



# Federal University Lokoja

Sic itur ad astra

**LECTURE BRIEF**

**ON**

**BIO 204: HYDROBIOLOGY (2CUs)**

**DEPARTMENT OF BIOLOGY**

**FACULTY OF SCIENCE**

**FEDERAL UNIVERSITY LOKOJA**

## **Course Aspect**

- ❖ Principles of Aquatic Biology with Reference to Limnology
- ❖ The Physical Properties of Water and their Biological Significances
- ❖ Thermal Stratification of Lakes
- ❖ Waves and Currents and their Effects on Substratum

## **Introduction**

Water covers about 75% of the earth surface and it accounts for about 35% of the world's plant production. Aquatic system contributes nearly 80% of the world's animal production. Freshwater contribute about 0.31%. Many of the large rivers of the world lie in the tropical and sub-tropical zones. While oceans, seas, and saline water constitutes 97.69% and few usually contains higher nutrient concentrations than the sea water. Water is a universal solvent. Water composition constitutes dilute solutions of alkali and alkaline earth bicarbonate and carbonate, sulphate and chloride, with variable quantity of largely not dissociated silicic acid which is often present in excess of sulphate and chloride. There are also a number of minor constituents in true solution, some of them being of great biological interest and a variety of colloidal materials, both inorganic and organic. Several gases are also found in natural water. Water contains larger or smaller concentration of all elements found in the earth crust and in the atmosphere. Furthermore, most of the organic compounds synthesized by living organisms may be found in water. Some of the more common substances found in water are; (a) Gases (b) Mineral Constitutes (c) Soluble Organic Matters (d) Suspended Inorganic Matters.

## **Principles of Aquatic Biology with Reference to Limnology**

### ***Preamble***

Hydrobiology is the scientific study of the biological components of aquatic environments, focusing on the interactions between organisms and their surroundings in freshwater and marine ecosystems. This discipline merges aspects of biology, ecology, chemistry, and geology to understand the dynamics of life in water bodies, including rivers, lakes, ponds, estuaries, and oceans. It addresses the biological, chemical, physical, and geological properties that influence aquatic life. The one distinguishing aspect is that all relate to aquatic organisms.

Much work is closely related to **Limnology** and can be divided into **Lotic System Ecology (Flowing Waters)** and **Lentic System Ecology (Still Waters)**. Much of the early work of hydrobiologists concentrated on the biological processes utilized in sewage treatment and water purification especially slow sand filters. Other historically important work sought to provide **Biotic Indices** for classifying waters according to the biotic communities that they supported.

### **Limnology**

**François-Alphonse Forel** who is considered the *Father of Limnology* coined the term *Limnology* from two Greek words "*Limne*" (*meaning lake*) and "*Logy*" (*meaning the study of*). Limnology is simply defined *as the science or study of freshwater bodies*. The study involves the physical and chemical features of the freshwater and the life forms that exist in such bodies mainly the streams, rivers, lakes and reservoirs.

### **Types of Water Bodies (Classification Based on Source)**

According to the United States Geological Survey (Winter *et al.*, 1998), most of the **Freshwater (84.9%)** is locked up as ice in glaciers. Of the balance, **14.16%** constitutes **Groundwater**, while that in **Lakes and Reservoirs** amounts to **0.55%**. Another **0.33%** is in form of **Soil Moisture** and **Atmospheric Water Vapour**. Thus, only a very small fraction of freshwater, about **0.004%**, flows through rivers and streams. The volume of **Sea Water** is **15 times** greater than that of **Freshwater**.

- ✓ **Natural waters** can be classified into three categories *viz.*, (a) sea water (b) estuarine water (c) freshwater.
- ✓ **Surface waters** might possess color, odor, taste, suspended solids, etc.
- ✓ **Groundwaters** are expected to be free from organic odor and have a relatively less variable composition at the same source.

### **Fresh Water Ecosystem**

Fresh water is naturally occurring water on the Earth's surface in ice sheets, ice caps, glaciers, bogs, ponds, lakes, rivers and streams, and underground as groundwater in aquifers and underground streams. Fresh water is generally characterized by having **low concentrations of dissolved salts** and other **total dissolved solids**. The term specifically excludes **seawater** and **brackish water** although it does include mineral rich waters such as **chalybeate springs**. The term "*Sweet Water*" has been used to describe fresh water in contrast to salt water. Freshwater ecosystems cover 0.80% of the Earth's surface and inhabit 0.009% of its total water.

They generate nearly 3% of its net primary production. Freshwater ecosystems contain 41% of the world's known fish species. 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 pools. 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. **Anadromous fish** are also an important source of nutrients. Environmental threats to rivers include **loss of water, dams, chemical pollution** and **introduced species**.

### Types of Freshwater

There are three basic types of freshwater ecosystems;

1. **Lotic**: rapidly-moving water, for example streams and rivers.
  2. **Lentic**: slow-moving water, including pools, ponds, and lakes.
  3. **Freshwater Wetlands**: areas where the soil is saturated or inundated for at least part of the time
1. **Lotic Ecosystems (Flowing-Water)**: This includes rivers, streams, creeks, and brooks which flow over land. The organisms that live in these environments are well adapted to the rate of flow. There is little plant life near the source but plenty of dissolved oxygen. With the flow downhill, sediments are picked up which enable plants to establish themselves. As the flow slows down, animal life such as beavers, otters, and turtles can make their home.
- ✓ Rivers have small volume but important for biodiversity, including evolution of several invertebrate groups. Average River replaces its water 20 times per year. Biology of a river depends on rate of flow and quality of water. The basic feature of river ecosystems is a predictable change of physical characteristics, habitats and organisms with stream order. Common rivers in Nigeria are **River Niger, River Benue, Kaduna River, Calabar River, Zamfara River, Osun River, Cross River, Oba River**, and numerous other rivers around.

**2. Lentic Ecosystems (Standing Water):** This includes lakes and ponds. Water flows in and out and circulates within. This helps to distribute oxygen, nutrients, and heat. Plankton live in these environments since there is standing water. Separation of lakes and ponds attempted by penetration of light to bottom, or development of thermal stratification. Lake needs a source of water & a depression. Africa has 20 times greater volume of lakes than South America, but lower rainfall.

Geologically there are three types of lake depressions:

- i. **Depressions in bedrock:** (a) Glacial - Northern Europe & North America. Great Lakes of the USA - Low nutrients (b) Volcanic - crater lakes, often large inorganic inputs (c) Tectonic - Rift lakes, where sections of crust sink or rise along faults.
- ii. **Depressions in sediment:** more nutrients available; (a) Glacial sediments - meres in Lake District (b) Fluvial sediments - oxbow lakes, isolated bends of river
- iii. **Barrier lakes:** usually less permanent; (a) Inland - landslides, lava flows, ice barriers, glacial moraine (b) Coastal sand bars - lagoons with freshwater inflow (i.e., estuaries) eventually become freshwater if connection to the sea is closed. Light/Little sediment or turbidity in lakes, light restricted by humic solutes or phytoplankton. Dense algal bloom can limit light to top few centimeter. If light reaches bottom then macrophytes & benthic algae grow.

**3. Freshwater Wetlands:** A wetland is an ecosystem in which water either cover the soil or is present at or near the surface of the soil for at least part of the year. Can be flowing, standing and fresh, salty, or brackish. Are productive ecosystems that serve as breeding grounds for insects, fishes and other aquatic animals, amphibians, and migratory birds. There are three main types of freshwater wetlands:

- i. **Bogs:** Dominated by sphagnum moss and form in depressions where water collects.
- ii. **Marshes:** Shallow wetlands along rivers that contain grass-like plants
- iii. **Swamps:** Water flows slowly through this and looks like flooded forests. The presence of trees and shrubs is what distinguishes a swamp from a marsh.

## Estuaries

Estuaries are wetlands formed where rivers meet the sea. Contain a mixture of fresh water and salt water. Affected by the rise and fall of ocean tides. Many are shallow to sunlight can reach the bottom to allow photosynthesis. Primary producers are algae, plants, and photosynthetic and chemosynthetic bacteria. Much of the organic material enters the food web as detritus. Detritus provides food for the organisms at the base of the estuary's food web. Clams, worms, and sponges feed on this detritus.

### Types of Estuary

- i. **Salt-wedge:** River flow is stronger than tidal flows and freshwater less dense than saltwater so it spreads over sea, with a sharp change in salinity between the two.
- ii. **Well-mixed:** River flow is lower than tidal flows. Tidal flows play the major part in mixing freshwater and saltwater.
- iii. **Partially-mixed:** River flow and tidal flows are strong. Tides force saltwater upwards, and tidal flows pulled down by turbulence.
- iv. **Negative:** River flow is low with high evaporation. It is only in the tropics. Creates hypersaline water at head of estuary, denser than saltwater, sinks and flows seaward along bottom.

## The Physical Properties of Water and their Biological Significances

### Properties of Water

Water is one of the most abundant substances on Earth and is essential for all known forms of life. It has unique physical properties that distinguish it from other substances, making it vital for various natural processes, biological functions, and industrial applications. Understanding these physical properties helps us appreciate the fundamental role water plays in both the environment and life. Water is a tasteless, odorless liquid at ambient temperature and pressure. Liquid water has weak absorption bands at wavelengths of around **750nm** which cause it to appear to have a **blue color**. This can easily be observed in a water-filled bath or wash-basin whose lining is white, large ice crystals and glaciers, also appear blue.

Under standard conditions, water is primarily a liquid, unlike other analogous hydrides of the oxygen family, which are generally gaseous. This unique property of water is due to hydrogen bonding. The molecules of water are constantly moving concerning each other, and the hydrogen bonds are continually breaking and reforming at timescales faster than **200 femtoseconds ( $2 \times 10^{-13}$  seconds)**. However, these bonds are strong enough to create many of the peculiar properties of water, some of which make it integral to life.

### 1. Molecular Structure and Polarity

Water (H<sub>2</sub>O) is a simple molecule composed of two hydrogen atoms covalently bonded to one oxygen atom. However, its molecular structure gives it unique properties of;

- i. **Bent Shape:** Water molecules have a bent or V-shaped structure due to the two lone pairs of electrons on the oxygen atom. This shape results in a bond angle of about 104.5 degrees, rather than a straight line.
- ii. **Polarity:** The oxygen atom is more electronegative than the hydrogen atoms, meaning it pulls the shared electrons in the covalent bonds closer to itself. This creates a partial negative charge ( $\delta^-$ ) on the oxygen atom and a partial positive charge ( $\delta^+$ ) on the hydrogen atoms, making water a polar molecule. This polarity allows water to form hydrogen bonds with other water molecules and with other polar substances, which is critical to many of its physical properties.

### 2. Cohesion and Adhesion

Water molecules exhibit strong cohesion, which is the attraction between like molecules. This property is primarily due to hydrogen bonding, where the partially positive hydrogen atom of one water molecule is attracted to the partially negative oxygen atom of another.

- ✓ **Cohesion** leads to the high surface tension of water, making it behave as if it were covered with a stretched elastic membrane. This is why small objects, such as insects, can float on water's surface without sinking.
- ✓ **Adhesion** is the attraction between water molecules and different substances, particularly those that are also polar or charged. This property allows water to “stick” to surfaces like glass, soil, and plant tissues. The combination of adhesion and cohesion enables capillary action, where water can travel up thin tubes or porous materials against gravity, a process vital for water transport in plants.

### 3. High Specific Heat Capacity

Water has a high specific heat capacity, meaning it can absorb or release a significant amount of heat with little change in its own temperature. Specifically, water's specific heat is about 4.18 joules per gram per degree Celsius (J/g°C). This high specific heat capacity is due to the hydrogen bonds between water molecules, which require considerable energy to break. This property makes water an excellent thermal buffer, moderating temperatures in the environment and within organisms. For example, large bodies of water, such as oceans and lakes, can absorb and store vast amounts of heat from the sun, helping to regulate the climate by reducing temperature extremes.

### 4. High Heat of Vaporization

The heat of vaporization of water is the amount of energy required to convert 1 gram of liquid water into vapor without a temperature change, which is approximately 2260 Joules per gram (J/g). This high heat of vaporization results from the strong hydrogen bonds that must be broken for water molecules to move from the liquid phase to the gas phase. This property is crucial for regulating temperature in living organisms through processes like sweating and transpiration. When water evaporates from the surface of an organism, it takes a significant amount of heat with it, cooling the organism down and helping to maintain homeostasis.

### 5. Density and the Anomalous Expansion of Water

The density of water exhibits unique behavior compared to most other substances. Water is most dense at **4°C (39°F)** with a density of about 1 gram per cubic centimeter (g/cm<sup>3</sup>). Unlike most substances, which become denser as they transition from liquid to solid, water expands upon freezing.

- ✓ **Anomalous Expansion:** As water cools below 4°C, it begins to expand again until it reaches the solid state (ice) at 0°C. This expansion occurs because the hydrogen bonds in water form a crystalline structure when frozen, which takes up more space than the liquid state.
- ✓ This property is vital for aquatic life. Ice, being less dense than liquid water, floats on the surface of bodies of water, forming an insulating layer that helps maintain relatively stable temperatures in the water below, allowing life to survive even in freezing conditions.



## 6. Surface Tension and Capillary Action

Surface tension is a measure of the elastic tendency of a fluid surface, caused by the cohesive forces between liquid molecules. Water has a high surface tension due to hydrogen bonding, making it capable of forming droplets and supporting small objects.

- ✓ **Capillary Action:** is the ability of water to flow in narrow spaces without the assistance of external forces. This phenomenon results from the combination of water's adhesive properties, which make it adhere to the walls of a container or tube, and cohesive properties, which pull additional water molecules along with it. Capillary action is essential for the movement of water (and nutrients) in soil and plant tissues, especially in the xylem vessels of plants.

## 7. Solvent Properties

Water is often referred to as the "universal solvent" because of its ability to dissolve a wide range of substances. This property arises from the polar nature of water molecules, which allows them to surround and interact with various ions and polar molecules.

- ✓ **Hydration Shells:** When ionic compounds like salt (NaCl) dissolve in water, the polar water molecules surround and separate the positive ( $\text{Na}^+$ ) and negative ( $\text{Cl}^-$ ) ions, forming hydration shells. Similarly, water can dissolve many polar molecules, including sugars and alcohols, due to hydrogen bonding.
- ✓ Water's solvent properties are essential for biological functions, as they enable the transport of nutrients, gases, and waste products in and out of cells and throughout organisms. Additionally, water facilitates chemical reactions in biological systems by dissolving reactions and allowing them to interact more freely.

## 8. Viscosity and Flow

Viscosity refers to a fluid's resistance to flow. Water has relatively low viscosity, allowing it to flow easily in its liquid state. This property is crucial for many natural processes, including the movement of water through rivers, soil, and plant roots, as well as the circulation of blood and other bodily fluids in animals.

The low viscosity of water also makes it an effective lubricant, reducing friction in various biological and mechanical systems. For example, synovial fluid in joints and mucus in the digestive tract rely on water's low viscosity to reduce friction and facilitate movement.

## 9. Transparency and Light Absorption

Water is transparent to visible light, allowing sunlight to penetrate aquatic environments. This transparency is vital for photosynthesis in aquatic plants and phytoplankton, which form the base of most aquatic food webs.

- ✓ **Light Absorption:** Although water is transparent to visible light, it absorbs light in the infrared and ultraviolet regions. As light penetrates water, its intensity decreases due to scattering and absorption, which can limit the depth to which photosynthesis can occur. The specific wavelengths absorbed and scattered depend on the water's purity and the presence of dissolved substances or suspended particles.

## 10. Compressibility and Sound Transmission

Water is nearly incompressible, meaning that its volume changes very little under pressure. This property is important for maintaining the structural integrity of aquatic environments under various pressures, especially in deep-sea conditions,

- ✓ **Sound Transmission:** Water is an excellent medium for sound transmission due to its density and elasticity. Sound travels faster in water than in air (approximately 1,500m/s in water compared to 343m/s in air), making underwater communication and sonar technologies possible. This property is also essential for marine animals that rely on echolocation and other sound

## Physicochemical Parameters of Water

The physicochemical parameters of water are critical indicators of its quality, determining its suitability for various uses, including drinking, industrial processes, agriculture, and ecological functions. These parameters reflect the physical and chemical characteristics of water, influencing its behavior, reactivity, and interactions with other substances. Understanding these parameters is essential for water quality assessment, environmental monitoring, and managing water resources.

### 1. Temperature

Temperature is a fundamental physicochemical parameter of water that influences various chemical and biological processes.

- ✓ **Effects on Solubility:** Temperature affects the solubility of gases and solids in water. For example, the solubility of gases like oxygen decreases with increasing temperature, which can impact aquatic life, particularly in warm water bodies where oxygen levels may drop below levels needed to sustain certain species.

- ✓ **Chemical Reactions:** The rate of chemical reactions generally increases with temperature, influencing the rate of decomposition of organic matter, the solubility of salts, and the speed of chemical reactions.
- ✓ **Biological Impact:** Temperature affects metabolic rates of aquatic organisms. Higher temperatures can increase metabolism in cold-blooded organisms, altering growth rates and reproductive cycles. It also influences the distribution of aquatic species, with different species adapted to specific temperature ranges. Temperature variations often lead to shifts in community composition, affecting cold-water, cool-water, and warm-water species differently.

## 2. pH

pH is a measure of the hydrogen ion concentration in water, indicating its acidity or alkalinity. It is a critical parameter that affects many chemical and biological processes in water.

- ✓ **Acidity and Alkalinity:** pH is measured on a scale from **0 to 14**, with **7 being neutral**. A pH less than 7 indicates acidity, while a pH greater than 7 indicates alkalinity. Most natural waters have a pH range of **6.5 to 8.5**, which is suitable for most aquatic organisms.
- ✓ **Impact on Aquatic Life:** Extremes in pH can be harmful to aquatic organisms. For example, low pH (acidic conditions) can lead to the release of toxic metals like aluminum, while high pH (alkaline conditions) can enhance the toxicity of ammonia.
- ✓ **Chemical Reactions and Solubility:** pH affects the solubility and availability of nutrients and pollutants. For instance, phosphorus availability decreases in highly acidic or alkaline conditions, affecting the growth of aquatic plants and algae.

## 3. Dissolved Oxygen (DO)

Dissolved Oxygen (DO) is the amount of oxygen dissolved in water, crucial for the survival of aquatic organisms. DO levels are influenced by various factors, including temperature, salinity, and biological activity.

- ✓ **Oxygen Solubility:** Cold water holds more dissolved oxygen than warm water. As temperature rises, the capacity of water to hold oxygen decreases, which can lead to **hypoxic (low oxygen)** conditions detrimental to aquatic life.

- ✓ **Sources of Dissolved Oxygen:** Oxygen enters water through diffusion from the atmosphere, photosynthesis by aquatic plants and algae, and aeration from moving water (e.g., rivers and waterfalls). DO levels can be depleted by the respiration of organisms and the decomposition of organic matter by bacteria.
- ✓ **Indicators of Water Quality:** High Dissolved Oxygen levels typically indicate good water quality, whereas low Dissolved Oxygen levels can signify **pollution, high levels of organic matter, or eutrophication** (excessive nutrients leading to oxygen depletion).

#### 4. Electrical Conductivity (EC)

Electrical Conductivity (EC) measures water's ability to conduct electricity, which is directly related to the concentration of dissolved ions (salts) in the water.

- ✓ **Indicators of Salinity:** Electrical Conductivity provides an indirect measure of the total dissolved solids (TDS) in water. High conductivity indicates high ion concentration, often due to the presence of salts like sodium chloride, magnesium, and calcium.
- ✓ **Water Quality Indicator:** Electrical Conductivity is used to assess water quality for various uses. For example, water with high conductivity may be unsuitable for drinking, irrigation, or industrial purposes due to its corrosive nature and the presence of potentially harmful salts.
- ✓ **Environmental Impact:** Elevated salinity levels, indicated by high Electrical Conductivity can affect aquatic life by altering the osmotic balance of organisms, leading to stress or mortality in species not adapted to such conditions.

#### 5. Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) represent the combined content of all inorganic and organic substances dissolved in water, including minerals, salts, metals, and ions.

- ✓ **Sources of Total Dissolved Solids:** Total Dissolved Solids can originate from natural sources such as mineral springs, sea water intrusion, and dissolution of soil and rock minerals, as well as anthropogenic sources like agricultural runoff, industrial discharge, and sewage.
- ✓ **Water Quality and Taste:** High Total Dissolved Solids levels can impart a bitter or salty taste to water and may indicate the presence of harmful contaminants. Total Dissolved Solids levels above **500mg/L** are generally considered

unsuitable for drinking according to the World Health Organization (WHO) guidelines.

- ✓ **Impact on Aquatic Life:** Elevated Total Dissolved Solids levels can affect the clarity of water, reducing light penetration and photosynthesis, and can be harmful to aquatic organisms due to changes in osmoregulation.

## 6. Turbidity

Turbidity measures the clarity of water and is caused by the presence of suspended particles, such as silt, clay, algae, plankton, and organic matter.

- ✓ **Sources of Turbidity:** Turbidity can result from natural sources, such as erosion, algal blooms, and bottom sediment re-suspension, or from human activities like construction, agriculture, and wastewater discharge.
- ✓ **Impact on Aquatic Ecosystems:** High turbidity reduces light penetration, affecting photosynthesis in aquatic plants and phytoplankton. It can also clog fish gills, reduce the growth rates of aquatic organisms, and smother benthic habitats.
- ✓ **Water Quality Indicator:** Turbidity is a critical parameter in assessing drinking water quality. High turbidity can harbor pathogens and interfere with disinfection processes, making water unsafe for human consumption.

## 7. Hardness

Hardness of water refers to the concentration of calcium and magnesium ions, which can combine with bicarbonates, sulfates, and other anions to form scale and reduce the effectiveness of soaps and detergents.

- ✓ **Sources of Hardness:** Hardness primarily comes from geological sources, such as limestone, gypsum, and chalk, which dissolve into water. It can also be influenced by industrial discharge and agricultural runoff.
- ✓ **Impact on Water Use:** Hard water can cause scaling in pipes, boilers, and appliances, reducing their efficiency and lifespan. It can also affect water taste and reduce the effectiveness of soaps and detergents,
- ✓ **Softening Processes:** Hardness can be reduced through water softening processes, such as ion exchange, where calcium and magnesium ions are replaced with sodium or potassium ions.

## 8. Alkalinity

Alkalinity is the water's capacity to neutralize acids, primarily due to the presence of bicarbonates, carbonates, and hydroxides.

- ✓ **Buffering Capacity:** Alkalinity is a measure of water's ability to resist changes in pH when acids are added. It is critical in maintaining stable pH levels in aquatic environments, which is essential for the survival of aquatic organisms.
- ✓ **Sources of Alkalinity:** Natural sources of alkalinity include the dissolution of carbonate rocks, such as limestone and dolomite. Human activities, such as agriculture and industrial processes, can also contribute to alkalinity.
- ✓ **Environmental Significance:** High alkalinity in water bodies can buffer against acid rain and acid mine drainage, protecting aquatic ecosystems from harmful pH fluctuations.

## 9. Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD)

Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) are measures of the amount of oxygen required to oxidize organic and inorganic matter in water.

- ✓ **Chemical Oxygen Demand:** Chemical Oxygen Demand measures the total quantity of oxygen required to oxidize both biodegradable and non-biodegradable substances. It is an indicator of water pollution, particularly from industrial effluents containing organic and inorganic pollutants.
- ✓ **Biochemical Oxygen Demand:** Biochemical Oxygen Demand measures the amount of oxygen required by microorganisms to decompose biodegradable organic matter under aerobic conditions over a specified period (usually 5 days at 20°C). High Biochemical Oxygen Demand levels indicate high organic pollution, often from sewage, agricultural runoff, and industrial discharge.
- ✓ **Indicators of Water Quality:** Both Chemical Oxygen Demand and Biochemical Oxygen Demand are used to assess the degree of pollution in water bodies. High levels indicate significant pollution, which can lead to oxygen depletion, harming aquatic life and affecting water quality.

## 10. Nutrients (Nitrogen and Phosphorus)

Nutrients such as nitrogen (N) and phosphorus (P) are essential for aquatic plant growth but can cause eutrophication when present in excess.

- ✓ **Sources of Nutrients:** Nutrients enter water bodies through agricultural runoff (fertilizers), wastewater discharge, and atmospheric deposition. Excessive nutrients can lead to algal blooms, which deplete oxygen and harm aquatic life when they decompose.
- ✓ **Impact on Water Quality:** Elevated nutrient levels can cause eutrophication, leading to decreased water quality, fish kills, and loss of biodiversity. Managing nutrient levels is crucial for maintaining healthy aquatic ecosystems. High concentrations of ammonia and nitrite can be toxic to aquatic organisms, particularly fish. Understanding their levels is crucial for assessing water quality and ecosystem health.

## 11. Metals and Trace Elements

Metals and Trace Elements are both essential and non-essential, are present in freshwater ecosystems due to natural processes and human activities. Some metals are vital for biological functions, while others, like lead, mercury, and cadmium, can be toxic even at low concentrations. Monitoring these elements is essential to prevent contamination and potential harm to aquatic life and humans.

## 12. Organic Matter Content

The presence of organic matter in freshwater ecosystems has significant ecological implications. Organic matter influences water clarity, nutrient cycling, and oxygen demand. High levels of organic matter can lead to increased microbial activity and oxygen depletion, impacting aquatic life.

## 13. Redox Potential

Redox potential, often measured as the oxidation-reduction potential (ORP), reflects the balance between oxidizing and reducing agents in water. It influences nutrient availability, microbial activity, and redox-sensitive chemical reactions. Variations in redox potential can indicate changes in water quality and ecosystem conditions.

## Thermal Stratification of Lakes

The development of relatively stable, warmer and colder layers within a body of water. **Thermal stratification** is related to incoming heat, water depth, and degree of water column mixing. Deep, large lakes such as the Great Lakes receive insufficient heat to warm the entire water column and lack adequate physical turnover or mixing of the water for uniform temperature distribution. Thus, they have an upper layer of water that is warmed by surface heating (**Epilimnion**) and a lower layer of much colder water (**Hypolimnion**), separated by a layer called the **Thermocline** in which the temperature decreases rapidly with depth. Both daily and seasonal variations in heat input can promote thermal stratification. Stratification in summer followed by mixing in the fall is a phenomenon commonly observed in temperate lakes of moderate depths (over 33ft/10m).

### Thermal Stratification Layers

- ✓ The shallowest layer is that warm surface layer, called the **Epilimnion**. The **Epilimnion** *is the layer of water that interacts with the wind and sunlight, so it becomes the warmest and contains the most dissolved oxygen*. Though dissolved oxygen doesn't play a direct role in lake stratification and turnover, it is important for all the aquatic organisms in a lake that require oxygen to survive.
- ✓ The deepest layer is the cold, dense water at the lake bottom, called the **Hypolimnion**. The **Hypolimnion** often remains around 4°C throughout the year, rarely gets any direct warmth from the sun and it is isolated from the air at the surface of the lake. The **Hypolimnion** contains the lowest amount of dissolved oxygen and can often become *anoxic (zero dissolved oxygen)* while the lake is thermally stratified.
- ✓ The middle layer is the transition zone of water between the warm Epilimnion and cold Hypolimnion, called the **Metalimnion**. The **Metalimnion** is a place where the shallowest of the cool waters in the hypolimnion gradually warm up until they mix into the epilimnion. The point of greatest temperature difference (and therefore density difference) is called the thermocline and occurs within the **Metalimnion**.



- ✓ Throughout the summer, wind and waves cause the warming water in the Epilimnion to mix deeper and deeper, slowly incorporating Hypolimnetic water through the Metalimnion. The ability of a lake to mix through wind turbulence is determined by the “stability” of thermal stratification. Stratification becomes increasingly stable with heating from the sun. The larger the difference in temperature (and density) between the epilimnion and the hypolimnion, the more stable the thermal stratification.
- ✓ Eventually, the epilimnion warms to the point where the difference in density between the epilimnion and hypolimnion (at the thermocline) is so large that wind and waves can no longer generate enough energy to incorporate hypolimnetic water.
- ✓ In summer, the surface waters cool and sink, mixing the epilimnion down towards the hypolimnion and weakening the thermocline; as the temperatures and densities of the epilimnion and hypolimnion become more similar, the water currents and wind can once again mix water between the two layers. Eventually, the epilimnion cools until the entire lake is the same temperature (isothermal). This allows Lake Turnover to occur.

### **Seasonal Dynamics of Stratification**

Thermal stratification in lakes is closely linked to seasonal changes, particularly in temperate climates.

1. **Spring:** During spring, as the ice melts and the water begins to warm, wind action helps to mix the lake, resulting in a period called “spring turnover.” During this time, the water column becomes nearly uniform in temperature and oxygen levels, allowing for the distribution of nutrients throughout the lake.
2. **Summer:** As air temperatures rise in summer, the lake surface warms faster than the deeper layers, leading to the development of a distinct thermal stratification. The warmer, less dense water forms the epilimnion, while the cooler, denser water settles in the hypolimnion. The metalimnion forms between these two layers, preventing mixing. During summers, *stratification is most pronounced*, creating distinct thermal and chemical gradients.

3. **Autumn:** As temperatures cool in autumn, the surface water loses heat and becomes denser. This cooling process, combined with wind-induced mixing, causes the epilimnion to cool and sink, gradually breaking down the stratification. This period, known as “fall turnover,” redistributes oxygen and nutrients throughout the lake.
4. **Winter:** In winter, especially in regions where lakes freeze over, an inverse stratification can occur. The coldest water (near 0°C) is at the surface, while slightly warmer, denser water (around 4°C) remains at the bottom. The ice layer insulates the lake, reducing wind mixing and maintaining a stable water column until spring.

### **Ecological Implications of Thermal Stratification**

Thermal stratification has profound ecological implications for lakes. It affects oxygen distribution, with the hypolimnion often becoming hypoxic or anoxic during summer stratification due to limited mixing and continued decomposition of organic material. This lack of oxygen can stress or kill aerobic organisms and release nutrients from sediments, leading to increased productivity (eutrophication) when the lake turns over. Stratification also influences the distribution of aquatic organisms, such as fish, which may migrate vertically or horizontally to find suitable temperatures and oxygen levels.

### **Types of lakes base on their mixing ability**

1. **Amictic:** covered in ice all year. This mixing patter is typical of lakes in the Antarctic.
2. **Cold monomictic:** water never gets warmer than 4°C and turnover occurs once in summer. Lakes in the Arctic are often cold monomictic.
3. **Dimictic:** like at IISD-ELA, lakes are stratified in summer and winter, and mix once in spring and once in fall.
4. **Warm monomictic:** water cools to near 4°C in winter, when turnover may occur. Lakes are stratified during other times of the year and are not ice covered. Lakes in the tropics or low altitudes in northern temperate areas can be warm monomictic.
5. **Oligomictic:** water generally warm and stratified, occasionally cools to generate circulation at irregular intervals. This mixing type can occur in lower latitude regions where there is little variation in annual temperature.

- 6. Polymictic:** frequent mixing throughout the year. This type of mixing can occur in lakes across the world and depends on characteristics like depth, size, and shape of a lake.

These are generalizations based on circulation patterns, and lakes can fall into many different classifications and classification systems. Many lakes can have periods of stratification, depending on lake depth. Shallow lakes may stratify following lake turnover and then mix completely for much of the year if sunlight penetrates to the lake bottom or there is enough wind energy to move water through the entire water column.

### **Waves and Currents and their Effects on Substratum**

#### **Waves**

Waves are actually the energy, not the water as such, which moves across the ocean surface. Water particles only travel in a small circle as a wave passes. Water waves are oscillations that occur on the surface of water bodies, driven primarily by wind, gravitational forces, and other disturbances. The most common type of water waves are wind-generated. When wind blows across the surface of a body of water, friction between the air and water creates small ripples. As wind energy continues to be transferred to the water, these ripples grow into larger waves. The size and energy of a wave depend on factors such as wind speed, the distance over which the wind blows (called "fetch"), and the duration of the wind. Waves consist of several key components:

- i. **Crest:** The highest point of the wave
- ii. **Trough:** The lowest point between two wave crests
- iii. **Wavelength:** The horizontal distance between two consecutive crests or troughs
- iv. **Amplitude:** The vertical distance from the wave's midpoint to its crest or trough, which reflects the wave's energy
- v. **Period:** The time it takes for two consecutive wave crests to pass a fixed point.

#### **Types of Water Waves**

- a) **Deep-water Waves:** In deep water, wave energy is confined w the surface. These waves do not interact with the seafloor and travel with longer wavelengths
- b) **Shallow-water Waves:** As waves approach shallow water near coastlines, their behavior changes. The wave's energy interacts with the seafloor, causing the wave to slow down, increase in height, and eventually break. This process is responsible for surf and coastal erosion.

Waves have significant impacts on coastlines and substratum. They erode beaches, transport sediments, and reshape coastal features. Powerful waves, especially during storms, can cause extensive coastal erosion. In contrast, gentle waves contribute to sediment deposition and beach formation. The interaction between waves and the substratum is crucial in maintaining the balance of Coastal ecosystems, influencing habitats for marine life and human activities along the shoreline. The largest waves are found in the open oceans. Waves continue to grow larger as they move and absorb energy from the wind. Most of the waves are caused by the wind driving against water. When a breeze of two knots or less blows over calm water, small ripples form and grow as the wind speed increases until white caps appear in the breaking waves. Waves may travel thousands of km before rolling ashore, breaking and dissolving as surf.

### **Tides**

Tides are actually waves, the biggest waves on the planet, and they cause the sea to rise and fall along the shore around the world. Tides exist thanks to the gravitational pull of the Moon and the Sun, but vary depending on where the Moon and Sun are in relation to the ocean as Earth rotates on its axis. The Moon, being so much closer to Earth, has more power to pull the tides than the Sun and therefore is the primary force creating the tides. The Moon's gravitational pull causes water to bulge on both the side of Earth closest to the Moon and on the opposite side of the planet. The Moon's gravity has a stronger pull on the side of Earth that is closest to it, which makes the ocean bulge on that side, while on the opposite side of the planet, the centrifugal force created by the Moon and Earth orbiting around one another pulls the ocean water out. Centrifugal force is the same force that smooshes riders to the outside walls of spinning carnival rides.

### **Tides and Nature**

The intertidal zone, the coastal area tides submerge for part of the day, is home to many ocean creatures. It takes a special set of adaptations to live a life half the time scorched by the Sun and the other submerged underwater. Moreover, the incoming de promises a constant pounding by ocean waves. Despite this, It is a place where species thrive. Shelled mollusks like periwinkles, muscles, and barnacles cling to rocks, sea stars wedge themselves in crevices, and crabs hide in fronds of algae.

## Types of Tides

Tides vary in their frequency, direction and movement from place to place and also from time to time. Tides may be grouped into various types based on their frequency of occurrence in one day or 24 hours or based on their height.

### A. Tides based on Frequency

- i. **Semi-diurnal Tide:** The most common tidal pattern, featuring two high tides and two low tides each day. The successive high or low tides are approximately of the same height.
- ii. **Diurnal Tide:** There is only one high tide and one low tide during each day. The successive high and low tides are approximately of the same height.
- iii. **Mixed Tide:** Tides having variations in height are known as mixed tides. These tides generally occur along the west coast of North America and on many islands of the Pacific Ocean,

### B. Tides based on the Sun, Moon and the Earth Positions

The height of rising water (high tide) varies appreciably depending upon the position of sun and moon with respect to the earth. Spring tides and neap tides come under this category.

- i. **Spring Tides:** The position of both the sun and the moon in relation to the earth has direct bearing on tide height. When the sun, the moon and the earth are in a straight line, the height of the tide will be higher. These are called spring tides and they occur twice a month, one on full moon period and another during new moon period.
- ii. **Neap Tides:** Normally, there is a seven day interval between the spring tides and neap tides. At this time the sun and moon are at right angles to each other and the forces of the sun and moon tend to counteract one another. The Moon's attraction, though more than twice as strong as the sun's, is diminished by the counteracting force of the sun's gravitational pull. Once in a month, when the moon's orbit is closest to the earth (perigee), unusually high and low tides occur.  
✓ During this time the tidal range is greater than normal. Two weeks later, when the moon is farthest from earth (**apogee**), the moon's gravitational force is limited and the tidal ranges are less than their average heights. When the earth is closest to the sun (**perihelion**), around 3rd January each year, tidal ranges are also much greater, with unusually high and unusually low tides.

- ✓ When the earth is farthest from the sun (**aphelion**), around 4th July each year, tidal ranges are much less than average. The time between the high tide and low tide, when the water level is falling, is called the **ebb**. The time between the low tide and high tide, when the tide is rising, is called the **flow or flood**.

### **Ocean Currents**

Ocean currents are like river flow in oceans. They represent a regular volume of water in a definite path and direction. Ocean currents are influenced by two types of forces namely: (i) primary forces that initiate the movement of water; (ii) secondary forces that influence the currents to flow

The primary forces that influence the currents are;

- |                            |                    |
|----------------------------|--------------------|
| i. Heating by solar energy | iii. Gravity       |
| ii. Wind                   | iv. Coriolis force |

Heating by solar energy causes the water to expand. That is why, near the equator the ocean water is about 8cm higher in level than in the middle latitudes. This causes a very slight gradient and water tends to flow down the slope. Wind blowing on the surface of the ocean pushes the water to move. Friction between the wind and the water surface affects the movement of the water body in its course. Gravity tends to pull the water down the pile and create gradient variation. The Coriolis force intervenes and causes the water to move to the right in the northern hemisphere and to the left in the southern hemisphere. These large accumulations of water and the flow around them are called Gyres. These produce large circular currents in all the ocean basins.

### **Characteristics of Ocean Currents**

Currents are referred to by their “**drift**”. Usually, the currents are Strongest near the surface and may attain speeds over five (5) knots. At depths, currents are generally slow with speeds less than 0.5 knots. The speed of a current is referred to as its “drift.” Drift is measured in terms of knots. The strength of a current refers to the speed of the current. A fast current is considered strong. A current is usually strongest at the surface and decreases in strength (speed) with depth. Most Currents have speeds less than or equal to 5 knots.