CE 213
WATER QUALITY & POLLUTION

L17 , 18, 19 - Module D.
Water Quality and Management

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Schedule : LEC: Tu Th 5:00-6:30;

Module D

- *Water quality assessment* –
  - parameters and permissible levels, Hydrologic Cycle, Sources of water pollution
- *Pollution indicators* –
  - physical, chemical, and biological.
  - Description of physical parameters: alkalinity, hardness, DO, BOD, COD.
- *Drinking water* –
  - sources and characteristics, standards, impurities and their sources.
  - Change in water quality downstream of a flowing river
- *Water Management* -
  - Water Availability and Use.

Presentation Topic -

Status of water availability in India AND

Efforts made by international and national agencies to mitigate water scarcity

Water Quality Parameters

- *Water quality* is *determined* by assessing three classes of attributes: physical, chemical, and biological.

- There are *standards* of *water quality* set for each of these three classes of attributes.

Physical Parameters of Water Quality assessment

- Colour
- Odour
- Turbidity
- Temperature
- Conductivity

Chemical Parameters for Water Quality assessment

pH
Acidity
Alkalinity
Hardness
Solids
Harmful Chemicals

- Chlorides
- Sulphates
- Iron
- Nitrates
- Heavy Metals
- Pesticides

Alkalinity

- Capacity to neutralize acid
- Presence of carbonates, bi-carbonates and hydroxide compounds of Ca, Mg, Na and K

Alkalinity

- Alkalinity measures the **buffering capacity** of the water against changes in pH.
- Water that has **a high alkalinity** can accept large doses of acids ***or*** bases without altering the pH significantly.
- Waters with **low alkalinity**, such as rainwater or distilled water, can experience a drop in the pH with only a minor addition of an acid or base.

- **In** natural waters much of the alkalinity is provided by the carbonate/ bicarbonate buffering system.

- Alkalinity is determined by measuring the amount of acid needed to lower the pH in a water sample to a specific endpoint; the results are usually reported in standardized units **as** milligrams $CaCO_3$ per liter.

- Carbon dioxide dissolves in water to form carbonic acid , which dissociates and is in equilibrium with bicarbonate and carbonate ions.

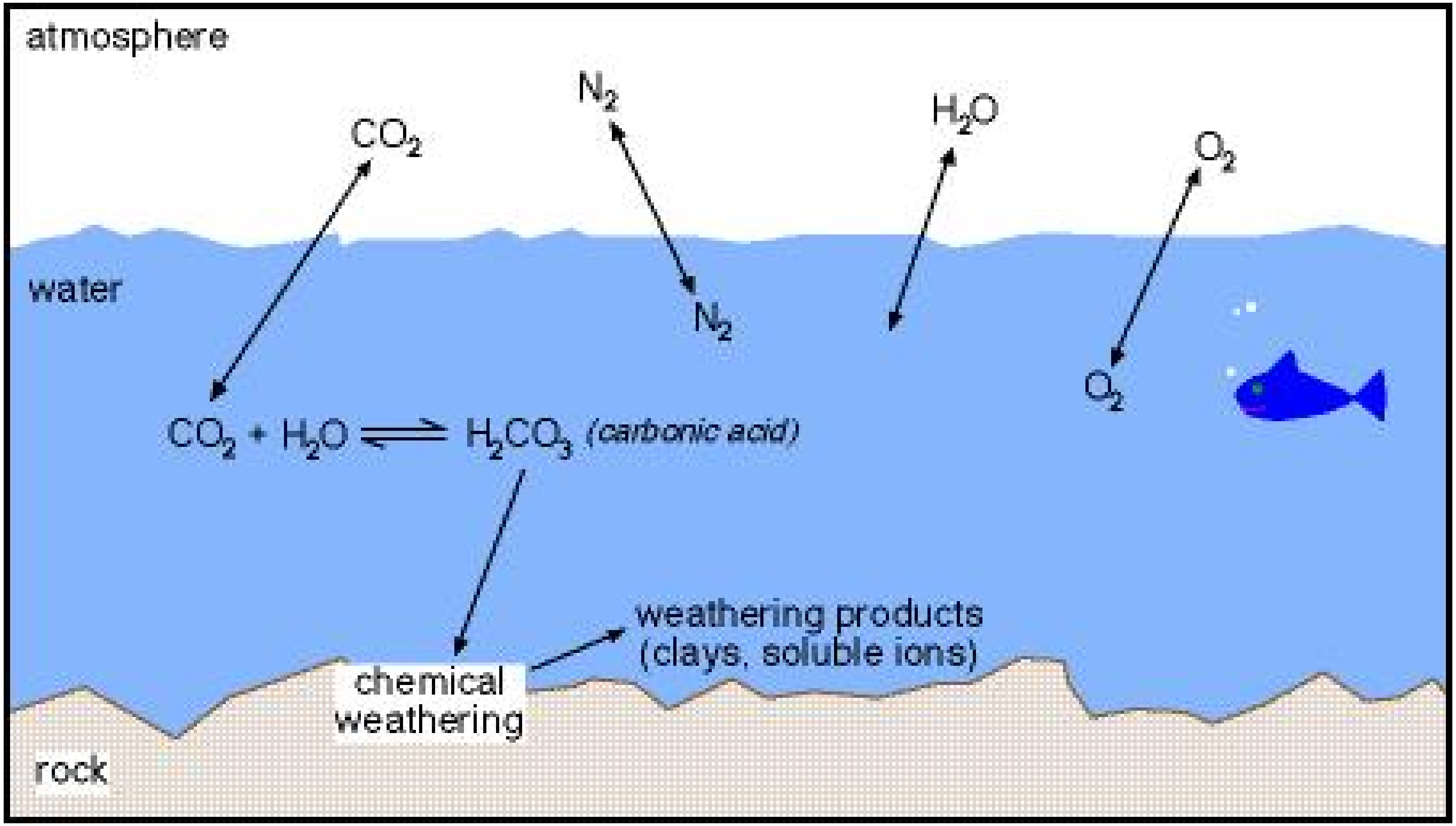
$$CO_2\ (gas) \longleftrightarrow CO_2\ (dissolved)$$

$$CO_2(dissolved) + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

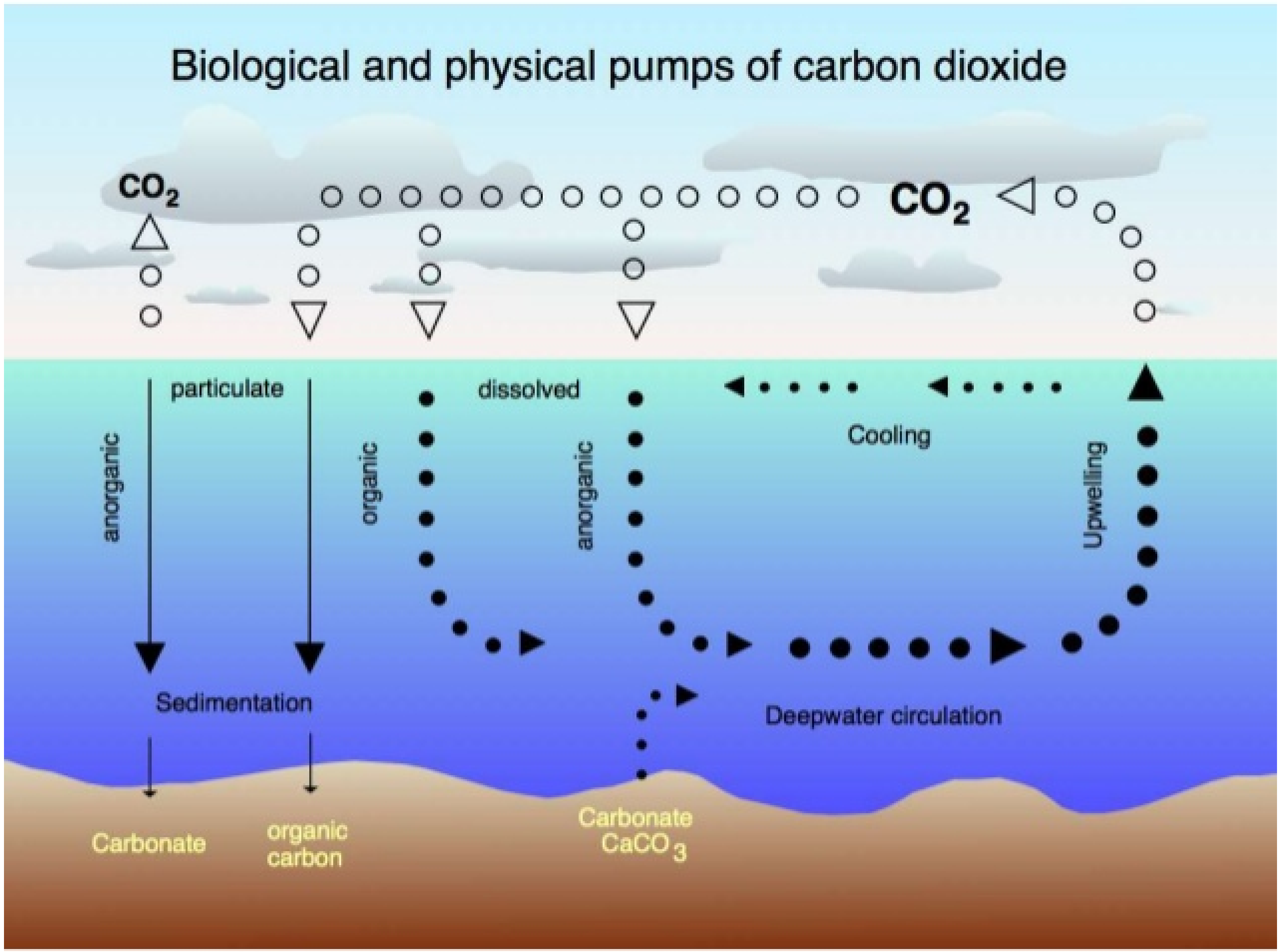
$$HCO_3^- \longleftrightarrow 2H^+ + CO_3^{2-}$$

- ***Buffering mechanism***: If an acid is added to the water, the hydrogen ion concentration is increased, and this combines with both the carbonate and bicarbonate ions, driving the equilibrium to the left, releasing carbon dioxide into the atmosphere.

Carbonate cycle in water



Biological and Physical pumps of CO2



Hardness

- Capacity of water for reducing and destroying the lather of soap
- **It is total concentration of calcium and magnesium ions**
- Types
  - Temporary – Bicarbonates of Calcium and Magnesium
  - Permanent – Sulphates , chlorides and nitrates of calcium and magnesium
- Impact
  - Causes encrustations in water supply structures

Total Hardness

- **Total Hardness**: total concentration of metal ions expressed in terms of mg/L of equivalent $CaCO_{3.}$
- Primary ions are Ca^{2+} and Mg^{2+}.
  - also iron and manganese.
- **Total Hardness approximates total alkalinity.**

Alkalinity vs. Hardness

Possibility of 3 cases

- Alkalinity = Hardness
  - Ca and Mg salts are present
- Alkalinity > Hardness –
  - presence of basic salts, Na, K along with Ca and Mg
- Alkalinity < Hardness –
  - neutral salts of Ca & Mg present

Common problems

Visible effects	Reasons
water turns black, smell	Waste water
Acidic taste	Low pH
Alkaline taste	High pH
Boiled Rice hard and yellow	High Alkalinity
White deposits on boiling	Hardness

Visible effects	Reason
Iron taste, change in color after exposure to atmosphere, change in colour of clothes & utensils Oily appearance on top of water body	Iron
Soap not lathering	hardness
Brownish black streaks on teeth	Fluride
Growth of Algae	Nitrate, phosphate
Fish kills	Low pH, less DO
Salty taste	chloride

Indicators of water pollution

1. **Physicochemical**

   - DO, BOD, COD
     - Measurement methods

   - Nitrogenous BOD,
   - Limitations of BOD test

2. **Bacterial**

   - coliforms, fecal coliforms

Dissolved Oxygen

- Oxygen, although poorly soluble in water, is fundamental to aquatic life.
- Without free dissolved oxygen, streams and lakes become uninhabitable to aerobic organisms, including fish and most invertebrates.
- Dissolved oxygen is inversely proportional to temperature, and the maximum amount of oxygen that can be dissolved in water at 0°C is 14.6 mg/L.
- The amount of oxygen dissolved in water is usually measured with the ***Winkler*** test.

Biochemical Oxygen Demand…….[1/10]

- Amount of oxygen required by bacteria and other microorganisms in **stabilizing decomposable organic matter** .

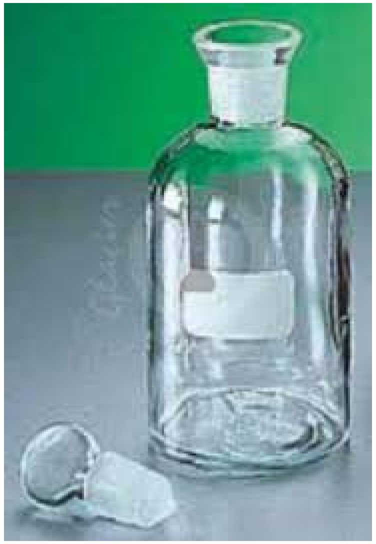
- A very low oxygen demand indicates either
  - clean water OR
  - the presence of a toxic or nondegradable pollutant.

The 5-day BOD test …….[2/10]

The 5-day BOD test (BOD5) begins by placing water or effluent samples into **two standard** 60- or 300-mL BOD bottles.

One sample is analysed immediately to measure the initial **dissolved oxygen** concentration in the effluent, often using a Winkler titration.

The second BOD bottle is sealed and stored at 20°C in the dark.
(The samples are stored in the dark to avoid **photosynthetic oxygen generation**.)



- After 5 days the amount of dissolved oxygen remaining in the sample is measured.
- The difference between the initial and ending oxygen concentrations is the BOD5.

$$[BOD\ ] = [DO]_{Final} - [DO]_{initial}$$

- **Test limitations** : One problem with the BOD test is that it takes ***5*** days to run.

Ultimate BOD (UBOD) …….[4/10]

- The ultimate biochemical oxygen demand ([UBOD]) is a parameter that quantifies the **oxygen required for the total biochemical degradation** of organic matter by aquatic microorganisms.

- **APPLICATION:** [UBOD] and the rate of oxygen consumption are frequently used in mathematical models to **predict the impact of an effluent on receiving bodies** such as lakes and rivers.

Sample Calculations for BOD

$$\mathbf{BOD_T = BOD_u\ (1 - e^{-KT}\ )}$$

Where, BOD_u is ultimate BOD

$$\mathbf{K_T = K_{20}\ (1.047^{Temp. - 20}\ )}$$

Question :

The BOD_5 of a waste water is determined to be 150mg/l at 20^0C. The K value is known to be 0.23 per day. What would be the BOD_8 be if the test were run at 15^0C ?

Kinetics for Streeter-Phelps Model

- **Deoxygenation**

L = BOD remaining at any time

dL/dt = Rate of deoxygenation equivalent to rate of BOD removal

dL/dt = $-k_1L$ for a first order reaction

k_1 = deoxygenation constant, f'n of waste type and temp.

$$-\frac{d[L]}{dt} = kL$$

$$\int_{C_0}^{C} \frac{dL}{L} = -k\int_0^t dt$$

$$\ln\frac{L}{L_0} = -kt \quad or \quad \frac{L}{L_0} = e^{-kt} \;->\; L = L_0\, e^{-kt}$$

Integration and substitution

The last differential equation can be integrated to:

$$D = \frac{k_1 L_o}{k_2 - k_1}(e^{-k_1 t} - e^{-k_2 t}) + D_o e^{-k_2 t}$$

It can be observed that the minimum value, D_c is achieved when dD/dt = 0:

$$\frac{dD}{dt} = k_1 L_o e^{-k_1 t} - k_2 D = 0$$

$$D_c = \frac{k_1}{k_2} L_o e^{-k_1 t}$$, since D is then D_c

Substituting this last equation in the first, when D = D_c and solving for t = t_c:

$$t_c = \frac{1}{k_2 - k_1} \ln\left\{\frac{k_2}{k_1}\left[1 - \frac{D_o(k_2 - k_1)}{k_1 L_o}\right]\right\}$$

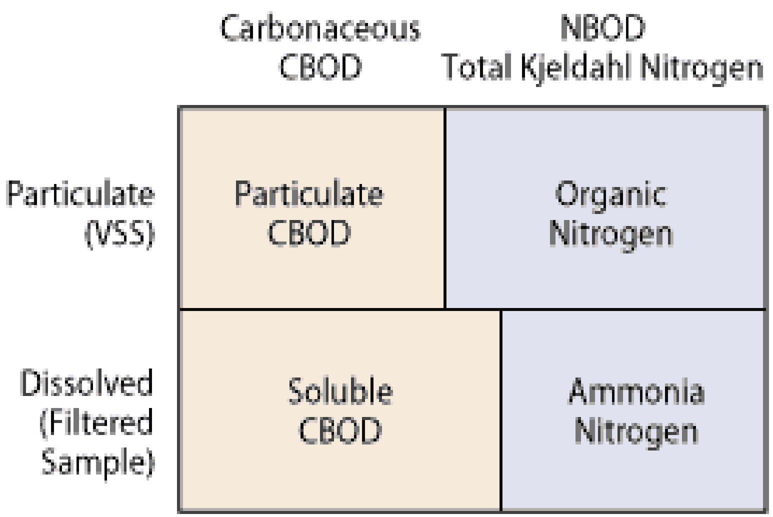
What is the difference between BOD, COD or TOC? Why do I have to measure them?

- Almost all wastewater treatment plants are required to measure one of these three items as a measure of the pollution value in the water.
- COD should always measure higher than TOC and then BOD.
- COD or Chemical Oxygen Demand is the total measurement of all chemicals in the water that can be oxidized.
- TOC or Total Organic Carbon is the measurement of organic carbons.
- BOD- Biochemical Oxygen Demand is supposed to measure the amount of food (or organic carbons) that bacteria can oxidize.

http://www.environmentalleverage.com/BOD%20vs%20COD.htm

BOD Components …….[6/10] CBOD, NBOD

Total Biological Oxygen Demand Components



BOD Observed with Various Decay Rates (mg/L)

$$BOD = 10\left(1 - BOD_{Ultimate}\right)\left(e^{-k \cdot Time}\right)$$

	Decay Rate, k (day^{-1})		
	0.05	0.10	0.10
0-Day	0.0	0.0	0.0
5-Day	2.2	3.9	5.3
10-Day	3.9	6.3	7.8
15-Day	5.3	7.8	8.9
20-Day	6.3	8.6	9.5
25-Day	7.1	9.2	9.8
30-Day	7.8	9.5	9.9
Ultimate	10.0	10.0	10.0
$BOD_{Ultimate}/BOD_5$	4.5	2.5	1.9
$BOD_{Ultimate}/BOD_{10}$	2.6	1.6	1.3

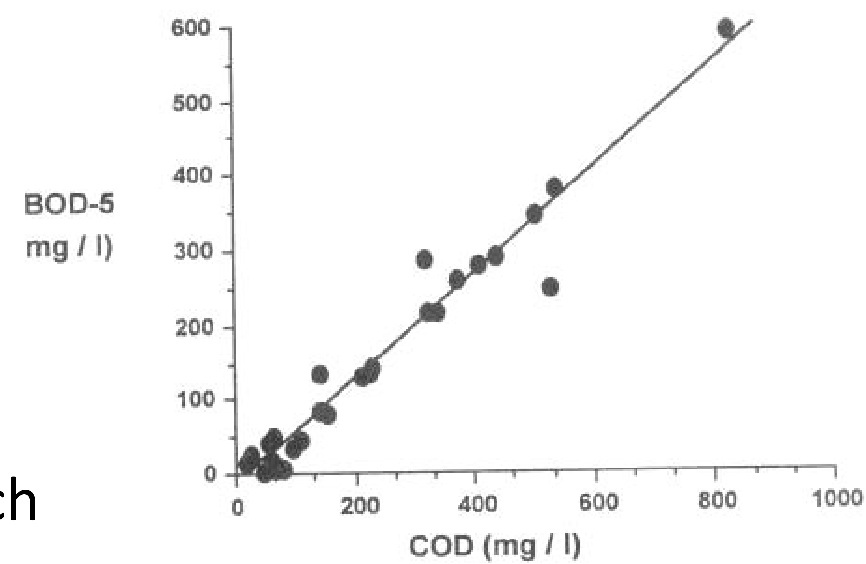
Chemical Oxygen Demand

It measures the amount of oxygen required to chemically oxidize organic compounds in water.

Why Measure COD?

- COD is used as a **general indicator of water qualit**y and is an integral part of all water quality management programs.

Additionally, COD is often used to estimate BOD as a **strong correlation** exists between COD and BOD, however COD is a much faster, more accurate test.



What is the relationship between the COD and BOD values in Waste water?

- COD or Chemical Oxygen Demand is the total measurement of all chemicals (organics & in-organics) in the water / waste water;
  BOD is a measure of, the amount of oxygen required for the bacteria to degrade the organic components present in water / waste water.
- The ratio of BOD/COD : COD is higher than BOD; maximum of up to 4 times in medium scale industries; but it varies based on the industrial process and nature of the raw materials used;

Water Quality

- ✓ Water Quality Assessment
  - Parameters
  - Standards for drinking water in India
- ✓ Water Pollution Indicators
  - Physicochemical, Bacterial

To be covered

- Changing water quality of a river – Ganga in UP
- Sources of drinking water
  - Surface vs. Groundwater
- Drinking water standards
- Drinking vs. potable vs. waste water

First hand experience of water quality assessment

1 : Preliminary Examination of Water.
Taste, Odor, Colour

2 : Common Chemical methods for Examination of Water .

2.A pH
2.B Turbidity.
2.C Conductivity .
2.D Alkalinity .
2.E Sulfate determination.

3 : Examination of Water: Solids, Sulfate & Hardness .

3.A TS, TSS, TDS .
3.B Sulfate.
3.C Hardness.

4, 5 : Examination of Water:

COD & Chloride .

DO & BOD.

6: Water Disinfection:

Free & Combined Residual Chlorine .

7 : Examination of Water :

Nitrogen, Phosphorus & Fluoride**.**

8 : Microbiological Testing of Water.

8.A Multiple Tube Fermentation Test (MPN)
8.B Heterotrophic Plate Count Method .

Potable (Drinking) water vs. Wastewater

- Potable water is water which is **fit for consumption** by humans and other animals. It is also called drinking water, in a reference to its intended use.
  - Water may be naturally potable, as is the case with pristine springs, or it may need to be treated in order to be safe.
  - In either instance, the safety of water is assessed with tests which look for potentially harmful contaminants.

- Wastewater is water **containing wastes** from residential, commercial, and industrial processes.
  - Municipal wastewater contains sewage, gray water (e.g., water from sinks and showers), and sometimes industrial wastewater. Large industries, such as refineries, also generate wastewater.
  - Wastewater requires treatment to remove pollutants prior to discharge.

Water characteristics

Characteristic	Surface Water	Ground Water
Turbidity	high	low
Dissolved minerals	low-moderate	high
Biological content	high	low
Temporal variability	very high	low

Water Uses and related parameters of concern

Use	Typical quality parameters
Public Water Supply	Turbidity, TDS, inorganic and organic compounds, microbes
Water contact recreation	Turbidity, bacteria, toxic compounds
Fish propagation and wildlife	DO, chlorinated organic compounds
Industrial water supply	Suspended and dissolved constituents
Agricultural water supply	Sodium, TDS
Shellfish harvesting	DO, bacteria

Water Quality Standards and Guidelines

Why do we have water-quality standards and guidelines?

- Standards and guidelines are established to **protect water for designated uses** such as drinking, recreation, agricultural irrigation, or protection and maintenance of aquatic life.
- Standards for **drinking-water quality** ensure that public drinking-water supplies are as safe as possible.

Who sets these standards and guidelines?

<u>International</u>: WHO, FAO

<u>Country specific</u>

India: CPCB, ICMR, BIS

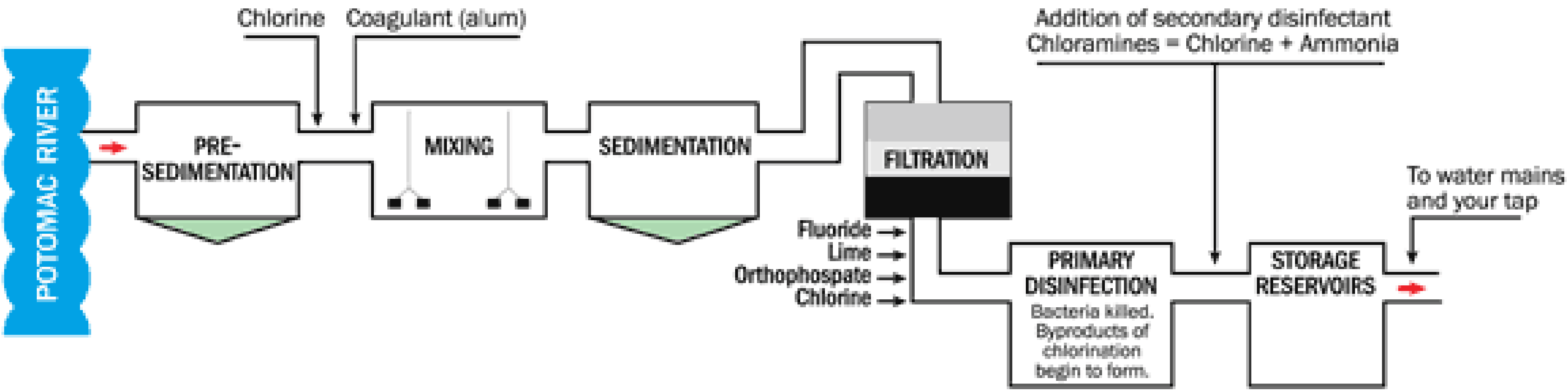
USA: EPA

In India, the design of water supply systems has been done using certain standards. Currently the standard being used is BIS 1172: 1993, reaffirmed in 1998.

Municipal Drinking Water Treatment

A combination selected from the following processes is used worldwide:

- Pre-chlorination for algae control and arresting biological growth
- **Aeration** along with pre-chlorination for removal of dissolved iron and manganese
- **Coagulation** for flocculation or slow-sand filtration
- Coagulant aids, also known as polyelectrolytes – to improve coagulation and for thicker floc formation
- Sedimentation for solids separation that is removal of suspended solids trapped in the floc
- **Filtration** to remove particles from water
- **Disinfection** for killing bacteria viruses and other pathogens.



Main Treatment Processes at Dalecarlia and McMillan Water Treatment Plants

Pre-Sedimentation - Allows large particles in untreated water to settle out naturally.

Mixing - "Coagulants" are added to the water to cause small particles to stick together when the water is mixed, making larger, heavier particles.

Sedimentation - Allows the newly formed larger particles to settle out naturally.

Filtration - Removes smaller particles by trapping them in sand filters.

Primary Disinfection - with Chlorine/Chloramines (after 11-1-2000). Other chemicals added include:
- Lime to adjust the pH (the water's acidity) to prevent corrosion.
- Fluoride at low levels to protect teeth (as recommended by the American Dental association)

Water Parameter and Treatment Method.......[1/4]

Constituent	Chemical Formula	Difficulties Caused	Means of Treatment
Turbidity	non-expressed in analysis as units	imparts unsightly appearance to water; deposits in water lines, process equipment, etc.; interferes with most process uses	coagulation, settling, and filtration
Hardness	calcium and magnesium salts, expressed as $CaCO_3$	chief source of scale in heat exchange equipment, boilers, pipe lines, etc.; forms curds with soap, interferes with dyeing, etc.	softening; demineralization; internal boiler water treatment; surface active agents
Alkalinity	bicarbonate(HCO_3^-), carbonate (CO_3^{2-}), and hydroxide(OH^-), expressed as $CaCO_3$	foam and carryover of solids with steam; embrittlement of boiler steel; bicarbonate and carbonate produce CO_2 in steam, a source of corrosion in condensate lines	lime and lime-soda softening; acid treatment; hydrogen zeolite softening; demineralization dealkalization by anion exchange
Free Mineral Acid	H_2SO_4 , HCl. etc., expressed as $CaCO_3$	corrosion	neutralization with alkalies
Carbon Dioxide	CO_2	corrosion in water lines, particularly steam and condensate lines	aeration, deaeration, neutralization with alkalies

Water Parameter and Treatment Method……[2/4]

Constituent	Chemical Formula	Difficulties Caused	Means of Treatment
Sulfate	SO_4^{2-}	adds to solids content of water, but in itself is not usually significant, combines with calcium to form calcium sulfate scale	Demineralization, reverse osmosis, electrodialysis, evaporation
Chloride	Cl^-	adds to solids content and increases corrosive character of water	demineralization, reverse osmosis, electrodialysis, evaporation
Nitrate	NO_3^-	adds to solids content, but is not usually significant industrially: high concentrations cause methemoglobinemia in infants; useful for control of boiler metal embrittlement	demineralization, reverse osmosis, electrodialysis, evaporation
Fluoride	F^-	cause of mottled enamel in teeth; also used for control of dental decay: not usually significant industrially	adsorption with magnesium hydroxide, calcium phosphate, or bone black; alum coagulation
Sodium	Na^+	adds to solids content of water: when combined with OH^-, causes corrosion in boilers under certain conditions	demineralization, reverse osmosis, electrodialysis, evaporation

Constituent	Chemical Formula	Difficulties Caused	Means of Treatment
Silica	SiO_2	scale in boilers and cooling water systems; insoluble turbine blade deposits due to silica vaporization	hot and warm process removal by magnesium salts; adsorption by highly basic anion exchange resins, in conjunction with demineralization, reverse osmosis, evaporation
Iron	Fe^{2+} (ferrous) Fe^{3+} (ferric)	discolors water on precipitation; source of deposits in water lines, boilers. etc.; interferes with dyeing, tanning, papermaking, etc.	aeration; coagulation and filtration; lime softening; cation exchange; contact filtration; surface active agents for iron retention
Manganese	Mn^{2+}	same as iron	same as iron
Aluminum	Al^{3+}	usually present as a result of floc carryover from clarifier; can cause deposits in cooling systems and contribute to complex boiler scales	improved clarifier and filter operation
Oxygen	O_2	corrosion of water lines, heat exchange equipment, boilers, return lines, etc.	deaeration; sodium sulfite; corrosion inhibitors
Hydrogen Sulfide	H_2S	cause of "rotten egg" odor; corrosion	aeration; chlorination; highly basic anion exchange
Ammonia	NH_3	corrosion of copper and zinc alloys by formation of complex soluble ion	cation exchange with hydrogen zeolite; chlorination; deaeration

Water Parameter and Treatment Method……[4/4]

Constituent	Chemical Formula	Difficulties Caused	Means of Treatment
Dissolved Solids	none	refers to total amount of dissolved matter, determined by evaporation; high concentrations are objectionable because of process interference and as a cause of foaming in boilers	lime softening and cation exchange by hydrogen zeolite; demineralization, reverse osmosis, electrodialysis, evaporation
Suspended Solids	none	refers to the measure of undissolved matter, determined gravimetrically; deposits in heat exchange equipment, boilers, water lines, etc.	subsidence; filtration, usually preceded by coagulation and settling
Total Solids	none	refers to the sum of dissolved and suspended solids, determined gravimetrically	see "Dissolved Solids" and "Suspended Solids"