normally receive.
3. The plankton populations of the inflows relative to those in the reservoir itself.
4. The management controls applied and their effects.

Increased turbulence can maintain phytoplankton in suspension or affect productivity by carrying them into deeper waters with insufficient light penetration to support photosynthesis. The increased turbulence can also maintain greater amounts of organic material in suspension, sustaining filter-feeding zooplankton when food resources might otherwise be much lower and limiting to their growth.

Extreme water level fluctuations of some reservoirs affect the establishment of rooting macrophytes and spawning areas for fish. The unusual vertical profiles of temperature and chemical variables present abnormal conditions for benthic organisms. Both reservoirs and natural lakes) may have issues of eutrophication as shown by enhanced phytoplankton growth. High phytoplankton densities cause problems for recreational users, treatment processes in drinking water supply and directly to consumers since they produce unwanted colour, taste and sometimes toxins. Warm water reservoirs (tropical/sub-tropical) may have problems with floating plants, such as *Eichhornia crassipes* (Van der Heide, 1982). Excessive macrophyte growths can significantly reduce dissolved oxygen concentrations in the water when they decompose; interfere with fishing and restricting potable and industrial use.

As in natural lakes, trophic relations in reservoirs vary from simple food chains to highly complex food webs. In reservoirs with simple morphometry, the possible absence of littoral zones and macrophyte refuges for herbivorous zooplankton can increase the zooplankton's exposure to predation by fish. Large fish stocks can deplete herbivorous zooplankton populations to levels which enable phytoplankton populations to grown restrained by any grazing by zooplankton (i.e. to the limits of nutrient or energy availability).

Factors which reduce fish stocks can allow zooplankton populations to reach levels which deplete phytoplankton populations through grazing even when phosphateis in excess. In reservoirs with a varied morphology (different shoreline habitats as well as sheltered and exposed and deep and shallow areas), many other inter-trophic effects may also take place because the niche diversity is sufficiently high to allow the coexistence of much more varied biological communities (Benndorf etal., 1988).

3.3.4 Microbiology

The microbiological characteristics of reservoirs are similar to lakes and the main source of energy for bacterio-plankton is decomposable organic material. Seasonal changes in bacterial populations relate mostly to seasonal variations in source water conditions and the primary productivity in the reservoir.

Microbiological activity is important in the degradation of organic compounds of industrial origin which are frequently present in the source waters of lakes and reservoirs in highly populated and industrialized areas. Together with dilution and elimination of the source of the organic contaminants, microbial breakdown is a major factor in maintaining a satisfactory drinking water quality in some reservoirs.

Many reservoir source waters contain viral and bacterial pollution because of effluent disposal and run-off. Reservoirs can form a barrier to the survival of pathogenic micro-organisms. Water storage for 20 days or more reduces river water coliform concentrations to about 1 per cent of initial value, due to the relatively alien reservoir temperature, exposure to ultra-violet radiation, and ionic conditions. This effect appears to be maintained even when reservoirs are subject to substantial mixing for thermal and chemical control purposes.

3.4 Water Quality Issues in Reservoirs

The water quality issues of concern in reservoirs are similar to those of natural lakes but there are some differences. Some issues of major concern in lakes are less of a general problem in reservoirs. For example, reservoirs are less susceptible to acidification than natural lakes.

3.4.1 Eutrophication

Reservoirs, like natural lakes, are affected by eutrophication. Some reservoirs undergo the full process of gradual ageing that ultimately converts lakes to wetlands and to terrestrial biomes (Rast and Lee, 1978).The time period is shorter than the geological time scale associated with most natural lakes.

Reservoirs are also susceptible to cultural eutrophication or an increased rate of ageing caused by human settlement and activities in the watershed. Some impoundments may be more productive than their natural counterparts because of their generally larger watershed areas and terminal location. High flushing rate is related to the greater watershed area delivering the water load to the reservoir than natural lakes. Artificial control of the normal responses to increasing eutrophication is possible in reservoirs. A reduction in the efficiency of primary production can take place even in the presence of large quantities of phosphorus and nitrogen.

Other measures to reduce nutrient concentrations within reservoirs are the use of flow by-passes, pre-impoundments, scour valves discharging nutrient-rich hypolimnetic (bottom) water, and modifications to the operating regime which can alter the effects of water and nutrient loads within the reservoir. Many other procedures (such as sediment removal, flocculation and flow control) have also been shown to be potential modifiers of the response of a reservoir to eutrophication (Jorgensen and Vollenweider, 1989; Ryding and Rast, 1989).

Drawdown by the withdrawal of aerobic surface waters for drinking water or irrigation supply purposes can make a reservoir more susceptible to overturn. This can introduce nutrient-rich bottom waters to the euphoticzone, enhancing algal growth and creating an intensified oxygen demand throughout the water column. Similarly, release of anoxic, hypolimnetic water from the eutrophic reservoirs can cause fish mortalities in the downstream waters.

3.4.2 Public Health Impacts and Contaminants

The construction of a reservoir can provide an avenue for transmission of diseases and their occurrence in areas where such diseases did not previously exist. For example in the tropics, where the construction of reservoirs has been implicated in the epidemic spread of river blindness (onchocerciasis), bilharzia (schistosomiasis), and guinea worm disease (dracunculiasis).

Industries and urban settlements in the drainage basin of, reservoirs compound human health problems through the release of contaminants and discharge of wastewaters to these water bodies or their source waters. The presence of a reservoir can attract development that could not otherwise be sustained due to a lack of process and drinking water. Contaminants of concern in reservoirs with respect to human and animal health include synthetic organic compounds, nitrates, pathogenic bacteria, viruses, and cyanobacterial toxins.

3.4.3 Stalinisation

Many reservoirs are situated in arid and semi-arid areas and for these reservoirs the problem of Stalinization (or salination/mineralisation) can be severe. Irrigation of these areas can cause leaching of salts from the soils, and transport to the reservoirs. Highly seasonal rainfall increases the evaporative concentration of the salinities in the water bodies during the dry season. High salinities limit the uses of the waters.

3.5 Differences between Natural and Man-Made Lakes

i. Reservoirs have larger drainage basins and surface areas than natural lakes. They receive larger river or stream inputs, nutrient loadings and are not intercepted by wetlands as natural lakes.
ii. Natural lakes are mostly located at the headwaters or sources of rivers or streams but manmade lakes are closer to the mouth of the river or stream.
iii. Levels of water in reservoirs are managed to meet the needs of man for hydroelectric power, agriculture etc. Low dissolved oxygen-containing water is released downstream with associated water quality problems but water released from natural lakes is usually well aerated.
iv. In reservoirs, sediments are released but alternate exposure and flooding of sediments does not allow vegetation or wetland growth. Release of excess nutrients by sediments causes increased algal growth. Excess sediments fill reservoirs faster than natural lakes giving them shorter lifespan than natural lakes
v. Living organisms in man-made lakes may differ from those in natural lakes. Stocking of fish in man-made ponds develops a different food chain from those in natural lakes. Impoundments disturb the natural cycles like migratory patterns and may change reproductive behavior of some fish.

vi. The differences in flow and sediments alter the base of the food web to one of suspended algae (phytoplankton), rather than the attached algae (periphyton) and detrital material that form the food base in rivers and streams.

vii. Natural and man-made lakes are water stores located in topographic depressions; receive inflows from more than one source. The outflow in natural lakes depends on water levels in the lake which results from natural inflows. In manmade lake, there are at least two outflows namely flows to the river and withdrawals for various uses.

viii. The water in a lake is the main hydrological variable and fluctuates naturally but the water levels of man-made lakes are dependent on the desire s of the reservoir‘s management. When a river becomes a lake, water becomes more exposed to evaporation and river runoff decreases. The creation of a reservoir in a river valley also changes the ecosystem such as changes in types of species.(Schultze, 1991)

4.0 CONCLUSION

Reservoirs serve several important functions such as water and hydroelectricity supply. They have similarities to and differences from natural lakes. They have public health significance due to the fact that some disease vectors and conditions may suddenly appear in areas not previously known due to the presence of reservoirs.

5.0 SUMMARY

In this unit, we discussed the characteristics of man-made with special reference to reservoirs which are usually created in areas of scarce or excess water resources to meet specific human needs. Due to the fact that they are more subject to control and management by man, they tend to have some characteristics that differentiate them from natural lakes.

6.0 TUTOR-MARKED ASSIGNMENT

1. Give the definition of reservoir and impoundments.
2. Discuss impoundments, off-river reservoirs and inter-basin transfers.
3. State the characteristics of reservoirs.
4. Explain the water quality issues in reservoirs.
5. Differentiate between natural and man-made lakes.

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UNIT 3 AQUATIC CHEMISTRY

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1.0 INTRODUCTION

Precipitation in the form of rainfall, snow, hail etc. is the source of all freshwater. Several properties are unique to natural water and impurities tend to change these properties. In this unit, we shall discuss the chemistry and some parameters important to water.

2.0 OBJECTIVES

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

- explain water chemistry and chemical constituents of natural waters
- discuss surface water and definitions of terms used in aquatic chemistry
- analyse alkalinity attributes and alkalinity cum carbon dioxide solubility

- distinguish between total hardness and mineral acidity
- discuss dissolved oxygen and its attributes
- discuss nitrogen, phosphates and phosphorus in natural water
- identify sulphur and organic matter in natural water.

3.0 MAIN CONTENT

3.1 Water Chemistry - Chemical Constituents of Natural Waters

The composition of natural waters depends on physical, chemical and biological factors. Precipitation (rainfall, snow, hail etc) is the source of all freshwater. Natural waters have properties such as alkalinity, acidity, dissolved oxygen, carbon dioxide, hardness, salinity, particulate organic matter dissolved organic matter, inorganic matter, oxidation-reduction potentials etc.

Iimpurities - sea salts, dust, industrial emissions from the atmosphere are nuclei for the condensation of water vapour to form clouds. Rainfall is slightly acidic as it contains carbon dioxide. Pollution of the atmosphere by the products of combustion of fossil fuels e.g. sulphur and nitrogen compounds make precipitation strongly acidic. Natural fresh waters contain alkali and alkaline earth metals, bicarbonates, carbonates, sulphates and chlorides, silic acid, organic and inorganic colloidal materials. Several gases are also dissolved in water.

3.2 Surface Waters

Runoff is the precipitation that flows over land without sinking into the soil or evaporating into the atmosphere. Water flowing over land dissolves substances from rocks and soils depending on the composition, solubility of geological formations, time of contact between water and mineral matter. Flowing water also dissolves organic compounds and contains particulate matter in dissolved or suspended forms. Several reactions occur between water and sediments or soils, different dissolved substances, and between dissolved and suspended substances.

Evaporation and dilution by freshwater increase or decrease concentrations of dissolved substances in water respectively. Biological processes e.g. respiration and photosynthesis alter the composition of water through the uptake or addition of metabolites, dissolved oxygen and carbon dioxide.

Surface waters vary in chemical composition and differ among regions of different geology and climate. Common substances found in water include:

(1) **Gases**: Oxygen, carbon dioxide, nitrogen, ammonia, hydrogen sulphide and methane.

(2) **Mineral Constituents**: Calcium, magnesium, sodium, potassium, iron, manganese, aluminum, zinc, copper, molybdenum, cobalt, carbon, phosphorus, nitrogen, sulfur, chlorine, fluorine, iodine, boron and silicon usually present as ions, complex organic or inorganic molecules.

(3) **Soluble Organic Matter**: Sugar, acids, humic acids, tannin, vitamins, amino-acids, peptides, proteins, plant pigments, urea and many other biochemical compounds.

(4) **Suspended Organic Matter**: Colloidal clay, coarse suspensions of soil particles, colloidal or suspended decayed or decaying organic matter, living phytoplankton, zooplankton, fungi and bacteria.

Concentrations of substances in water are expressed as mg/liter or μg/liter, part per million (ppm), parts per billion (ppb), or milli equivalents/liter (meq/liter).

3.3 Definitions

Alkaline water contain high levels of alkali metal cations especially sodium and potassium.

Biochemical or biological oxygen demand is a measure of the amount of oxygen removed from aquatic environments during respiration of aerobic microorganisms in the water column or sediments. Biochemical Oxygen Demand (BOD) is carried out by incubating samples for 5 days at 20^0C. It estimates the amount of "biodegradable" organic matter in the system.

Chemical oxygen demand is the oxygen equivalent of the dichromate used up during oxidation of raw water sample. It is a measure of organic matter.

Organic matter is the weight loss after ignition at 550^0C of the residue on the filter from the total particulate matter determination.

Salinity is the total concentration of all ionic constituents present in a water sample.

Settleable solids are the volume or weight of solid material which settles in one hour to the bottom of a 1m off cone containing a measured volume of water.

Specific Conductance (Electrical Conductivity or Conductivity) is the ability of a water sample to conduct an electrical current. The specific conductance of water increases with increasing concentrations of total dissolved solids and is measured in microSiemens per centimeter (μS/cm).The specific conductance increases with increasing temperature

Total dissolved solids describe the total amount of ions dissolved in water. It is the total residue remaining after the evaporation of a water sample which had been filtered to remove suspended matter.

Total non-volatile solids are the difference between total solids and total volatile solid. It represents inorganic substance.

Total particulate matter is the dry weight of matter retained on a fine filter. This fraction includes inorganic particles, living and dead organic matter.

Total solids describe the total residue left after the evaporation of raw water sample. It includes dissolved substances without dissolved gases, carbon dioxide from bicarbonates, and all suspended matter.

Total volatile solids are the loss of weight upon ignition of the total residue at 550^0C. This weight loss represents organic matter.

3.4 Alkalinity

Alkalinity measures acid-neutralizing capacity of a solution. It is the sum of the concentration of bases that can be titrated against a strong acid. The **acidity** can be defined as the negative of alkalinity. The total titrable bases in water expressed as equivalent $CaCO_3$ are referred to as total alkalinity. In most waters, HCO_3^-, CO_3^{2-} or both are the predominant bases. Alkalinity comes mainly from bicarbonate (HCO_3) and carbonate (CO_3^{2-}) ions. There are three types of alkalinity namely:

- bicarbonate alkalinity
- carbonate alkalinity
- hydroxide alkalinity

The alkalinity of water depends on carbonate contents of rocks, soils of watersheds and bottom mud. High total alkalinity is due to high carbonate deposits in the surrounding soils. Natural waters containing 40mg/liter or more total alkalinity as equivalent $CaCO_3$ are hard waters, while waters with lower alkalinities are soft. Hard waters are more productive than soft waters because of higher levels of phosphorus and other essential elements associated with increased alkalinity.

3.5 Alkalinity and Carbon Dioxide Solubility

Carbon dioxide (CO_2) is very soluble in water though it is a minor constituent of the atmosphere. Carbon dioxide acts as an acid in water:

$H_2O + CO_2 \rightleftarrows H_2CO_3$
$H_2CO_3 \rightleftarrows H^+ + HCO_3$

It is usually assumed that CO_2 cannot make water more acid than pH4.5.Bicarbonate resulting from the dissociation of carbonic acid dissociates to give carbonate.

$HCO_3 \rightleftarrows H^+ + CO_2$

Natural waters contain bicarbonate ions from the ionization of carbonic acid in water saturated with $CO_{2.}$ The carbon dioxide in natural waters reacts with bases in rocks and soils to form HCO_3^-, e.g. calcite ($CaCO_3$] and dolomite ($CaMg(CO_3)_2$)

$CaCO_3 + CO_2 + H_2O \rightleftarrows Ca^{2+} + 2HCO_3^-$
$CaMg(CO_3)_2 + 2CO_2 + 2H_2O \rightleftarrows Ca^{2+}\ Mg^{2+}\ 4HCO_3^-$

Both calcite and dolomite are poorly soluble in water. Feldspar is also attacked by carbon dioxide to give HCO_3^-.

$NaAlSi_3O_8 + CO_2 + 5½\ H_2O \rightarrow Na^+ + HCO_3^- + 2H_4SiO_4 + ½\ Al_2Si_2O_5)\ OH)_4$

Reactions involving the formation of HCO_3^- from carbonates are equilibrium reactions and a certain amount of CO_2 must be present to maintain a given amount of HCO_3^- in solution. The amount of carbon dioxide at equilibrium is increased or decreased .At equilibrium there will be a corresponding change in the concentration of bicarbonate ion. Dilute HCO_3^- solutions at equilibrium are weakly alkaline. This results because HCO_3^- can act either as a base or an acid.

$HCO_3^- + \rightleftarrows H_2O + CO_2$
$HCO_3^- \rightleftarrows H^+ + CO_3^{2-}$

Although the concentration of CO_2 in the atmosphere is low (0.033%), the CO_2 in water is relatively high. Photosynthesis requires carbon dioxide, and CO_2 is released during biological activities such as respiration or decay of organic matter. Carbon dioxide is very soluble in water and forms carbonic acid, which dissociates, raises the concentration of hydrogen ions and lowers the pH. The relative proportions of bicarbonate, carbonate, and free carbon dioxide depend upon the pH. At high pH, carbonate ions predominate but at low pH, free carbon dioxide and carbonic acid dominate.

The carbonates, sodium, calcium, potassium, and magnesium are important for carbon dioxide equilibrium in waters. They enter water when dissolved from carbonate rocks. Increased pressure of carbon dioxide in the system increases the carbonate solubility. Photosynthesis can also cause the precipitation of some carbonates. Biological activities producing or consuming CO_2 alter the equilibrium of inorganic carbon forms and pH. The consumption of CO_2 during photosynthesis removes H^+ and raises the pH; the biological oxidation of organic matter produces $CO_2$and lowers the pH.

The carbon dioxide system behaves as a buffer, because, a change in pH will cause a shift within the system that ultimately serves to offset the pH change. Most lakes have a pH between 6 and 8, but in nature also extremely acid volcanic lakes have pH values below 4. Some lakes have very high pH values (they are called soda lakes).

In freshwaters, calcium ion is associated with bicarbonate and carbonate ions. When $[CO_3^{2-}]$ increases appreciably, calcium carbonate precipitates. Photosynthesis removes carbon dioxide from water during the day and this increases pH.

pH of soft water ponds with heavy phytoplankton blooms may reach 9 or 10 during periods of intense photosynthesis. During the night, respiratory processes release carbon dioxide into the water and pH declines.

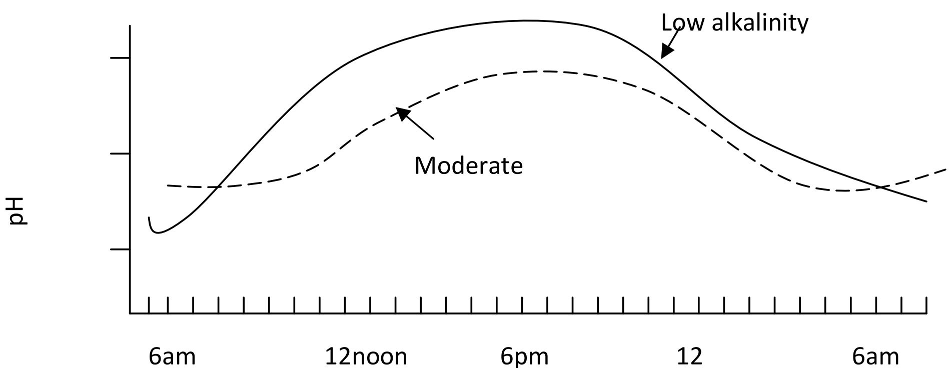

Fig 4: Diel Fluctuations in pH of Pond Water
(Source: Boyd, 1979)

Removal of CO_2 causes shifts in concentration of HCO_3^- and CO_3^{2-} during a diel cycle. During warm periods in eutrophic water, photosynthesis may exceed respiration so that early morning pH values gradually increase during the season.

3.6 Total Hardness

Calcium and magnesium are associated with carbonate minerals, the main sources of alkalinity in water. Divalent alkaline earth metals react with soap to form a precipitate. Waters containing high concentrations of any alkaline earth metals are called **hard waters**. Calcium and magnesium are the most abundant alkaline earth metals in fresh waters and their concentrations are equivalent to $CaCO_2$ hardness. Alkalinity and hardness are closely related. Water is categorized according to differences in hardness as 0 – 75 mg/litre (soft);75 – 150 mg/litre (moderately hard);150 – 300 mg/litre (hard) and300 plus mg/litre (very hard).

Carbonate hardness is the part of total hardness chemically equivalent to the total alkalinity. Carbonate hardness is also called **temporary hardness** because it precipitates on heating. When the alkalinity is equal to or greater than the total hardness, the carbonate hardness equals the **total hardness.** The carbonate hardness is the source of boiler scale from boiled water.

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$$

If the total hardness of water exceeds the total alkalinity, the water contains **non-carbonate hardness or permanent hardness,** which cannot be removed by boiling.

Total hardness – carbonate hardness = non-carbonate hardness

3.7 Mineral Acidity

The most common cause of mineral acidity in natural waters is sulphuric acid from the oxidation of iron pyrite.

$4FeS_2 + ISO_2 + 2H_2O \rightarrow 2Fe_2(So_4)_3 + 2H_2So_4$

Water receiving drainage from coalmines usually contains mineral acidity; some marine sediment contains deposits of sulphide compounds called "Cat Clay". Sulphide exposed to air oxidizes to sulphuric acid. Cat clay is found along coastal plains and ponds constructed on such formations may contain extremely acidic water.

3.8 Dissolved Oxygen

Dissolved oxygen (DO) concentrations decrease with increasing temperature and salinity. Water that contains the amount of DO it should at a given temperature, pressure and salinity is saturated with oxygen. Waters containing less than or more than the saturated concentrations of dissolved oxygen are **under saturated** or **supersaturated** with oxygen respectively.

Oxygen saturation is expressed as percent saturation and water saturated with O_2 is at 100 per cent saturation. The solubility of oxygen in water can also be expressed as **oxygen tension,** which represents the partial pressure of oxygen in the atmosphere required to hold a certain concentration of oxygen in the water. Oxygen concentration may also be reported as mg/litre. Dissolved oxygen concentrations constantly change in natural waters because of several biological, physical and chemical processes. Transfer of oxygen from air to water occurs when water is under saturated with dissolved oxygen. Water that is supersaturated with oxygen loses some to the air through diffusion. The net transfer of oxygen between air and water is due to the difference in oxygen tensions. Once equilibrium is reached, oxygen tensions in the air and water are the same, transfer ceases. The diffusion of oxygen into natural waters is slow except under strong turbulence.

Photosynthesis by aquatic plants is the most important source of oxygen in water. Oxygen release by phytoplankton is greatest near the surface and decreases with depth because of self- shading. Ponds with high densities of phytoplankton (eutrophic) have higher rates of oxygen production near the surface than ponds with less phytoplankton, but oxygen is produced to greater depths in ponds with lower densities of phytoplankton (oligotrophic). Factors affecting photosynthesis are temperature, light, nutrient concentrations, plant abundance, turbulence, and several other factors. Nutrient concentrations and phytoplankton abundance are high under high temperatures. Light penetration into ponds is regulated by suspended or colloidal particles (turbidity). Plankton increase turbidity by limiting light penetration. Rates of photosynthesis vary at different depths due to differences in nutrient concentration and light penetration.

Compensation point is the depth at which oxygen from photosynthesis equals that used in respiration and corresponds to the depth of the **euphotic zone**.

3.8.1 Diel Fluctuations of Oxygen

During the day, photosynthesis releases oxygen faster than it is used up in respiration but respiratory activity uses oxygen throughout the day. This pattern of daytime production and continuous use of oxygen leads to **diel fluctuation** of DO concentrations in the euphotic zone. Maximum concentration of DO occurs during the afternoon and minimum concentrations at dawn. Increasing phytoplankton abundance causes more organic production and greater respiration rates. A pond with a heavy bloom of plankton has wide fluctuations in diel DO concentrations. Moderate plankton production allows more stable DO regimes.

Vertical mixing and increased wind stirring replenish lakes with oxygen. In warm seasons, oligotrophic or non-productive, lakes' surface waters may remain as well saturated as deep waters. The oxygen concentration is almost uniform in the water column. In eutrophic or very productive lakes, surface waters can be supersaturated but deep waters depleted of oxygen due to biological decomposition. Freezing of surface water may reduce oxygen content to anoxic levels in bottom layers of eutrophic lakes. Fish die when the oxygen concentration is less 2 mg L^{-1}.

3.9 Nitrogen

Nitrogen is the most abundant gas in the atmosphere (about 79%). Living organisms require large quantities of nitrogen for proteins, nucleic acids and other cellular constituents. Nitrogen is a very inert gas and cannot be used directly by organisms. It must be "fixed" or combined with other elements to form more reactive compounds such as ammonium ion (NH4+) or nitrate ($NO3^-$).

Nitrogen enters water from biological activities such as nitrogen fixing bacteria, bacterial degradation of organic matter or human activities on land

and precipitation. In the aquatic environment the only organisms that can fix atmospheric nitrogen are anaerobic photosynthetic bacteria and cyanobacteria. Nitrogen appears as free nitrogen in solution, organic compounds, ammonia, nitrite, and nitrate. Losses of nitrogen occur mainly through effluents, denitrification, sediment formation and loss to the atmosphere.

3.10 Phosphates / Phosphorus

The most important phosphorous compounds in water are orthophosphate and organic phosphates. Phosphates and nitrates are used in large amounts in the upper layers of water during high productivity of phytoplankton. High concentrations of phosphorus occur in deeper layers of water due to mineralization from biological material in the sediments, especially during anoxic conditions. Phosphorus and (or) nitrogen are the limiting nutrients in fresh water.

3.11 Sulphur

Sulphur occurs as sulphate ion in freshwater. If the bacterial oxidation of biological material e.g. protein at the lake bottom occurs under anaerobic conditions, sulphur is reduced to hydrogen sulphide characterised by unpleasant odour.

3.13 Organic Matter

The lake water contains, in suspension and colloidal solution different amounts of organic matter from biological activity within the lake (autochthonous substances e.g. excretion and secretion by organisms, dead organisms) or from catchment areas (all ochthonous substances e.g. soil leaching, domestic and industrial wastes). The organic matter is determined as CO_2 coming from its oxidation at high temperature so that the expression organic carbon is often used instead.

i. **Volatile Organic Matter (VOM)**
   The VOM is made of both man-made and naturally- occurring chemical compounds, which have significant vapor pressures. The VOM has a tendency to evaporate at temperatures at which water is still liquid.
ii. **Dissolved Organic Matter**
   The Dissolved Organic Matter (DOM) is the fraction containing particles smaller than 1 - 0.2 µm. It contains mainly simple molecules such as sugars, amino acids, which are rapidly utilized by

bacteria. These molecules are released during photosynthesis. They are also called **extracellular organic carbon (EOC)**. DOM includes a "bioactive" fraction, which includes biochemically active molecules such as enzymes, vitamins and hormones. There are also all ochthonous substances from the degradation products of lignin or soil humus e.g. fulvic and humic acids. They are also called **"Colored Dissolved Organic Matter" (CDOM)** because they colour the water yellow-brown. Some CDOM have very high molecular weights and are colloids **(COM: Colloidal Organic Matter)**. They are not easily mineralised by bacteria and are called **Refractory Dissolved Organic Matter (RDOM)**.

iii. Particulate Organic Matter (POM)

This is the fraction made of detritus (dead organisms and fragments of cells or organisms) and the organisms (bacteria and protozoa and sometimes algae) colonising it. **Seston** is used to indicate the pool of small organic and inorganic particles, living and nonliving, suspended in water. The term **tripton** identifies the inorganic component of seston.

4.0 CONCLUSION

Natural waters contain several chemical constituents such as gases (oxygen, carbon dioxide, nitrogen), nutrients (sulphur, phosphates, nitrates, organic matter) and characteristics (total hardness, alkalinity, acidity). These characteristics allow water to be a habitat for aquatic organisms.

5.0 SUMMARY

In this unit, we discussed the different aspects of aquatic chemistry such as gases (e.g. oxygen, nitrogen), alkalinity, hardness, photosynthesis and pH, organic matter and some important mineral elements (sulphur, phosphorus). Each was mentioned giving its unique relevance in the aquatic environment.

6.0 TUTOR- MARKED ASSIGNMENT

1. Explain water chemistry and chemical constituents of natural waters.
2. Discuss the attributes of surface water and give definitions of terms used in aquatic chemistry.
3. Analyse the alkalinity attributes and alkalinity cum carbon dioxide solubility.
4. Explain total hardness and mineral acidity in natural water.
5. Discuss dissolved oxygen and its attributes.

6. Analyse nitrogen, phosphates and phosphorus in natural water.
7. Explain sulphur and organic matter in natural water.

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MODULE 2

Unit 1 Physicochemical Properties of Freshwater
Unit 2 Physicochemical Properties of Brackish Water
Unit 3 Physicochemical Properties of Marine (Sea) Water

UNIT 1 PHYSICOCHEMICAL PROPERTIES OF FRESHWATER

CONTENTS

1.0 Introduction
2.0 Objective
3.0 Main Content
3.1 Characteristics of Water
3.2 Latent Heat
3.3 Water Density
3.4 Alkalinity and Acidity
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/Further Reading

1.0 INTRODUCTION

Water has a different behaviour from other liquids due to the configuration of its molecules that produces weak hydrogen bonds. It exists in three states as solid, liquid and gas Water behaves as other liquids until the temperature decreases to 4°C when it exhibits an anomalous behaviour.

2.0 OBJECTIVES

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

- state the characteristics of freshwater
- explain latent heat and water density
- discuss acidity and alkalinity of water.

3.0 MAIN CONTENT

3.1 Characteristics of Freshwater

Water molecule contains one atom of oxygen and two of hydrogen. Both hydrogen atoms are on one side of the molecule while the molecules' electrons are clustered on the opposite side of the molecule. This makes water **polar** – one side is positively and the other side negatively charged (**dipolar**).The positive charge of one molecule is attracted to the negative charge on another molecule. This attraction forms a weak **hydrogen bond** which is weaker than the bond between the atoms.

The hydrogen bonds give water some of its unique characteristics such as **surface tension, cohesion** (molecules pull together to form droplets), **capillarity** (the ability to pull up a narrow tube like capillary tube or xylem of plants), water molecules have the ability to adhere to themselves and to other polar substances e.g. atoms in common salt – NaCl molecules are held together by ionic bonds. Water molecules interact with other molecules and can dissolve most substances except non polar substances like oil (**universal solvent**).

Water exists as solid, liquid and gas. To change the state of a substance, bonds between molecules must be broken. The amount of energy needed to raise the temperature of water by 1˚C is the **specific heat capacity**. If enough energy is added to ice, the bonds break and it becomes liquid water. The temperature at which this occurs is the **melting point**. If enough energy is added to water, it turns to gas or vapour. The temperature at which boiling occurs is called the **boiling point**. If the energy is removed, the gas reverts back to liquid and this happens at the **condensation point**. More energy removal turns liquid water into solid or ice at the **freezing point**.

3.2 Latent Heat

The heat energy needed to turn 1g of a substance at the boiling point temperature from liquid to gas is the **latent heat of vaporisation**. The heat that needs to be removed to turn 1 g of a substance from gas to liquid is **latent heat of condensation**. The heat energy needed to be removed to turn 1g of a substance at the melting point temperature from liquid to solid is **latent heat of freezing or latent heat of fusion**.

For a water molecule to escape from the surface, it must take energy from surrounding molecules to change to gas. This loss of energy cools the remaining molecules (**latent heat of evaporation**). The energy required is greater than the latent heat of vaporisation. These high heat exchanges allow life on earth. Energy is transferred from hot regions to colder areas. Water evaporates in warm regions. In colder regions, the water is released as precipitation (releasing heat). Heat is also released when ice forms, warming higher latitudes.

3.3 Water Density

Density is mass divided by volume or mass per unit volume. The density of pure water is $1 g/cm^3$. For all substances, density increases when they cool. Molecules lose energy and slow down coming close together. This is called **thermal contraction**. The density of water increases as it becomes cooler. Cold water is heavier than warm water. From 4˚C to 0˚C, the density of water decreases (Water expands instead of contracting). Ice is less dense than liquid water. Below 4 ˚C, crystals form. The crystals are large, bulky and take up more volume than liquid water. When water freezes, its volume increases by 9%.

3.4 Alkalinity and Acidity

An acid is a compound that releases hydrogen ions (H^+) when dissolved in water. An alkali or base releases hydroxyl ions (OH-) when dissolved in water. H^+ and OH^- are always present in small quantities because water molecules dissociate and reform. In pure water, H+ and OH- are present in equal amounts. Therefore the solution is neutral (pH=7). The pH scale measures acidity and alkalinity of substances. Carbon dioxide reacts with water forming acid and releasing hydrogen i.e.

$$H_2O + CO_2 \longrightarrow H_2CO_3 \; H^+ + HCO_3$$

Carbonic acid

4.0 CONCLUSION

Freshwater bodies are found in streams, ice/glaciers, groundwater, atmospheric, water etc. They have low salinity and can be used directly for industrial and domestic processes. They exhibit unique characteristics that differentiate them from other liquids.

5.0 SUMMARY

In this unit, we discussed the unique characteristics displayed by water such as high latent heat, ability to dissolve several elements and compounds including pollutants and contaminants. The density of water increases as it becomes colder but decreases between 4 and 0◦ C which is why ice floats on water.

6.0 TUTOR –MARKED ASSIGNMENT

1. Discuss the characteristics of water.
2. Explain latent heat and water density.
3. Distinguish between alkalinity and acidity.

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UNIT 2 PHYSICOCHEMICAL PROPERTIES OF BRACKISH WATER

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  3.2 Common Features of Estuaries
  3.3 Biological Features of Estuaries
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/Further Reading

1.0 INTRODUCTION

Brackish water is found at the meeting points between the fresh and saltwater environments. Estuaries represent the main brackish water environment. The water in estuaries varies depending on factors such as the tides and currents.

2.0 OBJECTIVES

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

- define what brackish water is
- discuss common features of estuaries
- highlight biological features of estuaries.

3.0 MAIN CONTENT

3.1 What is Brackish Water?

Freshwater, brackish and sea water can be differentiated based on salinity. **Brackish water** or **briny water** is water that has more salinity than fresh water, but not as much as seawater. It may result from mixing of seawater with fresh water, as in estuaries, or may occur in brackish fossil aquifers. Brackish water contains between 0.5 and 30 grams of salt per litre or 0.5 to 30 parts per thousand (ppt or ‰). Thus, brackish water covers a range of salinity regimes. The salinity of brackish surface waters can vary considerably over space and time. Brackish water condition occurs when fresh water mixes with sea water. The most extensive brackish water habitats are estuaries, where a river meets the sea. Brackish water is also found in salt marshes.

An estuary is a partially enclosed body of water where a river or stream meets the sea. Estuaries form the transition zones between the ocean and river environments. They contain a mixture of salt and fresh water with high levels of nutrients. They are among the most productive ecosystems in the world. Estuaries filter out sediments and pollutants from land –based sources. Estuaries are subject to marine influences (waves, tides, inflow of saline water) and river influences (fresh water flows and sedimentation).

The daily tides greatly influence the estuary environments and are dependent on factors like coastal shape, local winds, water depth, and water restrictions. The daily tides affect the abundance and distribution of plants and animals.

3.2 Common Features of Estuaries

Rivers provide continuous inputs of sediments into estuaries. Turbidity is a measure of the amount of suspended particles including fine sediments in water. Circulation within estuaries redistributes the suspended sediments and maximum turbidity occurs where fresh water from rivers meets with seawater.

There are chemical interactions between sediment particles and dissolved ions in sea water resulting in attraction between particles causing flocculation (particles stick together).The heavy particles settle out of the water column and are deposited. Most estuaries efficiently retain dissolved and particulate materials and so estuaries are very susceptible to pollution.

Salinity constantly changes in estuaries. The regular salinity change in estuaries is an important feature. The degree of salinity is influenced by tides, melting snow, heavy precipitation and dry periods or droughts.

Salinity varies within an estuary. It can be weak upstream of estuaries (about 0.5ppt) and very high downstream (up to 30 ppt).The zone where freshwater change to salt water is called a**pycnocline.** The degree of salinity can also be influenced by factors such as the level and intensity of the tides, the melting of snow in the spring, heavy precipitation, and dry periods during the summer season. An out-going tide can reduce salinity slightly.

The fresh water from rivers is lighter than seawater and flows on top of the seawater. If the estuary is deep enough, it may form a **salt wedge** where the fresh water flows over seawater for some distance into the sea while salt water flows under the fresh water for some distance into the river with low salinity up and high salinity below). In salt wedge estuaries, there is low turbulence and little mixing of water; there is very little salt in surface water and high salinity at the bottom.

Temperature

Temperatures of estuaries tend to be higher than sea surface temperature because estuaries are shallow and semi enclosed. Temperature is one of the main elements influencing reproduction of invertebrates and fish. Cold temperatures can negatively affect fish in their planktonic stages, slowing down the hatching and growth of the young.

Tides

Rise and fall of tides cause turbulence and upwelling of water and nutrients from the bottom to the surface. With the rise and fall of tides, nutrients are also brought into the estuary. Estuaries are usually funnel-shaped and incoming tides at the mouth tend to increase in amplitude as the channel narrows. The frictional contact from the shore and bottom act against the tide and tend to lower the height of the tide. The rise and fall of tides can be felt far up-river, especially in bigger estuaries.

Currents

In the estuary, river and tidal currents play a significant role in mixing the lower and upper layers of water. The estuarine circulation is important in determining the productivity of the estuaries.

Sediment

An estuary changes constantly and accumulates sediments from rivers, streams, brackish marshes located inland, salt marshes and sand dunes located near the mouth of the estuary. Sediments can be made of animal and plant matter, or inorganic material like mud or sand.

3.3 Biological Features of Estuaries

Phytoplanktons are minute plants such as dinoflagellates. Phytoplankton, along with bacteria and fungi, are the basis of life in the estuary and are carried by the currents. In order to survive, they must remain in a place where the salinity fits their needs. They use the sun and the nutrients from rivers and salt marshes to feed themselves.

Zooplanktons are the tiny animal part of plankton. In estuaries, zooplankton benefit from an abundant food supply: phytoplankton, microscopic algae, bacteria, and detritus coming from dead plants and animals.

Only certain types of plants can flourish in estuaries, and each of these plants can grow in only certain parts of the estuary. A major factor influencing the growth and distribution of plants in an estuary is its salinity or the amount of salt in the water. Some plants tolerate high concentrations of salt, and have special salt pore on their leave to lose excess salt. Other plants cannot tolerate salt and grow only where seawater cannot reach. Some plants can tolerate moderate concentrations of salt and can survive in brackish (or slightly salty) areas of the estuary.

Another factor affecting plants in an estuary is the amount of flooding. The longer and deeper an area is flooded with water, the less oxygen is available in the soil. Plant roots need oxygen to grow and survive and should be adapted to an oxygen shortage. Some plants transport oxygen from special storage cells in their leaves and stems to roots.

4.0 CONCLUSION

The brackish water environment has some unique qualities which depend on the dominance of either the marine or fresh water system. Low salinities reflect the dominance of inflowing fresh water from the rivers while high salinities depict sea water influence. These qualities can change within short time intervals which will also affect changes in water quality.

5.0 SUMMARY

In this unit, we discussed the physicochemical characteristics of briny or brackish water which vary easily due to both marine and brackish water influences.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is brackish water?
2. Explain the common features of estuaries.
3. Analyse the biological features of estuaries.

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UNIT 3 PHYSICOCHEMICAL PROPERTIES OF MARINE (SEA) WATER

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 3.2 Adaptations of Living Organisms to Marine Environment
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1.0 INTRODUCTION

Seawater contains both salt and water with most of the salt originating from the weathering of rocks and runoff from precipitation. Evaporation and formation of ice or snow lead to the removal of salts from sea water. Organisms living in the marine environment need some form of adaptation to survive in that environment.

2.0 OBJECTIVES

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

- enumerate the characteristics of seawater
- discuss the adaptations of living organisms to marine environment.

3.0 MAIN CONTENT

3.1 Characteristics of Seawater

Seawater is a mixture of salts and water. Most of the dissolved chemical constituents or salts found in seawater originate from rock weathering and runoff. Six elements and compounds make up about 99% of sea salts namely chlorine (55%), sodium, sulphur (SO_4^{2-}), magnesium, calcium, and potassium. The relative abundance of salt is constant regardless of the ocean involved. Only the amount of water in the mixture varies because of differences between ocean basins due to regional variations in freshwater loss (evaporation) and gain (runoff and precipitation). Typically, seawater has a salinity of 35 parts per thousand.

Freezing: Seawater freezes at a temperature slightly lower than for fresh water (0.0° Celsius). The freezing temperature of seawater changes with the concentration of salts with more salts lower the initial freezing temperature. At a salinity of 35 parts per thousand, seawater freezes at a temperature of -1.9° Celsius.

Sea ice contains less salt than seawater because most of the salts in liquid seawater are forced out during freezing. Because of the density difference between ice and seawater, ice floats on the surface of the ocean.

Dissolved gases: Sea water also contains gases dissolved from atmosphere. Dissolution of gases in seawater depends on temperature and salinity. Increasing temperatures and salinities decrease the amounts of dissolved gases in seawater. The gases dissolved in seawater include nitrogen, oxygen, and carbon dioxide (majorly in the form of bicarbonate). The dissolved carbon dioxide is usually more than other gases. Some gases are involved in oceanic organic and inorganic processes e.g. oxygen and carbon dioxide may be temporarily generated or depleted by such processes at varying concentrations at specific locations in the ocean.

The density of seawater increases with decreasing temperature, increasing salinity, and increasing depth in the ocean. Highest densities are achieved with depth because of the overlying weight of water. In the ocean, seawater density values vary between 1.022-1.030g/cm^3 depending on salinity. Density has important effects on ocean water. Denser bodies of water sink below less dense water bodies.

Factors that affect the density of seawater

1. **Temperature**: As temperature increases, density decreases. Temperature has the greatest effect on density of seawater. A layer of rapidly changing temperature is called the thermocline.
2. **Salinity:** As salinity increases, density increases (addition of more dissolved materials).
3. **Pressure:** As pressure increases, density increases (pressure compresses materials). A layer of rapidly changing density is called the pycnocline. Above the pycnocline, the layers of water are thoroughly mixed by currents, tides and waves. In the high latitudes (temperate and polar regions), pycnoclines and thermoclines rarely

form and the water column is described as **isothermal** and **isopycnal** i.e. same temperature and density.

Salinity: This is the total amount of solids dissolved in water including gases. The salinity of seawater is 3.5% i.e. 96.5% is pure water. But salinity is measured in parts per thousand i.e. 35parts per thousand or 35g/kg or 35‰ or 35ppt.The major constituents of seawater are chloride, sodium, sulphate, magnesium; calcium and potassium (contribute about 99% of sea salts). These elements are relatively constant regardless of which ocean is involved. Chlorine makes up about 55%of the salt in seawater. Minor constituents include bromine, carbon, nitrogen gas, carbon dioxide. Trace compounds are phosphorus, iodine, manganese and iron. Salinity varies in the ocean between35-38ppt. In coastal areas, salinity can be decreased e.g. 10 ppt in river estuaries (brackish water- freshwater and sea water mixing). Salinity in Red sea is 42 ppt (**hyper-saline**).

Hyper-salinity occurs in areas with limited circulation or connection with the open sea. Dead Sea has a salinity of 330ppt. Salinity varies with season and processes that increase salinity include removal of water through evaporation, formation of sea ice, loss of water through sea spray, addition of minerals from dead and decayed organisms form part of the sediments. Processes that decrease salinity include addition of water from melting if ice (iceberg, glacier), river/ stream flow and rainfall runoff.

Alkalinity and acidity: Oceans should be acidic but this is prevented by the **carbonate buffering system.** In deep cold water, more carbon dioxide dissolves in seawater, this should make the deep sea more acidic but when marine organisms that contain calcium carbonate in their skeleton or shells die, the calcium carbonate they contain is released and helps to buffer the acidic conditions.

3.2 Adaptations of Living Organisms to Marine Environment

Water is essential for life and constitutes 80% or more by weight of active protoplasm. It is the most efficient of all solvents and carries in solution gases, oxygen and carbon dioxide; the mineral substances necessary to the growth of plants and animals. It is an essential raw material in the manufacture of foods by plants.

Organisms living in the terrestrial environment have devised means for survival, such as impervious integuments, to conserve water. Plants on land have roots and vascular systems to transport water to all growing parts. In the marine environment there is freedom from desiccation, except at high-tide levels, and there are no highly specialised means for conservation of water or for its transport in plants.

The high heat capacity of water and its high latent heat of evaporation prevent the danger that might result from rapid change of temperature in the environmental medium. Owing to the high degree of transparency of water it is possible for the sea to sustain plant life throughout a relatively deep layer, and in animals the development of organs of vision and of orientation has progressed to a marked degree.

Sea water is a buffered solution implying that changes from acid to alkaline condition, or vice versa, are resisted. This property is of vital importance to the marine organisms, mainly for two reasons:

i. Abundant supply of carbon can be available in the form of carbon dioxide for the use of plants to synthesize carbohydrates without disturbance to the animal life that may be sensitive to small changes in pH.
ii. In the slightly alkaline habitat, organisms that construct shells of calcium carbonate or other calcium salts can carry on this function more efficiently than in a neutral solution.

Sea water supports the bodies of marine organisms reducing the need for special supporting skeletal structures e.g. jelly fishes, unarmored molluscs, unarmored dinoflagellates, and large marine mammals.

Sea water contains all the chemical elements essential to the growth and maintenance of plant and animal protoplasm. The ratios of the major salts to each other, and their total concentration, are similar in sea water and in the body fluids of marine invertebrates. The similarity of composition is also found in modified form in both terrestrial and fresh-water animals.

The teleost (bony) fishes in marine waters are hypotonic (the pressure of external medium is less than the internal medium) and, in order to keep their body fluids down to the required osmotic pressure, they secrete chloride through the “chloride cells” of the gills. This function is a regulation toward a low osmotic pressure of the blood, as opposed to regulation toward a high one as performed by the kidneys of animals in fresh-water environments. The elasmo branchs (sharks and rays) are isotonic with sea water

4.0 CONCLUSION

Sea water differs from freshwater and brackish water in having higher concentrations of salts from rock weathering and runoff. The presence of dissolved salts, gases etc affect the water quality.

5.0 SUMMARY

In this unit, we discussed the characteristics of sea water and the adaptation of sea organisms for life in this environment.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the characteristics of seawater.
2. Discuss the adaptation of living organisms to marine environment.

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MODULE 3

Unit 1 Major Water Compartments
Unit 2 Hydrology and Water Cycle
Unit 3 Transport and Exchange Processes

UNIT 1 MAJOR WATER COMPARTMENTS

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6.0 References/Further Reading

1.0 INTRODUCTION

There are many water compartments on earth. These include oceans(the largest store of saline water), galaciers, ice, snow(the largest reserves of freshwater. Others include groundwater, lakes, streams etc. Water molecules reside in each of these compartments and are transferred among compartments.

2.0 OBJECTIVES

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

- enumerate the attributes of marine ecosystem: oceans
- state the attributes of the freshwater ecosystem
- explain the residence time of a reservoir.

3.0 MAIN CONTENT

3.1 Marine Ecosystem: Oceans

Oceans contain about 97% of all liquid water and moderate the earth's climates though they are too salty for human use. More than 90% of the earth's biomass is found in the oceans. In tropical seas, surface waters are warmed by the sun, diluted by rain water and run off from land and aerated by wave action. In higher latitudes, surface waters are cold and denser than waters flowing from the equator. The dense water sinks to the bottom of deep ocean basins and flows towards the equator. The warm suface water of the tropics flows or stratifies on top of the cold dense water from higher latitudes. Sharp boundaries form between different densities,salinities and temperatures retarding mixing between layers.

Marine ecosystems cover approximately 71% of the Earth's surface. They generate 32% of the world's net primary production. They are distinguished from freshwater ecosystems by the presence of dissolved compounds especially salts in the water. Approximately 85% of the dissolved materials in seawater are sodium and chlorine. Seawater has an average salinity of 35 parts per thousand (ppt) of water but the actual salinity varies among different marine ecosystems.

3.2 Freshwater Ecosystem

Freshwater ecosystems cover 0.80% of the Earth's surface. Freshwater ecosystems contain 41% of the world's known fish species. There are three basic types of freshwater ecosystems:

i. Lentic: Slow-moving water, including pools, ponds and lakes.
ii. Lotic: Rapidly-moving water, for example streams and rivers.
iii. Wetlands: Areas where the soil is saturated or inundated with water for at least part of the time.

The greatest portion of the fresh water (68.7%) is in the form of ice and permanent snow cover in the Antarctic, the Arctic and in the mountainous regions. 29.9% exists as fresh ground water. 0.26% of the total fresh water on the earth is found in lakes, reservoirs and river systems, where it is most easily accessible for economic and domestic use.

The values for stored water given above are for natural, static, water storage in the hydrosphere. It is the amount of water contained simultaneously, on average, over a long period of time, – in water bodies, aquifers and the atmosphere. For shorter time intervals such as a single year, a couple of seasons or a few months, the volume of water stored in the hydrosphere will vary as water exchanges take place between the oceans, land and the atmosphere.

3.2.1 Glacier, Ice and Snow

About 3/4th of all 3% fresh water is found in glaciers , ice caps and snowfields. Glaciers are rivers of ice flowing downhill very slowly. The largest remnant of glaciers is found in Antarctica and contains about 85% of all ice globally.Salt is excluded during freezing and so most ice is fresh water.

3.2.2 Groundwater

The groundwater is the next largest reservoir of fresh water after glaciers. Precipitation that does not evaporate back into the atmosphere or run off over the earth's surface percolates through the soil, into pores and hollows of permeable rocks by infiltration. The upper layer that holds both air and water makes up the zone of aeration and provides moisture for plant growth. Depending on rainfall amount, soil type and surface topography the **zone of aeration** may be shallow or deep.

The lower soil layers where all pores and spaces are filled with water is called the **zone of saturation**. The top of this layer is called the **water table**.The water table undulates according to the topography of the area in question and its sub surface structure. The water table rises and falls according to precipitation and infiltration rates. Porous, water-bearing layers of sand,and gravel are called **aquifers**. Aquifers are underlain by impermeable layers of rock or clay that prevent water seeping out at the bottom. When a pressurized aquifer intersects the surface or is penetrated by a pipe or conduit, an artesian well or spring forms and water gushes out without pumping. Areas in which infiltration of water into an aquifer occurs are called **recharge zones**. Water moving from an aquifer into a stream or lake is called **ground water discharge** whereas any water entering an aquifer is called **recharge**.

3.2.3 Rivers and Streams

Precipitation that does not evaporate or infiltrate into the ground runs off over the surface drawn by the force of gravity towards the sea. Rivulets join to form streams and streams join to form rivers. The quantity of water involved is small. The best measure of the volume of water carried by a river is its discharge i.e. the amount of water that passes a fixed point at a given time which is usually expressed as litres or feet ^{3} /second.

The major zones in river ecosystems are determined by the river bed's gradient or by the velocity of the current. Faster moving turbulent water typically contains greater concentrations of dissolved oxygen, which supports greater biodiversity than the slow moving water of ponds. These distinctions form the basis for the division of rivers into upland and lowland rivers. The food base of streams within riparian forests is mostly derived from the trees, but wider streams and those that lack a canopy derive the majority of their food base from algae. Environmental threats to rivers include loss of water, dams, chemical pollution and introduced species. In their natural state most rivers are highly seasonal, alternating between periods of high and low flow.

3.2.4 Lakes and Ponds

Ponds are small,temporary or permanent bodies of water shallow enough for rooted plants to grow over most of the bottom. Lakes are bodies of water surrounded by land. Lakes are inland depressionswhich hold standing fresh water all year round. The maximum lake depth ranges from a few metres to greater than 1,600m in Lake Baikal in Siberia which contains 20% of global fresh water. The water in this compartment is more accessible than in groundwater and glaciers

3.2.5 Wetlands

This is a collective name for marshes, swamps, bogs etc.Wetlands represent an ecosystem which is intermediate between aquatic and terrestrial ecosystems. Bogs, swamps, wet meadows and marshes are important in the hydrological cycle. Lush plant growth stabilises the soil and holds back surface run off allowing time for infiltration into aquifers and producing even, year long stream flow. Wetlands filter sediments and nutrients from surface water, support food webs and biodiversity. Disturbance of wetlands reduces their water-absorbing capacities and surface waters run off quickly leading to floods and erosion during the rainy season and dry or nearly dry stream beds at other times which reduces biological diversity and productivity. The wetlands at the edge of the estuary or ocean where water meets land is called the **intertidal zone.** This zone is often flooded by high tides but left dry during low tides about 12 hours daily

Wetlands are dominated by vascular plants that can grow on saturated soils. Wetlands are the most productive natural ecosystems because of the proximity of water and soil. Due to their productivity, wetlands are often converted into dry land with dykes and drains and used for agricultural purposes. Their closeness to lakes and rivers means that they are often developed for human settlement. Swamps and marshes are often associated with rivers as extensions of their flooded area. Many of the world's greatest wetlands are riverine features either as internal or terminal deltas. In some cases large swamp areas may also be associated with depression lakes or exist as independent features of the landscape. Irrigated agriculture, particularly for rice, increases the area of seasonally flooded land.

3.2.6 The Atmosphere

The atmosphere contains less than 0.001% water supply. Of all the water compartments, the atmosphere has the most rapid turnover rate

3.3 Residence Times

The residence time of a reservoir or compartment within the hydrologic cycle is the average time a water molecule will spend in that reservoir. It is a measure of the average age of the water in that reservoir. Groundwater spends over 10,000 years beneath Earth's surface before leaving. Very old groundwater is called **fossil water**.

Water stored in the soil remains there very briefly, because it is spread thinly across the Earth, and is easily lost by evaporation, transpiration, stream flow, or groundwater discharge. The residence time of water in the atmosphere is about 9 days before condensing and falling to the Earth as precipitation. The major ice sheets (e.g. glaciers) in Antarctica and Greenland store ice for very long periods. Residence times can be estimated in two ways.

1. Residence times can be estimated by dividing the volume of the reservoir by the rate which water either enters or exits the reservoir. This is equivalent to timing how long it would take the reservoir to become filled from empty if no water were to leave (or how long it would take the reservoir to empty from full if no water were to enter).

2. The use of isotopic techniques is done in the subfield of isotope hydrology.

Table 1: Earth's Water Compartments and Estimated Volume of Water in Storage , Per Cent Total and Average Residence Times

	Volume (000 Km^3	% Total Water	Average Residence time
Total	1403,377	100	2,800 years
Ocean	1,370,000	97.6	3,000-30,000 years
Ice and snow	29,000	2.07	1-16,000 years
Groundwater down to 1km	4,000	0.28	From days to thousand years
Lakes and reservoirs	125	0.009	1-100 years depending on depth and other factors
Saline lakes	104	0.007	10-1000 years
Soil moisture	65	0.005	2 weeks – 1 year
Moisture in plants and animals	65	0.005	1 week
Atmosphere	13	0.001	8-10 days
Swamps and Marshes	3.6	0.03	Months to years
Rivers and streams	1.7	0.001	10-30 years

Source: Slide Player.com accessed on 18th May, 2016

4.0 CONCLUSION

The different water compartments described in this unit are important parts of the hydrological cycle. The ocean contains the highest volume of water while the least is in the atmosphere with the highest turnover and residence time.

5.0 SUMMARY

In this unit, we discussed the different water compartments which form part of the hydrological cycle. We also defined the term 'residence times'.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the attributes of marine ecosystem: oceans.
2. State the attributes of freshwater ecosystem.
3. Explain the residence time of a reservoir.

7.0 REFERENCE/FURTHER READING

http://ga.water.usgs.gov/edu/watercycleoceans.html USGS, The Water Cycle: Water Storage in Oceans - Retrieved on 2008-05-14

UNIT 2 HYDROLOGY AND WATER CYCLE

CONTENTS

1.0 Introduction
2.0 Objective
3.0 Main Content
3.1 Hydrologic or Water Cycle
3.2 Description of the Water Cycle
3.3 Changes in the Hydrologic Cycle over Time
3.4 Impacts of Human Activities on the Water Cycle
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1.0 INTRODUCTION

Hydrology is the scientific study of the movement, distribution and quality of water on earth and other planets including the hydrological cycle, water resources and environmental watershed sustainability. In this unit,we shall discuss the water or hydrologic cycle and its general features.The major processes involved in the cycle will also be discussed.

2.0 OBJECTIVES

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

- discuss the hydrologic or water cycle
- describe the changes in the hydrologic cycle over time
- explain the impacts of human activities on the water cycle.

3.0 MAIN CONTENT

3.1 Hydrologic or Water Cycle

The **water** or **hydrologic cycle** describes the circulation of water as it evaporates from land, water, organisms, enters the atmosphere, condenses and is precipitated back to the earth's surface, moves underground by infiltration or over land by runoff into rivers, lakes and seas. The water cycle is also the continuous process by which water is purified through evaporation and transported from the Earth's surface and the oceans. The total amount of water on earth remains about the same(>1,404 million km^3 or 370 billion gallons) from year to year but water moves from one compartment to another (compartments e.g seas, rivers etc).

The hydrologic process supplies fresh water to land masses and plays an important role in creating a habitable climate and moderating temperature all over the world.Water movement back to the seas and glaciers are important forces which shape the land masses and re-distribute materials.

Plants absorb water from the ground and pump it into the atmosphere through the process called **transpiration**. This process involves evaporation of water from plant and soil surfaces and is described as **evapotranspiration**.Water evaporates as water vapor into the air. Ice and snow can sublimate directly into water vapor. About 75% of annual precipitation is returned to the atmosphere by plants. Solar energy drives the hydrologic cycle by evaporating water from surfaces. All the physical, chemical and biological processes involving water as it travels in the atmosphere, over and beneath the Earth's surface and through growing plants are important in the hydrologic cycle.

There are many pathways that the water molecules may take in the continuous cycle of preciptation and returning to the atmosphere. It may take millions of years as when resident in ice caps or flow through rivers into the seas. It may soak into the soils (infiltration) and later be evapoated from the soil surface into the atmosphere or indirectly through plants (tranpiration) back into the atmosphere. It may percolate through the soil into the groundwater aquifers or reservoirs or may flow into streams, rivers or springs.

Water is tapped for use in homes, industries and used water is returned to the cycle by discharging into streams or on the soil surface from where it can evaporate or sink into the soil.The processes involved in the water cyle include evaporation, precipication, groundwater flow and other components.

The hydrologic cycle also involves the exchange of heat energy which causes temperature changes. For example, during evaporation, water takes up energy from the environment and this cools the environment. On the other hand, during condensation, water releases energy to its surroundings causing warming. The water cycle is important in maintaining life on earth. By transfering water from one place to another, or one reservoir to another, the water cycle purifies the water, replenishes the land with fresh water and transports minerals to different parts of the world. The water also reshapes the geological features of the earth through erosion and sedimentation. The water cycle also influences the earth's climate due to heat exchange.

In the hydrologic cycle, water moves constantly between aquatic, atmospheric and terrestrial compartments driven by the solar energy and gravity. The total annual run off from land to the oceans is about 10.3 x 10^{15} gallons.

3.2 Description of the Water Cycle

Rising air currents take the vapour up into the atmosphere where cooler temperatures cause it to condense into clouds. Air currents move water vapour around the world; cloud particles collide, grow, and fall out of the sky as precipitation. Some precipitation falls as snow or hail, and can accumulate as ice caps and glaciers (store frozen water for thousands of years).

Snow packs thaw, melt, and the water flows over land as snowmelt. Most water falls back into the oceans or onto land as rain, where the water flows over the ground as surface runoff. Some runoff enters rivers and flow towards the oceans. **Runoff** and **groundwater** are stored as freshwater in lakes. Part of the runoff flows into rivers, some soaks into the ground as **infiltration**. Some water infiltrates deep into the ground and replenishes aquifers (store freshwater for long periods of time). Some infiltration stays close to the land surface and can seep back into surface-water bodies (e.g. the ocean) as **groundwater discharge**. Some groundwater finds openings in the land surface and comes out as **freshwater springs**. Over time, the water returns to the ocean and the cycle starts again.

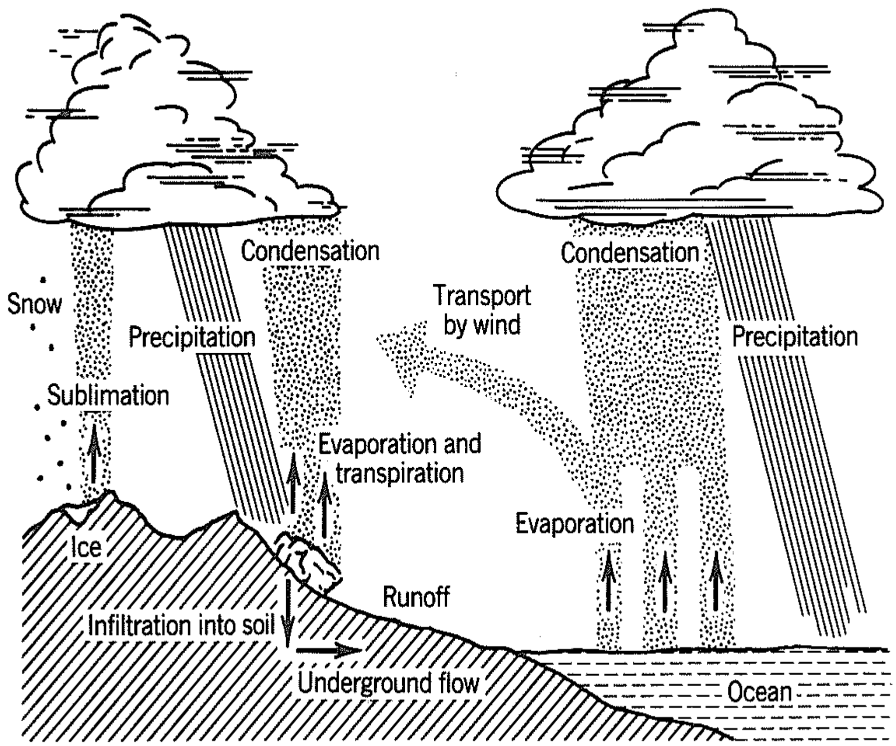

Fig 5: Schematic Representation of the Water or Hydrologic Cycle (Source:Domenico and Schwartz,1990)

The hydrologic cycle begins with the evaporation of water from the surfaces of the ocean and earth. As moist air is lifted, it cools and water vapour condenses to form clouds. Moisture is transported around the world and then returns to the surface as precipitation. On reaching the surface, 3 processes may occur:

1) Evaporation of water back into the atmosphere.
2) Penetration of water through the surface into the groundwater through a process called infiltration. Groundwater may seep into the oceans, rivers and streams or is released into the atmosphere through transpiration.
3) The balance of the water that remains on the earth's surface is the runoff which enters lakes, rivers, streams and is carried into the oceans where the cycle begins again.

3.3 Changes in the Hydrologic Cycle over Time

The water cycle describes the processes that drive the movement of water throughout the hydrosphere. The storehouses for most of the water on Earth are the oceans. It is estimated that about 95% of the 1,386,000,000 km^3 (world's water supply), is stored in oceans. The oceans supply about 90% of the evaporated water that enters the water cycle.
Ice caps and glaciers accumulate in the cold seasons and reduce the amounts of water in the other compartments but the ice melts in warm periods ice storage reduces and water contents of other compartments increase.

3.4 Impacts of Human Activities on the Water Cycle

Human activities that affect the global water cycle in some important ways include agriculture, industry, alteration of the chemical composition of the atmosphere, construction of dams, deforestation, aforestation, removal of groundwater from wells, water abstraction from rivers and urbanisation.

1) One of the main sources of atmospheric water is transpiration from the dense vegetation making up tropical rain forests. Deforestation changes the amount of water vapour in the air. This in turn most likely alters local and global weather patterns.
2) Another change in the water cycle caused by humans results from pumping large amounts of water from groundwater to use for irrigation and domestic purposes. This can incease therates of evaporation over land and unless this loss is balanced by an increased rainfall over land, groundwater supplies will get depleted.
3) The water cycle drives the movement of water through out the hydrosphere.Much of the water is stored in different compartments.

4.0 CONCLUSION

The water cycle is important for the circulation of water on earth among all the compartments. This cycle is driven by the solar energy and makes water available to man and other living organisms.

5.0 SUMMARY

In this unit, we discussed the hydrological cycle, changes in the cycle over time and the human influences that have affected the cycle over time.

6.0 TUTOR –MARKED ASSIGNMENT

1. Explain the hydrologic or water cycle.
2. Discuss the changes in the hydrologic cycle over time.
3. Explain the impacts of human activities on the water cycle.

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UNIT 3 TRANSPORT AND EXCHANGE PROCESSES

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1.0 INTRODUCTION

Transport involves the movement of water through the atmosphereand from oceans to land usually seen as clouds. Other processes include the jet stream, land and sea breezes, evaporation, condensation, precipitation, infiltration, runoff, subsurface flow. These transport processes enhance the exchange of moisture and other materials among different environmrntal compartments such as the atmosphere, lithosphere, hydrosphere etc.

2.0 OBJECTIVES

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

- define atmospheric transport
- explain the major transport and exchange processes.

3.0 MAIN CONTENT

3.1 Definition of Atmospheric Transport

Transport describes the movement of water through the atmosphere specifically from over the oceans to land. Some of the moisture transported is visible as clouds which consist of ice crystals and /or tiny water droplets. Clouds are moved from place to place by the jet stream (current of rapidly moving air found in the upper layers of the atmosphere), surface –based circulations like land breeze (a cool wind that blows from land to water) and sea breeze (a cool wind that blows off the water to land in the after noon). Most water is transported as water vapour.

3.2 Major Transport and Exchange Processes

3.2.1 Jet Stream

Jet streams are fast flowing narrow air currents found in the atmospheres of some planets including the Earth. Jet streams are currents of fast-moving air found in the upper levels of the atmosphere or an area of strong winds that are concentrated in a relatively narrow band in the upper troposphere in the middle latitudes and subtropical regions in the northern and southern hemispheres flowing in a semi-continuous band around the world. It is caused by changes in temperature when the cold polar air meets the warm equatorial air.

The main jet streams are located near the tropopause, the transition between the troposphere (where temperature decreases with altitude) and the stratosphere (where temperature increases with altitude). The major streams on earth are the westerly winds (flowing west to east). Their paths have a meandering shape. The strongest jet streams are the polar jets at around 7-12 km above sea level and weaker subtropical jets around 10-16 km above sea level.

The jet streams are caused by a combination of the Earth's rotation on its axis and atmospheric heating by solar radiation. Jet streams form near boundaries of adjacent air masses with significant differences in temperature such as the polar region and the warmer air towards the equator. The locations of jet streams are used to forecast weather conditions.

3.2.2 Sea Breeze(onshore breeze), Land Breeze and Prevailing Winds

Winds from the sea that develop over land near coasts during the day due to temperature differences between land and water.Sea breeze develops during the day and can carry moisture from water to land, causing rainfall in coastal areas.

Land breeze: Winds from the land to the sea at night since land cools faster than water at night due to the differences in their heat capacities.Can cause showers or thunderstorms over water.

Prevailing winds are winds that blow predominantly over a particular point in the Earth.They influence weather and climate patterns e.g The North East trade (harmattan winds) and the South West Monsoon Winds (rainfall) in Nigeria. Water moves fron one compartment to another in the hydrologic system by the following processes: evaporation, condensation, precipitation, infiltration, runoff, subsurface flow. When water evaporates, it takes up energy from its environment causing cooling but when it condenses energy is released and warms the environment. By transporting water from one reservoir to another, the water cycle purifies water, replenishes the land with fresh water and reshapes geological features through erosion and sedimentation.

Diffusion: Is one of several transport phenomena that occur in nature. A distinguishing feature of diffusion is that it results in the mixing or mass transport without requiring bulk motion to move molecules from one place to another.

Convection is the sum of transport by diffusion and advection.

3.3 Transport and Exchange Processes involved in the Hydrologic Cycle

3.3.1 Evaporation

This is the process where liquid is changed to vapour (gas phase) at temperatures well below its boiling point. Evaporation is the transformation of water from liquid to gas phase as it moves from the ground or bodies of water into the overlying atmosphere.Water is transferred from the surface to the atmosphere through evaporation, the process by which water changes from liquid to gas or vapour. Approximately 80% of all evaporation occurs over the oceans with the remaining 20% occuring from inland water and vegetation. Winds transport water around the world influencing the humidity of the air around the world. Most evaporated water exists as gas outside of the clouds and evaporation is more intense in the presence of warm temperatures. For instance,the strongest evaporation occurs near the equator. Evaporation controls the loss of fresh water. Evaporation into gas ceases when it reaches saturation. Energy breaks bonds that hold molecules together. Net evaporation occurs when the rate of evaporation exeeds the rate of condensation. Evaporation removes heat from the environment causing net cooling. The source of energy for evaporation is solar radiation.

Evaporation is the primary mechanism for surface to atmosphere water transport. Evaporation minus precipitation is the **net flux** of fresh water or the total fresh water in or out of the oceans . Evaporation minus precipitation determines the surface salinity of the oceans which helps to determine the stability of the water column salinity.

3.3.2 Sublimation

Water can also move between solid and gaseous states without becoming liquid by the process of sublimation. This occurs on bright, cold windy winter days, when the air is very dry, snow banks disappear by sublimation even though the temperature never gets above the freezing point. This same process causes freezer burn of frozen foods. Both evaporation and sublimation allow molecules of water to enter the atmosphere leaving behind salts: creates purified fresh water through a grand scale distillation.The purity of rain water has been reduced by the presence of pollutants in the air which dissolve in rainwater. Deposition is the conversion of water vapour to ice.

3.3.3 Condensation

Condesation is the conversion of water from gas to liquid (vapour to liquid water). Condensation generally occurs in the atmosphere when warm air rises , cools and loses its capacity to hold water vapour. As a result excess water vapour condenses to form cloud droplets. The upward motion that generates clouds can be produced by convection. As the earth is heated up by the sun, different surfaces absorb different amounts of energy and convection may occur where the surface heats up very rapidly. As the surface warms, it heats the overlying air which gradually becomes less dense than the surrounding air and begins to rise. Convergence can generate rising motion that leads to condensation of water vapour. Condensation creates fog and clouds.

3.3.4 Transport

In the hydrlogical cycle, transport is the movement of water through the atmosphere specifically from over the oceans to over land. Some of the earth's moisture transport is visible as clouds which themselves consist of ice crystals or tiny water droplets. Clouds propelled from one place to another by either jet stream (current of rapidly moving air found in the upper levels of the atmosphere), surface –based circulations like land (a cool wind that blows from land to water) and sea (a cool wind off the water in the afternoon) breezes. A typical 1 km thick cloud contains enough water for a millimeter of rainfall while the amount of moisture in the atmosphere is usually 10-50 times greater.Most water is transported in the form of water vapour which is usually the third most abundant gas in the atmosphere . Water vapour though invisible to the eye can be measured by satellite.

3.3.5 Precipitation

This is the transfer of water from the atmosphere back to the earth. There are several forms of precipitation such as rain, hail, snow, sleet and freezing rain. The vapour that accumulates, freezes on condensation nuclei is acted upon by gravity and falls to the earth's surface. Precipitation is the primary connection in the water cycle that provides for the delivery of atmospheric water to the earth.

Total precipitable water is the total atmospheric water vapour contained in a vertical column of unit cross-sectional area from the earth's surface to the top of the atmosphere. It is also the height to which the water would stand if completely condensed and collected in a vessel of same dimensions.

Approximately 505,000 km^3 (121,000 cu mi) of water fall as precipitation each year, 398,000 km^3 (95,000 cu mi) of it over the oceans.

i. **Canopy interception** describes the precipitation that is intercepted by plant foliage and eventually evaporates back to the atmosphere rather than falling to the ground.

ii. **Rain (liquid water)**
Rain develops when growing cloud droplets become too heavy to remain in the cloud and falls towards the surface of the earth.Rain can also begin as ice crystals that collect together to form large snow flakes. As the falling snow passes through the freezing level into warmer air, the flakes melt and collapse into rain drops.

- **Hail (frozen rain drops)**
Hail is a large frozen rain drop produced by intense thunderstorms, where snow and rain can co-exist in the central updraft. As snow flakes fall, liquid water freezes unto them forming ice pellets that will continue to grow as more droplets are accumulated. Upon reaching the bottom of the cloud, some of the ice pellets are carried by updraft back into to the top of the storm. This is repeated several times till the ice crystal becomes very large. The stronger the updraft, the more times a hail stone repeats the cycle and the larger it grows. Once the hailstone becomes too heavy to be supported by the updraft, it falls out of the cloud towards the surfcace of the earth. The hail stone reaches the ground as ice since it is not in the warm air below the thunderstorm long enough to melt before reaching the ground.
- **Snow:** Aggregates of ice crystals collect to each other as they fall towards the surface.They fall to the ground as ice. Snowmelt is the runoff produced by melting snow.
- **Sleet:** This describes frozen rain drops that bounce on impact with the ground and other objects. Sleet is less prevalent than freezing rain.
- **Freezing rain:** Rain that freezes on impact with a cold surface.

3.3.6 Transpiration

Is the transfer of water from the soil through the plants into the atmosphere. Evaporation of the water occurs from leaves and stems of plants. Plants absorb soil water through roots and this water can originate from deep in the soil. Plants pump the water up from the soil to deliver nutrients to their leaves. The pumping is driven by evaporation of the water through the small pores called stomata found mostly under leaves. Transpiration accounts for approximately 10% of all evaporating water.

3.3.7 Runoff

This is the transfer of water over land to the oceans. Run off is the movement of land water to the ocean, majorly in the form of rivers, lakes and streams. Run off is the precipitation that does not evaporate, transpire or infiltrate the surface to become groundwater.This includes both surface runoff and channel runoff. Even the smallest streams are connected to larger rivers that carry billions of gallons of water into oceans worldwide. Snow melt is the runoff produced by melting snow. Run off flows over land into rivers, and finally to the seas carrying solid and dissolved materials along

Factors affecting surface runoff:

- Meteorological factors that affect run off include type of precipitation, rainfall intensity, rainfall amount, distribution of rainfall over the drainage basin, direction of storm movement, precipitation that occured earlier and resulting soil moisture.
- Physical characteristics affecting run off are land use, vegetation, soil type, drainage area, basin shape, elevation, topography especially the slope of the land, drainage net work patterns, ponds, lakes and reservoirs, sinks in the basin which prevent or delay runoff from continuing downstream
- Human factors affecting run off are urbanisation produces more impervious surfaces which reduces infiltration and accelerates water motion; removal of vegetation and soil surface grading, artificial drainage net works increase volume of runoff and shortens runoff time to streams from rainfall and snow melt

3.3.8 Infiltration

The flow of water from the ground surface into the ground is called infiltration. Infiltrated water becomes soil moisture or groundwater. This proces losses dissolved oxygen and acquires dissolved carbon dioxide.
Factors affecting infiltration:

i. Precipitation - magnitude, intensity and duration.
ii. Soil characteristics, soil saturation: higher saturation leads to more run off.
iii. Land cover.

iv. Slope of land - hills enhance runoff velocity; evapotranspiration; it is a slow process – ground water moves slowly through the water shed.

v. Recharge rate is determined by precipitaion and depth; density of soil/rock increases with depth. The weight of the rocks above condense the rocks below and sqeeze out the open pore spaces deeper in the earth.

3.3.9 Subsurface Flow

The flow of water underground, in the vadose zone and aquifers is described as subsurface water which may return to the surface (e.g. as a spring or by being pumped) or eventually seep into the oceans. Water returns to the land surface at lower elevation than where it infiltrated, under the force of gravity or gravity induced pressures. Groundwater tends to move slowly, and is replenished slowly, so it can remain in aquifers for thousands of years.**Percolation** is the flow of water horizontally through the soil and rocks under the influence of gravity.

3.3.10 Advection

This is the movement of water in solid, liquid or vapour states through the atmosphere. It can also transport heat, salinity or humdity. It is important for the formation of clouds and the precipitation of water from clouds as part of the hydrological cycle. Advection causes precipitation to occur over land.

3.3.11 Humidity

Refers to the amount of water vapour in the air. Warm air holds more water than cold air. When a volume of air contains as much water vapour as it can at a given temperature , the air is said to reach **saturation point**.

Relative humidity is the amount of water vapour in the air expressed as a percentage of the maximum amount (saturation point) that can be held at that particular temperature. When saturation concentration is exceeded, water molecules begin to aggregate through **condensaton**. If the temperature at which it occurs is greater than $0^{o}C$,tiny droplets result at temperatures below freezing point , ice forms. For a given amount of water , the temperature at which condensation occurs is the **dew point**. Tiny particles like smoke,dust, sea salts, spores and volcanic ash (condensation nuclei) float in the air and facilitate condensation.

Cloud is an accumulation of condensed water vapour in droplets or ice crystals. Cloud particles are usually small enough to remain suspended in the air, but when cloud droplets and ice crystals become large,gravity becomes greater than the uplifting air currents and precipitaton occurs.

Some precipitation may not reach the ground. Temperatures and humidities in the clouds where snow and ice form are ideal for their preservation, but as they fall through lower warmer and drier air layers re-evaporation occurs. Rising air currents lift the water back into clouds to condense.

4.0 CONCLUSION

Major transport processes in the environment are discussed and they involve the movement of moiture and materials from one compartment to another.

5.0 SUMMARY

In this unit, we defined atmospheric transport and the different exchange and transport processes through which water and other materials are exchanged in the environment.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is atmospheric transport?
2. Explain the major transport and exchange processes.

7.0 REFERENCE/FURTHER READING

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MODULE 4

Unit 1 Ground Water
Unit 2 The Flowing Waters: Rivers
Unit 3 Lake Food Chain

UNIT 1 GROUNDWATER

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main Content
3.1 Features that Distinguish Groundwater from Surface Water Bodies
3.2 Characteristics of Groundwater Bodies
3.3 Chemical Characteristics of Groundwater
3.4 Reactions caused by Anthropogenic Effects
3.5 Biological Characteristics of Groundwater
4.0 Conclusion
5.0 Summary
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1.0 INTRODUCTION

Groundwater is a very important fresh water source and constitutes about two thirds of the freshwater resources of the in the world. Lakes, swamps, reservoirs and rivers account for 3.5 per cent and soil moisture 1.5 per cent (Freeze and Cherry, 1979).Water is drawn from the ground for many uses such as community water supply, farming and industrial processes. Unlike surface water, groundwater is rarely used *in situ* for non-consumptive purposes such as recreation and fisheries, except occasionally where it comes to the surface as springs.

2.0 OBJECTIVES

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

- highlight the features that distinguish groundwater from surface water bodies

- state the characteristics of groundwater bodies
- explain the chemical characteristics of groundwater
- describe the reactions caused by anthropogenic effects
- enumerate the biological characteristics of groundwater.

3.0 MAIN CONTENT

3.1 Features that Distinguish Groundwater from Surface Water Bodies

1. The slow movement of water through the ground implies that residence times in groundwater are generally longer than in surface waters. Polluted groundwater body could remain so for a very long time because the natural processes of flushing are very slow.
2. There is a high degree of physicochemical and chemical interdependence between the water and the soil material. Groundwater describes all the water underground, occupying the voids within geological formations. The properties of both the soil and water are important. Water quality is modified by interaction between the water and ground. This modification is enhanced by long residence times.

3.2 Characteristics of Groundwater Bodies

Groundwater occurs in different geological formations. Nearly all rocks in the upper part of the Earth's crust contain openings (pores or voids). The voids are the spaces between the grains, which may become reduced by compaction and cementation. In consolidated rocks, the only voids may be the fractures or fissures, which are generally restricted but may be enlarged by solution.

The volume of water in the rock depends on the percentage of the openings or pores in a given volume of the rock, the **porosity** of the rock. More pore spaces give higher porosity and more stored water. Under the influence of gravity when the water level falls, part of the water drains from the pores and part remains held by surface tension and molecular effects. The ratio of the volume of water that will drain under gravity from an initially saturated rock mass to the total volume of that rock is defined as the specific yield of the material and usually expressed as a percentage.

Groundwater is not static but flows through the rock. This flow depends on a combination of pore sizes and the degree to which they are interconnected. This is defined as the **permeability** of the rock. Materials which permit water to pass through them easily are **permeable** and those which permit water to pass with difficulty, or not at all, are impermeable. A layer of rock that is sufficiently porous to store water and permeable enough to transmit water in quantities that can be economically exploited is called an **aquifer**.

When rain falls, some infiltrate into the soil and part of this moisture is taken up by the roots of plants while some moves deeper under the influence of gravity. In the rock nearest to the ground surface, the empty spaces are partly filled with water and air. This is the **unsaturated or vadose zone** where soil, air and water are in contact and may react with each other. Downward water movement in the unsaturated zone is slow. Residence times in the unsaturated zone depend on its thickness and can vary from almost nothing to tens of years.

At greater depths, all the empty spaces are completely filled with water and this is called the **saturated zone**. If a hole is dug or drilled down into the saturated zone, water will flow from the ground into the hole and settle at the depth below which all the pore spaces are filled with water. This level is the **water table** and forms the upper surface of the saturated zone, at which the fluid pressure in the pores is exactly atmospheric.

All water that occurs naturally beneath the Earth's surface, including saturated and unsaturated zones, is called **sub-surface water**. An unconfined aquifer is one in which the upper limit of the zone of saturation, i.e. the water table, is at atmospheric pressure. At any depth below the water table the pressure is greater than atmospheric and at any point above the water table the pressure is less than atmospheric. In a confined aquifer the effective aquifer thickness extends between two impermeable layers. An imaginary surface joining the water level in many wells in a confined aquifer is called the **potentiometric surface.**

The origin of fresh groundwater is normally atmospheric precipitation either by direct infiltration of rainfall or indirectly from rivers, lakes or canals. Groundwater is the origin of much stream-flow and an important flow component to lakes and oceans. Groundwater is a part of the hydrological cycle. Water bodies such as marshes do form transition between groundwater and surface water.

Infiltration of rainfall occurs in a **recharge area**. After moving slowly through the aquifer, groundwater leaves the aquifer by springs, swamps and base flow to streams or ocean in a **discharge area.** In a recharge area, the water table often lies at considerable depth beneath a thick unsaturated zone. In a discharge area, the water table is usually at, or very near, the ground surface. Rivers, canals, lakes and reservoirs may either discharge to, or recharge from groundwater.

3.3 Chemical Characteristics of Groundwater

Groundwater occurs with geological materials containing soluble minerals. Higher concentrations of dissolved salts occur in groundwater than surface water. The type and concentration of salts depends on the geological environment, source and movement of the water. A hydrochemical classification divides groundwater into three types.

i. Meteoric groundwater is derived from rainfall and infiltration within the normal hydrological cycle. Meteoric groundwater can eventually become saline while entrapped sea water can become modified and moved from its original place of entrapment.
ii. Connate groundwater originates as sea water which has been entrapped in the pores of marine sediments since their time of deposition. The term is usually applied to saline water encountered at great depths in old sedimentary formations. Connate water describes groundwater that has been removed from atmospheric circulation for a significant period of geological time.
iii. Juvenile groundwater describes the relatively small amounts of water which have not previously been involved in the circulating system of the hydrological cycle, but are derived from igneous processes within the earth.

The quality of groundwater is controlled by the geochemistry of the lithosphere (solid portion of the earth), and the hydrochemistry of the hydrosphere (the aqueous portion of the earth).Atmospheric precipitation infiltrating through the soil dissolves CO_2 produced by biological activity forming a weak carbonic acid. This acid dissolves soluble minerals from the underlying rocks.

During the passage of precipitated water through the soil, soil microorganisms consume oxygen dissolved in the water. Groundwater in igneous rocks is lightly mineralised, although characterised by high silica contents (Hem, 1989). Sulphate maybe produced by the oxidation of metallic sulphides present in small amounts in many rock types. Groundwater in carbonate rocks has pH values above 7, and mineral contents are dominated by bicarbonate and calcium.

In arid and semi-arid areas, evapotranspiration rates are higher than rainfall for much of the year while recharge is limited. The long residence times and incomplete flushing of soluble minerals produce groundwater, which are of the sodium chloride type. In the discharge area, evapotranspiration is very high. Salt is concentrated in soil and water by direct evaporation and a salt marsh may be formed.

3.4 Reactions Caused by Anthropogenic Effects

Water movement in the unsaturated zone is mostly vertical and slow. The chemical condition is usually aerobic and often alkaline. As suggested by Foster and Hirata (1988), there is considerable potential for:

- interception, sorption and elimination of pathogenic bacteria and viruses,
- attenuation of trace elements and other inorganic compounds by precipitation, sorption or cation exchange, and
- Sorption and biodegradation of many hydrocarbons and synthetic organic compounds.

3.5 Biological Characteristics of Groundwater

Groundwater quality is influenced directly and indirectly by microbiological processes, which can change inorganic and organic constituents of groundwater. These biological transformations increase geochemical processes (Chapelle, 1993). Single and multi-celled organisms can use the dissolved materials, suspended solids in the water and solid matter in the aquifer, and release metabolic products back into the water. Some microbes tolerate extremes of pH and Eh, low temperatures (psychrophiles), or high temperature (thermophiles) while others are tolerant of high pressures (Ehrlich, 1990). The most biologically favourable environments occur in warm, humid conditions.

Organic compounds are potential sources of energy for organisms. Most organisms require oxygen for respiration (aerobic respiration) and the breakdown of organic matter, but when oxygen concentrations are depleted some bacteria can use alternatives, such as nitrate, sulphate and carbon dioxide (anaerobic respiration).Organisms which, can live in the presence of oxygen (or without it) are known as **facultative anaerobes**. Obligate anaerobes are organisms, which do not like oxygen. The presence or absence of oxygen is, therefore, one of the most important factors affecting microbial activity. For an organism to grow and multiply, nutrients must be supplied in an appropriate mix, which satisfies carbon, energy, nitrogen and mineral requirements (Ehrlich, 1990).

The population density of micro-organisms depends on the supply of nutrients and removal of harmful metabolic products (Matthess, 1982). Higher rates of groundwater flow supply more nutrients and remove the metabolic products more readily. Microbe populations are largest in the nutrient-rich humic upper parts of the soil, and decline with decreasing nutrient supply and oxygen availability at greater depths.

Microbiological activity affects compounds of nitrogen and sulphur, and some of the metals, principally iron and manganese. Sulphate reduction by obligate aerobes is a major biological process in groundwater. Nitrogen compounds are affected by both nitrifying and denitrifying bacteria. Reduction of nitrate by denitrifying bacteria occurs in the presence of organic material in anaerobic conditions, leading to the production of nitrite which is then broken down further to elemental nitrogen. Under aerobic conditions, ammonia is oxidised to nitrite and nitrate.

Iron can be reduced or oxidised depending on the Eh and pH conditions of the groundwater. Micro-organisms can break down complex organic materials dissolved in groundwater. Under anaerobic conditions, microbial breakdown proceeds either as a methane fermentation or by reduction of sulphate and nitrate (Matthess, 1982). The soil is effective against groundwater contamination by faecal organisms, and a number of processes combine to remove pathogens from infiltrating water flowing to the water table.

4.0 CONCLUSION

Groundwater forms a major freshwater compartment with higher dissolved substances than surface water depending on the type of rock in contact with the ground water. Surface water contains more dissolved oxygen and less carbon dioxide than groundwater.

5.0 SUMMARY

In this unit, we discussed the differences between surface and groundwater, the chemical, biological and microbiological characteristics of ground water. Three types of groundwater were also identified.

6.0 TUTOR–MARKED ASSIGNMENT

1. Explain the features that distinguish groundwater from surface water bodies.
2. State the characteristics of groundwater bodies.
3. Discuss the chemical characteristics of groundwater.
4. Explain the reactions caused by anthropogenic effects.
5. Enumerate the biological characteristics of groundwater.

7.0 REFERENCE/FURTHER READING

Chapman, D. (Ed.). (1992, 1996). "Groundwater." (2nd ed.). In: *Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring*. UNESCO/WHO/UNEP.

UNIT 2 FLOWING WATERS: THE RIVERS

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main Content
3.1 Characteristics of Rivers
3.2 Temperature and Oxygen of Rivers
3.3 Transport of Materials by Rivers
3.4 Ecological Zonation of Rivers
3.5 Springs and Upper River
3.6 Middle and Lower River
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/Further Reading

1.0 INTRODUCTION

The rivers represent another compartment of freshwater. They consist of the main streams and tributaries. The flowing river has three main stages (upper, middle and lower) with different characteristics and living organisms inhabiting each stage. Two major ecosystems in rivers are rhitron and potamon while three types of spring exist. They are rheocrene, limocrene and helocrene.

2.0 OBJECTIVES

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

- state the characteristics of rivers
- discuss the temperature and oxygen of rivers cum transport of materials by rivers
- explain the ecological zonation of rivers
- differentiate between the springs and upper river
- distinguish between the middle and lower river.

3.0 MAIN CONTENT

3.1 Characteristics of Rivers

A river system consists of the main stream and many tributaries. The main fluvial processes are **erosion**, **transportation** and **sedimentation**. In the upper area of a drainage basin, current velocity is high, erosion predominates and valleys composed of channels and slopes are formed. The materials swept downstream are the sediment load, produced mainly by weathering of the rocks that make up slopes. Sediment load is deposited to form an alluvial plain. The channel patterns forming in alluvial plains can be braided, meandering or straight. The channel patterns and forms bring about the river morphology which is decided by many factors such as discharge, water velocity, slope, depth and width of the channel, and riverbed geology.

The current speed, river bed geology, granulometry, flow rate, flooding, the amount of all ochthonous materials (materials sourced from outside the river) carried by rivers affect the nature and functioning of the biological components. The current speed is a key factor for organisms living in the river and partially controls a number of environmental parameters such as temperature, oxygen, and type of substrate, type of resources. The current speed decreases from upstream to downstream.

3.2 Temperature and Oxygen of Rivers

Close to the source the stream, waters are turbulent with low and constant temperature. Flowing downstream, the water temperature becomes more and more dependent on air temperature. The turbulence of rivers allows exchanges between air and water, ensuring an oxygen concentration in running waters close to saturation. In rivers of slow current velocity, the reduced turbulence limits the water oxygenation by reducing the contact between water and atmosphere. Here the oxygen concentration is more dependent on organisms' metabolism. For example, photosynthesis can cause oversaturation during the day but respiration causes oxygen deficiency at night, particularly at the bottom of the river, with high microbial decomposition of organic matter.

3.3 Transport of Materials by Rivers

The flowing river water carries large amounts of materials from the surroundings. Autochthonous production is close to zero in rivers and all ochthonous plant material provides more than 90% of energy input of a stream, making the heterotrophic metabolism the prevailing one.

During transport by rivers, the organic matter is attacked by fungi, bacteria and protozoa. It is broken into fragments while smaller fragments are filtered out by invertebrates e.g. insect larvae. The sizes of organic particles decrease along the flow of the river. Downstream, the all ochthonous supply tends to decrease while macrophytes, benthic algae and phytoplankton reduce the importance of heterotrophic contributions.

Near the source, the riverbed is irregular and provides a variety of shelters for organisms. There is abundant, diversified diets and good oxygenation. The sandy bottoms of rivers contain very low organic matter and are unstable but the silt-clay bottom is more stable because it incorporates small- sized particles that act as ligands (colloidal organic matter). The fauna of rivers include many organisms that can penetrate the fine sediments which are poorly oxygenated and unstable.

3.4 Ecological Zonation of Rivers

The flowing water course can be called a brook, stream, creek or river based on its average width. Rivers can be classified according to the morphological, physical and ecological conditions along the river length. There are two major ecosystems in rivers namely rhitron and potamon.

Rhitron has average monthly temperature never less than 20°C, high oxygen content and very turbulent waters. The river bed consists of boulders, pebbles and gravel which may alternate with sand or mud. The organisms in rhitron adapt to life in very turbulent waters, cold and well oxygenated waters. Plankton is rare or absent.

Potamon waters have a monthly average temperature greater than 20°C and may suffer oxygen deficiency. The current is very slow and the flow tends to be laminar with sandy or muddy bottom. Organisms can withstand large temperature changes or prefer fairly warm waters; they can tolerate weak oxygen concentrations and prefer calm waters. The plankton can be abundant. Within these two categories, three zones can be distinguished taking into account the invertebrates, particularly insects, living at the river bottom.

Vannote *et al*. (1980) developed the River Continuum Concept (RCC), a classification model for flowing water in addition to the classification of individual sections of rivers after the occurrence of indicator organisms.

The model is based on the concept of dynamic equilibrium in which stream forms balance between physical parameters (width, depth, velocity, and sediment transport) taking also into account biological factors.

3.5 Springs and Upper River

The springs are places where the groundwater reaches the surface emerging from the soil or the interface between groundwater and surface water. They generally occur when the impermeable layers above which the rainwater absorbed by soil flows get close to the surface. Spring waters are characterized by stable temperature, low oxygen and organic matter contents.These stable environmental conditions allow only organisms with strict ecological requirements such as planaria worm.

They host the interstitialfauna, consisting of small animals living in groundwater and in subsurface cavities. Among them are found copepods, blind cyclopids adapted to darkness and other small crustaceans belonging to different genera are found.According to the way the water emerges from the ground there are three types of springs.

1. **Rheocrene springs**
   These springs are formed on steep slopes and straight away originate a small stream. Few organisms colonise the rheocrene springs immediately after their emergence. Sessile algae (periphyton) cover the stones. In alpine and subalpine regions mosses of different genera are particularly important. Grasses and sedges flank the mountain springs. The fauna includes many benthic herbivore or detritivore organisms. In mountain areas the larvae of Ephemenoptera and Chironomidae are the most common.

2. **Limnocrene springs**
   These springs are found at the bottom of ponds and lakes. The biological communities of limnocrene springs are those of the surrounding lacustrine environments.

3. **Helocrene springs**
   Helocrene springs are found at outcrops of the graundwater and give rise to wetlands, ponds and bogs. Unlike other sources, they offer highly variable conditions particularly for temperature. Amphibians and many insect larvae adapted to weak currents inhabit this ecosystem.

The upper river has fast current, turbulent flow, intense erosion and low temperatures. The highwater turbulence limits the development of vegetation. Higher plants are absent but some species can develop in the calmer zones of the river. Mosses and algae form dense mats on the stones hosting invertebrate herbivores. The abundant allochthonous supply of organic matter provides energy for the development of detritivorous organisms. The good oxygenation of the water allows the development of predator invertebrates with high energy requirements.The coarse bottom of the river provides shelter to many organisms, often avoiding the direct exposure to strong currents. Other invertebrates include crustacea, molluscs and worms. The upper reach of the river is dominated by salmonids, adapted to cold (5-10°C) and well oxygenated waters.These fishes require an oxygen concentrations of 8-12 ml L-1.

3.6 Middle and Lower River

At the bottom of the valley, the river loses its power, and its bed is coarse sand and gravel, alternating with a finer substrate covered with vegetation. The mosses and filamentous algae are accompanied by higher plants rooted in the river bottom. In periphyton rich areas the grazer organisms dominate, such as larvae of mayflies and dipterans.

In summer the temperatures of slowly flowing waters can exceed 20°C. The river carries a large load of suspended particles, the water has low transparency and reduced light penetration, limiting the macrophytes and periphyton growth. The autotrophic production is carried out by phytoplankton and macrophytes in stagnant waters. Anoxia is not rare at the sediment – water interface particularly in summer.

The benthic fauna includes organisms resistant to low oxygen concentrations e.g. oligochaetes (especially tubificids), dipteran and chironomid larvae. Grazer organisms, abundant in the middle part of the river, are sparse while the detritivores and filter feeders are abundant. Along the river banks the invertebrate community consists of Odonata, Coleoptera, crustaceans, leeches, snails (Limnea, Planorbis), bivalves and molluscs. The zooplankton fauna is dominated by rotifers while the microcrustaceans (Copepods and Cladocera), forming the most important component in lakes, are mostly benthic species in the rivers.

At the river mouth freshwater and marine water mix following the tides and many marine fish can be occasionally found in this brackish water zone. In particular, this is the case for migratoryanadromous fishes swimming up rivers to spawn.

4.0 CONCLUSION

A flowing river has three main stages with distinct characteristics, formations and living organisms. The river flows into the sea and mixes with sea water in the estuaries (river mouths) producing a brackish water environment. The river flow is highly variable in time, depending on the climatic situation and the drainage pattern. Thorough and continuous vertical mixing is achieved in rivers due to currents and turbulence. Lateral mixing may take place only over considerable distances downstream of major confluences.

5.0 SUMMARY

In this unit, we discussed the running fresh water typified by rivers. The stages of the rivers were explained and examples of living organisms in each stage of the river were given.

6.0 TUTOR-MARKED ASSIGNMENT

1. Enumerate the characteristics of rivers.
2. Discuss the temperature and oxygen of rivers cum transport of materials by rivers.
3. Explain the ecological zonation of rivers.
4. Differentiate between springs and upper river.
5. Distinguish between middle and lower river.

7.0 REFERENCES/FURTHER READING

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UNIT 3 LAKE FOOD CHAIN

1.0 Introduction
2.0 Objectives
3.0 Main Content
3.1 Differences between Aquatic and Terrestrial Organisms
3.2 Classification of Aquatic Organisms Depending on the Roles they Play in the Ecosystem
3.3 Classification of Aquatic Organisms Based on their Habitats
3.4 Composition of Fresh Water Phytoplankton Communities
3.5 The Zooplankton
3.6 Benthos
3.6.1 Phytobenthos or Periphyton (or "Aufwuchs")
3.6.2 Macrophytesorhydrophytes
3.7 Nekton, Neuston and Psammon
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/Further Reading

1.0 INTRODUCTION

In this unit, we shall discuss the lake food chain. The food chain describes the transfer of food energy from one organism to another within a system. The primary producers- phytoplankton, bacteria synthesise their feeds which also become available to consumers.

2.0 OBJECTIVES

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

- differentiate between aquatic and terrestrial organisms
- classify aquatic organisms depending on the roles they play in the ecosystem
- classify aquatic organisms based on their habitats
- explain the composition of freshwater phytoplankton communities
- estimate algal population and give measurement of primary production
- discuss zooplankton, benthos, Nekton, neuston and psammon.

3.0 MAIN CONTENT

3.1 Differences between Aquatic and Terrestrial Organisms

Differences in chemical and physical characteristics of water and air expose aquatic and terrestrial organisms to different environmental conditions.

i. Aquatic organisms do not need supporting body structures as strong as those for terrestrial organisms.
ii. Water has a density close to that of many organisms living in it. The viscosity of water is about 50 times higher than air. This makes the moving energy cost for a comparable displacement higher for an aquatic than for terrestrial organisms.
iii. The oxygen concentration is lower in water than in air and allows the aquatic organisms to perform more work than the terrestrial ones to provide the same amount of oxygen for respiration.
iv. The concentration of free carbon dioxide is higher in water than in the atmosphere. Aquatic plants have more inorganic carbon available than the terrestrial ones in the surface layer.
v. Aquatic autotrophs access dissolved nutrients in water without requiring specific transporting structure.

In both aquatic and terrestrial ecosystems, matter and energy flow through a chain of organisms transforming it and constituting the food chain. The energy flowing through the food chain progressively degrades to heat and matter is recycled, passing through stages of variable molecular complexity.

3.2 Classification of Aquatic Organisms Depending on the Roles they Play in the Ecosystem

1. Primary Producers

These are autotrophic organisms which synthesise organic matter using energy from the sun and inorganic substances. The primary producers include unicellular algae, free floating phytoplankton or periphyton that adhere to substrates and aquatic plants (macrophytes) growing in the littoral zone. Autotrophic organisms also include photosynthetic and chemosynthetic bacteria.

2. Consumers

Consumers depend on primary producers directly or indirectly for their food. These include primary (feeding on autotrophs), secondary (feeding on animals eating plants or autotrophs), tertiary consumers (feeding on secondary consumers), and so on. Carnivorous fish, birds or fish-eating mammals, occupies the last link in the aquatic consumer chain. The consumers are heterotrophs and use organic matter already produced. They cannot synthesise organic matter from inorganic compounds.

3. Detritivores

These are organisms that feed on the remains of dead organisms and on the waste products of metabolism, degrading it to less complex chemical structures.

4. Decomposers

Decomposers are mainly the heterotrophic bacteria, oxidising (decomposing) the organic molecules till they are reduced to their inorganic constituents (mineralisation). These are made available for the autotrophs and are thus re-cycled.

3.3 Classification of Aquatic Organisms Based on their Habitats Plankton

Aquatic organisms consist of animals (zooplankton), plants (phytoplankton), bacteria and archaea (bacterioplankton) and virus (virioplancton). Plankton occupies the littoral and the pelagic zones of water bodies. Autotrophic phytoplankton and bacterioplankton, carry out photosynthesis, a light-dependent activity, and are limited to the euphotic zone (zone of light penetration). The freshwater zooplankton community consists of microscopic organisms belonging to different systematic groups, ranging from protozoa to crustaceans. Though some plankton classes have organs to move, the plankton cannot oppose the current movement and is transported by the water mass hosting it.

1. The Virioplankton

Viruses are the smallest known organisms. They have simple structures, made of nucleic acids as RNA or DNA, contained in a protein capsule called capsid. They range in size between 20 – 200nmand reproduce within living cells. They are obligate parasites. A virus develops through both extracellular and intracellular phases. The virus particle (virion) is stable, resistant to denaturation and floats freely in the water. When a virion meets a host, it adsorbs to it, protruding protein structures that are receptors of the host's cell surface.

In the intracellular phase, the virus or viral DNA, enters the host cell where replicates. The newly formed viral particles lyse the host cell, not necessarily destroying it, and are released into the environment. This is called the **lytic cycle**. Viral replication can also occur through the **lysogenic cycle**. The viral genome becomes part of the host's genome, integrated in it or as an autonomous plasmid. The viral genome remains in a dormant stage (prophage) ending when thechanged environmental conditions (UV radiation, stress, chemicals, etc.) induce the lytic phase. The abundance of the virioplanktonic community depends on the abundance of hosts.

2. The Bacterioplankton

These are prokaryotes, between 0.2 and 2 μm in size. They can be autotrophs and heterotrophs. The autotrophs include cyanobacteria, photosynthetic and chemosynthetic bacteria. This group includes the bacteria that harvest light. Bacterial photosynthesis does not occur in the presence of oxygen but only in anoxic environments. Chemosynthetic bacteria meet their energy requirements through the oxidation of minerals substrates. **Heterotrophic** bacteria are more abundant than autotrophic bacteria and form the largest component of bacterioplankton. **Archaea** are genetically different from bacteria but are part of bacterioplankton. They are adapted to life in extreme environments such as hot springs and acidic water.

Roles of bacteria in the food chain

i. Breakdown of the organic substances, first-hydrolysed by the exoenzymes produced by bacteria and then mineralized, thus making their mineral constituents available.
ii. Recycling of dissolved organic matter, through the production of new bacterial cells usable by larger organisms, unable to use directly the dissolved organic matter.

3. The phytoplankton

The algal cells constituting the phytoplankton are at the beginning of the food chain. They synthesise the organic matter necessary to maintain the whole food chain working. The process ending with the production of organic compounds from inorganic substances and light is known as photosynthesis. The organic product of photosynthesis is glucose ($C_6H_{12}O_6$). The carbon and the oxygen necessary to build up the organic matter are provided by atmospheric CO_2. The equation summarising the process is:

$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$

Photosynthesis occurs in two phases:

1. **Light-dependent phase**
   Light energy from the sun is harvested by special pigments such as chlorophyll (the most important). In the light-dependent reaction, an energy-rich electron of a chlorophyll molecule is passed along a chain of molecules known as the electron transfer system. The energy lost by the electron as it moves along the chain is used to make NADP, (Nicotinamide or niacinamide Adenine Dinucleotide Phosphate) and ATP (Adenosine Triphosphate). These are very energy-rich but relatively unstable molecules.

2. **The dark phase or Calvin cycle**
   ATP and NADP are used to produce energy-rich carbohydrate molecules, which can be stored and used as a basis for the production of all other forms of organic molecules. The synthesis of new organic matter leads to an increase in cell size and a division in two daughter cells. These can be completely separated or they can remain connected though their cell walls, forming a colony.

3.4 Composition of Fresh Water Phytoplankton Communities

Freshwater phytoplankton communities consist of prokaryotes, Cyanobacteria, and eukaryotes from several taxonomic groups e.g. Diatoms, Chrysophytes (golden algae), Cryptophytes, Dynophytes, Euglenophytes and Chlorophytes (green algae).

i. **Prokaryotic cells:** The chromosomes are dispersed in the protoplasm. Photosynthesis occurs in invaginations of the cell membrane.
ii. **Eukaryotic cells**: The chromosomes are present in the nucleus and there are specific organelles, the chloroplasts, devoted to photosynthesis.
iii. **Cyanobacteria:** Cyanophyta or blue - green algae are bacteria with the cell structure of prokaryotes. They differ from bacteria by having chlorophyll *a*, which is also found in eukaryotic algae. They contain phycocyanin and allophycocyanin (pigments) which make them blue-green. Examples of blue –green algae are genera *Anabaena, Microcystis* and *Planktothrix*. They form massive blooms of Cyanobacteria which produce toxins, reduce water quality and dissolved oxygen.

iv. **Diatoms** are an important group of algae. They contain siliceous cell walls, called frustules. They contain chlorophyll (photosynthesis) and carotenoids (yellow-golden brown colour).

i. **Chrysophytes (Chrysophyceae)** are single-celled and typical of freshwater environments poor in calcium. They have two flagella. Examples include *Synura, Mallomonas*, *Ochromonas, Dinobryon* and *Uroglena*. Many species lack a true cell wall but may have a layer of scales, the lorica, made of cellulose and can be accompanied by limestone, silica or iron oxides. They contain photosynthetic pigment, chlorophyll.

ii. **Cryptophytes (Cryptophyceae)** have two flagella almost as long as the cell. The outer portion of the cell or periplast is composed of a plasmatic membrane and a series of plates placed beneath. The Cryptophytes contain chlorophyll, phycobilins phycocyanin and phycoerythrin (pigments)

iii. **Dynophytes** (division **Dynophyta**) are made by an upper part (the epicone) and a lower part (the hypocone) separated by a belt. They contain chlorophyll. The Dynophytes have an intermediate chromosomes falling between that of prokaryotes and eukaryotes and are thus defined **mesokaryotes.**

iv. **Euglenophytes** (division: **Euglenophyta**) are flagellate algae present mostly in eutrophic freshwater environments. The Euglenophytes have two basal bodies with one or two emerging flagella. Their chloroplast contains mainly chlorophyll *a* and *b*.

v. **Chlorophytes**, or green algae, (division **Chlorophyta**) are similar to higher plants. Their chloroplasts contain Chlorophylls *a* and *b* and they are green and contain no accessory pigments. They have two or more flagella similar in structure but different in length.

3.5 The Zooplankton

The zooplankton commonly found in freshwater are:

1. **Protozoa** are unicellular organisms between tens and hundreds microns in size. They feed on bacteria or detritus particles which are incorporated in a vacuole where digestion occurs (phagocytosis). Planktonic protozoa move mostly by cilia. They transform dissolved organic matter into forms usable by higher organisms.
2. **Cnidarians** are diverse in form such as siphonophores, medusae, corals, feathery hydoids, and box jellies with complex eyes. They are all armed with stinging cells called nematocysts. Many cnidarians live in the ocean while a smaller number of species are found in

fresh waters. There are four classes of Cnidarians namely Anthozoa, Cubozoa, Hydrozoa and Scyphozoa.

3. **Rotifera** are animals related to worms and are not segmented. They measure length 100 µm- 1 mm in length. They have a crown of cilia moving around their mouth to suck inside the food. They feed on algae, protozoa, bacteria, debris and some are carnivorous. Examples include the genera *Asplanchna, Keratella*, *Kellicottia* and *Brachionus*). They reproduce by parthenogenesis (without egg fertilization by males).
4. There are two groups of planktonic crustaceans namely Cladocerans e.g. Daphnia (water flea) and copepods. Daphnia and other cladocerans, are filter feeders because their limbs have filaments (setae) used to filter food particles from water. Cladocerans reproduce by parthenogenesis while sexual reproduction occurs in copepods and eggs are carried by females within ovigerous bags attached to the mother's body.

The transformation of organic matter by heterotrophs is called **secondary production**. The annual net secondary production of a zooplankton population is the sum of all biomass produced by the population during the year, taking into account the losses due to mortality, predation and emigration.

3.6 Benthos

This is the community living in the benthic zone, at the surface or inside the bottom sediment. It is a complex community consisting of both mobile and sessile organisms. The benthos includes fungi, bacteria, plant and animal forms which include algae, protozoa, rotifers, tardigrades, mollusks, worms, arthropods. Aquatic macroalgae and macrophytes grow in close relationship with the sediment as the benthos and account for a large portion of primary production in water.

3.6.1 Phytobenthos or Periphyton (or "Aufwuchs")

This is the community of microscopic autotrophs attached to submerged inorganic (epilithic algae) and organic surfaces, including living plants (epiphytic algae). They grow in areas of light penetration. Protozoa, sponges, bryozoans and other animals are usually associated with the periphyton. Examples of periphyton are filamentous algae, unicellular or colonial algae belonging to the cyanobacteria, diatoms and chlorophytes.

3.6.2 Macrophytesorhydrophytes

These are plants growing in aquatic environments or on substrates that are fully or periodically submerged. Aquatic macrophytes may be **emergent**, **floating** or **submerged**. The emergent and submerged hydrophytes are always rooted in the substrate but the floating hydrophytes may be rooted in the substrate or freely floating. Examples of emergent macrophytes are Phragmites spp (reeds), Scirpus, Typha, Sagittaria sp. The floating macrophytes include Nymphaea sp., Trapa natans (water chestnut) and Potamogeton sp. The free floating macrophytes include Lemna minor and *Eicornia crassipes*. The shading effect of floating hydrophytes reduces the penetration of solar radiation, leading to a reduction in phytoplankton populations.

3.7 Nekton, Neuston and Psammon

The term nekton describes aquatic animals that can move actively in the water, independent of water movement. These include fish, mollusks, amphibians, reptiles and mammals. The fish community includes both littoral and pelagic species. The species composition of the fish population depends on aquatic morphology, which influences the thermal regime, on water chemistry (in particular on oxygen availability) and on the biological characteristics of the water, which determines the quality and quantity of available food (Matthews, 1998).

Neuston consists of microscopic organisms, protozoa and bacteria, living in the surface film at the water-air interface. This group also includes larger organisms such as insects which can move on the water surface.

Psammon refers to the animal community, including protozoa, rotifers, tardigrades, crustaceans, worms, larvae of some insects, living in interstitial water of sandy beaches.

4.0 CONCLUSION

The lake food chain shows the energy transfers and organisms present in fresh water that make up such food chain. In the aquatic environment, the phytoplankton and bacteria comprise the producer organisms and there are several groups of consumers.

5.0 SUMMARY

In this unit, we discussed the different aspects of the lake food chain which is concerned with the transfer of food energy from plants through herbivores to carnivores. The producers (phytoplankton, chemosynthetic bacteria and aquatic macrophytes) form the basis of aquatic food chains while the carnivores such as large fish are at the apex.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the differences between aquatic and terrestrial organisms.
2. State the classification of aquatic organisms depending on the roles they play in the ecosystem.
3. List the classification of aquatic organisms based on their habitats.
4. Analyse the composition of freshwater phytoplankton communities.
5. Discuss the estimation of algal population and measurement of primary production.
6. Describe zooplankton, benthos, nekton, neuston and psammon.

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MODULE 5

Unit 1 Estimation of Algal Population and Measurement of Primary Productivity
Unit 2 Thermal Stratification
Unit 3 The Role of Soils

UNIT 1 ESTIMATION OF ALGAL POPULATION AND MEASUREMENT OF PRIMARY PRODUCTIVITY

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main Content
 3.1 Estimation of Algal Population
 3.2 Measurement of Primary Production
 3.3 Oxygen Method
 3.4 ^{14}C Method
 3.5 Oxygen Versus ^{14}C Method
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/Further Reading

1.0 INTRODUCTION

Photosynthesis is the major method of primary production in the aquatic environment. Primary production is measured by two methods described and contrasted in this unit. Algal population is also estimated.

2.0 OBJECTIVES

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

- state the estimation of algal population
- highlight the measurement of primary production
- differentiate between the oxygen and ^{14}C methods.

3.0 MAIN CONTENT

3.1 Estimation of Algal Population

Chlorophyll concentration is a proxy of algal biomass. To measure the chlorophyll content of an algal population requires the following:

1. Concentrate the phytoplankton through filtration of water sample by using appropriate filters.
2. Extract the chlorophyll with solvents (acetone, ethanol or methanol).
3. Determine the chlorophyll concentration in the extract with a spectrophotometer or fluorometer.
4. Calculate the chlorophyll concentration in the sample, taking into account the filtered sample volume and the appropriate calibration curves obtained from chlorophyll standards.
5. There are underwater probes that can measure the chlorophyll concentration directly *in vivo* (i.e. without extracting the pigment) and *in situ* using the fluorescence emission of chlorophyll excited by a radiation of appropriate wavelength.

3.2 Measurement of Primary Production

The synthesis of organic matter by autotrophs is called **primary production**. To assess the state of an ecosystem besides the phytoplankton abundance and composition, it is essential to know its productivity, measuring the phytoplankton primary production, i.e. the quantity of organic carbon synthesised by algae per unit of lake surface and per unit of time. The methods for evaluating primary production are based on the measurement of the concentration change of a product or a reagent of photosynthesis reaction in water samples incubated for several hours in transparent and non-transparent bottles. In light and dark bottles algae are exposed to light or kept in the dark, thus making the photosynthetic activity possible and impossible, respectively.

3.3 Oxygen Method

The O_2 concentration rise in light bottle corresponds to Net Primary Production (NPP) and is due to oxygen released by photosynthesis minus the O_2 consumed for autotrophic and heterotrophic respiration (R). This corresponds to the O_2 decrease measured in dark bottles in absence of production. Thus:

$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$
Gross Primary Production (GPP) = Net Primary Production (NPP) + respiration (R).

This method is not useful in oligotrophic and mesotrophic lakes which are too unproductive to produce changes in oxygen concentration. Primary production is expressed per unit area, dividing the production per unit of volume measured at different depths for the thickness of the euphotic zone.

3.4 ^{14}C Method

This method was introduced to overcome the sensitivity limits of the oxygen method. It is based on the addition of ^{14}C labeled inorganic carbon as bicabonate to water samples in light and dark bottles. The algae, during an incubation lasting about 4hours take up the radioactive ^{14}C with the ^{12}C naturally present in the water. The algal cells are concentrated trough filtration and incorporated ^{14}C is measured with a liquid scintillation counter. Knowing the amount of inorganic carbon originally present in the water and the amount of ^{14}C incorporated by algae, it is possible to calculate the total inorganic carbon taken up by algae from the equation:

$^{12}CO_2$ assimilated = ($^{14}CO_2$ incorporated/$^{14}CO_2$ added) x $^{12}CO_2$ concentration in lake

3.5 Oxygen versus 14C Method

The ^{14} C method is certainly the more sensitive method but it is expensive. From ^{14}C data no respiration can be measured and therefore no net production can be calculated, whereas the oxygen method gives a good estimate of assimilation and dissimilation. The ^{14}C method shows a finite rate of dark uptake or fixation. Another disadvantage of the ^{14}C method is that the excretion of extracellular products makes results inaccurate if a cell synthesises and then excretes organic molecules, whereas this does not affect the amount of oxygen produced. Estimation of ^{14}C in cellular material will give no measure of any excreted extracellular organic compounds. A source of inaccuracy in the 0_2, method is the assumption that 0_2, utilisation is equal in dark and light bottles.

4.0 CONCLUSION

Primary production is carried out by algae, bacteria and macrophytes in the aquatic environment. There are two major methods of estimating primary productivity which we describe in this unit.

5.0 SUMMARY

In this unit, we took a look at the method of estimating the algal population, calculating the primary production. We also compared the two methods.

6.0 TUTOR- MARKED ASSIGNMENT

1. Explain the estimation of algal population.
2. Discuss the measurement of primary production.
3. Differentiate between the oxygen and ^{14}C method.

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UNIT 2 THERMAL STRATIFICATION

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main Content
 3.1 Definition of Thermal Stratification
 3.2 Factors Affecting Lake Mixing , Transport and Exchange of Substances
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/Further Reading

1.0 INTRODUCTION

Thermal stratification is a condition in which water of different temperatures or densities tend to exist in different layers. For example, cold water usually floats below warm water and both layers do not mix easily. Stratification produces different layers called epilimnion, thermocline (or metalimnion) and hypolimnion. Wind is the major factor that affects the mixing, transport and exchange of materials or substances in water.

2.0 OBJECTIVES

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

- define thermal stratification
- discuss the factors affecting lake mixing, transport and exchange of substances.

3.0 MAIN CONTENT

3.1 Definition of Thermal Stratification

Temperature affects the rates of chemical and biological activities in water. This in turn affects the water quality. Warm temperatures increase the growth of algae, plants and animals; accelerate the decay of organic matter especially near the bottom of water. In the temperate region, there are four distinct seasons. Rising temperatures in spring warm the upper layers of the water. Warm water is lighter than cold water and the warm water floats over the cold and denser water. Temperature and density differences create distinct layers of water in the lake which do not mix easily. Warmer temperatures tend to increase the density differences and cause a separation between the water layers. This process is called **thermal stratification**.

The upper layer of water receiving more sunlight is called **epilimnion** and most biological activities and growth occur here. The colder, denser and darker bottom waters are called the **hypolimnion** where dead plants and animals sink. The **metalimnion (thermocline)** is the narrow band between the upper and lower waters where the temperature changes quickly with depth. **Fall turnover** describes the mixing of the upper layers and lower layers of water in the cold season when the temperature and density differences between layers disappear. Shallow lakes mix readily and have greater potential to release nutrients from the lake bottoms which fuel algal blooms.

The warm water fish ponds average about 2 meters in depth. Marked thermal stratification may develop in very shallow ponds because of turbid conditions resulting in rapid heating of surface waters on calm sunny days.

Stratification is less stable in ponds than large bodies of water. Ponds which stratify during daylight hours can de-stratify at night when the upper layers of water cool by conduction. Strong winds may supply enough energy to cause complete circulation of water. Disappearance of a heavy plankton bloom may allow heating to agreeable depth and also lead to complete mixture. Temperatures of the epilimnion in turbid waters are greater than those of clear waters because of greater absorption of heat by particulate matter.

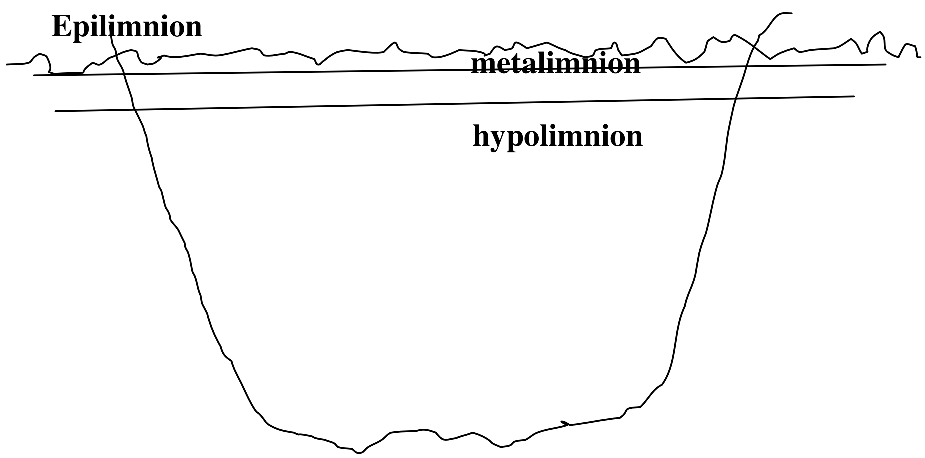

Fig.6: Schematic Diagram Showing the Layers Formed during Thermal Stratification of Lakes

The surface water of deep tropical lakes never reaches the temperature of maximum density; there is no process that makes the water mix. Bottom layers are depleted of oxygen but can be saturated with carbon dioxide, or other gases such as sulfur dioxide. Earthquakes or landslide can cause mixing which upturns the deep layers and may release a vast cloud of toxic gases. This is called a limnic eruption e.g. 1986 disaster at Lake Nyos in Cameroon.

Thermal stratification may cause fish kills due to thermal gradients, stagnation, and ice cover. Excess growth of plankton limits commercial and recreational activities in lakes and reduces drinking water quality. Thermal stratification can be reduced by aeration.

Destratification: Is a process in which the air or water is mixed in order to eliminate stratified layers of temperature, plant life or animal life.

3.2 Factors Affecting Lake Mixing, Tranport and Exchange of Substances

1. **Wind**

   Wind is the dominant external energy input responsible for mixing of water. Wind generates local currents that break lake boundaries and induce basin-scale motions. Wave breaking is an important mixing mechanism and enhances gas exchange with the atmosphere. Strong wind induces **Langmuir circulations** which are large-scale counter-rotating helical vortices. Langmuir circulation is responsible for mixing of the surface layer and deepening of the epilimnion.

Processes that increase turbulence also decrease residence time and increase interaction with bottom water, reduce stratification and enhance mixing.

2. Radiation

Two major types of radiation play a role in lake and reservoir stratification. These are short-wave ultraviolet and long-wave infrared radiations. The sun produces the **short-wave radiation** some of which is reflected at the water surface. The remaining radiation penetrates into the lake and is absorbed in the water column then gets converted to heat. Different wavelengths of the radiation are absorbed at different depths of water. Blue light travels the farthest and heats the deepest layers of water. It can travel full circle and escape from the lake, giving the lake a blue colour.

Long-wave radiation originates from black-body radiation. The lake (water bodies) and the atmosphere emit black-body radiation. Long-wave atmospheric radiation is partially reflected at the lake surface, and the penetrating radiation is absorbed, causing heating. Black-body radiation results in a loss of thermal energy and cooling of the lake water.

3. Evaporation and condensation

Evaporation is the conversion of liquid water to water vapor while condensation is the conversion of water vapor to liquid water. Both evaporation and condensation are accompanied by fluxes of heat. Evaporation from the lake surface extracts heat from the lake and results in cooling of the water surface. Condensation extracts heat from the atmosphere and adds it to the water surface, resulting in heating at the water surface. Evaporation and condensation are also accompanied by a flux of water and affect the total water budget of the lake.

4. Direct Inflows and outflows

Direct inflows to lakes and reservoirs can include surface inflow from rivers and streams, groundwater inflow, and precipitation. Outflows from the lake can be either surface or groundwater outflow. Each of these flows is accompanied by a flux of heat which may also add or remove kinetic energy. Among the inflows and outflows, surface flows have the greatest potential for kinetic energy input to a lake.

Below the mixing action of the wind and the penetration depth of the solar radiation, a strong temperature and accompanying density gradient develops. This region of strong gradients is called the **thermocline**, or sometimes **picnocline**. Below the thermocline a weaker temperature gradient is observed and the water is cool and comparatively quiescent. The bottom region of the lake is called the hypolimnion. In very deep lakes, where solar radiation and thermal conduction cannot penetrate to the lake bottom, the bottom water will have a temperature near 4 ˚C, the temperature of maximum density of water. The strong density gradients in the thermocline inhibit exchange between the epilimnion and the hypolimnion. Bottom water in a stratified lake does not actively interact with the atmosphere and can easily become deprived of important dissolved gases.

As the air temperature gets cooler and the solar radiation input decreases in the fall, the surface water cools. The surface water and thermocline cool down to the temperature of the hypolimnion and the lake destratifies becomes mixed (turnover). This gives the bottom water an opportunity to aerate with the atmosphere.

If the air temperature goes below 4 ˚C so that the surface water can cool below this temperature, then the surface water becomes lighter than the bottom water and a so-called winter inverse stratification develops. The term inverse refers to the fact that the surface water is colder than the bottom water; however, the surface water remains less dense. When ice forms at the water surface, wind mixing is not possible and the winter density profile may not exhibit a well-defined thermocline. The surface water heats up again in the spring, the lake will again reach a state of thermal homogeneity and in the presence of a light wind will turn over. As the surface waters become warmer, stratification sets in and we return to the summer stratification state. Lakes that experience this full cycle of stratification states are called dimictic because they stratify twice. Lakes that only stratify in the summer are called monomictic.

THERMAL STRATIFICATION

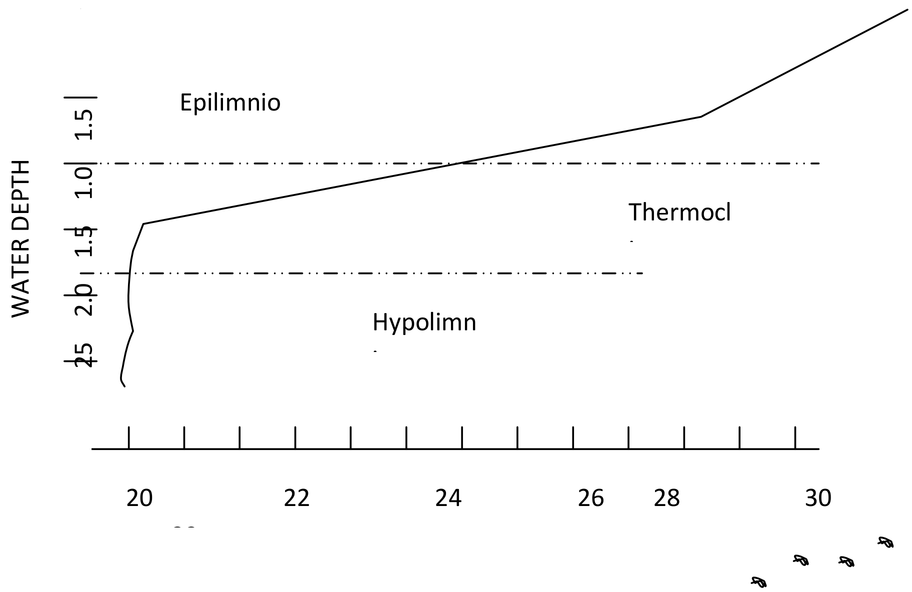

Fig 7: Thermal Stratification in a Lake. (Sketched after Boyd, 1979)

Temperatures of the epilimnion in turbid waters are greater than those of clear waters because of greater absorption of heat by particulate matter.

4.0 CONCLUSION

Temperature, density and wind are major factors responsible for proper mixing and circulation of nutrient in water. Lack of adequate mixing leads to thermal stratification which may have negative effects on aquatic populations.

5.0 SUMMARY

In this unit, you have learnt about thermal stratification, its possible effects and important factors that aid the proper mixing of lakes and other water bodies.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define thermal stratification.
2. Explain the factors affecting lake mixing, transport, and exchange of substances.

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UNIT 3 THE ROLE OF SOILS

1.0 Introduction
2.0 Objectives
3.0 Main Content
    3.1 Soil Characteristics that Influence Run Off or Infiltration
    3.2 Surface Run Off and Watershed
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/Further Reading

1.0 INTRODUCTION

The soil plays a role in the aquatic environment in the water shed and at the bottom of water bodies. The fate of precipitated water or pollutants depends on the soil characteristics.

2.0 OBJECTIVES

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

- enumerate soil characteristics that influence both infiltration or run off
- discuss surface run off and watershed.

3.0 MAIN CONTENT

3.1 Soil Characteristics that Influence Run Off or Infiltration

As water reaches the land, surface, it can seep downwards through the pores between soil particles. Soil is made up of tightly packed particles of many shapes and sizes. Soil has the ability to hold large amounts of water due to the presence of many pore spaces. If the pores are well connected and allow water to flow easily, the soil is permeable. The size and shape of the clay particles along with the arrangement of the pores between these particles result in clay soils being relatively impermeable and resistant to infiltration. Sands and gravel allow more rapid infiltration due to high permeability.

The initial water content of the soil is also important. Water infiltrates drier soils more quickly than wet soils. The intensity of a storm or the length of time during which precipitation occurs can also influence infiltration. If rain or snow melt reaches the soil surface faster than it can seep through the fine pores, the water pools at the surface and may run downhill to the nearest stream. This limitation on the soil's capacity to allow infiltration is one of the reasons why short, high intensity storms produce more flooding than lighter rains over a long period of time. Flooding occurs when the entire area below the ground is saturated with water. Subsequent precipitation remains on the surface.

The rate at which water flows through the soil is defined as its permeability. Different surfaces hold different amounts of water and absorb water at different rates. Surface permeability is extremely important to monitor because as a surface becomes less permeable, an increasing amount of water remains on the surface, creating a greater potential for flooding.

3.2 Surface Runoff and Watersheds

The portion of water which does not infiltrate the soil but flows over the surface of the ground to a stream is called runoff. Water always follows the path of least resistance, flowing downhill from higher to lower elevations towards a river or tributaries.

All of the land which eventually drains to a common lake or river is considered as the same water shed. Water sheds are defined by the topography which separate surface flows between two water systems. A lake or river is a reflection of its watershed's size, topography, geology, land use, soil fertility and erodibility, and vegetation. The impact of the watershed is evident in the relation of nutrient loading to the watershed: lake surface area ratio.

Land use activities in a water shed can affect the water quality of surface water as contaminants are carried by runoff. Groundwater can also be contaminated due to the infiltration of pollutants.

Understanding the factors that influence the rate and direction of flow of surface and groundwater helps determine where good water supplies exist and how contaminants migrate.

4.0 CONCLUSION

Soil characteristics such as porosity and permeability are important factors that decide the fate of water falling on the soil as precipitation.

5.0 SUMMARY

In this unit, we discussed the role of soils in the water cycle. We also defined permeability and porosity of the soil.

6.0 TUTOR –MARKED ASSIGNMENT

1. Explain the soil characteristics that influence run off or infiltration.
2. Discuss surface runoff and watershed.

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MODULE 6

Unit 1 Paleolimnology and Sediments
Unit 2 Other Sediment Depositional Environments
Unit 3 Littoral, Pelagic Zones and their Dynamics

UNIT 1 PALEOLIMNOLOGY AND SEDIMENTS

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main Content
 3.1 Lake Sediment as Climate Archives
 3.2 Methods of Obtaining Paleolimnological Records
 3.3 Sediment Coring Tools
 3.4 Application of Paleolimnology in Lake Management
 3.5 Major Factors Controlling Sedimentation in Lakes
  3.5.1 Watershed Geology
  3.5.2 Watershed Climate
  3.5.3 Mode of Lake Formation and Evolution
  3.5.4 Inflow and Outflow Hydrology
  3.5.5 Internal Water Circulation
  3.5.6 Organic Productivity
 3.6 Sediment Classification
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/Further Reading

1.0 INTRODUCTION

Paleolimnology (Greek).“Paleo” means old, “limne” lake; “logos”study). Paleolimnology is the study of the paleoenvironments of inland bodies of water. Paleolimnology is the study of past conditions of inland fresh water bodies. It is also the study of ancient lakes from their sediments, erosional features left by past lakes, fossils and geophysical data obtained from surveys of lake floors (www.goe.arizona.edu/about). Lake sediments are repositories and sources of information about lake history. Depositional products tell us about the mechanisms of transport or accumulation of important geochemical and fossil archives, important clues about the history are embedded in the pattern of sedimentation. Paleolimnological techniques are used to investigate everything from how local watersheds have responded in the recent past to human impacts to patterns of global change.

2.0 OBJECTIVES

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

- explain lake sediments as climate archives
- highlight methods of obtaining paleolimnological records
- discuss sediment coring tools
- discuss applications of paleolimnology in lake management
- enumerate major factors controlling sedimentation in lakes
- analyse sediment classification.

3.0 MAIN CONTENT

3.1 Lake Sediments as Climate Archives

Sediments are naturally-occurring materials that are broken down by the processes of weathering and erosion, transferred by the actions of wind, water, ice or the force of gravity acting on the particles. Sediment is transported by water (fluvial processes of transport and deposition e.g, beach sands, river channel deposits), wind (Aeolian processes of transport and deposition e.g. desert sand dunes and loess) and glaciers (glacial moraine deposits and till). Aquatic environments accumulate sediments for several thousands of years. Sediments consist of biological remains from a lake and its surroundings, soil particles and other non-biological materials from the catchment and atmosphere. The sediment sequence in a lake carries information about the history of the lake and its watershed.

Much climate-related information can be obtained from lake sediments while some physical and geochemical properties of lake sediments are related to climatic variables (Bigler accessed 2016). For example, the thickness of each annual layer (varve) gives valuable information on the past productivity or erosional input. Textual analysis (mineralogical composition, grain size, form of minerals) can give information on the origin of deposited material. The amount of organic matter in the sediment can be used as an indicator of past primary production in the lake and its catchment.

Most lakes are surrounded by watersheds that are larger relative to the lake's area. This makes lakes different from oceans where the ratio of land supplying sediment, or dissolved salts that can become sediment to water is small. The implication of this difference is that lakes are environments of relatively rapid sediment accumulation in comparison with the oceans or terrestrial environments. Accumulation rates in lakes are faster than in the oceans, over comparable durations in observation. Even the largest and deepest lakes like Lake Baikal accumulate sediment on their abyssal plains at rates of 0.3-0.6 mm/year (0.007-0.31 gcm^{-2} yr^{-1}) (Appleby *et al,* 1998) much faster than comparable basin settings in the deepest sea.

The ability to discriminate historical events in sediments is not strictly a result of sediment accumulation rate, but also a consequence of secondary modification, through transport or bioturbation that results in time-averaging of a deposit, placing a lower limit on the duration of what can be resolved. Lakes are favourable settings for obtaining highly resolved records since depths of bioturbation (in millimetre to few centimetres), tend to be considerably shallower than in terrestrial or marine settings, and sedimentation rates in lakes are on average, rapid. This implies that decadal or annual events can be discriminated, an impossibility in many other depositional environments (Cohen, 2003).

Another factor that differentiates lake sedimentation from most other depositional settings is the greater degree of depositional continuity evident in lakes. Lakes are relatively small compared to the oceans and can respond more quickly to an external forcing variable. Changes in air temperature or regional land use can be reflected within months to decades in the inputs to the lake's sedimentary record. Small lakes respond more quickly and more definitively to a perturbation than large lakes.

3.2 Methods of Obtaining Paleolimnological Records

According to Cohen (2003), paleolimnological records are contained in three types of archives namely:

i. **The lake water**: Water and its contents have residence times in the lake. In lakes with long residence times, the water may provide important clues to lake history.
ii. The **geomorphology** of a lake basin, particularly its shoreline and shape characteristics give a more durable container archive.
iii. **Sediments** provide the most durable archive for paleolimnology since they may persist long after the lake or its geomorphology is gone.

Content archives are the physical sedimentary inputs to the lake's record e.g. terrigenous (derived from erosion of land-based rocks); chemical and biogenic (produced by living organisms or by biological process) sediments; cosmogenic (produced by cosmic rays) and volcanogenic particles, fossils that originated outside of the lake, like pollen, or in the lake like fish, aerosol and water-borne pollutants. Many methods are used to obtain information from sediments. Among them are the following:

i. Some lakes have annually laminated sediments or "varves" where light and dark bands are formed yearly similar to tree rings and allow good chronological control by counting the layers. On the other hand, the sedimentary records can be homogenous with no pronounced annual layers.
ii. Commonly applied methods of dating are based on radio-isotopic dating such as lead (Pb 210, half-life 223 years and carbon -14 (C-14, half- life 5500 years). The lead method is applied to sediments that are not older than 150 years while C -14 method is for those up to thousands of years old. These methods have high dating uncertainties than the use of varved sediment sequences.
iii. Near infrared spectroscopy (NIRS) is used to characterise the amount and composition or quality of the organic matter in lake sediments, giving reliable climate estimates. The use of stable isotope analysis provides estimates of past climate and sometimes the amount of sediments.
iv. Remains of past vegetation in Lake Catchment are usually deposited as pollen and plant microfossils. The analysis of pollen spectra in lake sediments allows an indirect reconstruction of vegetation patterns. Much pollen is wind-dispersed and records can be affected by long distance transported pollen leading to a wrong picture of the vegetation within the catchment.
v. **Sediment coring:** Is the most common method of obtaining paleolimnological data. Cores are one –dimensional columns of sediments. Even the collection of several cores only allows a limited perspective on the spatial variability of sedimentary archives in a lake. Cores are the most practical means of obtaining physical samples but, no single coring tool is appropriate for all circumstances.
vi. **Outcrop analysis** is another common means of obtaining paleolimnological records. Outcrops allow larger samples to be obtained than cores and allow two dimensional or three – dimensional reconstructions of variation in sedimentary deposits. Outcrop analysis is limited to paleolakes or deposits exposed around existing lakes. Limitations are imposed by the pattern of exposure, from either natural outcrops or road cuts. Also the lake beds that have been exposed to air or near surface conditions will have undergone additional diagenetic (chemical, physical and biological changes sediments undergo during and after lithification not including weathering) and pedogenetic (soil-

forming) processes that may alter important aspects of their content archives.

vii. **Geomorphological Archives from Lake Paleoshorelines-** Terraces form at or near a lake's surface through erosional and depositional processes on exposed coasts of large lakes, with prominent wave action on shoreline (Adams and Wesnousky, 1998). Low lake levels expose the terraces, allowing their elevations to be measured. The terraces provide information on what at their time of formation, were horizontal surfaces, often preserved over a large lateral extent around the paleolake basin. When paleolakes are not deformed by subsequent tectonic activity, their elevations allow the estimation of ages of undated or undatable lake levels. Where paleoshorelines are deformed by secondary tectonic activity, terraces provide information about the viscous properties of the earth's mantle (Clark *et al*, 1994).

viii. **Geophysical archives from seismic records:** Seismic reflection profiles provide an important type of paleolimnological archive. Although it is expensive, the information provided by seismic stratigraphy complements coring and outcrop studies, and provides three –dimensional data on the geometry of sedimentary deposits that cannot be obtained in other ways (Sheriff and Geldart, 1995). Seismic reflection profiling relies on the fact that different types of sediments have different acoustical properties. Acoustical impedance for a material is the product of its density times the velocity at which it transmits sound waves.

Other geophysical archives

i. Side-scanning sonar is used to obtain acoustical images of depositional features on a lake's floor (Johnson and Ng'ang'a, 1990).

ii. Ground- penetrating radar is used to generate cross-sectional profiles that look very similar to those created by seismic sources (Smith and Jol, 1997).

iii. Down –hole geophysical logging tools are used in the petroleum industry for determining sediment properties such as electrical conductivity, gamma ray production, or temperature. Such tools provide auxiliary information on bed history and lithology when collected along with coring or drilling.

3.3 Sediment Coring Tools

Different coring tools have been developed to serve different purposes. These include:

i. **Chamber Samplers** are used to sample peats. The sampler is driven into the sediment while it is closed, and opened using a rotating side aperture to allow the sample to enter the chamber.

ii. Hand operated or motorised **augers** employ rotation of a hollow screw into the sediment collecting a sediment column inside the driving screw.

iii. **Gravity box** and **multi-corer** use the corer's weight to force themselves into the sediment. They are lowered to the lake floor under controlled conditions to ensure vertical entry into the sediment and to prevent the corer from over penetrating, or becoming completely buried. A closing mechanism at the top of the core prevents downward hydrostatic pressure after core collection causing the core to be held within the barrel as it is retrieved. A jaw-like device, called a core catcher, is located just inside the cutting end of the corer, preventing the sample from falling out of the bottom during retrieval. Gravity cores are limited to a few metres in length.

iv. A box corer is a specialised gravity corer that takes larger box-like samples rather than cylinders, allowing some spatial variation to be seen and larger samples to be collected.

v. A multicorer collects several adjacent short cores (<1m) from a single device, allowing large sample size, precise collection of the water-sediment interface and the observation of some spatial variation.

vi. **Piston corers** are designed to overcome hydrostatic pressure that affects gravity corers. They use the suction created by a sealed piston within the core barrel and immediately above the sediment. It is driven mechanically or hydraulically to eliminate internal hydrostatic pressure over the sediment sample. As the core barrel penetrates the sediment, the stationary piston allows sediment to enter the barrel without the sediment-deforming effects of internal hydrostatic pressure. It collects a longer undisturbed sample. A piston sampler is typically 1-15 m. Piston and gravity samplers do not work in lithified (sediments turned into solid rocks) or coarse-grained sediments.

vii. **Vibracorer** is used for the penetration of coarse-grained, unconsolidated sediments. A vibra corer has a large, vibrating motor head attached to the top of the core barrel. When the motor is turned on, the vibrations drive the barrel into the sediments.

viii. **Freeze sampling** is used for similar purpose to multicoring, to collect the sediments immediately below the sediment-water interface without disturbance, particularly in sediments with high water content. Freeze samplers allow sediments to adhere by freezing to the outside surface of a hollow chamber that has been previously filled with a dry ice/alcohol mixture.

3.4 Applications of Paleolimnology in Lake Management

i. The extremely high –resolution records that can be obtained from lake deposits make them ideal for application to problems in ecology. The combination of temporal and spatial scales available for study in lake deposit records allows them to work with ecological experiments and ecosystem monitoring. Compared with other depositional systems, lakes are ideally suited for addressing questions about ecosystem dynamics on scales comparable with those of ecology.

ii. Another application of paleolimnology involves the exploration of rapid change in the atmospheric composition and climate-driven by human activities. High temporal resolution, rapid response of indicators to forcing variables, and indicator sensitivity in lakes are very important. Individual lakes provide records with these characteristics, but one of the most valuable aspects of the lake archives comes from the use of records from multiple lakes within a region to examine an impact.

iii. Lakes serve as unintentional, repeated experiments that evaluate human impacts on several chemical and biological systems. Lakes have responded to changing climate through warmer water temperatures and longer periods of ice-free conditions at mid and high latitudes or warmer water surface temperatures in the tropics leading to more stable water column stratification.

3.5 Major Factors Controlling Sedimentation in Lakes

3.5.1 Watershed Geology

Topographical relief, bedrock composition and underlying structure of a lake's watershed play major roles in determining the rate of sediment input and sediment geochemistry. Watershed geology influences the texture of available sediments for deposition based on the initial composition of the bedrock. The range of dissolved solutes and buffering capacity of lakes depend on bedrock composition and determine the types of minerals that can form in a lake.

Bedrock geology, along with watershed microclimate, regulates the rate of surface versus subsurface runoff and groundwater discharge to lakes by influencing factors like permeability and porosity of land surfaces and their local erodabilty. Bedrock relief, composition and texture also influence the response of watersheds and sediment discharge rates to land clearing.

Watershed geology directly influences water chemistry. Despite aerosol and dust contributions, the watershed provides the most direct source of input to the lake. Alkalinity and pH are directly affected by the composition of watershed bedrock.

3.5.2 Watershed Climate

Precipitation within a lake's watershed affects the vegetation cover, soil development and watershed erosion rates. All these factors influence the rate of sediment delivery to a lake, the chemistry of particulate matter and dissolved solids entering the lake. Lakes in cold and dry climates have clays dominated by minerals like chlorite with easily removed cations. These ions are stripped under wetter and warmer conditions of increased weathering leaving a residue of cation-poor clays like kaolinite. Because of the seasonality of vegetation growth in the humid tropics, peak discharges and the degree of seasonality of discharge may have a greater influence on sediment yields to lakes than mean annual precipitation alone.

Temperature determines sediment delivery patterns to a lake through its influence on soil, vegetation or ice development. Warmer temperatures cause higher rates of biochemical weathering, and sedimentation rates. Higher discharge and lacustrinese dimentation rates are associated with higher mean annual temperatures, longer run off seasons and higher mean annual precipitation. Glacial scour generates fine sediment, but much of it is bound for long periods in ice and not deposited in a lake. More sediment is delivered at high temperatures, melting and discharge rates. Temperature affects the density relationships between inflow and lake water, determining the formation of outflows or underflows and, the spatial distribution of sediment delivered to a lake.

3.5.3 Mode of Lake Formation and Evolution

The processes involved informing and maintaining a lake basin affect strongly its sedimentary infill. To produce and maintain the topographical depression that contains a lake, either material was physically evacuated or the margins of the depression were relatively raised. In either case, a large mass of erodible material on the lake margin originate through the same processes that caused the depression.

Many sedimentological differences between lakes that are related to lake origin result from the differences in sub-aerial and sub aqueous slope associated with basin –forming processes. For example, deposits from gravity flows are characteristic of the steep lake margins associated with lakes formed by volcanic caldera collapse, over-deepening of glacial rock basins, or along major border faults in tectonically formed rift basins. In tectonic lakes and collapsed caldera basins, long-term sediment accumulation rates are controlled by underlying rates of fault motion and subsidence, which vary systematically along the lake floor.

3.5.4 Inflow and Outflow Hydrology

The connections with upstream water sources and downstream discharge place a constraint on depositional patterns in lakes. Presence or absence of spillway determines the extent to which lake level can fluctuate and the extent to which deposits linked to a particular zone of the lake canmigrate spatially over time. Whether a lake is closed or open can change over time depending on climatic conditions but also occasionally on upstream changes in river flow direction.

Lakes with surface outlets undergo relatively small changes in surface elevation, because increased upstream discharge to the lake is compensated by increased outflow. Closed lakes undergo much more spatial and temporal variation in area, environmental boundaries and local sediment accumulation rates. Variations in lake levels have numerous sedimentary consequences. Deltas in closed basins undergo large and erratic changes in position in response to rapid lake level fluctuations. At low lake levels, deposits that previously accumulated along the margins of a lake may be eroded and re-deposited in the deeper parts of the basin, leaving behind erosional surfaces. In large lakes, wave action in the surf zone where waves break can cause erosion as lake levels rise. Spillway blockage by ice can cause lakes to rapidly rise until a new outlet spillway level is reached.

Hydrological closure allows increase in ionic concentration over time in lakes producing evaporate deposits from concentrated brines. Except in relatively rare circumstances where saline ground water discharge causes hydrologically open lakes to become saline, low levels of salinity and absence of evaporate deposits characterise most open –basin lakes. The accumulation of dissolved solids also determines what organisms can inhabit the lake, and secondarily affects depositional processes (extent of bioturbation, accumulation of shelly deposits etc.).

Groundwater discharge and recharge are important regulators of lake levels. Most aspects of inflow and outflow hydrology are either directly or indirectly linked to climate. In regions with low precipitation to evaporation rates (P/E), inflow is insufficient to infill depressions and there is always some minimum threshold of P/E required to maintain a lake's spillway flow. Therefore, while groundwater discharge may dampen seasonal fluctuations in lake inflow, it is also sensitive to long term changes in precipitation and evaporation.

3.5.5 Internal Water Circulation

Internal circulation and mixing affects the redox state of sediments, their re-suspension following deposition and transport, and the accumulation of organic matter in sediments. Amictic and meromictic lakes provide paleolimnological records that can be more highly resolved in time than those of monomictic or dimictic lakes, as a result of lack of re-suspension and/or bioturbation in the former lake types.

Without re-suspension or seasonal turnover, sedimentary signals can be preserved that resolve monthly events. Re-suspension from bottom current activity reduces the potential resolution of sedimentary records. Mixing blurs seasonal signals and moves sediments, especially fine particulates over long distances. Under conditions of extremely vigorous circulation or slow accumulation, re-suspension causes mixing of deposits accumulated over decades or longer. Fine particulate matter can be maintained in suspension for long periods by internal hydrodynamic mechanisms like internal waves. Internal circulation also affects diagenetic alteration of sediments after deposition mainly through impacts on redox state. Methanogenesis can lead to the formation of minerals such as siderite or dolomite.

Horizontal transport causes physical mixing of sediments from different watersheds and allows sediments to be carried to particular areas of a lake. Coupled with vertical mixing (gravitational flows), and re-suspension, this generates the phenomenon of sediment focusing, an increment in sediment rate in a particular part of a lake basin.

3.5.6 Organic Productivity

Sedimentary consequences of changing organic productivity are observed most directly in the accumulation rates of “organic” sediments. These include combustible organic matter, the skeletal remains of organisms such as biogenic silica and calcium carbonate precipitation associated with photosynthesis. On short time scales, the rates of organic accumulation are affected by the rate at which phytoplankton debris settle to the lake floor, a function of water depth, vertical circulation, particle aggregation and the formation of fecal pellets. Particle degradation, re-suspension and grazing all impose limits on our ability to resolve short term productivity changes from accumulation rate data alone.

3.6 Sediment Classification

Sediments can be classified based on the grain size and/or composition. Based on grain size, sediments are measured on a log base 2 scale called the "phi" scale which classifies particles by size from colloid to boulder.

Table 2: Sediment Classification Based on Grain Size

φ Scale	Size range (metric)	Size range (inches)	Aggregate class (Wentworth)	Other names
<-8	256mm	10.1 in	Boulder	
-6 to -8	64-256mm	2.5-10.1in	cobble	
-5 to -6	32-64mm	1.2-2.5 in	Very coarse gravel	pebble
-4to-5	16-32 mm	0.63-1.26	Coarse gravel	pebble
-3 to -4	8-16mm	0.31-0.63	Medium gravel	pebble
-2 to-3	4-8mm	0.157-0.31in	Fine gravel	pebble
-1 to -2	2-4mm	0.079-0-157in	Very fine gravel	granule
0 to -1	1-2mm	0.0.039-0.079in	Very coarse sand	
1-0	0.5-1mm	0.020-0.039in	Coarse sand	
2 to 1	0.25-0.5mm	0.010-0.020	Medium sand	
3 to 2	125-250μm	0.0049-0.010in	Fine sand	
4 to 3	62.5-125μm	0.0025-0.0049	very fine sand	
8 to 4	3.9-62.5μm	0.00015-0025in	silt	mud
>8	>3.9 μm	0.00015in	clay	mud
>10	<1μm	0.000039 in	colloid	mud

Source: www.wikipedia.org

The composition of sediments can be measured in terms of parent rock lithology (study of rocks with particular emphasis on their description and classification or the general composition of a rock sequence

4.0 CONCLUSION

Paleolimnology is the study of old lakes and sediments provide one very reliable archive for such studies. Many methods and tools are employed and several factors determine sedimentation in lakes.

5.0 SUMMARY

In this unit, we discussed paleolimnology and sediments as an archive for paleolimnological studies. We also discussed different sediment coring tools and factors controlling sedimentation in lakes.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain lake sediments as climate archives.
2. List the methods of obtaining paleolimnological records.
3. Discuss sediment coring tools.
4. Explain applications of paleolimnology in lake management.
5. Enumerate major factors controlling sedimentation in lakes.
6. Discuss sediment classification.

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UNIT 2 OTHER SEDIMENT DEPOSITIONAL ENVIRONMENTS

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1.0 INTRODUTION

Sediments are deposited from the surrounding environment through the activities of wind or water in several aquatic environments such as the littoral zone, lacustrine environments, shallow water, lacustrine fans and the open water. Several depositional features form. In this unit, we discuss some of such depositional environments and features**.**

2.0 OBJECTIVES

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

- discuss littoral depositional environments
- describe depositional processes in lacustrine coastal zone
- highlight classification of unconsolidated, organic –rich sediments of shallow lakes
- explain shallow water carbonate depositional environments in lakes
- discuss sublacustrine fans cum open water (pelagic and hemipelagic) deposition.

3.0 MAIN CONTENT

3.1 Littoral Depositional Environments

Lacustrine beaches and shallow littoral environments receive sediments from several sources. River-derived sediments can be redistributed along coastlines away from their original sources, especially in large lakes with strong secondary transport mechanisms.

On exposed coastlines, under coastal currents, several geomorphic features can form, e.g. spits, barrier ridges. Local alluvial sources and coastal erosion processes provide sediment away from major river deltas, especially in lakes surrounded by large amounts of unconsolidated materials. Wind-derived sediment is important in arid regions. Winds generate dune fields around lakes.

3.2 Depositional Processes in Lacustrine Coastal Zone

Lacustrine beaches are areas of temporary sediment storage and subject to frequent erosion. Their deposits are less informative for paleolimnological studies than deeper water zones or subsiding deltas. Beaches are useful for recording episodic events such as high lake stands, since they accurately mark paleolake level. Within the zone of coastal sediment transport, wind-driven waves are the most important agents for redistributing coarse-grained sand and gravel. Tides, even in the largest lakes are minor features and create only insignificant currents (Sly, 1978).

Long shore currents are weaker than in coastal marine environments, and coastal pileup of water is rare. In lakes with steep, offshore profiles, longshore transport is limited to small pocket beaches, beyond which sand is carried into deep water by gravity flows (Soreghan and Cohen, 1993). Where coastal waves and longshore transport energies are adequate to move sand, they create a mix of planar and ripple bedding. Lacustrine fossils tend to be rare and/or abraded in these deposits. Larger bed-forms like mega ripples, or large sand bars, are features of exposed coastlines in larger lakes.

In small lakes or protected embayment of large ones, the ‘‘coastal belt’’ may be only metres wide, and muddy shorelines are typical features of small ponds. This is described as thin-bedded, laminar to massive (bioturbated) silt and silty sand. These deposits are much more likely to contain fossil invertebrates and aquatic macrophytes. Pond and embayment deposits are dominated by aquatic plant debris.

3.3 Classification of Unconsolidated, Organic-Rich Sediments of Shallow Lakes

Unconsolidated, organic-rich sediments of shallow lakes were originally classified on the basis of their organic content (Cohen, 2003). These include:

i. **Gyttja (copropels)** is a grey or dark brown sediment, containing humic material, plant fragments, terrigenous sediment, diatom, and other algal and zooplankton remains. Gyttja has a textured appearance and feel when wet, having been transformed as a mass of fecal pellets by chironomids or other benthos. Gyttjas form underoxygenated conditions.

ii. **Dy**is a type of gyttja formed under acidic or bog conditions, with high concentrations of acidic humic materials. It is brown and fibrous in appearance, from abundant peat particles.

iii. **Sapropels** are glossy black (when fresh, from reduced FeS) and generally finer-grained organic sediments. They contain abundant methane, hydrogen sulphide (CH_4 and H_2S) and other products of microbial reduction. Sapropels require reducing conditions to retain their appearance and composition, although this can develop seasonally from low oxygen conditions, or the rapid accumulation of organic-rich sediment, without permanent anoxia.

3.4 Shallow-Water Carbonate Depositional Environments in Lakes

Many lakes meet the environmental conditions for the accumulation of calcium carbonate deposits such as high rates of photosynthesis and relatively alkaline water conditions. Lime muds and sands are common features of lake deposits. **Marls** are carbonate muds produced with low amounts of clastic material. Where both siliciclastic and carbonate sediment sources exist in sub-equal proportions mixed carbonate/clastic deposits will accumulate.

3.4.1 Carbonate Sediments

Carbonate sediments behave differently from siliciclastic sediments, during and after deposition. Carbonate minerals are relatively reactive under varying lake and diagenetic conditions, and mineral dissolution and replacement is common. These processes are very important in highly concentrated brines, near shorelines, and in areas of groundwater–sediment interaction.

The exposure of carbonate sediments through falling lake level causes them to develop characteristic diagenetic and soil-forming features, including the formation of carbonate nodules, calcite-filled cracks, dissolutions paces (microkarst), and secondary cementation around roots (Platt, 1992). Such features provide paleolimnological evidence of lake-level change.

Some carbonate minerals form in lakes such as low (0–5%)-Mg calcite, high-Mg calcite, and aragonite. Carbonate mineral assemblages provide information about lake water chemical and temperature conditions and brine evolution at the time of precipitation. Brine evolution causes Mg concentration to rise during evaporative concentration, and favors carbonates that form under high Mg conditions, such as high-Mg calcite, aragonite, dolomite. The formation of some carbonates is sensitive to temperature variation (Shearman *et al.*, 1989).Carbonate sediment is produced primarily within the photic zone, through the formation of a number of distinctive types of particles. The most common are:

i. Lime muds are formed mainly by direct calcite precipitation, and secondly by degradation of larger particles. The precipitation of clay and silt-sized calcite or aragonite particles occurs seasonally as a result of photosynthesis-induced precipitation, for example around bacteria, or charophyte stems. Calcium carbonate muds are common in shallow water along a variety of low-energy lake margins such as small lakes and ponds, among macrophytes, or, in large lakes, along protected or gentle-gradient coastlines.
ii. Sand and gravel-sized carbonate particles are produced by several mechanisms in lakes. In lakes occupying limestone bedrock basins, eroded carbonate clasts can be transported into the lake.
iii. Bioclastic sediments mainly fragments from ostracode and mollusk shells or charophyte oogonia and stem coatings are a major source of *in situ*-carbonate grains. Another source is from the formation of coated grains, concentrically layered particles of calcite, aragonite or other minerals.
iv. The most characteristic types of coated grain in lakes are ooids, sand-sized particles with spherical or other rounded shapes. Ooids gain their shape through a combination of accumulation of calcite or aragonite around some nucleus, coupled with continuous rolling to expose new surfaces to growth. Internally they display a wide variety of crystalline fabrics, some of which have paleo-environmental significance (Popp and Wilkinson, 1983). They form on wave-swept beaches or platforms in shallow water and may be transported and deposited in deeper water through gravitational flow.
v. Oncoids are larger coated grains which nucleate around gravel or cobble-sized objects like shells or rocks. Calcite precipitation on

most oncoidsis mediated by cyanobacteria; thus they can be thought of as a special type of stromatolite (Verrecchia *et al*., 1997).These objects are too large to roll continuously and their coatings are more irregular (Jones and Wilkinson, 1978).

vi. Lithified carbonate forms cemented surfaces in lakes through the development of beach rock (near shore pavements formed by carbonate cementation around existing sand grains, algal bioherms), and spring-deposited tufas. Beach rock pavements provide excellent paleo-shoreline indicators. They comprise variably cemented sand and gravel surfaces that dip gently in a lake-ward direction (Last and DeDeckker, 1990).

vii. Carbonate bioherms are formed by cyanobacteria in lakes and some by green algae. They form into many shapes, from encrustations on existing surfaces, to extremely large ''reefs,'' with relief of as much as 18 m off the lake floor (Rouchy *et al*., 1996).

viii. Tufas are porous carbonate spring mound deposits. They most commonly form as thickly layered deposits with numerous spongy cavities, and incorporate surrounding particulate matter (Pedley, 1990).The formation of tufas involves a combination of microbial calcite precipitation and inorganic degassing. They often build up into spectacular columns.

The type of carbonate sediment formed in any near shore setting is strongly influenced by lake's floor gradient and local wave energy conditions (Platt and Wright, 1991).

3.5 Sublacustrine Fans

In deep lakes with steep margins, large deltas cannot form, as sediment is carried through various gravity flows directly into deep water. This also occurs offshore from deltas, where complex''stair-step'' type topography occurs. Under these conditions, sediment may be transported as unconfined sheets of mud and sand that cascade downward as gravity flows. Mass movements of debris and grain flows result in chaotic deposits of sand, gravel, and boulders at the foot of steep slopes. Active scour from gravity flows and faults or tectonically formed ramps can also produce similar features. In cases where confined or partially confined sediment/water gravity flows moving through a relatively steep channel are discharged onto a relatively flat lake floor, a sublacustrinefan can develop.

Sublacustrine fans resemble alluvial fans and some types of deltas, in lobate or radiating geometry, and in some smaller-scale aspects of their sedimentology. Sublacustrine fans grade into, or are replaced over time by deltas, as deep and steep lake margins are transformed to gentler ones through sediment infill (Wells *et al.,* 1999).

When lithified, channel deposits preserve current indicator features such as ripple marks, tool marks, and flute casts, indicating the direction of paleo flow. Soft-sediment deformation features are common here. Levees surrounding the channels are generally composed of finer-grained, laminated, or massive muds. At a large (kilometre) scale they often form lens-shaped or radiating bodies of mud, forms that can be observed in seismic profiles (Soreghan et al., 1999).

In extremely distal settings (far from their original source), deepwater lacustrine turbidites become very muddy (siltstones and shales when lithified), with only occasional thin fine sands. Fossil content in sublacustrine fan deposits is limited. Some gravity flows introduce shelly fossils e.g. ostracodes, mollusks, chironomids, and benthic diatoms into deep water. Planktonic or other suspension-settled fossils (diatoms, other algae, and pollen) are found in the finer hemipelagic deposits that are inter-bedded with the fan.

3.6 Open Water (Pelagic and Hemipelagic) Deposition

In the central parts of a lake basin, sedimentation is dominated by the accumulation of materials settling from suspension. These include three important categories of sediments:

i. Hemipelagic muds are transported far offshore by surface or midwater currents. These sediments are derived from a combination of river or shoreline erosion processes. Organically derived particles are primarily skeletal ‘‘oozes,’’ or partially degraded organic matter, mostly from phytoplankton.
ii. Chemically precipitated sediments include carbonates, Fe & Mn oxides, and hydroxides, and to a lesser extent, evaporite or other authigenic (generated where it is found) minerals.
iii. Wind-blown particles (terrigenous dust, pollen, and volcanogenic tephra) are important in some lakes.

All of these deposits are characteristic of the central parts of most large lakes, or small lakes where river input is limited. In large but shallow lakes, with central lake floor within the photic zone, organic debris from macrophytes or benthicalgae can be added. Small lakes and ponds often lack a true pelagic depositional zone, as most or all of the lake floor comes under the direct influence of coastal or prodeltaic depositional processes.

Pelagic sediments are mostly silt and clay-sized particles. Sand-sized particles, if present, are derived from eolian origins, the occasional large turbidite, or from fecal pellet aggregates. Because these areas are far from river inputs they have slow rates of sediment accumulation. These types of sediments provide the highest degree of stratigraphical resolution obtainable from lake deposits.

Organic sediments can be derived from both autochthonous and all ochthonous sources (Kelts, 1988). In the central portions of large lakes the primary source of organic matter is autochthonous, from mid-lake production. This can consist of epilimnetic phytoplankton, bacteria growing at chemocline, or benthic microbial mats (Valero-Garce´s and Kelts, 1995). In small lake basins organic matter may represent more of a mix of both autochthonous and all ochthonous organic matter sources.

Alkaline lakes are particularly prone to accumulation of laminated organic sediments because alkaline lakes take up CO_2 rapidly as carbon is fixed by photosynthesis, allowing very high biomass levels to accumulate. Even after sedimentation there is continued loss of organic content in sediments because of bacterially-mediated diagenesis. Organic matter undergoes microbial decomposition in sediment through a variety of processes. In the aerobic zone this involves oxidation, whereas anaerobic processes involve reduction of manganese, nitrate, iron, sulfate, and carbonate. All produce simpler organic and hydrocarbon compounds. In some lakes part of the organic matter is secondarily transformed as bacterial mats on the lake floor. Pyrite commonly forms in sulfate-rich lakes under meromictic conditions or where organic accumulation rates are extremely high (Kelts, 1988).

4.0 CONCLUSION

Other sediment depositional environments include the littoral zone, lacustrine coastal zone and open water. Lacustrine deltas are the major entry points of sediments into lakes, and important zones of accumulation. Lacustrine coastal environments are areas of short-term sediment storage and vigorous sediment reworking. Carbonate deposits present in lakes, yield valuable information about biological activity, productivity, and water depth. Open lake and pelagic deposits give the most continuous and highest resolution records available from lakes, and are often varied, recording sub-annual events.

5.0 SUMMARY

In this unit, we discussed other sediment depositional environments. We also discussed different sediment types and features formed in each depositional environment.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain littoral depositional environments.
2. Discuss depositional processes in lacustrine coastal zone.
3. List the classification of unconsolidated, organic –rich sediments of shallow lakes.
4. Explain shallow water carbonate depositional environments in lakes.
5. Analyse sublacustrine fans cum open water (pelagic and hemipelagic) deposition.

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UNIT 3 LITTORAL, PELAGICZONES AND THEIR DYNAMICS

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1.0 INTRODUCTION

The littoral and pelagial environments constitute major zones in the both freshwater and marine systems. In this unit, we consider the different zones, roles and characteristics of the littoral and pelagic environments.

2.0 OBJECTIVES

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

- define littoral zone
- define pelagial system
- describe oceanic zones cum demersal zone

- highlight the classification according to light penetration zones
- explain the limnetic zone cum benthon-bottom dwellers
- enumerate factors that affect the distribution of living organisms
- discuss adaptations of pelagic organisms cum pelagic food web.

3.0 MAIN CONTENT

3.1 The Littoral Zone

The littoral, foreshore or intertidal zone is located between low and high tides and is affected by tidal movements while the infratidal zone is located below the low tide line. The littoral zone can refer to the shoreline of a body of fresh or saltwater and also means any area close to the water or influenced by the water. For a freshwater biome, the littoral zone is the area with abundant light close to the shore. The littoral zone in a pond or lake allows for prolific photosynthetic activity and consequently hosts almost all of the aquatic plant life.

The living organisms in the foreshore of the beach must be adapted to both wet and dry conditions as this area is under water at high tide. Animals like sea anemones, barnacles, chitons, crabs, isopods, limpets, mussels, sea stars, snails and whelks are adapted to this zone. Because the water is so near to littoral zones, both freshwater and saltwater, the organisms existing here are often found in dunes or estuaries. The large amount of water available creates a habitat for a variety of plants and animals. This allows for the survival of a variety of living organisms. Large human populations also live close to littoral zones.

The **littoral zone** is the region near the shore where sufficient light reaches the bottom to support rooted plants. In many shallow lakes and ponds this zone may extend completely across the basin. There are usually distinct community associations within the littoral region. Near the shoreline there is the **zone of emergent vegetation**. This region is usually dominated by grasses, rushes, and sedges. Cat-tail and arrowhead are also common. The plants of the emergent zone utilise atmospheric carbon dioxide and oxygen. Minerals and water are derived from the lake substrate.

As depth increases, a transition to plants with long stems or petioles, and floating leaves occurs. This marks the **zone of floating vegetation**. This community includes water lily and pondweed. Localized masses of spongy tissue aid in buoyancy. Stomata are restricted primarily to the upper surface of the leaves where they access atmospheric gases. Absorption of ions takes place on the underneath side of the leaf.

The innermost region of the littoral zone forms the **zone of submersed vegetation**. These plants may be considered to be truly aquatic, deriving their gases from the water. Prominent submersed vegetation includes stonewart, hornwort, milfoil, waterweed, and hydrilla. Within the littoral region there are usually a number of non-rooted free-floating hydrophytes. Water fern, duckweed, and water hyacinth are examples. Free-floating plants derive their nutrients from the water.

The littoral zone is where water self-purification occurs and it also acts a buffer for the pelagial system, protecting it from pollution. It is the zone where intensive processes of phytoplankton primary production occur and the freshly produced organic matter can stimulate activities in the littoral zone and the whole lake. Understanding the dynamics of phytoplankton metabolism in both the littoral and pelagic zones and the factors responsible for these changes are essential for the control of lake trophic status. A very severe threat to water quality in this zone is uncontrolled growth of phytoplankton including toxic cyano-bacterial algae.

The littoral habitat zones of lakes and ponds extend from the water's edge out as far as rooted plants grow. In most lakes and ponds, the littoral area may reach from shore to shore. The littoral habitat has the tallest plants and the greatest diversity of life living among it. The water in the littoral zone is the warmest because it is the shallowest.

The littoral zone consists of three sub zones namely the **supra-littoral** zone or **spray** zone, which is only under water during storms and is located between the high tide-line and dry land. The **intertidal** zone is located between the high and low tides. The **sub-littoral** zone is always under water and is below the low tide line. This zone extends all the way to where the continental shelf drops off into the abyssal plane. Everything except areas near the coast and the sea floor is called the **pelagic zone** (MarineBio.org, 2016).

3.1.1 Supra-Littoral Zone

The supra-littoral (splash, spray or supra-tidal) zone is the area above the high tide line that is regularly splashed but not submerged by ocean water. Seawater penetrates these elevated areas only during storms with high tides. Organisms here must adapt to exposure to fresh water from rain, cold, heat and predation by land animals and seabirds. At the top of this area, patches of dark lichens can appear as crust on rocks. Animals here include periwinkles, isopods.

3.1.2 Eulittoral Zone (Mid-Littoral, Medio-Littoral or Intertidal)

The intertidal zone extends from the high tide line which is rarely inundated to the low tide line, which is always inundated. The wave action and turbulence of recurring tides shapes and reforms cliffs, gaps and caves, offering a wide range of habitats for sedentary organisms. Protected rocky shorelines show a narrow eulittoral strip marked by the presence of barnacles. The area also includes steep rocky cliffs, sandy beaches or wetlands

The eulittoral zone can include different types of habitats with many types of animals e.g. starfish, sea urchin and different species of corals. The intertidal zone is also home to many several species from different taxa such as Porifera, Annelids, Coelanterates, Mollusks, Crustaceans, Athropods etc. Organisms in the intertidal zone are adapted to an environment of harsh extremes. Water varies from fresh to saline between tidal inundations. Some microclimates in the littoral zone are ameliorated by local features and larger plants such as mangroves. An adaptation in the littoral zone allows the use of nutrients available from the sea moved to the zone by tides.

The intertidal zone is divided into three sub zones namely:

i. low,
ii. middle
iii. High, based on the overall average exposure of the zone.

The low intertidal zone, which borders the shallow sub tidal zone, is only exposed to air at the lowest of low tides and is primarily marine in character. The mid intertidal zone is regularly exposed and submerged by average tides. The high intertidal zone borders on the splash zone (the region above the highest still-tide level, but which receives wave splash). On shores exposed to heavy wave action, the intertidal zone will be influenced by waves, as the spray from breaking waves will extend the intertidal zone. Depending on the substratum and topography of the shore, additional features may be observed. On rocky shores, tide pools form in depressions that fill with water as the tide rises.

3.1.3 Sub-Littoral Zone

The sub littoral zone starts immediately below the eulittoral zone. This zone is permanently covered with seawater and is approximately equivalent to the neritic zone. The sub littoral zone refers to coastal regions with significant tidal flows and energy dissipation, including non-linear flows, internal waves, river outflows and oceanic fronts. This typically extends to the edge of the continental shelf (the stretch of the seabed adjacent to the shores of a country to which it belongs) with depths around 200 metres.

The sub-littoral zone refers to the areas where sunlight reaches the ocean floor that is where the water is never so deep as to take it out of the photic zone. This results in high primary production and makes the sub-littoral zone the habitat for most sea life. The benthic zone in the sub-littoral is more stable than in the intertidal zone; temperature, water pressure and the amount of sunlight remain fairly constant. Sub-littoral corals do not have to adapt to as much change as the intertidal corals. Corals are more common in the sub-littoral zone. In the sub littoral zone, the sub zones identified are:

i. Infralittoral zone (the algal dominated zone to about 5metres below the low water mark.
ii. The circalittoral zone is the region beyond the infralittoral that is below the algal zone and dominated by sessile animals such as oysters.
iii. Shallower regions of the sub-littoral zone extending not far from the shore are sometimes called the sub tidal zone.

In freshwater environments, littoral zones occur on the edge of large lakes and rivers often with extensive areas of wetland. These are sometimes called **fringing wetlands**. Here the effects of tides are minimal. The littoral zone may form a narrow or broad fringing wetland, with extensive areas of aquatic plants sorted by their tolerance to different water depths. Four zones are recognised from higher to lower on the shore:

- wooded wetland
- wet meadow
- marsh
- Aquatic vegetation.

The relative area of these four types depends on both the profile of the shoreline and past water levels. The area of wet meadow is particularly dependent on past water levels. Generally, the area of wet meadows along lakes and rivers increases with natural water level fluctuations. Many of the animals in lakes and rivers are dependent on wetlands of littoral zones since the rooted plants provide habitat and food.

Littoral zones are at risk for two main reasons:

i. Human settlements often disrupt breeding habitats for littoral organisms. Some settlements are constructed on wetlands after draining and filling them.
ii. The tendency to stabilise lake or river levels with dam remove floods which carry nutrients into littoral areas and reduces the natural fluctuation of water levels upon which many wetland plants and animals depend. Overtime, dams reduce the areas of wetlands.

Some of the organisms in the sublittoral zone are abalone, sea anemones, brown seaweed, chitons, crabs, green algae, hydroids, isopods, limpets, mussels, starfish, nudibranchs, sculpin, sea cucumber, sea lettuce, sea palms, sea urchins, shrimps, snails, sponges, surf grass, tube worms and whelks.

Creatures in this zone can grow to larger sizes than in the other three intertidal sub-regions due to better water coverage. The water is shallow enough to allow plenty of light to reach the vegetation to allow substantial photosynthetic activity and the salinity is at almost normal levels. The area is also protected from large predators because of the wave action and the relatively shallow water.

Aquatic ecosystem metabolism has been determined using various methods such as diel O_2, TCO_2, oxygen isotopes, ecosystem budgets and incubations. These methods vary in ability to measure gross or net processes. Statistical and modeling approaches based on diel O_2/DIC technique have been used to account for the mixing of O2 due to tides, wind or flow and to estimate metabolic properties (Dunalska *et al*, 2013).

3.2 The Pelagial System

The pelagic realm is subdivided into ecological zones based on depth (Figure 1). The largest concentrations of biomass are located in the epipelagic and mesopelagic zones which are the uppermost layer.

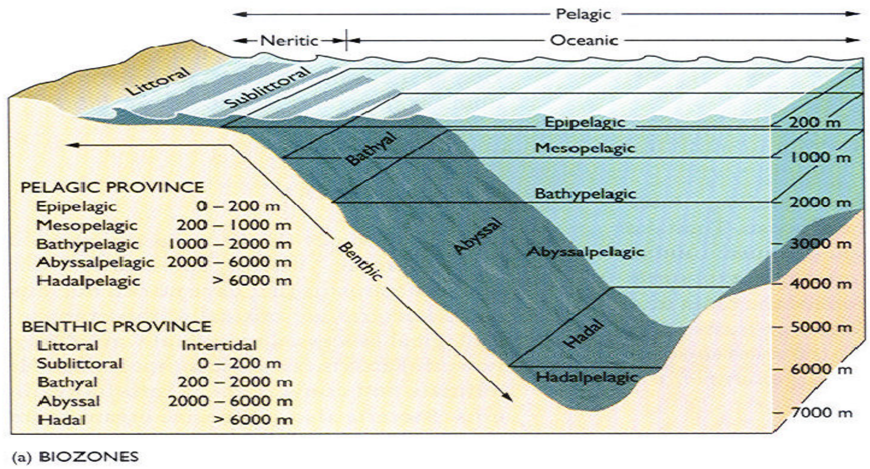

Fig 8. A Schematic Diagram Showing the Different Marine Zones Source: Marine Ecology

The pelagic system consists of water in a sea or lake that is not close to the bottom or near the shore. The word pelagic is derived from Greek meaning “open sea” or “open ocean zone”. Conditions in the pelagic zone differ with depth. For instance, pressure increases with depth while temperature and light penetration reduce. The pelagic zone occupies 1330 million Km^3 with mean depth of 3.68 km (Costello *et al*, 2010; Charette and Smith, 2010; Wikipedia.org, 2016). The pelagic zone is affected by light intensity, pressure, temperature, salinity, the supply of dissolved oxygen and nutrients, and the submarine topography or bathymetry. Coastal water not near the bottom is also in the pelagic zone.

The benthic and dermersal zones are at the bottom of the seas just above the benthic zone and can be significantly affected by the seabed and the aquatic life there. The benthic zone is at the bottom and includes the sediment surface and some sub surface layers. Marine organisms living in the benthic zone are called benthos.

The pelagic ecosystem is based on the phyto-planktons that are at the base of the food chain. They inhabit the upper sunlit epipelagic zone which includes the coastal or neritic zone. Biodiversity decreases sharply in the deeper zones as dissolved oxygen decreases, water pressure increases, temperatures decrease and food decrease. Light diminishes and finally disappears.

The Pelagic Zone is divided into two main areas namely:

i. Neritic zone – shallow water above the continental shelf.
ii. Oceanic zone – deep water of Open Ocean beyond the shelf break.

3.3 Oceanic Zones

3.3.1 Epipelagic Zone

The epipelagic zone extends from surface (0) to 200 m,the maximum depth of lightpenetration. This is the illuminated surface layer. The largest concentrations of biomass are located in the epipelacic and mesopelagic zones. The epipelagic is usually not light-limited and supports primary production by phytoplankton. Below the epipelagic realm, organisms operate in near –darkness. The pelagic zone is home to two groups of organisms, namely plankton (zooplankton or planktonic animals e.g. jelly fish, small crustaceans; and phytoplankton or planktonic plants). The second group of pelagic marine organisms is the free-swimming nekton such as marine mammals, fish squid and larger crustaceans.

3.3.2 Mesopelagic Zone

The mesopelagic zone (middle pelagic or twilight zone) is situated at depths between 200 and1000 m below the surface of water in the ocean. No photosynthesis occurs here because of the low light penetration. It lies between the photic epipelagic and above the aphotic bathypelagic below where there is no light at all.

The temperature in this zone varies less at any height than at epipelagic zone but the mesopelagic zone is the location of the thermocline. The temperature varies from 20^{o}C at the top to about 4^{o} C at the boundary with the bathyal zone. Water moves slowly in the mesopelagic zone and the residency time is about 100 years. A lot of animals move vertically through the zone daily.

The life forms are mainly daytime visiting herbivores, detrtivores that feed on dead organisms or faecal pellets and some carnivores. Animals in this zone include swordfish and squid. As the fish participate in the food chain, they acquire carbon rendered from carbon dioxide absorbed by surface waters. After death, they transport the carbon into the abyss (Trujillo and Thurman, 2010).

3.3.3 Bathypelagic Zone

The Bathypelagic zone is situated between 1000and 4000 m depth below the ocean surface. It is totally dark with no living plants. The Bathypelagic zone is also called the midnight zone. It lies between the mesopelagic above and the abyssal pelagic or abyssopelagic below. The mean temperature is about 4^{o}C. The volume of the bathyal zone is greater than the euphotic zone but it is less densely populated. Sunlight does not reach this zone and primary production is almost absent. Some animal species here have small or no eyes. Examples of animals that occupy the zone are squid, large whales and octopi. Sponges, brachiopods and sea stars are common. The fish in the zone are energy-efficient as it is difficult to get nutrients. Many organisms here have slow metabolic rates to conserve energy. The fish have weak muscles, soft skin, transparent skin and slimy bodies. There are no plants here because of the absence of photosynthesis. Large whales feed in this zone. Except in very deep areas, the bathyal zone extends to the benthic zone.

3.3.4 Abyssalpelagic or Abyssopelagic Zone

Abyssalpelagic (abyssopelagic) zone is a layer of the pelagic zone that lies between 4000and 6000 m, contains more than half of the oceans' volume."Abyss" means it is in perpetual darkness and never receives daylight. It is also characterised by continuous cold and lack of nutrients. Temperature ranges between 2-3^{o}C. Giant tubeworms are found close to the hydrothermal vents. Living organisms in this zone must be able to adapt to very high pressures.

3.3.5 Hadal-Pelagic Zone

The hadalpelagic zone lies at depths below the ocean surface greater than6000 m and include deep-sea trenches. It is found below the abyssopelagic zone but above the bathyal zone. This is the delineation for the deepest trenches in the ocean. The hadal zone has low population and low diversity of marine life. Most of the life here is supported by marine snow or the chemical reactions around the thermal vents. The low nutrient level, extreme pressure and lack of sunlight create hostile living conditions in which few species can exist.

No sunlight reaches this zone and deep sea creatures have reduced eyesight, with very large eyes for receiving bioluminescent flashes. The most common organisms are jellyfishes, tube worms and sea cucumbers. The pressure in this zone reaches or exceeds 1,100 standard atmospheres.

3.4 Demersal Zone

The demersal zone is part of the sea, ocean or deep lake comprising the water column that is near the seabed and the benthos. The demersal zone is just above the benthic zone and forms a layer of the **profundal zone** (a deep zone of an inland body of free-standing water, such as a lake or pond, located below the range of effective light penetration). This is below the thermocline (the vertical zone in the water through which temperature drops rapidly). The temperature difference may be large enough to hamper mixing with littoral zone in some seasons which causes a decrease in oxygen concentrations. The profundal zone is defined as the deepest, vegetation-freeand muddy zone of the lacustrine benthal (Thienemann, 1925). The profundal zone is often part of the aphotic zone.

The lack of light and oxygen in the profundal zone determines the type of biological community that can exist in this zone and is distinctly different from the ones in the overlying waters. The profundal macro-fauna is characterized by physiological and behavioural adaptations to low oxygen concentration. Oligochaetes and chironomids dominate the benthic fauna of the profundal zone as they have haemoglobin-like molecules to extract oxygen from poorly oxygenated water). (Int Panis *et al*, 1995).

3.5 Classification According to Light Penetration Zones

The ocean can be divided according to the levels of light penetration in different zone as shown in Figure 2.

The Euphotic or Photic Zone describes the depth where light is sufficient for photosynthesis and covers from 0 to 100 (or 200 m). The producers of the euphotic zone are the phytoplankton.

Dysphotic zone (mesopelagic zone) constitutes the depth where light is too weak for photosynthesis to occur. It is also called the twilight zone, has less than 5% sunlight and covers 100 to 200 m.

Aphotic Zonerefers to the bathypelagic, abyssalpelagic and hadalpelagic zones where there is no light penetration. It is the depth beyond which less than 1% sunlight penetrates. Bioluminescence is essentially the only light found in this zone. Most of the food in the zone comes from dead organisms that sink to the bottom of the lake or ocean from overlying waters. The depth of the aphotic zone can be affected by turbidity and season of the year. The aphotic zone lies beneath the photic zone which receives adequate sunlight.

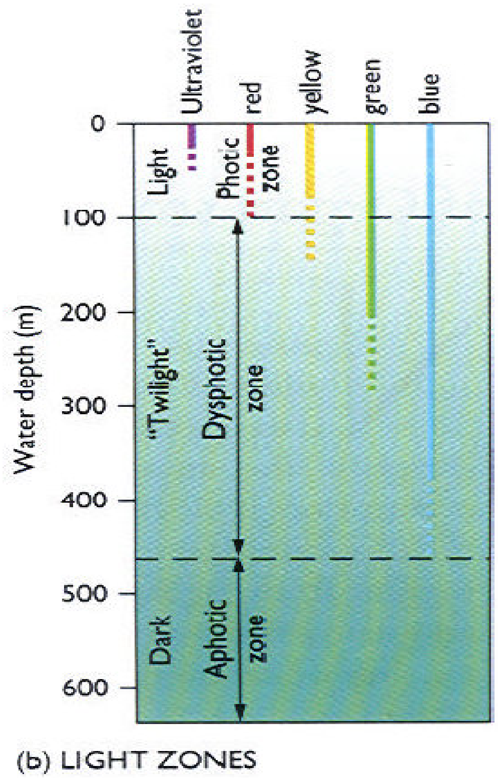

Fig. 9: Marine Ecology

3.6 The Limnetic Zone

The **limnetic zone** is the area of open water bounded by the littoral region. It is well-lit surface waters located away from the shoreline. Water temperatures at the surface will be warmest. That part of the limnetic region which possesses sufficient sunlight for photosynthesis to exceed respiration (P>R) is called the **trophogenic zone**. The **tropholytic zone** is the part of the limnetic region where respiration is greater than productivity (P<R). This region is also known as the **profundal zone**. This zone typically contains the colder, darker, poorer oxygenated deep water of a lake. Relatively few organisms are adapted to the deeper profundal regions. The border between these is the **compensation point**, the depth at which light intensity results in P=R.

Gross primary production (GPP) is the total autotrophic conversion of inorganic carbon to organic forms, independent of its fate. Ecosystem respiration (R) is the total oxidation of organic carbon to inorganic carbon by both heterotrophic and autotrophic organisms. Net ecosystem production is the difference between GPP and R and reflects the balance between all anabolic and catabolic processes. Ecosystems in which photosynthesis exceeds total respiration (P>R) are net autotrophic. They are net sinks for CO_2 and net producers of O_2 and organic matter. On the other hand, wherever respiration exceeds photosynthesis (P<R),

ecosystems are net heterotrophic. They are net sources of CO_2 and net consumers of organic carbon.

3.7 Benthon – Bottom Dwellers

The Benthic habitat zone is the lowest level of the water. Benthic organisms live at the bottom of the lake or pond. They include epifauna and epiflora. Others are buried within the sediments (infauna). For example marine invertebrates – clams, mussels, oysters, snails, barnacles, lobsters, crabs, sea urchin, star-fish, sea cucumbers, corals, anemones, sponges, worms.; attached plants-(sea grasses) and algae (kelp and other seaweeds)., ground fish e.g. sole, flounder, cod and haddock.

3.8 Factors that Affect the Distribution of Living Organisms

Rates of diffusion, osmosis and metabolism are strongly temperature-dependent. The higher the temperature, the higher the rate of molecular movement into or out of cells, and the higher the rate of biological activity including growth rate, mortality and life span. Temperature also controls the concentrations of dissolved gases in water e.g. CO_2 for plant photosynthesis and O_2 for animal respiration. The higher the temperature of water the lesser the dissolved gases. Cold water holds more dissolved gases than hot or warm water. Stenothermal organisms can tolerate only a narrow range of temperatures (deep and/mobile organisms). Eurythermal organisms can tolerate a wider range of temperature (shallow or sessile organisms).

Salinity is also an important control on the distribution of organisms because of osmotic pressure. Stenohaline organisms can tolerate only a narrow range of salinity (deep and/or mobile organisms). Many organisms cannot tolerate the salinities (>40‰) of some subtropical lagoons or the reduced salinities (<30 ‰) of coastal waters or estuaries. Euryhaline organisms can tolerate a wider range of salinities (surface and/or sessile organisms).Coastal organisms must be able to cope with daily and seasonal swings in salinity related to tidal movement, evaporation, precipitation and river run off

3.9 Adaptations of Pelagic Organisms

The pelagic environment is home to two basic groups of marine organisms namely plankton and nekton. Planktonic plants are called phytoplankton while planktonic animals are zooplankton. Nekton consists of the free swimming mammals, reptiles, fish, squids and larger crustaceans.

All organisms within any living environment must be able to perform three major functions of finding food, avoiding predators and reproducing. Some aspects of the pelagic environment pose special challenges and have led to unique adaptations for the organisms that live there.

i. The pelagic environment is three-dimensional. This implies that the organisms living there must be able to move and see in all directions.
ii. There are no solid substrates to provide refuge.

Superior swimming ability is important for survival for many large fish such as tuna, allowing them to capture prey and avoid predators. Many pelagic fish are migratory having stream-lined bodies with heavy musculature. Various forms of camouflage are common in pelagic organisms. Fishes in the epipelagic zone are usually **counter shaded** so their bodies show a colour gradient from dark on the dorsal surface to light on the ventral surface. This makes them difficult to spot both from above and below. Others are silvery, helping them to reflect sunlight near the surface and blending in with the surroundings.

Mesopelagic organisms live in deeper, darker waters, use different forms of camouflage. They are black or red in colour making them more difficult to spot. Many mesopelagic fish and squids have photophores used for **counter illumination**. This works in the same way as counter shading. **Photophores** are light –producing organs capable of matching the intensity and colour of the light from the surface helping to obscure the organism’s silhouette.

Above 400m the light from the surface becomes too intense for counter illuminating organisms to match, so their vertical distributions are limited to below 400m in the daytime. Some mesopelagic fish have lights on their tails called **sternchasers** which advertise them to members of the same species and opposite sex. Photophores are usually arranged in species –specific patterns for easy identification.

Low light levels in the mesopelagic zone make it difficult to spot prey. Many fish use photophores mounted on the ends of their fins or dangling projections that act as lures to bring prey in close to the fish. Mesopelagic fish can also have tubular eyes with increased sensitivity to light and enhanced depth perception. Many have eyes two times larger than normal which may be set at upward-looking angles, increasing the ability to look for shadows cast by other animals.

Any organisms in the mesopelagic zone such as fish, shrimp and squids undergo a **diel vertical migration**. At dusk, mesopelagic animals migrate from depth 500-1000 to the surface to feed in the epipelagic zone. In the pre-dawn hours, they migrate back to depths. Most vertically migrating fish have gas bladders and store gases that help the fish to be buoyant at any depth.

3.10 The Pelagic Food Web

A food web is a representation of the transfer of energy and organic materials through various trophic levels of marine organisms. Each trophic level consists of organisms that obtain their food in a similar way. At the foundation of the food web are primary producers-photosynthetic organisms that produce organic materials using energy from the sun. Herbivorous species of zooplankton feed on the primary producers and are called primary consumers. All other levels of consumers consisting of carnivorous zooplankton, fishes and other predators are secondary, tertiary consumers etc.

Food web consists of organic materials contained in various trophic levels. Only a fraction of the energy and material contained in the living organisms at one trophic level is transferred into living tissue at the next level. That fraction is usually 10-15 % and is called ecological transfer efficiency (*Encyclopedia Britannica*, Inc, 2010; OCN 201L, 2011).

4.0 CONCLUSION

The littoral zone is made of three zones namely supralittoral, eulittoral and sub littoral which have vegetation adapted to suit each zone. The littoral environment plays a major role in water purification and serves as a buffer for the pelagic zone. The pelagic zone plays a major role in the primary production of the water body and is also divided into zones with the epipelagic and mesopelagic zones accommodating most of the aquatic organisms.

5.0 SUMMARY

In this unit, we discussed the littoral and pelagial systems giving the zonations, characteristics and roles in the aquatic environment. We also discussed the different adaptation strategies for the survival of living organisms in this environment.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is littoral zone?
2. Describe the pelagial system.
3. Discuss the oceanic zones cum demersal zone.
4. Explain the limnetic zone cum benthos.

5. Highlight factors that affect the distribution of living organisms.
6. Analyse adaptations of pelagic organisms cum pelagic food web.

7.0 REFERENCES/FURTHER READING

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