Nutrient Cycling in an Aquatic Ecosystem

2.1 Productivity
2.2 Oxygen
2.3 Salinity
2.4 Carbon
2.5 Nitrogen
2.6 Phosphorous
2.7 Iron
2.8 Sulphur
2.9 Silica
Phosphorous in Freshwaters

• Phosphorous plays a major role in biological metabolism. In comparison to other macronutrients required by biota, phosphorous is least abundant and commonly is the first element to limit biological productivity.

• Many quantitative data exist on the seasonal and spatial distribution of phosphorous in streams and lakes and the loading rates to recipient waters from drainage basins.

While concentration of $P_S$ (Soluble Phosphorous) and $P_T$ (Total Phosphorous) of oligotrophic lakes exhibit little variation with increasing depth, eutropic lakes with strongly clinograde oxygen profiles commonly show a marked increase in phosphorous content in the lower hypolimnion.
Phosphorous in Freshwaters

- **Orthophosphate** ($\text{PO}_4^{3-}$) is the only directly utilizable form of soluble inorganic phosphorous. **Phosphate** is extremely reactive and interacts with many cations to form relatively insoluble compounds.

- A large proportion of phosphorous in freshwaters is bound in organic phosphates.

- The range of total phosphorous in freshwaters is large, from $< 5 \mu g/L$ in very unproductive waters to $> 100 \mu g/L$ in highly productive waters.

- Most uncontaminated freshwaters contain between 10 and 50 $\mu g/L$ total P/L.
Where does phosphorus come from?
Phosphorus – external sources

• Nonpoint sources
  – Watershed discharge from tributaries
  – Atmospheric deposition

• Point sources
  – Wastewater
  – Industrial discharges
Phosphorus – nonpoint sources

• Watershed discharges from tributaries
  – Strongly tied to erosion (land use management)
  – Stormwater runoff (urban and rural)
  – Agricultural and feedlot runoff
  – On-site domestic sewage (failing septic systems)
  – Sanitary sewer ex-filtration (leaky sewer lines)

• Atmospheric deposition
  – Often an issue in more pristine areas
  – Arises from dust, soil particles, waterfowl
Phosphorus – point sources

• Wastewater
  – Municipal treated wastewater
  – Combined sewer overflows (CSOs)
  – Sanitary sewer overflows (SSOs)
• Industrial discharges
Phosphorus – internal sources

- Mixing from anoxic bottom waters with high phosphate levels is closely tied to iron redox reactions
  - $O_2 > 1\text{ mg/L}$ – Insoluble ferric (+3) salts form that precipitate and settle out, adsorbing $PO_4^{-3}$
  - $O_2 < 1\text{ mg/L}$ (anoxic) – ferric ion reduced to soluble ferrous ion ($Fe^{+2}$) – allowing sediment phosphate to diffuse up into the water
- Wind mixing (storms and fall de-stratification) can re-inject high P water to the surface, causing algal blooms
Phosphorus – Lake budget
Nutrients – phosphorus cycle

• Major pools and sources of P in lakes
  – “Natural” inputs are mostly associated with particles
  – Wastewater is mostly dissolved phosphate
  – P is rapidly removed from solution by algal-bacterial uptake or by adsorption to sediments
Phosphorus cycling – major sources

- Sewage
  - Dissolved
- Tributaries and deposition
  - Particulate
- Erosion
  - Particulate
- Sediments
  - Particulate and dissolved
Phosphorus cycling – internal recycling

- Rapid $\text{PO}_4^{\text{-3}}$ recycling
  - Bacterial uptake
  - Algal uptake
  - Adsorption to particles
  - Detritus mineralization
  - Zooplankton excretion
  - Fish excretion
Phosphorus cycle – major transformations

- The whole phosphorus cycle

Iron in Fresh Waters

- The most common form of iron in natural waters is hydrated ferric hydroxide (Fe OH₃).

- Under low pH and low redox potential, ferrous diffuse from the sediments and accumulate in anaerobic hypolimnetic water of productive lakes.
Iron in Fresh Waters

- Iron is an essential micronutrient to freshwater flora and fauna
- Under restricted availability of iron, photosynthetic productivity can be limited.
- Certain chemosynthetic bacteria can utilize the energy of inorganic oxidations of ferrous salts in relatively inefficient reactions involving carbon fixation.
- Other autotrophic and heterotrophic iron oxidising bacteria deposit oxidised iron. These bacteria are restricted to zones of steep redox gradients between reduced metal ions and oxygenated water.
Iron Cycle in Fresh Waters
Sulphur Cycle in Aquatic Ecosystems

• Sulfur is one of the components that make up proteins and vitamins. Proteins consist of amino acids that contain sulfur atoms. Sulfur is important for the functioning of proteins and enzymes in plants and animals that depend upon plants for sulfur. Plants absorb sulfur when it is dissolved in water. Animals will consume these plants, so that they will take up enough sulfur to maintain their health.

• Most of the earth’s sulfur is tied up in rocks and salts or buried deep in the ocean in oceanic sediments.

• Sulfur can also be found in the atmosphere. It enters the atmosphere through both natural and human sources.

• Natural resources can be for instance volcanic eruptions, bacterial processes, evaporation from water, or decaying organisms.

• When sulfur enters the atmosphere through human activity, this is mainly a consequence of industrial processes where sulfur dioxide (SO2) and hydrogen sulphide (H2S) gases are emitted on a wide scale.
Sulphur Cycle in Aquatic Ecosystems

Vertical distribution of sulphate and hydrogen sulphide for stratified lake is depicted in the figure below.

Under oxic conditions, as in the case in many oligotrophic and mesotrophic lakes, H$_2$S is absent and SO$_4^-$ concentration change little with depth.
Sulphur Cycle in Aquatic Ecosystems

• When sulfur dioxide enters the atmosphere it will react with oxygen to produce sulfur trioxide gas (SO3), or with other chemicals in the atmosphere, to produce sulfur salts.

• Sulfur dioxide may also react with water to produce sulphuric acid (H2SO4). Sulphuric acid may also be produced from demethylsulphide, which is emitted to the atmosphere by plankton species.

• All these particles will settle back onto earth, or react with rain and fall back onto earth as acid deposition. The particles will then be absorbed by plants again and are released back into the atmosphere, so that the sulfur cycle will start over again.
Sulphur cycle

A schematic representation of the sulfur cycle:
Sulphur cycle in natural waters
Silica Cycle in Aquatic Ecosystems

- The silica cycle is similar to phosphorus in that there is no atmospheric reservoir as with nitrogen and carbon.
- Silica occurs in relative abundance in natural waters as dissolved silicic acid and particulate silica.
- Diatom algae assimilate large quantities of silica and markedly modify the flux rates of silica in lakes and streams.
- Utilization of silica in the trophogenic zones of lakes by diatoms often reduces the epilimnetic concentrations
2. Silica and lake trophic status.

- Figure 14-16 of Wetzel presents a stylized view of Si distribution in oligotrophic and eutrophic lakes. Lake Erie is a famous example of the consequences of phosphorus based eutrophication leading to the complete exhaustion of dissolved Si.

When the concentration of silica is reduced below about 0.5mg/L, many diatoms species cannot compete effectively with non-siliceous algae, and their growth rates decline until silica supplies are renewed, usually during autumnal circulation.