**Addis Ababa University**

**College of Natural Sciences**

**Department of Zoological Sciences**

**(General Biology Program Unit)**

# Aquatic Sciences and Wetland Management (Biol. 4061)

**(Distance Module In-Service Program)**

**Prepared by**

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# Chapter One

**Chapter Objectives**:

At the end of this chapter, students will be able to:

- Define an aquatic ecosystem
- Distinguish between the freshwater, marine and estuarine ecosystems
- Describe relative proportions of aquatic ecosystems in the world.
- Understand the crises trend and shortage of freshwater worldwide
- Explain why Aquatic Sciences and Wetland Management module is included in the Biology Degree program.

*"Water is life. All living organisms are predominantly made of water: human beings about 60%, fish about 80%, plants between 80% and 90%. Water is necessary for all chemical reactions that occur in living cells—(it) is essential for food production and all living ecosystems."*

***World Water Council***

It's clear that water is a critical resource —without it, life cannot exist.

*Water is life but finite: conserve and practice wise-use*

**Introduction to Aquatic Sciences and Wetland Management**

Aquatic refers to watery, and that encompasses oceans, streams, lakes, ground water and marshes/wetlands- both saline and freshwater bodies.

Aquatic sciences is the study of the planet's freshwater and oceanic environments including both biotic and abiotic factors.

Two discipline of the aquatic sciences: **Oceanography and Limnology**

***Oceanography*** is the study of the biological, chemical, geological, optical and physical characteristics of oceans and estuaries.

***Limnology*** is the study of inland water bodies (Inland waters are continental bound) embracing: both freshwater and saline/marine water
standing waters and flowing waters
ephemeral and permanent water bodies
***Limnology*** is the study of the biological, chemical, geological, optical and physical characteristics of inland standing and flowing waters or
**It** is the Ecosystem oriented study of inland standing or flowing waters

To distinguish saline and freshwater, the cutoff value for salt concentration is 3‰ ($g\ L^{-1}$). Freshwater is defined as having a low salt concentration—usually less than 3‰. Ocean is salty water with average value of >35‰.

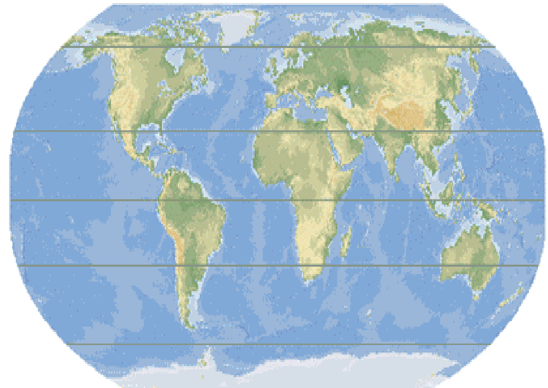
**Aquatic Science** is an interdisciplinary science integrating biology, chemistry, geology, physics, mathematics, statistics, botany, zoology, ecology, meteorology and geography.

**Understand parts per …**

- Parts per ***hundred*** (denoted by % and very rarely 'pph' – denotes the amount of a given substance in a total amount of 100 regardless of the units of measure as long as they are the same. Eg. 1 gram per 100 gram. 1 part in 100.
- *One part per **thousand*** denoted by "ppt". "One part per thousand" denotes one part per 1000 parts, one part in $10^3$, and a value of $1 \times 10^{-3}$. This is equivalent to one drop of water diluted into 50 milliliters (ten spoon-fulls), or about one and a half minutes out of one day.
- *One part per **million*** (**ppm**) denotes one part per 1,000,000 parts, one part in $10^6$, 1/1,000,000 * 100% = 0.0001% (or 1% = 10,000 ppm), and a value of $1 \times 10^{-6}$. This is equivalent to one drop of water diluted into 50 liters, or about 32 seconds out of a year.

### Distribution of water

- a basic feature of the earth is an abundance of water
- The Earth is often referred to as the "blue planet" because when viewed from space it appears blue. This blue color is caused by reflection from the oceans which cover roughly 71% of the area of the Earth.



### Distribution of Earth's Water

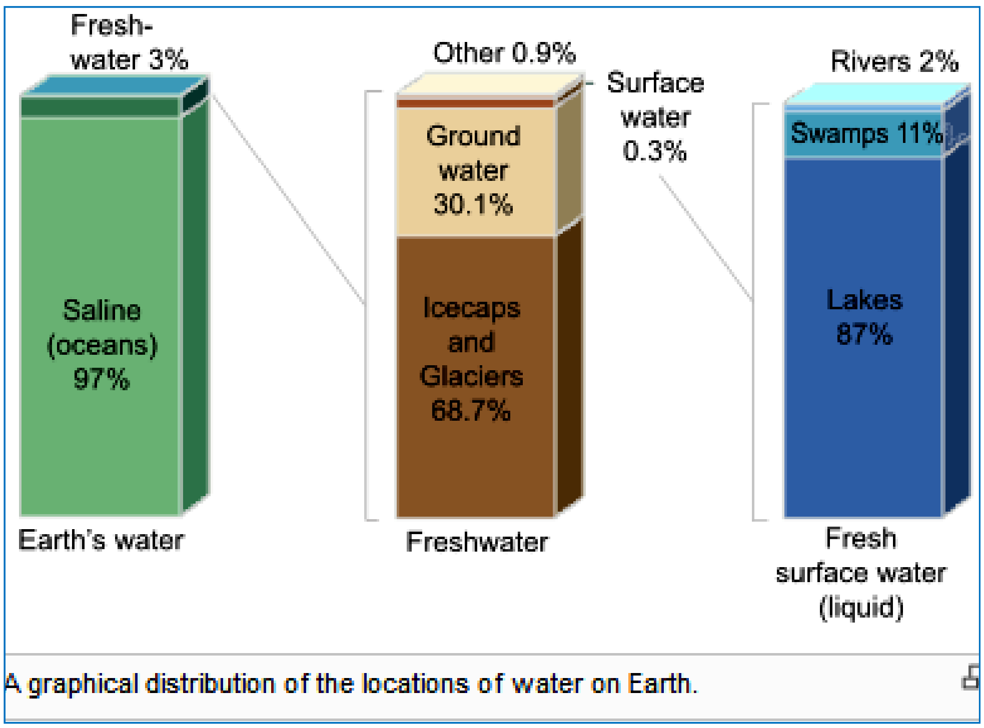



Figure 1. A graphical distribution of the locations of water on Earth

**Location and amount of water on earth**

* They are the most extensively used and highly depleted in less managed tropical ecosystem than recharging/ replenishing ability as well as misused and polluted.

Table 1. Location and amount of water on earth and its relative distribution.

| Location | Amount (thousands of $Km^3$) | Total (%) | % of inland liquid water |
|---|---|---|---|
| **Freshwater lakes*** | 125 | 0.009 | 1.45 |
| **Saline lakes and inland seas** | 104 | 0.008 | 1.2 |
| **Rivers (average volume)*** | 1 | 0.00011 | 0.01 |
| **Shallow and deep soil water** | 67 | 0.005 | 0.77 |
| **Ground water to 4000 m depth*** | 8,350 | 0.61 | 96.56 |
| **Ice caps and glaciers** | 29,200 | 2.14 | |
| **Atmosphere** | 13 | 0.001 | |
| **Oceans** | 1,320,000 | 97.3 | |

*These relatively small amounts of water are important for the maintenance and survival of terrestrial life including drinking and irrigation.

**Why Aquatic Sciences and Wetland Management as a course in the curriculum?**

Water is a critical resource for all of life on Earth. It is a life-or-death issue for satisfying thirst and supplying agricultural needs.
However, fresh water is in short supply in many parts of the world, and water conservation should be a prime task in many countries.

Human interactions with water most often involve fresh waters (streams, rivers, marshes, lakes and shallow ground waters), thus we rely heavily on a relatively rare commodity.

As is true of all organisms, our very existence depends on this water; we need an abundance of fresh water to live

Water is unique, has no substitute, and thus is extremely valuable

The answer should be beyond our personal interest to complete the BSc program or simply because we found it on the curriculum

I would like to highlight some of the importance of water for human kind for your consideration in conserving the aquatic ecosystem, and to trigger your interest to study the course with full interest

- First and foremost, you need to have insight about the aquatic system because several courses of the degree program appear to focus on terrestrial ecosystem.

- The biodiversity of aquatic organisms are huge

With 25,000 recognized species, fishes make up the most diverse vertebrate group, comprising about half of all known vertebrate species

**Fish:** 41% of fish species are found in freshwater bodies
58% of the fish live in marine environment

In Ethiopia, there are more than 200 fish species, of which about 40 are endemic to the country. In Lake Tana and its catchment alone, 20 of the twenty seven species are endemics and such high endemicity could be attributed to the high cyprinid endemicity (about 18 species) reported for Lake Tana.

However, there has been a 35% decline in freshwater species since 1970

- Aquatic bodies have immense important function to humankind.
  Some economic value of water
  - Domestic water consumption (cost of drinking water, cleaning)
  - Food (fish protein represents about 25% of the total animal protein consumed by the world's population, second only to beef)
  - Transportation (bulky freights are transported through the medium of water)
  - Hydro-electric power generation
  - Industry
  - Irrigation – worldwide, 40% of the food comes from irrigated cropland
  - Universal solvent

- Recreational purpose: it has splendor scenic and also fish game
  Rift valley lakes such as Langano, Awasa and also highland lakes

- Lakes have played a part in history, economy and culture of many nations

Lake Tana and Lake Zway was a place to hide Ark Covenant during critical times in the history of the country.
Understanding of the killer lakes of Africa

- 1700 people died on 21 August 1986 near Lake Nyos in Cameroon
- Some survivors reported smelling an odor like rotten eggs, then losing consciousness
- When awaken after 6-36 hours later they are very weak and many of their family members were dead
- Researchers later revealed: the deaths resulted from a catastrophic release of $CO_2$ from the lake
- $CO_2$ is heavier than $O_2$
- The larger amount of $CO_2$ released from the lake filled the valley by displacing $O_2$ and suffocating people and animals

Large number of lesser flamingos died in Tanzanian and Kenyan lakes

- Massive fish kills were observed in Lakes Hayq, Hashenge, Ziway, Chamo..
  Fish and livestock died in Lake Chamo
- Freshwater bodies cover only small percentage of the planet
- Even if the distribution of fresh water are very small world wide, the ecosystems are over-exploited and misused. They are dried and some of them are highly polluted as a result of conscious and unconscious activities of human being.
  - One good example is Lake Alemaya- completely dried because of unbalanced and mis-use of the water
  - Lake Abijata – is getting more and more shrinked
  - Mojo river- is highly polluted due to the effluent that comes from Tannery factories
  - Lake Koka is highly polluted and eutrophic

See the crises trend that human being has passed and will pass

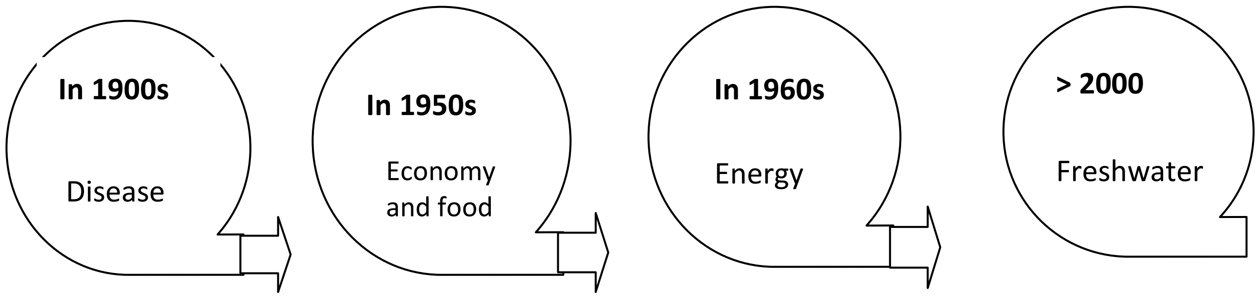



Figure 2. Crises trend

In the near future the world faces freshwater crises that may be the worst crises ever happened.

In the near future whether we like it or not, freshwater would be one of the most expensive commodities especially if we keep using as we are using it now.

Major reasons for depletion of freshwater. Two major interrelated reasons.

**1. Demotechnic growth**

The stress on freshwater supply has been increased over the years
This is because of industrialization/ technology development since at this time people were using water at a much faster rate for irrigation and industry purposes

**2. Human population growth –**

Technology indirectly increase population number and urbanization
Human population increases at an exponential rate (rapidly growing)
The increment of population demands greater amount of water for different purposes – a pressure on a key resource – for cleaning, irrigation …

**How much water do we need** …

- People in developed countries generally are not aware of the quality and quantity of water that is necessary to sustain their standard of living
- High quality of water (treated for drinking) is used for
    - Filling swimming pool
    - Watering gardens
    - Flush toilets
    - Turning on the tap while brushing teeth
    - We Ethiopians also use chlorinated (treated) water for car washing, toilet flushing– we use a scarce and expensive resource unnecessarily)

## HOW MUCH WATER DOES IT TAKE TO...

- Brush your teeth? - 2 to 5 gallons
- Wash the car? - 50 gallons
- Use the dishwasher? - 8 to 15 gallons
- Flush the toilet? - 1.5 to 4 gallons (each flush)
- Take a shower or bath? - 17 to 24 gallons
- Run the washing machine? - 35 to 50 gallons (each load)

It's important that we all work to save water. About half the water we use each year is used outdoors - watering the garden and lawn, filling the swimming pool and washing the car. Ways to reduce your water use outside include using a shut-off faucet when washing the car and landscaping with plants that use less water.

Indoors, most of the water a family uses is in the bathroom. Saving water is important. In the bathroom, the easiest way to save water is to shut off the faucet while you brush your teeth or take

### *How much water does humankind need?*

- A wide disparity occurs between per capita water use in developed and developing countries

Table 2: General ranges of water use with varied socioeconomic conditions on a per capita basis

| Society | Range or mean ($m^3$ $year^{-1}$ $capita^{-1}$) |
|---|---|
| **Irrigated semiarid industrial countries** | 3000-7000 |
| **Irrigated semiarid developing countries** | 800-4000 |
| **Temperate industrial countries** | 170-1200 |
| **United States** | 2200 |
| **Switzerland** | 480 |
| **Israel** | 500 |
| **Jordan** | 200 |
| **Ghana** | 75 |

The table above demonstrated that Israel and Switzerland are likely the most water-efficient developed countries, with per capita water use of 500 $m^3$ per year, about 4 times as efficient as the United States.

United states are an extravagant country. If all the people on Earth used water at the rate it is used in America, much of the water available through the hydrological cycle would be used in a short period of time.
In fact, increases in standard of living lead to greater water demands (per capita water use)

In Ethiopia urbanization increasing, so does the standard of living…
Degradation of water quality has substantial economic and life consequences
The population of the earth is currently over 7 billion people
According to current projections, the global population will reach eight billion by 2025–2030,
Imagine how the demand on the finite resources (land and fresh water) will increase
Plus bear in mind the uncertainty over climate change in the future
Human impact on water quality and quantity and biodiversity is inevitable

Fresh water is a finite resource even though it is partially renewable (slightly)
As the human population increases, the severity of the crises will increase

One may think to use ocean water because we have huge reserve, but the salt concentration is very high >35 ppt- not directly suitable for drinking and irrigation

- Desalinization of ocean water requires tremendous money and energy expenditure for the treatment process
- Distribution of the "freshwater" becomes very difficult because the location of counties, cities, towns are far from the ocean

Freshwater ecosystems are worth trillion dollars each year
They provide food and livelihood for millions

An understanding of aquatic ecosystem and their function and threats by humankind will assist in making decisions to minimize adverse impacts on aquatic resources, stop mis-using it and will ultimately support policy makers to produce sustainable water use practices.

**Question summary**

1. What is aquatic science?
   Define fresh water and saline water?
2. Explain the significance of the course to your over all profile.
3. Mention some of the importance of water.
4. Write the major reason for depletion of fresh water.

# Chapter Two

## *Physical factors*

## *Water as an environment:*

*The physical and chemical characteristics of water affects the aquatic organisms as well as the ecological theater of ecosystems*

Environmental factors that affect aquatic organisms can be broadly categorized into 2: **Physical and chemical factors**

*In this chapter we will focus on*
*Physical factors including morphometry, unique characterstics, light …*

**Chapter objectives**

At the end of this chapter, students will be able to:

- To understand the importance of the morphometric parameters for water quality
- To get insight how to measure morphometric parameters
- To understand the unique properties of water
- To understand the physical and chemical variables of water

## 2.1 Morphometry

Morphometry is one of the 1st ways that people classify water bodies such as the surface area or maximum depth of a lake. It is related to the measurements of shape and size of the water bodies (e.g. lake basin)

- It actually indicate external and internal structure of the basin
- It provide about the productivity, distribution of biota etc
- It means the shape and size of a lake basin affects physical, chemical and biological variables (parameters)

Morphometry is best described by a bathymetric map, which means maps showing depth-contours within a lake basin (outline)

Bathymetric map are created from depth sounds made along transects followed by connecting the points of a particular depth with a contour line

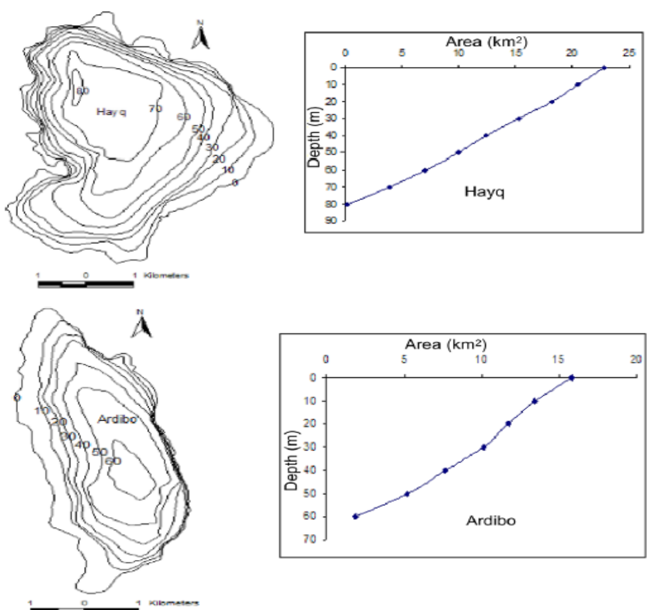



Fig. 2.1 Bathymetric maps and depth-area relations

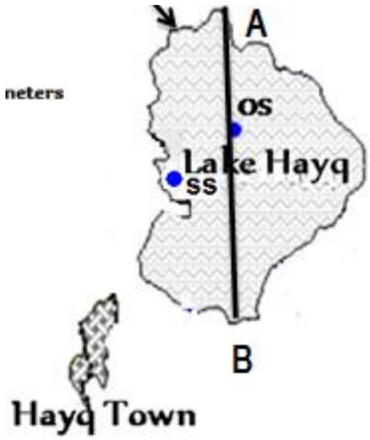
Bathymetric map provides important information on geomorphologic properties of water bodies.

Morphometry such as the shape and size of a lake can be studied from ***surface and subsurface dimension of the lake***

### 2.1.1 Surface Dimensions

Dimensions that can be measured from the surface of a lake

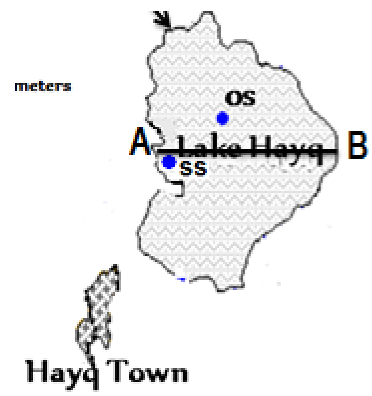
**a. Maximum length (l)** – the longest distance of two point of the lake




It can be measured using tape or ruler from the outline map

The wind-effective length or actual fetch of the wind

The exposure of a lake to wind has a direct effect on water movement and thus indirect effects on the biota within the lake




**b. Breadth** (maximum width) (b) – maximum distance from shore to shore (A to B), which is perpendicular to the axis of the maximum length

**c. Surface area (A)** – total area enclosed by shoreline

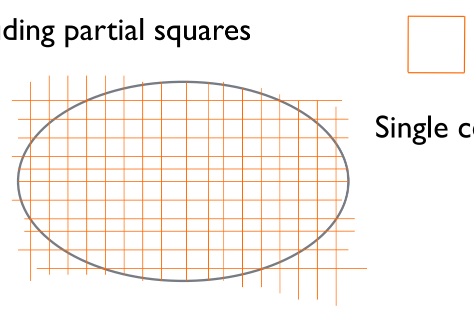
- It is an important dimension, for it is at the surface that solar energy enters the aquatic habitat
- Several data is also described as per unit area

**Surface area is measured by three methods/techniques**

1. **Planimeter** -instrument that measure the perimeter and convert to area using proportional method, if the planimeter is mechanical. If the instrument is digital, the machine automatically convert the perimeter to area.

**2. Grid method**

Count total grids including partial squares



Single cell

The area can be determined from aerial photographs or topographical maps
The map should have a scale (unit: $m^2$, $km^2$)

***Procedure to determine surface area using grid method***

- Count all complete squares
- Approximate every partial (incomplete) squares and count
- Sum all counted squares (**$T_1$**)
- Draw reference polygon (square or rectangle) with known surface area (**$R_A$**)
- Count all the squares of known area polygon (**$R_1$**)
- The area in question can be determined by a direct proportional equation (**$T_A$**)
  - **T1/TA= R1/RA**
    - **Where:** RA= area of known plane surface (square or rectangle)
      R1= total count of known plane
      TA= area of unknown plane surface (e.g. map of the lake); the area to be determined?????
      T1= Total count of unknown plane surface (lake map)

**3. Balance method**

- The third method is to use an accurate balance
- If the lake outline is drawn on paper of fairly uniform density, it can be cut out and weigh to yield a mass
- Weigh a know area from the same paper
- Ratios can give good degree of accuracy

**Table 2.1** shows surface area of some popular lakes

| **Lake** | **Surface Area ($Km^2$)** | **Remark** |
|---|---|---|
| Lake Tana | 3,150 | The largest lake in Ethiopia |
| Lake Hayq | 23 | |
| Lake Awasa | 90 | |
| Lake Arenguade | 0.5 | |
| Lake Victoria | 68,800 | It is the planet's second largest freshwater lake and Africa's largest lake |
| Lake Baikal | 31, 500 | |
| Lake Superior | 83,300 | The largest freshwater lake in the planet-North America |

d. **Length of shoreline (L)**

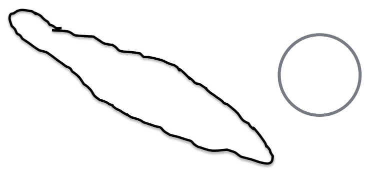
It is the perimeter of the lake
Shoreline is the external boundary or surface of a figure or object

It can be determined from the map using thread and pin, then measure the thread by a ruler

**e. Shoreline Development index ($D_L$)**

It is expressed as the ratio of the shoreline (L) to the circumference of a circle that has same area as the lake

The formula : $D_L = L_{/2*\sqrt{\pi A}}$



Shoreline development index reflects the degree of shoreline irregularity, the more irregular the shoreline, the greater the DL

It is a parameter that measure the potential for littoral development, which tells about the potential productivity of the lake. Because there will be direct relationship between nutrients input and size of the shoreline; that means the watershed influence will be high.

If $D_L$ is equal to 1, it means the lake is cone shaped or circular such as crater lakes and indicates little littoral area

If $D_L$ > 1 littoral area increases

$D_L$ >= 3.5 for reservoirs, irregular shores, high littoral area, and could be productive

- Most natural lakes have values between 1.5 and 2.5

**2.1.2 Subsurface dimensions** are dimensions that are measured under/beneath the surface of water.

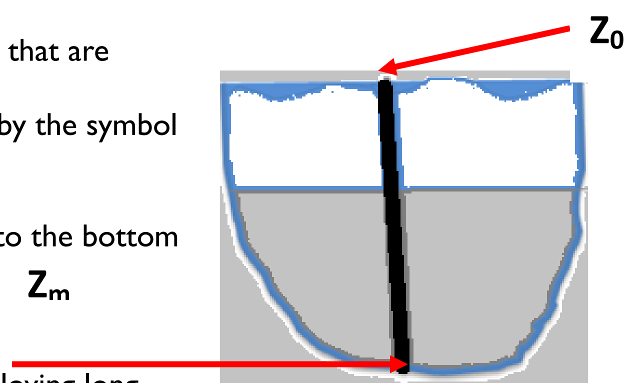
a. **Maxmum depth ($Z_m$):** Depth is designated by the symbol Z.

$Z_0$ is the surface, that means a depth of zero

$Z_m$ is the maximum depth from the surface to the bottom of a lake

$z_{mean}$ = average depth

Unit: m

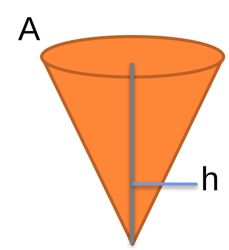



Depth can be measured by eco-sounder or employing long rope and weigh (anchor) and measuring with tape.

**Table 2.2** Depth and surface area of some selected popular lakes

| Lake | Surface Area ($Km^2$) | Maximum Depth (m) | Remark |
|---|---|---|---|
| Lake Tana | 3150 | 14 | |
| Lake Hayq | 23 | 88 | |
| Lake Awasa | 90 | 22 | |
| Lake Arenguade | 0.5 | | |
| Lake Victoria | 68,800 | | It is the planet's second largest freshwater lake and Africa's largest lake |
| L.Tanganiyka | | >1400 | The second deepest lake in the world |
| Lake Baikal | 31, 500 | >1600 | The deepest lake in the world |
| Lake Superior | 83,300 | | The largest freshwater lake in the planet- North America |
| L.Shala | | 266 | |

b. **Volume (V):** the total amount of water contained in a lake



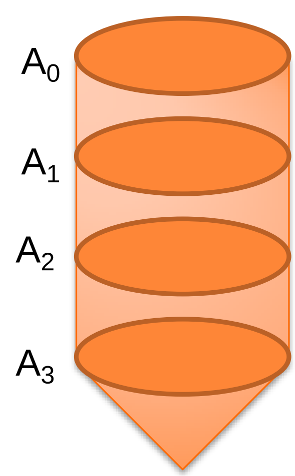

Unit: $km^3$, $m^3$, liter

Volume can be calculated in two ways:

1. Assuming the lake to be cone shaped:
   - use cone formula to calculate volume

   $V=1/3\ (A_0*h)$, replace h by $Z_m$

2. ∑ of volume at different strata




Let's assume that the area ($A_0, A_1, A_2$ …) and depth ($Z_0, Z_1, Z_2$ …) of each contour is known. Then we can use the following formula to calculate volume between two strata

$$\mathbf{V_{Z1}\text{-}_{Zo}=1/3(A_{Zo}+A_{Z1}+\sqrt{A_{Zo}*A_{Z1}})*(Z_1-Z_o)}$$

Total volume= $\sum V_i$

c. **Volume development (Dv)**

Provides information about the shape of lake basin

Dv is a measure of departure of the shape of the lake basin from that of a cone

$$Dv= 3*(\text{mean depth}/Z_{max})$$

Dv=1 means perfectly cone shaped.

d. **Mean depth:** Mean depth can be calculated as**= V/A**

**Where:** V = lake volume

A = lake surface area

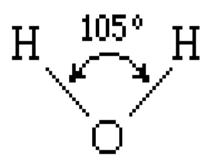
**2.2 Unique properties of water**

Water has very unusual (strange) properties which makes it vey important as a medium for aquatic organisms to live in.

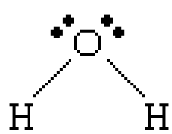
These unique physical properties have strong biological implication and form the foundation for aquatic sciences.

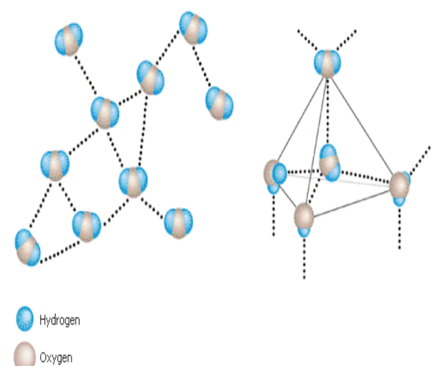
Hydrogen bonding is responsible for several unique characteristics of water (without hydrogen bonding, water would be a gas at room temperature).

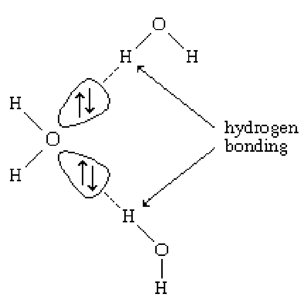
- The water molecule is not linear but bent in a special way. The two hydrogen atoms are bound to the oxygen atom at an angle of 104.5°.

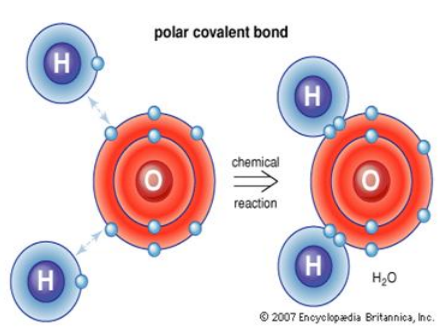



- The electronic structure of the water molecule plays a role in water anomalies. Many special characterstics of water are a result of its molecular shape. The water molecule has two hydrogen atoms jutting out from one side of the oxygen.




A water molecule is made up of two hydrogen atoms and one oxygen atom. A single oxygen atom contains six electrons in its outer shell, which can hold a total of eight electrons. When two hydrogen atoms are bound to an oxygen atom, the outer electron shell of oxygen is filled.

Water ($H_2O$) is a good example of hydrogen bonding. The oxygen atom pulls the electrons more tightly toward itself and away from the hydrogen atoms. The oxygen gains a slight negative charge, while the two hydrogen atoms each become slightly positive. These small charges on the atoms allow them to attract atoms of neighboring water molecules. Each hydrogen atom of water molecule A forms a hydrogen bond to the oxygen atom of another water molecule, such as molecule B or molecule C, and so forth.

These special hydrogen bonds are so important in living systems that some scientists consider the hydrogen bond to be the most important chemical bond of all. Hydrogen bonds keep water molecules together in the liquid state, preventing the molecules from separating and evaporating at a lower temperature. Without hydrogen bonds, water would boil near –80° C (near -110° F) instead of at 100° C (212° F). Liquid water would not exist in most places on Earth.

**What are unique properties of water?**

1. Water has a very **high surface tension.** In other words, water is sticky and elastic, and tends to clump together in drops rather than spread out in a thin film.

*Several organisms, such as water striders, take advantage of this surface tension to walk on the surface of water. Some lizards also run across the surface of water using the support of surface tension.*

2. Water has high **specific thermal capacity**: defined as the ratio of heat capacity to the mass or volume of water

the amount of heat required to raise the temperature of 1gm of water by 1 $^{O}$C (unit= cal $g^{-1}$ per $^{O}$C)

**Example: Rock=0.2 cal $g^{-1}$ $^{O}$C; Al= 0.212;**
**Ethanol= o.581; pure water= 1.00**

The reason for the high specific heat of water is the high heat energy required first to stretch and then to break the hydrogen bonds of water molecules.

Water absorb a lot of heat before it begins to get hot. That is why water is valuable to industries and in cars' radiator as a coolant.

This heat-requiring and heat-retaining properties of water provide a much more stable environment than is found in terrestrial situations.

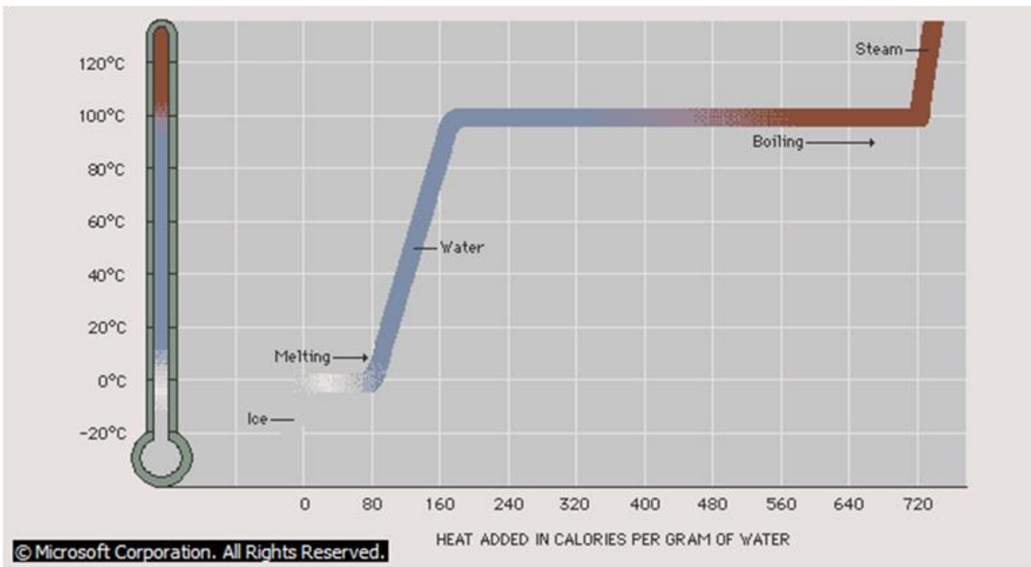
- In short, water temperature fluctuation are very gradual (small) and this has some biological implications:

  - The organisms require less energy for homeostasis and hence they used the energy for other purposes.

- The organisms will get enough time to adjust themselves with the changing environment (the organisms adjust themselves with slow changing environment)

**Temperature Change Versus Heat Added in Water**

The graph represents the temperature change that occurs when heat is added to water. At 0° C and at 100° C, you can add heat to water without changing its temperature. This "latent heat" breaks bonds that hold the molecules together but does not increase their kinetic




energy. Note that approximately seven times more heat must be added to evaporate one gram of water than to melt it. This is represented by the relative lengths of the horizontal portions of the graph. The slopes of the inclined lines represent the number of degrees that the temperature changes for each calorie of heat that is added to one gram. The reciprocal of this number is the amount of heat that must be added to make the temperature of one gram change by one degree. This is called the specific heat.

- **Because of high specific heat, water has:**

   a. High latent heat of melting

The heat required melting 1gm of ice into water; it is 79.72 cal $g^{-1}$ $^{O}C$.
Because large amount of heat is required to melt, the polar ice caps do not melt easily.
So the ice caps remain ice and the world is safe from flood due to ice caps melt.

   b. High latent heat of fusion

The amount of heat required to change 1g of water to ice. Hence the ocean/lake do not crystallized (become freezed) as it required large amount of energy to form ice; 79.72 cal $g^{-1}$ $^{O}C$

   c. High latent heat of evaporation

The amount of heat required to change 1gm of water (liquid) into vapor; it is 540 cal $g^{-1}$ $^{O}C$
Hence lakes/oceans do not all evaporate

d. High latent heat of sublimation
The amount of heat required changing 1gm of ice directly to vapor; it is 679 cal $g^{-1}$ $^{O}C$.

Hence all ice do not evaporate

- That is why winter ice takes time to melt in temperate region.
- The liquid in summer becomes crystallized in winter and you can walk on your foot or you can play skiing.

**3. Water is unique** in that it is the only natural substance that is found in all **three states**– liquid, solid (ice), gas (water vapor) – at the ambient temperature normally found on earth.

**4. Unusual density relationship:**

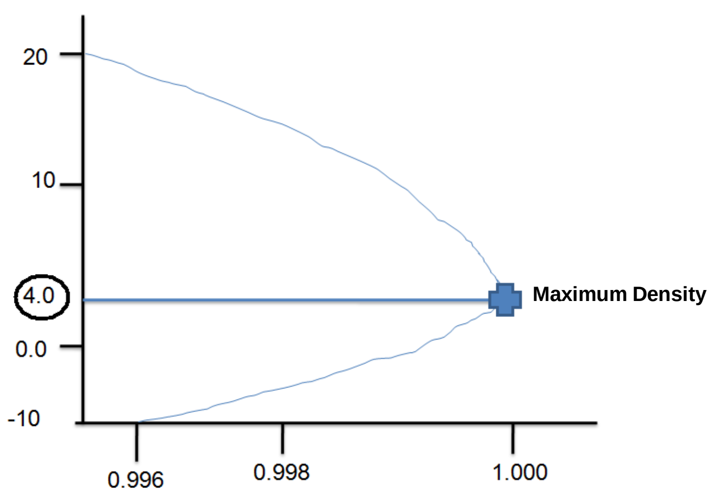
With temperature, salinity, hydrostatic pressure

***4.1 Density vs. temperature***

Density is the mass of water in a unit volume (D=m/v)
The density (weight/volume) of water is about 775 times greater than that of air at standard temperature and pressure (0 $^{O}C$, 760 mmHg)

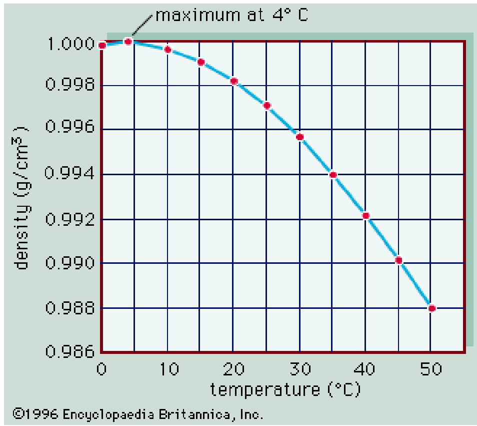
The maximum density of water, 1.00 $g/cm^{-3}$, reaches at 3.96 °C ≈ 4 °C

The density of the water decrease, either the temperature increases or decreases




As one keeps increasing temperature above 4°C, the density of the water decreases

Density relationship to temperature in water




Relationship between the density of pure water and temperature.

Because the distance between water molecules (inter-atomic distances) increases with rising temperature

The result is expansion of the liquid and eventually the density decreases or volume increases

In a similar manner, when the temperature decreases the density also decrease

Water expands upon freezing and greater distance between water molecules occurred.

**Water expands about 9% upon freezing**

Water contained in cracks (rock) expands upon freezing, forcing the rock apart- it plays an important role in the mechanical breakdown of rock known as physical weathering

Put a full bottle of water in deep freeze; the bottle would break because of expansion

Therefore, ice has lower density (0.9170 g $cm^{-3}$) than liquid water at 4 $^{o}$C (1.000 g $cm^{-3}$)

Water is unusual in that the solid form, ice, is less denser than the liquid form

Therefore, ice floats on the liquid warmer water and this has the following implications:

Without this temperature vs. density property, the ice would sink to the bottom during winter in temperate region eventually freezing the lake solid.

Because of this unique property, organisms living in the denser, warmer water below remain protected from freezing temperatures.

The relationship between temperature (T, $^{o}$C) and density (D) is nonlinear with the density readily estimated from the equation:

$D = 1 - 6.63 \times 10^{-6}(T-4)^2$

### 4.2 Density vs. Salinity

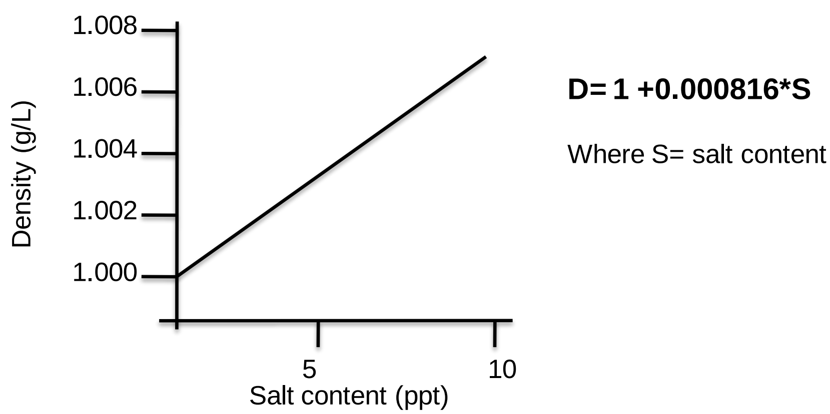
Water density is also influenced by factors other than temperature

Salinity (concentration of dissolved salts) affects density of the water

When salinity of the water increases, density of water also increases
Example: sea water with 35ppt salinity, the density is 1.028 g/cm$^3$
This results that the temperature of maximum density is depressed because of high salinity

Hence seawater, the temperature of maximum density reaches at -3.5°C

- In the deeps of Manitou Lake, the freezing point has been lowered to -1.1 °C, and the maximum density is at -0.3 °C.
- The temperature of maximum density declines at a rate of about 0.2 °C per 1 g/L salt increment, lowering the freezing point of saline waters




- The salinity of most inland waters is within a range of 0.01 and 1.00 g/L and usually between 0.1 and 0.5 g/L

| Salinity (ppt) | Density (at 4 °C) |
|---|---|
| 0 | 1.00000 |
| 1 | 1.00085 |
| 2 | 1.00169 |
| 3 | 1.00251 |
| 10 | 1.00818 |
| 35 (average conc. of sea water) | 1.02822 |

### 4.3 Density vs pressure

Pressure is the force per unit area applied to an object a direction perpendicular to the surface

Hydrostatic pressure is what is exerted by a liquid when it is at rest

Hydrostatic pressure can be sufficient to compress water and thereby lower the temperature of maximum density

Pressure increases 1 atmosphere per 10 m of depth

The temperature of maximum density decreases about 0.1 °C per 100 m of depth

## 2.3 Solar radiation in water



Aquatic Ecosystems are open systems and it requires solar radiation as a continuous source of energy

- Importance of light in water:
  - Photosynthesis – conversion of solar energy to chemical energy
  - Affect thermal structure and stratification of water masses and circulation
  - For visual communication: light
- The wavelengths of the solar radiation could be from 100 to 3,000 nm
  **(1m=$10^{-9}$ nm (1 billionth of a meter)**

Irradiance is normally expressed in nanometers (nm) when described by wavelengths

However, photochemical reactions (photosynthesis and vision) depends on the number of quanta absorbed
This means that solar energy is either a continuous flow of electromagnetic waves or discrete packets of energy

Discrete packet of energy or a quantum of light is called photon (photon is an indivisible entity of light)

The photon is an elementary particle, or a particle that cannot be split into anything smaller

Energy can be used to carry out work

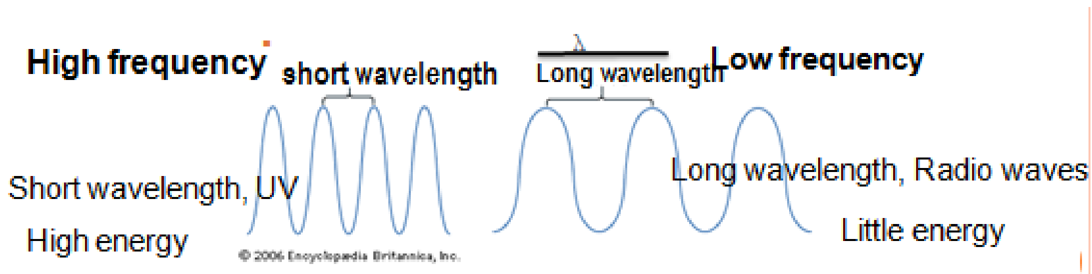
The energy (E) content of photons:

- E=hV where h is Planck's universal constant ($6.625*10^{-34}$J) and V is the frequency (number of vibration per second); h is used to describe the sizes of quanta

- Photons with high frequencies carry more energy than do photons with low frequencies

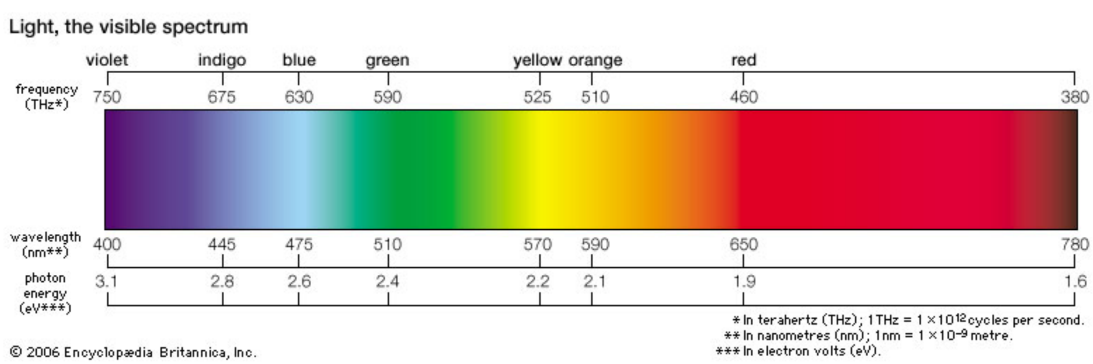
- The energy is determined by the frequency -- which is directly related to energy; as the frequency increases, energy content of individual photons increases
- However, wavelength is inversely related to frequency, as wavelength increases, frequency decreases: $\lambda$=C/V where C is speed of light ($3*10^8$m/s)

- The energy content of photons declines with increasing wavelength
- Wavelength is the distance between two consecutive wave peaks




Electromagnetic radiation travels in waves. A wavelength is the distance from the peak of one wave to the peak of the next wave. Short wavelengths have a shorter distance between peaks than long wavelengths.

The frequency of visible photons corresponds to the color of their light. Photons of violet light have the highest frequencies of visible light, while photons of red light have the lowest frequencies.



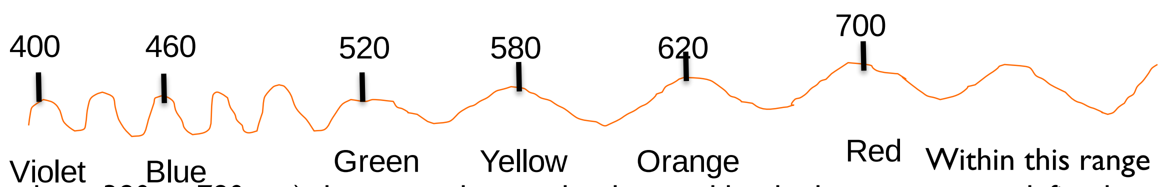

When white light is spread apart by a prism or a diffraction grating, the colours of the visible spectrum appear. The colours vary according to their wavelengths. Violet has the highest frequencies and shortest wavelengths, and red has the lowest frequencies and the longest wavelengths.

Photons that are visible to the human eye have energy levels around one electron volt (eV) and frequencies from $10^{14}$ to $10^{15}$ Hz (hertz or cycles per second). The number $10^{14}$ is a 1 followed by 14 zeros.

**Photosynthetically Available Radiation (PAR)**

The wavelength visible to humans (380-780 nm) and the PAR (photosynthetically available radiation, 400-700 nm) are portion of light that interest us.

Representative colors selected from the continuum of the spectrum are:




Within this range (from about 380 to 780 nm) the waves that can be detected by the human eye, are defined as "light". In other words The widely used term "light" refers to the radiation visible to humans

The sun's radiation can be divided into 3 categories based on wavelength and their effects:

| Wavelength | Name and Effect |
|---|---|
| **100-380 nm** | **Ultraviolet:** damaging effect on organisms, very high energy photons may cause structural damage to DNA and proteins |
| **380-780 nm** | **Visible radiation:** including PAR (400-700nm)<br>PAR mostly absorbed by pigments Chla-445 and 660 nm<br>Algae + aquatic vegetation use PAR<br>Visual purpose |
| **780-3000nm** | **Infrared radiation:** produces heat,<br>Lower energy photons |

- A large portion of irradiance is in the infrared portion of the solar spectrum and has major thermal effects on the aquatic system.

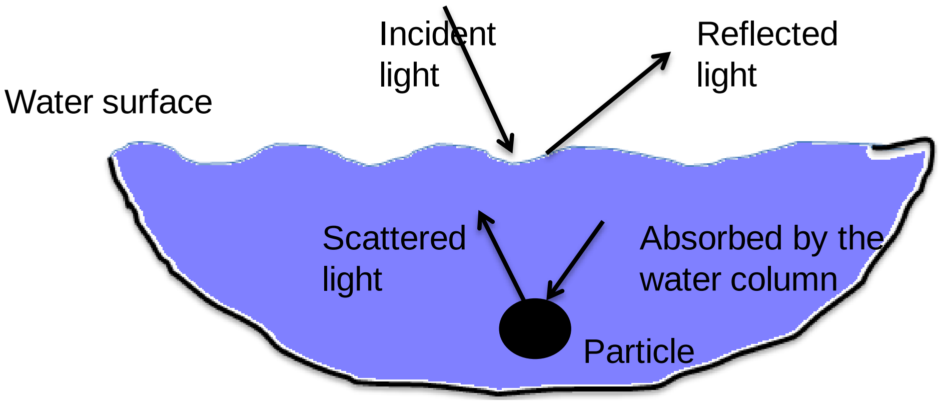
### *Factors that affect the irradiance received by water:*

The amount of cloud cover: full cloud cover reduces the incident solar radiation by about 30% whereas fog reduces radiation 80% over that obtained under cloudless condition.

Surrounding topography

**Tall trees (canopy)** } Greatly reduces incident radiation over that
**Mountains** recorded in an open location nearby

3. Atmospheric condition: Dust, air pollution, gas, water droplets
Once the solar radiation reaches a lake, some amount is reflected back, and the remaining penetrate down to the water column where it is absorbed




**Reflection of light** from the surface of water depends on:
The angle of the sun (incidence)

The greater the sun's elevation, the smaller the reflection would be

| **Angle of the sun** | **90** | **80** | **70** | **60** | **50** | **40** | **30** | **20** | **10** | **0** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Reflectivity (%)** | **2** | **2.1** | **2.1** | **2.1** | **2.5** | **3.4** | **6** | **13.4** | **34.8** | **100** |

In clear day the reflection from the water surface is small – about 8%

Even when the sun is only 10 degrees above the horizon, 2/3 of the sunlight enters the lake, and 1/3 is reflected

b) Meteorological conditions

c) Surface wave condition (surface characteristics of water)

Reflection can increase 30-40% when there is a strong wave action.

## Fate of light in water

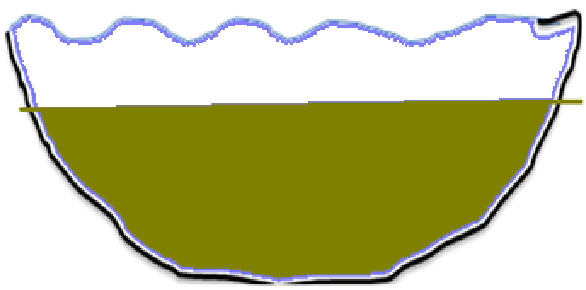
- Absorption

Light intensity decreases with depth because of absorption and scatter
PAR entering the water is attenuated (absorbed) by:

- Organic particles
- Colored DOM (yellow-red; suspended particles)
- Small silt-clay sized inorganic particles
- Water molecules

- When the radiation is absorbed, little light radiation is left to penetrate further i.e. less and less light spectrum/amount penetrate deep and it stops somewhere down the column

- That is way after some vertical depth, you do not get light



- In transparent lakes and in the open ocean (both characterized by very few particles almost no DOM)
  - The red end (600-700nm) is largely attenuated
  - Blue light is transmitted or penetrate deep

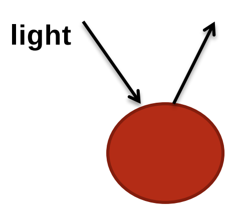
In pure water, about 65% of the red light (700nm) is absorbed in the 1[st] meter (kd=1.05)

Only 0.5% of blue light (475nm) is absorbed in the same distance (kd=0.005)

As a lake becomes more eutrophic, more blue and red wavelength is absorbed and relatively more green is transmitted and reflected

On the other hand, blue light and UV (<400 nm) are particularly attenuated by colored DOM

2) Scattering is the result of deflection of photons by water molecules, dissolved substances in the water, and suspended particulates matter (dead organic matter, plankton and neckton) Some photons are scattered rather than absorbed upon striking particulate matter.



Scattering depends on wavelength of the spectrum
In pure water, scattering increases inversely with the fourth power of the wavelength $(1/\lambda)^4$

This means that short wavelength light is more scattered than long wavelengths
Making blue and UV portions of the spectrum most prone to scattering

That is why transparent lakes (oligotrophic lakes) and open oceans are looking blue

Because blue light is strongly back scattered to surface by water molecules producing characteristics blue color

Chlorophyll content provide green colors to water
Humic substances provide brown colors to water
Turbidity does not change the color but it does reduce the color intensity

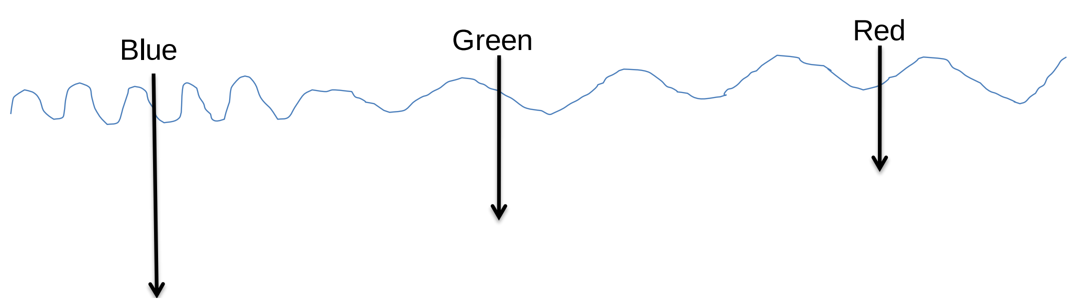
Red portion of the spectrum penetrate deep in waters containing much silt or clay

In productive (eutrophic) lakes green wavelength penetrate relatively deep and green light reflected back giving highly productive lakes their green color

3. **Transmission (light penetration)**

– the amount of light (solar radiation) that pass the surface water and penetrate the water column

- energy versus penetration ability in water




- In pure water: the penetration of water is determined by wavelength
  - The shorter $\lambda$, the higher energy and hence high penetration ability

Blue light is transmitted (penetrate) best in highly transparent waters and at the same time subject to high scattering

In inland waters containing much silt or clay, red portion of the spectrum penetrate deep

Red light is absorbed most rapidly in pure water

**Light extinction:**

- The degree of light retention by a layer of water is referred to as light extinction
- Light extinction can be expressed using extinction coefficient ($k_d$)
  - **Kd=100 (Io—Iz)/Io OR**

Percentage transmission per meter= **100 [1-(Io-Iz/Io)]**

Where: Io= light intensity just below the surface of water

Iz= the light intensity at depth Z

- Extinction coefficient ($k_d$): tells how much of surface light (Io) is attenuated at each depth (Iz)
- Light extinction coefficients ($k_d$) for natural lake waters range from 0.2 for clear oligotrophic lakes to about 4.0 in highly stained eutrophic lakes (Wetzel, 1975). Light extinction coefficient ranges for lakes of varying trophic status provided by Likens (1975) are: ultra-oliogotrophic (0.03 - 0.8), oligotrophic (0.05 - 1.0), mesotrophic (0.1 - 2.0), and eutrophic (0.5 - 4.0).
- The vertical attenuation of PAR is simply expressed as a percent reduction through a water layer of specified depth:
- The reduction of light intensity with depth is exponential. The change in light intensity caused by light absorption and/or light scattering is described by the Lambert-Beer law
- Lambert-Beer's law is a mathematical means of expressing how light is absorbed by a matter. The law states that the amount of light emerging from a sample is diminished by three physical phenomena:

1. The amount of absorbing material in its path length (concentration)

2. The distance the light must travel through the sample (optical path length)

3. The probability the photon of that particular wavelength will be absorbed by the material (absorptivity or extinction coefficient)

- The relationship may be expressed as: $A=\varepsilon dc$

**Where:** A= absorbance
ε = molar extinction coefficient
d= path length in cm
c= molar concentration

- Total light intensity changes (decreases) with depth.
- Rather than expressing the amount of underwater PAR as a percentage of surface PAR, it is more useful to compute the downwelling radiation by means of the vertical extinction (or vertical attenuation) coefficient (designated as Kd)
- The formula to calculate light intensity at particular depth

**$Iz=Ioe^{-KdZ}$ -- exponential form**

**OR**

**$Kd=(\ln I_o—\ln I_z)/Z$ --- lan form**

**$Kd=2.303(\log_{10}Io—\log_{10}Iz)/Z$ – log form**

**Example:**

- Oligotrophic and transparent Lake Hayq: assume Io=100% and Iz=14% yields an average vertical extinction coefficient of 0.2 $m^{-1}$ over 10 m below surface.
- In highly eutrophic and colored lake Tooms, the extinction rate is large – 2.2m-1
- Ultra-oligotrophic Crater Lake (Oregon, US)
- Kd (PAR) of about 0.05m-1 and an even lower 0.03m-1 in the amictic antarctic Lake Vanda (lying in a catchment with almost no organic matter)

The mean attenuation coefficient (Kd, PAR) is a composite measure of attenuation by water, suspended particles, Chl-a, and colored dissolved plus colloidal organic matter (DOM)

**How to measure $K_d$:**

1. Directly using light meter
2. In the absence of light meter measurement, the vertical light extinction coefficient ($k_d$) is estimated from Secchi disc (Zsd)

The conversion factor is: $K_d$ ($m^{-1}$)=1.7/Zsd for lakes

$K_d$=1.45/Zsd for Oceans

Secchi depth corresponds to the depth at which approximately 10% of the surface light remains

The unit for Kd is dimensionless – $m^{-1}$

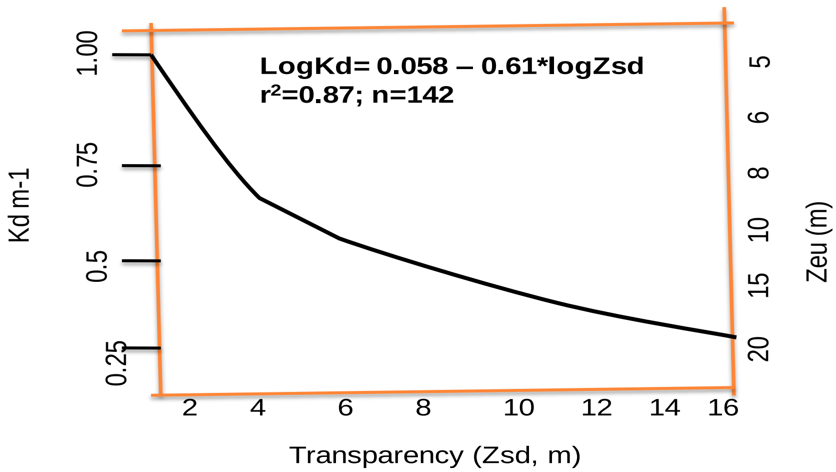
Examples: 0.50 $m^{-1}$ – this means that 50% of surface light extinguished every meter

Eutrophic lake Kd= 1.3 $m^{-1}$– light is absorbed more rapidly

Oligotrophic lake Kd= 0.3 $m^{-1}$ – only 30% of surface light attenuated every meter; i.e. much light penetrates deep (clear water)

Light extinction among lakes and large slow-flowing rivers increases with – increasing algal biomass
-- Increasing inorganic turbidity
-- Increasing water color

Increased light extinction results: Thinner euphotic zone (Zeu)

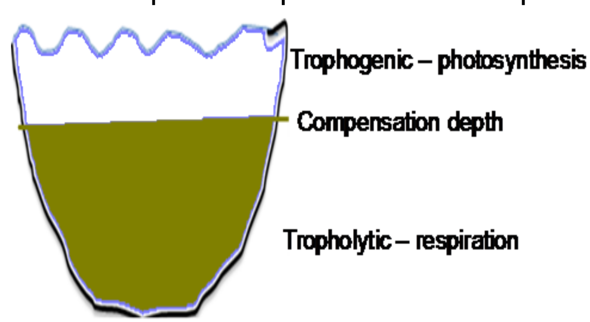



Relationship between Zsd, Kd and thickness of the euphotic zone (Zeu=1% Io)

## Euphotic depth (Zeu)

Portion of water column where phytoplankton photosynthesis is greater than respiration called euphotic, photic or trophogenic zone.

The euphotic depth is the depth where photosynthesis is equal to respiration Or the depth at which the light intensity is 1% of the surface radiation




As a rule of thumb, photosynthesis is not possible at depths below the 1% light intensity level. Even though there is photosynthesis, the net result is negative production.At the bottom of this zone (euphotic), the compensation depth, is where phytoplankton photosynthesis just balances respiration on a daily basis

Below this level –respiration dominate and called aphotic or tropholytic zone

**Euphotic depth (Zeu) is measured in various ways:**

- Using Extinction coefficient
- Zeu=4.6/Kd (Zeu=ln100/Kd)
- From Secchi disc depth reading
- Zeu≈ 3*Zsd – approximation

**Secchi Disc (Zsd)**

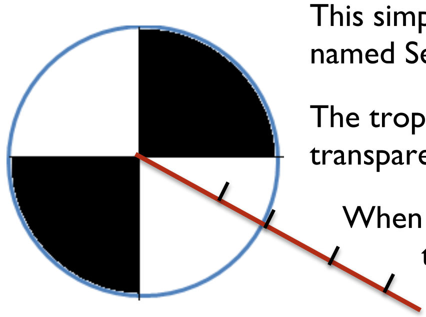
Is a limnological instrument used to measure water transparency (how clear is the water?)

The white or black-and-white metal disc, which is normally 20cm in diameter, is attached to a marked line, and then lower under water until it disappear

Record the depth where it just disappears

Record the depth where it reappears

Take the average value; that would mean water transparency



This simple method was first used in 1865 by an Italian oceanographer named Secchi to test the clarity of the ocean

The trophic state of lakes can be characterized by their Secchi disc transparency reading (Zsd)

When the turbidity is largely attributable to phytoplankton rather than inorganic particles or color

Trophic disc transparency and the trophic classification

| Trophic class | Mean Transparency (m) |
|---|---|
| **Ultra-oligotrophic** | >=12 |
| **Oligotrophic** | >=6 |
| **Mesotrophic** | 3-6 |
| **Eutrophic** | 3-1.5 |
| **Hypertrophic** | <=1.5 |

## Heat and stratification

A large portion of irradiance is in the infrared portion of the solar spectrum and has major thermal effects on the aquatic system

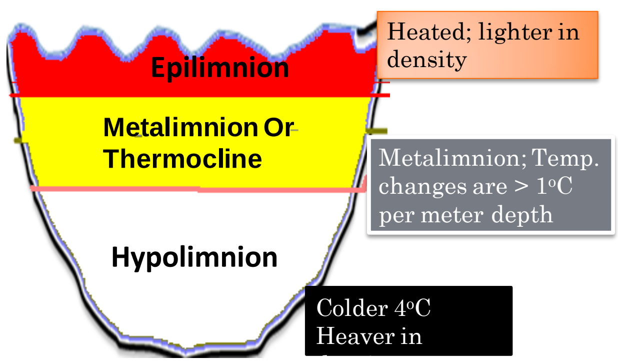
The absorption of water (in %) is very high in the infrared portion (long wavelengths)

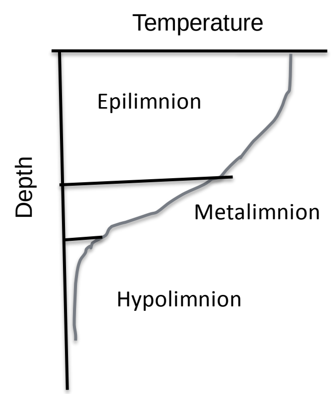
And results in rapid heating of water by incident light (the upper water column)
Approximately 53% of total light energy is transformed into heat in the 1st meter of water
Heat has two function in water bodies:

1. Thermal stratification
2. Regulates rates of chemical and biological process

## Thermal stratification

The formation of different layers of water bodies due to temperature difference
Because of temperature difference, the density differs.
The following picture shows stratification of temperate lakes



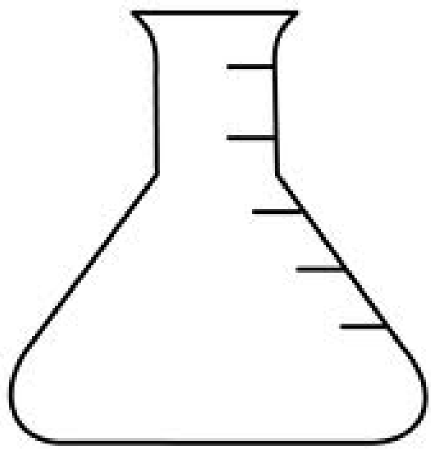




## Question summary

1. Define morphometry.
2. Mention and explain the surface & sub surface dimension.
3. Mention & explain the major important unique properties of water.
4. Explain the unusual water density relationship with temperature.
5. Describe the relationship between light wavelength and frequency.
6. Mention and discuss factors that affect the amount of light received / interrupted by water .
7. Describe briefly the fate of light in water.
8. What is Secchi disc and describe the importance in aquatic science study.

# Chapter Three

## *Chemical factors*



## *Chemical factors*

In this chapter we will discuss about dissolved oxygen, conductivity, alkalinity, salinity and nutrients

**Chapter objectives**
At the end of this chapter, students will be able to:

- Understand the importance of Dissolved Oxygen for aquatic organisms
- Identify the source of dissolved oxygen in aquatic ecosystems
- Understand the importance of inorganic carbon for aquatic organisms
- Identify the source of inorganic carbon in aquatic ecosystems
- The importance of alkalinity and how to measure alkalinity
- The importance of nutrients particularly N and P

### 3.1 Dissolved Oxygen (DO)

DO is found in microscopic bubbles of oxygen that are mixed in the water and occur between water molecules. DO is a very important indicator of a water body's ability to support aquatic life. Fish "breathe" by absorbing dissolved oxygen through their gills. Oxygen enters the water by absorption directly from the atmosphere or by aquatic plant and algae photosynthesis. Oxygen is removed from the water by respiration and decomposition of organic matter.

Dissolved oxygen (DO) refers to the volume of oxygen that is contained in water.

Every aerobic organism requires oxygen. It is essential to the metabolic activity of all aerobic aquatic organisms (e.g. respiration)

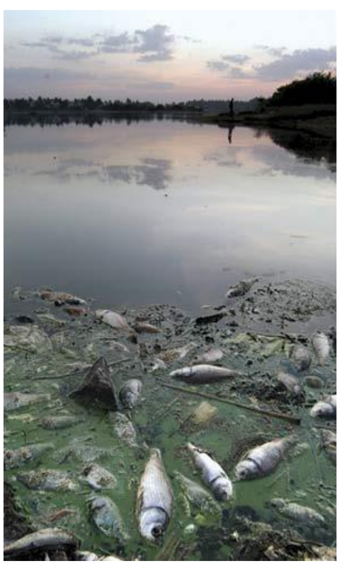
1. Terrestrial animal use oxygen in its gaseous state (atmospheric oxygen)
2. Aquatic organism (e.g. fish) are dependent on dissolved oxygen found in water

Oxygen plays important role in the determination of chemical and biological features of a lake

Atmospheric air contains about 21% of oxygen by volume; and oxygen supply is never a problem for air-breathing organisms in terrestrial environment

However in aquatic environments sufficient amount of oxygen are not always available.

Oxygen depletion can result from a number of factors:



Most often due to pollution and eutrophication in which plant nutrients enter a river, lake, or ocean, and phytoplankton grows abundantly forming bloom. The dense population of a bloom reduces DO saturation during the night by respiration though phytoplankton, through photosynthesis, will raise DO concentration during daylight hours.

When phytoplankton cells die, they sink towards the bottom and are decomposed by bacteria, a process that further reduces DO in the water column.

If oxygen depletion progresses to **hypoxia**, fish dies as shown in the figure 3.1.

A worldwide study in 2005 noted an increase in eutrophication, which was blamed for the death of these fish in a lake near Bangalore, India.

Fig. 3.1. Massive fish kill due to hypoxia

Oxygen depletion may occur in hypolimnion during stratification.

Oxygen depletion (Hypoxia) can also occur in the following ways.

In estuaries, for example, because freshwater flowing from a river into the sea is less dense than salt water, stratification in the water column can result.

Vertical mixing between the water bodies is therefore reduced, restricting the supply of oxygen from the surface waters to the more saline bottom waters. The oxygen concentration in the bottom layer may then become low enough for hypoxia to occur.

Amount of DO in water is critical to all life forms.
It has a threshold value
Example:

- 9 mg $L^{-1}$ -- DO level of good water
- 4-5 mg $L^{-1}$– minimum amount of DO to support aerobic organism (fish) population
- DO < 2 mg $L^{-1}$ – fish die

### 3.1.1 Source of oxygen

1. Diffusion from atmosphere (atmospheric exchange)

When atmospheric gas is in contact with water surface oxygen become soluble.
Diffusion depends on:

**a) Partial pressure**

The pressure between the atmosphere and water should be suitable for the oxygen to be diffused
The atmospheric pressure constantly 'pushes' the tiny molecule of DO gas into the water

**b) Various forms of agitation** such as wave action and water fall (rainfall)

However, diffusion of oxygen is a slow process and it is a minor factor in determining oxygen availability particularly during calm condition.
It is insignificant in the contribution of DO in aquatic system

**2. Photosynthesis**

Photosynthetic organisms (e.g., phytoplankton, benthic algae, submerged macrophytes) add DO to the euphotic zone according to the simplified formula:

Photosynthesis (in the presence of light and chlorophyll):

Carbon dioxide + Water----> Oxygen + Carbon-rich biomass

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

Biomass, including new cells are continuously produced and as a by-product – DO gas is being released
It is a reliable source of DO in aquatic system as long as photosynthesis takes place

The depth to which oxygen occurs depends on the depth of the light penetration, because photosynthesis is dependent on light

Most oxygen is found in the upper part of the water column (euphotic zone), that means phytoplankton and larger submerged plants (macrophytes) release oxygen directly into the water

### 3.1.2 Factors Affecting DO conc.

***Volume* and *velocity* of water flowing in the water body**

In fast-moving streams, rushing water is aerated by bubbles as it churns over rocks and falls down hundreds of tiny waterfalls. These streams, if unpolluted, are usually saturated/oversaturated with oxygen.

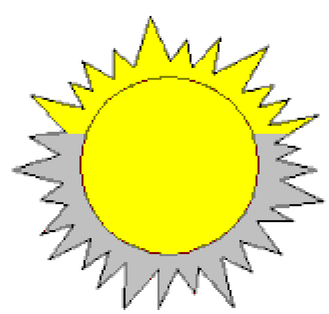

**Fig. 3.2 Tisisat Falls on the Blue Nile**

From Lake Tana in northwestern Ethiopia, the waters of the Blue Nile travel about 32 km (20 mi) before plunging over the spectacular Tisisat Falls. One of Ethiopia's major rivers, the Blue Nile curves to the southeast from Lake Tana, then flows westward into Sudan, and finally northward to Khartoum, where it merges with the White Nile to form the Nile


Fig. 3.3 Slow river

In slow, stagnant waters, oxygen only enters the top layer of water, and deeper water is often low in DO concentration due to decomposition of organic matter by bacteria that live on or near the bottom of the stream.

***Climate/Temperature***



The solubility of oxygen in freshwater is primarily determined by water temperature.

Being pressure constant, as temperature increases solubility of a gas decreases

i.e. solubility of gas is inversely related to temperature

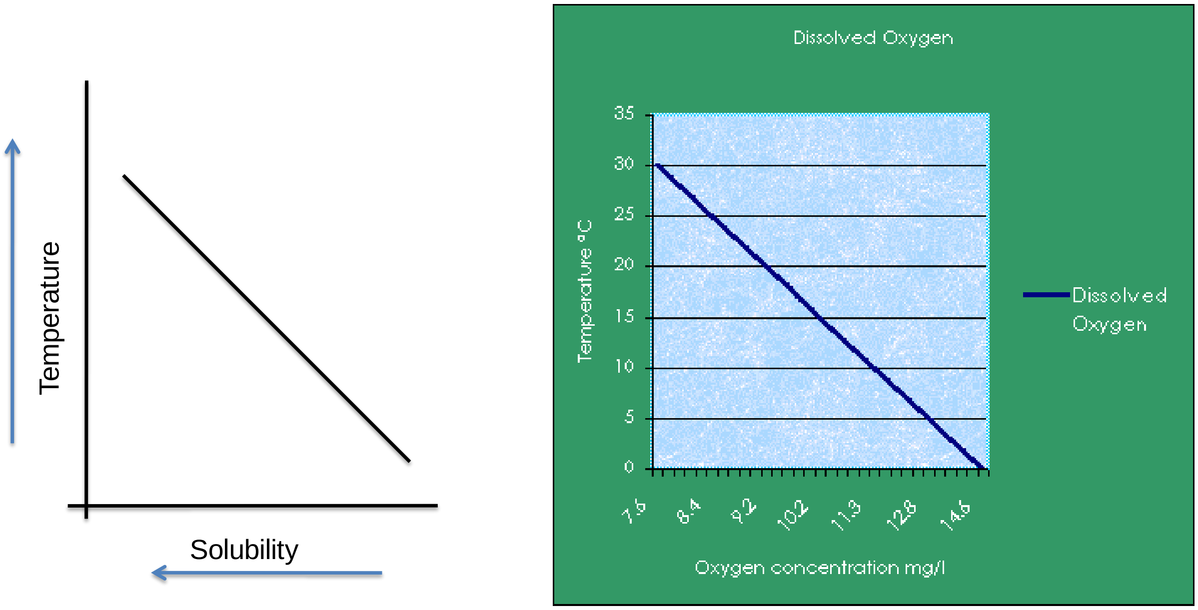



Fig. 3.4 Saturation values of dissolved oxygen for specific temperatures

Increase temperature – intermolecular space increase (loose), then difficult to hold (trap) the gas molecule.

The colder the water, the higher the oxygen holding capacity

The colder the water, the more oxygen can be dissolved in the water. Therefore, DO concentrations at one location are usually higher in the winter than in the summer.

During dry seasons, water levels decrease and the flow rate of a river slows down. As the water moves slower, it mixes less with the air, and the DO concentration decreases. During rainy seasons, oxygen concentrations tend to be higher because the rain interacts with oxygen in the air as it falls, and rainfall increases surface area to interact with atmospheric oxygen.

On the other hand, when the water becomes warmer and warmer, fish and other aquatic organisms become more active, which results in more $O_2$ consumption at faster rate, even faster than plants and algae are able to produce oxygen via photosynthesis

***The type and number of organisms in the water body***
During photosynthesis, plants release oxygen into the water.

During respiration, plants remove oxygen from the water. Bacteria and fungi use oxygen as they decompose dead organic matter in the stream. The type and number of organisms present (plant, bacteria, fungi) affect the DO concentration in a water body. If many plants are present, the water can be supersaturated with DO during the day, as photosynthesis occurs. Concentrations of oxygen can decrease significantly during the night, due to respiration. DO concentrations are usually highest in the late afternoon, because photosynthesis has been occurring all day

***Altitude***

As altitude increases, the amount of oxygen in a water body decreases

This is due to the fact that at higher altitudes, there is less atmospheric pressure available to push oxygen molecules into water

Increases in altitude, decrease atmospheric pressure and hence reduces gas solubility

**Henry's law- the solubility of any gas in a volume of liquid is proportional to the pressure that the gas exerts.**

Hence the solubility of oxygen decline with decreasing barometric pressure.

DO solubility increases with depth in deep lakes due to hydrostatic pressure

Oxygen is more easily dissolved into water at low altitudes than at high altitudes, because of higher atmospheric pressure.

***Dissolved* or *suspended solids***

The solid particles and oxygen compete for the same space.

Salts reduce intermolecular space, which could have been available for the gas

Oxygen is more easily dissolved into water with low levels of dissolved or suspended solids. Waters with high amounts of salt, such as the ocean (which contains about 35 grams of salt for each 1000 grams of water) have low concentrations of DO.

Seawater compared to distilled water, seawater holds about 20% less DO at saturation

Freshwater lakes and streams generally contain much less salt, so DO concentrations are higher. As the amount of salt in any body of water increases, the amount of dissolved oxygen decreases. An increase in salt concentration due to evaporation of water from an ecosystem tends to reduce the dissolved oxygen available to the ecosystem's inhabitants.

Runoff from roads and other paved surfaces can bring salts and sediments into stream water, increasing the dissolved and suspended solids in the water.

**Amount of *nutrients* in the water**

Nutrients are food for algae, and water with high amounts of nutrients can produce algae in large quantities. This process is called eutrophication. When these algae die, bacteria decompose them, and use up oxygen. DO concentrations can drop too low for fish to breathe, leading to fish kills. However, nutrients can also lead to increased plant growth. This can lead to high DO concentrations during the day as photosynthesis occurs, and low DO concentrations during the night when photosynthesis stops and plants and animals use the oxygen during respiration. Nitrate and phosphate are nutrients. Nitrate is found in sewage discharge, fertilizer runoff, and leakage from septic systems. Phosphate is found in fertilizers and some detergents.

***Organic Wastes***

Organic wastes are the remains of any living or once-living organism. Organic wastes that can enter a body of water include leaves, grass clippings, dead plants or animals, animal droppings, and sewage. Organic waste is decomposed by bacteria; these bacteria remove dissolved oxygen from the water when they breathe. If more food (organic waste) is available for the bacteria, more bacteria will grow and use oxygen, and the DO concentration will drop.

Directly downstream from where sewage effluent is discharged to a river, DO content often decreases, because of the increase in growth rate of bacteria that consume the organic matter contained in the effluent. The degree and extent of the DO "sag" depends on the Biological Oxygen Demand (BOD) of the effluent (how much oxygen the effluent can consume) (Giller and Malmqvist, 1998).

***Riparian Vegetation***

Shading tends to lower average summer temperature and reduce the daily duration of higher temperature. Removing trees reduces shade on the creek, allowing the sun to warm the water. This can affect DO concentrations in different ways. As mentioned above, in general, as water temperature increases, DO drops. Also, the bare soil exposed from removing the tree can erode, increasing the amount of dissolved and suspended solids in the water. This also leads to a decrease in DO concentrations. However, direct sunlight, along with increased nutrients can increase the growth rate of aquatic plants. These plants release oxygen to the water during the day, but then remove oxygen from the water at night. This can cause DO concentrations to become very high during the day, then very low during the night.

***Groundwater Inflow***

The amount of groundwater entering a river or stream can influence oxygen levels. Groundwater usually has low concentrations of DO, but it is also often colder than stream water. Therefore, groundwater may at first lower the DO concentration, but as groundwater cools the stream or river, the ability of the water to hold oxygen improves.

**How to measure DO concentration**

There are two ways: Dissolved Oxygen can be measured with an electrode probe and meter

**OR**

Winkler Oxygen Method (titration method which will be explained in detail when we discuss primary production)

**Unit**: DO levels are reported in $mgL^{-1}$

Dissolved oxygen levels are also often reported in percent saturation.

Temperature affects DO concentrations, and calculating the percent saturation will remove the effect of temperature.

The "saturation level" is the maximum concentration of dissolved oxygen that would be present in water at a specific temperature, in the absence of other factors. Scientists have determined the saturation DO level for various temperatures.

Saturation levels also vary with elevation. Percent saturation is calculated:

**% Saturation = (DO / Saturation Level) x 100**

Inland fresh waters at a temperature of 20 °C are expected to hold 9.09 mg $L^{-1}$ DO

If a particular system is shown to hold 7.02 mg $L^{-1}$, the water is at 77% saturation and is thus sub-saturated

Conversely, if the observed concentration is 10.31 mg $L^{-1}$, the water would be at 113% saturation and is supersaturated

**Environmental Impact**
Total dissolved gas concentrations in water should not exceed 110 percent. Concentrations above this level can be harmful to aquatic life.

Fish in waters containing excessive dissolved gases may suffer from **"gas bubble disease";** however, this is a very rare occurrence. The bubbles or emboli block the flow of blood through blood vessels causing death.

External bubbles (emphysema) can also occur and be seen on fins, on skin and on other tissue. Aquatic invertebrates are also affected by gas bubble disease but at levels higher than those lethal to fish.

Adequate dissolved oxygen is necessary for good water quality. Oxygen is a necessary element to all forms of life.

Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms.

As dissolved oxygen levels in water drop below 5.0 mg/l, aquatic life is put under stress. The lower the concentration, the greater the stress.

Oxygen levels that remain below 2 mg/l for a few hours can result in large fish kills.

## 3.2 Inorganic carbon

Carbon is the currency of energy exchange in aquatic ecosystems. Understanding carbon cycling is central to understanding food webs and how aquatic communities are structured and supported.

**Importance**
The concentration of dissolved inorganic carbon (DIC) is of tremendous importance in aquatic ecosystems.

1. Determines the amount of carbon available for photosynthesis

**Organic compounds produced from inorganic carbon through photosynthesis**

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

2. It buffers freshwaters against rapid changes in pH, meaning it enables water bodies to resist rapid changes in pH
3. Make large contribution to anion concentration

-- it is the dominant anion in tropical freshwaters and saline alkaline lakes (determine the pH of the ecosystem)

Inorganic carbon occurs in the form of:

a. Carbon dioxide ($CO_2$)

b. Bicarbonate ($HCO_3^-$)
c. Carbonate ($CO_3^{2-}$)

**Sources of $CO_2$ in water**:
1.Respiration – plants, animals
2.Atmospheric $CO_2$ – 0.033% (350 ppm by volume)

1. Rain water dissolves $CO_2$ to $H_2CO3$
2. Dissolve when it come in contact with surface water

3. Fossil fuel burning: Global warming due to "green house effect"
The concentration of $CO_2$ has been constantly increasing since the industrial revolution, leading to the green house effect
4. Geologic weathering of $CO_3^{2-}$
5. Decomposition of organic matter by bacteria

**Loss of $CO_2$**
1. Photosynthetic uptake of $CO_2$ is taking place only by plants:

- **Algae**
- **Submerged macrophytes in water**

**2.** Shell/skeleton of invertebrates (sponges, corals, mollusks)

$$\mathbf{Ca(HCO_3)_2 \rightleftharpoons CaCO_3 + CO_2 + H_2O}$$

When $CO_2$ used by photosynthesis, $CaCO_3$ precipitate

The earth's atmosphere contains relatively small amounts of $CO_2$. The following table shows the gaseous composition of atmosphere in percent by volume

| Gas | Percent |
|---|---|
| **Nitrogen (N2)** | 78.084 |
| **Oxygen (O2)** | 20.946 |
| **CO2** | 0.033 |

Despite the small proportion of $CO_2$ among the gases of the air; it is relatively abundant in natural waters
88% of the earth's annual photosynthetic production is in the oceans (i.e. large amount of $CO_2$ stored in the Oceans)

It is abundant because CO2 is highly soluble in water, more so than N2 and O2.

- CO2 is >60X more soluble than N2
- CO2 is > 30X more soluble than O2

When CO2 enters water, it is hydrated to form carbonic acid.

$$CO2 + H2O \rightleftharpoons H_2CO_3$$

Some of this carbonic acid dissociates into bicarbonate and hydrogen ions, bringing about a lowering of the pH

$$H_2CO_3 \rightleftharpoons HCO_3 + H^+$$

Dissociation of carbonic acid in water is a function of temperature and pH

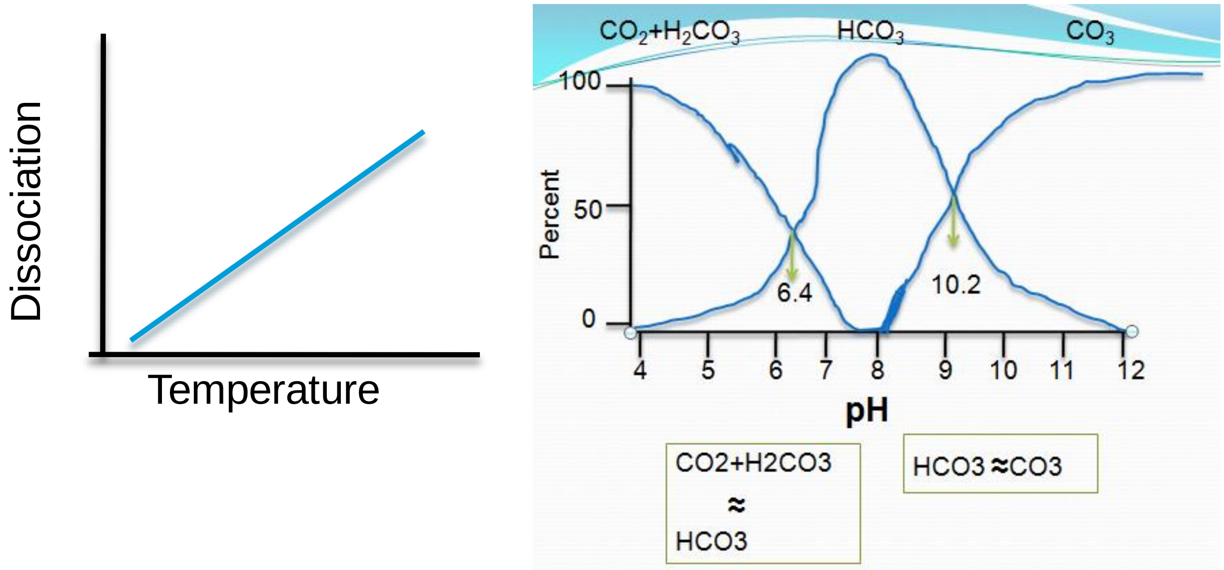



Fig. 3.5 Temperature and pH vs dissociation of carbonic acid

From the curve, it is obvious that by the time pH has dropped to about 4.5, (or pH 4.3)

❶ $H_2CO_3 \rightleftharpoons HCO_3 + H^+$ --- this reaction proceeded to the left and almost no bicarbonate ion is present

As pH rises, however, the reaction goes to the right and H2CO3 dissociate hence CO2 and H2CO3 decrease as pH increase until pH 8.3

On the curve HCO3- begins to decline above pH 8.3 because of the following reaction

❷ $HCO_3 \rightleftharpoons CO_3^{2-} + H^+$

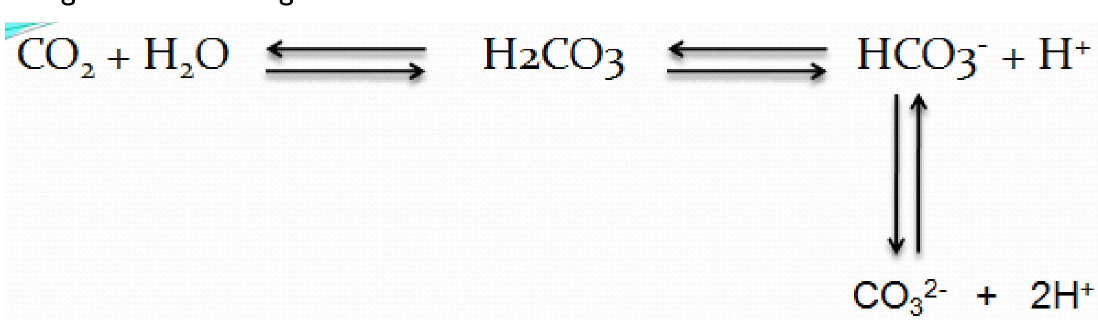
It is the second dissociation of carbonic acid. Hence, carbonic acid dissociates twice, depending on pH.

Similarly it is neutralized at two points on the pH scale

Above pH 8.3, the second dissociation prevails resulting in the ions $CO_3^{2-}$ and H+, which are neutralized to HCO3- as pH is lowered to 8.3, the phenolphthalein end point.

Below pH 8.3, $HCO_3^-$ and H+ dominate until pH 4.4, the turning point of methyl orange. Where most of these ions are neutralized to undissociated $H_2CO_3$

Putting the reaction together:



Therefore, between pH 4 and 6 --- H2CO3 + CO2 dominate
Between pH 6 and 10 --- $HCO_3^-$ + H+ dominate
Above pH 10 ----- $CO_3^{2-}$ + H+ dominate

## 3.3 Alkalinity

Alkalinity is the buffering capacity of a water body.
Alkalinity is used interchangeably with acid neutralizing capacity, which refers to that capacity to neutralize strong acids such as HCl, $H_2SO_4$ and $HNO_3$.
It measures the ability of water bodies to neutralize acids and bases thereby maintaining a fairly stable pH.
There are three kinds of alkalinity in water: hydroxide ($OH^-$), normal (mono) carbonate ($CO_3$) and bicarbonate ($HCO_3$); the three are summed as total alkalinity.
Borate silicate, phosphate, and sulfide are usually present only in trace quantities and thus contribute negligible amounts of alkalinity.

Expected total alkalinities in nature usually range from 20 to 200 mg $L^-$.
Alkalinity is determined by titrating a water sample with a strong acid (e.g. H2SO4)

Which neutralizes all } Hydroxyl
Carbonate
Bi carbonate presents ions

That is why alkalinity is the equivalent concentration of titratable base present
High alkalinity (high pH) means the water is more buffered – a small change in pH in response to the addition of acid or base
Lakes with high alkalinity can resist effect of acid rain i.e. they have high buffering capacity

| **Lake** | **pH** | **Alkalinity (meq $L^{-1}$)** |
|---|---|---|
| L. Abijita | 9.2 | 325 |
| Lake Awasa | 8.65 | |
| Lake Chittu | 10.15 | 573 |
| L. Arenguade | 10.5 | |
| L. Hayq | 9 | |

Alkalinity can be two types:

1. Phenolphethalein alkalinity (PA)

Alkalinity due to $CO_3^{2-}$
Add a few drops of phenolphthalein indicator into a water sample
If the color changed to Pink

- The pH is 8.3 or above
- Carbonate and OH-1 present
- No carbonic acid or free CO2

- Determined by titration with acid

If no color change (colorless) PA=0

- The pH is below 8.3
- Carbonic acid and free CO2 present
- Carbonate present
- Mainly bicarbonate contribute for DIC species

*This means that a few drops of phenolphthalein can reveal much about the nature of a water sample and the forms of DIC (CO2) it contains*

2. Total alkalinity (TA)

Alkalinity due to HCO3- and others $CO_2$, $CO_3^{2-}$, $OH^-$, $H_2CO_3$

Determined by titration with acid using 0.02N H2SO4

Procedure to determine alkalinity

Collect 250 ml or greater samples without aeration in glass or polyethylene bottles. Alkalinity is susceptible to change between time of collection and analysis. The major problem is loss of carbon dioxide from solution, which results in the conversion of bicarbonate to carbonate. Hence, analysis must be done within a few hours of collection, and the sample must be kept sealed until analysis is ready to begin. The sample must not be filtered, diluted or altered in any way.

Gently pour out 100 ml of sample and place in 250 ml Erlenmeyer flask (if indicators are to be used) or a 200 to 250 ml beaker (if pH meter is to be used) and the same quantity of distilled water into another-glassware. Follow procedure A or B.

A) Titration with pH meter:

2. Place the prepared sample on a magnetic stirrer and add spin bar (If a magnetic stirrer is not available, swirl the sample gently by hand). Place prepared pH electrodes in sample. Turn on stirrer at slow speed (don't agitate surface of liquid), and record sample pH when meter drift stops.
3. Titrate with standard acid solution, and record titrant volume at pH 8.3 and pH 4.4.

B) Titration with indicators:

2. Add 3 drops of phenolphthalein indicator to the sample. If a pink color appears, hydroxide or normal carbonate is present.
3. Titrate with standard sulfuric acid until color disappears, and record ml of acid used.
4. If no pink color appear, or after phenolphthalein titration, add 3 drops of methyl orange indicator, and titrate to a faint orange [this could be a difficult end point and usually requires some experience to recognize, as a result over titration could produce a pink color]. As an alternate method, one can substitute bromocresol green–methyl red indicator for the methyl orange and titrate until the blue changes to a clear pink (a gray-pink appears before the final change). It is wise to practice recognizing end point by using pH meter and indicator together.

**Calculation**

Phenolphthalein alkalinity ($\mu$eq $L^{-1}$)

$$\frac{[(volume\ of\ standard\ acid\ used\ to\ first\ end\ point\ (ml)) * (Normality\ of\ acid * 10^6)]}{Volume\ of\ sample\ (ml)}$$

Total alkalinity ($\mu$eq $L^{-1}$)

$$\frac{[(Total\ volume\ of\ standard\ acid\ used\ (ml)) * (Normality\ of\ acid * 10^6)]}{Volume\ of\ sample\ (ml)}$$

## 3.4 Salinity

In most circumstances the vast majority of dissolved solids are salts and hence terms dissolved solids and salts can be used interchangeably

Salinity is the measurement of the mass of salts present in a given amount of water

The total salinity is the sum (mg $L^{-1}$ or meq $mL^{-1}$ or g $L^{-}$ or ppt) of ionic compounds dissolved in the water

Usually expressed as the sum of the 8 major ions:

- 4 cations --- Na+, K+, Ca++, Mg++
- 4 anions– $HCO_3^-$, $CO_3^{2-}$, $SO_4^{2-}$, $Cl^-$

The concentration of these ions constitute over 99% of the total salinity

Other such as Fe, N, P, Co, Mo etc do occur in low quantities and have a negligible effect on the salinity measurement

Others present in nonionic form (like silica) and have a negligible effect on the salinity measurement

When Na+ and Cl- are dominant and the water sample gives salty taste, it is due to common salt – NaCl

Salinity is measured in grams of salt per kg of solution which can also be expressed as ppt.

**Measurement of salinity**

1. Salinity can be obtained by determining the concentration of each of the individual major ions and adding them

   = time consuming procedure subjected to analytical errors

2. A second quick and simple method is to measure by Salinity meter (salinity-conductivity-temperature meter)

3. Estimated from conductivity (C)

Another quick way is to use conductivity meter and read the electrical conductivity

Salinity of fresh water can be estimated by: S=0.75*C

   Where C= conductivity (µS/cm) and S=total salinity based on a summation of the individual major ions (mg/L)

4. Estimated from chlorinity

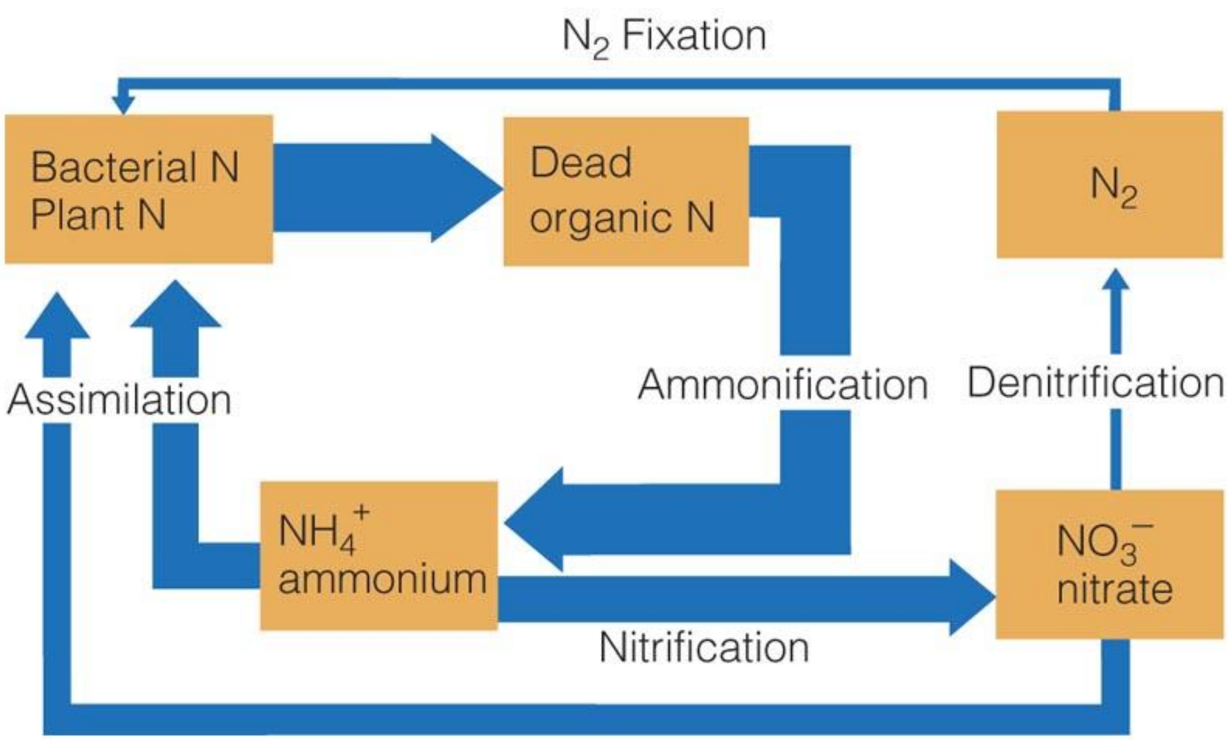
   The empirical formula is: Salinity= 0.03 + 1.805 (chlorinity)

Generally, chloride conc. is not a good estimator of salinity in inland water . But it is a good index of salinity in seawater because most of the salts are in Cl form.

- Classes of water based on salinity:
  - Freshwater < 1,000 ppm
  - Slightly saline water –between 1,000 and 3000 ppm
  - Moderatly saline water – from 3,000 to 10,000 ppm
  - Highly saline water – from 10,000 ppm to 35,000 ppm

## 3.5 Nutrients

Nitrogen and its cycle




The **nitrogen cycle** is the process by which nitrogen is converted between its various chemical forms.
This transformation can be carried out via both biological and non-biological processes. Important processes in the nitrogen cycle include fixation, mineralization, nitrification, and denitrification.The majority of Earth's atmosphere (approximately 78%) is nitrogen, making it the largest pool of nitrogen.
However, atmospheric nitrogen is unavailable for biological use, leading to a scarcity of usable nitrogen in many types of ecosystems.
The nitrogen cycle is of particular interest to ecologists because nitrogen availability can affect the rate of key ecosystem processes, including primary production and decomposition.

The major forms of N available to phytoplankton and aquatic plants are $NO_3^-$ and $NH_4^+$ (rapidly taken up by algae)
Nitrogen is an element needed by all living plants and animals to build protein
Nitrogen is a much more abundant nutrient than phosphorus in nature
Nitrogen, could be a limiting nutrient in particular in tropical water bodies

**Nitrogen exists in 3 states:**

1. Gases (molecular form) – $N_2$ – 78% of atmosphere this form, however, is not usable for most aquatic plants/algae for growth
2. Inorganic compound N– $NO_2$, $NO_3$, $NH_3$, $NH_4$
3. Organic N ---- proteins, aminoacids

**Where does N comes from?**
**Source of nitrogen**

1.Atmospheric N
Precipitation plus diffusion directly on the lake surface from the atmosphere
(in oligotrophic lakes precipitation is the principal source of N)
Burning fossil fuels releases nitrogen oxides into the atmosphere
2. Stream, river, ground water and surface inflows
3. N-fixation – blue green algae in the euphotic depth
4. Invertebrate excrete (zooplankton) and fish – excretion of nitrogen by organism is an important flux

**Forms of N and related process**

Precipitation from the atmosphere:
depends on

- Local meteorological conditions
- Wind pattern
- The location of streams and lakes with respect to industries and agricultural output

Present in different forms: $NH_4$, $NO_2$, $N_2$, $NO_3$

- Atmospheric ammonia can be oxidized to nitrate so that precipitation contains both $NH_3$ and $NO_3$

$NH_3$ (ammonia):

- is the predominant form of $N_2$ found in precipitation but gets oxidized to $NO_3$ because of the presence of $O_2$.

In oligotrophic lake– precipitation is the principal source of nitrogen

**Nitrogen – fixation**

Biological conversion of elemental (gaseous) $N_2$ to $NH_3$
So they are independent of other sources
Atmospheric $N_2$ could be converted in industry or lab but it requires high temperature (450 °C) and pressure (200-300 atmospheric pressure)

- Unlike the industry, biological fixation can be done at ordinary temperature and pressure because of the presence of enzyme called **<u>Nitrogenase</u>** (which catalyze the conversion process)

- The enzyme cannot function in the presence of O2 (it becomes quickly inactivated upon exposure to O2)
- Hence N2-fixation requires anaerobic condition
- N-fixation in eutrophic lakes could be a major source but in oligotrophic lakes, it is a minor sources.
- Major forms of N available to phytoplankton and aquatic plants as well as fungi and bacteria are NO3- and NH4+ (rapidly taken up by algae)
    - NO3- can only be metabolized after transformation by nitrate reductase
    - Presence of ammonium causes direct feed back inhibition and repression of nitrate reductase.

**Ammonification process**

- Ammonium is often the primary form of N2 that is excreted by aquatic organisms.

Primary end products of metabolic activity in aquatic animals

**Ammonification**

When a plant or an animal dies, or an animal expels waste, the initial form of nitrogen is in organic form.

Bacteria, or in some cases, fungi, convert the organic nitrogen within the remains back into ammonium ($NH_4^+$), a process called ammonification or mineralization.

- For instance, zooplankton excrete NH3 as waste product
    - On a dry weight basis, 1 g of Daphnia excretes 5.1 mg of N each day
- Bacterial mineralization of dead plants and animals
- NH3 found in the form of NH4+ in the body of water which results from
    - NH3 + H2O → NH4OH dissociate into
    - NH4OH → NH4+ +OH

↳ Rapidly taken up by algae (is the most significant energy of suspended algae)

- The concentration of NH3 is low in trophogenic zone and high in tropholytic zone (decomposition is high)
- NH3 in trophogenic zone (epilimnion zone) either comes from bacterial mineralization or excreted by living animals.
- High concentration of ammonia when present as the undissociated NH4OH are toxic.
- The relative proportion of the toxic NH4OH increases with pH

**Nitrification**

- The oxidized form of N2
- It is the biological oxidation of NH4+ usually to NO3, which is catalyzed by a variety of microorganisms who thereby obtain energy for their metabolism.
- Biological conversion of the reduced form of NH4+ to more oxidized state – nitrification.
- It is biologically-mediated conversion, not chemical oxidation
- It is primarily responsible for high ratio of NO3:NH4+ observed in the well-oxygenated epilimnia of unpolluted clear-water lakes

Nitrification therefore exerts large demands on the pool of DO stored in hypolimnia.

Nitrification is carried out by two groups of Nitrifying bacteria:

1. the ammonium oxidizing bacteria e.g. Nitrosomonas which oxidize NH4+ to NO2- and

$NH_4^+ + 1\frac{1}{2} O_2 \rightarrow 2H^+ + NO_2^- + H_20$ ---Nitrosomona is responsible

2. Nitrite oxidizing bacteria e.g. Nitrobacter

$NO_2^- + \frac{1}{2} O_2 \rightarrow NO_3^-$ Nitrobacter

The ammonium oxidizing bacteria is better adapted to low DO conc. But both are chemoautotrophic.

**The overall nitrification reaction**

$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$

2 moles of dissolved oxygen (DO) are needed for the oxidation of each mole of NH4+ to NO3-

**Denitrification**

- The process of restoring the gaseous N2 and N2O (nitrous oxide) to the atmosphere
- Denitrification is a bacterially mediated process of dissimilatory reduction of nitrogen oxides (NO3- and NO2-), first to gaseous nitrous oxides (NO and N2O) and then di-nitrogen gas (N2)
- The process is carried out by many heterotrophic, facultative anaerobic bacteria and fungi at oxic –anoxic interfaces in lakes, rivers and wetlands.
- Denitrification is the process responsible for the loss of fixed nitrogen to the atmosphere, primarily as N2 but some as N2O
- Facultative anaerobic bacteria carrying out denitrification includes genus *Pseudomonas*, species *Achromobacter, Bacillus* and *Micrococcus*.

Tropical lakes may exhibit primary nitrogen limitations more often than their temperate zone counter parts: this is because of higher denitrification rates in the year round warm waters, characterized by lower DO conc. And greater probability of the anoxic conditions required for denitrification.

**II. Phosphorus**

Nitrogen, although absolutely necessary for life as we know it, does not command the attention that phosphorus does, because N is more abundant and has more sources for living organisms.
Phosphorus is absolutely necessary to all life form
Important in nucleic acids – DNA, RNA, and energy storage – ATP (Adenosine triphosphate)
P is one of the most common limiting elements for growth and reproduction for organisms on land and in water

**There are three reasons**

1. Geochemically scarce

Rock that contain P are scarce
Normal nutrient supply from rock breakdown will be P-poor.
P-oxidizes very readily and occurs in the earth's rocks principally as orthophosphate ($PO_4^{-3}$)

Phosphorus cycling is circulation of phosphorus in various forms through nature.

Of all the elements recycled in the biosphere, phosphorus is the scarcest and therefore the one most limiting in any given ecological system.

The main source of PO4-3 is igneous rocks containing the  phosphatic mineral apatite, $Ca_5(PO_4)_3^+$ united with either OH-, Cl- or fluoride
In other words apatite usually exist in the form of
hydroxide apatite
Fluoro apatite– } the chief mineral source in igneous material
Chloro apatite

2. P –lack equivalent to N2-fixation in the P cycle because no gaseous phase in P cycle.
3. P is tightly bound to  soil particles

It is active to get adsorbed onto particles
And hence become unavailable to phytoplankton
PO4-3 is the available form to phytoplankton

**Nature of Phosphorus**
P exists in different forms: Occur in both organic and inorganic forms

a) **Inorganic form**: can be particulate or dissolved

1. Particulate form include clay, carbonate, ferric hydroxide (phosphate can be adsorbed as clay, carbonate $Fe(OH)_3$)

   → is a precipitate

2. Dissolved inorganic phosphorus (DIP)

Exist in the form of phosphate– $HPO_4^{2-}$, $H_2PO_4^-$, $PO_4^{3-}$(Orthophosphate)

$PO_4^{3-}$ -- is the major form of P

- Extremely reactive and interacts with many cations (Fe, Ca) and become insoluble.
- The only directly utilizable form of soluble inorganic phosphorus

b) **Organic form**: particulate or dissolved

1. Particulate include ATP, DNA, RNA
2. Dissolved organic phosphorus

Occur in phosphate esters – between an alcohol and acid P-O functional group
Phosphate compounds excrete from excretion of zooplankton
It is also decomposition products
Most of the dissolved form of P is in form of DOP
Total phosphorous could be:
< 1 μg L-1 in very unproductive water system and up to  > 3000 μg in highly eutrophic water bodies

Table Total phosphorus content of Ethiopian lakes

| **Lakes** | **TP concentration (µg L-1)** | **Remark** | | |
|---|---|---|---|---|
| Lake Arenguade | > 4000 | very high conc. of P | This high conc. Is the result of weathering of basaltic rock. | |
| Lake Chitu | 4800 | very high conc | | |
| Lake Kilole | 5400 | | | |
| Lake Koka | 9.5 | very low conc. | | |
| Lakes Abaya | 300 µg L-1 | | | |
| Lake Chamo | 300 µg L-1 | | | |
| Lake Awasa | < 50 µg L-1 | | | |

Most P is present in particulate P in living and dead biomass; small amounts are excreted as soluble organic P compounds, which some phytoplankton are able to convert to $PO_4$ by releasing alkaline phosphatase

Phytoplankton are able to overcome P-deficits in 3 ways:

**1.Luxury consumption**
Uptake of more $PO_4$ than required for growth and storage as polyphosphates granules in cells
2. **Ability to use phosphate at low levels** – most lakes phosphate growth constant, Ks, is low for natural phytoplankton
Species difference in K may play a role in species succession
High uptake rate may compensate somewhat for lack of ability to remove P at low levels

3. **Alkaline phosphatase**
Enzyme which cleaves bond between $PO_4$ and organic molecule to which it is attached
Enzyme is produced in response to P- deficiency and is released in free dissolved form into environment
Is unique to P metabolism

**Sources of Phosphorus**

1. Precipitation (rainfall)

The contribution is less than that of $N_2$ precipitation
Dust contain P and hence washed by rainfall
P originated from dust and smoke (e.g. burned remains of crops) over the land
Is also originated from industrial contaminants
2. Groundwater: concentrations are generally low, often less than 20 ugL-1
3. Surface runoff and inflowing water

Surface runoff (soil erosion) is the main contributor of P to lakes and rivers

Amount of P contributed by runoff is dependent on

1. The amount of P found in the soil particle (Phosphorus content of parent geology is highly variable)
2. Quantity and duration of runoff
3. Land use (agriculture, pasture) and pollution level
4. Topography – extent of erosion is influenced by slope: Flat– slow runoff
   Steep– strong /fast runoff
5. Pollution from detergents is a major source of phosphorus; sodium pyrophosphates and polyphosphates are added to complex with cations and inactivate them to enhance cleaning action (refer to hardness)

C. **Recycling of phosphorous**

Upon death and decay of organisms, phosphates are released for recycling.
P is excreted by fish and zooplankton
Excreted P consists of about 50% of PO4-P and the rest as organic phosphorous
In some cases zooplankton excretion may supply most of daily phytoplankton demand
DO has role in controlling P release from sediments
When sediment-water interface becomes anoxic, PO4 moves rapidly into the waters above due to Fe kinetics

**Question summary**

1. Define DO.
2. What are the sources of dissolved oxygen in aquatic ecosystems?
3. Mention and explain three factors that affect the concentration of DO?
4. How do you measure Do?
5. Assume the temperature of a fresh water lake is 20 $^{o}$C with $O_2$ concentration of 6 mg $L^{-1}$. Calculate the % saturation of the lake?
6. Carbon is the currency of energy exchange in aquatic ecosystem. What are the forms of inorganic carbon?
7. What are the sources of carbon dioxide in water?
8. Define alkalinity?
9. How do you measure alkalinity?
10. Describe the nitrogen cycle briefly.
11. Nitrogen exists in 3 states. Mention them.
12. What is the difference between ammonification and nitrification?
13. Phosphorus is one of the most common limiting elements in water. Mention and discuss the major reasons.

# Chapter Four

## *Biological organisms: they are the engineers of the ecosystems*


Pediastrum

Cladocera

Copepod

**Chapter objectives**

At the end of this chapter, students will be able to:

- Understand about plankton – phytoplankton and zooplankton
- Understand the density relationship of phytoplankton with the water medium
- Explain the adaptive mechanisms of phytoplankton to remain in the euphotic depth
- Explain the major three groups of zooplankton

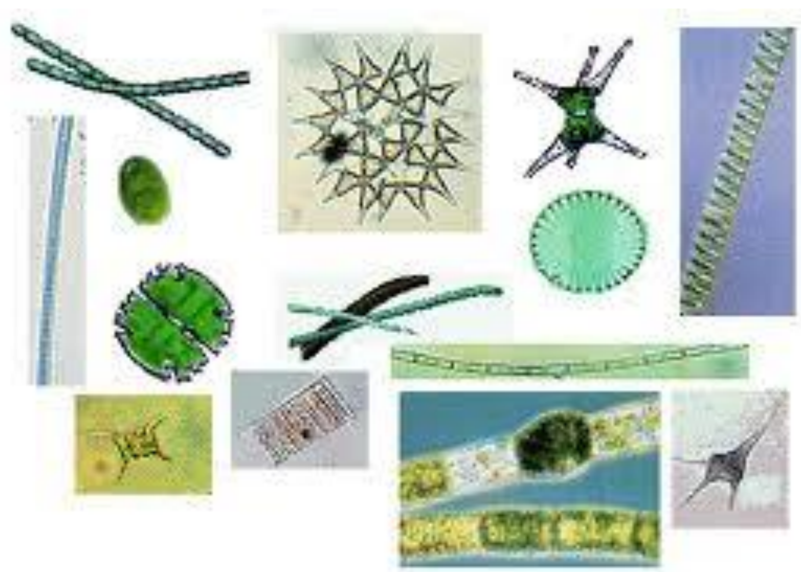
## 4.1 What is plankton?

- Plankton is the name given to the millions of organisms suspending freely in water. They are mostly microscopic, but they can include larger species such as shrimp and jellyfish.
- That is, plankton are defined by their ecological niche rather than phylogenetic or taxonomic classification.
- They provide a crucial source of food to larger, more familiar aquatic organisms such as fish.
- There are three main types:
    - plant plankton, also called phytoplankton
    - animal plankton, or zooplankton
    - bacteria, which usually feed on dead organisms.

### 4.1.1 Phytoplankton

What is phytoplankton?

- Plant-like photosynthetic organisms that are suspended in the water (and sometime some of them floats)
- Like plants, most algae use the energy of sunlight to make their own food, a process called photosynthesis
- They are passively transported by winds or water currents, i.e. their position are determined by the mercy of water currents and winds




**Phytoplankton**

- Phytoplankton are the primary producers of water bodies (pelagic zone of lakes and oceans)
- Hence they are important to the ecology of lakes and oceans
- It forms the foundation of most aquatic food webs, they support an abundance of animals.
- It is the base of the food chain
- Some of them are economically important. Example: *Spirulina*

Phytoplankton is slightly denser (1.01 to 1.03 times) than water medium and forced to sink down in undisturbed water system

The velocity of sinking varies (depends on):

1. Viscosity of the medium – the resistance to flow
2. Excess density (P' – P) of the phytoplankton where

    P' --- density of the phytoplankton

    P – density of the medium $kgm^{-3}$

    - Larger sized species are particularly subjected to sinking and may be removed in this way from the euphotic zone
    - Since diatoms have silica deposit in their cell wall they are denser than other algae (10 to 20% greater than fresh water)

3. The condition of the organism

- Healthy diatoms for example, have a sinking velocity about half that of dead or senescent cells
- All the component of living protoplasm, except lipids have a density greater than freshwater
- Generally phytoplankton are subjected to sinking

- However, they tend to remain in the euphotic zone for sufficient light energy as they are photosynthetic organisms

In order to stay in the euphotic zone, they involve different adaptive mechanisms

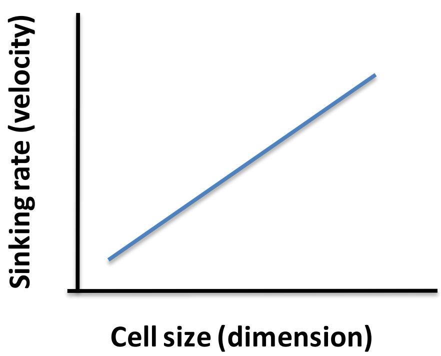
1. **Smallness ---Size**

The greater majority of the phytoplankton is small in size (they are microscopic)

There is linear relationship between sinking rate and cell size

Meaning as the cell size increases, the sinking rate also increases

Which implies smallness is advantageous to remain in the upper water column




**2. Reducing density**

This can be done by storing excess photosynthetic produced mass as lipids (because lipids are less denser than water: 860 kg $m^{-3}$)

A very simple experiment is to mix water and oil they form layer being oil on the top.

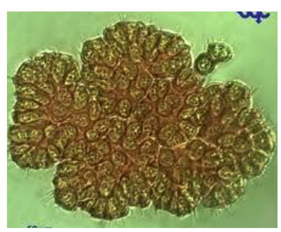
This shows lipid (oil) is less denser than water

E.g. colonial Green algae – *Botryococcus fernando* that store excess photosynthetic biomass as lipids

they usually form surface algal bloom (red scum or strip) in the water e.g. in Lake Awasa

*Fats* and oils normally accounted to 2-20% of the dry weight of algae. But in some circumstances, the contribution can goes up to 40% of the dry weight of phytoplankton

*e.g. Botryococcus brauni*

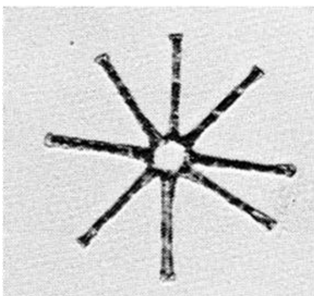


**3. Gas vacuoles**

Some algae (blue green algae) have a sac like structure which is permeable to gas and not water

Gas is lighter than the medium (the density of water is about 775 times greater than that of air at standard temperature and pressure)

e.g. Blue green algae (*Microcystis aeroginosa* – found in L. Chamo, Koka)



**4. Out growth (projection)**

Increases the surface area,

This increase frictional resistance and therefore slow the rate of sinking e.g. Asterionella – colonial diatom

Form parachute-like projected morphology such projection primarily increase the surface area of the species to get in contact with the water thereby rate of sinking decrease: *Scendesmus* ( a colonial green algae) vs Spined versus non-spined (sink at faster rate)

**5. Production of mucilage**

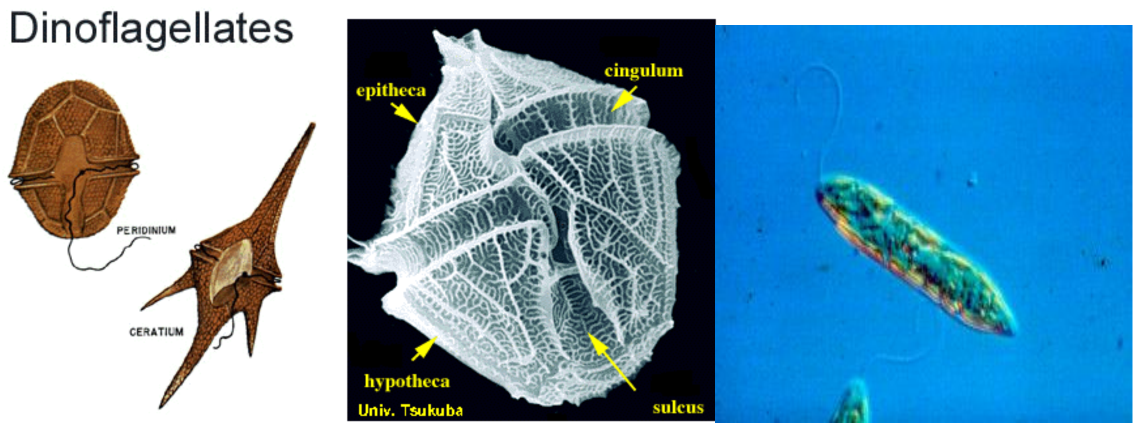
Mucilage is a gel that consists mainly of $H_2O$ held together by a network of hydrophilic polysaccharides

95% of the volume of the colony is water that make the algae very close to the medium density

E.g. Volvox

**6. Flagella** – whip-like appendages

Less important during turbulence; under calm condition, flagella help to determine their vertical migration (position) e.g. Dinoflagella




Size Structure of phytoplankton

They are generally "small", but show a large size range  from about 0.5 um to about 1mm

However, for ease study and clear understanding of the phytoplankton

It can be divided into 3 groups considering maximum linear dimension

- Picoplankton < 2 um diameter
- Nanoplankton (microplankton) 2—30 um
- Net plankton (macroplankton)  > 30 um

Size is important which determine the ecology and position of the phytoplankton

As phytoplankton increases in isze

- Volume of the phytoplankton increases by 3 fold ($r^3$)
- Surface area increases by $r^2$ (double)

This implies when a cell increases in size, the volume of the phytoplankton increases more rapidly than SA

As a consequence smaller cells have much larger SA to Volume ratio; Hence the nutrient uptake by  smaller sized phytoplankton is higher and growth is faster

Larger sized – Macroplankton

-- > 50 μm – are immune to grazer because of large size

--- they sink faster than small sized algae

**Small and large size have both advantages and disadvantage**

- Small sized phytoplankton (pico- and nano-plankton) < 30 μm
    - Have large surface area to volume ratio
    - And an associated large number nutrient uptake sites per unit volume
    - Readily consumed by protozoans, rotifers and crustacean zooplankton; such small algae are known as "edible algae"
        - hence high loss due to predation
    - Primary production is generally dominated by smaller sized phytoplankton
    - Negligible sinking rate

Large sized phytoplankton – microplankton > 30 μm

- Relatively little surface area to volume ratio
- Total phytoplankton biomass is dominated by larger sized phytoplankton
- Because of their size, they are immune to grazing
- Generally high sinking rate and because of this often disappearing from the euphotic zone

**Loss processes**

1. **Sinking**

It is unavoidable that phytoplankton will sink, since they are usually heavier than water.

Losses by sinking are related to the level of turbulence, the frequency of turbulence and the depth of the mixed layer

Sinking does not necessarily imply permanent loss: some species are capable of later re-suspension.

2. **Death**

Death due to toxicity, allelopathy and pathogenic organisms

Algae are also subject to parasitic infections: viruses, bacteria, protozoa and fungi are all potential parasites of algae

3. **Grazing**

Grazing depletes the standing biomass of phytoplankton

Herbivorous zooplankton (in particular cladocerans are filter feeders )

Feeding of zooplankton is size dependent smaller zooplankton take smaller algae

Losses through zooplankton predation have received much attention

**Phytoplankton measurement**

**Biomass**

- The total weight of all living phytoplankton present in a unit area or volume at a given time
- Used as a base of reference in primary productivity study
- Used as a measure of food availability for zooplankton and herbivorous animals
- As an index of lake fertility using Chlorophyll- a conc. (mg/m3)
    - < 3 – oligotrophic
    - 3—15 – mesotrophic
    - > 15 – eutrophic

**Measurement**

Biomass of phytoplankton can be estimated by counting and volume measurement (Biovolume) and by measuring the Chl a concentration.

Chl a– "is the dominant phytoplankton pigment" used as index or surrogate method for community algal biomass determination

The technique is easy and relatively accurate for surveys and studies

**General Procedure:**

1. Take water sample
2. Filter it with filter paper (GF/C)
3. Phytoplankton will be retained here
4. Extract the pigment (Chl a) by grinding and acetone or methanol
5. Read the absorbance with spectrophotometer

Procedure Flowchart

Water sample will be filtered using glass fiber filter; wrap with aluminum foil and put the filter paper in refrigerator

⇩

**Pigment extraction:** Tear filters papers into quarters; Place filter in a test tube, add 10 mL 90% acetone and homogenize (grind with rod);

⇩

Pour in a 15 ml centrifuge tube, cap and centrifuge for 10 minutes in 3000rpm;

⇩

**Absorbance measurement:** Carefully pour or dispense the supernatant of the extracted sample into the 1cm cuvette.

⇩

Use a 90% acetone solution to zero the instrument at each of the wavelengths 750 nm and 665 nm

⇩

Read the absorbance of the sample at 665 nm and 750 nm

$$\boldsymbol{Chl\ a\ \mu g\ L - 1 = \frac{[13.9\ (E665 - E750) * Ve]}{Vs * Z}}$$

The concentration of Chl a is calculated by :

Where: E665= extinction at 665 nm

E750= extinction at 750 nm

Ve= volume of extract (in ml)

Vs= volume of sample filtered (in liters)

Z= path length of the cuvette (in cm)

**Primary production**

The term primary production refers to the rate at which energy is stored by photosynthetic activity in the form of organic substances.

The weight of new organic material formed by photosynthesis over a period of time.

The most import input of energy into the ecosystem is by phytoplankton photosynthesis

The complex biochemical reactions of photosynthesis can be summarized as

$$6CO_2 + 12H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

There are different methods to measure rate of photosynthesis (primary production) and

The technique is based on the above reaction:

1. Rate of oxygen production
2. Rate of utilization of CO2
3. Changes in the concentration of organic matter

In situ primary production can be estimated:

- Winkler Oxygen method (measures oxygen production)
- $^{14}$ C method (measures the carbon fixation rate which is the basis for the synthesis of organic matter)

**Oxygen production method**

Gross photosynthesis – refers to the gross synthesis of organic matter resulting from exposure to light (i.e. the rate of carbon fixation before respiration is taken into account)

Net photosynthesis – refers to the net formation of organic matter after losses from respiration have been taken into account.

Disadvantage : The respiration measured is not only that of the phytoplankton, but also includes respiration of bacteria and zooplankton in the sample.

**$^{14}$C method**

Radioactive isotopes (e.g. $H^{14}CO3$) will be added into a sample

Incubate into different depths and photosynthesis takes place

Retrieve the samples

Filter the sample using filtration paper

Counting $^{14}$C will be takes place using Liquid Scintillation counter – $^{14}$C assimilated

**Calculation:**

$$\frac{{}^{14}C \text{ available}}{{}^{14}C \text{ assimilated}} = \frac{{}^{12}C \text{ available (DIC)}}{{}^{12}C \text{ assimilated}}$$

Advantage: It is sensitive: that means it gives you more accurate result

**Disadvantages**

It is not clear whether the estimate is gross or net photosynthesis

Expensive

**4.2 Zooplankton**

Zooplankton are animal plankton organisms which show active swimming behavior for searching food and for escaping predators. However, they are not powerful swimmers enough to swim against major currents or water movements. The larger species show often pronounced diel vertical migration for escaping visual predators (e.g. fish) or to escape damage by ultraviolet light in the surface water layers during day-time.

Zooplankton are an important part of lake and ocean ecosystems, because they are important part of the food chain.

Zooplankton feed on phytoplankton and transfer the energy to higher animals (fish); so they are the link between higher trophic levels and phytoplankton.

<u>There are 3 major groups of zooplankton</u>

1. Copepods: Phylum Arthropoda, Class Crustacean.
    - Found in both inland water bodies and oceans
    - Male and female sex is always present
    - Sub order: Calanoida---- freshwater and marine
    - Sub order: Cyclopoida ---- fresh water and marine

2. Cladocera: Phylum Arthropoda, Class Crustacean
    - Largely fresh water
    - Generally no males present in the population, only females. Often, males present during short periods of sexual reproduction. In Daphna spp. generally twice per year. In this periods sexual eggs (=resting eggs = ephippia) are produced .

3. Phylum Rotifera: have more species in freshwater than in marine habitats

Zooplankton communities in fresh waters are divided into two groups based on size:

Microzooplankton < 80 µm --- Rotifers, Larval instars of copepods (e.g. nauplii, early copepodite instars)

Macrozooplankton > 80 µm --- copepods and cladocerans

**Copepoda**

- About 500 freshwater species have been described world wide
- They are characterized by a cylindrical body;
- They have conspicuous 1st antenna, and single, simple anterior eye
- Their size ranges generally  between 0.2 and 2 mm long

**The sub-order are:**

- Calanoida--- adult can be seen with naked eyes (L. Arenguade, Tana)
- Cyclopoida

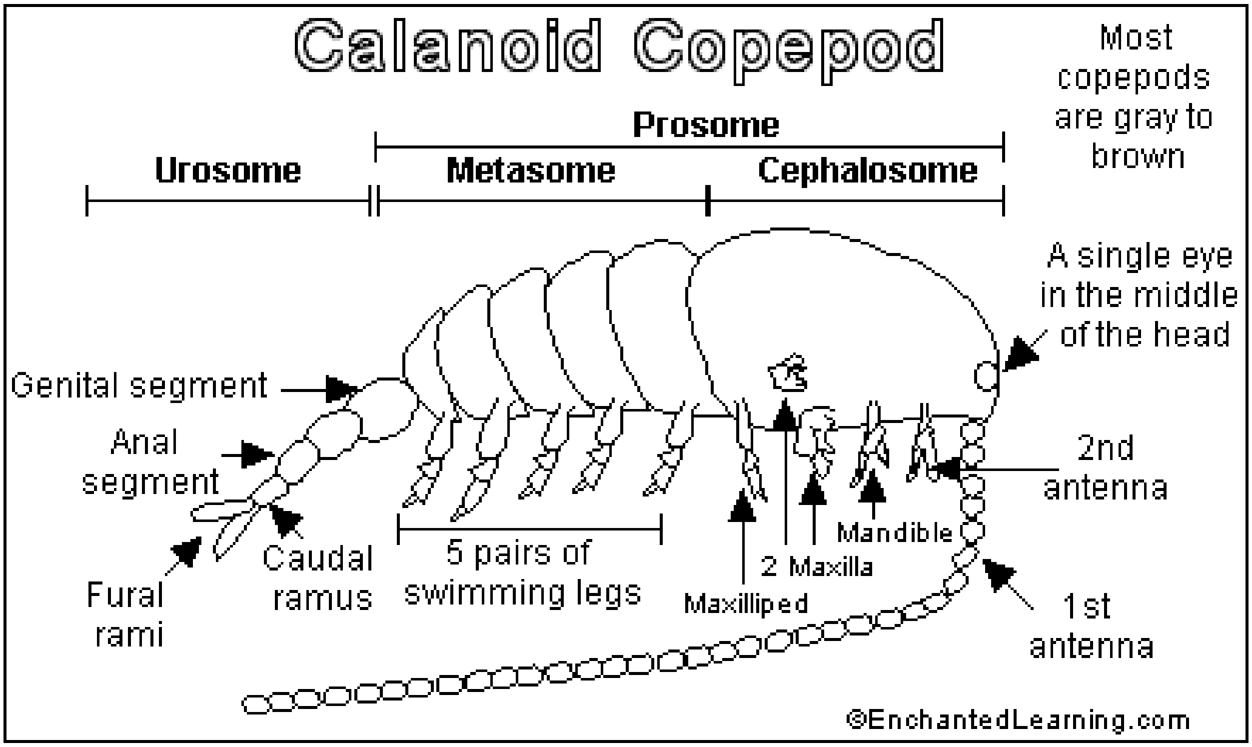
**Morphology**

- ➢ Head region– Cephalosome
- ➢ Thorax – Metasome
- ➢ Abdomen – Urosomal

On the head region there are two antenna:

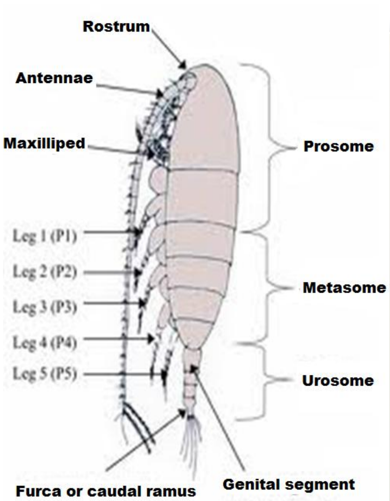
1. A1 (long) – water current creater vortex
2. A2 (small) – sensory (chemo) for sensing food particle

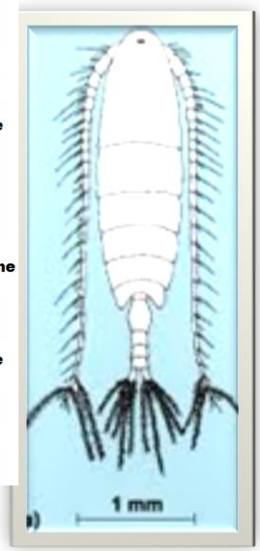
The 3 sub orders distinguished by their morphology (to species level you need to work some detail using identification key)




## Calanoids

- The anterior part of body is broader than posterior
- Planktonic




- Good swimmers than others: large antennae provide a gliding movement


- Has 1 egg sac carried medially

**Cyclopoid**

- The anterior part of body is broader than posterior
- It is planktonic
- The antenna is short but at least 2x as long as that of harpacticoids
- Has two egg sacs carried laterally

**Feeding**

The feeding habit of copepoda is diverse– all are not grazers

They can be herbivorous, detritivorous, carnivorous, or omnivorous

Calanoids are predominantly herbivores. They are able to filter feed (grazing) but can also feed on particles one by one (particulate feeding)– maxilla for grinding

- They are predominantly herbivores but may also feed omnivorous on ciliates and rotifers as well as on algae, bacteria and detritus

Cyclopoids: are particulate feeders

a. Raptorial (prey) – analogous to hyena feeding, snatching the prey

The prey can be as big as mosquito larvae (malaria can be controlled)

Maxilliele –for pierce

Maxilliped – grabing

} Which are not effectively used by calanoid are used here

b. They are generally predatory (carnivores) on other zooplankton, fish larvae and tadpoles

**Reproduction:**

Copepods reproduced sexually at all times, but may form resting stages to survive poor environmental conditions.

All species are bisexual and transfer sperm form male to female of different individuals

Fertilizer may occur immediately or several months later

Eggs are carried in egg sacs

The fertilized eggs hatch into free-swimming larvae called nauplii

After hatching, the young molt 11 times before becoming adults (pass nauplii (6 stage) and copepodite (5 stages)– the final copepodite stage (copepodite stage 6) is an adult

**Cladocera (water fleas)**

Phylum Arthropoda, Class Crustacea; Order – Cladocera

Cladocerans are extremely important zooplankton in lakes and hence they are well studied.

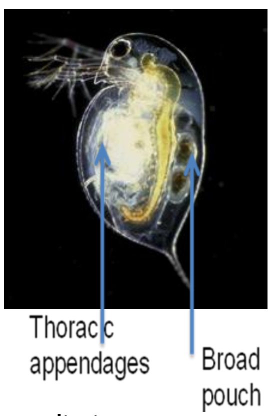
Fairly large in size that ranges from 0.2 – 3mm

Some can be seen with naked eyes

The thorax has 4 to 6 pairs of legs that beat continuously and create water currents that bring in algae, protozoa, and detritus

The food is filtered onto the many fine setae on the legs and move towards the mouth.

The appendages generate feeding and respiratory currents




- Have a distinct head
- The body is covered by a bivalve cuticular carapace (a hard chitinous cover)
- Have a large compound eye
- The second antennae are large swimming appendages and constitute the primary means of locomotion
- Cladocerans are very important grazers, especiall the large Daphnia spp. are very efficient grazers; they are size selective but the large daphnids can ingest a broad size spectrum
- Large daphnids are responsible for removing a large fraction of the phytoplankton biomass and causing a clear water phase in late spring or early summer in lakes of the

temperate region. They are also used in biomanipulation management schemes to make the water clear and improve the water quality.

**Reproduction and life cycle of Cladocera**

1. The major form of reproduction is parthenogenesis – reproduction occurs without fertilization of eggs by male gametes (do-it-yourself reproduction).

Parthenogenic – females are encountered most time of the year

- Male are absent
- Diploid (2N) amictic eggs hatching directly into miniature adults that typically mature in about 3 to 6 weeks
- Females produce diploid eggs by mitosis; and each egg develops into another diploid female– all in the absence of male

2. Sexual phase

During unfavorable condition, haploid (N) eggs and male (certain months of the year) are produced.

The fertilized resting eggs (2N), covered by resistant cases known as ephippia (singular ephippium), settle to the sediments until favorable condition returned.

- This resistant eggs are deposited in brood pouch (chamber) and is dark in color.
- Ephippia will hatch under favorable conditions into parthenogenetic females

- E.g. *Daphnia; Diaphanosoma; Moina;*

Under certain conditions, mictic females produce their eggs through meiosis, so the eggs are haploid.

In the absence of fertilization, mictic eggs develop into haploid males

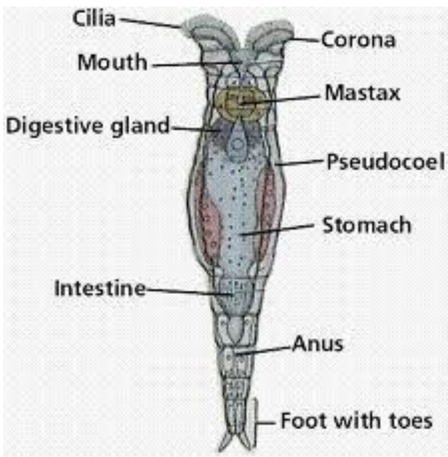
Resting eggs have the ability to resist adverse physical or chemical condition

**Rotifer (Wheel animal)**

Phylum Rotifera

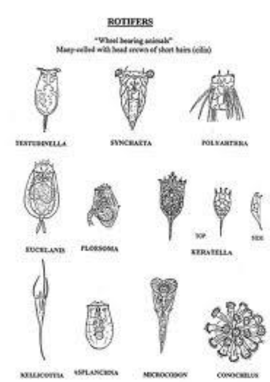
- 2000 speceis of rotifers occur in freshwaters
- They can be found in all freshwater habitats
- They are small in size– small metazoans (20—200 μm long)

- ➢ Distinguished by a ciliated head region (corona) that moves water in a circular fashion – that is why they are called wheel animal
- ➢ The cilia rotate (wheel) – is used for:
    - Locomotion
    - Sweeping food particles towards the mouth
- Usually associated with vegetation of littoral zone
- The young reach maturity in days




**Feeding**

They are omnivorous, feeding on picoplankton, small flagellates and small ciliates (<20 μm)



They have different shape, no typical shape of rotifer

Radio labeling and cenimatography method: used for detecting the food type they are eating

More rotifers could be expected in littoral zone than pelagic zone since they are associated with macrophytes. But there are pelagic species as well.

Rotifers have a well-developed digestive system that includes a mastax to grind food,  a stomach, an intestine and anus

**Reproduction and life cycle of rotifers**

Two types are the most common:

1. Parthenogenic (Asexual) only female
2. Sexual phase overlying parthenogenic

Males appear during certain time of the year

Produce resistant (resting) eggs – this helps to pass harsh condition – winter dry season and resume their life cycle

Rotifers have a relative short life cycle under favorable conditions of temperature, food and photoperiod. Duration of life cycle depends on temperature, the higher the temperature the shorter the life cycle. It also depends on adult size, the smaller the size the shorter the life cycle. In general – because rotifers are smaller – rotifers have shorter life cycles than cladocerans and copepods.

**Vertical Migration**

A conspicuous feature of cladocerans and copepods is large diurnal (daily) vertical migrations due to light stimulus. This is especially true for the larger individuals of the larger species. Because the larger the individuals, the larger the predation pressure by fish.

They migrate (move) down during the day and come back to the surface at night to feed on phytoplankton

Why vertical migration? hypotheses:

- To avoid predation from visual predators such as fish. Migrating has cost: If they migrate below the thermocline (day-time) there is less food and the temperature is lower, thus lower growth and productive rate (lower fitness).

## What and how to work with zooplankton?

1. Zooplankton identification
2. Counting and biomass determination
3. Grazing study
4. Bio-indicator

**Question summary**

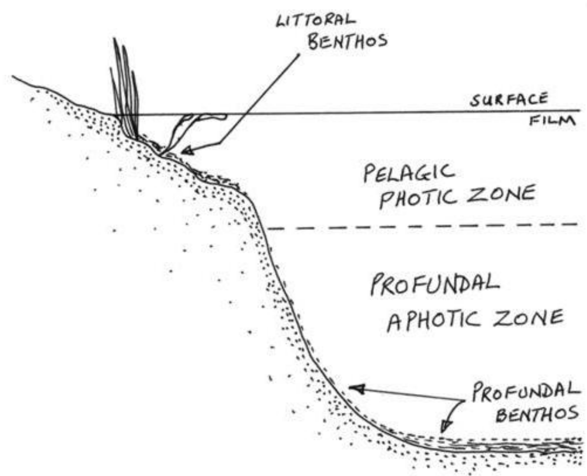
1. Define plankton.
2. What is the difference between phytoplankton an zooplankton?
3. Explain the factors that determine the velocity of sinking phytoplankton.
4. Mention and discuss the adaptive mechanisms of phytoplankton to remain in the euphotic depth
5. Compare the pros and cons of small and large size phytoplankton.
6. Define primary production.
7. What are the 3 major groups of zooplankton? What is the significance of zooplankton in food chain/web?
8. Distinguish the three major zooplankton group morphologically.
9. What is parthenogenesis?
10. What is vertical migration? What are the possible driving forces for vertical migration?

# Chapter Five

## Major Inland Aquatic Biomes:

1. Lentic Ecosystems Habitats (Lakes, Reservoirs, Wetlands)

2. Lotic Ecosystems




## Chapter objectives

The students will be able to

- Understand the similarity and difference between lotic and lentic ecosystems
- The geological origin of lakes
- The productivity of lakes
- Lake zonation and lake stratification

## 5.1Lentic Ecosystems:

Lentic refers to standing/still water habitat

The word lentic is derived from the Latin *Lentus* which means sluggish

They are the ecosystems of lakes, ponds and swamps.

This ecosystem includes the biotic interactions (amongst plants, animals and micro-organisms) together with the abiotic interactions (physical and chemical)

A lake is any inland body of water that is found in topographic depression. They are fed by surface water runoff and direct precipitation and contain about 0.26 percent of the water of the earth and covers about 1.8% of the earth surface including saline lakes (Raven and Johnson, 1988; Pennington and Cech, 2010). Around the world there are 100 million lakes that are greater than one hectare and approximately one million lakes that are greater than one km2 (Wetzel 2001). But only 0.01 percent of the vast amount of freshwater on this planet is available as surface water contained in lakes and rivers (Smol, 2002).

Freshwater is a finite resource exploited in every possible way (Wetzel 1983).

## Lakes

*Ethiopian lakes broadly categorized: rift valley lakes, crater lakes (Bishoftu lakes), highland lakes and mountain lakes.*

There are different types of lakes on the basis of geomorphological inception. But I will limit myself with the following major and distinct types of lakes, each formed by different processes.

Geological origin of lakes: how do lakes are created or formed?

1. **Tectonic lakes**– relating to the forces that produce movement and deformation of the Earth's crust.

It is the forces resulting in mountain formation or lowering of an area are called *tectonic forces*

Faulting, fracturing, folding, quacking are words that apply to deformation and adjustment of the earth's crust (shell)

Because of crustal movement at deeper portion of the earths crust a depression (hollow) is formed that can hold water, a lake

These forces have been most active in areas of low rainfall

*A graben is the depression left by a shift in land due to tectonic movements. Graben lakes are lakes formed by the filling in of these depressions.*

Most of the larger tectonic lakes are old (anicient) and deep: Lake Baikal of Siberia – 1.7 km depth

Lake Tankanyika of East Africa -- > 1.4 km depth (2nd deepest)

Ethiopian Rift Valley lakes: L. Zway, Awasa, Chamo, Abaya …

Rift valleys are long, deep valleys bounded by parallel faults. They form where Earth's crust is being pulled apart. Rift valleys can appear on land or beneath bodies of water.
Fault (Geology) displacement in Earth's crust: a displacement of rock layers in the Earth's crust in response to stress accompanied by a break in the continuity of the rocks on each side of the fault line.

Tectonic – of deformation of rocks: relating to the forces that produce movement and deformation of the Earth's crust.

2. **Volcanic lakes**– formed after volcanic eruption and create a void (empty space)

Volcanic lakes include crater lakes (formed after an eruption) and those resulting from flowing lava damming river valleys.
Crater lakes– Bishoftu lakes (Debre-Zeit lakes) including Bishoftu, Hora, Babogaya, Arenguade--Lake Oregon (USA) – deepest lake in USA
Because of the basaltic nature of these lake basins and their low drainage areas, many such lakes (lakes associated with volcanic activities) contain low concentrations of nutrients and are relatively unproductive.

Crater Lake in Oregon, USA

How do volcanic lakes form?

- Volcanic lakes are generally formed by one of three mechanisms:
  - 1. explosive excavation (crater lakes)
    2. collapse (caldera lakes)

3. blockage of common waterways (rivers, streams) by mudflows, lava flows or ash

3. **Glacial lakes**
Glacier – ice mass
Lakes which is formed by the movement of large masses of ice
Lakes of glacial origin are far more numerous than lakes formed by other processes
Most temperate lakes are glacial origin
E.g. Sweden has about 100,000 lakes

**Trophic status and lake productivity**

The trophic status of a lake can be classified into 3 for our purpose.
A lake receives its nutrients from its watershed mainly through erosion and/or authochthonous

1. **Oligotrophic lakes**
    - Not productive lakes
    - Usually tends to be deep with mean depth > 15 m and a maximum depths > 25m
    - The water is transparent, high Secchi disc depth
    - Have low density of plant life occurring at various depths (phytoplankton)

Nutrient supply is low in relation to the volume of water (particularly the internal loading is low)

2. **Mesotrophic lakes**
    - A convenient term for lakes that are borderline between oligotrophic and eutrophic lakes
    - They are intermediate with respect to nutrient supply, depth, biological productivity, water clarity and oxygen depletion in the hypolimnion
3. **Eutrophic lakes**
    - Are usually shallow with mean depths < 10 m and maximum depths < 50 m
    - Have high nutrient supply in relation to volume
    - And dense growth of plankton in the surface waters
    - Water column is turbid and biological productivity is high
    - Bottom water become anoxic during summer stratification
    - Internal nutrient loading is a primary source of nutrient

**Note that:**
These trophic descriptions of oligotrophic and eutrophic have no absolute meaning but are generally used now to:

- Denote the nutrient status of a water-body OR
- To describe the effects of nutrients on the general water quality and/or trophic conditions of a water-body

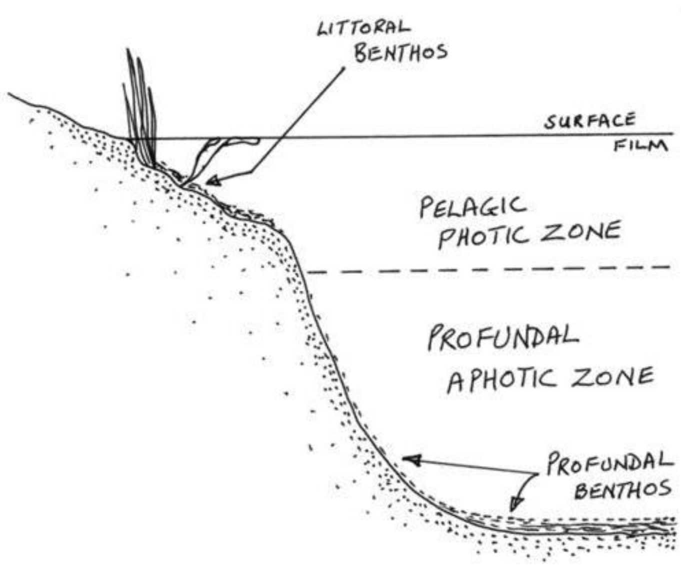
**Factors that affect lake productivity:**
Under natural conditions there are four factors that affect lake productivity

a) Edaphic factor– geology, soil type; this is related to catchment area
b) Morphometry – related to the formation of lakes (volcanic or tectonic); related to surface area and depth (the deeper lakes are generally unproductive)

Morphometric parameters : mean depth– indicates productivity; shoreline modification

c) Climate– light, temperature, precipitation (erosion); stratification and mixing

d) Human activities– e.g. land use (grazing, agricultural, forest).
Human activity in the vicinity of the lake is important via shoreline modification and nutrient loading
Industries or factories --- constructed nearby the lake




**Littoral zone**

Dominated by plant vegetation called macrophytes
Near-shore region of lakes (it is a bridge between terrestrial and pelagic zone)
The sediments lie within the photic zone
Macrophytes could be:

a) Submerged
b) Emergent
c) Floating

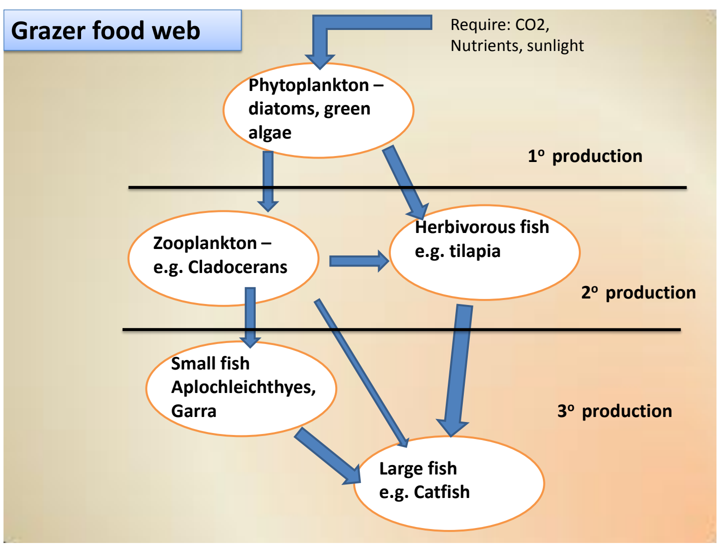
Role of macrophytes

1. Protect the bank from erosion
2. Release nutrients to pelagic zone (via decay – decomposition and lysis)
3. 3. Take up nutrients and toxic substances, improve the water quality
4. Serve as food for fish, invertebrates (e.g. Tilapia zillii, Gambusia fish---)
5. Can be used as a refuge (shelter) for zooplankton, juvenile and small sized fish, invertebrates
6. Feeding and reproduction ground of fishes
   e.g. Tilapia (commercially important fish species)

**Pelagic Zone** (lacustrine or limnetic zone)
It is the open water region beyond the littoral zone
Dominated by plankton (animal or plant) and some fish dependent on plankton (Nekton– active swimmers both horizontal and vertical)
No attachment or substratum
Plankton – the microscopic and small macroscopic community of the open water adapted to suspension and subject to passive movements imposed by wind and currents
Benthic zone–
region associate with aphotic zone and bottom layer
Benthic invertebrates dominate
The community associated with the bottom– refers most commonly to the animal community

**Lake food web/ food chain**
Populations within a community are bound by a network of interactions
The most important interactions are of a trophic nature that is “eat” and “be eaten”--- preys and predators.
Abundance and species composition is highly affected by this interaction
Food web can be of three types (grazer, detrital and microbial)

Food web




The relationship is not as linear as food chain: the food chain concept is too simple for natural systems
Food-web complication is a little bit solved by using bold or narrow (thin) arrows
The width of arrow shows the strength of the relationship
The diagram don’t show the amount of energy transferred from one trophic level to the next trophic level

Once energy is incorporated into carbon bonds via photosynthesis, it is passed from organism to organism through the food chain
At each trophic level, some of the energy is used in respiration (metabolic process and locomotion) and is lost from the ecosystem in the form of heat (second law of thermodynamics)
This means that less and less energy is available at each successive level of the food chain.
So the shorter the food chain, the greater the available energy in the form of food and predators

The ecological efficiency refers to the ratio predator production to prey production
This is a measure of the amount of energy that is passed from one link of the food chain to the next:
Ecological efficiencies are usually ranges from 0.05 to 0.2; that is 80—95% of the energy is lost at each transfer in the food chain

Because of these losses, unlike the flow of matters, energy must always flow in one direction in ecosystem

Phytoplankton → Herbivorous fish → large fish

(is efficient)

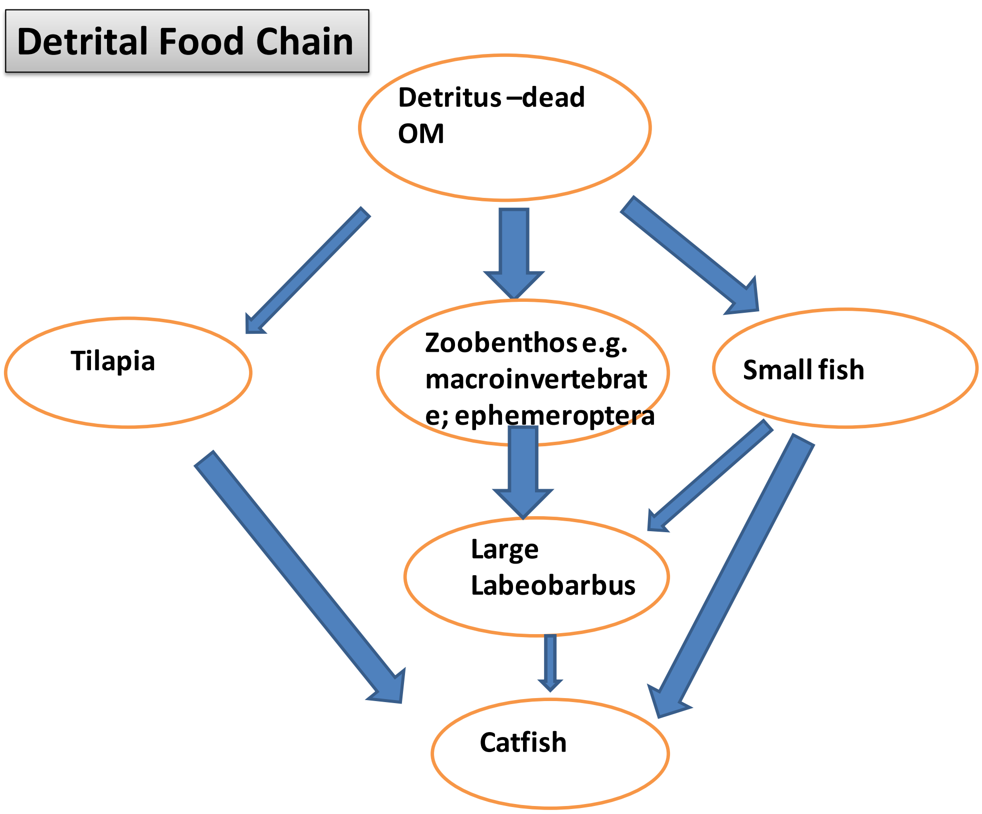
Phytoplankton → zooplankton→ small fish→ large fish

The efficiency (effectiveness) of energy transfer is expressed by several energy flow quotients

1. Assimilation efficiency is the ratio of assimilation to ingestion
2. Gross production efficiency is the ratio of production to ingestion
3. Net production efficiency (K2) is the ratio of production to assimilation

**Detrital food web/ food chain**

Incompletely oxidized organic matter is excreted and egested. This material in turn can be used as an energy source by detritivores, so it is related to dead organic matter




**Stratification and mixing in lakes**

As solar radiation passes downward from the surface of a lake, it disappears exponentially as it goes down to the compensation depth

And the heating wavelengths are usually absorbed very quickly eventually the lake stratify

The light curve is different from temperature curve

The difference between light and temperature curve is explained by the wind mixing the upper layer of water and distributing downward the heat that had been absorbed in these surface strata had been absorbed in these surface strata

The temperature difference and hence density difference in the water column create stratified lake, strata which cannot mix with each other

Stratification separates water into three zones in freshwater lakes

1. The deep water zone, the hypolimnion

Is largely non-turbulent and separated from contact with the atmosphere

Cold and heavier water region

It is dominated by respiratory processes that utilize organic matter

2. Epilimnion

Light irradiated

The upper warm region, mixed thoroughly by wind to a more or less uniform temperature

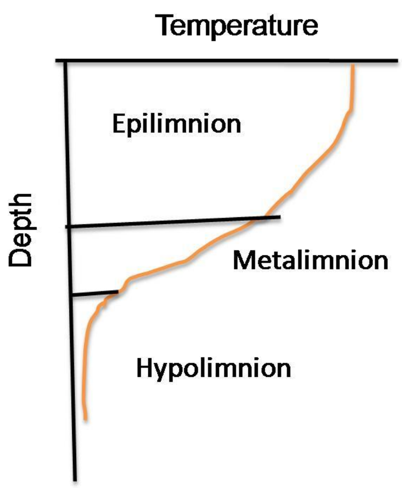
Primary production

3. Metalimnion (thermocline, steep temp. gradient)

Is the transition zone separating the epilimnion from the hypolimnion

It is characterized by temperature gradient, where temperature drops rapidly with increasing depth

The temperature of this zone in temperate lakes drops at least 1°C with each 1m increase in depth




Vertical temp. profile showing vertical stratification

Isothermal or homothermal

The temperature and density of the lake becomes uniform as a result of external force to break the difference– wind and temp. gradient

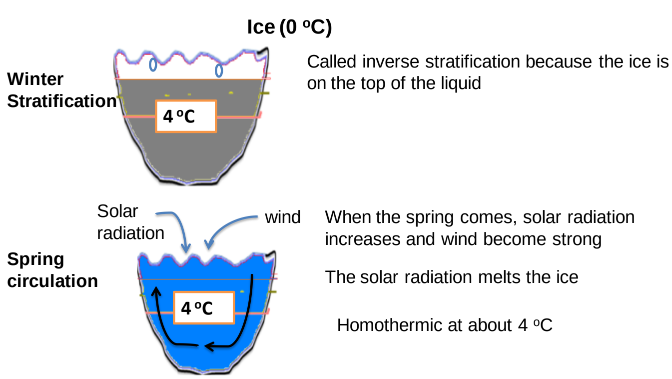
This kind of phenomenon is called mixing/ circulation

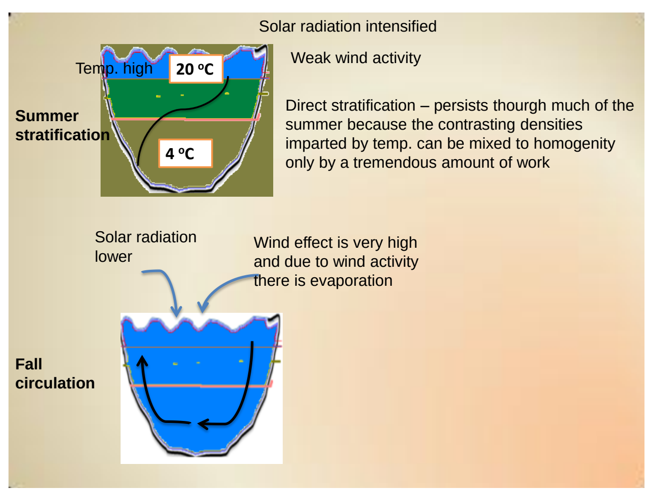
Mixing is important for nutrient distribution

Stability of stratification – the amount of work (e.g. wind) necessary (required) to mix a body of water to uniform density

**Annual temperate stratification and mixing**

Temperate regions have four distinct seasons – Winter, Spring, Summer, Fall (Autumn) and have different stratification and mixing pattern



<u>Lakes can be classified based on the frequency of stratification and mixing</u>

1. Monomictic – lakes that mixes once per year
2. Dimictic – mixes 2x per year
3. Polymictic – mixes several times per year

**Tropical lakes**

Lakes found in higher solar radiation and continuously high temperature throughout the water column
Small temperature difference can cause stratification
It can be broken by night, if the night gets cool and windy

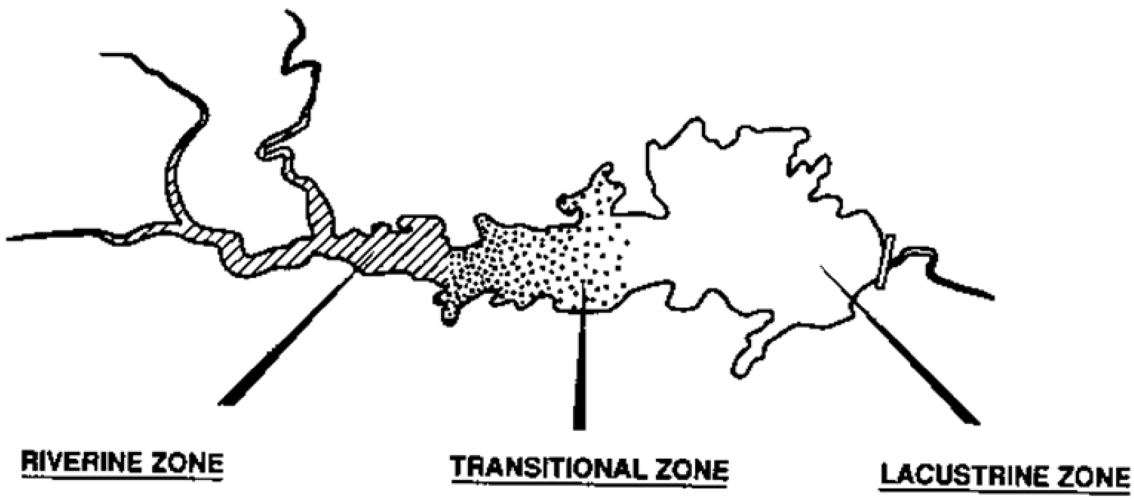
The density difference between water increases above 4oC i.e. high density difference between 24-25oC than between 4-5oC in water
The amount of energy required to mix layered water masses between 29 and 30 oC is 40 times Between 24 and 25oC is 30 times, than required for the same masses of water between 4 and 5 oC
Tropical lakes can stratify with small temperature change between epilimnion and metalimnion
Stratification is broken down by external forces (energy) such as wind or tides
The resistance to mixing is called Stability (S) and is a measure of the density difference between epilimnion and hypolimnion.

**Question summary**

1. Define lentic ecosystem.
2. How do lakes formed?
3. Explain the trophic status of a lake.
4. What are the major factors that affect lake productivity?
5. Describe and explain lake zonation.
6. What are the role of macrophytes?
7. What is lake stratification? Describe the vertical zonation due to temperature difference and its significance to aquatic ecosystem.
8. Explain annual temperate stratification and mixing.

# Chapter six

***Lentic waters – Reservoirs***



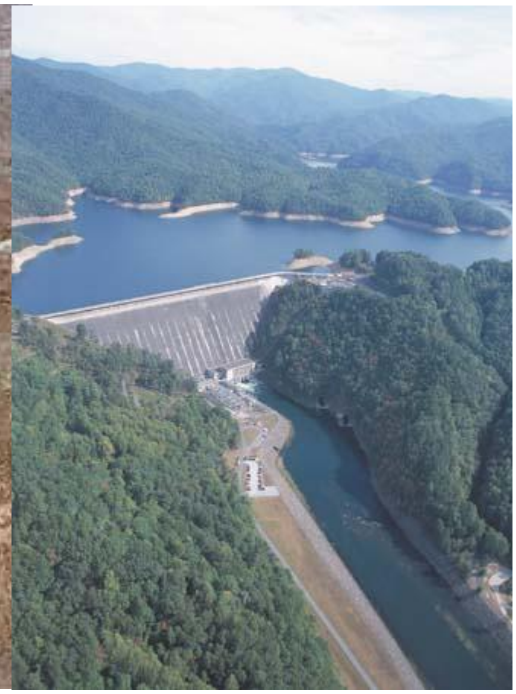

**Chapter objectives**
At the end of this chapter, students will be able to:

- Explain the uses of reservoirs
- Understand the formation of reservoirs (damming) and zonation
- Discuss reservoir problems and the consequences of damming
- Similarity and differences with natural water bodies

**Reservoirs/Dams**

- A **reservoir** (etymology from French *réservoir* a "storehouse") or an **artificial lake** is used to store water.
- structure built across a stream, or river to retain water
- Reservoirs may be created in river valleys by the construction of a dam or may be built by excavation in the ground or by conventional construction techniques such a brickwork or cast concrete.

Reservoirs and dam are used interchangeably

**Reservoirs (man-made lake)**

Two mammals, the beaver-semi aquatic rodent and human, are particularly effective in constructing dams across river valleys to impound water into lakes/ponds

By creating a dam these mammals change a lotic system (running water) into a lentic system (standing water)

- The longevity of reservoirs is often very short, generally less than 100 years, because of the riverine sediment loads (there are reservoirs in Sri lanka which are ca. 2000 years old).
- Most reservoirs are constructed by damming rivers in regions where evaporation approaches or exceeds precipitation

**Uses of reservoirs** (why people build dams?)

Reservoirs used for different purposes

1. **Drinking water supply**

Dams are built to provide water for human consumption,
(that is why many cities are built near rivers)
e.g. Lege Dadi, Gefersa, Dire Dewa

**2. Irrigation:** people build dams to capture water to irrigate crops in areas where rainfall does not provide enough ground moisture for plant growth
(for irrigating arid and semiarid lands),
Irrigation – worldwide, 40% of the food comes from irrigated cropland
e.g. Aswan High Dam
Aswān High Dam, dam across the Nile River in southern Egypt, located near the city of Aswān. The dam impounds Lake Nasser, one of the largest reservoirs in the world.
The water is used to irrigate farmland and has enabled Egypt to double its agricultural production since the dam was completed.
During the rainy season the dam also controls the yearly flooding of the Nile.
The dam has a generating capacity of 2,100 megawatts of electricity.

**3. Hydroelectric power generations**
They are used to generate hydroelectric power,
e.g. Koka Reservoir (on Awash river), Gilgel Gibe (I, II, III, IV), Tana-Belese, Millennium Dam is coming (on Abay)
Large volume reservoirs built primarily for hydroelectric power generation
Hydroelectric power is regarded by some as a relatively clean source of energy because it emits fewer greenhouse gases than thermal power plants.

**4. Flood control:** to reduce peak discharge of floodwater created by large storms or heavy snowmelt, i.e. protect low-lying areas from floods
e.g. Rosiers and Aswan Dam were built to control floods from Ethiopian highlands + storage
There is siltation problem.

**5. Recreation**
Dams can also provide a lake for recreational activities such as swimming, boating, and fishing.

**6. Fish stocking**
- less common

However, fishes stock in reservoirs built for other purposes E.g. Fincha, Melka Wakena …

Many dams are built for more than one purpose; for example, water in a single reservoir can be used for fishing, to generate hydroelectric power, and to support an irrigation system. Water-control structures of this type are often designated as multipurpose dams.

Types of Dams (based on constructing material)
1. Earthen and rock fill e.g. Melka wakena
2. Masonary (concrete)

Lege-Dadi, Gelgel Gibe
Dams create new ecosystems that have hybrid characteristics of lakes and rivers (Soballe and others 1992) that appear as longitudinal zones in **reservoirs**.

**Reservoir longitudinal zonation**
The longitudinal transition from upstream river to downstream lacustrine characteristics can be seen as a series of zones in a reservoir

There are three distinct zones along the longitudinal gradient: Riverine zone, transitional zone and Lacustrine zone

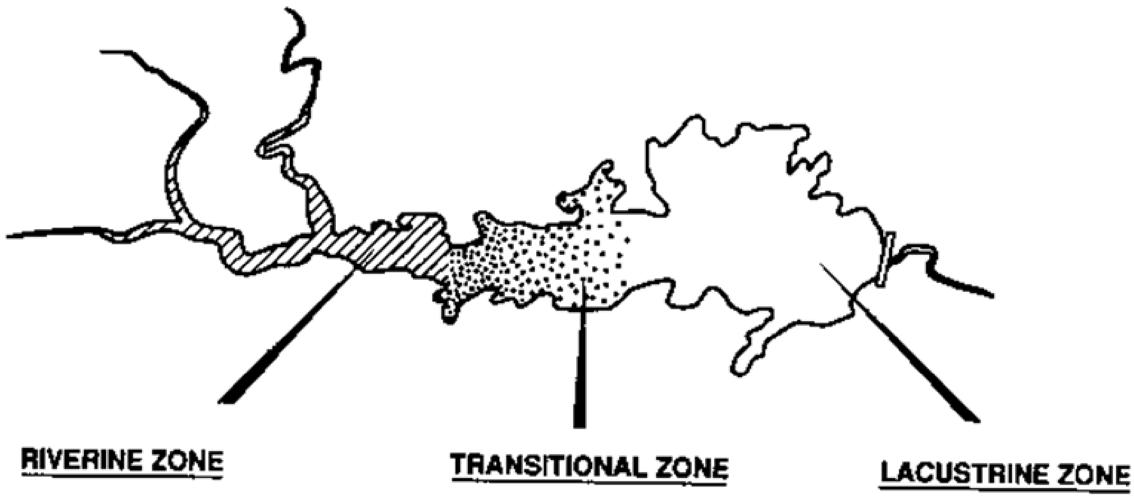



Figure. Generalized zones along longitudinal gradients in reservoirs

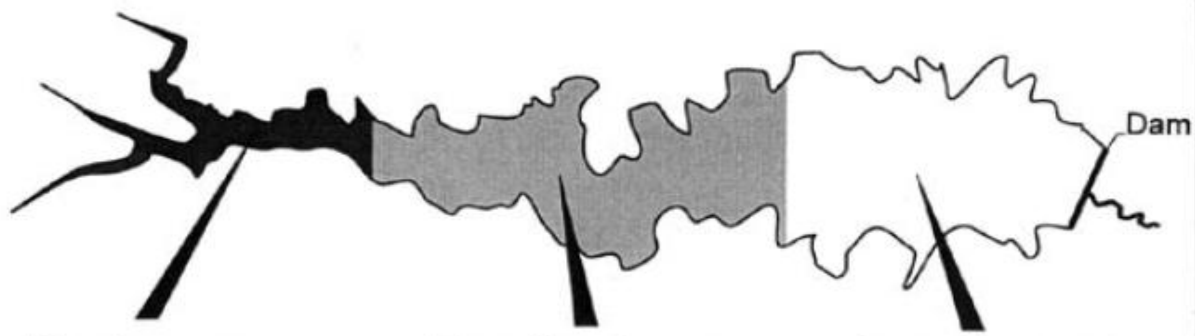
Each zone posseses unique and dynamic physical, chemical and biological characteristics:
**Riverine zone:**

- The riverine zone is often relatively narrow as a result of river geomorphology
- Water is usually well-mixed
- Carries fine suspended particulates (silts, clays and organic particulate matter)
- High particulate turbidity commonly reduces light penetration and limits primary production within the water of this zone.
- Loading of organic matter from allochthonous sources is high in proportion to water volume in the riverine zone
- Aerobic conditions generally prevail in the shallow, well-mixed riverine zone

**Transitional zone**
Riverine water velocities decreases as energy is dispersed over larger areas in the transitional zone
As a result the turbidity load settles
out of the upper water strata
Decreased turbidity results in enhanced depth of light penetration and increased rates of photosynthetic productivity by phytoplankton
Generally, a shift occurs to an increasing percentage of total organic matter loading from phytoplankton and in some shallow reservoirs, from rooted vascular plants.

**Lacustrine zone**
Within the lacustrine zone, characteristics become more similar to lake ecosystems
This portion of the reservoir often stratifies thermally and assumes many of the properties of natural lakes in regard to planktonic production, limitations by nutrients, sedimentation of organic matter, and decomposition in the hypolimnion

**Comparison between zonation**




| Riverine zone | Transitional zone | Lacustrine zone |
|---|---|---|
| Narrow, channelised basin | Broader, deeper basin | Broad, deep, lake-like basin |
| Relatively high flow rates | Reduced flow rates | Low flow rates |
| High suspended solids; low light availability at depth | Reduced suspended solids; light availability at depth | Relatively clear; high light availability at depth |
| Nutrient supply by advection; relatively high nutrient levels | Advective nutrient supply reduced | Nutrient supply by internal recycling; relatively low nutrient levels |
| Light-limited primary productivity | Primary productivity relatively high | Nutrient-limited primary productivity |
| Cell losses primarily by sedimentation | Cell losses by grazing and sedimentation | Cell losses primarily by grazing |
| Organic matter supply primarily allochthonous | Intermediate | Organic matter supply primarily autochthonous |
| More eutrophic | Intermediate | More oligotrophic |

Damming converts the terrestrial to an aquatic habitat,  a large body of water cover the previous terrestrial habitat)
As a result there are physical, chemical and biological changes

1. **Physical changes**

Impounding (damming) changes flowing rivers (lotic) to standing (lentic) waters
Morphologically the narrow channelized river changed to broader (wider) size (lake type)
Temperature: rivers tend to have fairly homogenous temperatures; reservoirs forms thermal stratification
Damming may affect (become a barrier) for migratory fish species.
e.g. Anadromous fish: Sea (feeding) → freshwater (breeding area).
For Salmon fish Dams create problems for returning to breeding site; Fish ladder constructed

2. **Chemical changes**

a. Turbidity is reduced leading to higher primary production
b. DO concentration: rivers tend to have fairly homogenous DO concentration
c. In the lower reaches of reservoirs, depletion of oxygen and cold water.

Usually water from the hypolimnion is released downstream, i.e. it is colder water containing low DO conc. Cold hypoxic water may not be suitable to downstream organisms.
Plus, the water may contain $H_2S$--- which is unfit for domestic use

d. Bioaccumulation of toxic substances (trace metals) like Hg (mercury) and Pb

**3. Biological changes**

a) Change from oligotrophic, heterotrophic, lotic to eutrophic, autotrophic, lentic system
b) From free inorganic nutrients → inorganic nutrients locked in biota (organism biomass)
c) Planktonic diversity and production increases

**<u>Trophic upsurge</u>**

During the early years after it is filled, nutrient concentration and productivity at all trophic levels are usually elevated --- this is known as **trophic upsurge**
The subsequent decline, **trophic depression**, may similarly last for a period of years but will ultimately yield a more stable community composition and productivity
e) Fishes are derived from inflowing rivers which are not well-adapted to lentic environments (but the fish fauna could be rich in young reservoirs; the food type is also changed to planktonic and nutritious)

**In summary:** the river system changes dramatically when dammed because of changes in flow, channel geomorphology, chemistry, and biological communities.

The **residence time** of a reservoir (the time it takes a molecule of water to pass through) is much longer than that of an equivalent length of river, but usually shorter than that of a lake. Reservoir residence time may be only a quarter that of a similar-sized lake

**River and Lake Characteristics of Reservoirs**

Reservoirs display characteristics of both rivers and lakes because they are formed by the damming of a river:
Similar to rivers, reservoirs have longitudinal and lateral gradients in certain features:

- Current velocity decreases from the upper portion (where the river enters) toward the dam, and from mid-channel to the banks.
- Width generally increases from upper to lower portions of the reservoir.
- Channel depth increases from upper to lower portions of the reservoir, and decreases from mid-channel to the banks.

Similar to lakes, large reservoirs can have vertical (depth) gradients of several important characteristics (Cole 1983):

- Light -- Light is attenuated by travel through water, constraining the growth of plants and algae to shallower, termed the euphotic zone.
- Temperature -- Solar radiation, like light, is absorbed rapidly by water. Deeper reservoirs can stratify into layers: a warm layer near the surface (epilimnion), a cold layer near the bottom (hypolimnion), and a temperature gradient between them termed the thermocline.
- Oxygen -- Oxygen is dissolved in water by surface exchange with the atmosphere, and from photosynthesis of aquatic plants and algae; at greater depths (and reduced light) oxygen can be low (hypoxic) or depleted (anoxic).

**Environmental Problems**
Dams alter the water temperatures and microhabitats downstream. Water released from behind dams usually comes from close to the bottom of the reservoirs, where little sunlight penetrates. This frigid water significantly lowers the temperatures of sun-warmed shallows downstream, rendering them unfit for certain kinds of fish and other wildlife. Natural rivers surge and meander, creating small pools and sandbars that provide a place for young fish, insects, and other river-dwelling organisms to flourish. But dams alter the river flow, eliminating these microhabitats and, in some cases, their inhabitants.

Dams also prevent nutrient-laden silt from flowing downstream and into river valleys. Water in a fast-moving river carries tiny particles of soil and organic material. When the water reaches a pool or a flat section of a river course, it slows down. As it slows, the organic matter it carries drops to the river bottom or accumulates along the banks. Following heavy rains or snowmelt, rivers spill over their banks and deposit organic matter on their floodplains, creating rich, fertile soil. Some of the organic matter makes it all the way to river mouths, where it settles into the rich mud of estuaries, ecosystems that nourish up to one-half of the living matter in the world's oceans. Large dams artificially slow water to a near standstill, causing the organic matter to settle to the bottom of the reservoir. In such cases, downstream regions are deprived of nutrient-laden silt

**Problems and management**

1. Siltation from flooded area – during initial phase silt and other particulate like clay comes from the catchments and settle down (dredging is an expensive practice --- Lake Koka)
2. In deep reservoirs – anoxia and stink water ($H_2S$) unsuitable for domestic uses (compensation– it could be nutrient rich water)
3. Drawdown practices during floods/high rainfall

Can cause flooding of surrounding areas (affect local people)
Affect fish spawning areas
Habitat destruction of birds and others organisms ( can be minimized by spillway, flood control methods etc)

**4. Human evacuation (resettlement)**
e.g. Aswan Dam (egypt), Volta Dam (Ghana), Kainji Dam (Nigeria); Kariba Dam (Zumbabwe-Zambia) --- large number of peopled have been displaced.
How can government compromise development vs. human evacuation?

**5. Seismic changes** leading to earthquakes and landslides below dams: the terrestrial turns to aquatic ecosystem, holds large volume of water leading to seismic changes may result in earthquakes

6. **Increase in tropical diseases---** Malaria, Schistosomiasis
(increase flow rate downstream to reduce water retention time in reservoir so that the eggs as well as the larvae may not be comfortable)

**7. Political tensions between countries**

Reparian rights vs downstream countries
e.g. Euphrates river dam --- Turkey, Syria and Iraq
Nile River --- Ethiopia, Sudan and Egypt
Needs political decisions….
Omo river and Lake Turkana --- found on the border of Ethiopia and Kenya …

**8. Water diversion** and the resulting shrinking of downstream wetlands certainly have strong negative effects to

- Aquatic biota and water birds (and affects biodiversity)
- Human communities dependent on the river for irrigation, drinking water supply, domestic use (washing, bathing), fishing

The negative environmental consequences and social impacts of large reservoirs are becoming gradually better appreciated and a prior EIA (Environmental Impact Assessment) are required
Development is undoubtedly very important for the society, so it is a must to construct dam
But it should not be at the expense of

- Biodiversity loss
- Society

It means even though difficult to avoid the impact totally, the negative environmental and social impacts due to damming should be minimized
For this prior EIA should be done

The following are the world's ten largest reservoirs by surface area:

1. Lake Volta (8,482 $km^2$ or 3,275 sq mi; Ghana)
2. Smallwood Reservoir (6,527 $km^2$ or 2,520 sq mi; Canada)
3. Kuybyshev Reservoir (6,450 $km^2$ or 2,490 sq mi; Russia)
4. Lake Kariba (5,580 $km^2$ or 2,150 sq mi; Zimbabwe, Zambia)
5. Bukhtarma Reservoir (5,490 $km^2$ or 2,120 sq mi; Kazakhstan)
6. Bratsk Reservoir (5,426 $km^2$ or 2,095 sq mi; Russia)
7. Lake Nasser (5,248 $km^2$ or 2,026 sq mi; Egypt, Sudan)
8. Rybinsk Reservoir (4,580 $km^2$ or 1,770 sq mi; Russia)
9. Caniapiscau Reservoir (4,318 $km^2$ or 1,667 sq mi; Canada)
10. Lake Guri (4,250 $km^2$ or 1,640 sq mi; Venezuela)

**List of reservoirs by volume**

1. Lake Kariba (180 $km^{-3}$ or 43 cu mi; Zimbabwe, Zambia)
2. Bratsk Reservoir (169 $km^3$ or 41 cu mi; Russia)
3. Lake Nasser (157 $km^3$ or 38 cu mi; Egypt, Sudan)
4. Lake Volta (148 $km^3$ or 36 cu mi; Ghana)
5. Manicouagan Reservoir (142 $km^3$ or 34 cu mi; Canada)
6. Lake Guri (135 $km^3$ or 32 cu mi; Venezuela)
7. Williston Lake (74 $km^3$ or 18 cu mi; Canada)
8. Krasnoyarsk Reservoir (73 $km^3$ or 18 cu mi; Russia)
9. Zeya Reservoir (68 $km^3$ or 16 cu mi; Russia)

**Question summary**

1. What is reservoir?
2. How reservoir is formed? Why people built dams/reservoirs?
3. Describe and characterize the longitudinal zonation of reservoirs.
4. Discuss the physical, chemical and biological changes that resulted due to damming.
5. Mention the environmental problems resulted from damming.

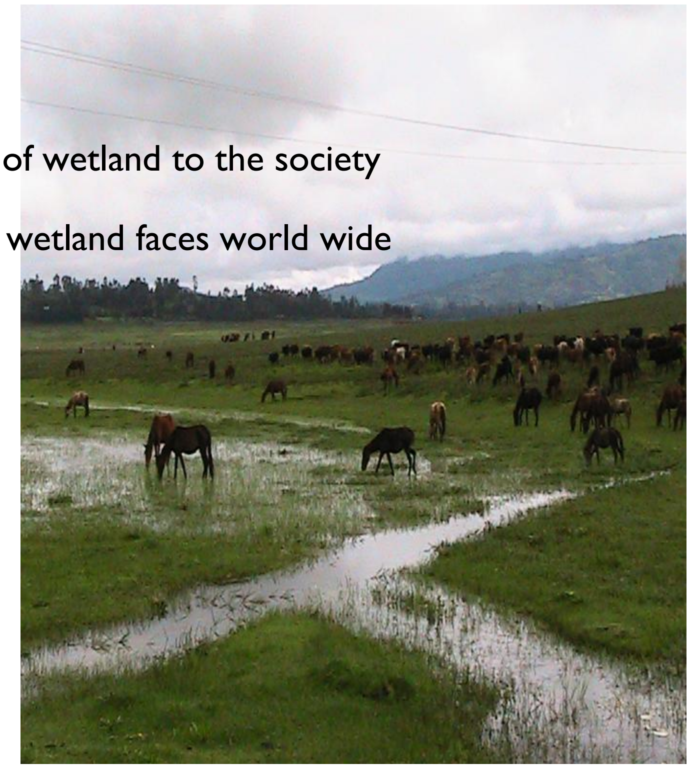
# Chapter Seven

## *Lentic waters -Wetland ecology*

### Chapter objectives

The students will be able to:

- Define wetland
- Understand the importance of wetland to the society
- Understand the threats that wetland faces world wide



***Wetlands*** *are "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed 6 m".*

## Wetland definition

- **Wetlands – lands covered with water all or part of a year**

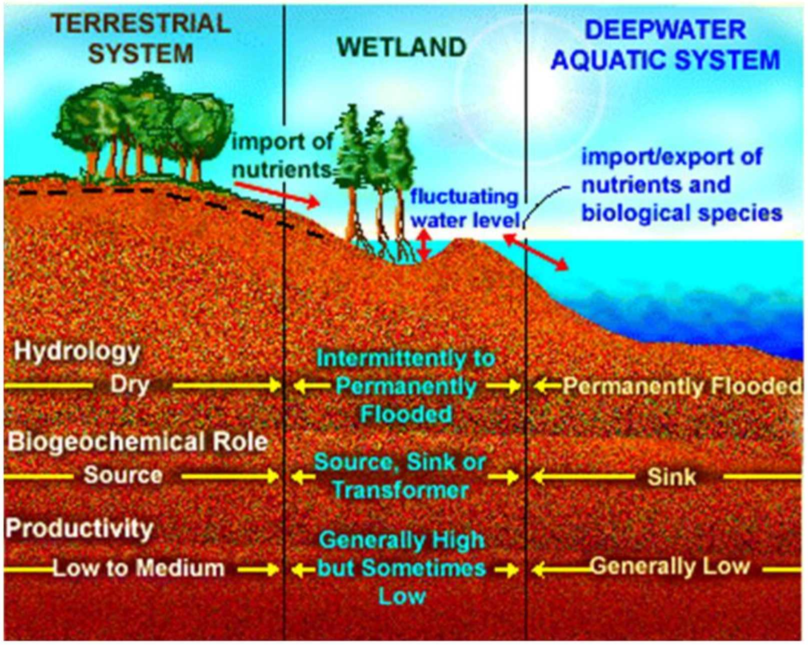
- **Clean Water Act Section 404:** Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

**Ramsar definition:** wetlands are "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed 6 m".

Until the 1980's, wetlands were mostly viewed as a transitional stage in a sequence of ecosystem development (i.e. succession) from pond/lake to climax grassland or forest.

However, wetland scientists and others now recognize wetlands as distinct ecosystems that are highly connected with, but distinct from aquatic and terrestrial ecosystems.


| Tier | Hydrophytic (flooded) | | | Helophytic (exposed) | | | | |
|---|---|---|---|---|---|---|---|---|
| Class | Aquatic plant community | Marsh | | Wet prairie | Swamp | | | |
| Association | Submerged and floating herbaceous vegetation | Herbaceous vegetation with *Scirpus americanus* | Herbaceous vegetation | Graminoids | Willow with shrubs | Willow with other trees | Silver maple | American elm or eastern cottonwood |




**Diagnostic characteristics of wetland**

1. **Hydric (saturated) soils –** saturated long enough to create an anaerobic state in the soil horizon
2. **Hydrophytic plants –** plants adapted to thrive in wetlands despite the stresses of an anaerobic and flooded environment
3. **Hydrologic regime –** dynamic or dominant presence of water

**What are Wetlands? Wetlands area that**

- contain hydric soil - saturated by water.
- soil lacks oxygen when saturated
- land that is seasonally wet.
- habitat for many aquatic and terrestrial species.
  - Some found only in wetlands.
  - Wetland plants known as hydrophytes.

**Wetland classification chart**

| **Major Categories of *Inland Wetlands*** | **General Location** | **Wetland types** |
|---|---|---|
| Riverine (associated with rivers and streams) | River channels and floodplains | Bottomlands, freshwater marsh, delta marsh |
| Lacustrine (associated with lakes) | Lakes and deltas | Freshwater marsh, shrub and forest wetlands |
| Palustrine (shallow ponds, freshwater wetlands) | Ponds, peatlands, uplands, ground water seeps | Ephemeral ponds, tundra peatland, ground water spring oasis, bogs |

Wetlands include swamps, marshes, bogs and similar areas.

## What do wetlands do? Wetland Functions

Wetland functions are physical, chemical, and biological processes or attributes that are vital to the integrity of the wetland system.

### 1.Physical/Hydrological Functions of Wetlands

**Flood Control**

- Correlation between wetland loss and downstream flooding can capture, store, and slowly release water over a period of time

**Coastal Protection:** Serve as storm buffers

**Ground Water Recharge**

- Water has more time to percolate through the soil
- The capacity of wetlands to absorb a great amount of water also benefits developed areas: they act as "sponges" of the landscape.
- In wetlands, the surface of the water, called the water table, is usually at, above, or just below the land surface

**Sediment Traps**

- Wetland plants help to remove sediment from flowing water

**Atmospheric Equilibrium**

- Can act as 'sinks' for excess carbon and sulfur
- Can return N back to the atmosphere (denitrification)

Wetlands provide many opportunities for recreational activities, such as bird-watching, hunting, fishing, trapping, and hiking, and they provide educational opportunities for nature studies and scientific research.

Wetlands are also valuable for the food and timber harvested

### 2.Chemical Functions of Wetlands

**Pollution Interception**

- Nutrient uptake by plants
- Settle in anaerobic soil and become reduced
- Processed by bacterial action

**Toxic Residue Processing**

- Buried and neutralized in soils, taken up by plants, reduced through ion exchange
- Large-scale / long-term additions can exceed a wetland's capacity
- Some chemicals can become more dangerous in wetlands (Mercury)

**Waste Treatment**

- High rate of biological activity can consume a lot of waste
- Heavy deposition of sediments that bury waste
- High level of bacterial activity that breaks down and neutralizes waste

➢ Several cities have begun to use wetlands for waste treatment

**3.Biological Functions of Wetlands**

- **Biological Production**
  - 6.4% of the Earth's surface → 24% of total global productivity
  - Detritus based food webs
- **Habitat**
  - 80% of all breeding bird populations along with >50% of the protected migratory bird species rely on wetlands at some point in their life
  - 95% of all U.S. commercial fish and shellfish species depends on wetlands to some extent
  - 100% of Tilapia fish (*Oreochromis niloticus*) depends on wetlands for reproduction

**Wetlands dogma**

1. Wetlands are among the most productive ecosystems in the world
   - ☐ Because they have both land and aquatic characteristics, wetlands are some of the most diverse ecosystems on earth.

2. Wetlands are hotspots of biodiversity or "***Biological supermarkets***" because of the extensive food webs and rich biodiversity they support.

   - ☐ The different plant species of a wetland provide habitat for varied animal communities. In addition to microorganisms and invertebrates, reptiles, such as turtles, snakes, and alligators, are common in wetlands. Many amphibians—frogs, salamanders, and toads—live in wetlands during at least part of their life cycle. A large number of fish species require wetland habitat for spawning, feeding, or protection from predation. Birds are attracted to wetlands by abundant food resources and sites for nesting, resting, and feeding. Many breeding and migratory birds, especially waterfowl, are associated with wetlands, as are mammals such as muskrats, nutria, mink, raccoons, and beavers. About one-fourth of the plants, one-half of the fishes, two-thirds of the birds, and three-fourths of the amphibians listed as threatened or endangered in the United States are associated with wetlands.
3. Wetlands are **The kidneys of the landscape** because of the functions they perform in the hydrological and chemical cycles
   - ☐ A wetland system can, , prevent floods, and recharge groundwater aquifers, earning wetlands the sobriquet "the kidneys of the landscape."
   - ☐ Wetlands can reduce wave action and slow down the flow of water (protect shorelines), lessening erosion and causing sediments to settle out of the water. This improves water quality, as does the removal of nutrients and contaminants from the water by growing wetland plants and by chemical processes in wetland sediments (cleanse polluted waters). Wetlands may also serve as sites where surface water can seep into the ground and replenish the groundwater.

**Distribution of wetland**

- ☐ In Ethiopia, 1.14 -- 2% of the Ethiopian land is covered by wetland that is greater than half of Djibouti (Djibouti has an area of 23,200 sq km)

**Why are wetlands important? Wetland Values**

The difference between a wetland function and a wetland value is that functions are properties that a wetland naturally provides. Values are wetland properties that are valuable to humans.

**1. Hydrologic functions**

- ☐ Values of wetlands as a result of the functions of hydrologic flux and storage include:
  - Maintain water quality,
  - water supply,
  - flood control/ reduce flood damage
  - erosion control,
  - wildlife support,
  - recreation, culture,
  - climate control and commercial benefits.

**2. Biogeochemical cycling**

- ☐ Wetlands may be a sink for, or transform, nutrients, organic compounds, metals, components of organic matter and may also act as filters of sediments and organic matter.
- ☐ Wetland processes play a role in the global cycles of carbon, nitrogen, and sulfur by transforming them and releasing them into the atmosphere.

**3. Water quality**

- ☐ Wetlands are good at filtering the waters. They help filter nutrients and waste from the flood waters and runoff.
- ☐ They are natural reservoirs and erosion controllers, and they function as natural sewage systems.
- ☐ Wetlands retain or remove nutrients in four ways:
  - uptake by plant life,
  - adsorption into sediments,
  - deposition of detritus (organic materials), and
  - Chemical precipitation.

**4. Biological productivity & species habitat**

- ☐ Wetlands produce great quantities of plants which provide shelter and food to diverse species.
- ☐ Wetlands produce great volumes of food as leaves and stems break down in the water; this enriched material is called detritus.

- ☐ Detritus is food for insects, shellfish, and forage fish, and it provides nutrients for wetlands plants and algae.
- ☐ Fishes, as well as mammals, reptiles, and amphibians, eat aquatic invertebrates and forage fish.
- ☐ maintain biodiversity
- ☐ provide habitat for animals

**5. Other services of wetlands**

- ☐ Recreation:
- ☐ bird watching, boating

  *Did you know?*

  - ☐ Nationwide in US, an estimated 50 million people spend approximately $10 billion annually observing and photographing wetland-dependent birds.

- ☐ Grazing and haying of wetland vegetation are extremely important to livestock producers.
- ☐ Agriculture (e.g. rice production)
- ☐ support commercial fishing, forestry

**Wetland management**

- ☐ It is "the wise use of wetlands is their sustainable utilization for the benefit of mankind in a way compatible with the maintenance of the natural properties of the ecosystem."
- ☐ The UN Millennium Ecosystem Assessment determined that environmental degradation is more prominent within wetland systems than any other ecosystem on Earth. Indeed, values of wetland remain little understood and their losses are increasingly becoming an environmental disaster. It was found out that approximately 50% of the world's wetlands have been lost in the past century alone. In Canada, for example, up to 70 per cent of wetlands have disappeared in settled areas. The loss could be significantly higher in developing countries like Ethiopia as there is little scientific record and their values were not and are not still well understood.

**Major Causes of wetland degradation in Africa (e.g. Ethiopia)**

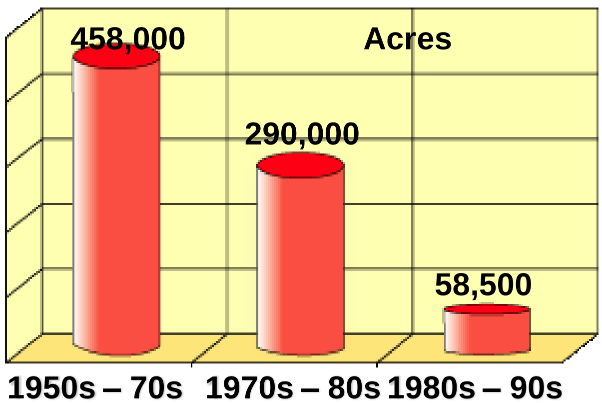
- ☐ Related to development in urban areas; ***urbanization***.
- ☐ Agricultural Activities –draining wetlands for agricultural purposes and mosquito control
- ☐ Industries

**How do Wetlands help?**

- A key link in watershed management.
- Protects water quality
- Controls flooding

- Serves as home for many plants and animals.
- Economy has a significant connection to wetlands.

**Estimated rate of wetlands loss 1950s – 1990s**




**Average annual net wetland loss for the conterminous United States**

Wetlands Status and Trends 2000

How wetland loss did affect countries? Or Implications of Loss of wetlands?

- Wetland lost ---> increased salt levels
- The high amount of salt kills vegetation and trees.
- Decreased natural barrier against extreme weather events
- ☐ Increased flooding
- ☐ Increased destruction due to storms
- ☐ Destruction of fisheries and their infrastructure

## The way that wetlands are viewed has evolved over time:

- The public, especially user groups, began to recognize the resource values of wetlands.
- Concern began to grow in the 1950's and 1960's over an alarming rate of wetland loss in the U.S.
- Consequently, appreciation of wetlands increased…
  - "*don't it always seem to go you don't know what you've got 'til its gone*"—Joni Mitchell, Big Yellow Taxi

**US Government Action to Preserve Wetlands**

- The **"No-Net-Loss" plan** (Dec. 2002) – for every acre (equal to 4,046.86 sq. m.) of wetland lost, it would be replaced with an acre of artificial wetland.
- **Section 404 of the Clean Water Act** was enacted to control wetland development

- This law is not effective and has many loopholes.
- Few states have wetland programs
- No true national program to protect wetlands

More recent programs and legislation provide indirect protection and incentives to conserve and restore wetlands;

- Conservation provisions of the 1985-2000 Farm Bills (Food Security Acts)
- Coastal Zone Management Act
- North American Wetlands Conservation Act

Beginning in the early 1980s, *wetland science* emerged as a separate field of study, and better information concerning the importance of wetlands was made available to the public. As a result of the heightened awareness of wetland values, attitudes began to change; laws such as Section 404 of the Clean Water Act of 1972 (revised 1975), which regulates the dumping of solids into wetlands and waterways, and the 1985 Swampbuster provisions of the Flood Securities Act were passed to protect and preserve wetlands; public and private programs were developed to restore wetlands; and wetland losses began to decrease. In 1988 recommendations were made by the National Wetlands Policy Forum for a program of "no net loss of wetlands," with stronger wetland protection policies but also recognition that some wetlands will inevitably be destroyed by development. Under this program, lost acreage and function may be recovered by the creation of new wetlands and the restoration of degraded wetlands.

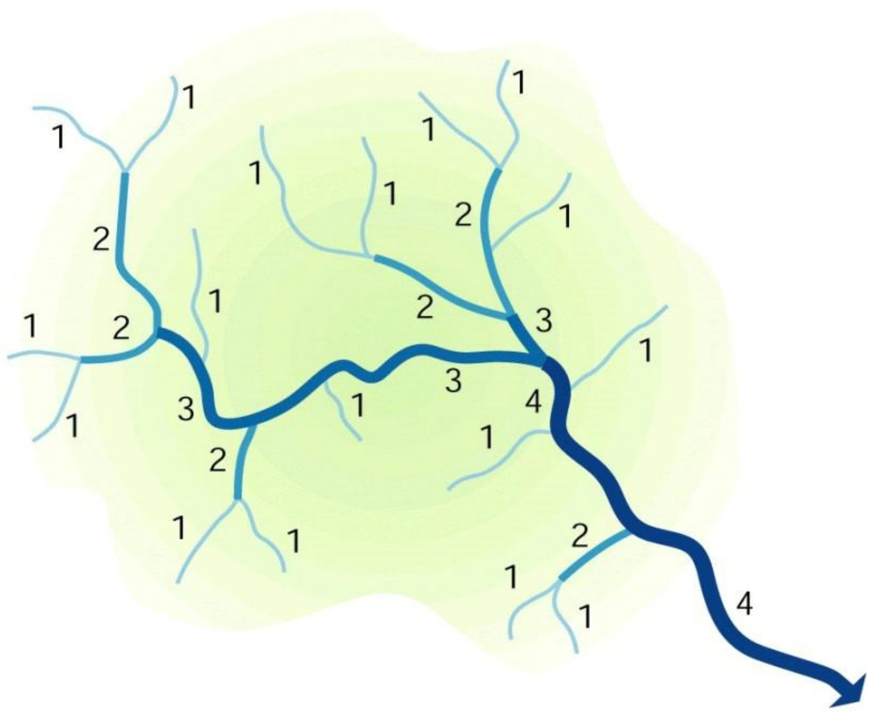
By 1991 over 60 countries had joined the Convention on Wetlands of International Importance Especially as Waterfowl Habitat, adopted in Ramsar, Iran, in 1971 (enforced since 1975) and known as the Ramsar Convention. Member countries are required to designate at least one wetland as a conservation project to add to the List of Wetlands of International Importance. The Ramsar List includes more than 30 million hectares (74 million acres) of wetlands in more than 500 locations—still only 3 percent of the total wetland area of the world. Twenty of these sites are considered to be seriously at risk, and many have no management program.

**Question summary**

1. Define wetland based on Ramsar definition.
2. What are the major threats of wetland in Ethiopia?

# Chapter Eight

***Lotic ecosystem: Rivers/streams***




**Chapter objectives**

At the end of this chapter, students will be able to:

- Understand lentic and lotic ecosystems
- Describe stream classification
- Understand the similarities and differences of lentic and lotic systems

***Brief introduction***

A lotic ecosystem is the ecosystem of a river, stream or spring. Both biotic interactions (amongst plants, animals and micro-organisms) as well as the abiotic interactions (physical and chemical) are important components of the system.
The word Lotic refers to flowing water, from the Latin lotus, past participle of lavere, "to wash".
Streams, also called creeks, rivers, channels, etc., receive their water from 2 sources, both grounded in some form of precipitation (rain, snow).

Stream is an open system, where there is constant input of water and nutrients

Precipitation flows into streams via 2 routes:

- Overland flow through surface runoff
- Infiltrating soil surface, then flowing underground and into streams as groundwater (In this case, water infiltrates into the soil and finds its way to the water table. This groundwater, as it is now called, flows horizontally under the soil surface. Occasionally, the groundwater table meets up with the bed of the stream and contributes water in this way).

Lotic ecosystems can be contrasted with lentic ecosystems. Together, these two fields form the more general study area of freshwater or aquatic ecology or limnology.

Rivers/streams constitute an insignificant amount (0.001 or 0.1%) of the land surface. Only 0.0001% of the water of the earth occurs in river channels. Inspite of these low quantities, running waters are of enormous significance to humans. There is no real distinction between streams and rivers, except that the former are smaller and hence, you can use streams and rivers interchangeably.

Lotic waters can be diverse in their form, ranging from a spring that is only a few centimeters wide to a major river that is kilometers in width. Despite these differences, the following unifying characteristics make the ecology of running waters unique from that of other aquatic habitats.

1. Flow is unidirectional
2. There is a state of continuous physical change
3. There is a high degree of spatial and temporal heterogeneity at all scales (microhabitats)
4. Variability between lotic systems is quite high
5. The biota is specialized to live with flow conditions.

**Stream Classification based on flows**

Streams, which are very diverse systems, can be classified in many ways. One way is to determine how water flows in the stream on a spatial scale.

a. **Permanent streams** are "typical" streams in which, for the entire stream length, water is present above-ground throughout the year.

b. **Intermittent streams**, water flow is heavily influenced by seasonal water inputs. During certain parts of the year (e.g., late summer and early fall) when it is hotter and drier, water may not flow in the streams. All that remains is a dry creekbed. However in the early spring when snow melts and water is plentiful, these streams may hold a great deal of water.

c. **Interrupted streams** may flow aboveground for part of their length, then move belowground (using the groundwater) for another part, then resurface further down in the stream.

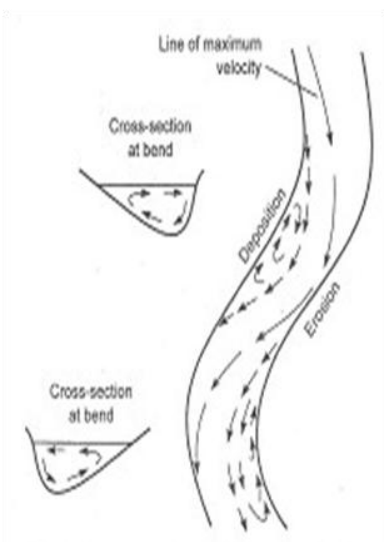
**Stream Classification based on size**

The smallest streams – the headwater streams - are first order streams—they receive their water from a water source (e.g. spring, glacier) but not from another stream. When 2 first-order streams merge into one stream, they become a larger 2$^{nd}$ order stream. When two second order streams merge, they become a larger 3$^{rd}$ order stream, etc..

**Differences and similarities in lentic systems**

A number of characteristics differentiate running waters from standing ecosystems (e.g. lake).

- The unidirectional movement of water is a fundamental property of lotic system. The flow of water along a slope is in response to gravity (wind has no effect on it).
- The relative residence times of the water (water renewal rates), very slow in lakes continuous and rapid in running waters
- There is a state of continuous physical change (Figure 2).




**The presence of plankton**

In general, plankton has low densities in  major parts of the river except in stream pools or under very slow flowing conditions near the river mouth. In contrast, plankton densities may be high in ponds and lakes. In first and second order streams benthic algae and benthic invertebrates are often abundant, this is not the case in lakes or ponds.

- Turbidity – rivers are more often turbid.

- In many cases, both lotic and lentic systems are freshwater.

**Morphology and flow in river ecosystems**

The hydrological, chemical and biological characteristics of a stream or river reflect the climate, geology and vegetation cover of the drainage basin.

Streams and the landscape units they drain form nested hierarchies. Several methods have been used for ordening the streams and rivers in a drainage network. However, the Horton-Strahler method (Horton, 1945; Strahler, 1952) is widely used. Accordingly, the smallest permanently flowing stream is referred to as first order. The union of two first-order streams results in a second-order stream, the union of two streams of second order results in a third-order stream (n + 1), and so on (Figure). Stream order is an approximate measure of stream size and correlate with area drained, volume of water discharged and channel dimension. As a simple classification system it provides an informative tally of the numbers of small streams and large streams (Table ).

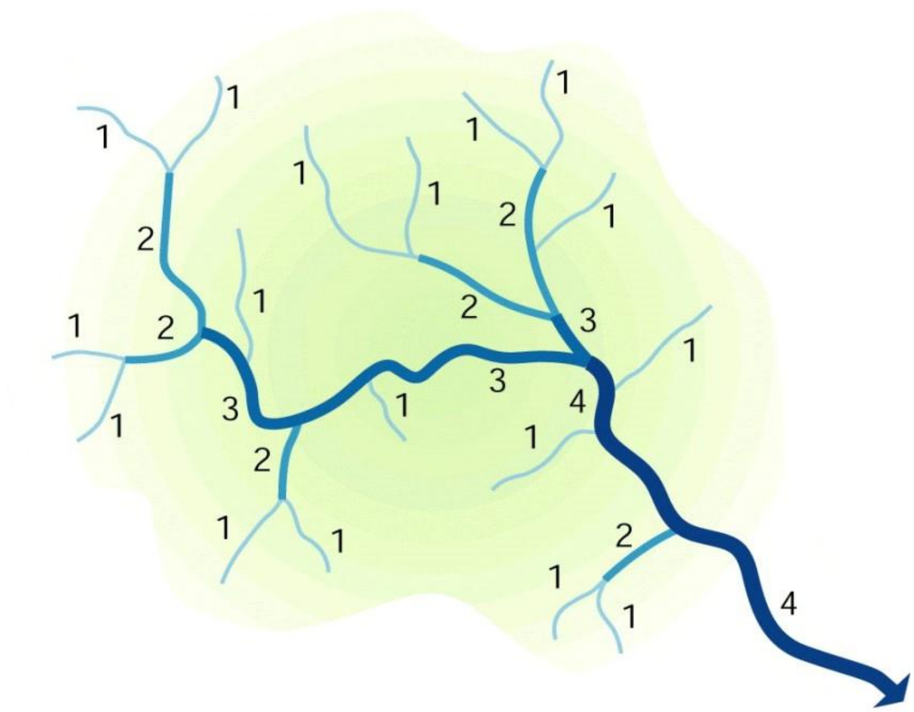



Figure 3: A drainage network illustrating stream channel order within a fourth-order catchment. 1=first order stream; 2= second order stream etc. Intermittent streams occur upstream of the first-order tributaries.

The great majority of the total length of river systems is comprised of lower-order or headwater system, each of short length and small drainage area.

The streams can be grouped into 3:

1. Headwater streams ---order 1 to 3.

2. Medium size streams--- order 4 to 6
3. Large rivers --- order greater than 6

Streamside vegetation has marked effects on headwater brooks by shading the water and contributing leafy and woody detritus. As a result, allochthonous surpasses autochthonous production of organic matter and the stream is essentially heterotrophic.
Hence, the ratio of gross photosynthesis (P) to community respiration (R) is low, $P/R < 1$.
In arid regions, where headwaters are unshaded, the impact of riparian vegetation may be far less significant.
Large river systems approach lentic conditions, , and at last the plankton community can develop in its waters. Now the effect of phytoplankton primary production or autochthonous source becomes significant. Accordingly, the P/R ratio rises and become greater than one. As a result, the fish fauna now includes some planktivorous fish forms for the first time in the river continuum.
Generally, the ratio of the coarse particulate organic matter (CPOM) to the fine particulate organic matter (FPOM) will decrease on the journey through space from headwaters to the big rivers.
However, turbidity of large rivers may be greater than upstream because of fine particulate organic matter arriving from upstream and nearby tributaries.

- -Turbidity:
  - a. Reduces light penetration
  - b. Increases the respiratory burden of the river and therefore $P/R<1$

**Water influx and movement**

Water from all types of precipitation that enters the drainage basins, it either moves or is temporarily stored

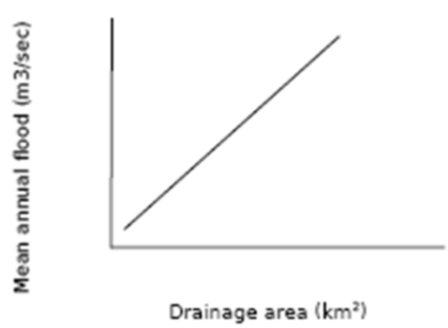
-Surface flow depends on vegetation and soil capacity to hold water as well as on the topography of the area.

Stream flow or discharge is the volume of water passing through the cross-sectional area stream channel per unit time

$$Q=Av$$

Where Q= discharge in $m^3 s^{-1}$ A= cross-sectional area in $m^2$, and v=mean velocity in $mS^{-1}$

Discharge can vary greatly from season to season or within and following a precipitation event. Stream flow and discharge are directly related to the drainage area. This relationship has been used to predict discharge for flood events.




**Types of flow (current)**

There are two principal types of flow ---Laminar and turbulent

a) Laminar flow-is by far less common
   - It is characteristic of very viscous fluids, it occurs only when water is moving very slowly

- It resembles motionless water
- Flow over regular substratum and flow is smooth, flat and regular
- Can be easily described mathematically

b) Turbulent flow

- Flow over irregular and rough substrata
- Cannot be easily modeled mathematically
- Natural substratum---- boulders, stones
- As the velocity increases, turbulent flow arises and it is characterized by irregularity

Pools have fine grained bottom deposits whereas the faster shallower riffles are paved by stones and gravel from which silt is washed away. Ideally a lentic fauna is found in pools and in quiet environments.

At the very bottom of the riverbed, currents are reduced and it is believed that salmonid fishes moving upstream find the valley path (deep channel) to be the easiest route.

Distribution of organisms related to current velocity
E.g. Odonata --- maximum velocity of 10 cm/sec is tolerated
Diptera (Tipulid)---- maximum velocity of 220 cm/sec is tolerated

**Advantages and Disadvantages of the flow system for organisms**

**Advantages**

1. Easy respiration
2. Easy filter feeding
3. Easy transportation (if organisms can control it)
4. Chemical communication -water flow increases chemical movements-prey can detect upstream predatory dangers.

**Disadvantages**

1. Can dislodge organisms
    - Current is the defining feature of rivers and streams. It conveys benefits, such as transport of resources to the organism and removal of wastes and also risks, of which being swept away is the most obvious.
2. Shearing action of flowing water transports and deposits material, continually changing the physical/ morphology of the system

**Lotic Zones and distributions**

A. Riparian zone-normally above water line; may be inundated during floods
    1. Allochthonous inputs -inputs to the system from outside-DOM (Dissolved Organic Matter), leaves, etc.
    2. Water and nutrient inputs

B. Shore zone – often bare; colonization difficult – water level often fluctuates

C. Water column

1. Potamoplankton – river plankton; usually algae
2. 'Tychoplankton' – don't belong there but are washed in
3. Drift – mostly aquatic insects-organisms being carried downstream;
4. May include zooplankton in large rivers
5. Fish

D. Benthos - attached or free-living on bottom

1. 'Aufwuchs' (benthic algae and detritus with associated organisms): – fungi, algae, bacteria, protozoans and some organisms feeding on them
2. Rooted plants
3. Animals: aquatic insects, mollusks, fish

Streams can be described by their physical features, like channel shape and pattern. The habitats of certain reaches (sections) of the stream are divided into alternating pools and riffles. Pools are deeper, slow-moving areas of the stream, and riffles are faster-moving areas of water that are shallower. Different species of fish and aquatic invertebrate communities can be found in pools and riffles, because of the differences in water velocity and substrates.

**Morphological and behavioral adaptations of organisms in running water**

**Morphological Adaptations**

Current is the most significant characteristics of running water and the following are some of the adaptations to live in flowing water.

**Macroinvertebrates adaptation:**

a) **Flattening of Body**—this adaptation can allow the animal in the water to bear less of the impact of the force of water moving downstream. This flat shape also allows the animals to enter confined area (such as under stones) that may present a useful environment for them to live in. Many animals that live on stones are flattened.

E.g. Mayflies, planarians (flatworm), leeches

b) **Streamlining** – Just like man-made transport (such as airplane or ship) animals who have underwent streamlining adaptations on their external appearance means that less resistance is presented by the running water when the animal attempts to move. It is well known that fusiform body offers least resistance to fluids and many fishes and invertebrates closely approach this shape.

More effective adaptation than body flattening

Eg. Ephemeroptera(Baetidae), Caddisfles ( They build cases to reduce water contact with their body).

C) **Suckers**-These suckers attach themselves to a surface which helps to maintain their position and can also assist movement in any given direction.

This is a very efficient means of attachment to smooth surfaces of substratum

Eg. Leeches

d) **Hooks** – Most stream-dwelling arthropods have well-developed tarsal claws with which they hold on to rough objects on the surfaces of stones.

The small beetles (elminthids) rely entirely on their sprawling large-clawed legs for attachment.

E.g. Diamesa, Limnophora (lake maggot)

e) **Sticky secretions**-Many stream-dwelling arthropods employ secretions of silk or similar material to attach themselves to stones or other objects with silk when they pupate

## Behavioral Adaptations

Besides morphological adaptations, there are behavioral adaptations specific to each stream community.

Invertebrate adaptations

a) Avoidance of current by living under stone or vegetations

E.g. Flatworms, Annelids, Crustaceans, Insects

b) Burrowing

Animals which actually burrow down into the substratum are less affected by changes in current.

E.g. Annelids and some larvae of Diptera

Algal Adaptations

1. Firmly attached to hard substrates
2. Motile
3. Body from

a. Flattened-trying to remain in boundary layer where there is little current

b. Trailing filaments- increase exposure to nutrients

Adaptations of Higher Plants (angiosperms, liverworts, mosses)

1. Attached to rocks
2. Rooted in substrate- tough yet flexible stems

## Trophic relationship

Energy sources can be autochthonous or allochthonous.

- Autochthonous energy sources are those derived from within the lotic system. During photosynthesis, for example, primary producers form organic carbon compounds out of carbon dioxide and inorganic matter. The energy they produce is important for the community because it may be transferred to higher trophic levels via consumption. Additionally, high rates of primary production can introduce dissolved organic matter (DOM) to the waters.[4] Another form of autochthonous energy comes from the decomposition of dead organisms and feces that originate within the lotic system. In this case, bacteria decompose the detritus or coarse particulate organic material (CPOM; >1 mm pieces) into fine organic particulate matter (FPOM; <1 mm pieces) and then further into inorganic compounds that are required for photosynthesis.

- Allochthonous energy sources are those derived from outside the lotic system, that is, from the terrestrial environment. Leaves, twigs, fruits, etc. are typical forms of terrestrial CPOM that have entered the water by direct litterfall or lateral leaf blow. In addition, terrestrial animal-derived materials, such as feces or carcasses that have been added to the system are examples of allochthonous CPOM. The CPOM undergoes a specific process of degradation. Alla gives the example of a leaf fallen into a stream. First, the soluble chemicals are dissolved and leached from the leaf upon its saturation with water. This adds to the DOM load in the system. Next, microbes such as bacteria and fungi colonize the leaf, softening it as the mycelium of the fungus grows into it. The composition of the microbial community is influenced by the species of tree from which the leaves are shed (Rubbo and Kiesecker 2004). This combination of bacteria, fungi, and leaf are a food source for shredding invertebrates, which leave only FPOM after consumption. These fine particles may be colonized by microbes again or serve as a food source for animals that consume FPOM. Organic matter can also enter the lotic system already in the FPOM stage by wind, surface runoff, bank erosion, or groundwater. Similarly, DOM can be introduced through canopy drip from rain or from surface flows

**Invertebrates**

Invertebrates can be organized into many feeding guilds in lotic systems. Some species are shredders, which use large and powerful mouth parts to feed on non-woody CPOM and their associated microorganisms. Others are suspension feeders, which use their setae, filtering apparatus, nets, or even secretions to collect FPOM and microbes from the water. These species may be passive collectors, utilizing the natural flow of the system, or they may generate their own current to draw water, and also, FPOM.

Members of the gatherer-collector guild actively search for FPOM under rocks and in other places where the stream flow has slackened enough to allow deposition. Grazing invertebrates utilize scraping, rasping, and browsing adaptations to feed on periphyton and detritus. Finally, several families are predatory, capturing and consuming animal prey. Both the number of species and the abundance of individuals within each guild is largely dependent upon food availability. Thus, these values may vary across both seasons and systems.

Feeding Guilds -The grouping of animals according to the feeding strategies they employ, whether they remain stationary and filter food out of water that passes over specialized body parts that serve as nets or sieves, dig in the bottom sediments, or chase after other animals.

Feeding – functional group concept --'guilds' in river

1. Shredders-biters and chewers; take large food and produce small Foods; herbivorous or detritivorous (leaves and microfauna)
2. Scrapers-feed on periphyton (on substrates); specialized mouth parts to scrape material on substrates
3. Collectors – spin nets or use setae to collect organic matter; feed on fine particulate organic matter; filter with nets, hairs; cephalic fan (blank flies)
4. Predators – carnivorous; swallow prey whole or bite pieces or suck out contents

Detrital material – much of the food web in a stream is detrital; this detritus is broken up into different categories by size:

1. CPOM – coarse particulate organic matter; >1 mm; leaves, wood litter
2. FPOM – fine particulate organic matter; 50 µm – 1 mm
3. DOM - < 0.45µm

**Fish**

Fish can also be placed into feeding guilds. Planktivores pick plankton out of the water column . Herbivore-detritivores are bottom-feeding species that ingest both periphyton and detritus indiscriminately. Surface and water column feeders capture surface prey (mainly terrestrial and emerging insects) and drift (benthic invertebrates floating downstream). Benthic invertebrate feeders prey primarily on immature insects, but will also consume other benthic invertebrates. Top predators consume fishes and/or large invertebrates. Omnivores ingest a wide range of prey. These can be floral, faunal, and/or detrital in nature. Finally, parasites live off of host species, typically other fishes. Fish are flexible in their feeding roles, capturing different prey with regard to seasonal availability and their own developmental stage. Thus, they may occupy multiple feeding guilds in their lifetime. The number of species in each guild can vary greatly between systems, with temperate warm water streams having the most benthic invertebrate feeders, and tropical systems having large numbers of detritus feeders due to high rates of allochthonous input.

**River Continuum Concept**

The River Continuum Concept (RCC) was an attempt to construct a single framework to describe the function of temperate lotic ecosystems from the source to the end and relate it to changes in the biotic community (Vannote et al. 1980). The physical basis for RCC is size and location along the gradient from a small stream eventually linked to a large river. Stream order is used as the physical measure of the position along the RCC.

According to the RCC, low ordered sites are small shaded streams where allochthonous inputs of CPOM are a necessary resource for consumers. As the river widens at mid-ordered sites, energy inputs should change. Ample sunlight should reach the bottom in these systems to support significant periphyton production. Additionally, the biological processing of CPOM (Coarse Particulate Organic Matter -larger than 1 mm) inputs at upstream sites is expected to result in the transport of large amounts of FPOM (Fine Particulate Organic Matter -smaller than 1 mm) to these downstream ecosystems. Plants should become more abundant at edges of the river with increasing river size, especially in lowland rivers where finer sediments have been deposited and facilitate rooting. The main channels likely have too much current and turbidity and a lack of substrate to support plants or periphyton. Phytoplankton should produce the only autochthonous inputs here, but photosynthetic rates will be limited due to turbidity and mixing. Thus, allochthonous inputs are expected to be the primary energy source for large rivers. This FPOM will come from both upstream sites via the decomposition process and through lateral inputs from floodplains.

Biota should change with this change in energy from the headwaters to the mouth of these systems. Namely, shredders should prosper in low-ordered systems and grazers in mid-ordered sites. Microbial decomposition should play the largest role in energy production for low-ordered sites and large rivers, while photosynthesis, in addition to degraded allochthonous inputs from upstream will be essential in mid-ordered systems. As mid-ordered sites will theoretically receive the largest variety of energy inputs, they might be expected to host the most biological diversity (Vannote et al. 1980).

Just how well the RCC actually reflects patterns in natural systems is uncertain and its generality can be a handicap when applied to diverse and specific situations. The most noted criticisms of the RCC are: 1. It focuses mostly on macroinvertebrates, disregarding that plankton and fish diversity is highest in the high order rivers; 2. It relies heavily on the fact that low ordered sites have high CPOM inputs, even though many streams lack riparian habitats; 3. It is based on pristine systems, which rarely exist today; and 4. It is centered around the functioning of temperate streams. Despite its shortcomings, the RCC remains a useful idea for describing how the patterns of ecological functions in a lotic system can vary from the source to the mouth.[2]

**River continuum concept**

An ecosystem-based view of streams and rivers as a continuum from small forested head water stream to large rivers.

Streams change as you go from the headwaters to the high order rivers:

1. Predictable physical features and gradients
   - Stream velocity, suspended particulate load, width and depth of stream

2.Predictable biological features –
   - Structure of community and function;
   - P/R (production/respiration)

3.Correlation of 1 and 2

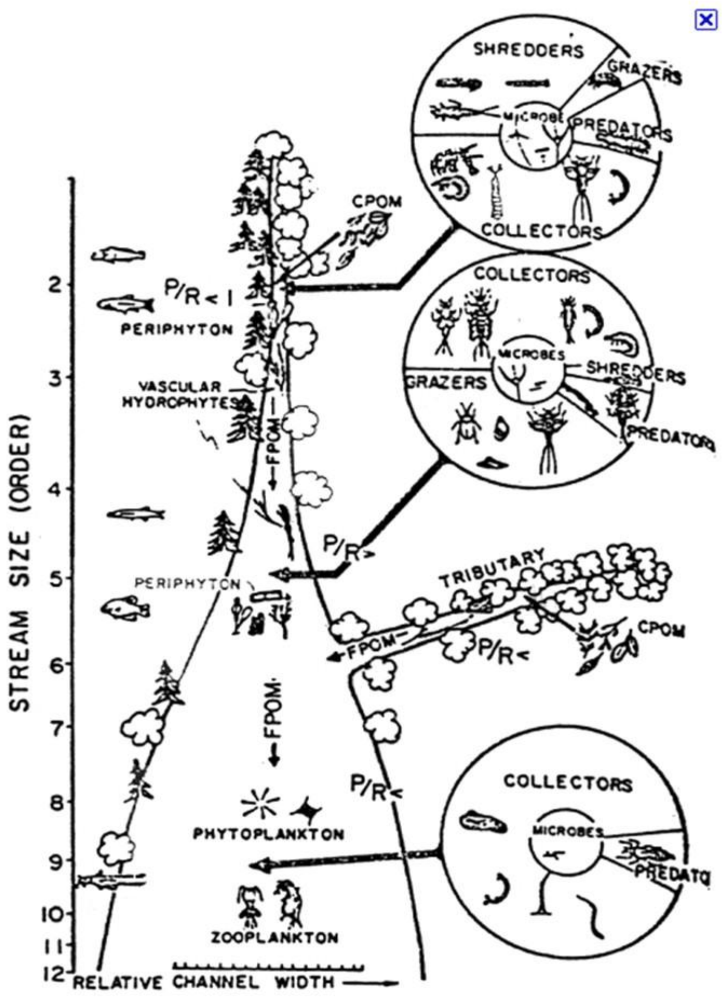


Figure: The river continuum concept summarizes expected longitudinal changes in energy inputs and consumers as one proceeds from a first-order stream to a large river. A low P/R ratio indicates that the majority of the energy supplied to the food web derives from organic matter and microbial activity, and mostly originates as terrestrial production outside the stream channel. A P/R approaching 1 indicates that much more energy to the food web is supplied by primary production within the stream channel.

-Why P<R at 1st order
Lots of CPOM input to stream and it is being decomposed.
Low production due to light limitation (stream is shaded)

In the middle order: ☐Less COPM; more collectors and scrapers (fewer shredders);
☐More light leaders to more production
-Higher order streams☐More FPOM,☐Light-limited due to suspended sediments

**River Characteristics**

**Upper reaches (head water) versus Lower reaches (river mouth)**

| **Upper reaches** | **Lower reaches** |
|---|---|
| Very turbulent | Less turbulent |
| Riffles common | Backwaters and pools common |
| Lotic | More like lentic (e.g. lake) |
| Highly adapted organisms live here | Organisms similar to those found in lake shores |

The headwater and river mouth have different biological features

| **Headwater** | **Downstream (River mouth)** |
|---|---|
| Most organic matter from outside (allochthonous) as leaves etc | Organic matter from internal (autochthonous) |
| Production<respiration i.e. P/R < | Production<respiration i.e. P/R>1.00 |
| Coarse particulate Organic Matter (CPOM) | Fine Particulate Organic Matter (FPOM) |
| Shredders abundant | Detritivores, collectors and Scrapers common |
| Fish of insectivores type | Fish of planktivore type |

**Methodology in Rivers**

1 Physical and chemical measurement is the same as measurement for lakes (meters, Winkler Oxygen methods, nutrient analysis method etc)
2 Biological parameters Aufwuchs (periphyton) – through scrapping (you can also use artificial substratum to study aufwuchs accumulation)
3 Macrophytes cutting and uprooting, identification, biomass and primary production
4 Surber sampler- drift collection, stone kicking for benthos
5 Fish --- Electro-fishing, beach seining

**Question summary**

1. Describe stream classification based on flows and size.
2. What are the difference and similarities of running and standing water?
3. What are the pros and cons of running water?
4. Describe lotic zonation.
5. Mention the behavioral adaptation of invertebrates.
6. Mention the physical adaptation of invertebrates.
7. Discuss river continuum concept.

# Chapter Nine

**Anthropogenic impacts on aquatic ecosystem**

**Chapter objectives**
At the end of this chapter, students will be able to:
- Understand the common pollutants for aquatic ecosystem
- The cause and consequences of anthropogenic impacts
- Know methods of controlling for some anthropogenic impacts.

**Anthropogenic impacts on aquatic ecosystem**
Human effects on aquatic ecosystems can result from pollution, changes to the landscape or hydrological systems, and larger-scale impacts such as global climate change.

**Eutrophication: causes and consequences**
Eutrophication is a process whereby water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients that stimulate excessive plant growth (algae, periphyton attached algae, and nuisance plants weeds).
This enhanced plant growth, prolific or excessive growth is often called an algal bloom.
- Eutrophication was recognized as a pollution problem in European and North American lakes and reservoirs in the mid-20th century. Since then, it has become more widespread.
- Surveys showed that 54% of lakes in Asia are eutrophic; in Europe, 53%; in North America, 48%; in South America, 41%; and in Africa, 28%.
- Eutrophication can be human-caused or natural.

**Natural eutrophication**
- The lake basin gradually fills with sediments and nutrients from the catchments area, and as a result they become shallow and more fertile (nutrient to volume ratio become high).
- It is caused by the change in form and depth of the basin as it gradually fills in with sediment.
- happens over geological periods of time

**Cultural eutrophication**
- Eutrophication has proved to be one of the most widespread and serious anthropogenic disturbances to aquatic ecosystems, though sometimes beneficial for higher fish production.
- Cultural eutrophication is the rapid enrichment of water with nutrient derived from human activities.
- Main nutrients are P and N and they are derived from sewage, agricultural and livestock holding operations.

**Sources of high nutrient runoff**
**point** *and* **nonpoint** *sources of chemical inputs*
**Major causes of eutrophication**
Anthropogenic form of accelerated eutrophication is essentially caused by three factors, which are inter-related and directly linked to worldwide demographic changes.

- Rapid increase in population with a strong tendency toward urbanization and resulting rapid increase in urban waste discharged directly into the waterways.
- Rapid industrialization linked to population growth with the corresponding increase in industrial waste of all kinds, some of them containing the nutrients needed for the growth of algae and macrophytes. An added factor to this since the end of World War II is the production of detergents containing polyphosphate
- Intensification of agriculture, increased use of chemical fertilizers, concentration of livestock production and direct discharge of agricultural wastes into the waterways, etc

**Consequences of eutrophication**

**(1)** Penetration of light into the water is diminished. This occurs because the algae forms mats/suspended in the water column as a result of being produced faster than they are consumed. Diminished light penetration decreases the productivity of plants living in the deeper waters (and hence their production of oxygen).
**(2)** The water becomes depleted in oxygen. When the abundant algae die and decompose, much oxygen is consumed by those decomposers. Oxygen in the water is also lowered by the lack of primary production in the darkened, deeper waters.
**(3)** Lowered oxygen results in the death of fish that need high levels of dissolved oxygen ("DO"), such as trout, salmon, tilapia and other desirable fish species. The community composition of the water body changes, with fish that can tolerate low DO, such as carp predominating. As you can imagine, changes in fish communities have ramifications for the rest of the aquatic ecosystem as well, acting at least in part through changes in food webs.
(4) The bloom can degrade recreational use of the water bodies
**(5)** Further, some of the algal species that "bloom" produce toxins that render the water unpalatable. Some blooms can become toxic (like neurotoxins and hepatotoxins) and can have devastating effects on the aquatic ecological systems.

**Controlling algal blooms**

**1. Controlling nutrients**
  - **Watershed (out of lake) management**
  - **In-lake management**

**2. Chemical treatment**
- Algicide is a toxic chemical, which is added to water body in order to kill and reduce the abundant algae population.

**3. Biomanipulation**
- Biomanipulation is a technique used to restore eutrophic lakes through biological means.

## Acidification

- Acidification is the second most widespread anthropogenic change in lakes and streams, particularly it is mainly a problem in Scandinavian countries where the lakes are poorly buffered.
- Aquatic acidification is defined by a decrease of the Acid Neutralizing Capacity (ANC) of waterways.

**Sources and distribution**

- The principal anthropogenic sources of acid precipitation are sulfur dioxide (SO2) and nitrogen oxides (NO and NO2), collectively denoted as NOx, released during the combustion of fossil fuel (coal or oil), gasoline (vehicle), and the smelting of ores containing sulfur.

$CO_2 + H_2O \rightleftharpoons$ H2CO3 Carbonic acid

$SO_2 + H_2O \rightleftharpoons H_2SO_3$ Sulphurous acid

$SO_3 + H_2O \rightleftharpoons$ H2SO4 sulphuric acid

$NO_2 + H_2O \rightleftharpoons$ HNO3 nitric acid

- Reaction 1 is a natural component of most surface waters. Reactions 2 and 3 contribute about 67% of the acidity of acid precipitation and reaction 4 is responsible for the remaining 33%.

**Global Warming**

- Global Warming is the increase in the average temperature of the atmosphere, oceans, and landmasses of Earth.
- At present Earth appears to be facing a rapid warming
- The chief cause of this warming is thought to be the burning of fossil fuels, such as coal, oil and natural gas, which releases into the atmosphere carbon dioxide and other substances known as Greenhouse Gases. As the atmosphere becomes richer in these gases, it becomes a better insulator, retaining more of the heat provided to the planet by the Sun.

- greenhouse gas is water vapor
- Carbon dioxide is the next most abundant
- Methane is an even more effective insulator
- a newly identified synthetic compound called trifluoromethyl sulfur pentafluoride.

**Effects of Global Warming**

- ***Shrinking Greenland Ice Sheet***
- ***Sea Levels raises and Flooding***

**Efforts to control global warming**

***Cooling It: the World Acts to Slow Global Warming***

- reducing emissions of gases that many scientists believe may lead to global warming.

**Carbon Sequestration**

- The simplest way to sequester carbon is to preserve trees and to plant more.

## Question summary

1. What are most common antropogenic impact on aquatic ecosystems?
2. What are point and non-point sources? Give examples.
3. Define eutrophication, and discuss the cause and consequences of eutrophication
4. Mention methods of controlling algal blooms. Of the methods, which one is biologically recommended? Discuss.
5. What are the causes and consequences of global warming?

## Further reading materials


Allan, J.D. and Castillo, M.M. (2007). Steam Ecology: Structure and Function of Running Waters. 2$^{nd}$ Edition. Springer.
Cole, G. A. (1994). Text Book of Limnology. 4$^{th}$ edition. Waveland Press, Inc., Illinois.
Horne, A. J. and Goldman, C. R. (1994). Limnology. McGraw-Hill Book Company, New York.

Kalff, J. (2002). Limnology. Prentice Hall, New Jersey.

Mitsch, W.J. and Gosselink, J.G. (2007). Wetlands. John Willey & Sons, Inc.

Redeat Habteselassie (2012). Fishes of Ethiopia, Annotated Checklist with Pictorial Identification Guide, 250 pp.

Wetzel R. (2001). Limnology: Lake and River Ecosystems. 3$^{rd}$ Edition. Academic Press, 1006 pp.