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River Water Quality

Section **2a**: Hydrology & Ecology of Running Waters

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Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
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ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

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Hydrology & Ecology of Running Waters

Physical & Chemical Factors

Section Contents

Section Goals

- To show which are the main hydro-morphological, physico-chemical, chemical & biological parameters that characterize rivers and streams.

Introduction

- The geologic origin of a river or lake sets the limits for the morphometry or shape of its basin
- Physical, chemical, & biological factors form a discernible structure despite the aquatic ecosystem being in continual motion
- Discharge & Current interact with the substrate to determine the streambed's structure. A variety of habitats are largely determined by gradient and substrata, over a relatively short distance
- Physical structures in streams may have a regular vertical and horizontal periodicity. The periodicity of riffles and pools in the streams may be a regular periodic chemical recycling , the nutrient spiralling causing a great biotic variability
- Horizontal meanders occur in the flatter portions due to the water seeking the least energetic path
- Biological structure of streams depends on spatial patterns of drift (alive invertebrates & algae with no attachment to substrate) & detritus (dead organic fragments coated with bacteria, fungi protozoans etc mainly in lake sediments and estuarine environments)

Introduction

- Chemicals & nutrients in water from:
  - ✓ Erosion
  - ✓ Sediment re-suspension
  - ✓ Watershed leaching (urban-forest-agricultural areas)

  modify the chemical environment & alter the morphometry

- Abiotic factors = parameters in water analyses not directly linked to living organisms (e.g. temperature, pH, D.O., conductivity, turbidity) that act as guides of water quality & the kind of flora & fauna expected to live in & around

Introduction

- **Pollution**: Direct or indirect introduction as a result of human activity, of substances, vibrations, heat or noise into the air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment (European Community Water Policy 1996).

- **Eutrophication** (natural or human caused): Accumulation of nutrients in water and associated sediments, which lead to an excessive growth of algae (phytoplankton & periphyton) & higher plants (macrophytes) with multiple effects. The source of nutrients may be a variety of point & diffuse sources.

Water - H_20

Chemically & Physically & Biologically Unique:

- 3 phases (gas-liquid-solid) at atmospheric temperature & pressure
- Strong hydrogen bonds
- High heat capacity, high heat fusion and vaporization
- Conducts heat more readily as a liquid
- Its solid phase is less dense than its liquid phase
- High surface tension (usable in cell membranes)
- Most common solute (dissolves a great variety of salts & other)
- Necessary in most chemical reactions in living systems

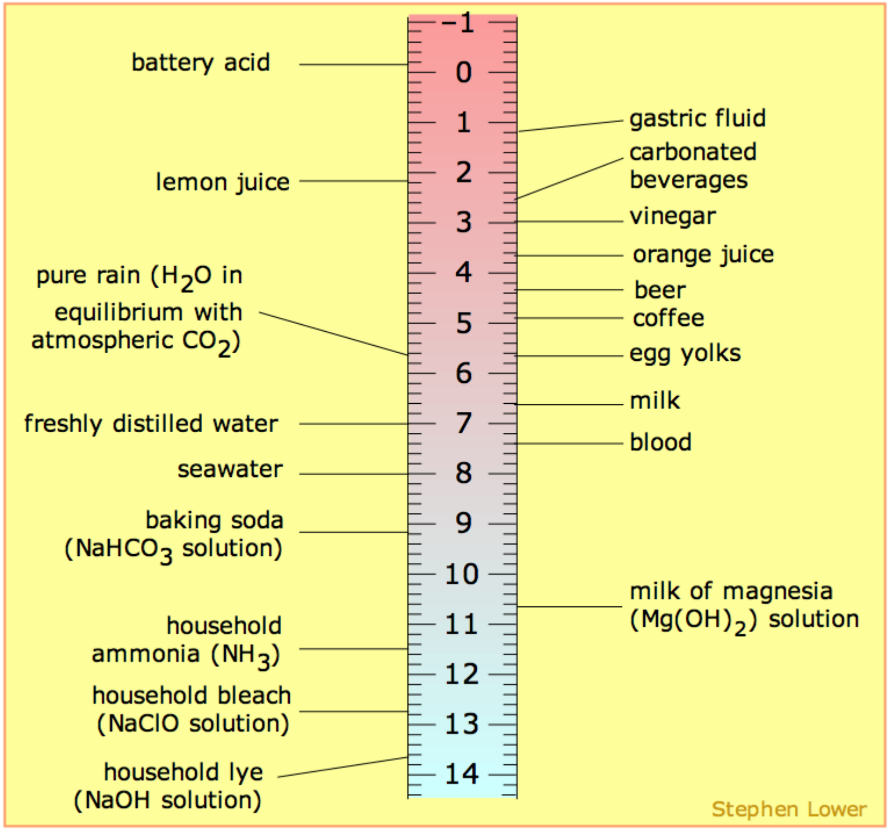
Temperature

Key environmental parameter:

- The sun is the natural heat resource and is lost by evaporation
- Affects distribution, behaviour & metabolic rates of freshwater organisms who all have their own temperature ranges for survival
- Affects many chemical processes
- Water diurnal changes - inversely of its volume
- Human activities that alter water temperature can have important effects on the biota

pH

- Is the logarithm of the reciprocal of the activity of the free hydrogen ions
- Is a measure of the acidity or alkalinity of a solution
- Depends on the salts and acids or bases that are dissolved in the water
- The pH of natural waters varies between the 2 – 12, although usually varies between 6 (< alkaline) & 9 (> basic)



- Modified pH scale showing common substances, from http://en.wikipedia.org/wiki/File:PH_scale.png by Lower Stephen, CC-BY-SA

Oxygen

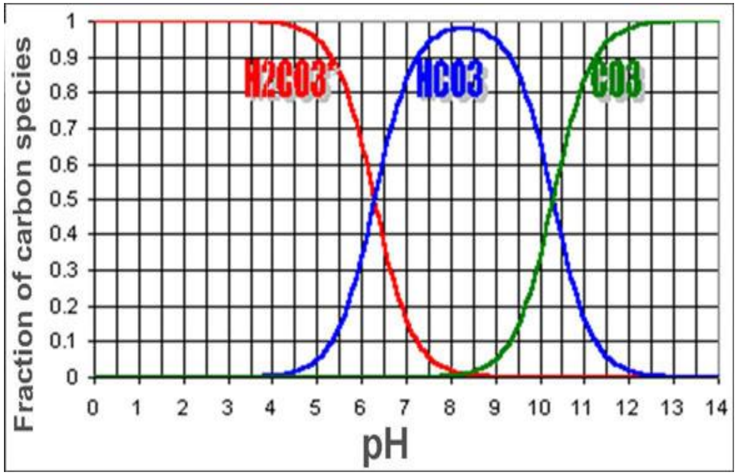
- Continually consumed in respiration by autotrophs & heterotrophs
- Produced by photosynthesis
- Its concentration in water (lakes & rivers) is limited compared to air (cold water contains less than 5% O_2 in a similar volume of air)
- When in low supply, is a limiting factor for life
- Reduction of oxygen saturation with the augmentation of temperature, alkalinity, atmospheric pressure and others
- Oxygen saturation depends on the organic load of the water and the photosynthetic organisms
- Organic matter inflow may result in serious depletion of dissolved oxygen due to decomposition caused by micro-organisms

Standards for oxygen in rivers	Dissolved O_2 (% saturation)	Comment
High (upland-lowland)	70-80	Supports high class fisheries
Good (upland-lowland)	60-75	Still high quality (Salmonidae)
Moderate (upland-lowland)	54-60	
Poor (upland-lowland)	45-50	Cyprinidae
Very poor	<10	No fish

Variations in dissolved oxygen give a good measure of their trophic state (UK Technical Report of the Advisory Group on the Water Framework Directive, 2008)

Carbon Dioxide – CO_2

- Carbon source for photosynthesis - product of respiration by plants & animals
- Entrance in aquatic ecosystems with diffusion from air near the surface, sediment dissolution & respiration
- Dissolves in water easily producing carbonic acid (H_2CO_3), which dissociates into various fractions (HCO_3^-, CO_3^-) depending upon the pH
- Free CO_2 necessary to maintain HCO_3^- in solution is called equilibrium of CO_2
- CO_2 limitation limits photosynthesis during calm days in productive waters



H_2CO_3 speciation with pH variation (ARMS K. 1994 . “Environmental Science”Saunders Clege Publishing).
)

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Biochemical Oxygen Demand – BOD

- The amount of oxygen and carbon dioxide provides a convenient measure of organic production, decomposition and organic enrichment of the water
- **Biochemical Oxygen Demand** (BOD_5) is measured to evaluate the organic load. Is an empirical measurement & focuses on the oxygen required by the microorganisms to decompose the organic load in five days in the dark and at 20 ^oC.
- Organic load is proportional to the oxygen needed for its decomposition.
- BOD level of 1-2 ppm is very good, 3-5 ppm is moderately clean, 6-9 ppm is polluted, >10 ppm is very polluted with organic waste

    - Instead of BOD, Chemical Oxygen Demand is used for faster measurement by oxidizing the organic matter in a sample of water (couple of hours)

Alkalinity

- HCO_3^- is the most common carbonate within the usual range of pH values of rivers (6-9)
- Concentration of these ions is strongly related to Ca^{++} concentrations which reflect the weathering of limestones ($CaCO_3$) and dolomites ($CaCO_3$, $MgCO_3$). When these rocks are present the risk of acidification is low.
- HCO_3^- concentrations naturally range from 0 - 350 mg L^{-1} in streams (<100 km^2) & 10 - 170 mg L^{-1} in major rivers (100 000 km^2)

Salinity

- Is the salt content of a water body (a measure of saltiness) & determinative of the organisms that will be found there. The density of water (measured with hydrometer) is related to the amount of salt dissolved in it.
- The salinity is determined from the density & water temperature and is a parameter measured for **brackish waters only** (parts per thousand parts of water-‰). **For fresh waters conductivity is measured instead**.
- Saltwater plants & animals have a salt content inside their cells equal or less than the salinity of the surrounding water. They have mechanisms for maintaining their salt balance. In brackish waters live plants & animals that can tolerate changes in salinity.

Acidification

- Is the process when rainwater with augmented acidity, increased by the presence of sulphur dioxide (SO_2) & nitrogen oxides (NO_X) (atmospheric pollutants originating mainly from fossil fuel combustion) affects a surface water system
- These pollutants are carried by winds from urban, mining, thermo-electric power plants & industrial emission sources. During rainfall the acidic pollutants are washed out as sulphuric and nitric acids over vast areas, and may affect pristine location hundreds or thousands of kilometres away from pollutant sources
- Acidified waters are characterized by a major decrease in biological density & diversity. Regional areas at risk from acid rain have been estimated by combining the source areas and the occurrence of sensitive soils in wet & humid region.

Conductivity

- Conductivity of a water sample is a measure of its ability to carry an electric current. More impurities (total dissolved solids) in water, the greater its electrical conductivity. By measuring the conductivity, the amount of total dissolved solids in the sample can be determined
- To convert the electrical conductivity (microSiemens/cm) to the concentration of total dissolved solids (ppm) in the sample, the conductivity must be multiplied by a factor of between 0.54 and 0.96 for natural waters
  - Widely accepted: TDS (ppm) = Conductivity (microSiemens/cm) x 0.67

Total Dissolved Solids - TDS

- Is a measure of the total amount of major ions in water.
- TDS are highly variable in surface waters
- There is no global reference value that can be used to assess the pollution level
- TDS concentrations are <u>generally</u> inversely proportional to river discharge (Q)
- TDS can rise proportionately with flow (Q) <u>in arid regions</u> where leaching of salt deposits can occur during the rising stage of the flood.

Salts & Salinization of surface waters

- Positively charged ions (Cations) interact with negatively charged (Anions) and form Salts.
- The cations (Ca^{++}, Mg^{++}, Na^{+}, and K^{+}) & anions (Cl^{-}, $SO4^{--}$, HCO_3^{-}) are collectively known as major ions.
- Concentrations of these major ions are basic descriptors of water quality on which many criteria for water uses (such as drinking water, agriculture and industrial use) are based

Calcium, Magnesium & Potassium

- Calcium (Ca^{++}), is the most common cation found in surface waters, due to the geology (carbonate or gypsum deposits)
- Hard water is water containing compounds (carbonates and sulphates) of calcium & magnesium. The “total hardness” of the water is usually expressed as ppm $CaCO_3$ & focuses on the measurement of calcium and magnesium salts, which are not only carbonate or bicarbonate
- Magnesium (Mg^{++}) is not an indicator of pollution because its concentrations are not strongly influenced by anthropogenic activities
- Potassium (K^+) concentrations in rivers are very low even though it is affected by fertilizers. Naturally, it occurs from the solution of (poorly soluble) minerals (feldspar & mica)
- It is found in high concentrations downstream from major mining districts (e.g the Rhine, Weser & Elbe rivers)

Sodium & Chloride

- Both originate from natural weathering of rock, from atmospheric transport of oceanic inputs, from evaporation in arid areas & from anthropogenic sources
- Large rivers (as the Rhine) are affected by potash & salt mines as by urban & industrial wastes (Chlorine products, Water Treatment Chemicals etc)

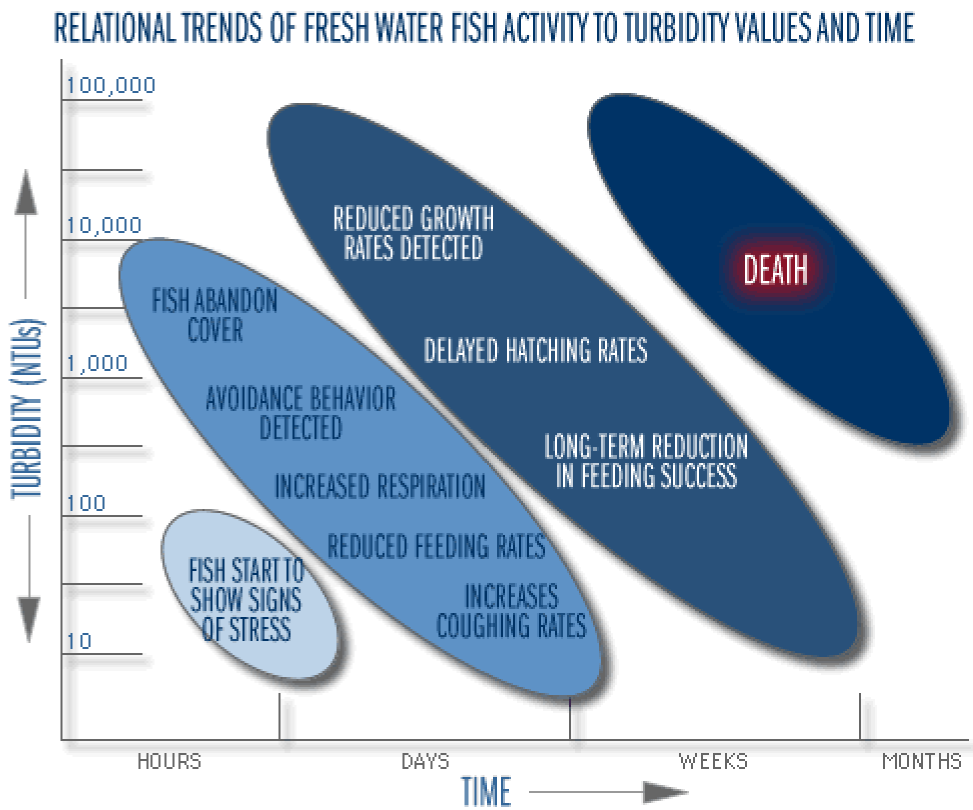
Sulphate

- The sulfate ion ($SO4^{--}$), linked to sulphur-bearing minerals, is highly variable in surface waters. Its concentrations can be increased by industrial and agricultural activities, mining, and oil exploration.

Suspended solids & Water Quality

- Total Suspended Solids (TSS) is comprised of organic and mineral particles that are transported in the water column. TSS is closely linked to land erosion and to erosion of river channels. Can be extremely variable, ranging from less than 5 mg L^{-1} to extremes of 30,000 mg L^{-1} in some rivers.
- TSS is often referred to as turbidity & is an important measure of erosion in river basins and of nutrients & chemicals transport through river systems
- High TSS (1000 mg L^{-1}) may greatly affect water use by limiting light penetration and can limit reservoir life through sedimentation of suspended matter.
- TSS-levels and fluctuations influence aquatic life, from phytoplankton to fish.
- In rivers, lakes and coastal zones these fine particles (<68 μm - usually toxic substances) are a food source for filter feeders which are part of the food chain, leading to bioaccumulation of chemical pollutants in fish & man. Also, can blanket the river bed, thereby destroying fish habitat
- In deep lakes deposition of fine particles removes pollutants from the overlying water by burying them in the bottom sediments of the lake.
- Time series of instantaneous TSS loads (kg s^{-1}) provides useful information about the physical behaviour of rivers as an indicator of discharge. The amount of sediment in transport can vary over three or more orders of magnitude during the year with a peak during short periods
- Turbidity shows the degree to which light traveling through water is scattered by the suspended organic and inorganic particles. The scattering of light increases with a greater suspended load. Augmented turbidity reduces light penetration – suppressing photosynthetic activity

Suspended solids & Water Quality



- The way Turbidity can have major impacts on the freshwater biota, from: http://www.waterontheweb.org/under/waterquality/turbidity.html. Turbidty: A Water Quality Measure", Water Action Volunteers, Monitoring Factsheet Series,UW-Extension, Environmental Resources Center. It is a generic, un-calibrated impact assessment model based on Newcombe, C. P., and J. O. T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management. 16: 693-727.

Nutrients

Nitrogen

- Is the most abundant element in living cells (1-10 % dry weight) reflecting the environmental availability
- NO_3 usable by organisms (except blue-green algae & bacteria that can use N_2 via nitrogen fixation)
- Denitrification (by bacteria) = reduction of nitrate to gas nitrogen. Important for the nitrogen budget of an aquatic ecosystem as additional oxygen source
- Sources: atmospheric diffusion, runoff, anthropogenic inputs from sewage discharge & agricultural fertilizers
- NO_3^- is the most common most & highly oxidized form of nitrogen in aquatic systems. The supply depends on the land-uses of the surrounding watershed.
- The second form of nitrogen is the nitrite ions (NO_2^-) that gets oxidized to NO_3^-
- NH_4^+ is much more reactive& toxic in alkaline environment. Is the main excretory product of aquatic animals & its concentration depends on the excretory rates, the plant uptake and the bacterial oxidation

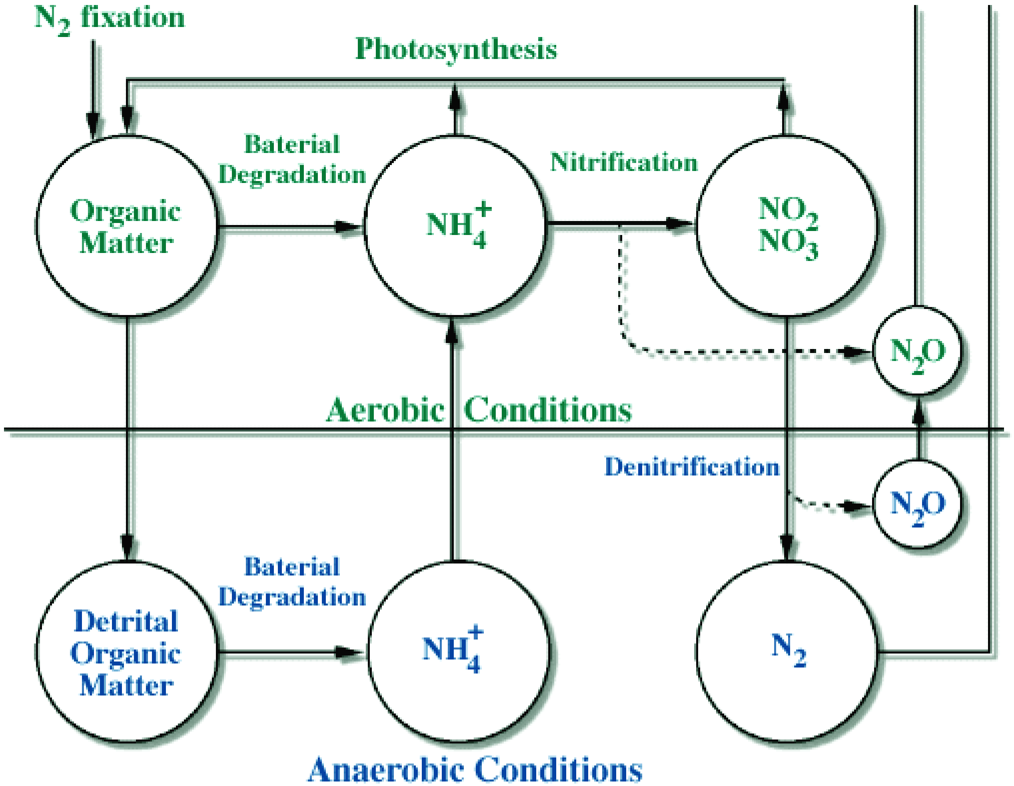
Nutrients

Nitrogen

- All natural waters contain some dissolved organic nitrogen (DON). DON is more abundant in eutrophic than in oligotrophic aquatic ecosystems. They are excreted like amino sugars by some plants and they are utilized as energy & nitrogen sources.
- Nitrogen in water can be divided into the following forms:
  Dissolved Inorganic Nitrogen (DIN) including NO_3^- NO_2^- NH_4^+
  Dissolved Organic Nitrogen (DON)
  Particulate Organic Nitrogen (PON)

Nutrients

Nitrogen



The processes controlling the conversion of one form of nitrogen into another in aerobic and anaerobic conditions,
R. Robarts & R. Wetzel, SIL News V. 29, Jan 2000 from*:* http://www.globalchange.umich.edu/globalchange1/current/lectures/kling/water_nitro/water_nitro.html#II

Nutrients

Phosphorus

- Minerals containing phosphorus (natural source) are geochemically scarce => the normal supply from rock breakdown is poor
- Has no gaseous form => there is no fixation
- Is bound to soil (forms compounds with the soil)

most common phytoplankton growth-limiting factor

- Algae can use orthophosphate PO_{4-3}
- Increase in phosphorus quantity can lead to an increase in algal growth (eutrophication)
- The primary anthropogenic sources of phosphates are sewage & artificial fertilizers
- Phosphorus occurs in the form of:
  - ✓ Dissolved Inorganic Phosphorus (DIP)
  - ✓ Dissolved Organic Phosphorus (DOP)
  - ✓ Particulate Organic Phosphate (POP)
  - ✓ Particulate Inorganic Phosphorus (PIP)

Nutrients

Phosphorus

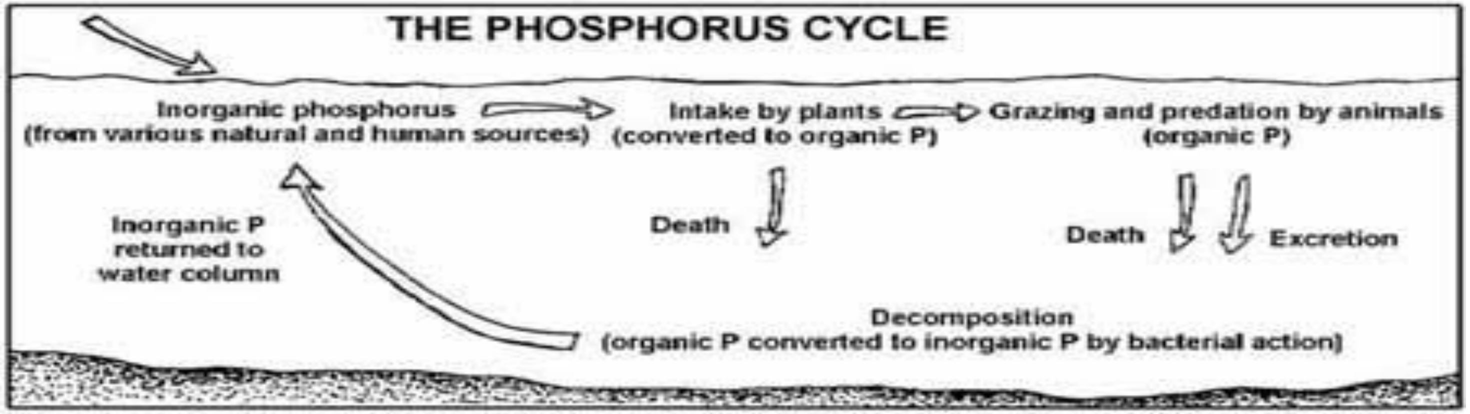


Diagram of the aquatic phosphorus cycle. US - EPA: Monitoring and assessing water quality, section 5.6 Phosphorus. From http://www.epa.gov/volunteer/stream/vms56.html

Amounts of Total phosphate-phosphorus according to EU legislation

Total phosphate-phosphorus	Effects
0.01 – 0.03 mg/L	Found in uncontaminated lakes
0.025 mg/L	Accelerates the eutrophication process in lakes
0.1 mg/L	Recommended maximum for rivers and streams

Nutrients

N / P ratio

- N & P can be limiting factors to plant growth
- N/P ratio varies widely & indicates which is likely to limit algal growth.
- A plant requires a ratio 16:1 by element (Redfield ratio- stable in algal tissue).
- When N/P ratios fall bellow 16:1 => nitrogen is the limiting factor,
- When N/P ratio is higher that 16:1 => phosphorus is lacking
- When N/P ratio is between 10:1 - 20:1 => joint limitations