Lecture 5

CE 433

Excerpts from Lecture notes of Professor M. Ashraf Ali, BUET.

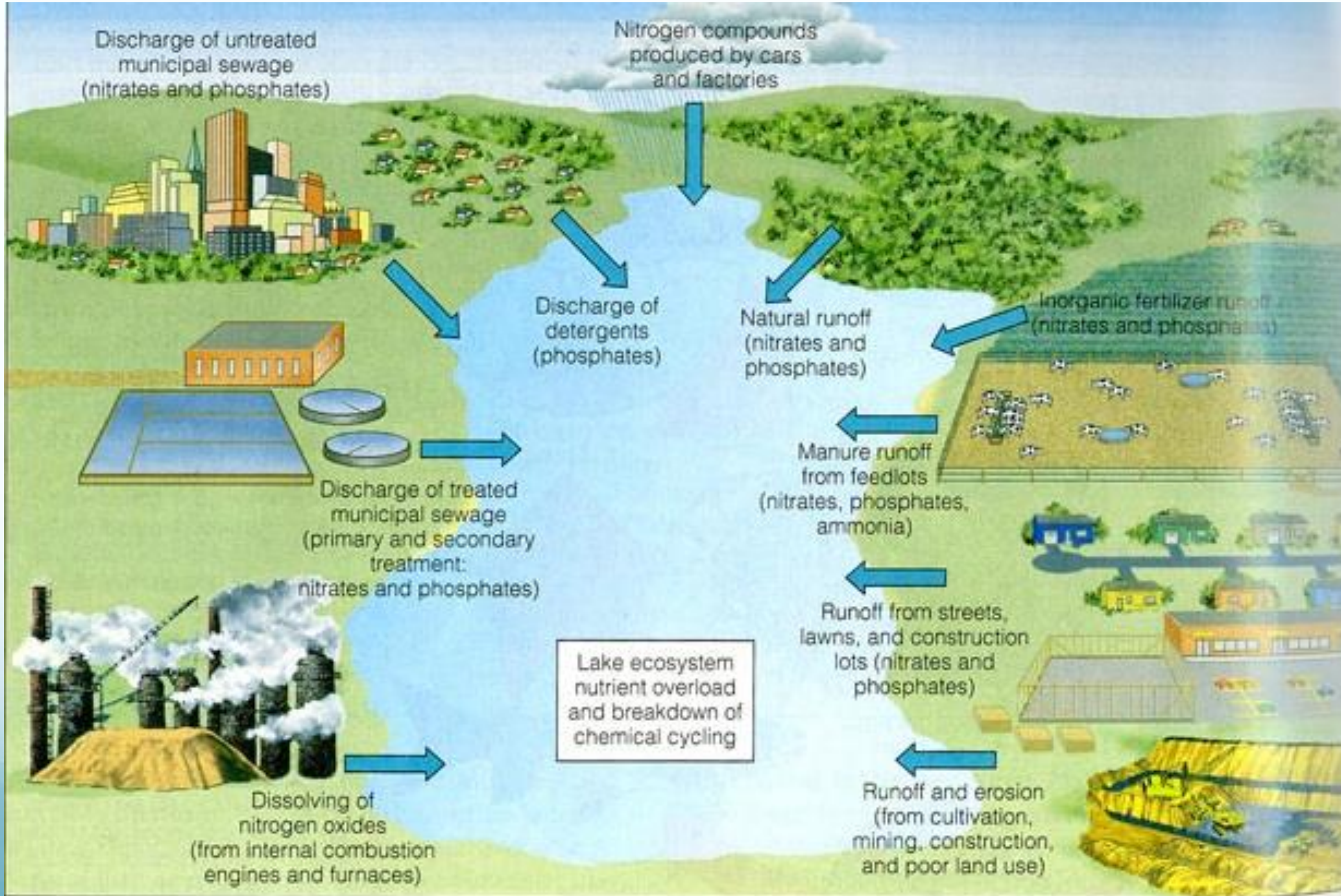
Surface Water Quality: Lakes and Reservoirs

- Lakes can be classified according to the degree of enrichment of nutrient and organic matter. Three classes are generally recognized:
  - Oligotrophic lakes: Are nutrient poor, have low levels of algae and organic matter, good transparency, and abundant O_2
  - 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.

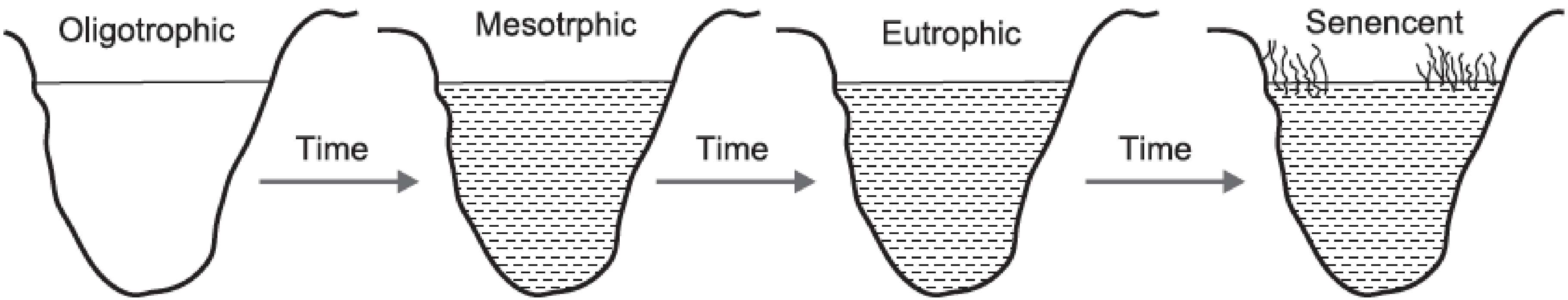
Eutrophication

- 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 and industrial wastewater). Such cases are called cultural eutrophication

Cultural Eutrophication



The Different Stages of the Life Cycle of a Lake



Deep, clean, cold nutrient-poor water, with very little aquatic life

Nutrients and sediment being to accumulate, increasing population of aquatic life

Nutrient rich, relatively shallow, warmer water with much plant growth and other aquatic organisms, algal blooms occur

Oldest stage of lake, very shallow, overgrown with emerging rooted plant life

Principal Factors Controlling Eutrophication

- 1) Availability of sunlight: Amount of light available is related to transparency – which in turn is related to the level of eutrophication
- 2) Concentration of Nutrients: Most important nutrients: C, N, P.
  - C -> not usually limiting
  - N,P -> Usually limiting
- Important terms:
  - Euphotic zone: top layer of water in a lake, where plants produce more O_2 by photosynthesis than they remove by respiration
  - Profundal zone: bottom zone
  - Light compensation level: transition between two zones

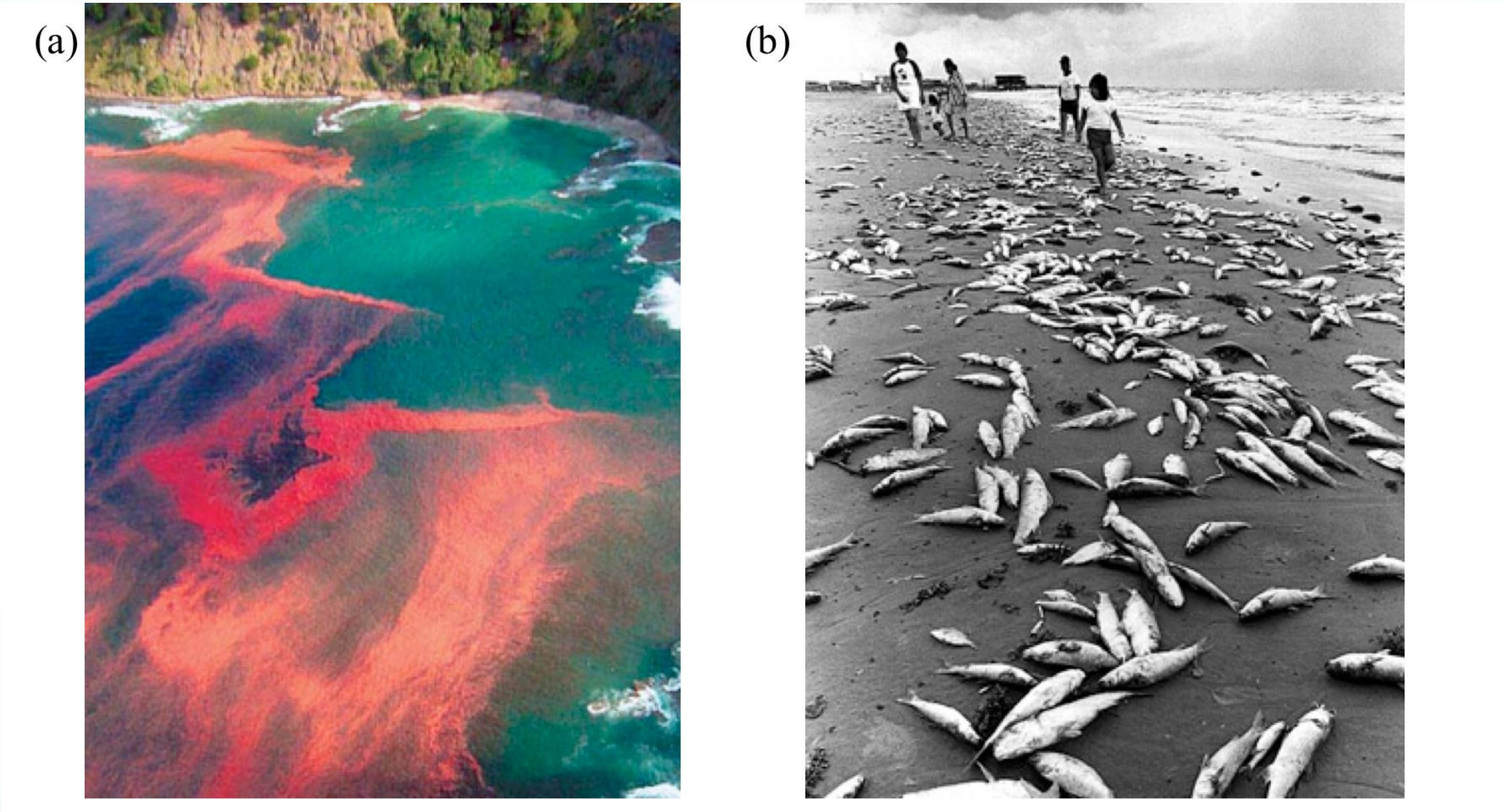
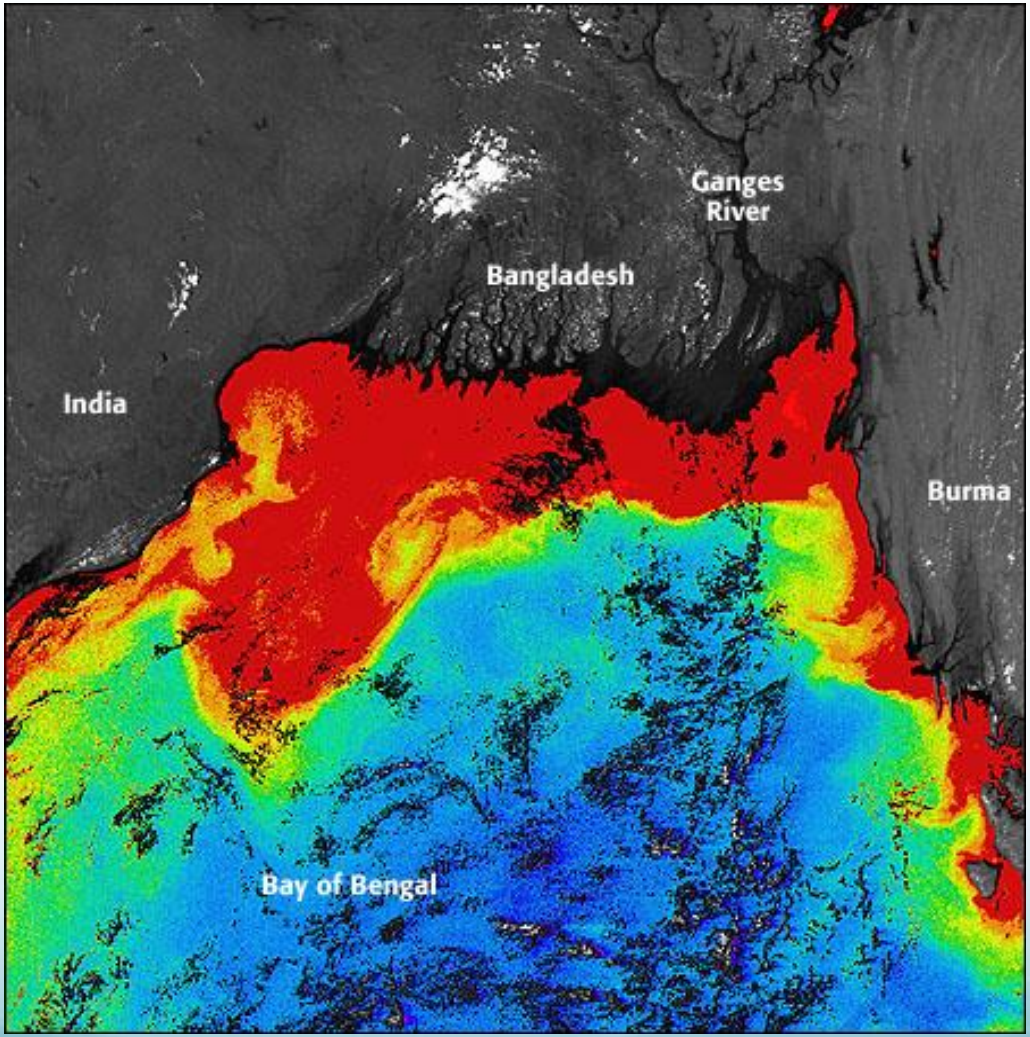


Figure 11.16 (a) A spectacular "red tide" bloom (non-toxic) of Noctilucascintillans in New Zealand. (Photo by M. Godfrey) (b) Dead fish from a Kareniabrevis bloom in Texas. At high concentrations, toxins produced by this organism can cause massive fish kills. (Photo by Brazosports) (Image source: Woods Hole Oceanographic Institute).

Algal Bloom in Bay of Bengal and its Human Health Implications



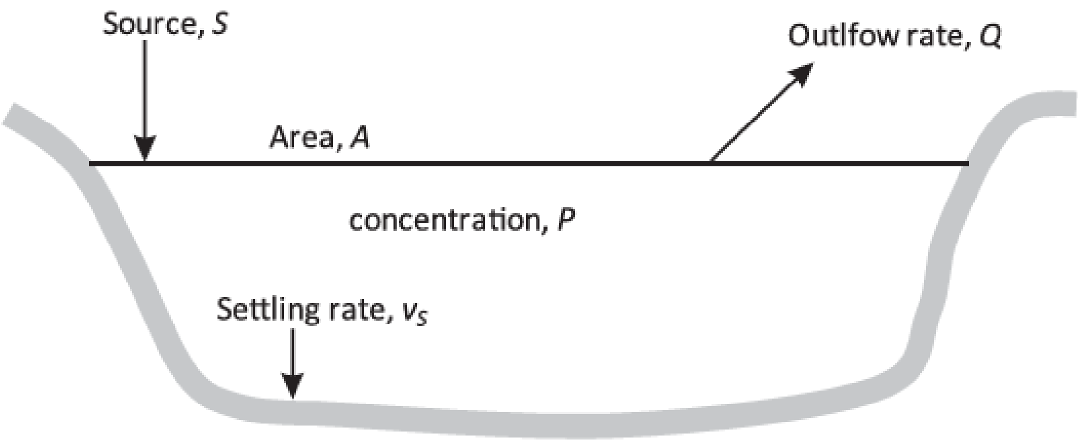
Simplified Representation of algal Photosynthesis

- $106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+ \rightarrow C_{106}H_{263}O_{110}N_{16}P + 138O_2$; =>N/P
- Usually if N/P> 20, P is limiting nutrient
- If N/P< 5, N is limiting nutrient
- Minimum concentration required for algal bloom: P= 0.015 mg/L ; N = 0.3 mg/L
- Susceptibility of a lake to Eutrophication:
  - Check concentration of P and N, compare with minimum required for eutrophication
  - Check ratio of N/P to determine limiting nutrient

Simple Phosphorus Model for Lakes

- Since phosphorus is the most common limiting nutrient for eutrophication, research mostly centered around its availability and significance in the lake environment
- Phosphorus can enter the lake from a variety of sources, including the incoming streamflow, runoff from adjacent lands, and industrial or municipal point sources. It is removed by both settling into sediments and by flowing out with the stream flow leaving the lake

Simple Phosphorus Model for Lakes



P = Phosphorus concentration 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

Mass balance of P in the lake,

$V\, dP/dt = S - v_s.A.P - Q.P$

Under steady-state condition, dp/dt = 0

$\Rightarrow S = v_s.A.P + Q.P$

$\Rightarrow P = S / (Q + v_s.A)$

Note: difficult to measure or estimate v_s ; usually varies from 3-30 m/yr

Problem

- A lake fed by a stream also receives wastewater.
  - $A = 100 \times 10^6\ m^2$
  - $Q_w = 0.4\ m^3/s$
  - $P_w = 10.0\ mg/L = 10.0\ g/m^3$
  - $Q_s = 20\ m^3/s$
  - $P_s = 0.0\ g/m^3$
  - $v_s = 10\ m/yr = 3.17 \times 10^{-7}\ m/s$

i) Estimate average P concentration in lake

ii) Estimate P removal rate at a treatment plant to keep P concentration below 0.01 mg/L

Thermal Stratification & its Impact on DO

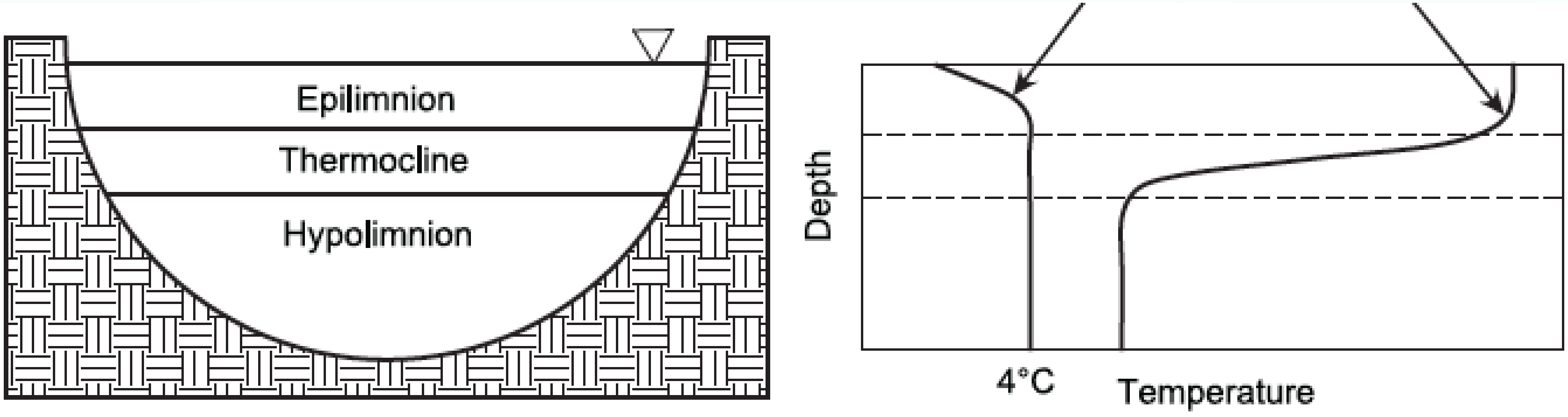


Figure 11.19 Thermal stratification of a lake showing winter and summer stratification

- At 4degreeC, density of water is highest
- Oligotrophic lake (Clear water, sunlight reaches at bottom)
- Eutrophic lake (Murky water, sunlight does not go beyond Thermocline)

Thermal Stratification & its Impact on DO

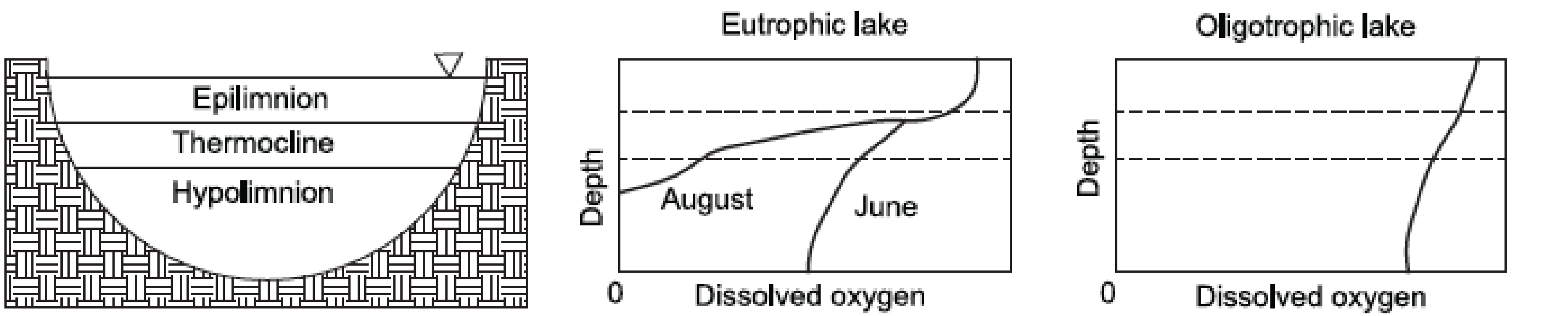


Figure 11.20 **Dissolved oxygen profiles under the conditions of the summer thermal stratification for eutrophic and oligotrophic lakes.**

- 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 & its Impact on DO

- 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
- Winter Stratification:
  - Adverse effect less, as metabolism rate is low (ie, low O_2 requirement) and O_2 holding capacity of water is higher.

Water Quality Management in Lakes

- Primary objective of controlling cultural eutrophication is to control release of P into lakes
  - Controlling industrial and municipal discharge
  - Controlling phosphorus fertilizers from agricultural runoff
  - Controlling seepage from septic tanks
  - Avoiding phosphorus based detergents
- Reversing or slowing the eutrophication process can be achieved such as
  - precipitating phosphorus with additions of aluminum (alum),
  - removing phosphorus-rich sediments by dredging or even sealing the bed or bottom of the lake using perforated membrane-like materials in order to prevent exchange of phosphorus between water and sediment