ESCOLA SUPERIOR DA CETESB
GESTÃO DO CONHECIMENTO AMBIENTAL

2017

# Module 1 - Introduction to water quality

Classes supporting material:

- Sampling and Preservation of Water and Sediment Samples
- Water Quality Monitoring and Assessment

## Cursos e Treinamentos

*Gestão do Conhecimento*

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# Module 1 - Introduction to water quality

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- Sampling and Preservation of Water and Sediment Samples
- Water Quality Monitoring and Assessment

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São Paulo, Abril de 2017

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# Foreword

Water is one of the most important assets for biological activity and throughout the universe it has been sought out as something essential for life, yet it is unfortunately treated in an inconsequential way by most members of humanity. The human perception is that water is infinite and inexhaustible. Because of this, it is inadequately approached in ecological terms.

A full understanding of the correlation water-quality and quantity versus multiple uses - must be fully understood in order to change this behavior so as to leave future generations with possibilities for survival that unite their basic needs with environmental preservation.

The conception of a course of this magnitude indicates that there is a need for a continuous knowledge acquisition that requires topics that might gradually lead us to a comprehensive understanding of the natural aquatic environment (increasingly rare) and its progressive alterations, regarding external as well as internal metabolism in the aquatic ecosystem, in order to fully understand nature and the influence of human beings.

Based on these initial conceptualizations, the course will therefore be aimed at learning about the various types of aquatic environments and their main compartments, emphasizing intrinsic inorganic and organic characteristics, correlations between changes that are native and non-native in origin and those that are primarily considered to be natural environments without any anthropogenic interference.

Thus, over time, the knowledge acquired in each of these modules will lead to an increasingly richer understanding of the influence that human actions have on the balance of aquatic ecosystems.

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A Biologist at CETESB since 1980, Claudio Roberto Palombo graduated from the Institute of Biosciences at the University of São Paulo and has a bachelor’s degree in Ecology (1978). He also received a master's degree (1989) and doctorate (1997) from the Department of General Ecology in the Institute of Biosciences at the University of São Paulo. He has experience in limnology with an emphasis on altered environments. He is a University Professor and Technical Analyst of FEHIDRO Projects related to aquatic ecosystems and has developed methodologies for integrated weed management.

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# Summary



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# Introductory Aspects to Water Quality

Biol. Dr. Claudio Roberto Palombo

*Cadernos da Gestão do Conhecimento*

# General Introduction

Limnology, the area of science that studies fresh water bodies and inland waters, was established in the early nineteenth century and has been developing and amassing knowledge in order to be more and more able to meet the various growing human demands related to agriculture and industry.

As a consequence of these multiple activities, the water quality required to supply each of these demands will increasingly require knowledge that covers the water production starting point and its multiple uses up until its disposal at some place on the planet, which might be a point or diffuse release.

Due to the enormous amount of knowledge needed to fully comprehend the water cycle in this context, this content was divided into several chapters where discussions will touch upon themes such as the natural environment, free of anthropogenic interferences, and also themes such as the consequences that each human activity has on water bodies.

In this introduction, the theoretical technical aspects of the natural lentic and lotic limnetic zones, suffering no human interference, will be presented so that it during the course it will be possible to observe the modifications taking place at various levels of the aquatic environment within the ecosystem.

Therefore, a duplication of information may sometimes exist; however, each topic will be presented in a more detailed manner so that, at the end of the course, the student will have the ability to understand and evaluate the complex relationships among the various physical, chemical and biological environmental parameters at play in the dynamics of water environments on this planet called Earth (called the Ecosphere, in ecology).

# INTRODUCTORY ASPECTS TO WATER QUALITY

## I. Introduction

Limnology is the science that studies the "freshwater" aquatic environment, both in the lentic environment=the environment of still waters or of little movement such as lakes, ponds and reservoirs, and of the lotic environment=environment of busy waters such as rivers and rapids. This term is a compound of the Greek word *Límné*, meaning "swamp, lake, pond", plus the suffix *Logus*=study.

Thus, limnology is the part of environmental science that focuses on understanding how the aquatic environment behaves in its most diverse ecological aspects, meaning the correlation between the physical, chemical and biological parameters in the dynamics of the various water bodies that are found on our planet.

One concept that should always be kept in mind is that "every lake is one of the Earth's organs". This means that each aquatic environment should be considered as unique, comparable to each other, but never the same regarding their most diverse ecological aspects.

Throughout the history of environmental sciences there have been several attempts to classify aquatic environments. One of them established types according to geographic position, such as temperate and tropical, etc.; another one referred to the chemical aspects of water such as the absence or presence of dissolved oxygen during the year. Since neither the aquatic dynamics nor the geographic position could establish identical conditions, these attempts did not achieve the desired result, therefore making the classification of water bodies occur within a broader context that involves relevant ecological concepts.

Therefore, in Brazil, attention to these environments has been mainly related to waterborne diseases, mostly to those that provoked widespread epidemics, as observed throughout the country's history.

With regard to water requirements for aquatic ecosystems and for humans, relevant literature offers a number of values, depending on the location and the level of development. Normally, minimum and maximum values are set for various human activities, according to the internal and external physiological aspects (urine and feces); even according to the domestic and industrial activities taking place; food production and agriculture in general, etc.

## II. Limnology Activities

From its conception up to the present moment, limnology has been structured as a science, researching the metabolism of continental aquatic ecosystems, within the following stages:

- Analysis: investigation of environmental variables;

- Synthesis: energy and matter exchanges related to management and maximization;
- Holistic: interactions between aquatic and terrestrial ecosystems.

Using these concepts, research and studies for world aquaculture were oriented; fish farms, crustaceans farms and other organisms of commercial interest; minimization of the negative ecological effects of the creation of artificial lakes related to the inventory phases, viability, basic design, construction and operation; rational use of hydric resources; control of water quality for various purposes and recovery of aquatic ecosystems.

## III. Distribution of Water on the Planet

There are several tables in the literature, with the most varying values regarding water distribution in the most diverse terrestrial environments. The location of aquatic ecosystems, their respective volumes and relative percentage can be highlighted. Table 1 shows one of the examples found in the relevant literature.

Table 1 - Distribution of water on the Earth.

| Reservoirs | Volume ($km^3$) | Percentage (%) |
|---|---|---|
| Oceans | 1 320 305 000 | 97,24 |
| Icebergs and polar ice caps | 29 155 000 | 2,14 |
| Subterranean water | 8 330 000 | 0,61 |
| Lakes | 124 950 | 0,009 |
| Seas | 104 125 | 0,008 |
| Soil humidity | 66 640 | 0,005 |
| Atmosphere | 12 911 | 0,001 |
| Rivers | 1.250 | 0,0001 |
| **TOTAL** | **1 358 099 876** | **100** |

## IV. The genesis of lacustrine ecosystems

Nature constantly creates "holes" that are then filled up by water, thus forming new bodies of water, which is generally called the genesis of lacustrine ecosystems. (The case of rivers will be discussed later).

Within this concept, there are:

Lakes formed by differential movements of the earth's crust:

- Through epyrogenic movement

Characterized as a diastophic process (tectonism) of great amplitude, by slow movements upwards or downwards of great areas of the terrestrial crust that lead to the formation of continents; epirogeny. Figure 1 shows a design of tectonism, highlighting the respective geneses.


Figure 1 – Design of tectonism,

**Tectonism-pressure from the Earth's interior moves the crust upwards**
**It can be epyrogeny or orogeneny**

Planetary examples of such lakes are: the Caspian Sea and Lake Aral (Russia), Lake Okeechobee (USA), Lake Victoria (Central Africa) and Lake Kioga (East Africa).

- **Through tectonic faults**

They result from tectonic movements that cause irregularities in the earth's crust. Examples of this type are the following lakes: Baikal (Russia), Tanganyika, Edward and Albert (Africa), Tahoe (USA), Manacapuru Grande, Anamã, Badajós, Piorini and Mina (Brazil). Figure 2 shows the types of tectonic stress zones.

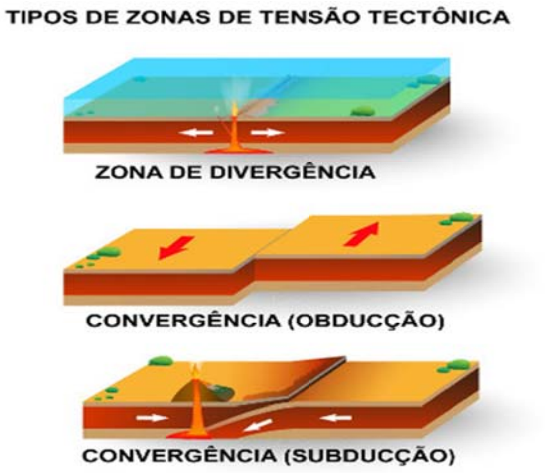


Figure 2 – Types of tectonic stress zones

**Divergence zone/convergence/obduction/convergence/subduction**

## Lakes of a volcanic origin

These lakes can be formed from the cone of volcanic discharge and/or damming of valleys due to the magma.

Figure 3 shows an example of a crater lake. Some examples include Big Soda (USA) and Rotomahana (New Zealand).

Figure 3 – Example of crater lakes

Figure 4 – Maar type lakes

Figure 4 shows an example of a "maar" type lake that emerges from subterranean gas explosions, followed by the sinking of the affected region's surface

Examples of this type found in Germany include Toten, Gemundener and Weifelder.

Kettle lakes are formed by an intense volcanic eruption with the destruction of the central cone. Some examples are the Crater lakes (USA), Bolsena and Albaner (Italy) and Toyako (Japan).

Figure 5 shows an example of these types of lakes.

Figure 5 – Example of a kettle lake

Figure 6 – Example of a lake with a volcanic dam

Volcanic dam lakes are formed in the preexisting valleys through solidified lava. Examples include the Kivu and Bunyoni lakes (Central Africa).

Figure 6 shows the presence of a volcanic dam

## Glacial lakes

Glacial lakes were formed during the last glaciation, approximately 10,500 years ago and are located in high latitude regions, in temperate regions. In this way, they are presented in several configurations, such as:

Lakes formed in a cirque result from freezing and thawing, are small and shallow and common in the mountains. They possess a circular or amphitheater configuration.

Examples are: Watendlath (England), Wildseelodersee (Austria) and there are several in the Alaskan mountain range.

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Figure 7 shows a lake in a cirque.

Figure 7 – Example of a lake in a cirque

Figure 8 – Lake formed by the damn of a moraine

The lakes in moraine dammed valleys were formed by the obstruction of valleys through sediment transported by glaciers, usually blocks of clay.

Examples include: Lucerne (Switzerland), Constance (Germany-Switzerland), Finger (USA).

An example can be seen in Figure 8.

Fjord lakes result from the excavation of valleys on the cliffs of mountains through glacial erosion. They are long, narrow and deep.

Example: lakes in western Norway

A view of this type is shown in Figure 9.

Figure 9 – Example of a lake in fjords

Figure 10 –Example of a lake formed on a glacial landform

Lakes of glacial sedimentation terrain can be formed through an existing depression in locations with ancient continental glaciers; blocks of ice that detach from glaciers and a mix of the previous ones. Lake Grosse Ploner (Germany) and Barret (USA) are examples in the first one; in the second and third is Lake Pluss (Germany).
Figure 10 demonstrates an example of the first type.

**Lakes formed by the dissolution of rocks (lakes of dissolution or erosion)**

They result from the accumulation of water in depressions formed from the solubilization of limestone, sodium chloride or calcium sulfate called salt rock and gypsum respectively.

Lakes formed from the erosion of limestone or chasm rocks are found in the limestone regions of the Alps, parts of Florida and on the Balkan Peninsula (Yugoslavia). Examples: Lakes Luner (Austrian Alps), Seewli (Swiss Alps), Deep, Iamonia and Jackson (USA), Vrana (Balkan Peninsula). They are normally small and circular lakes; However they may merge with each other, as in the example of Lake Muten (Switzerland). In Brazil, in Uberlândia, there is the example of Lake Poço Verde (MG); Other lakes with these characteristics are found on the west coast of France and Siberia. Figure 11 shows a lake and the rock of spisa salt (halite).

Figure 11 - Rock of spisa salt solubilization lakes

Lakes formed by the dissolution of gypsum rocks. Examples: La Girotte, Tignes (French Alps), Magalhães and Uberaba (Brazil). A lake and gypsum rock are shown in Figure 12.


Figure 12 - Gypsum salt solubilization lakes

Biological activity also actively participates in the "construction" of natural retention systems, making a suitable habitat for their ecological needs. In this way, we can register beaver activity in Canada, USA and Europe. These animals use branches, mud, etc., Example: Lakes Beaver and Echo (USA).

Figure 13 shows beaver dam lakes, highlighting the two main species that have this behavior.

Figure 13 – Lakes formed by beavers

**(Castor candensis and Castor fiber)**

The lakes formed by the impact of meteorites are rare. The impact power of the astrolite on the Earth’s surface has a direct relation with the size of the cavity produced. Example: Negra Lagoon (Argentina) and Lake Chubb (Canada). Figure 14 shows an example of a lake and a meteor.

Figure 14 – Example of a lake formed from the impact of a meteorite and example of meteors

**Lakes formed from river activity**

Rivers can form lakes in various ways, among which are:

Dam Lakes - the main river transports amounts of sediment deposited along the bed, causing its level to elevate and, as a consequence, damming. Examples are: Lake Dom Helvécio, Carioca, Belgo Mineira, Thirty-Three and Jacaré (mid Rio Doce) and a number in the Amazon on solid ground.

An example is shown in Figure 15.

Figure 15 – Example of a dam lake

Oxbow or meandering lakes - some rivers have sinuous curves called meanders. The lakes are formed by the isolation of these meanders from erosion and sedimentation of the margins (in German "Altwasser"). These types of lakes are quite common in Brazil, especially in the Pantanal of Mato Grosso and in the Amazon Region and they are known as "sacados". In São Paulo, they can be seen in the Mogi-Guaçu River as well as in the Paraíba do Sul river. Figure 16 shows the formation of a lake by the interception of a meander, as an example.

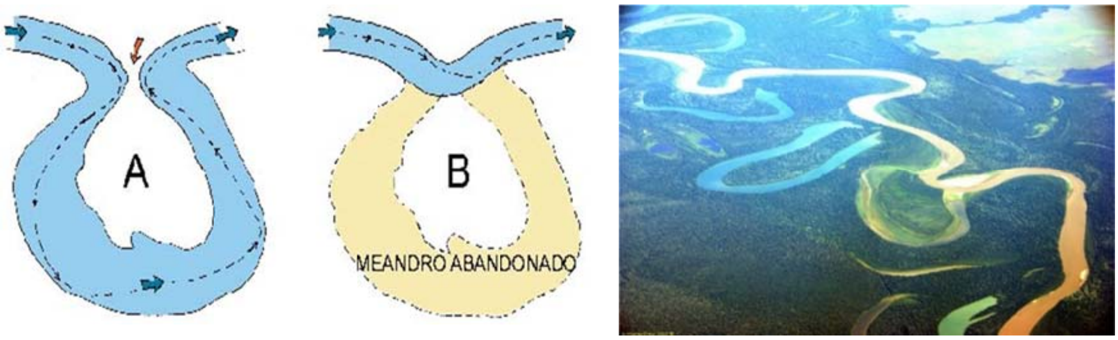


Figure 16 – The formation of a lake from an abandoned meander; view of an oxbow lake.

Figure 17 – View of a flood plain lake

Flood lakes - formed from great fluctuations in water levels, primarily through precipitation. They are referred to as "baías" (bays) in the Mato Grosso Pantanal and as "lagos de várzeas" (flood plain lakes) in the Amazon Floodplain. There are numerous examples including Lake Castanho, Maicá, Redondo, Poção, etc.

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It is also interesting to point out that intercommunication can occur between the various lakes in the rainy season, forming a single system. They remain isolated and or communicate through channels in droughts.

Figure 17 shows an example.

Lakes formed by wind activity (Wind Dam) - shaped by deposits of sand in a river and occurring frequently in the Brazilian northeast. Example: Lake Abaetê, in Bahia and in the small lagoons on the southern coast of Santa Catarina.

Lake Abaetê (BA) can be seen in Figure 18.

Figure 18 – View of Lake Abaetê (BA)

### Lakes associated with the coastline (coastal pools)

In order to understand the dynamics of the formation of coastal lakes, given many forms in the literature, some configurations were formulated, such as:

Figure 19 – View of a cove lake

Isolation of a sea cove or inlet - formation of these lakes is based on the existence of *Cordões de Areia* that develop from rocky pontoons. Its progressive growth is due to marine sediment deposits and marine submersion from currents and waves. Examples include: Mangueira, dos Quadros (RS), Araruana, Saquarema. (RJ).

A view of this type can be seen in Figure 19.

Obstruction of river mouths from marine sediments - derive from the deposition of marine sediment at the mouth of small rivers or the estuary isolation of various rivers. Examples: Lake Mundaú and Manguaba (AL), Carapebus, Comprida and Cabiúnas (RJ).

This type of lake can be seen in Figure 20.

Figure 20 – View of a estuarine lagoon

Figure 21 – View of a coral reef intercepting a river

Obstruction of river mouths by coral reefs - this biological structure can dam the river mouths near the sea. Example - Lake Rodeio (AL), an obstruction formed by the São Miguel River.

Figure 21 demonstrates an example of this type.

Obstruction of river mouths by fluvial-marine sediments - originating from sediments with a fluvial and marine origin. Example - Lake Feia (RJ), Juparanã, Nova, Palminhas, Palmas (ES).

This type can be seen in Figure 22.

Figure 22 – View of a lake formed by mixed
View of lake formed by mixed deposits.

Figure 23 - View of a sandbank lagoon.

Depression among strips of sand that make up the sandbanks - they appear morphologically shallow and fed by small streams and rainwater. Example - Água Preta, Taí Lagoons. Grande e Pequeno, Periperi and Robalo (RJ).

A view can be seen in Figure 23.

**Dams and Dykes (anthropogenic origin)**

Several human activities interact with the natural environment in many ways. A very relevant example is the interception of lotic environments that get transformed into lentic ones. Such changes lead to significant changes in the dynamics of aquatic ecosystems. Thus, the individualized study of each new environment requires information from before its existence up to the final phase of implementation of the enterprise.

In view of this fact, all the civilizations that have or had a part in the history of man, executed projects that aimed at having constant and permanent water resources.

Therefore, this analysis of this subject requires great detail that will gradually get exposed during this course. Therefore, it will be cited here only in its didactic character.

It is also worth mentioning that due to the importance of this theme, several concepts might get be repeated during the course.

Figure 24 shows an example of a dam and a reservoir.

Figure 24 – Example of a dam and a reservoir

## V. Residence Time

Defined as the average amount of time a particle resides (passes) in a particular system; this measurement varies directly with the amount of substance that is present in the system according to the formula.

<u>Ability of a system to retain a substance</u>
Flow rate of the substance in the system
or

Where □ is used as the variable for residence time, $V$ is the capacity of the system, and $q$ is the flow for the system.

Table 2 describes one of the examples from literature, from the Water Residence Time.

Table 2 - Water residence time.

| Compartments | Residence Time |
|---|---|
| Oceans | 3.000 a 30.000 Years * |
| glaciers | 1 a 16.000 Years * |
| subterranean water | 330 a 10.000 Years *) |
| lakes and reservoirs | 1 a 100 Years * |
| salt lakes | 10 a 10.000 Years * |
| soil humidity | 2 weeks to 1 year |
| biological humidity | 1 weeks |
| atmosphere | 8 a 10 days |
| wetlands and ponds | weeks to 1 year |
| rivers and streams | 10 a 30 days |

*depends on the depth and other environmental factors

## VI. Continental Waters

Continental waters are those present on the surface of the Earth, being distributed in rivers, lakes and glaciers and most aquifers, with a salinity near zero, as opposed to sea water, which has a salinity of nearly 35 grams of dissolved salts per liter, in addition to the brackish waters, just as the water in estuaries, which has an intermediate salinity.

- Characteristics
  - High capacity for solubilization of organic and inorganic compounds;
  - Vertical and horizontal gradients through the uneven distribution of light, nutrients, temperature, gases (distribution of organisms);
  - Low content of dissolved salts → majority of hypertonic organisms → maintain the osmotic balance;
  - High density and viscosity (775 times denser than air) → organisms have profound morpho/physiological adaptations.

- Compartments
  - **Littoral region**
    - Contact between terrestrial and aquatic ecosystems (transition = ecotone);
    - Large number of ecological niches and food chains, both herbivores and detritavores (representatives: oligochaetes, molluscs, crustaceans, insects);
    - All trophic levels - considered as an autonomous compartment;
    - Little developed or absent in volcanic lakes;
    - Subdivided in eulitoral and sublitoral.
  - **Limnetic or Pelagic Region**
    - Characteristic communities: plankton and nekton;
  - **Deep region**
    - Absence of photoautrotrophic organisms;
    - Benthic community formed by oligochaetes, crustaceans, mollusks, insects;
    - Populational diversity and density depend on the amount of food and dissolved oxygen.
  - **Water/Air Interface**
  - **Communities: neuston (bacteria, fungi, algae) and pleuston (macrophytes and insects)**

In Figure 25, each of these compartments is shown.

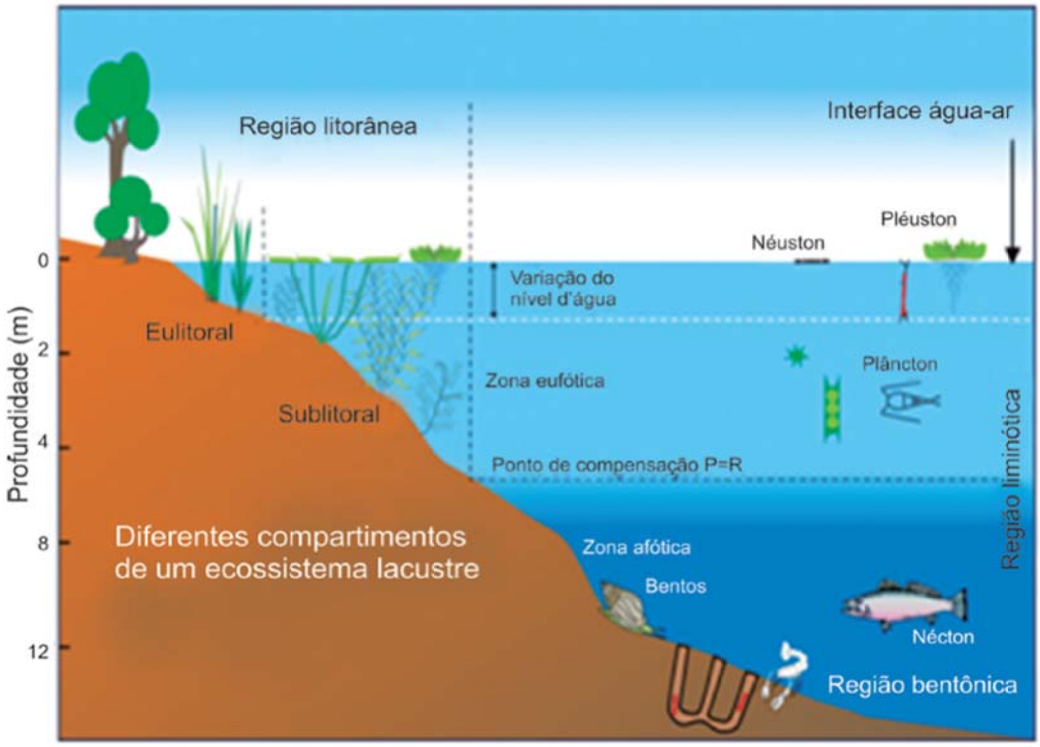


Figure 25 – A cut showing the various departments of a lacustrine ecosystem.

**Depth/Littoral Region/Water-Air Interface/Water level variation/Neuston/Pleuston/Plankton/Nekton/ eulitoral and sublitoral/aphotic zone, euphontic zone/compensation zone. Benthic region/limnotic region/Different compartments of a lacustrine ecosystem**

## VII. Physical and chemical properties of water and its limnological importance.

Discussing the importance of water in limnology would be extremely redundant; However, some pertinent aspects should be considered for a better understanding of aquatic ecosystems. (Figures 26 and 27)

Among these, we can highlight:

- The water molecule.

If you enter the term "water molecule" on any research site, you will see the enormous amount of information available. In view of this finding, only a few aspects, important for this course, will be considered.

Figures 26 and 27 show some of the properties of water, with a great interest in limnology, because they lead to environmental conditions that act directly on the behavior of the limnosphere (physical and chemical) and the biosphere (biological community).

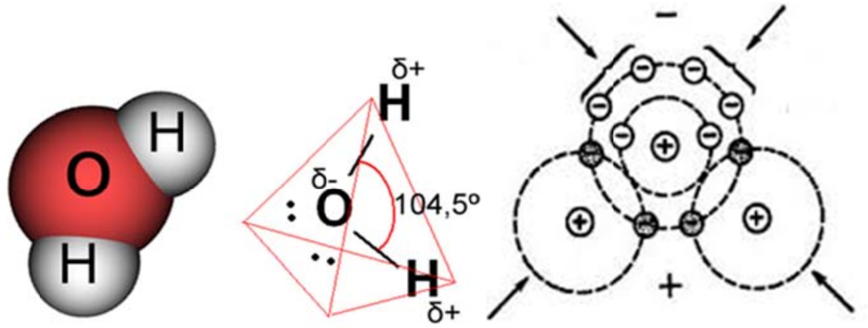


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Figure 26– Some characteristics of a water molecule with a focus on its structure.

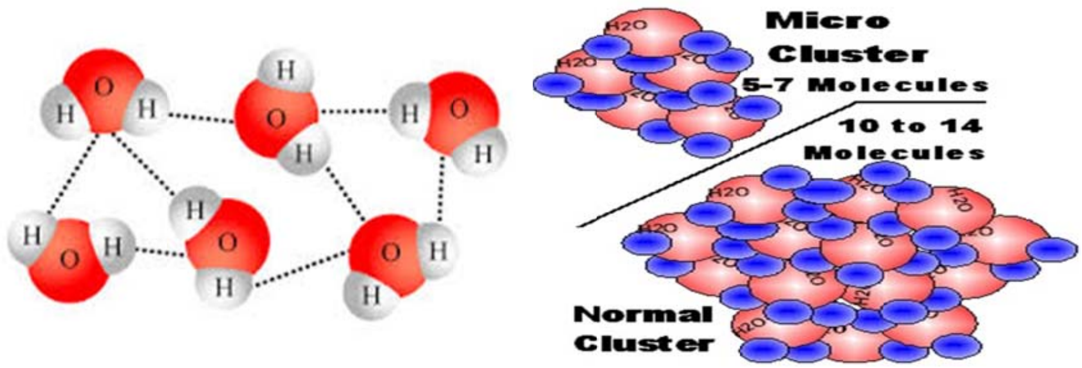



Figure 27 – The water molecules forming hydrogen points and a cluster.

❖ Water properties

Table 3 shows some of the properties of water, mainly related to its most significant limnological aspects.

Table 3 - Water Properties

| Property | Characteristic |
|---|---|
| Fusion point at 1 atm | 0,00 °C |
| Triple point | 0,01 °C, 4,60 torrg .$cm^3$ |
| boiling point 1 atm | 100,00 °C |
| critical point | 347,0 °C, 218 atm |
| solid density 0 ° C | 0,917 g .$cm^3$ |
| liquid density 0 ° C | 0,999 g .$cm^3$ |
| liquid density 4 ° C | 1,000 g .$cm^3$ |
| liquid density 10 ° C | 0,999 g .$cm^3$ |
| liquid density 25 ° C | 0,997 g .$cm^3$ |
| liquid density 100 ° C | 0,958 g .$cm^3$ |
| liquid heat capacity | 1,00 cal. $g^{1}$ . $°C^{1}$ |
| fusion heat 0 °C | 1,44 kcal . $mol'^{1}$ |
| dielectric constant 25 °C | 78,5 |

❖ The surface tension of water

Surface tension: a physical effect that occurs at the interface between two chemical phases, causing the surface layer of a liquid to behave like an elastic membrane. This property is caused by the cohesive forces between similar molecules whose vector result is different at the interface (Figure 28).

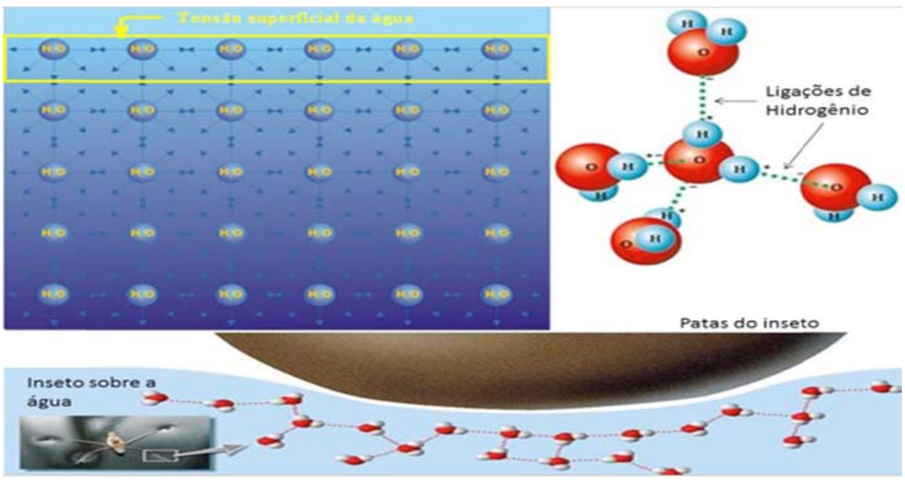



Figure 28 –Formation of surface tension and the ecological importance aspect.

- Viscosity of water

Viscosity: the property the fluids have corresponding to the microscopic transport of the quantity movement by diffusion; therefore, the higher the viscosity, the lower the speed at which the fluid moves. In the aquatic environment, the temperature and the percentage of dissolved salts must also be considered.

## VIII. Radiation in the Aquatic Environment

Figure 2 shows some aspects of respective angles of luminous incidence on a water body. The euphotic zones are also highlighted (where all the photic processes necessary for aquatic metabolism occur); the dysphotic zone, not indicated in the diagram, is where the compensation point occurs, that is, the point where there is enough light for the photosynthesis of the autotrophs and aphotics without the presence of light.

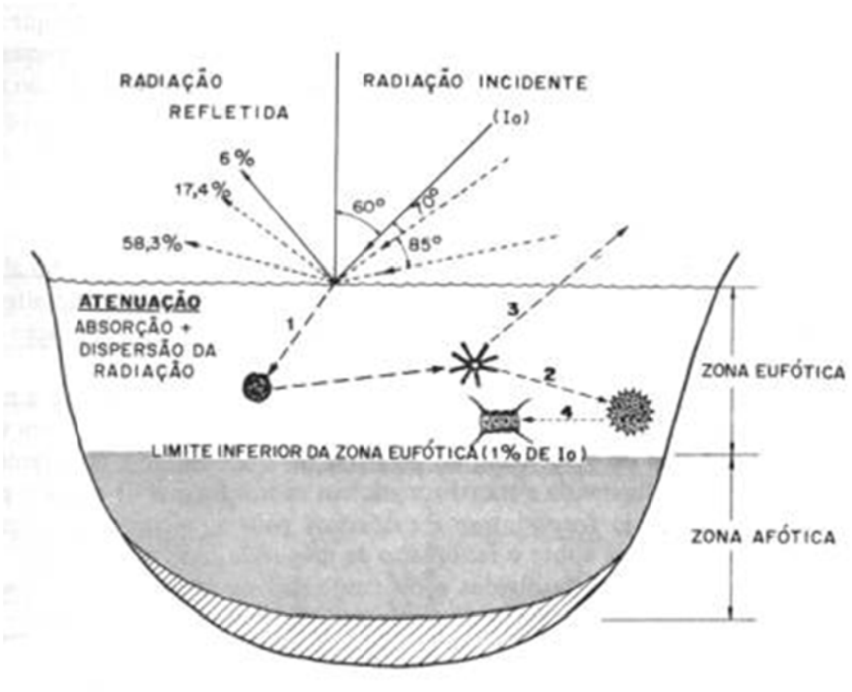
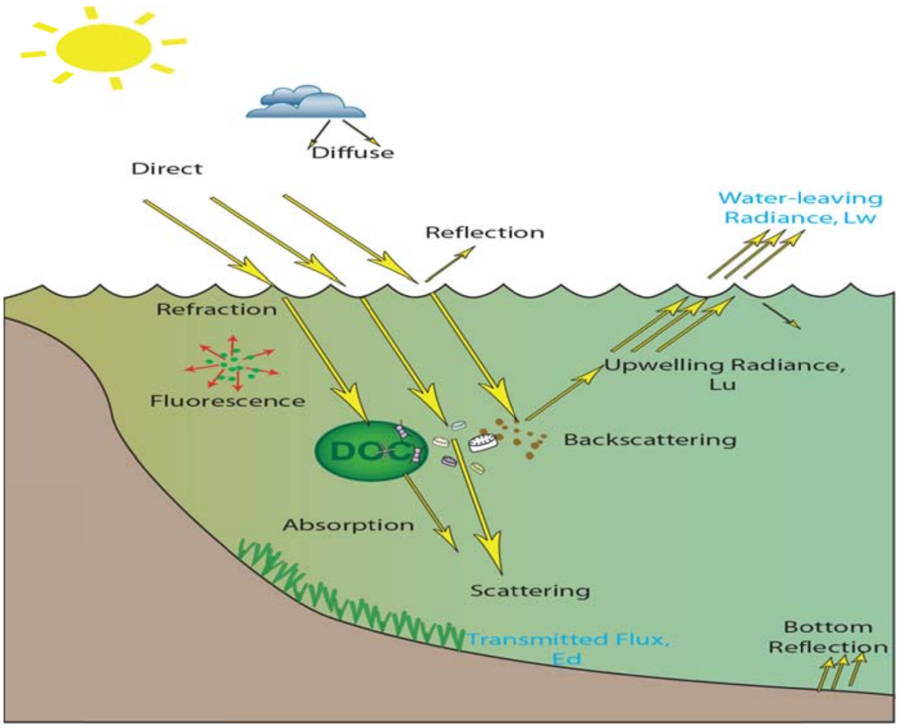



Figure 29– Diagram showing the behavior of solar radiation in an aquatic environment

**Reflected radiation/incident radiation/euphotic zone/aphotic zone/attenuation absorption and dispersion of radiation.**

Figure 30 shows some aspects of solar radiation on some components of the aquatic environment:




Due to the complexity of this theme in the context of aquatic ecosystems, a few more relevant aspects will be taken into account for a better understanding of their importance and environmental effects.

- ❖ Absorption processes

    - o ) Radiation (Figure 31)

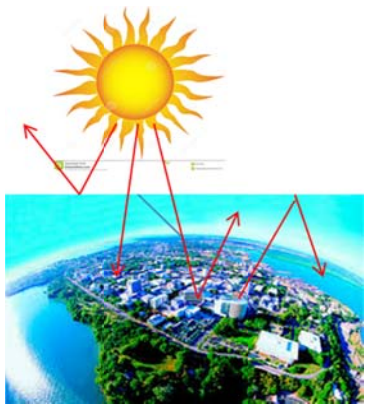


Figure 31–Image showing solar radiation on the planet, where part of it is absorbed by the aquatic biome, as shown in Figures 32 and 33.

- Water molecule (Figure 32)

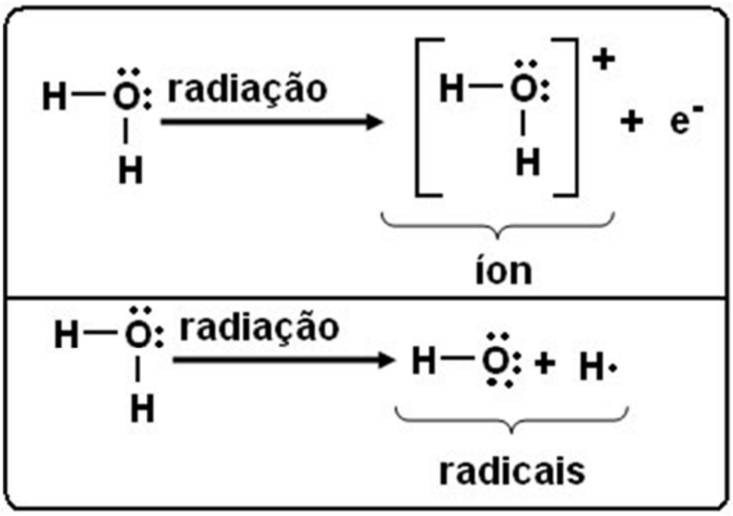



Figure 32– Esquema sobre o efeito da radiação sobre a molécula de água.

Display of the effect of radiation on a water molecule.

**Radiation/radicals**

Figure 33 highlights the luminous incidence undergoing reflection, dispersion and absorption within the energy dynamics of the aquatic ecosystem. The following items should be emphasized, in the context dispersion and absorption:

- Humic substances *
- Photosynthetic Organisms (with chlorophyll)

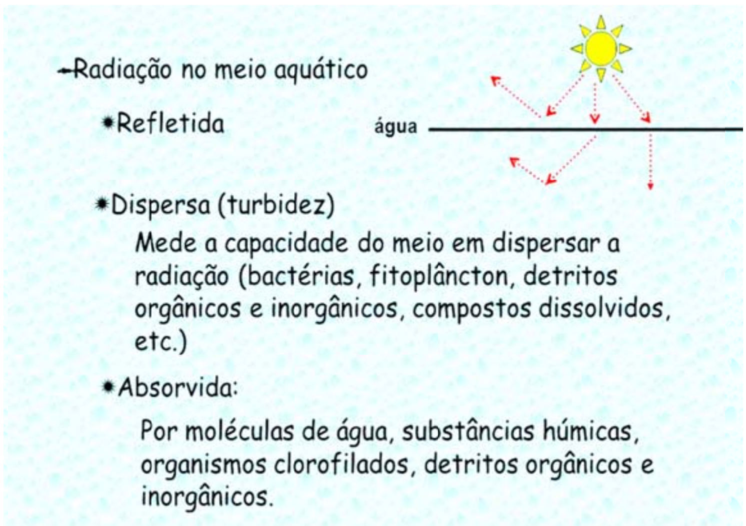



Figure 33 – Image showing the dispersion and absorption of diverse components of the hydric ecosystem.

**Radiation in the aquatic environment/reflected/disperse/turbidity/measures the capacity of the environment to disperse the radiation/bacteria, phytoplankton, organic and inorganic waste, dissolved compounds, etc./absorbed/by water molecules, organic and inorganic waste**

* Humic substances: a complex, dispersed and heterogeneous mixture of various organic compounds originating from the remains of necromasses left by decomposers (microorganisms = fungi and bacteria). Therefore, humic substances exist in a wide variety of structures and chemical composition (named as the universal substance of ecosystems).

- Radiation dispersion (Figure 34)

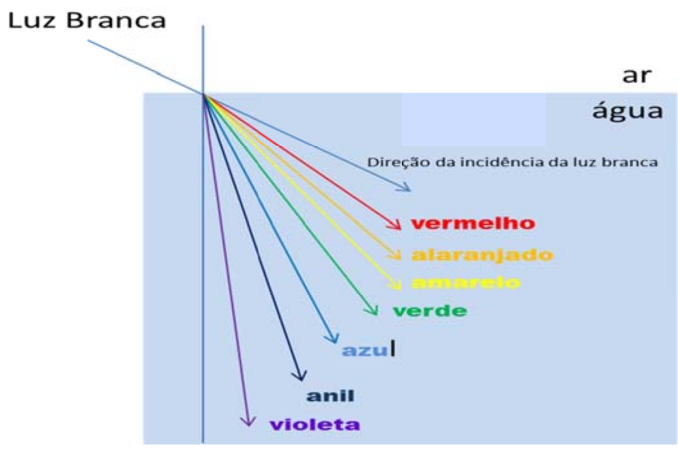



Figure 34 – Image of water dispersion according to the wave length.

**White light/air/water/direction of white light/red/orange/yellow/green/blue/indigo/violet**

- Evaluation of transparency through the Secchi disk *

Figures 35A and B show the equipment (Secchi Disc) and an example of a transparency measurement using this equipment, respectively.

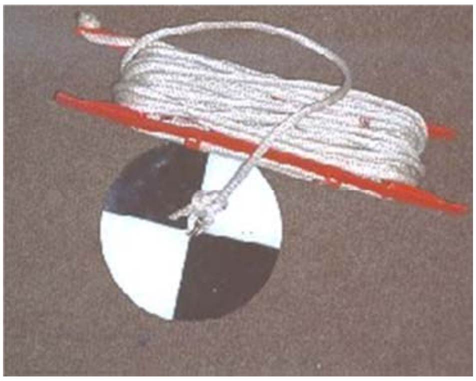


Figure 35 A –Secchi disk tied with a graduated cord.

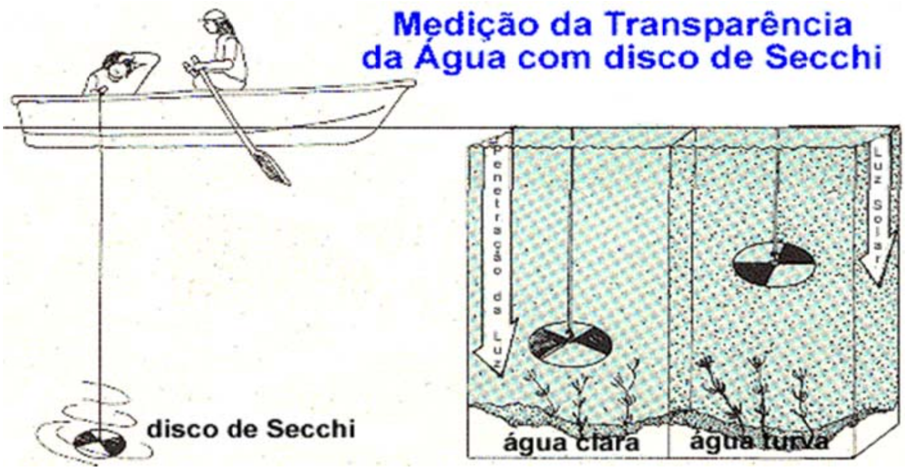



Figure 35B – Measuring water transparency with a Secchi disk.

* Secchi Disk - (created in 1865 by Pietro Ângelo Secchi): a disk constructed to measure the transparency and turbidity levels of water bodies like oceans, lakes, and rivers. Traditionally, the disc comes mounted on a stick, rope or tape so that it may be gradually lowered down into the depths of the waters.

## IX. Radiation and its multiple effects on inland waters

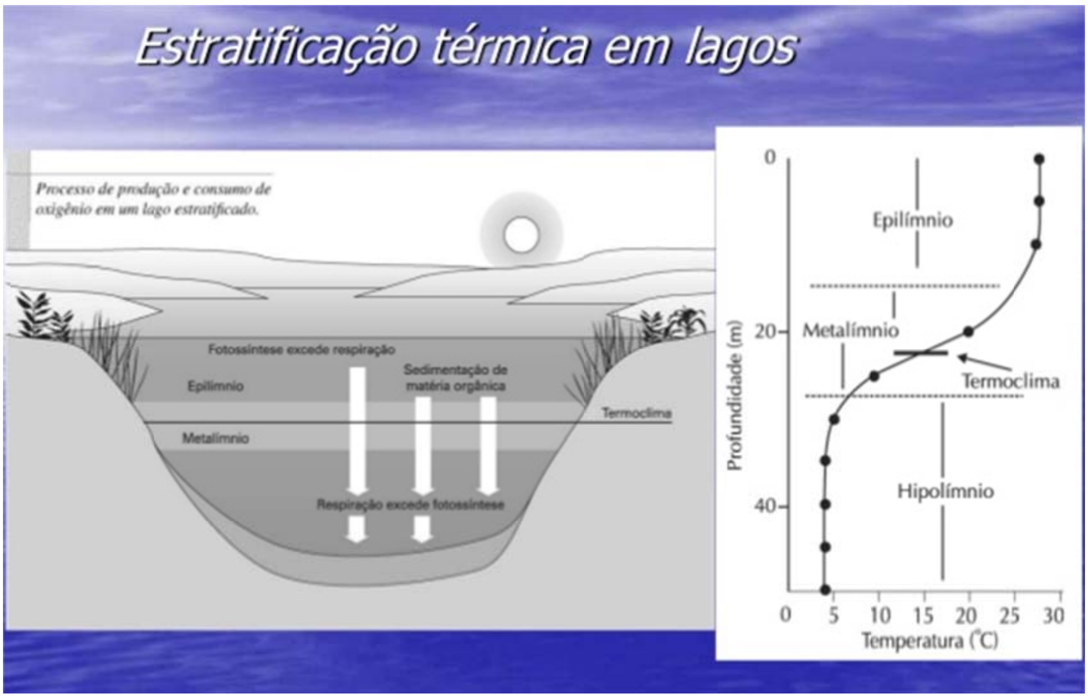



Figura 36 – Thermal stratification in a lake.

**Process of oxygen production and consumption in a stratified lake.**

**Photosynthesis exceeds respiration/sedimentation of organic matter/respiration exceeds photosynthesis/depth/temperature/hypolimnion/epilimnion/metalimnion/thermocline**

Thermal effects of radiation on water bodies

- Thermal instability and stability of water bodies
- Instability = lakes that have uniform temperature throughout the water column;
- Stability = lakes with thermal stratification;
- The strata formed are differentiated physically, chemically and biologically.

- Thermal stratification of inland aquatic ecosystems
  - Temperate climate region
    - Early spring → ice-layer destruction - homothermia - water circulation - effective in shallow lakes;
    - Summer - surface heats up - makes mixing difficult - presence of three layers:
      - Epilimnion (upper |) = uniform and hot temperature;
      - Hypnomnion (lower) = cooler and maximum density (~ 4°C);
      - Metalimnion (intermediate) = temperature discontinuity → Thermocline;
    - Autumn - breaking of thermal stratification and circulation;
    - Winter = surface freezing - only the lower circulates (winter stratification).
  - Tropical climate region
    - Daily stratification and de-stratification;
    - Stratification of spring, summer and autumn and winter de-stratification;
    - Dynamics associated with depth, seasonal temperature variation, wind direction, geographical position of the water body, presence of aquatic macrophytes in the littoral region, etc.

Figure 37 shows examples of stratification and thermal de-stratification related to seasonal and nictemeral aspects.

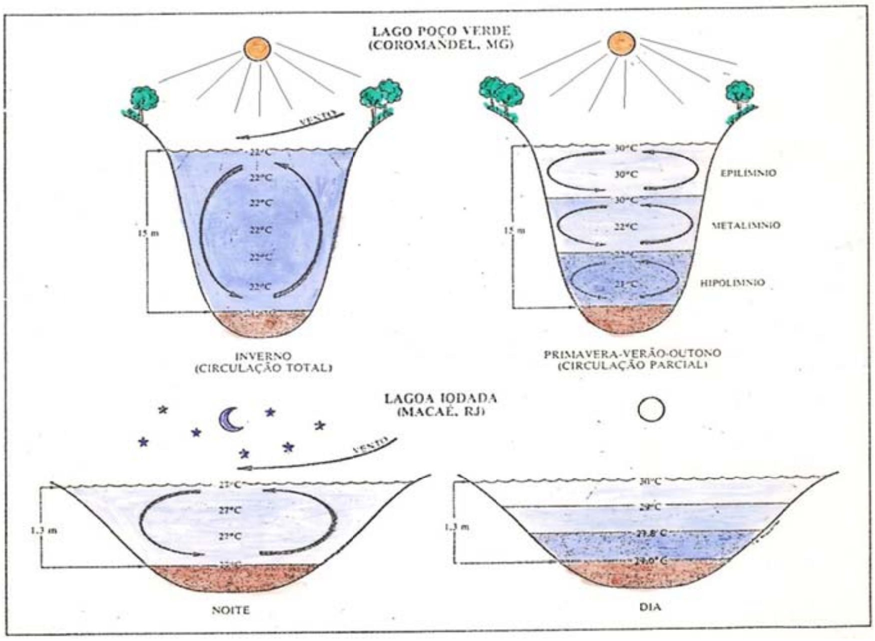



Figure 37– Examples of stratification and de-stratification in lakes

**Lake Poço Verde/winter/total circulation/wind/spring/summer/autumn/partial circulation/night/day**

- Classification of lakes regarding the number and types of circulation

  - Lagos Holomíticos = Holomictic Lakes = circulation reaches the entire water column
    - Dimictic = two circulations per year (autumn and winter)
    - Monomictic = one circulation per year
      - Warm Monomictic = circulation only in winter
      - Cold Monomictic = circulation only in summer
    - Oligomictics and Polymictics = lakes with few or many circulations per year
    - Olygomictic = depths where there is little seasonal variation of temperature

      Polymictic = shallow and extensive with daily circulation

  - Meromictic lakes = circulation does not reach the entire water column
    - Geomorphological meromixis

- Chemical or ectogenic meromixis

## X. Physical, Chemical and Biological Elements.

❖ DISSOLVED OXYGEN - DO

In the terrestrial environment, oxygen comes from the photosynthetic metabolism of plants through complex metabolic processes that occur at the intracellular level in chloroplasts; within the aquatic environment, this element is called dissolved oxygen (DO) and comes predominantly from the photosynthesis of the aquatic biotic or by diffusion on the surface of the water (less important).

The DO concentration may vary due to some circumstances, such as:

- Temperature - The solubility of oxygen in water increases with decreasing temperature. Therefore, cold waters retain more oxygen than warmer waters. In cold waters, the dissolved oxygen levels can reach about 10 ppm (mg. L-1);
- Salinity - The higher the amount of salt dissolved in water, the lower the DO. Thus, it may be reported that sea water contains less DO than other waters;
    - ➢ Solubility also depends on temperature and pressure.

- Diffusion and Distribution
    - Dynamics in temperate lakes
        - Hypolimnion with high DO deficits during summer (decomposing activity) in shallow and eutrophic lakes; In the deep and oligotrophic waters there are no interferences in DO levels.
    - Dynamics in tropical lakes
        - The high temperature as a direct factor of DO concentration control;
        - Indirect control factors of DO concentration.
            - o Extension of the thermal stratification period;
            - o Concentration of organic matter (particulate and dissolved)

In Brazil, for example, some aspects should be highlighted due to the construction of dams in tropical forests, directly influencing OD concentration. Biomass, which is initially transformed into necromass after filling, drastically increases DO consumption, significantly altering the water quality of the water body. Depending on the system's thermal stability conditions, the strata may undergo anaerobiosis that provoke alterations in the aquatic biota.

In aquatic environments undergoing a eutrophication process (enrichment of nutrients), an extremely high variation of DO concentration may happen, reaching peaks during periods of greater photic intensity and deficiency in the other periods.

In tropical lakes, due to a complex dynamics of environmental variations related to several parameters, among them the DO, during the evolutionary process some aquatic organisms, for example, the fish, developed several adaptations to support the low DO concentrations. However, these adaptations have often occurred throughout the planet's geological history and rapid changes do not allow for this possibility, unfortunately showing events of fish mortality in several episodes reported in the literature.

- OTHER ELEMENTS

During the course the implications of each element present in the aquatic environment, its dynamics and interrelations of the biotic/abiotic environment will be presented in detail, so here is only a brief summary of each of them:

- Carbon (C) (Figure 38)
    - Organic = detrital and particulate (COP biota)
    - Total Organic (TOC) and Organic Dissolved (DCO)
    - Inorganic ($CO_2$)
- Nitrogen (N)
    - $NO_3$, $NO_2$, $NH_3$, $NH_4$+, $N_2O$, $N_2$, DON (dissolved organic nitrogen) and OPN (organic particulate nitrogen)
        - Classification of lakes according to TIN (total inorganic nitrogen) and nitrogen compounds
- Phosphorus (P)
    - P (Orthophosphate - more important)
    - Total - insoluble
        - Classification of water bodies
- Sulfur (S)
    - $SO_4^{-2}$, $SO_3^{-2}$, $S^{-2}$, $H_2S$, $SO_2$, $H_2SO_4$, S+metals
- Silicon (Si)
    - Soluble $SiO_2$

- Colloidal and Particulate

- Cations
    - Calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), Iron (Fe), manganese
- Anions
    - Chloride, sulfate, carbonate, bicarbonate.
- Trace elements (ppm-part per million, ppb-part per billion)
    - Zinc (Zn), copper (Cu), cobalt (Co), molybdenum (Mo) boron (B)
    - They act in small or very small amounts in biotic metabolism
- Toxic elements
    - Mercury (Hg), lead (Pb), cadmium (Cd), nickel (Ni)

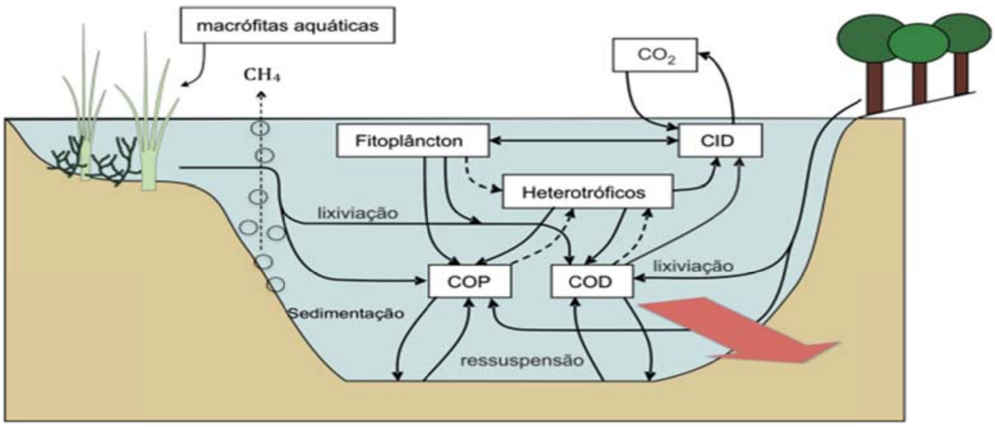



Figure 38–Example of some interactions related to carbon

**Aquatic macrophytes/phytoplankton/heterotrophs/sedimentation/resuspension/leaching**

## XI. Sediment

The study and understanding of the importance of sediment in the dynamics of an aquatic environment would require a specific, long and detailed course. In order not to prolong this topic, we will try to reduce the material to the more relevant aspects within the context of this text.

The importance of sediment is related to the interaction of all processes within the aquatic ecosystem, where biological, physical and chemical processes occur, still being fundamental in the study of the historical evolution between the aquatic ecosystem and the land adjacent to it and in the evaluation of the intensity and form of impact to which aquatic ecosystems are or have been subjected.

In order to establish some sediment study criteria, we can classify them as organic sediment and mineral sediment (each with isolated ecological aspects and associated in the dynamics of the water column). The layers of limnic sediment may be recent or biological and permanent.

Sediment is still able to be:

- An object of the study of paleolimnology
- Used as an indicator of trophic status
- Employed to assess the pollution level

In both natural and altered conditions in aquatic environments, sediment plays an important role in nutrient dynamics. Phosphorus (P) is the main element that determines the trophic state of an aquatic environment, along with nitrogen (N). Figure 39 shows an example of the interaction of Phosphorus (P) relative to the water/sediment correlation.

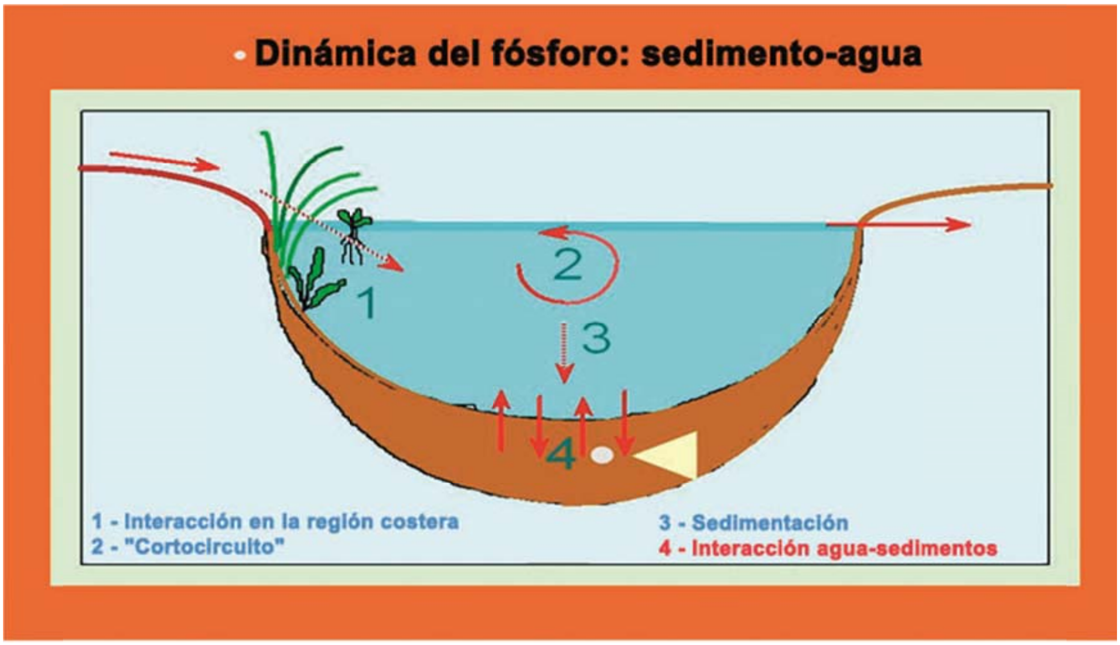



Figure 39 - Example of the dynamics of Phosphorus (P) relative to the water/sediment interaction..

## XII. The community of aquatic macrophytes (Figure 40)

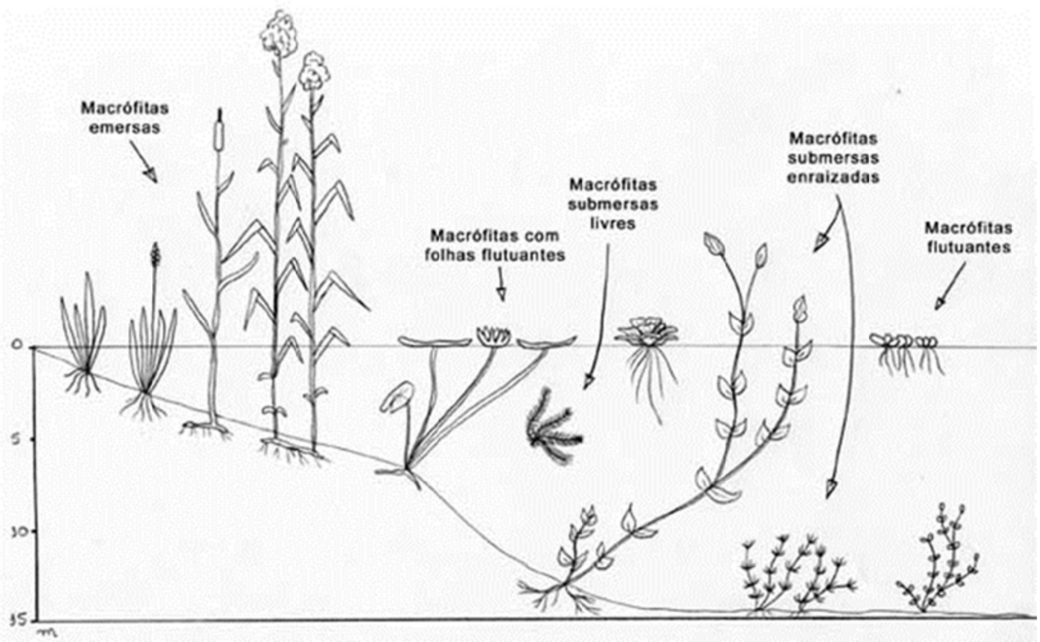



Figure 40– Image of the various types of aquatic macropytes related to their position in the hydric environment.

**Emersed macrophytes/macrophytes with floating leaves/rooted submersed macrophytes/floating macrophytes**

Figure 41 shows some types of aquatic macrophytes: rooted submerged, with floating leaves and free floating, respectively. (Specific literature identifies several species that live in harmony with the environment as well as those that are mistakenly denominated of weeds)

Figure 41 – Examples of macrophytes in different ecological niches.

As with sediment, researching the influence that aquatic macrophytes have on the dynamics of aquatic ecosystems would require an entire chapter to explain their vast importance. Therefore, some topics will be described in order to have a basic notion of the complexity of this topic. Thus, studies should be directed to:

- The main habitats of aquatic macrophytes (emersed, floating, etc.);
- The vegetal communities of the littoral region;
- The importance of aquatic macrophytes in the dynamics of ecosystems (both terrestrial and aquatic in the ecotone);
- The relationship between aquatic macrophytes and floodable areas;
- The anatomical and physiological adaptation of aquatic macrophytes to their environment;
- Biomass and primary productivity of aquatic macrophytes;
- The biomass of rhizomes and aquatic macrophyte roots;
- Comparison between productivity of aquatic macrophytes, phytoplankton and periphyton;
- The importance of aquatic macrophytes in forming organic waste;
- Aquatic macrophytes and the role of nutrient storage and cycling;
- The relationship between trophic states and the biomass of aquatic macrophytes;
- Using aquatic macrophytes to control pollution and artificial eutrophization;
- Controlling aquatic macrophyte populations;
- Using aquatic macrophyte biomass.

## XIII. The phytoplankton community

The entire biological aspect of the aquatic environment requires specialists to identify each species, just as limnological processes do (quantity, metabolism, interaction, etc.). Therefore, only a few aspects of these interactions will be considered.

Phytoplankton classification can be performed by size, thus:

- Macro = >1000 µm
- Meso = 500 – 1000 µm
- Micro = 50 – 500 µm
- Nano = 10 – 50 µm
- Ultra = 0,5 – 10 µm

Some "algae" types (phytoplankton) that exist in aquatic environments: (Figures 42A to F).

Cyanobacteria (example)

Figure 42 A

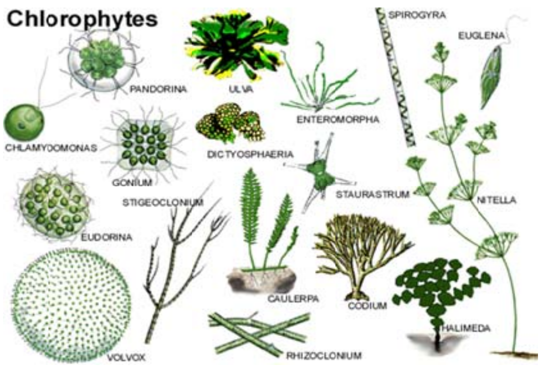



Figure 42 B

*Chlorophyte*

*Euglenophytes*

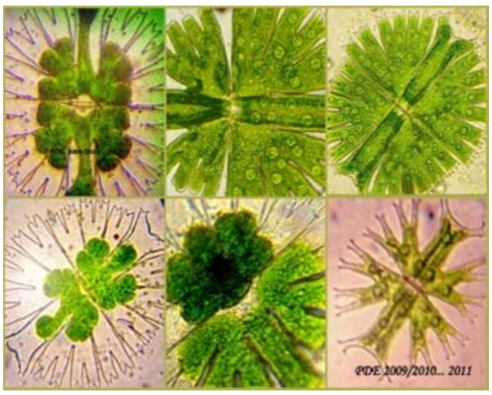



Figure 42 C

Chrysophyte

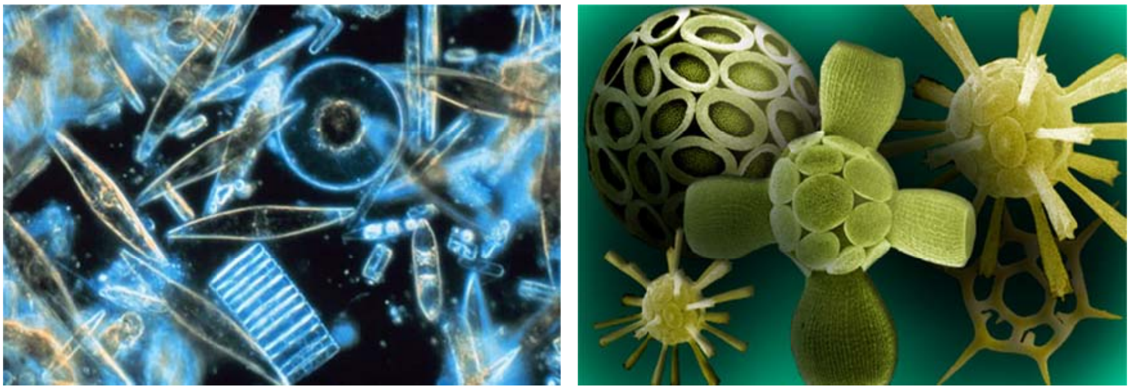
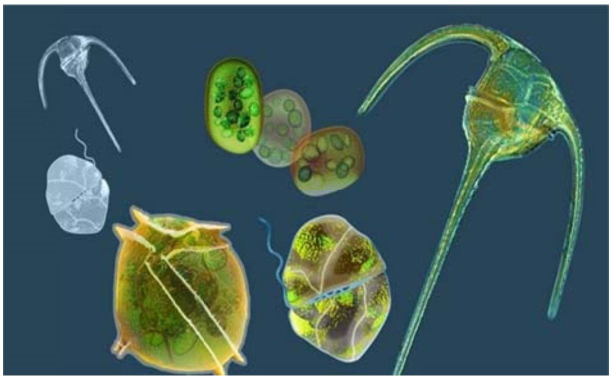


Figure 42 D



Pyrrophyte

Figure 42 E

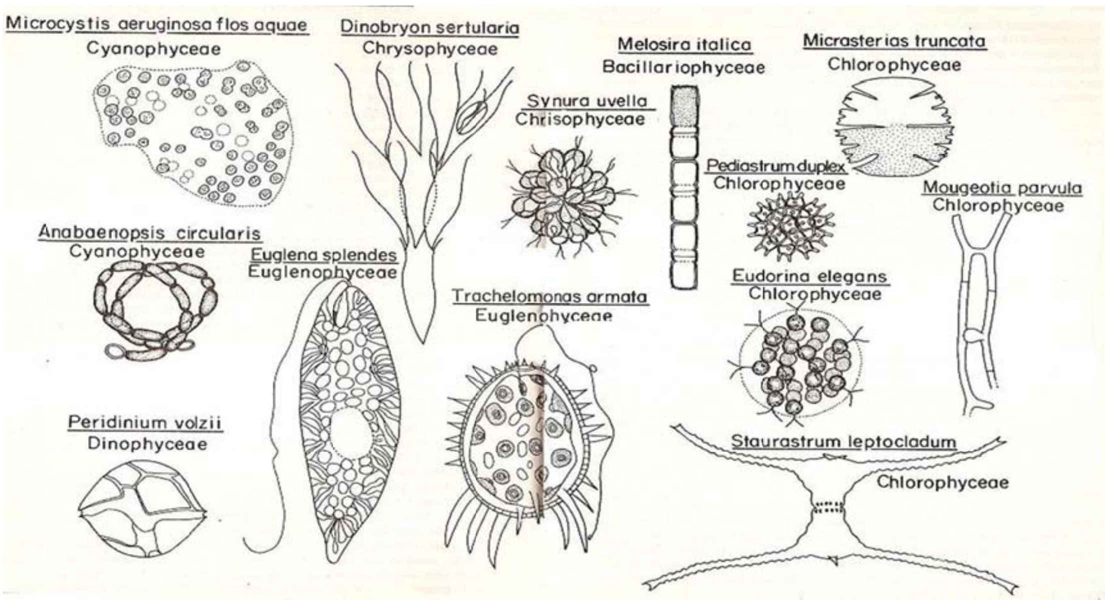



Figure 42 F

Figure 42F- Examples of groups generally known as “algae”

Table 4 describes the algal groups with representatives of limnic and marine phytoplankton

Table 4 - Groups of algae with representatives in limnic and marine phytoplankton

| | Phylogenetic group | Divisions or classes | Limnics | Marine |
|---|---|---|---|---|
| **PROKARYOTES** | **Bacteria** | Cyanobacteria | Importante | Importante |
| **EUCARYOTICS** | **STRAMENOPILES** | Bacillariophyceae | Poco importante | Importante |
| | | Chrysophyceae | Importante | Ausente o escaso |
| | | Raphidophyceae | Ausente o escaso | Importante |
| | | Eustigmatophyceae | Ausente o escaso | Importante |
| | | Pelagophyceae | Ausente o escaso | Importante |
| | | Silicoflagelados | Ausente o escaso | Importante |
| | | Cryptophyceae | Importante | Poco importante |
| | **DISCICRISTATA** | Euglenophyceae | Importante | Poco importante |
| | **ALVEOLATE** | Dinophyceae | Poco importante | Importante |
| | **VIRIDIPLANTAE** | Chlorophyceae | Importante | Ausente o escaso |
| | | Prasinophyceae | Poco importante | Poco importante |
| | | Conjugatophyceae | Importante | Ausente o escaso |
| | | Glaucophyte | Importante | Ausente o escaso |

Importante    Ausente o escaso    Poco importante o menor diversidad o distribución

## XIV. PCI –Phytoplankton Community Index

The index uses the dominance of the large groups that make up phytoplankton, the density of organisms and the Trophic State Index (TSI), in order to separate the water quality into categories. With the change to the TSI in 2005, a new weighting of this variable was established, valid for both rivers (ICFRIO) and reservoirs (ICFRES), as shown in Table 5.

Table 5 - Classification of the Phytoplankton Community Index - PCI

| Category | Weighting | Trophic State Index - Levels |
|---|---|---|
| Excellent | 1 | There is no dominance between the Algae Groups<br>Total Density < 1,000 org .mL$^{-1}$<br>TSI ≤ 52 |
| Good | 2 | Dominance of Chlorophyceae (Desmidiaceae) or Diatoms<br>Total density > 1,000 and < 5,000 org .mL$^{-1}$<br>52 < TSI ≤ 59 |
| Normal | 3 | Dominance of Chlorophyceae (Chlorococcal), Phytoflagellates or Dinoflagellates<br>Total Density > 5,000 and < 10,000 org .mL$^{-1}$<br>59 < TSI ≤ 63 |
| Bad | 4 | Dominance of Cyanobacteria or Euglenaceae<br>Total Density > 10,000 org .mL$^{-1}$<br>63 < TSI |

The final value, which generates the diagnosis or final quality classification, will be the arithmetic mean of the three partial weights related to the dominance, density and value of TSI.

* The purpose of the Trophic State Index (TSI) is to classify water bodies at different trophic levels, such as evaluating water quality for nutrient enrichment and its effect regarding the excessive growth of algae and cyanobacteria.

## XV. The zooplankton community

Just as phytoplankton community requires a number of specifications, the zooplankton community also needs skilled professionals to understand the correlations of these organisms with aquatic ecosystems.

In this way, only some aspects related to these organisms will be addressed. Figure 43 shows some organisms representatives from this group:

Figure 43 – Respresentatives of the zooplankton community

The main representatives of the freshwater zooplankton community are: Protozoa (flagellates, sarcodines and ciliates); Metazoans: Rotifers; Cladocerans (crustaceans); Copepods (crustaceans); Larvae and eggs of fish and molluscs; Insect larvae (Diptera); Some worms (turbelary and trematodes); Cnidarians (jellyfish). In continental aquatic ecosystems, zooplankton is mainly represented by: Copepods, Cladocerans; Protozoa (radiolaria, foraminifera and tintinnids); Chaetognatha; Larvae and eggs of fish and molluscs; Cnidarians (Hidromedusae). These organisms play a decisive role in the dynamics of these environments, especially in nutrient cycling and energy flow. (Figures 43 and 44).

In ecological terms, it is possible to add the dynamics of the predation of fish and aquatic invertebrates upon the zooplankton community. When conditions of ecological imbalance of zooplankton populations occur, they can be controlled by the introduction of planktophage fish, with this type of management called biomanipulation.

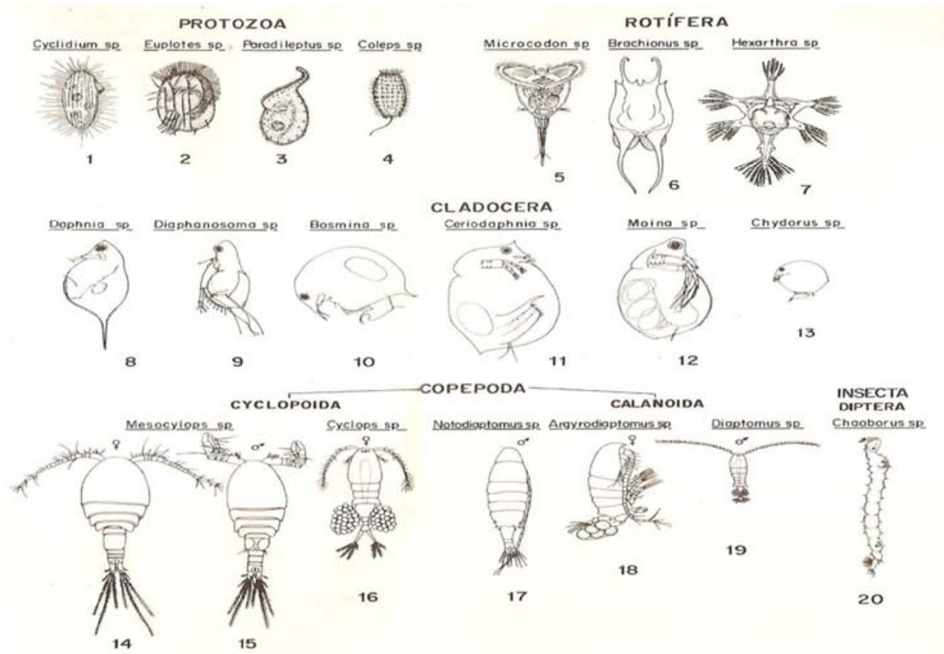
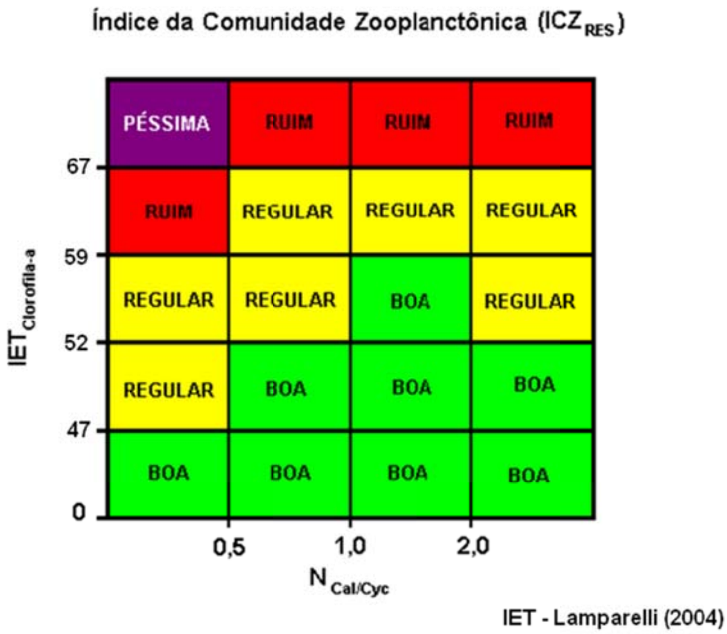



Figure 44 – A few representatives of zooplankton

**PROTOZOA / Cyclidium sp / Euplotes sp / Paradileptus sp / Coleps sp / ROTIFER / Microcodon sp / Brachionus sp / Hexarthra sp / CLADOCERA / Daphnia sp / Diaphanosoma sp / Bosmina sp / Ceriodaphnia sp / Moina sp / Chydorus sp / COPEPODA / CYCLOPOIDA / CALANOIDA / INSECTA DIPTERA / Mesocylops sp / Cyclops sp / Notodiaptomus sp / Argyrodiaptomus sp / Diaptomus sp / Chaoborus sp**

## XVI. $ICZ_{res}$–Zooplankton Community Index for Reservoirs

The Zooplankton Community Index for Reservoirs relates the ratio of the total number of calanoids to the total number of cyclopoids (Ncal/Ncyc), with the Trophic State Index (TSI) for chlorophyll a. These two results are associated with Good, Fair, Poor and Very Poor categories, obtained from Figure 45.




**Zooplankton Community Index/Horrible/Bad/Normal/Good**

Figure 45 – Classification according to zooplankton communities for reservoirs

The use of the $ZCI_{RES}$ diagnostic matrix requires the presence of three zooplankton groups: rotifers, cladocerans and copepods (calanoids & cyclopoids) in the total sample. In the absence of calanoid copepods, $N_{Cal}/N_{Cyc} < 0.5$; is used; in the presence of calanoids and absence of cyclopoids, $N_{CAL}/N_{CYC} > 2.0$; is employed; in the absence of rotifers or cladocerans, assign Poor and, in the absence of copepods, attribute Very Poor condition.

### XVII. The benthic community

The same considerations mentioned above also apply to this group. Figure 46 shows some representatives of benthos.

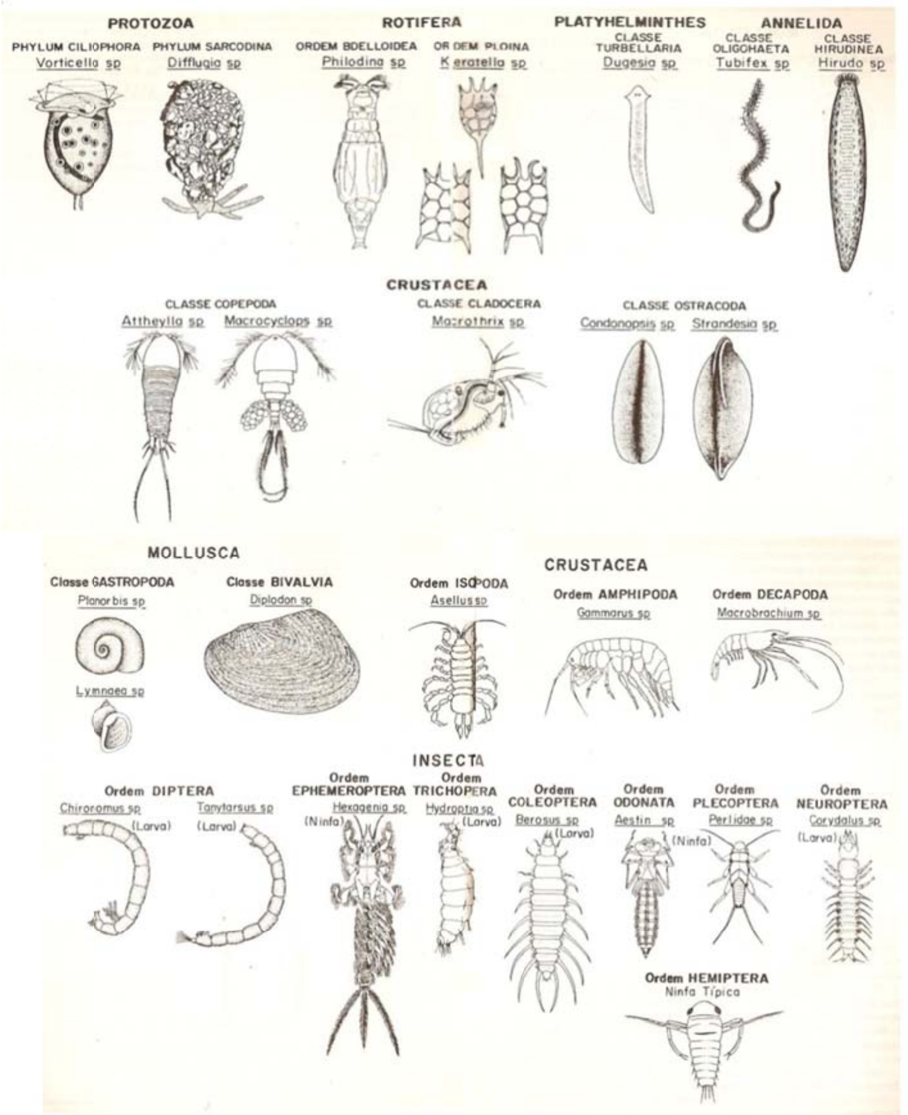



Figure 46 – Some representatives of the benthic community

Benthos: a community of organisms (benthic or benthic) that lives in the substratum of aquatic environments (Greek word meaning deep, lower) and refers to life forms inhabiting the bottom of aquatic environments (the word benthos has been a collective one and must be used with an article and verbal agreement in singular, there is no plural of the term benthos). This term represents the organisms that live fixed to the substratum or free, and is often used in areas of science such as ecology, marine biology, limnology and oceanography (Figure 17)

The penetration of light into the water column establishes a distribution of benthic vegetation to the surface layers of the environment; Therefore, the occurrence of phytobenthos is confined to the littoral areas. Benthos that is found in deep areas consists mostly of bacteria and zoobenthos.

Benthic communities are often used as biological indicators since they provide information on environmental conditions due to the sensitivity of a single species (indicator) or due to some general feature that makes the community integrate environmental sign over time.

Due to the complex structure of this community, specific aspects of sediment carry a significant importance in nutrient dynamics.

### XVIII.BCI – Benthic Community Index

For diagnosis, the descriptors, detailed in the methodology, were fused into multimetric indices, suitable for each type of environment, such as the sub-littoral reservoir zone (Table 6), deep reservoir zone (Table 7) and rivers (Table 8).

Table 6 - Benthic Community Index for sub-littoral reservoir zone ($BCI_{RES-SL}$)

| Category | Weighting | Levels | | | | |
|---|---|---|---|---|---|---|
| | | S | ICS | H' | T/DT | Ssens |
| Excellent | 1 | ≥ 25 | ≥ 25.00 | > 3.50 | < 0.10 | ≥3 |
| GOOD | 2 | 17 - 24 | 15.00 - < 25.00 | > 2.25 - ≤ 3.50 | 0.10 - < 0.40 | 2 |
| NORMAL | 3 | 9 - 16 | 5.00 - < 15.00 | > 1.50 - ≤ 2.25 | 0.40 - < 0.70 | 1 |
| BAD | 4 | 1 - 8 | < 5.00 | ≤ 1.50 | ≥ 0.70 | 0 |
| HORRIBLE | 5 | AZOIC | | | | |

Table 7 - Benthic Community Index for deep reservoir zone ($BCI_{RES-P}$)

| Category | Weighting | S | Levels | | | |
|---|---|---|---|---|---|---|
| | | | ICS | H' | T/DT | Tt/Chi |
| Excellent | 1 | ≥ 10 | > 7.00 | > 2.00 | < 0.20 | ≥ 0.10 |
| GOOD | 2 | 7 – 9 | > 3.50 - ≤ 7.00 | > 1.50 - ≤ 2.00 | ≥ 0.20 - < 0.50 | > 0.06 - < 0.10 |
| NORMAL | 3 | 4 – 6 | > 1.00 - ≤ 3.50 | > 0.50 - ≤ 1.50 | ≥ 0.50 - < 0.80 | > 0.03 - ≤ 0.06 |
| BAD | 4 | 1 – 3 | ≤ 1.00 | ≤ 0.50 | ≥ 0.80 | ≤ 0.03 |
| HORRIBLE | 5 | AZOIC | | | | |

Table 8 - Benthic Community Index for rivers ($BCI_{RIO}$)

| Category | Weighting | Levels | | | | |
|---|---|---|---|---|---|---|
| | | S | ICS | H' | T/DT | Ssens |
| Excellent | 1 | ≥ 21 | > 20.00 | > 2.50 | ≤ 0.25 | ≥3 |
| GOOD | 2 | 14 – 20 | > 9.50 - ≤ 20.00 | > 1.50 - ≤ 2.50 | > 0.25 - < 0.50 | 2 |
| NORMAL | 3 | 6 – 13 | > 3.00 - ≤ 9.50 | > 1.00 - ≤ 1.50 | ≥ 0.50 - ≤ 0.75 | 1 |
| BAD | 4 | ≤5 | ≤ 3.00 | ≤ 1.00 | > 0.75 | 0 |
| HORRIBLE | 5 | AZOIC | | | | |

Due to the complexity of this community, a detailed calculation is described in the CETESB – Appendices of their Water Quality Reports

## XIX. Natural events that alter water quality

Since the advent of Planet Earth, water has acted as a formative element and has suffered the consequences of many changes along the various geological ages.

Therefore, water quality in both salt water and fresh water has undergone changes over time, dividing said changes into before and after the development of human civilization, changes that intensified with the growth of the population and technological complexity, since they led to a higher hydric demand.

Therefore, it should be kept in mind that the quality of natural water is not an immutable entity. It is constantly changing according to natural modifications, at the beginning of time and currently, added to by anthropogenic changes as well.

Water was the main agent in the initial formation of the planet, according to the pertinent literature. Simultaneously, the movement of the tectonic plates (Figure 47) leading to the continental drift modified the boulder and planetary relief, dividing it into Epinocycle (terrestrial), Limnocycle (freshwater) and Talassocycle (saltwater).

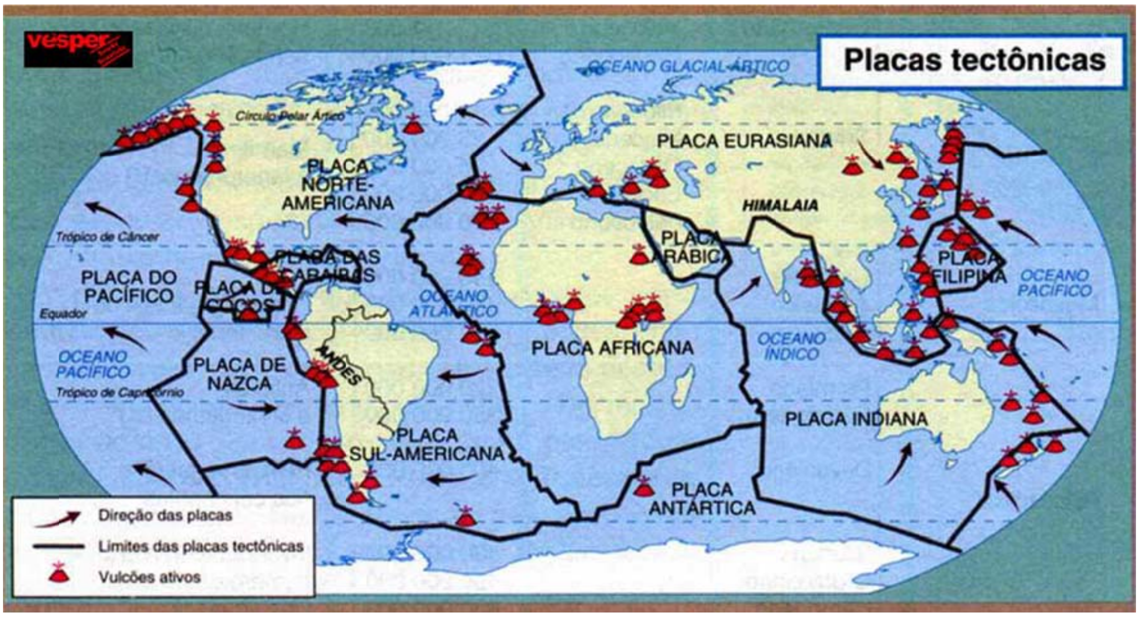



Figure 47 –The planet’s main tectonic plates

**Direction of the plates/Borders of the plates/Active volcanoes.**

So, to isolate separate natural events that alter water quality is not practical; it is only possible to abstract them in a purely didactical way

The following sequence is not hierarchical but strictly informative.

The atmospheric dynamics, a direct consequence of seasonality, interacting with the longitudinal and latitudinal positions, act by altering the natural quality of the water; however, such disturbances get assimilated by natural aquatic ecosystems.

In this way, it is possible to highlight events that lead to floods due to excessive rains such as long droughts. On the other hand, throughout the geological ages, the entire biotic community of these environments developed morpho-physiological adaptations that are able to handle these impacts and undergo a simultaneous evolution, in a two-way interaction where the environment influences living beings and these also alter the environment. (Figure 48)

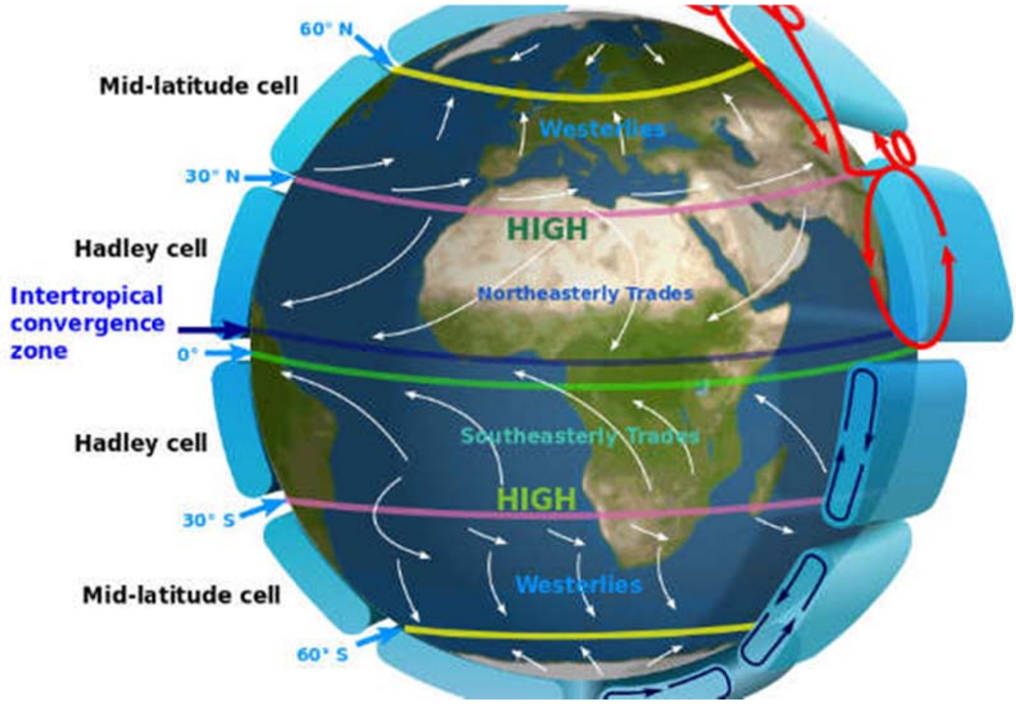



Figure 48.- A simplified example of the planet's atmospheric dynamic.

Thus, changes in water quality interfered in the evolution of the biosphere and this biological activity modified the environment for its best adaptation. (Gaia Hypothesis).

Earthquakes, which drastically alter a landscape, can both make an aquatic environment disappear as it can also create one, acting as an active agent in the quality of the affected waters. (Figure 49)


Figure 49 – An image of some aspects of an earthquake

**Movement/primary waves/secondary waves.**

Volcanic activity, which configured the planetary landscape, acted and continues to act as a dynamic agent affecting water quality with both hot gases and particles, called volcanic ash, and with lava. Figure 50 details some aspects of volcanic activity.

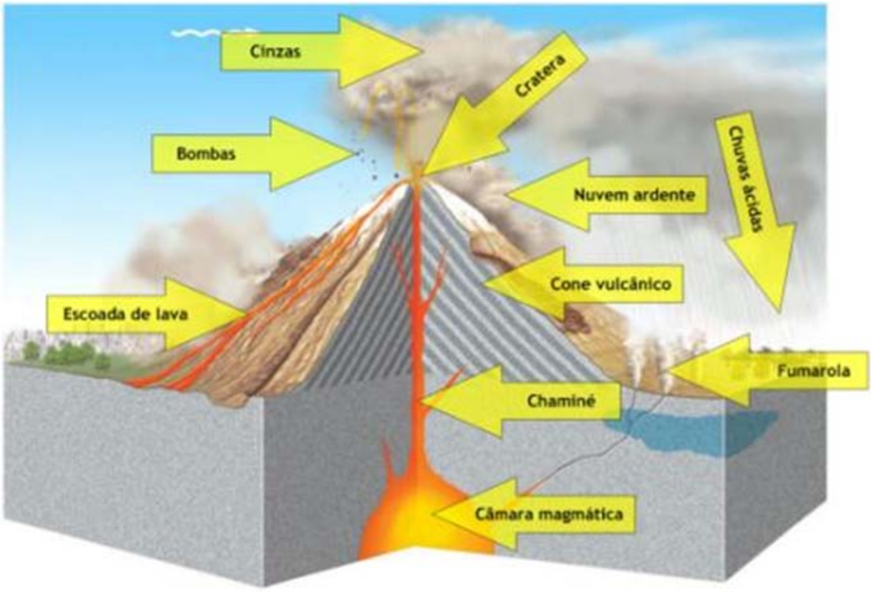



Figure 50 – Some aspects of volcanic activity.

Ash/crater/bombs/hot cloud/chimney/magmatic chamber/lava flow/acid rain/fiumaroles.

Among the natural modifications, worth noting is the ecological succession that takes place where aquatic environments are transformed into a terrestrial environment and vice versa (Figure 51). In view of this, natural eutrophication can be emphasized. (Figure 52)

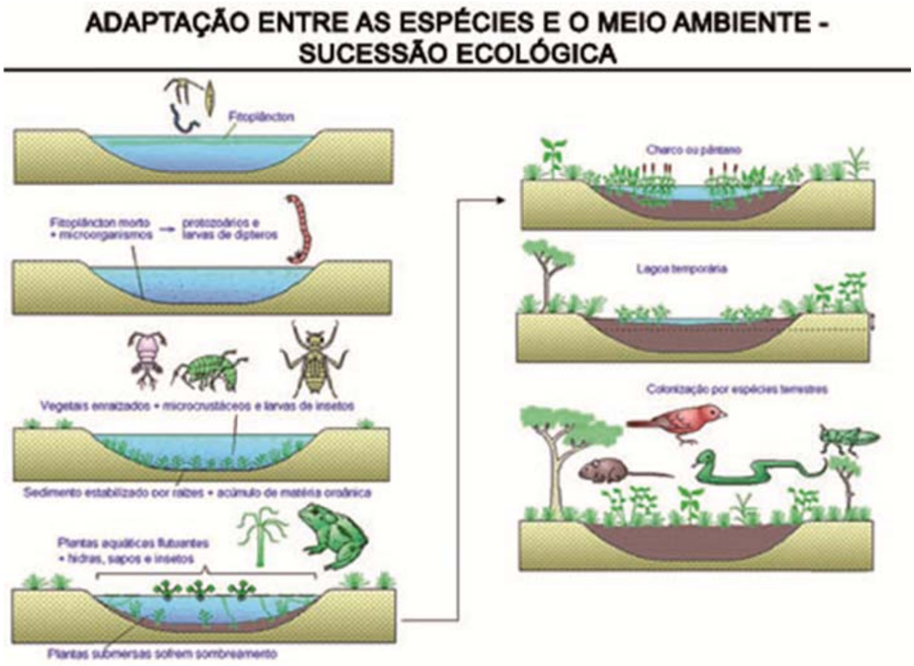



Figure 51 – Examples of ecological succession

**Adaptation between species and the environment**
**Phytoplankton / dead phytoplankton + microorganisms / protozoa and dipterous larvae / Rooted vegetations + microcrustaceans and insect larvas / Sediment stabilized by roots + accumulation of organic material / Floating aquatic plants + hydras, frogs and insects / submerged plants undergoing shading**
**Waterhole or swamp / Temporary lagoon / Colonization by terrestrial species**

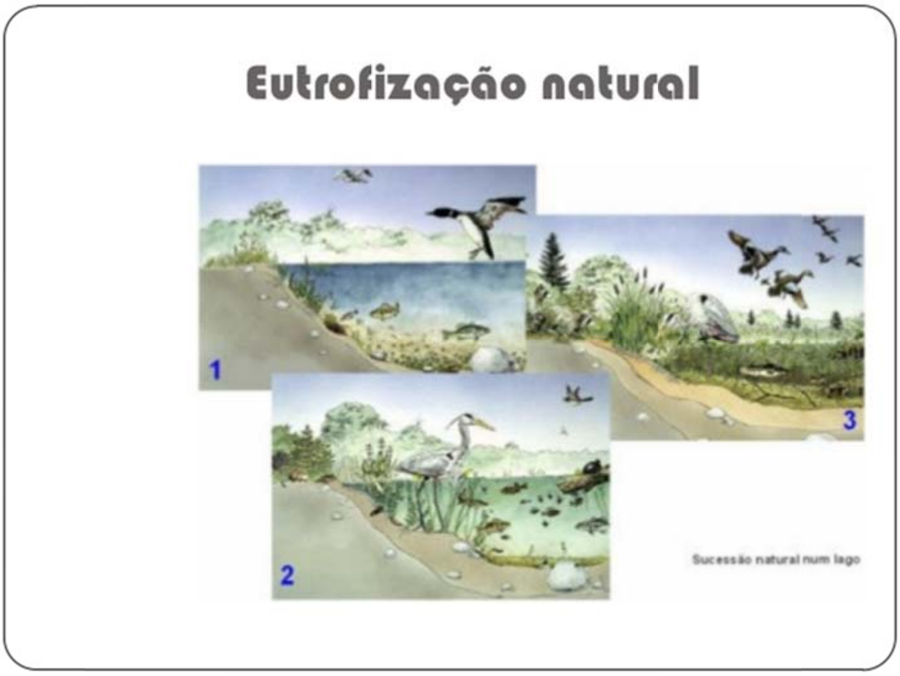



Figure 52 – Example of natural eutrophication

**Natural succession in a lake**

If only one element is considered in isolation, it will be found to contain many elements, influencing water quality both positively and negatively. However, according to the cited examples, it has been verified that none acts alone. It is an extremely complex dynamic to understand the main variables that act or operate in water quality in that particular aquatic ecosystem.

Currently, the main concern is to interpret the changes in water quality that are of anthropogenic origin, the basic focus of this course.

## XX. Eutrophication

Eutrophication is the process of excessive, permanent and continuous fertilization of a body of water from which massive and undesirable development of algae and aquatic macrophytes can result.

Eutrophication is a natural process that gradually transforms an aquatic environment into a terrestrial environment. On the other hand, the environmental concern for this process is a cultural or accelerated one (Figure 53).

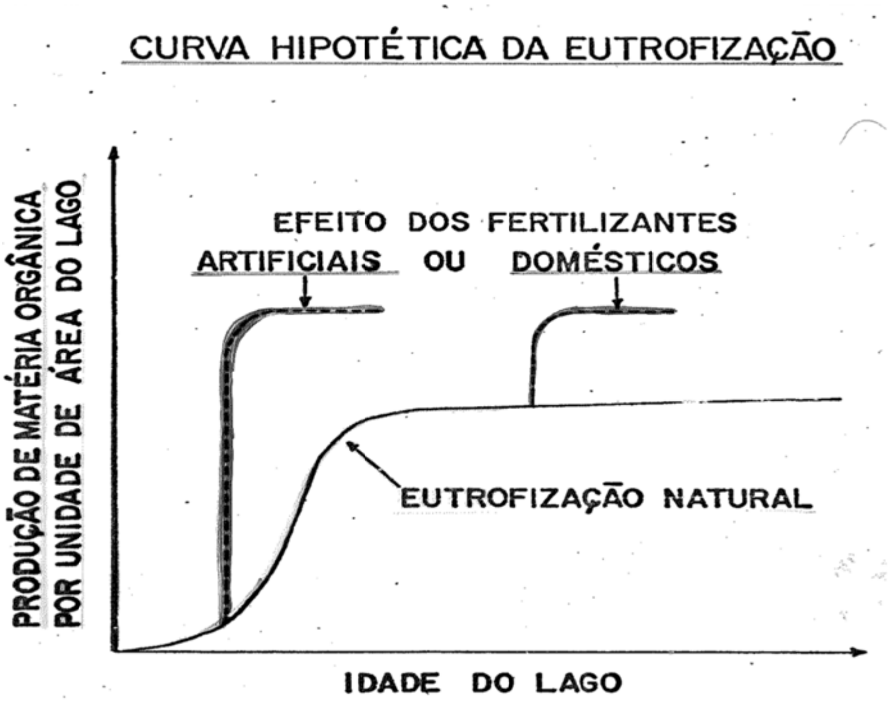



Figure 53 – Image of the hypothetical curve of eutrophication related to natural and artificial factors.

**Production of organic material by lake area unit/effects of artificial or domestic fertilizers/natural eutrophication/the lake's age**

The eutrophication process may be related, alone or in combination, with:

- Excessive presence of nutrients - mainly P and N;
- Conditions relating to water quality;
- To ecological aspects;
- Physical and morphological characteristics of water bodies;
- Flow velocity and renewal;
- Residence time;
- Climate conditions;
- Depth of water bodies;

The origin of the nutrients may have a one-time or concentrated character (ie: domestic effluent) and either dispersed or diffuse (ie: leaching of agricultural area);

The wide variation of DO concentration, the diversity and density of plankton, the transparency level, turbidity values, and the concentration of both chlorophyll *a* and particulate nitrogen can all be established as the main indicators of eutrophication. Table 9 describes and establishes the classification of water bodies related to eutrophication levels.

Table 9 - Classification of water bodies related to eutrophication levels.

| Categories (Trophic State) | TSI Values | Characteristics |
|---|---|---|
| **Ultraoligotrophic** | TSI ≤ 47 | Bodies of clean water, very low productivity and concentrations of insignificant nutrients. Water usage is not hindered. |
| **Oligotrophic** | 47 < TSI ≤ 52 | Low productivity bodies of clean water in which there is no undesirable interferences over the use of water arising from the presence of nutrients. |
| **Mesotrophic** | 52 < TSI ≤ 59 | Bodies of water with intermediate productivity that have possible implications over water quality in acceptable levels for the majority of cases. |
| **Eutrophic** | 59 < TSI ≤ 63 | Bodies of water with high productivity in relation to natural conditions and a reduction of transparency that is generally affected by anthropogenic activities in which there are undesirable changes in water quality arising from an increased concentration of nutrients and interference in their multiple uses. |
| **Supereutrophic** | 63 < TSI ≤ 67 | High productivity bodies of water in relation to natural conditions, low transparency and generally affected anthropogenic activities in which there are frequent undesirable occurrences in water quality, such as the occurrence of algae blooms. |
| **Hypereutrophic** | TSI > 67 | Bodies of water significantly affected by elevated concentrations of organic materials and nutrients and compromised uses associated with episodes of algae blooms and fish kills, with undesirable consequences for their multiple uses, including on livestock in littoral regions. |

* TSI = The Trophic State Index classifies water bodies in different trophic degrees, evaluating water quality for nutrients and its deleterious effect related to excessive algae growth.

Chlorophyll *a* and Total Phosphorus concentrations are used to calculate the Trophic State Index (TSI). The index results, calculated from the phosphorus concentration, should be taken as a measure of the eutrophication potential (the main nutrient causing the process).

The calculation of the TSI from the Pt concentration is performed by the formula:
TSI = 10. (6 - ((0,42-0,36. (Ln.PT) / ln2)) - Pt is expressed in µg $L^{-1}$ (rivers)
TSI = 10. (6- (1.77-0.42. (Ln.PT) / ln2)) - Pt is expressed in µg. $L^{-1}$ (reservoirs)
.

Eutrophication causes a number of negative environmental effects, such as:

- An excessive and harmful development of aquatic plants, including algal blooms, proliferation of aquatic macrophytes, etc.;

- A deep alteration of the biota, with replacement of fish species and other organisms;
- The organic decomposition, consumption and depression of DO and a consequent anoxia;
- Degradation of water quality, with changes in composition, color, turbidity, transparency, etc.;
- Gas emissions and production of bad odors;
- Benthal deposit formations and nutrient recycling;
- Considerable losses for the use of water for public supply;
- Losses for irrigation and hydroelectric use;
- Miscellaneous damages for recreation, tourism and landscaping;
- Increased evaporation;
- Elevation of level and barriers for the flow of water;
- Production of toxic substances and possible losses in livestock;
- Conditions conducive to the proliferation of mosquitoes, larvae and other vectors.

Eutrophication, as already mentioned, leads to the development of blooms related to the presence of algae in hypereutrophic lakes. Therefore, the following parameters may be applied:

- Number of cells of cyanobacteria per milliliter;
- Volume of algae per cubic meter of water;
- Weight of algae per cubic meter of water;
- Content of chlorophyll *a* per liter of water.

One of the most visible consequences of eutrophication is the appearance of large infestations of aquatic macrophytes, causing:

- Loss of water by evapotranspiration;
- Impaired navigability;
- Impaired flow of water in canals and rivers;
- Interference with the operation in hydroelectric plants;
- Interference with irrigation systems;
- Occupation of the useful volume in storage facilities;

- Interference with fishing activity;
- Devaluation of nearby areas;
- The creation of stagnating conditions in the water due to organic material deposits;
- Impaired photosynthesis;
- The harboring and promotion of disease carrying vectors, such as mosquitos, snails etc.

In order to compare two extreme environments, the oligotrophic and eutrophic systems, Table 10 was created.

Table 10 - Characteristics of Oligotrophic and Eutrophic environments.

| Parameter | Oligotrophic | Eutrophic |
|---|---|---|
| Nutrients | Low concentrations and slow recycling of Nitrogen, Phosphorus and Silica. | High concentrations and rapid recycling of nutrients, mainly N and P. |
| Dissolved Oxygen | Often close to saturation in both the hypolimnion and epylimnion. | Large variation in relation to saturation: depression in the hypolimnion and oversaturation in the epylimnion (photic period). |
| Communities | low biomass of phytoplankton, zoobenthos and fish. | High biomass and phytoplankton, zoobenthos and fish sediment (low diversity and higher density). |
| Subaquatic solar radiation | High transparency in the euphotic zone. | Low transparency in the euphotic zone. |
| River basin | Deep lakes with morphometry characterized by V-shaped valleys and slightly modified. | Shallow lakes with low stratification, cultivated and highly modified. |

.

Figures 54, 55 and 56 describe aspects of eutrophication related to changes in the water quality of a lake ecosystem. The presence of nutrients, mainly P and N, have become limiting factors for aquatic biota, leading to major physical, chemical, biochemical and biological changes.

In order to better clarify and understand eutrophication, we should focus on two aspects:

1. Natural eutrophication - as already noted, every aquatic environment during its lifespan will gradually undergo eutrophication over time. Under natural environmental conditions, this time is a correlation between nutrient inputs (organic and inorganic) and self-purification processes (Figure 56). It can therefore be observed that there is a specific tendency to return to the conditions before impact. However, throughout the geological ages, the transformation of aquatic environments into terrestrial ones takes place, called ecological succession.

2. Cultural or accelerated eutrophication - the occurrence of this phenomenon is related to the continuous nutritional discharge ( from point and non-point sources) and the temporal incapacity of the self-purification process, that is, not being able to slowly transform the ecological imbalance into a new balance since the impacts take place in a constant ongoing manner (permanently polluted water bodies). Figure 54 highlights the modifications of the aquatic environment when there is a nutrient input of nitrogen and phosphorus; Figure 56 details a simplified eutrophication system.

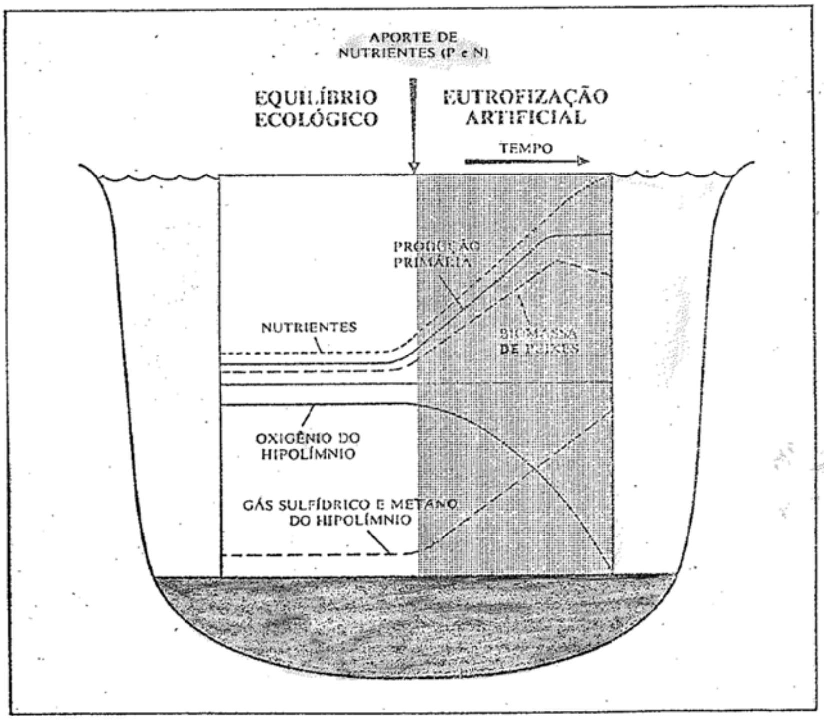



Figure 54 – Image showing consequences of the artificial eutrophication process through P and N input into the lacustrine ecosystem.

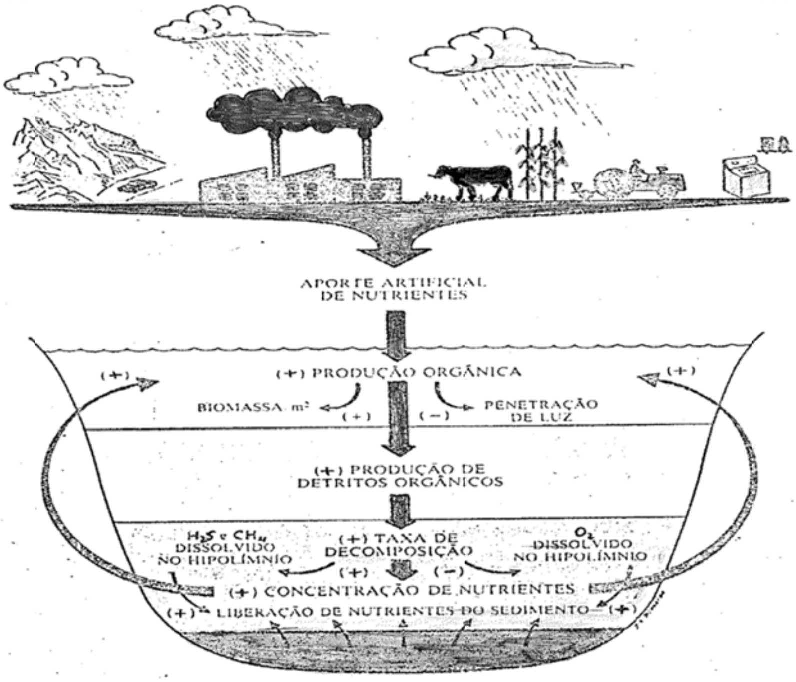
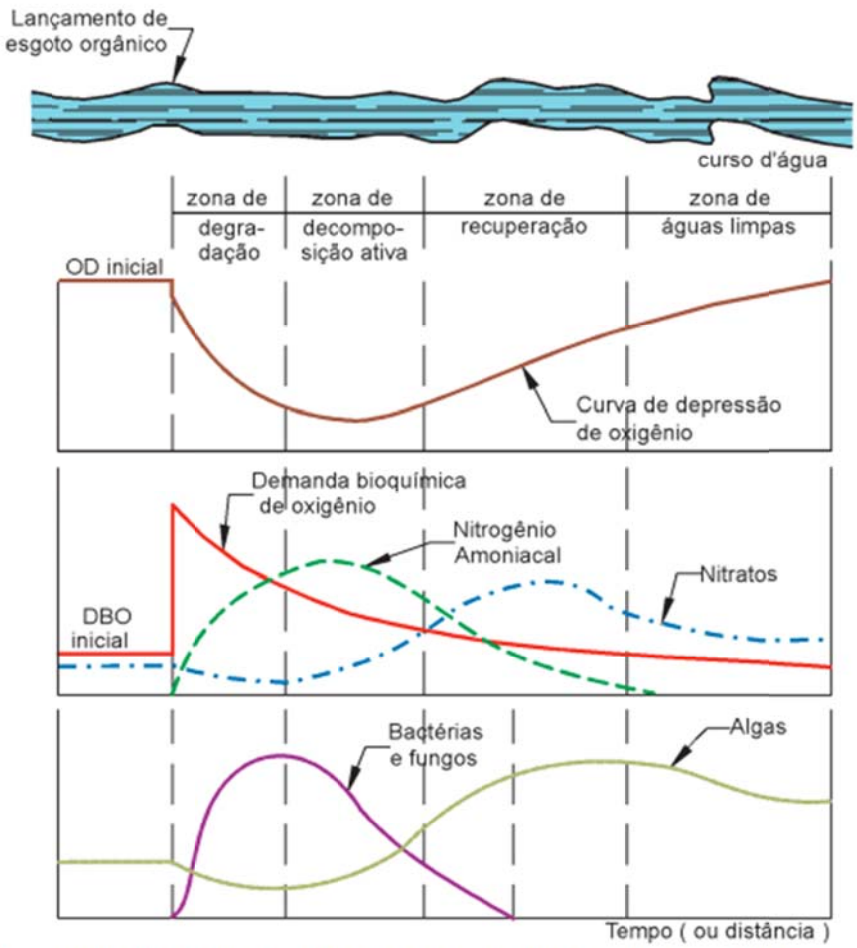



Figure 55 – Image of simplified artificial eutrophication modifying the balance of the lacustrine ecosystem.

**Placement of artificial nutrients/organic production/biomass/light penetration/organic waste production/dissolved in the hypolimnion/decomposition rate/nutrient concentration/nutrients freed from the sediment**




**Conseqüências do lançamento de carga orgânica em um curso d'água.**

**Release of organic waste / watercourse / degradation zone / active decomposition zone / recovery zone / clean water zone / Oxygen depression curve**

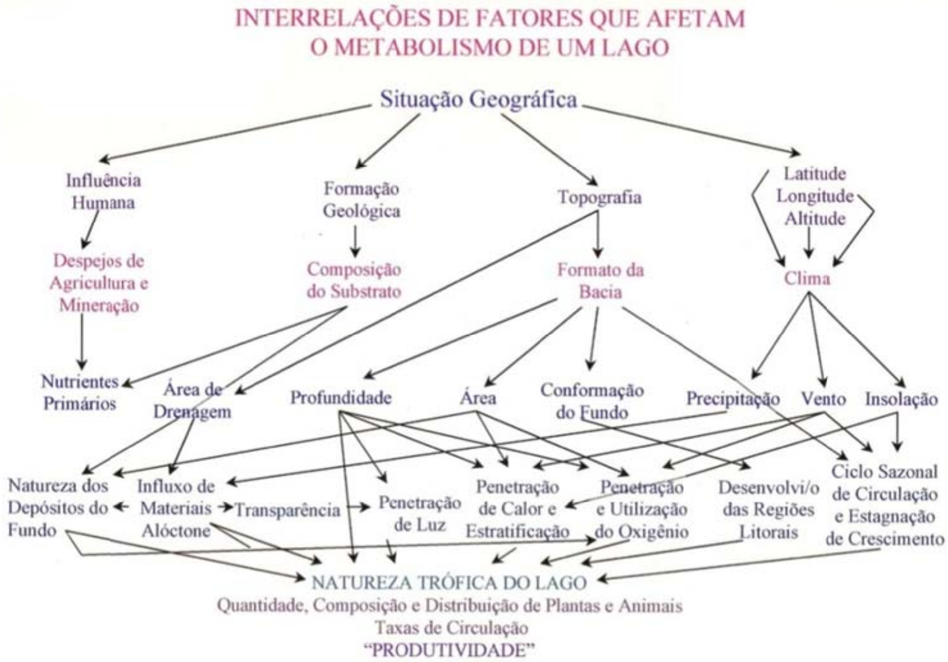
**Biochemical demand of oxygen / Amonniacal nitrogen / nitrates /**

**Bacteria and fungi / Algae**
**Time (or distance)**

**Consequences of the release of organic load in a watercourse**

Figure 56 – Image of the self-purification process throughout time after the input of nutrients (domestic effluent).

In order to reach a broader view of the dynamics in an aquatic environment, Figure 57 portrays a simplified image of the interrelationships among the factors (abiotic and biotic) affecting metabolism (balance) in a lake, especially to the productivity processes of several orders. Depending on the impact, the water trophy level is then established.




**INTER RELATIONS OF FACTORS THAT AFFECT THE METABOLISM OF A LAKE**

**Geographic Situation**
**Human Influence / Geographic Formation / Topography / Latitude Longitude Altitude /**
**Agricultural and Mining Dumps / Substrate Composition / Basin Shape / Climate /**
**Primary Nutrients / Drainage Area / Depth / Area / Bottom Shape / Precipitation / Wind / Insulation /**
**Nature of bottom deposits / Influx of Allochthonous Materials / Transparency / Light Penetration /**
**Heat and Stratification Penetration / Penetration and Use of Oxygen / Littoral Regions Development**
**/ Seasonal Cycle of Circulation and Growth Stagnation /**
**TROPICAL NATURE OF THE LAKE /**
**Quantity, Composition and Distribution of Plants and Animals / Circulation Rates /**
**"PRODUCTIVITY"**

Figure 57– Simplified design of the interrelationships of factors that affect the metabolism of a lake, related to productivity.

In view of the above, some measures of a therapeutic and/or corrective nature should be added to the possible recovery, or in more modern terms, rehabilitation of an aquatic ecosystem. The processes described in Table 11 can be described in the literature, highlighting the physical, chemical and biological ones. However, it should be noted that each of them have positive and negative points, mainly related to costs/benefits. (This implantation of more than one mechanism directed towards a certain objective is called Integrated Weed Control)

Table 11 - Physical (mechanical), chemical and biological processes such as therapeutic measures (corrective) of an impacted aquatic environment.

| Therapeutic measures | Corrective measures |
|---|---|
| Mechanical processes | Destratification<br>Hypnolimion aeration<br>Deep water withdrawal<br>Best quality water supply<br>Sediment removal<br>Sediment covering<br>Removal of aquatic macrophytes<br>Removal of planktonic biomass<br>Shading / Decrease of water level |
| Chemical processes | P chemical precipitation<br>Sediment oxidation with Nitrate<br>Herbicide application<br>Lime application |
| Biological processes | Herbivorous fish usage<br>Use of fish that eat cyanobacteria<br>Food chain manipulation |

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# Spatial and Temporal Variations in Water Quality, Main Water Quality Parameters and Emerging Contaminants

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*Cadernos da Gestão do Conhecimento*

# SPATIAL AND TEMPORAL VARIATIONS IN WATER QUALITY, MAIN WATER QUALITY PARAMETERS AND EMERGING CONTAMINANTS.

## 1. The Concept of Water Quality

Water is one of the most intensively used natural resource and therefore must be present in the environment in the appropriate quantity and quality. In this context, quality means the capacity of water to continuously maintain itself within the limits associated to its varied uses. Other views adopted to explain the concept of water quality were proposed by Chapman (1996), as follows:

- Set of concentrations, chemical species and physical partitions of inorganic and organic substances;
- Composition and state of the aquatic biota in a water body; and
- Description of spatial and temporal variations due to internal and external factors influencing the water body.

## 2. Water use and quality requirements

According to Braga (et al., 2005), water can be intended for the following uses:

- Human supply;
- Industrial supply;
- Pollution dilution;
- Generation of electricity;
- Irrigation;
- Navigation;
- Preservation of flora and fauna;
- Aquaculture; and
- Recreation.

## 3. Main sources of water pollution

The term pollution can be used to characterize a change in the quality of a natural resource due to the addition of substances that come to undermine the multiple uses of that resource. Brazilian Law No. 6,938 of August 31, 1981, which deals with the National Environmental Policy, defines pollution in the following terms:

*"Pollution: the degradation of environmental quality resulting from activities that directly or indirectly:*

- *adversely affect the health, safety and well-being of the population;*
- *create adverse conditions for social and economic activities;*
- *adversely affect biota;*
- *affect aesthetic or sanitary conditions of the environment;*
- *release matter or energy out of line with established environmental standards.*

The effects resulting from the introduction of pollutants into the aquatic environment depend on the nature of the pollutant introduced, its path through the environment and the use made of the water body. Pollutants may get introduced into aquatic environments from point or diffuse sources (Figure 58).

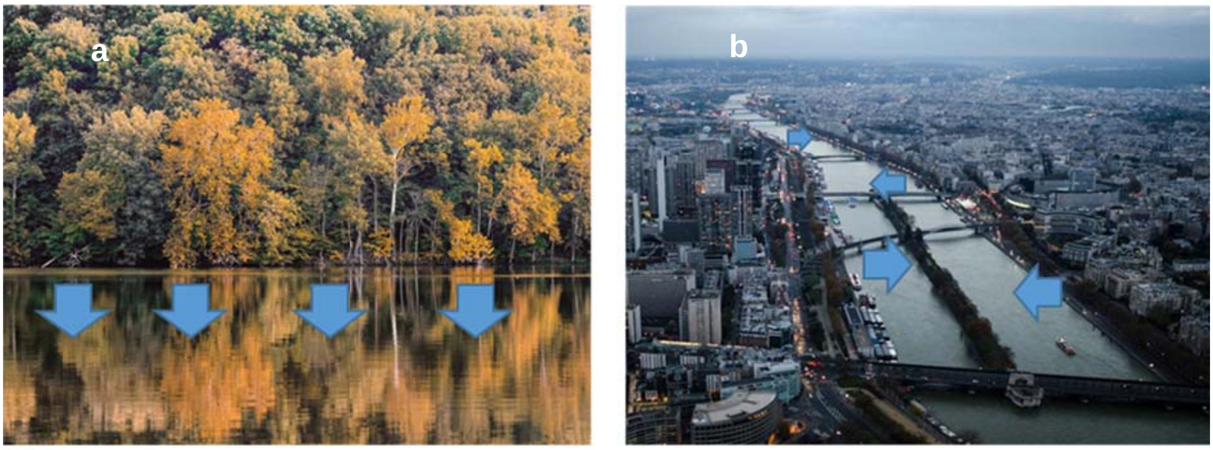


**Figure 58** - Water pollution from diffuse sources (a) and from point sources (b).

Point loads are introduced through the release of domestic and industrial effluents and are easily identifiable. These sources are controlled by treating the effluent that is generated. Diffuse loads do not originate from a specific point of release, but get distributed on the surface of the basin and are introduced into water bodies at intermittent intervals, primarily when there is heavy rainfall. Key sources of diffuse pollution include:

- agricultural areas;
- atmospheric deposition;
- detrition of paved surfaces;
- vehicles;
- vegatation remains;
- solid waste;
- dust;
- animal excrement;
- accidental spills;
- erosion, and
- release of household sewage into nature.

Controlling diffuse loads requires non-structural measures that focus on the prevention and control of pollutant emissions and on the implementation of structural measures that permit a reduction or removal of pollutants that come from the superficial runoff of agricultural and urban areas (Porto, 2012).

An evitable consequence of the development is the generation of pollutants. Therefore, it is fundamentally important for water quality management to establish a handling strategy, principles and methodologies that provide an integration of water resources management with the environmental management of soil use and occupation.

Among the impacts resulting from water quality alteration due to the introduction of pollutant loads, are:

- aesthetic changes;
- sediment deposition (siltation);
- depletion of dissolved oxygen concentration;
- contamination by pathogenic organisms;
- eutrophication;
- biota damage due to the presence of toxic substances.

## 4. Major aquatic pollutants

According to Braga *et al.* (2005), pollutants can be classified according to their nature in:

- Biodegradable organic matter;
- Organic refractory pollutants (pesticides, synthetic detergents, petroleum derivatives, organochlorine substances);
- Toxic metals (mercury, cadmium, lead and arsenic);
- Nutrients (phosphorus and nitrogen);
- Pathogenic organisms (bacteria, viruses and protozoa);
- Solids in suspension;
- Heat;
- Radioactive (radioactive substances and radiation coming from outer space);

Besides this, a new category of pollutants - called emerging pollutants - has drawn the attention of the scientific community and environmental agencies. These substances have been detected in very low concentrations in the air, water, soil, food and in human and animal tissues, characterized by not having regulatory criteria, yet they are persistent in the environment and are capable of interfering in the physiology of target receptors. Within this category are personal hygiene products, pharmaceutical substances that include natural and synthetic estrogens, plasticizers, flame retardants and nanomaterials (Yan *et al.*, 2010).

## 5. Water Quality Variables

Water quality is represented by a set of variables of a physical, chemical and biological nature, which are used to evaluate water characteristics. For the diagnosis of water quality in the State of São Paulo, the following variables are evaluated by the CETESB Monitoring Network (CETESB, 2016):

### 5.1) Physical

- Conductivity: the numerical expression of water's ability to conduct an electric current. It depends on the ionic concentrations and the temperature, indicating the amount of salts in the water column and, therefore, representing an indirect measure of the concentration of pollutants.

- Color: associated to the degree of reduction of intensity that light undergoes when crossing the water (and this reduction occurs through absorption of part of the electromagnetic radiation), due to the presence of dissolved solids, mainly material in organic and inorganic colloidal state.

- Solids: correspond to all the matter that remains as residue, after evaporation, drying or calcination of the sample, at a pre-established temperature during a fixed time; operationally it is possible to define the different fractions of solids present in the water (total solids, in suspension, dissolved, fixed and volatile). For the water resource, solids can cause damage to fish and aquatic life.

- Temperature: generally, as the temperature increases, the solubility of the dissolved oxygen decreases and the physical, chemical and biological reaction rates increase. Aquatic organisms have upper and lower thermal tolerance limits, optimal temperatures for growth, preferred temperature in thermal gradients and temperature limitations for egg migration, spawning and incubation.

- Transparency: with the Secchi disk measurement it is possible to estimate the depth of the photic zone, for example the depth of the vertical penetration of sunlight into the water column, indicating the level of photosynthetic activity in lakes or reservoirs.

- Turbidity: is the degree of attenuation of intensity that a light beam undergoes when crossing water, due to the presence of suspended solids, such as inorganic particles (sand, silt, clay) and organic debris such as algae and bacteria, plankton in general, etc.

- Discharge: is the volume of water flowing for a given period of time, usually represented by the symbol “Q” and expressed as $m^3 s^{-1}$ (cubic metres per second).

## 5.2) Chemicals

- Alkalinity: can be defined as the ability to react quantitatively with a strong acid up to a defined pH value. The main components of alkalinity are carbonic acid salts such as bicarbonates and carbonates, and hydroxides.

- Caffeine: has been used as a chemical tracer for the presence of human fecal matter and some pharmaceutical substances in the group of emerging contaminants.

- Total Organic Carbon (TOC): originates from living matter and is also a component of several effluents and wastes. It is a useful indicator of the degree of pollution in a water body. A TOC analysis considers the biodegradable and non-biodegradable portions of organic matter that do not undergo any influence from other atoms that are bound to the organic structure, thus quantifying only carbon atoms present in the sample.

- Chlorides: discharges of sanitary sewers are important sources of chloride, which can have concentrations that exceed 15 mg $L^{-1}$ and can provoke a salty taste in the water. In coastal regions, through what is called a salt intrusion, water has high chloride levels.

- Biochemical Oxygen Demand (BOD): is the amount of oxygen consumed over a given period of time, at a specific incubation temperature. A time period of 5 days at an incubation temperature of 20°C is often used and referred to as $BOD_{5.20}$. The maximum rises in BOD within a water body are mostly provoked by organic waste. The presence of a high content of organic matter can induce the complete depletion of the oxygen in the water, causing the disappearance of fish and other forms of aquatic life.

- Chemical Oxygen Demand (COD): is the amount of oxygen required to oxidize the organic matter of a sample by means of a chemical agent, such as potassium dichromate. COD values are normally greater than $BOD_{5.20}$ levels and the test is performed in a shorter period. Increased COD concentration in a water body is mostly due to industrial waste.

- Hardness: is the measure of water's ability to precipitate soap, that is, in the waters that have soap, they transform into insoluble complexes, not foaming until the process is finalized. There are four main compounds that create hardness in water: calcium bicarbonate, magnesium bicarbonate, calcium sulfate and magnesium sulfate, originating from the dissolution of limestone rocks.

- Phenols and their derivatives: they appear in natural waters through discharges of industrial effluents. Phenols are toxic to humans, aquatic organisms and micro-organisms that are part of sewage treatment and industrial effluent treatment systems.

- Iron: it can originate from detachment of soils due to erosive processes or the release of effluents from metallurgical industries. Even though it is not toxic, it creates various problems for public water supplies because it causes water to have a color and flavor.

- Phosphorus: comes mainly from sanitary sewage discharges. Powder detergents, fertilizer industry effluents, pesticides, chemicals in general, canned foods, slaughterhouses, and dairy products can also generate excessive amounts of phosphorus along with drained water in agricultural and urban areas. Since it is a limiting nutrient for biological processes, excess phosphorus leads to eutrophication processes in natural waters.

- Metals: may be soluble or adsorbed to suspended particles in surface water. Examples of metals evaluated in monitoring programs are aluminum, arsenic, cadmium, lead, copper, chromium, mercury, manganese, nickel and zinc. Aquatic organisms exposed to metals may cause acute or chronic toxic effects, depending on the concentrations. Some metals, such as mercury, can bioaccumulate and biomagnify, boosting their harmful effect along the food chain.

- Nitrogen: associated with the release of domestic, industrial and fertilizer sewage. It may be present as molecular and organic nitrogen, ammonia, nitrite and nitrate. The presence of ammonia indicates recent pollution events. In excessive concentrations, it is also associated with eutrophication processes. Ammonia is very toxic for fish.

- Dissolved Oxygen (DO): indispensable to aerobic organisms. Waters with low DO content indicate the presence of organic matter. The decomposition of organic matter by aerobic bacteria is accompanied by the consumption and reduction of DO. The absence of oxygen favors the growth of anaerobic organisms that release substances that provoke a bad odor, taste and undesirable aspects to water.

- Hydrogenionic Potential (pH): In addition to influencing chemical equilibria, that happen naturally, pH also affects the physiology of various aquatic species. Under certain Redox conditions, pH may contribute to the precipitation of heavy metals and exert effects on nutrient solubilities. Aquatic life protection criteria have established a pH between 6 and 9.

- Organic Substances: non-biodegradable pollutants or those with a slow rate of biodegradation belong to this group. In the aquatic environment these can be toxic to the biota or they may bioaccumulate in the tissues of some organisms. They are substances that originate from industrial processes, from agricultural crops or from the disposal of different kinds of waste. Examples include agrochemicals, organochlorine substances (polychlorinated biphenyls, dioxins and furans), petroleum derivatives, etc.

- Surfactants: are defined as compounds that react with methylene blue under certain specified conditions. Sanitary sewers have 3 to 6 mg $L^{-1}$ of detergents. The indiscriminate release of detergents into natural waters leads to negative aesthetic impacts caused by the formation of foams. Detergents have also been blamed for the acceleration of eutrophication, since they contain phosphorus.

### 5.3) Microbiological

- Thermotolerant coliforms: microorganisms capable of fermenting lactose at 44-45°C, represented mostly by *Escherichia coli* and also by some bacteria of the *Klebsiella, Enterobacter* and *Citrobacter* genera. Among these microorganisms, only *E. coli* is exclusively fecal in origin.

- *Escherichia coli*: Main bacterium of the subgroup of thermotolerant coliforms, being of exclusively fecal origin. It ferments lactose and mannitol, with acid and gas production at 44.5 ± 0.2°C in 24 hours. It produces indole from tryptophan, oxidase negative, does not hydrolyze urea and has activity of the enzymes β-galactosidase and β-glucuronidase. *E.coli* is present in great quantities in human and warm-blooded feces and is rarely detected in the absence of fecal pollution. It is considered the most appropriate indicator of fecal contamination in fresh water.

- Enterococci: a valuable bacterial indicator for determining the extent of fecal contamination of recreational surface waters. Studies in seawater and freshwater waters have indicated that gastroenteritis associated with bathing is directly related to the quality of the recreational waters and that enterococci are the most efficient bacterial indicators of water quality.

## 5.4) Hydrobiological

- Chlorophyll *a*: one of the pigments responsible for the photosynthetic process. Chlorophyll *a* is the most universal of chlorophylls (a, b, c, and d), therefore, an indicator of the algal biomass and is considered the main variable indicative of the trophic state of aquatic environments.

- Phytoplanktonic community: constituted mainly by chlorophyllic, diatomaceous, euglenofacial algae, chrysophyceae, dinophytes and xanthophyceae and cyanobacteria. It can be used as an indicator of water quality and trophic status, mostly in reservoirs, and the analysis of its structure makes it possible to evaluate some of the effects that result from environmental changes. The presence of some species in high densities may compromise the water quality, causing restrictions of its treatment and distribution. Special attention is given to cyanobacteria, which have potentially toxic species. The occurrence of these organisms has been related to events of animal mortality and damage to human health.

- Zooplanktonic community: formed by microscopic animals that live in suspension, being protozoans, rotifers, cladocerans and copepods the dominant groups in freshwater environments. This community is important in maintaining balance in the aquatic environments and is able to act as a regulator of the phytoplankton community (using it as food) and to recycle nutrients, in addition to serving as food for several fish species.

- Benthic community: corresponds to the set of organisms that live all or part of their life cycle on the substrate in aquatic environments. Macroinvertebrates, for example, take place in all kinds of aquatic ecosystems, display a wide variety of tolerances at varying degrees of pollution, have low motility and are continuously subject to changes in the quality of the aquatic environment. They provide the temporal component in the diagnosis since, as continuous monitors, they allow got the medium- and long-term evaluation of the effects of regular, intermittent and diffuse releases of variable concentrations of pollutants.

## 5.5) Ecotoxicological

- Ecotoxicological test with *Ceriodaphnia dubia*: conducted with raw water samples and used to evaluate the presence of toxic effects, both acute and chronic ones in water bodies where preservation of aquatic life is an established goal. The test result is expressed as acute (when there is a significant effect on the survival of the organisms within the initial 48 hour period) or chronic (when there is a significant effect on the reproduction and/or survival of organisms within the seven day trial period). The sample is considered non-toxic when there is no evidence of any toxic effects on test organisms.

- Reverse mutation assay (Ames test): Also called the *Salmonella* microsome assay, it is efficient at detecting a wide variety of mutagenic compounds that cause genetic diseases or that induce tumors in humans and experimental animals. A positive response for the Ames test indicates the presence in the sample of one or more compounds that are capable of interacting with the genetic material and causing a mutation. Samples of water systems used for public supply and that show any mutagenic activity suggest the need for different levels of treatment, as well as a reduction in contamination sources at the STP.

### 5.6) Bioanalytics

- Determination of estrogenic activity: endocrine disruptors are compounds capable of interfering in the production or action of hormones and may cause damage to the reproductive and immune systems of higher organisms, especially aquatic ones. These compounds can affect aquatic systems through contamination from domestic sewage or from pesticides or other compounds applied to the soil. Several classes of compounds can cause estrogenic activity (a type of endocrine disruptor) such as natural and synthetic hormones (estradiol, estriol, ethinyl estradiol), phytoestrogens or other pollutants (bisphenol A, PCBs, pesticides).

## 6. Water Quality Standards

Water quality standards express desirable physical, chemical and biological characteristics in the waters in order to meet their predominant uses. Such uses in Brazil are protected by the standards set forth in the following laws: CONAMA Resolution No. 357/2005, Ministry of Health Ordinance No. 2914/11, CONAMA Resolution No. 274/2000 and CONAMA Resolution No. 430/2011, which establishes the standards for the discharge of effluents into water bodies.

6.1) CONAMA Resolution No. 357/2005

The National Environmental Council (CONAMA) determined the water quality classes for fresh, salt and brackish water bodies through CONAMA Resolution No. 357/2005. For each class, current or future predominant uses are associated with quality standards getting set or adopted, which correspond to the threshold values of the quality parameters established in the laws. This resolution also presents the environmental guidelines for the classification of water bodies, that is, the mandatory water quality goals or objectives to be achieved or maintained in a stretch according to the intended predominant uses over time. This classification is one of the instruments foreseen in the National Water Resources Policy, defined by Law No. 9433/1997, which is fundamental for the management of water resources and for environmental planning. **CONAMA Resolution No. 357/2005** established 13 classes for water bodies, 5 for fresh water, 4 for brackish water and 4 for salt water. In the State of São Paulo, freshwater bodies were framed by **State Decree No. 10,755 of 1977**, but did not include saline and brackish waters, which must meet the standards of class 1, according to Article 42 of CONAMA Resolution No.357/2005.

6.2) Ministry of Health Ordinance No. 2914/2011

This ordinance establishes the procedures and responsibilities regarding the control and surveillance of water quality for human consumption and its potability standard. It also establishes the competencies and responsibilities for the Union, for states and municipal health secretariats and for those responsible for water supply systems and alternative supply solutions for human consumption, as well as penalties for those who do not observe the determinations contained in the ordinance.

6.3) CONAMA Resolution No. 274/2000

This ordinance defines the criteria of Brazilian water bodies (fresh, salt and brackish) for bathing (primary contact recreation) and establishes classifications, either proper or improper, based on the results for analyzing fecal coliforms (thermotolerant) in a set of five samples collected weekly from the same place.

6.4) CONAMA Resolution No. 430/2011

This ordinance regulates the conditions and standards for the release of effluents into receiving water bodies complementing and amending CONAMA Resolution No. 357/2005. According to this resolution, the indirect release of effluents, that is, those effluents that have or have not been submitted to treatment through the collecting network, must follow the provisions of this resolution when it has been proven that there is no specific legislation or rules and other provisions by the competent environmental agency, and not confer the receiving water body with the water quality characteristics that are in disagreement with the goals of its classification.

## 7. Spatial and temporal variations

Systematic monitoring is one of the main instruments used to evaluate the evolution of water quality at spatial and temporal levels, since it is based on a continuous monitoring of the quantitative and qualitative aspects of water. For this, field surveys, water sampling, laboratory analysis, flow measurement and others tests are required. The information obtained from monitoring makes it possible to diagnose water quality, which thus allows for the identification of priority areas in order to control water pollution, such as stretches of rivers and estuaries where their quality may be threatened, therefore enabling preventive and corrective actions by the environmental agencies (Figure 59).

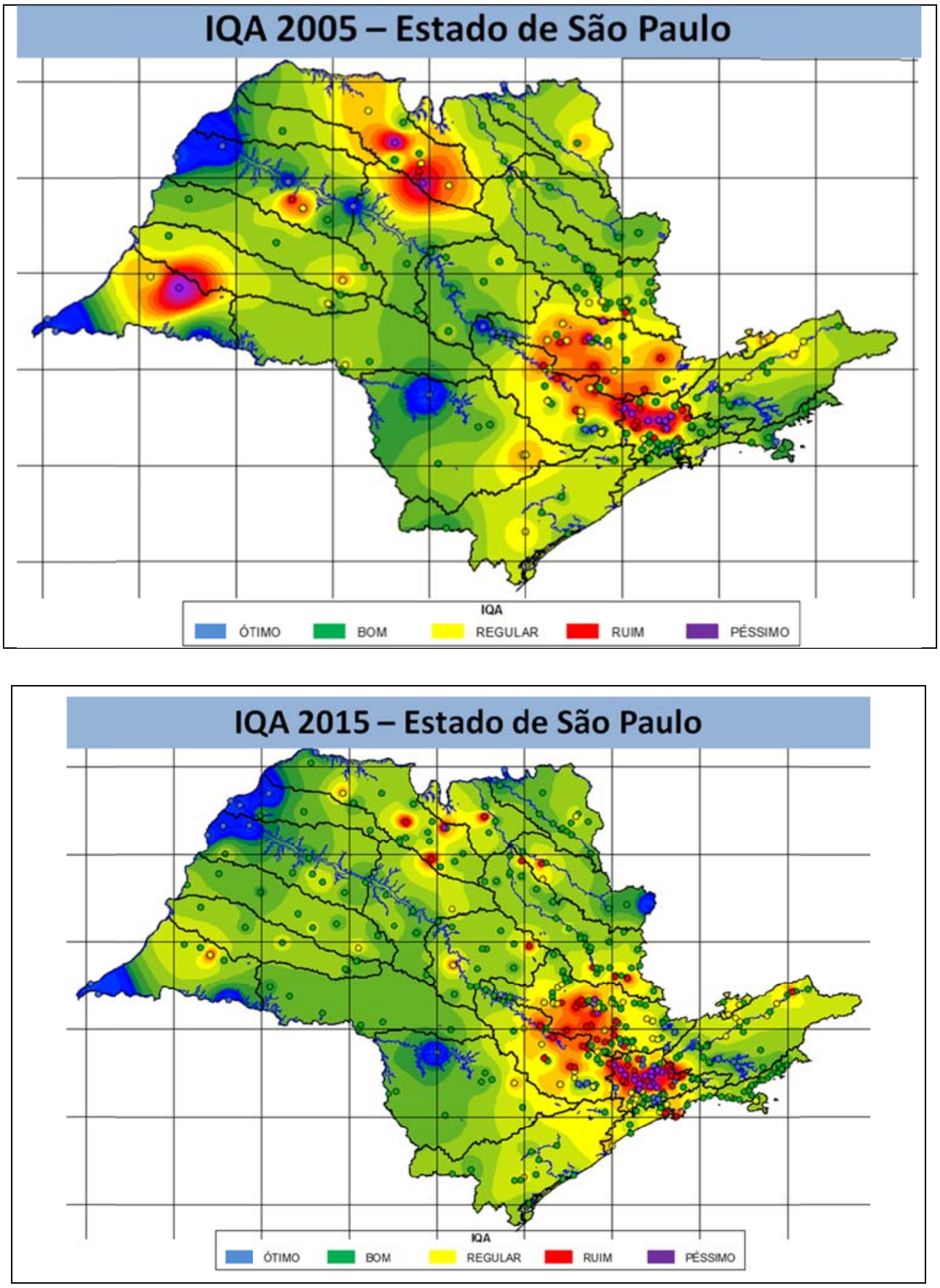


**Figure 59** - Spatial and Temporal Variation of the WQI- Water Quality Index for 2005 and 2015 in the State of São Paulo. (Midaglia, C.L., 2016)

Changes in water quality and quantity in river systems are predominantly influenced by point sources and by underground flow (basal) during periods of drought. In rainy periods, on the other hand, water quality is more influenced by diffuse sources that contribute pollutants from surface and sub-surface runoff processes (Horowitz, 2013). In lakes and reservoirs, on the other hand, chemical changes can happen as a function of the water retention time and the morphometric characteristics of these water bodies, as already explored in chapter 1.

## 7.1 Point Sources

Domestic sewage still plays a significant role in the degradation of water bodies in urban areas and agricultural regions, not only in the state of São Paulo but also at the national level (CETESB, 2016). One of the most important aspects of water quality impacted by domestic sewage is the quantification of the tributary loads, which is expressed in mass of a particular pollutant per unit of time:

$$\text{Load (kg d}^{-1}) = \text{Contribution (g m}^{-3}) \times \text{Flow (m}^{3}\text{ d}^{-1}) \times 0{,}001 \text{ (kg g}^{-1}) \quad (1)$$

While the domestic sewage load that is released without treatment into the receiving bodies is called the remaining organic load, represented by the biochemical oxygen demand (BOD). This load is obtained from the potential organic load, which represents the amount of organic matter generated per inhabitant per day and the percentages of collection and treatment, as well as the overall efficiency of the sewage treatment system. For the purpose of calculating the remaining organic load in the State of São Paulo, the value that was adopted from the literature was 0.054 kg/day for the potential organic load ($C_{OP}$).

$$C_R = [C_{OP} - (C_{OP} \times C \times T \times E)] \times 0.001 \quad (2)$$

Where:

$C_{OP}$ = Population x 0.054 (kg BOD habitants$^{-1}$ day$^{-1}$);
$C_R$ = Remaining Load (t BOD d$^{-1}$);
C = coefficient of sewage collection;
T = coefficient of sewage treatment;
E = Coefficient of the efficiency of the system
0.001 = Conversion factor (t kg$^{-1}$)

Figure 60 displays the evolution of the annual remaining BOD load in the State of São Paulo between 2010 and 2015. A reduction of the remaining BOD load of about 18% between 2010 and 2015 is observed, meaning that around 225 t BOD d$^{-1}$ were no longer thrown into the state's water bodies. Compared to 2014, however, this reduction was only 4.9%.

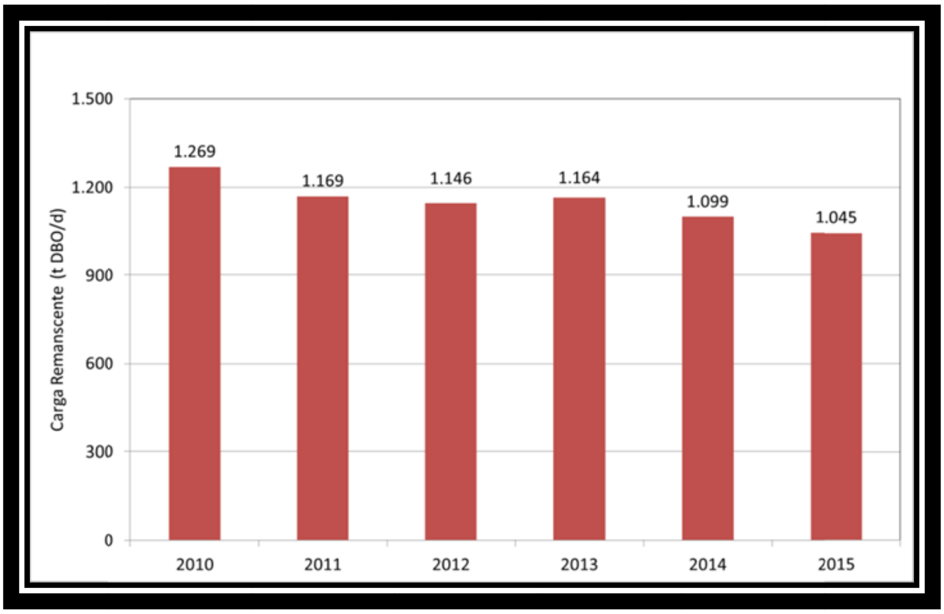


**Figure 60** - Evolution of the remaining load in the State of São Paulo - 2010 to 2015 (CETESB, 2016).

In spatial terms, Figure 61 shows the remaining BOD loads for each of the 22 Water Resources Management Units (UGRHIs) of the State of São Paulo. Due to the population density in the Metropolitan Region of São Paulo and the sanitation indices, the remaining load of the Alto Tietê (UGRHI 6 - 579 t BOD d$^{-1}$) is responsible for 55% of the total load released into water bodies in the State of São Paulo. Therefore, there is an expressive BOD load concentrated in the stretch of the Tietê River inserted in the UGRHI 6. The UGRHI 5 – PCJ with 102 t BOD d-1, releases the second largest remaining load into the Piracicaba, Capivari and Jundiaí rivers and represents 10% of the remaining load generated in the State of São Paulo.

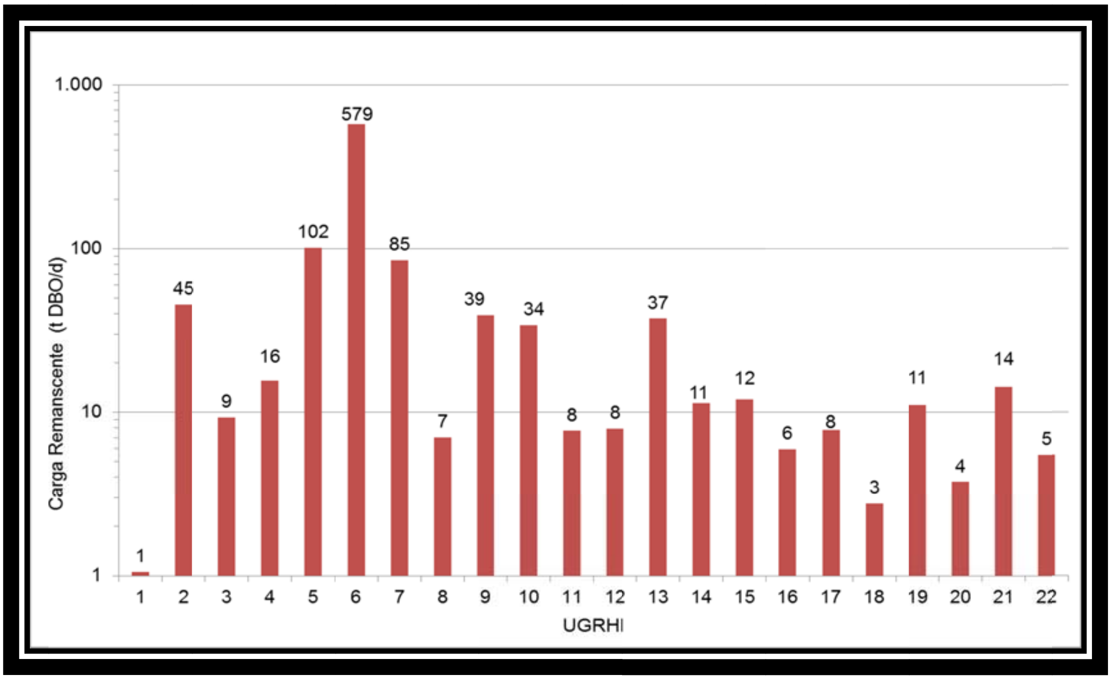


**Figure 61** - Remaining BOD load per Water Resources Management Unit (UGRHI) (CETESB, 2016)

## 7.2 **Diffuse Sources**

Changes in water quality from diffuse sources can originate from air, land surfaces and sub-surface zones, in addition to urban drainage systems. The pollutants loads from diffuse sources are transported through both the surface and sub-surface of the soil before reaching the receiving bodies (Figure 62).

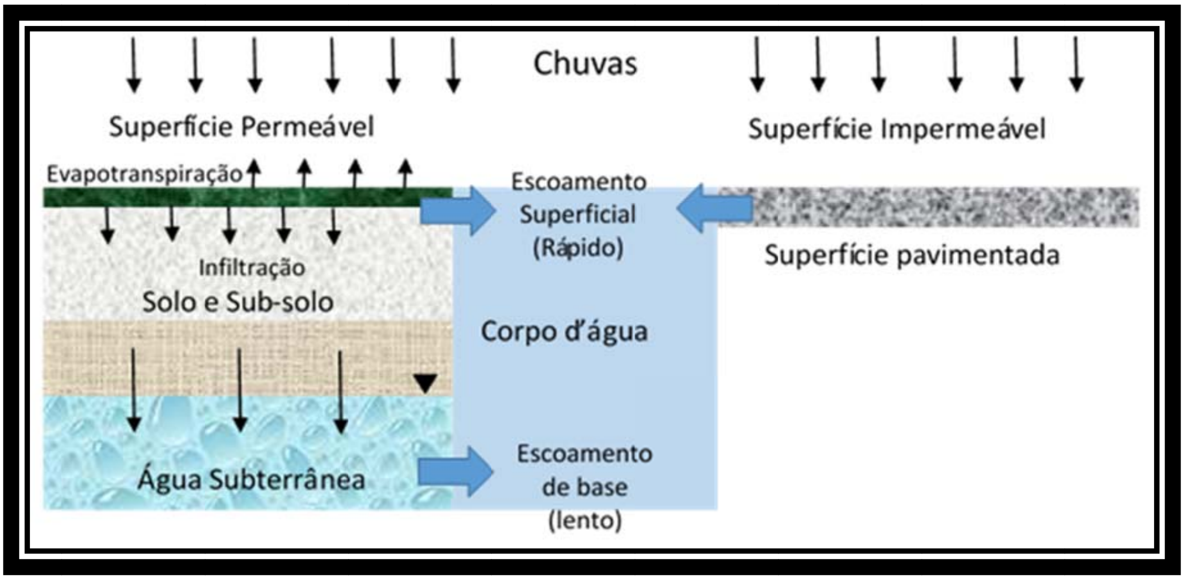


**Figure 62** - Transport of pollutants of diffuse origin across the surface and sub-surface (adapted from Novotny, 2003).

**Rain/Permeable surface/impermeable surface/surface runoff (fast)/evapotranspiration/paved surface/Soil and sub-soil infiltration/groundwater/body of water/basal runoff (slow)**

According to Novotny (2003), the diffuse loads can be derived from:

1. Atmospheric sources
   - pollutants loads in dry and wet deposition (pollution from the atmosphere).

2. Terrestrial sources
   - pollutants accumulated on impermeable surfaces that are washed and transported in the surface runoff;
   - erosion of soil particles and associated pollutants in permeable areas by precipitation and runoff and transported by surface flow;
   - dissolved pollutants from soil and transported by surface flow;

3. Sub-surface sources
   - Chemical constituents applied to the surface of soils and leached towards the groundwater by infiltration;
   - Chemical constituents transported by the horizontal flow in groundwater;

- Infiltration into groundwater from sewers and rainwater collectors and other underground facilities;
- Leakage of contaminants from underground storage tanks and landfills into groundwater;

4. <u>Miscellaneous sources</u>
   - Solids accumulated in sewage collectors;
   - Erosion of drainage channels;
   - Erosion of banks and riverbeds;
   - Chemical substances released from contaminated aquatic sediments

It should be stated that the release of domestic sewage can be seen as a point load or diffuse load, especially in those municipalities that are not universalized in relation to the implementation of sewage collection and treatment systems. In this case, dry weather contributions related to untreated sewage disposal should also be considered as diffuse charge (Menegon Jr, 2005).

Surface flows and loads are intermittent and occur only during rainy or defrosting events. The flow component carrying the surface water load is referred to as the surface runoff, which is equivalent to the residual precipitation, with a nearly horizontal flow direction and a velocity with a range that varies from centimeters per second to meters per second. However, sub-surface loads that depend on the water infiltrating the soil and the leaching of pollutants in the profile, from the application of substances on the soil surface (e.g. fertilizers and pesticides), have a predominantly vertical flow and may be changed to almost horizontal, depending on the water table depth. The contribution of these loads to the receiving water bodies is continuous and the flow component that carries them is called the basal flow or groundwater flow, originating from the discharge of groundwater (Novotny, 2003).

The surface loads of diffuse origin are called export coefficients or unit loads and their values or functions represent the pollution generated by unit area and time, for each soil use, or weighted over a small basin. Their units for a given soil use or uniform stretch of a basin may be expressed annually in kg $ha^{-1}$ or kg $person^{-1}$, with their quantification in a basin being greatly dependent on the use and occupation of the soil and on the demographic, geographical and hydrological factors.

It was originally assumed that unit loads could be correlated to soil use and occupation. However, the Nationwide Urban Runoff Program-NURP, 1983 *apud* Novotny, 2003) conducted in the Great Lakes Region of the USA obtained results for the concentration of pollutants in the runoff that could be correlated only with the impermeable area of the basin, instead of urban soil use. Even results for the unitary pollutant load from agricultural use, within the same category of crops, presented variations of orders of magnitude in a relatively homogeneous region from the meteorological and hydrological points of view (Figure 63).

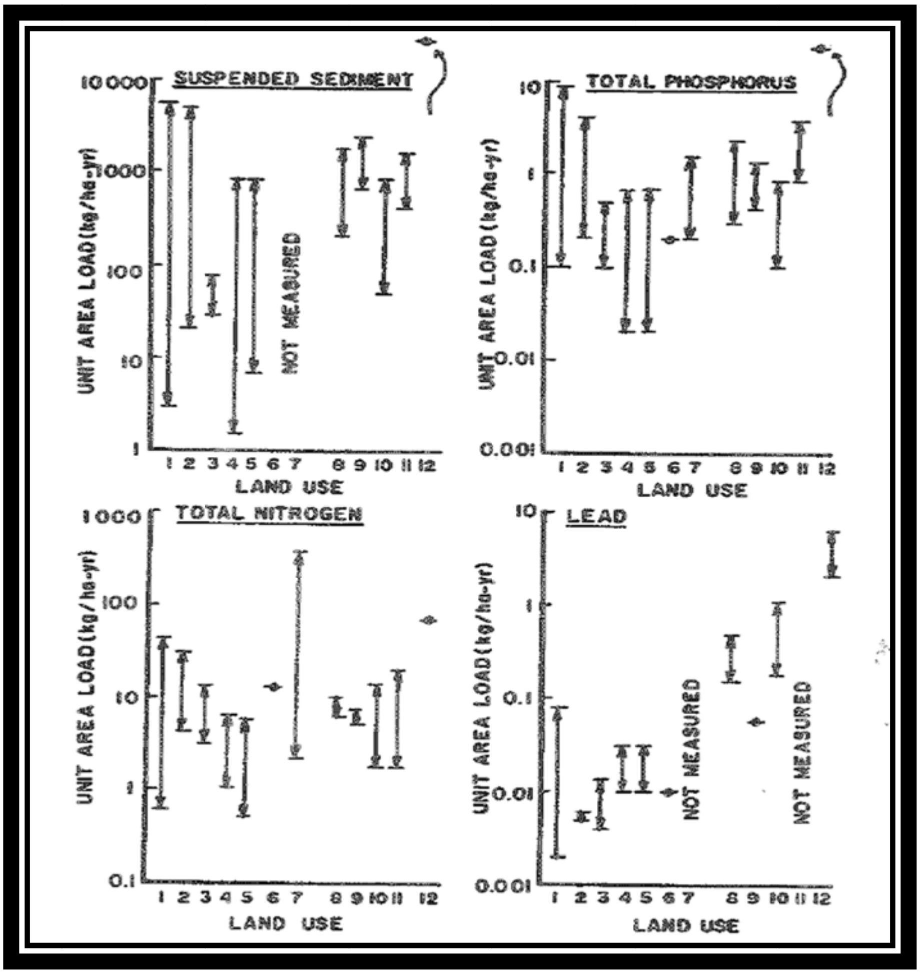


**Figure 63 -** Variations in unit loads of suspended sediment, total phosphorus, total nitrogen and lead in the Great Lakes Region, USA, in the year 1970 before lead was banned from fuel. Uses of the soil: 1- Agriculture in general, 2- Agricultural crops; 3- Pasture; 4- Forests; 5- Perennial/exotic cultures; 6-Sewage sludge; 7-Sprinkler irrigation; 8- Urban in general; 9- Residential; 10- Commercial; 11- Industrial; 12-Urban under development (Source: Novotny, 2003).

According to Menegon Jr. (2005), diffuse loads are affected by several factors that can influence both the runoff and the concentration, being the volume of precipitation, the duration of the event and the interval between the events and the variables used for its estimation. Many researchers have attempted to characterize the concentration distribution within a surface runoff event based on the First Flush concept, which refers to the first part of the flow (peak flow), which possesses the greatest part of the pollutant load. As a general rule, it was assumed that in urban areas the initial flow, corresponding to 40% of the surface runoff, could have about 60% of the pollutant load (Figure 64). However, this rule does not apply to surface runoff events in agricultural areas, just as the First Flush effect cannot be verified from collector discharges that are separate from sewers (USEPA, 1983).

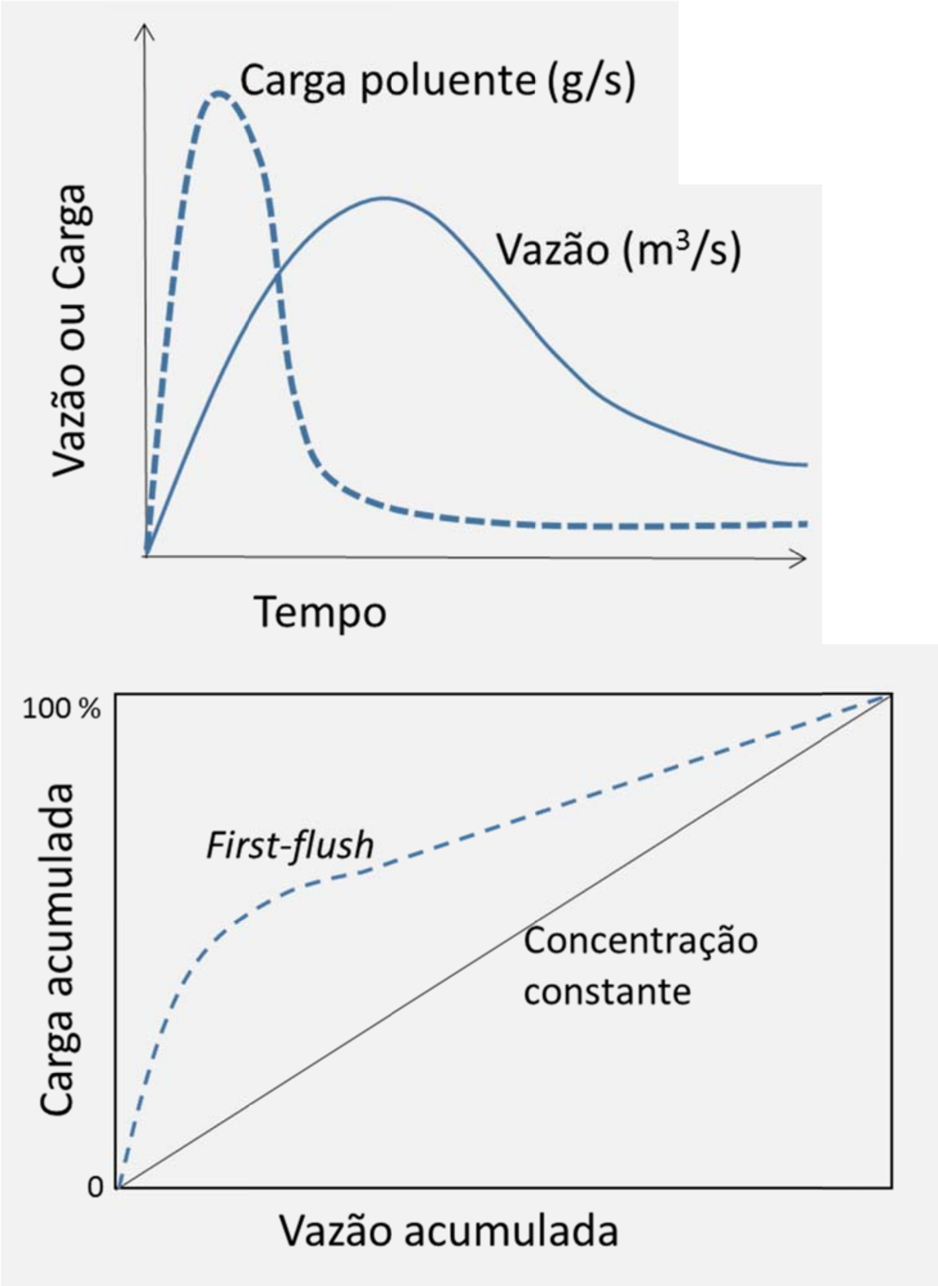


**Figure 64** – First Flush concept. In an urban outflow event, the peak flow in the hydrograph may contain a greater fraction of the pollutant load than the final fraction (adapted from Novotny, 2003).

**Time/accumulated load/constant concentration/accumulated flow**

**Event Mean Concentrations**

Considering that there are no concentration patterns within a flow event, the Nationwide Urban Runoff Program (NURP) focused its attention on the event mean concentrations (EMC), which can be defined as the mass of the pollutant contained in the runoff event divided by the total volume of flow volume in a rain event:

$$EMC = \sum Q_i C_i / \sum Q_i \quad (3)$$

Where:

$Q_i$ = simple measurements of flow on the event's hydrograph

$C_i$ = corresponding concentrations in the pollutogram

The EMC therefore represents the concentration of a flow-weighted composite sample related to a runoff event which that, is in most cases, more relevant than individual discrete concentrations within the event.

The NURP study also concluded that the correlation of EMC with variables such as flow volume, geographic location, effects of soil use, slope, soil type and precipitation characteristics were not able to explain the similarities or differences in EMC between the various locations sampled in the USA. Since these variables do not have significant impacts on EMC and do not explain spatial or temporal variability, information from all sampled sites was combined in order to obtain a characteristic EMC (median or 90th percentile) per variable. In addition, using the data and methodology from the NURP study, the following relationship can be used to estimate the unit load of a basin:

$$\text{Load (kg ha}^{-1}) = 0{,}01 \text{ CR x R x EMC} \qquad (4)$$

Where:

CR = runoff coefficient (dimensionless) extracted from the relation shown in Figure 65;

R = precipitation (mm);

EMC = event mean concentration (mg $L^{-1}$) (= g $m^{-3}$)

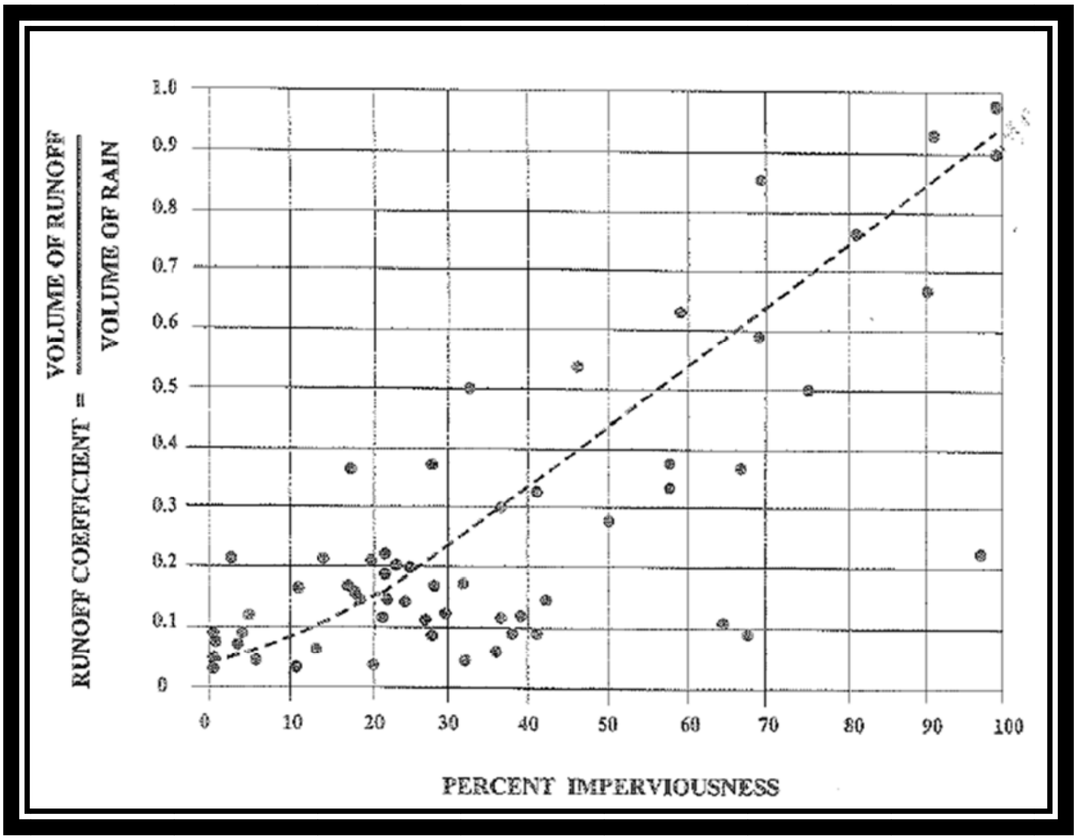


**Figure 65** - Relationship between the flow coefficient (CR = volume of outflow/ volume of precipitation) and the percentage of impermeable areas in urban areas obtained from the NURP study (Source: Novotny, 2003).

For example, for a typical residential urban area that has a 50% impermeable area, the runoff coefficient (CR), according to Figure 65, will be 0.45. For the case of estimating the annual unit load of dissolved organic carbon (DOC) in this area with an annual rainfall of 800 mm, the median and 90th percentile for the DOC should be used, which corresponds to 82 and 176 mg $L^{-1}$, respectively. These values were obtained through equation 3 and represent the characteristic EMC for the COD in the residential urban area. Thus, by means of equation 4, the mean unit load and the 90th percentile for COD will be 295.2 and 633.6 kg $ha^{-1}$, respectively.

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## Instituições Colaboradoras

UN environment

GEMS Water

OTCA
Organização do Tratado de Cooperação Amazônica

## Instituições Organizadoras

UNESCO
Cooperação
Representação no Brasil

ABC
Agência Brasileira de Cooperação
Ministério das Relações Exteriores

Escola Superior da CETESB

CETESB

Governo do Estado de São Paulo

ANA
Agência Nacional de Águas

Ministério do Meio Ambiente