

CE 435 (January 2018 Semester)

**Environmental Pollution and Management:
Water Pollution**

CN-4: Lake Water Quality

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Water quality in lakes and reservoirs

- ❑ Water in lakes is retained for longer periods whereas in streams, the water is always flowing
- ❑ In the presence of nitrogen and phosphorous (nutrients), algal bloom occurs
 - affects DO in lakes
 - toxins from some algal species kill fish
 - renders the lake unsuitable for recreational purpose
 - increase cost of water treatment
 - alters the ecological environment of the lake

Phosphorus is usually the **limiting nutrient**.

Algal bloom in lakes and estuaries

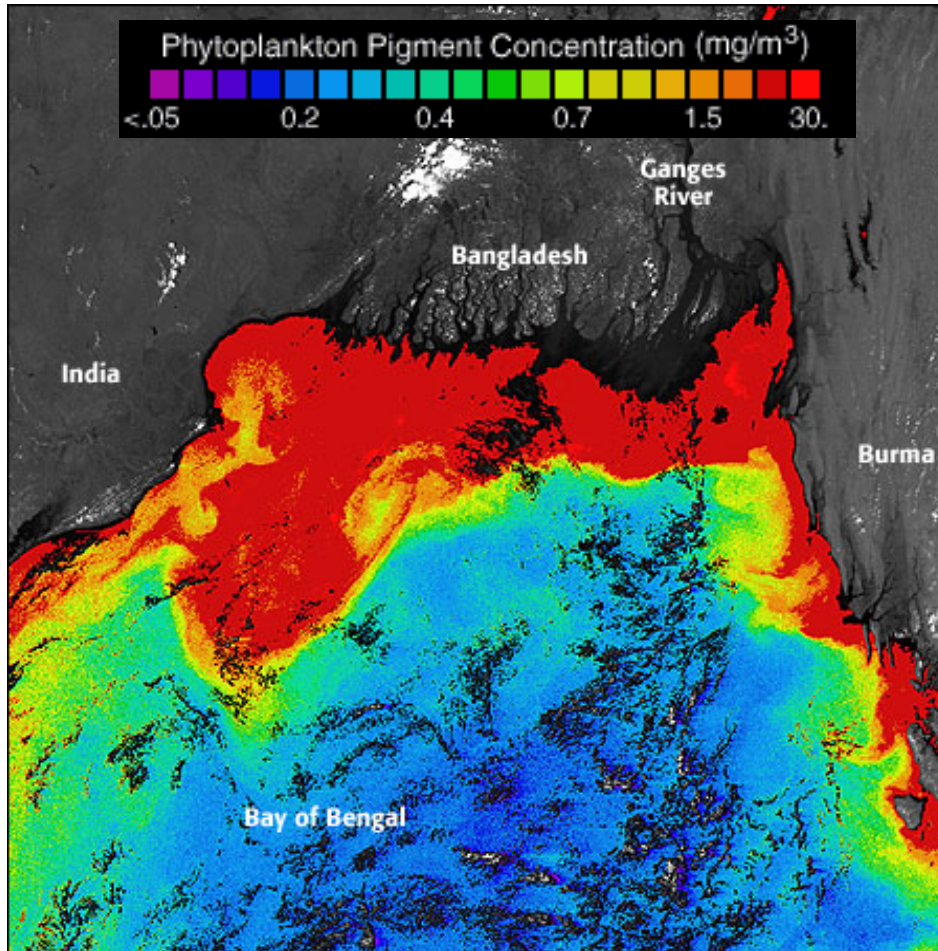


'Red tide' bloom



Toxins produced from algal blooms can cause massive fish kills

Algal bloom in the Bay of Bengal



A Coastal Zone Color Scanner (CZCS) image showing the ocean color of Bay of Bengal

Algal blooms along the coast triggered by the nutrient loading brought to the bay by the major rivers and their tributaries.

Surface Water Quality: Lakes and Reservoirs

Lakes can be classified according to the degree of enrichment of nutrient and organic matter. Three classes are generally recognized:

- Oligotrophic
- Mesotrophic
- Eutrophic

Oligotrophic Lakes: are nutrient poor, have low levels of algae and organic matter, good transparency, and abundant O_2 .

Surface Water Quality: Lakes and Reservoirs

Eutrophic lakes: are nutrient rich, have high levels of algae and organic matter, poor transparency, and are often oxygen-depleted.

Mesotrophic lakes: are intermediate, often with abundant fish life because they have both elevated levels of organic matter and adequate supply of oxygen.

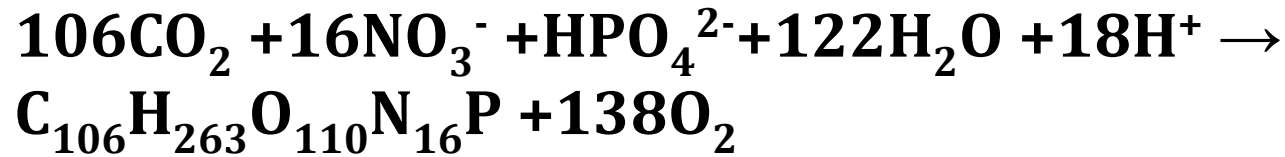
Surface Water Quality: Lakes and Reservoirs

The process of nutrient enrichment in a lake, with increase in organic matter, is termed eutrophication. This is considered to be a natural aging process in lakes, that may take thousands of years.

However, it is possible to greatly accelerate the rate of change through human activities (eg. discharge of domestic & industrial wastewater). Such cases are called cultural eutrophication.

Nutrients and eutrophication

General algal photosynthesis equation:



$$N/P = \frac{16 \times 14}{1 \times 31} = 7.2$$

If $N/P > 20$, P is the limiting nutrient

If $N/P < 5$, N is the limiting nutrient

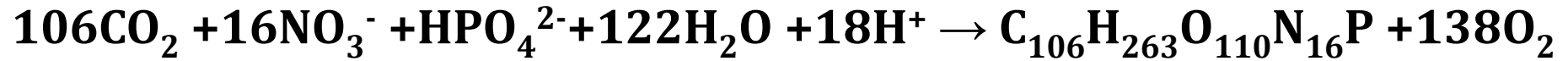
Minimum concentration required for algal bloom:

$$P = 0.015 \text{ mg/L}$$

$$N = 0.30 \text{ mg/L}$$

Why is Phosphorus the limiting nutrient?

general algal photosynthesis equation:



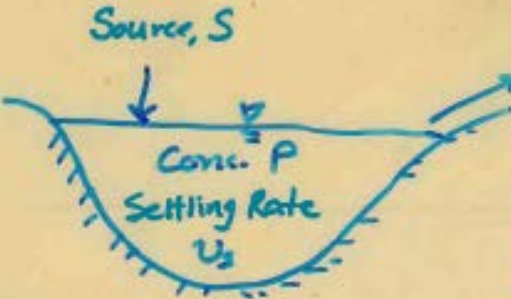
Of all the nutrients, only phosphorus is not readily available from the atmosphere or the natural water supply

It typically takes only a concentration of about 0.02 mg/L of inorganic phosphorus to cause algal blooms in a lake

There is a direct correlation between the phosphorus concentration and chlorophyll a:

$$\log (\text{Chlorophyll } a) = -1.09 + 1.46 \log P_T$$

Surface Water Quality: Lakes and Reservoirs



Source, S

Conc. P

Settling Rate v_s

Outflow rate, Q

P = Phosphorus conc. in lake (mg/L).

S = rate of addition of P from all sources (g/s)

Q = outflow rate

v_s = "P" settling rate (m/sec.)

A = Lake surface area

V = Volume of lake.

$$V \cdot \frac{dP}{dt} = S - v_s A P - Q \cdot P$$

Under steady-state condition - $\frac{dP}{dt} = 0$

$$\therefore S = v_s \cdot A \cdot P + Q \cdot P$$
$$\therefore P = \frac{S}{Q + v_s \cdot A}$$

(Note: difficult to measure or estimate v_s ; Usually varies from 3-30 m/yr.)

Example Problem:

Ex.

$$A = 100 \times 10^6 \text{ m}^2$$

$$Q_w = 0.4 \text{ m}^3/\text{s}$$

$$P_w = 10.0 \text{ mg/L} = 10.0 \text{ g/m}^3$$

$$Q_s = 20 \text{ m}^3/\text{s}$$

$$P_s = 0.0 \text{ g/m}^3$$

$$U_s = 10 \text{ m/yr} = 3.17 \times 10^{-7} \text{ m/s}$$

a lake fed by
a stream also
receives wastewater.

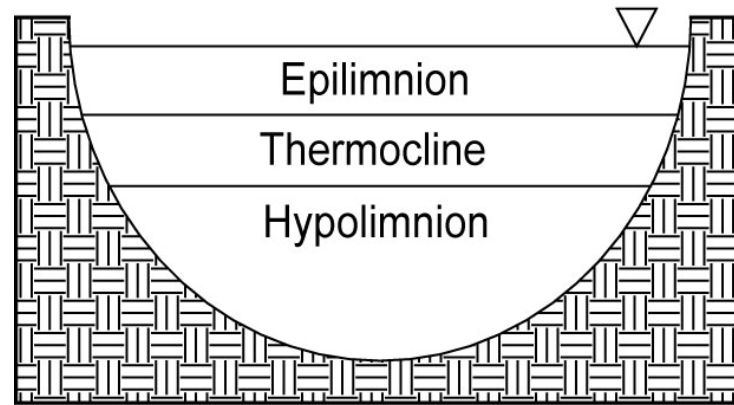
- (i) Estimate average P conc. in lake.
- (ii) Estimate P removal rate at a treatment plant to keep P conc. below 0.01 mg/L .

Thermal stratification in lakes

A major difference between lakes and rivers lies in their mass transport **characteristics**

In temperate latitudes, lakes undergo **thermal stratification**, twice annually, dividing the system into layers and **restricting mass transport**

Thermal stratification in lakes



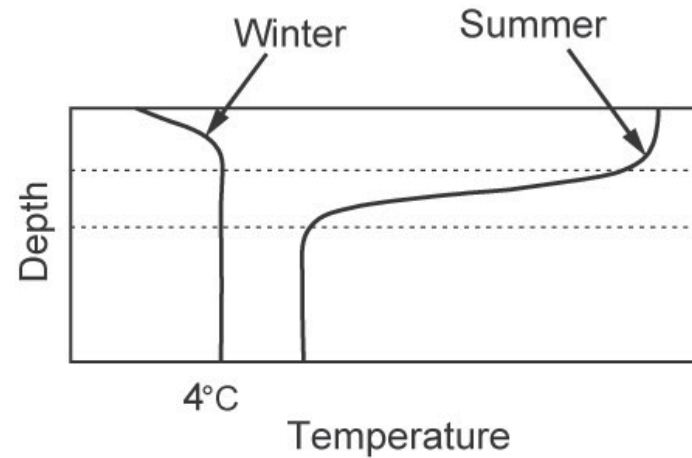
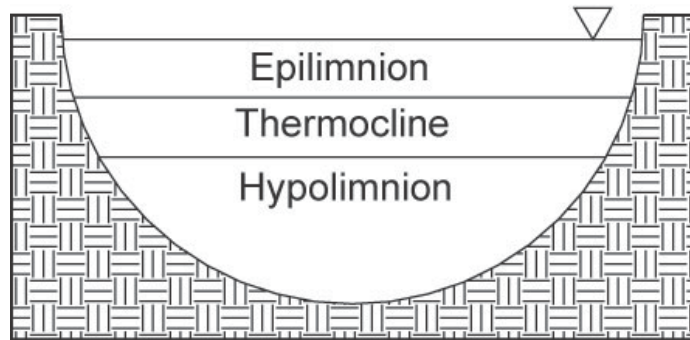
Epilimnion: the warm, the surface layer that is well mixed with respect to temperature

Metalimnion: the region of transition where temperature changes $\geq 1^{\circ}\text{C}$ with every meter of depth

Hypolimnion: the cold bottom layer that is also well mixed with respect to temperature

The plane in the metalimnion where the temperature-depth gradient is steepest is termed **thermocline**

Thermal stratification in lakes



In winter, a layer of cold water floats on top of the more dense, 4°C water below.

In Summer, a layer of warm water floats on top of the cold, denser water

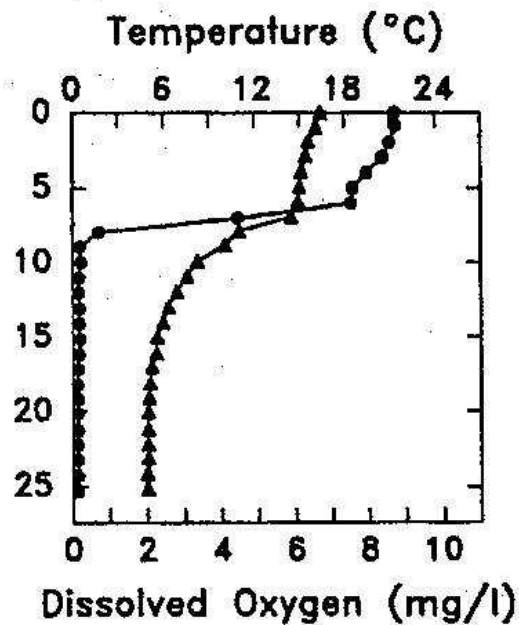
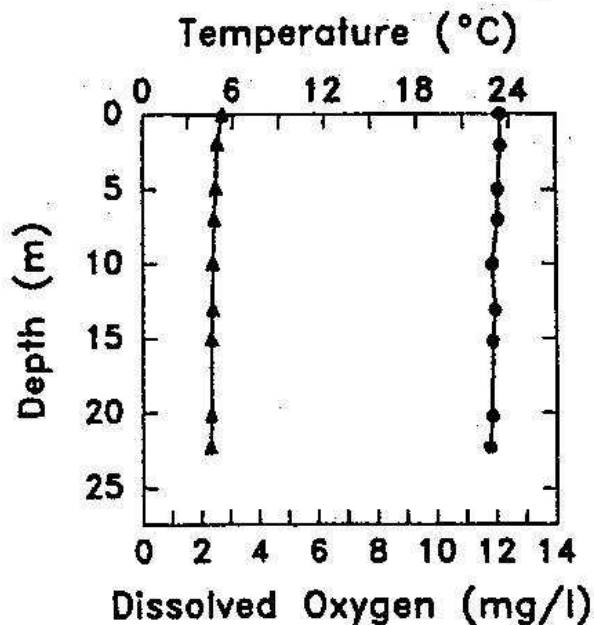
The density difference inhibits vertical mixing and creates three stable layers (thermal stratification)

Thermal stratification in lakes

Spring

Summer Stratification

(• DO ▲ Temp)



well mixed



stratified

Fall and Spring overturn

As seasons progress, there may be two distinct periods when the temperature stratification disappears

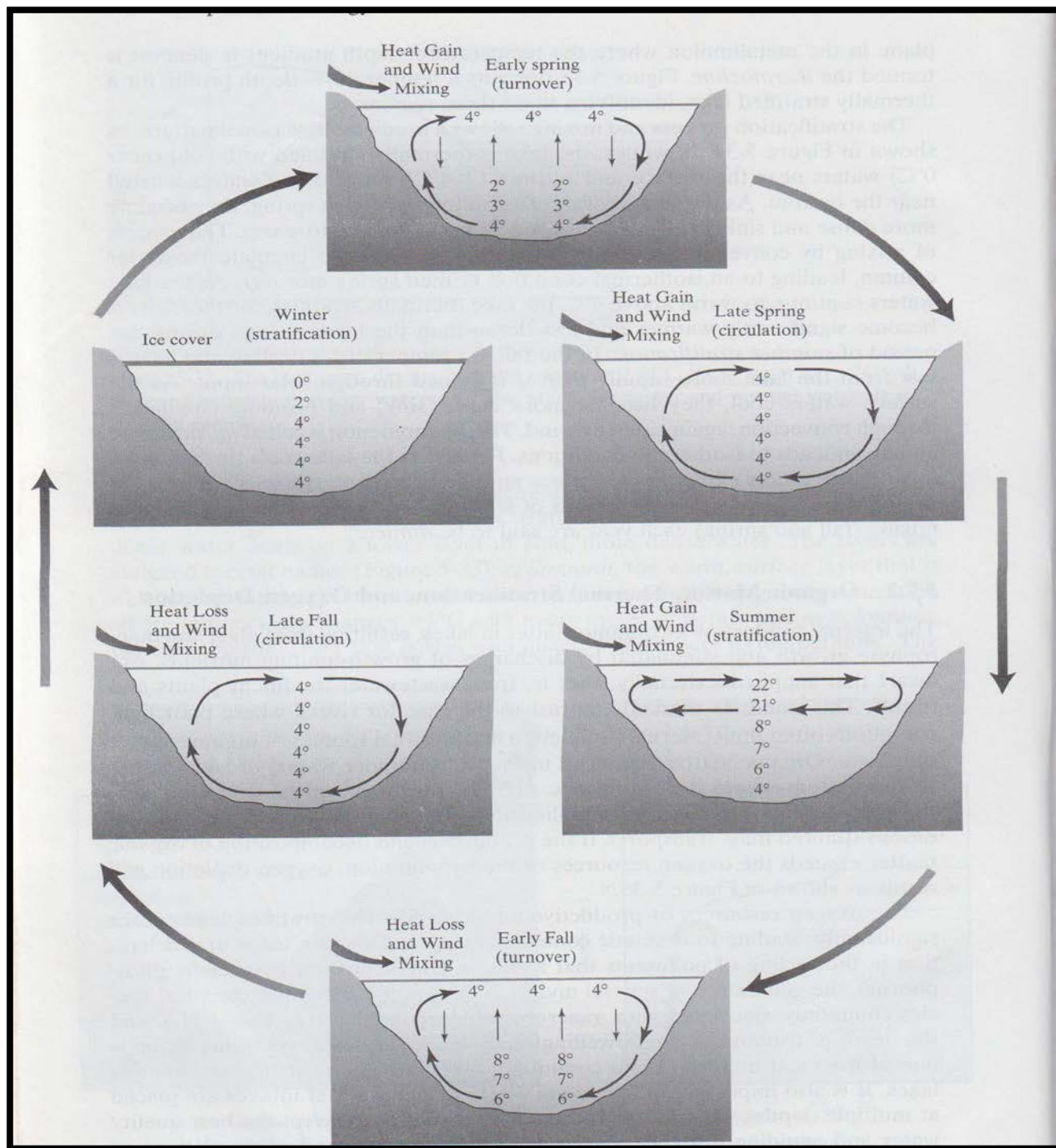
This allows a mixing of DO and nutrients throughout the lake

Going from summer to winter **fall overturn**

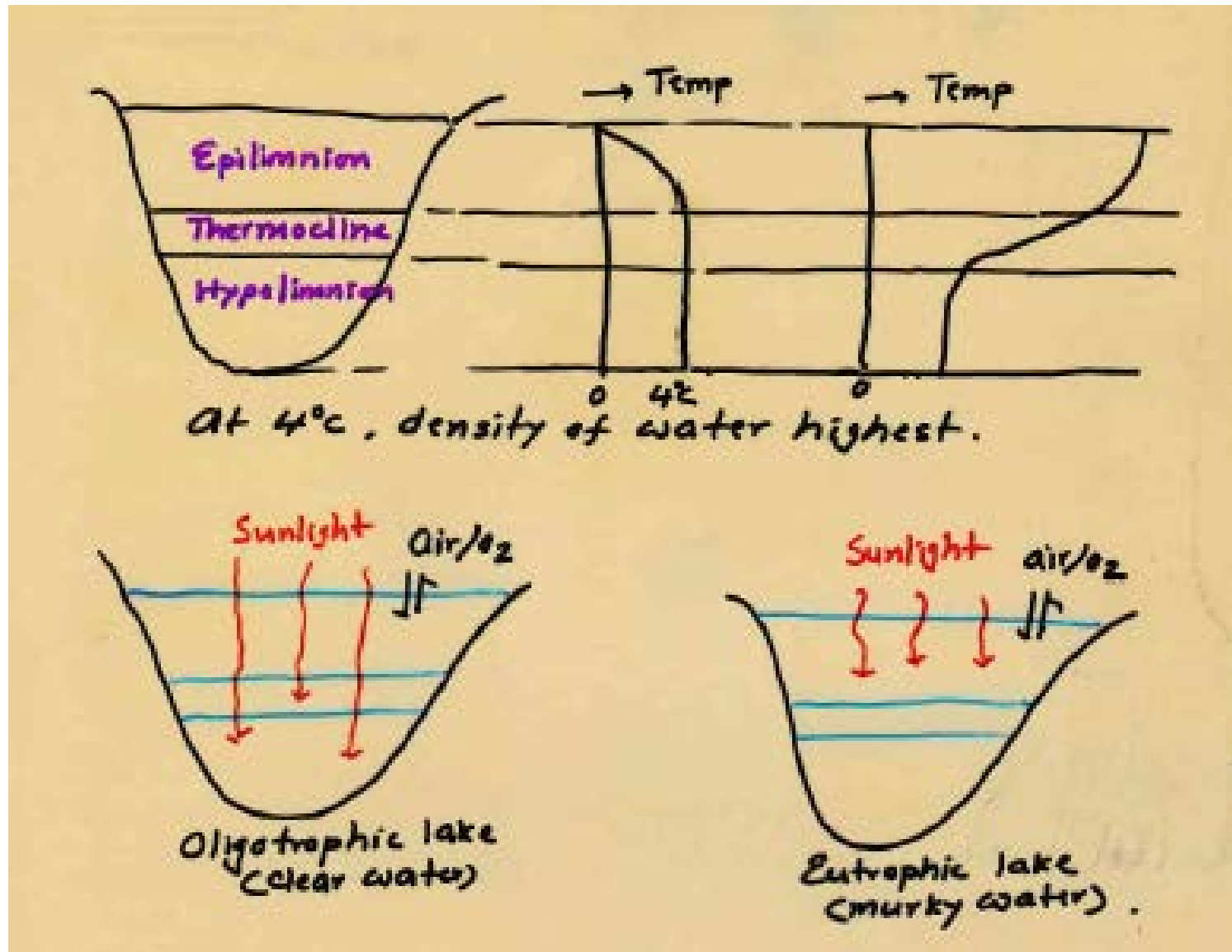
Going from winter to summer **spring overturn**

The effects of winter stratification is not as severe as summer stratification

The cycle of Stratification, Turnover and Circulation in Temperate lakes



Thermal Stratification in Lake



Thermal Stratification in Lake

- Hypolimnion: - cutoff from epilimnion by stratification
- Photosynthesis is the only source of O_2
 - Photosynthesis occurs if sunlight reaches hypolimnion.

In oligotrophic lake, some photosynthesis will occur in hypolimnion (because water is clear and sunlight will reach).

But in eutrophic lake, almost no photosynthesis will occur due to absence of sunlight.

Thermal Stratification in Lake

Summer Stratification:

- Less O_2 available (O_2 holding capacity of water less), especially in eutrophic lake
- more O_2 demand, due to faster decomposition of organic matter.
- As DO begins to drop, it drives out fish to the upper layer which is warmer. Thus, fish that requires cold water for survival becomes the first victim.

Thermal Stratification in Lake

Winter Stratification:

- Adverse effect less, as metabolism rate is low (i.e., low O_2 requirement) and O_2 holding capacity of water is higher.

Water quality management in lakes

- Adding alum to precipitate phosphorus
- Dredging to remove phosphorus-rich sediments
- Copper Sulfate to kill excessive algal blooms, introduction of vegetation-eating fish, physical removal of algae by rakes
- Advanced sewage treatment options
- Diversion of effluent wastewater to streams
- Waste minimization (encouraging farmers to use small amounts of phosphorus fertilizers and to take action against soil erosion)