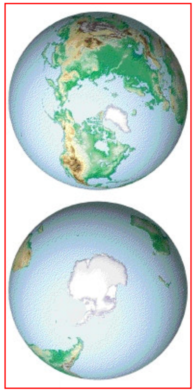
Water Quality

Ogwal Harold

71% of Earth's surface is covered with water, so it is important to know something about the water surrounding us

The Hemispheres of the Earth



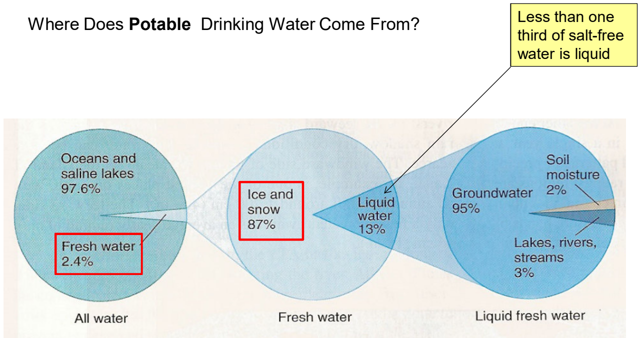
Northern Hemisphere

61% is water and 39% is land, thus it is called the "Land Hemisphere".

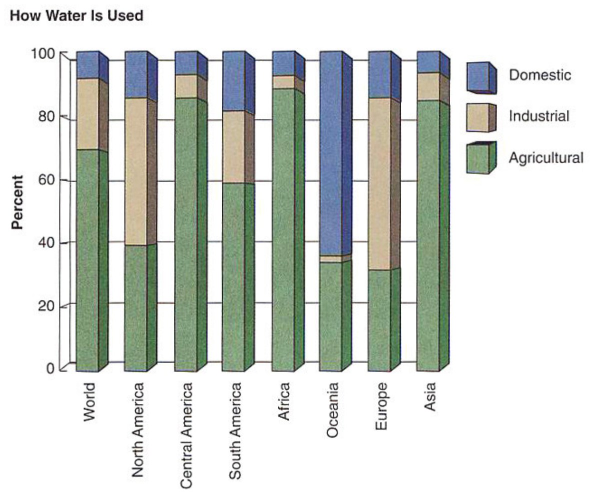
Southern Hemisphere

In the Southern Hemisphere, 81% is water and 19% is land, thus it is called the "Water Hemisphere".

Where Does **Potable** Drinking Water Come From?



Surface water: from lakes, rivers, reservoirs (< 0.01 % of total)
Ground water: pumped from wells drilled into underground aquifers (0.3 %)



Aquatic Systems

Marine

- Ocean
- Seas

Oceanography

Fresh

- River and Streams
- Lakes

Limnology

Water: Sources and Characteristics

Natural Waters

- Atmospheric waters
  - Rain
  - Hail
  - Snow
- Surface waters
  - Streams
  - Ponds
  - Lakes
  - Rivers and estuaries
  - Oceans
- Ground (or underground) waters
  - Springs
  - Wells
  - Underground streams

Artificial Waters

Reservoirs

Dams

Ponds

Man-made lakes

Canals

Characteristics

Fresh Water

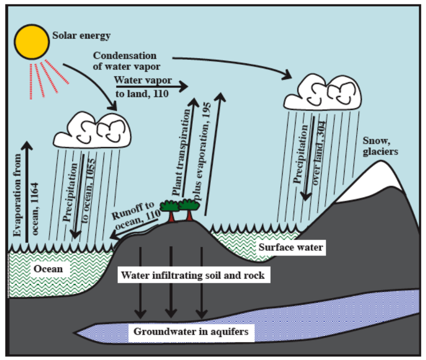
Brackish Water

Saline Water

Sources and use of Water: The hydrological Cycle

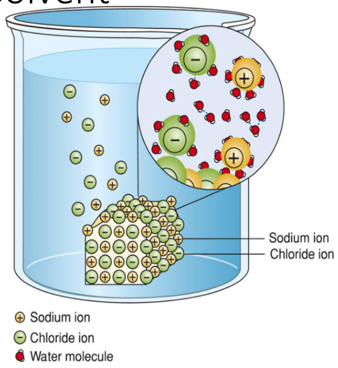
The world's water supply is found in the five parts of the hydrological cycle. (Figure 3.1). About 97% of Earth's water is found oceans. Another fraction is present as water vapor in the atmosphere (clouds). Some water is contained in the solid state as ice and snow in snowpacks, glaciers, and the polar ice caps. Surface water is found in lakes, streams, and reservoirs. Groundwater is located in aquifers underground.

Figure 2.2. The hydrologic cycle, quantities of water in trillions of liters per day.



Water: The Universal Solvent

- Water dissolve many things and is known as the universal solvent, esp. salts.
- Again, H^+ bonding plays a role hear by interacting with other charged atoms.



The properties of water, a Unique Substance

2.2. IMPORTANT PROPERTIES OF WATER

Three characteristics of the water molecule that determine water's properties

- **Unsymmetrical molecule** • **Polar molecule** • **Hydrogen bonding**

Important properties of water

- **Excellent solvent for a number of materials, including salts, acids, bases, and substances that have H, O, and N atoms capable of forming hydrogen bonds.**
- **Weathers minerals and transports dissolved minerals in the geosphere**
- **Transports nutrients to plant roots in soil**
- **Many industrial uses in the anthrosphere**

Water Quality : Definition

Water quality is commonly defined by its physical, chemical, biological and aesthetic (appearance and smell) characteristics. Water may be used for drinking, irrigating crops and watering stock, industrial processes, production of fish, shellfish and crustaceans, wildlife habitats, protection of aquatic ecosystems, navigation and shipping, recreation (swimming, boating), and scientific study and education.

Bio-indicators

These are large insects and animals or bacteria (E. Coli and Coliform) that live in the water body. If they are present then the water must be of a certain quality

Why we need to study water quality

Factors influencing water quality

- ❖ Water quality is closely linked to the surrounding environment and land use.
- ❖ Liquid water is never pure and is affected by agriculture, urban, industrial and recreation uses.
- ❖ The modification of natural stream flows and the weather can also have a major impact on water quality.

Water quality and ecosystems

An ecosystem is a community of organisms - plants, animals, fungi and bacteria – interacting with one another and with the environment in which they live. Protecting aquatic ecosystems is in many ways as important as maintaining water quality because the world conservation strategies stress the importance of maintaining healthy ecosystems and genetic diversity.

Water Quality Assessment

These water quality indicators can be categorized as:

- ❑ **Physical:** temperature, turbidity and clarity, color,odour,
- ❑ **Chemical:** pH, dissolved gases, nutrients (including nitrogen and phosphorus), organic and inorganic compounds (including toxicants)
- ❑ Biological: algae, bacteria

Physical Parameters

1. Color in water may be caused by the presence of minerals such as iron and manganese or by substances of vegetable origin such as algae and weeds.

2. Odour and taste are associated with the presence of living microscopic organisms; or decaying organic matter including weeds, algae; or industrial wastes containing ammonia, phenols, halogens, hydrocarbons.

This taste is imparted to fish, rendering them unpalatable.

3. Temperature

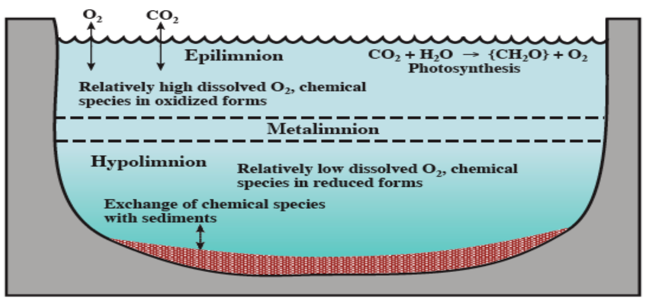
Greatly influences:

- DO solubility; hence saturation point & content.
- Solubility of other gases and solutes (weathering)
- Speed of chemical and biological reactions.
- Biological populations (directly and indirectly)
- **Thermal stratification of Lakes**

- Measured by:
  - standardized thermometer or thermal conductor probe.
  - Like DO; must consider time of day and daily range.
- Influenced by:
  - Climate / Solar Radiation
  - Turbulent mixing with other water masses.

Thermal Stratification of a lake.

Figure 2.3. Thermal Stratification of Water



4. Turbidity & Suspended Solids

- ❖ Turbidity is used to quantify the degree to which light traveling through a water column
- ❖ Light scattering increases with the quantity of solids suspended in water.
- ❖ Turbidity may be due to organic and/or inorganic constituents.
- ❖ Organic particulates may harbor micro organisms. Thus, turbid conditions may increase the possibility for waterborne disease.
- ❖ Inorganic constituents have no notable health effects.

Turbidity & Suspended Solids

- Turbidity: measured optically:
  - Secchi Depth
  - Spectrophotometer: (890 nm); linear path.
- Suspended Solids: measured gravimetrically
  1) Filtration of known volume onto filter.
  2) Oven dry at 105ºC
  3) Weight dried suspended solids and subtract filter weight.
  4) Divide sample weight by volume filtered (= mg SS/L).

Chemical Parameters

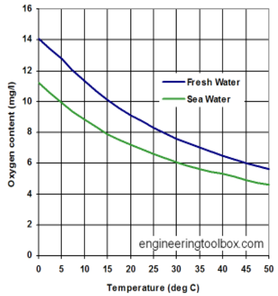
- Dissolved Oxygen
- BOD
- COD
- pH
- Salinity
- Total Acidity
- Total Alkalinity
- Total Hardness (Calcium and Magnesium
- Total Suspended Solids
- Total Dissolved Solids
- Sulphates
- Nutrient Salts (Nitrites, Nitrates , Phosphates)
- Trace elements (Cu, Zn, Hg , Cd and Pb).
- Heavy metals (Fe and Mn).

1- Dissolved Gases

- The major gases found in seawater are: nitrogen, oxygen, carbon dioxide. Others are found in small quantities
- Gases freely move between the water and the atmosphere at the sea surface
- Direction of exchange governed by:
- 1) Saturation Solubility: that is The maximum amount of gas that can be dissolved in water at a given temperature, salinity and pressure
- 2) Concentration of the gas in seawater

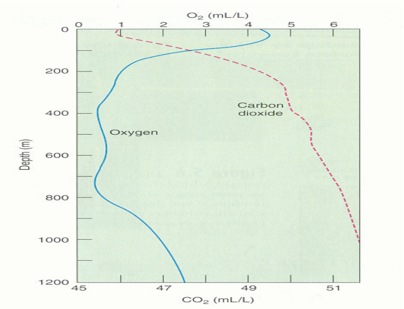
- If seawater undersaturated → transfer is from the atmosphere to the sea
- If seawater oversaturated → transfer is from the sea to the atmosphere

- Solubility increases with:
  - Decreasing temperature
  - Decreasing salinity
  - Increasing pressure
  - Therefore, cold, brackish water can dissolve more gas than can warm salty water at the same pressure



- In the water column, proportions of dissolved gases primarily changed by biogeochemical processes
  - In the photic zone (the region of the ocean penetrated by light), Carbon Dioxide (CO_2) is consumed and Oxygen (O_2) produced by photosynthesis and dissolution from atmosphere
  - In the deep ocean, oxygen is used by respiration and decomposition, with these processes producing excess CO_2 as a by product

Distribution of Gases



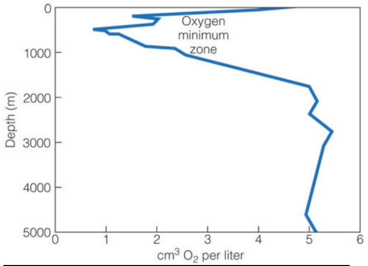
Oxygen

✓Oxygen is a very important gas in the ocean because of its role in biological processes.

✓Marine plants such as phytoplankton , seaweed, and other types of algae produce organic matter from carbon dioxide and nutrients through photosynthesis , the process that produces oxygen.

✓The upper 10 to 50 meters of the ocean can be highly supersaturated with oxygen owing to photosynthesis.

Oxygen Profile in water column



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phytoplankton photosynthesis

organic matter settles

oxygen consumption

circulation

‹ 1000 m

oxygen content of deep ocean waters is renewed by a process called **thermohaline** circulation

When surface waters cool or become more saline sink

- It is important to distinguish between oxygen ***solubility,*** which is the maximum dissolved oxygen concentration at equilibrium; and ***dissolved oxygen concentration,*** which is generally not the equilibrium concentration and is limited by the rate at which oxygen dissolves.

[O2] (25 °C, 760 mm Hg) = 8.32 mg/L

Consumption of oxygen in aquatic environment

- biodegradation of pollutants
- degradation of biomass of algae
- metabolic process of algae

If the organic matter of biological origin is represented by the formula $\{CH_2O\}$, the consumption of oxygen in water by the degradation of organic matter may be expressed by the following biochemical reaction.

$$\{CH_2O\} + O_2 \text{ ------> } CO_2 + H_2O$$

Problem. What weight of organic matter consumes oxygen, [O2] = 8.32 mg/L, from 1 L of water at 25 °C ?

$$\{CH_2O\} + O_2 \text{ ------> } CO_2 + H_2O$$

30 g/mol 32 g/mol

x, mg 8.32 mg

x = (8.32 mg × 30 g/mole) / 32 g/mol = 7.78 mg

~ 7.8 mg of organic matter consumes all oxygen from 1 L of water at 25 °C !!

Temperature effect on Solubility of O2

- 0 °C -------> 14.74 mg/L
- 25 ° C -------> 8.32 mg/L
- 35 ° C -------> 7.03 mg/L

2) Biological Oxygen Demand (BOD)

- The capacity of the organic and biological matter in a sample of natural water to consume oxygen, a process usually catalyzed by bacteria, is called BOD5
- **Procedure**: measure O_2 in the stream or lake. Take a sample and store at 25°C for five days and remeasure O_2 content. The difference is the BOD5
  - BOD_5 corresponds to about 80% of the actual value.
  - Sewage has BOD of ~100 mg L^{-1}

3) Chemical Oxygen Demand

- **COD**: Chemical Oxygen Demand; oxidation by strong chemical oxidant, usually $K_2Cr_2O_7$ (potassium dichromate) in the presence of sulfuric acid at elevated temperatures (~ 150 ºC), during 2 hours
- The recovery of organic material is usually >95% (meaning that also most non-biodegradable substances are taken into account).
- For various types of (waste)waters, there is usually a more or less constant ratio between BOD and COD:
  - domestic wastewater: BOD/COD = 0.65
  - surface water: BOD/COD = 0.40

Sources of BOD and COD

Mainly from domestic and industrial sources.

Some examples are given below:

	BOD (mg/L)	COD (mg/L)
Medium-strength domestic wastewater *Metcalf & Eddy (2003)*	190	430
Textile wastewater (Rwanda) *Sekomo (2006)*	197	2497
Paper mill wastewater (Kenya) *(Abira, 2008)*	93 - 633	571 – 3085
Landfill leachate *Kjeldsen et al. (2002)*	20 – 57,000	140 – 152,000

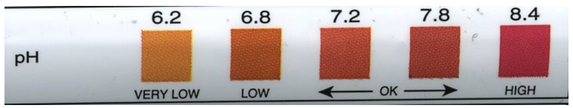
4. pH

- pH is defined as the negative log-base 10 of the hydrogen ion activity:

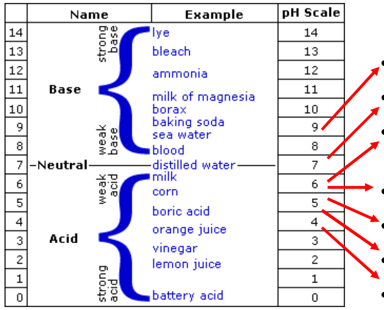
$$pH = - \log10 [H+]$$

- A reduction in pH (more acidic) may allow the release of toxic metals that would be adsorbed onto sediments and essentially removed from the water system. Once mobilized, these metals are available for uptake by organisms and cause extreme physiological damage to aquatic life
- At low pH, ammonia combines with water (H2O) to produce an ammonium ion (NH4+) and a hydroxide ion (OH-). The ammonium ion is non-toxic and not of concern to organisms.
- Above a pH of 9, ammonia (un-ionized) is the predominant species, which is very toxic to organisms. Thus, organisms experience ammonia toxicity more readily at higher pH.

- Fresh water generally has a pH between 6.0 and 8.5. If the pH of water becomes too high (basic) or too low (acidic), aquatic organisms begin to die.
- At extremely high or low pH levels all aquatic life will die.
- pH is probably the single most important factor initiating all chemical reactions in water.



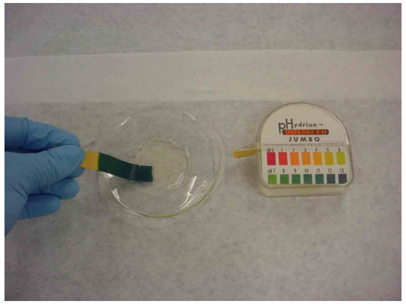
pH Range 0-14



- All fish die (9)
- Best level for fish (6.5-8.5)
- Snails & Tadpoles begin to die
- Bass & Trout begin to die
- Salmon eggs die
- Caddisflies & Mayflies die
- All fish die (4)

Chart provided by EPA

How to Measure pH Using pH Paper



Always use a clean, unused strip of pH paper for each mixture you test.

When measuring pH with pH paper, dip the end of a strip of pH paper into each mixture you want to test. After about two seconds, remove the paper, and immediately compare the color at the wet end of the paper with the color chart provided with that pH indicator.

Write down the pH value and color

www.carolina.com/.../detail/894720_chm.jpg

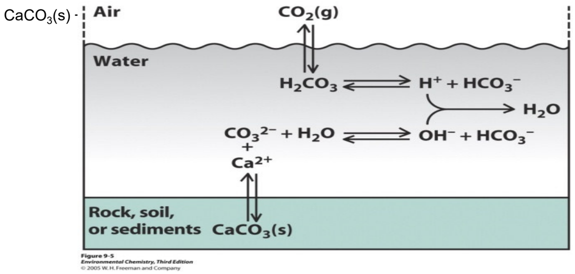
Hand Held pH Meters

Effect of Aquatic Plants & Animals on pH

- During photosynthesis, hydrogen atoms are used by phytoplankton and the pH will rise, becoming more basic.
- Respiration and the breakdown of organic matter will lower the pH, making the water more acidic.

Buffer action in aquatic systems

$CO_2(g) + H_2O(aq) \rightleftharpoons H_2CO_3(aq)$	K_H
$H_2CO_3(aq) \rightleftharpoons H^+ + HCO_3^-$	K_a
$CaCO_3(s) \rightleftharpoons Ca^{2+} + CO_3^{2-}$	K_{sp}
$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$	K_b
$H^+ + OH^- \rightleftharpoons H_2O$	$1/K_w$



5. Salinity

- Salinity is the total amount of dissolved salts in water; grams of salts per kilogram of water (g/kg) or as parts per thousand (ppt).
- Seawater has 11 major constituents that make up more than 99.99% of all dissolved materials.
- Although salinity may vary, the major constituents are well mixed and present in the same relative proportions.

Major Constituents of Seawater (% by weight)

Chloride (Cl^-)	55.07%
Sodium (Na^+)	30.62%
Sulfate (SO_4^{2-})	7.72%
Magnesium (Mg^{2+})	3.68%
Calcium (Ca^{2+})	1.17%
Potassium (K^+)	1.10%
Bicarbonate (HCO_3^-)	0.40%
Bromide (Br^-)	0.19%
Strontium (Sr^{2+})	0.02%
Boron (B^{3+})	0.01%
Fluoride (F^-)	0.01%

Why Study Salinity…

- Determines the distribution of plants and animals that live in the ocean.
- Affects other properties of seawater, such as its density and the amount of dissolved oxygen.

Significant Values for Salinity

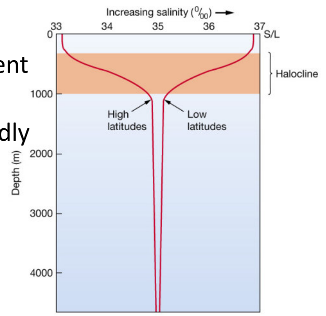
- The average salinity of the world's oceans is 35 ppt.
- Freshwater has a salinity of <1 ppt.
- Inshore waters with salinity values between 1 - 25 ppt are called brackish.
- Waters with salinity greater than 40 ppt are called hypersaline.

Processes affecting seawater salinity

- Processes that <u>decrease</u> seawater salinity:
  - Precipitation
  - Runoff
  - Sea ice melting
- Processes that <u>increase</u> seawater salinity:
  - Sea ice forming
  - Evaporation

Salinity variation with depth

- Curves for high and low latitudes begin at different surface salinities
- **Halocline** = layer of rapidly changing salinity
- At depth, salinity is uniform



6) Alkalinity and Acidity

6.1. Alkalinity

– the capacity of water to accept H^+

- Measure of the ability of a water body to neutralize acidity
- Serves as a pH buffer
- Helps determine ability of water to support algal growth and aquatic life

- Alkalinity is produced by dissolution of limestone and other minerals

  e.g.

  $CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-}$

  $CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$

- Water supply with high total alkalinity is resistant to pH change (>> buffering capacity)
- Two samples with identical pH but different alkalinity behave differently on addition of acid
- Different capacity to neutralize acid

- Measurement of the buffer capacity (resistance to pH change)

  e.g. Carbonate neutralization reaction

  $CO_3^{2-} + H^+ \rightleftharpoons HCO_3^-$

  Bicarbonate neutralization reaction

  $HCO_3^- + H^+ \rightleftharpoons H_2O.CO_2 \rightleftharpoons H_2O + CO_2$

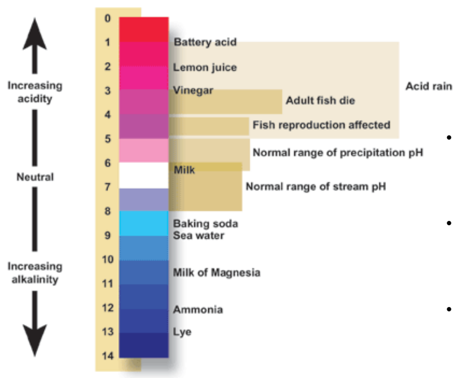
  Hydroxide neutralization reaction

  $H^+ + OH^- \rightleftharpoons H_2O$

  Alkalinity = $[OH^-] + [HCO_3^-] + 2[CO_3^{2-}] - [H^+]$

- Units are mg L^{-1} $CaCO_3$ (regardless of species)

Acidity



pH = - log $[H^+]$

- H^+ usually surrounded by water of hydration, written H_3O^+
- 'Master Variable' – controls parameters e.g. speciation
- Ranges 5.5 - 9

6.2. Acidity

- Acidity results from presence of weak acids: $H_2PO_4^-$, CO_2, H_2S, proteins, fatty acids, metal ions (e.g. Al^{3+}, Fe^{3+})

  e.g. $[Al(H_2O)_6]^{3+} + H_2O \rightleftharpoons [Al(H_2O)_5OH]^{2+} + H_3O^+$

  simplifies as $[Al(H_2O)_6]^{3+} \rightleftharpoons [Al(H_2O)_5OH]^{2+} + H^+$

- Difficult to measure due to volatility of gases

7) Total Hardness

- Ca^{2+} generally has highest conc. and most influence on aquatic chemistry
- *Why?*
- Calcium is a key element in many geochemical processes
- Primary minerals: gypsum ($CaSO_4.2H_2O$), anhydrite ($CaSO_4$), dolomite ($CaMg(CO_3)_2$, calcite and aragonite ($CaCO_3$)

Hard water contains high concentrations of dissolved calcium and magnesium ions

Soft water contains few of these dissolved ions.

Hardness = $[Ca^{2+}] + [Mg^{2+}]$

Alkalinity is a good indicator of hardness and vice-versa

Carbonate minerals:
limestone - $CaCO_3$
dolomite - $CaCO_3.MgCO_3$
sulfates - $CaSO_4$

(also Al^{3+}, Fe^{3+}, Mn^{2+} and Zn^{2+})

Problems with increasing hardness

- Deposition of white solid $CaCO_3$ or $MgCO_3$ with increasing temperature
  - blocks pipes and lowers efficiency of industrial processes
- Formation of scum (insoluble ppt) with soap and water

$$Ca^{2+}_{(aq)} + 2Na(C_{17}H_{33}COO^-)_{(aq)} \longrightarrow 2Na^+ + Ca(C_{17}H_{33}COO^-)_{2(s)}$$

  - detergent action is blocked

A pipe with hard-water scale build up

Some Chemical Parameters with limits

Parameter	Limit value	Unit
Ammonia	0,50	mg/l
Chlorine	250	mg/l
Conductivity	2.500	μS cm^{-1} la 20^{0}C
Nitrate	50	mg/l
Nitrite	0.5	mg/l
pH	≥ 6,5; ≤ 9,5	unități de pH
Sulphate	250	mg/l
Sulphyde	100	μg/l
Turbidity	≤ 5	UNT
Chromium total	50	μg/l
Zinc	5.000	μg/l
Iron	200	μg/l
Manganese	50	μg/l
Copper	0.1	mg/l
Alpha global activity	0,1	Bq/l
Beta global activity	1	Bq/l

USA National Primary Drinking water Regulations

National Primary Drinking Water Regulations

	MCL or TT[a] ($mg\,L^{-1}$)	Potential Health Effects from Ingestion of Water
Inorganic Chemicals		
Antimony	0,006	Increase in blood cholesterol; decrease in blood glucose
Arsenic	0,01	Skin damage; circulatory system problems; increased risk of cancer
Asbestos (fiber > 10 micrometers)	7 MFL	Increased risk of developing benign intestinal polyps
Barium	2	Increase in blood pressure
Beryllium	0,004	Intestinal lesions
Cadmium	0,005	Kidney damage
Chromium (total)	0,1	Some people who use water containing chromium well in excess of the MCL over many years could experience allergic dermatitis
Copper	TT[8]; Action Level = 1.3	Short-term exposure: Gastrointestinal distress. Long-term exposure: Liver or kidney damage. People with Wilson's disease should consult their personal doctor if their water systems exceed the copper action level
Cyanide (as free cyanide)	0,2	Nerve damage or thyroid problems
Fluoride	4	Bone disease (pain and tenderness of the bones); children may get mottled teeth
Lead	TT[8]; Action Level = 0.015	Infants and children: Delays in physical or mental development. Adults: Kidney problems; high blood pressure
Mercury (inorganic)	0,002	Kidney damage
Nitrate (measured as nitrogen)	10	"Blue baby syndrome" in infants less than 6 months—life threatening without immediate medical attention. Symptoms: Infant looks blue and has shortness of breath
Nitrite (measured as nitrogen)	1	"Blue baby syndrome" in infants less than 6 months—life threatening without immediate medical attention. Symptoms: Infant looks blue and has shortness of breath

USA National Primary Drinking water Regulations

Selenium	0,05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems
Thallium	0,002	Hair loss; changes in blood; kidney, intestine, or liver problems
Organic Chemicals		
Acrylamide	TT[9]	Nervous system or blood problems; increased risk of cancer
Alachlor	0,002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer
Atrazine	0,003	Cardiovascular system problems; reproductive difficulties
Benzene	0,005	Anemia; decrease in blood platelets; increased risk of cancer
Benzo(a)pyrene (PAHs)	0,0002	Reproductive difficulties; increased risk of cancer
Carbofuran	0,04	Problems with blood or nervous system; reproductive difficulties
Carbon tetrachloride	0,005	Liver problems; increased risk of cancer
Chlordane	0,002	Liver or nervous system problems; increased risk of cancer
Chlorobenzene	0,1	Liver or kidney problems
2,4-D	0,07	Kidney, liver, or adrenal gland problems
Dalapon	0,2	Minor kidney changes
1,2-Dibromo-3-chloropropane (DBCP)	0,0002	Reproductive difficulties; increased risk of cancer
o-Dichlorobenzene	0,6	Liver, kidney, or circulatory system problems
p-Dichlorobenzene	0,075	Anemia; liver, kidney or spleen damage; changes in blood
1,2-Dichloroethane	0,005	Increased risk of cancer
1,1-Dichloroethylene	0,007	Liver problems
cis-1,2-Dichloroethylene	0,07	Liver problems
trans-1,2-Dichloroethylene	0,1	Liver problems
Dichloromethane	0,005	Liver problems; increased risk of cancer
1,2-Dichloropropane	0,005	Increased risk of cancer
Di(2-ethylhexyl)adipate	0,4	General toxic effects or reproductive difficulties
Di(2-ethylhexyl)phthalate	0,006	Reproductive difficulties; liver problems; increased risk of cancer
Dinoseb	0,007	Reproductive difficulties
Dioxin (2,3,7,8-TCDD)	0	Reproductive difficulties; increased risk of cancer
Diquat	0,02	Cataracts
Endothall	0,1	Stomach and intestinal problems
Endrin	0,002	Nervous system effects
Epichlorohydrin	TT[9]	Stomach problems; reproductive difficulties; increased risk of cancer
Ethylbenzene	0,7	Liver or kidney problems
Ethylene dibromide	0,00005	Stomach problems; reproductive difficulties; increased risk of cancer
Glyphosate	0,7	Kidney problems; reproductive difficulties
Heptachlor	0,0004	Liver damage; increased risk of cancer
Heptachlor epoxide	0,0002	Liver damage; increased risk of cancer

Water Quality Testing

- Identify problems
- Select an appropriate water source
- Determine the effectiveness of water treatment technologies
- Ensure safe drinking water
- Adopt precautionary measures
- Raise awareness
- Influence policies to supply safe water