

**Environmental Engineering-I**

**Drinking water Quality  
and Monitoring**

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# Drinking water Quality and Monitoring

1. Definition
2. Identification and measurement of water quality
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  1. Physical parameters
  2. Chemical parameters
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# 3.1. Introduction

- Freshwater is a finite resource essential for human existence, agriculture and industry.
- Water pollution and wasteful use of freshwater threaten development projects and make water treatment essential to produce safe drinking water.
- Discharge of toxic chemicals, over-pumping of aquifer, long range atmospheric transport of pollutants and contamination of water bodies with substances that promote algal growth are some of today's major causes of water quality deterioration.

- Gross organic pollution leads to disturbance of the oxygen balance and is often accompanied by severe pathogenic contamination.
- Accelerated eutrophication results from enrichment with nutrients from various origins, particularly domestic sewage, agricultural run-off and agro-industrial effluents

- The main problems associated with agriculture are **salinization, nitrate and pesticide contamination**, and erosion leading to elevated concentrations of **suspended solids** in rivers and streams and the siltation of impoundments.
  
- Direct contamination of surface waters with metals in discharges from mining, smelting and industrial manufacturing is a long-standing phenomenon

- The extent of the human activities that influence the environment has increased dramatically during the past few decades; terrestrial ecosystems, freshwater and marine environments and the atmosphere are all affected.
  - **Large-scale mining and fossil fuel burning** have started to interfere measurably with natural hydro-geochemical cycles, resulting in a new generation of environmental problems.
  - The scale of socio-economic activities, **urbanization, industrial operations and agricultural production**, has reached the point where they cause a worldwide impact

- Very complex inter-relationships between socio-economic factors and natural hydrological and ecological conditions have developed.
  - Therefore, a pressing need has emerged for comprehensive and accurate assessments of trends in water quality.
  - Reliable monitoring data are the indispensable basis for such assessments.

- **Monitoring** is defined by the International Organization for Standardization (ISO) as: “**the programmed process of sampling, measurement and subsequent recording or signaling, or both, of various water characteristics, often with the aim of assessing conformity to specified objectives**”.



□ This general definition can be differentiated into three types of monitoring activities that distinguish between **long-term**, **short-term** and **continuous monitoring** programs as follows:

- ✓ **Monitoring** is the **long-term**, standardized measurement and observation of the aquatic environment in order to define status and trends.
- ✓ **Surveys** are **finite duration**, intensive programs to measure and observe the quality of the aquatic environment for a specific purpose.
- ✓ **Surveillance** is **continuous**, specific measurement and observation for the purpose of water quality management and operational activities.

## 3.2. Identification and measurement of water and wastewater quality

- Water quality is affected by a wide range of natural and human influences.
- The most important of the natural influences are geological, hydrological and climate, since these affect the quantity and quality of water variables.
- The effects of human activities on water quality are both widespread and varied in the degree to which they disrupt the ecosystem and/or restrict water use.
- Most common water quality degradation include waste disposal, industrial activities, agricultural activities and mining.

**Table 2.2 Important processes affecting water quality**

Process type	Major process within water body	Water body
Hydrological	Dilution	All water bodies
	Evaporation	Surface waters
	Percolation and leaching	Groundwaters
	Suspension and settling	Surface waters
Physical	Gas exchange with atmosphere	Mostly rivers and lakes
	Volatilisation	Mostly rivers and lakes
	Adsorption/desorption	All water bodies
	Heating and cooling	Mostly rivers and lakes
	Diffusion	
Chemical	Photodegradation	
	Acid base reactions	All water bodies
	Redox reactions	All water bodies
	Dissolution of particles	All water bodies
	Precipitation of minerals	All water bodies
	Ionic exchange <sup>1</sup>	Groundwaters
Biological	Primary production	Surface waters
	Microbial die-off and growth	All water bodies
	Decomposition of organic matter	Mostly rivers and lakes
	Bioaccumulation <sup>2</sup>	Mostly rivers and lakes
	Biomagnification <sup>3</sup>	Mostly rivers and lakes

<sup>1</sup>Ionic exchange is the substitution of cations, for example in clays.

- The quality of water may be described in terms of the concentration and state of some or all materials present in the water, together with certain physical characteristics of the water.
  
- The main elements of water quality monitoring are, therefore, on-site measurements, the collection and analysis of water samples, the study and evaluation of the analytical results, and the reporting of the findings.

- ❑ One purpose of a monitoring program is, therefore, **to gather sufficient data to assess spatial and/or temporal variations in water quality.**
  
- ❑ The quality of the aquatic environment is a broader issue which can be described in terms of:
  - water quality
  - the composition and state of the biological life present in the water body,
  - the nature of the particulate matter present
  - the physical description of the water body (hydrology, dimensions, nature of lake bottom or river bed, etc.).

- Complete assessment of the quality of the aquatic environment can be achieved by
  - chemical analyses of water, particulate matter
  - analysis of aquatic organisms (such as planktonic algae and selected parts of organisms such as fish muscle),
  - biological tests, such as toxicity tests and measurements of enzyme activities
  
  - descriptions of aquatic organisms, including their occurrence, density, biomass, physiology and diversity
  
  - physical measurements of water temperature, pH, conductivity, light penetration, particle size of suspended and deposited material, dimensions of the water body, flow velocity, hydrological balance etc.

### 3.3. Designing a monitoring program

- The design of a monitoring program should be based on clear and well thought out aims and objectives and should ensure, as far as possible, that the planned monitoring activities are practicable
- It is useful to prepare a program document or study plan, which should begin with a clear statement of the objectives of the program and a complete description of the area in which the monitoring is to take place.
- The geographical limits of the area, the present and planned water uses and the present and expected pollution sources should be identified.

- Subsequent sections of the study plan should cover the locations and frequency of sampling and the variables for analysis.
- The plan should also specify whether the analyses will be done in the field or in the laboratory.
- This decision must take into consideration the resources available for all the necessary field and laboratory work, data handling, analysis and interpretation, and the preparation and distribution of reports.



## **The principal elements of a study plan are:**

- a clear statement of aims and objectives
- information expectations and intended uses
  
- a description of the study area concerned
- a description of the sampling sites
  
- a listing of the water quality variables that will be measured,
- proposed frequency and timing of sampling
  
- an estimate of the resources required to implement the design, and a plan for quality control and quality assurance

## 3.4. Purposes of water quality monitoring

- The principal reason for monitoring water quality has been, traditionally, the need to
  - verify whether the observed water quality is suitable for intended uses.
  - determine trends in the quality of the aquatic environment and how the environment is affected by the release of contaminants
  - estimate nutrient or pollutant fluxes discharged by rivers or ground waters to lakes and oceans, or across international boundaries.

□ Water quality monitoring and assessment can combine the following goals in different ways:

- Uses of water. Does water meet user requirements for quantity and quality?
- Influences on water quality from direct use or from other human activities or natural processes. What are these influences?
- Impacts on water quality
- Control and regulation of water quality
  
- How does water quality differ geographically in relation to uses and quality influences?
- How have past trends in water quality, influences and policies led to the present status?
- How does water quality influence other parts of the environment

## 3.5. The need for information for management

- Examples of the type of information that may be generated by a monitoring program
  - How the quality and quantity of water in a water body relate to the requirements of users.
  - How the quality and quantity of water in a water body relate to established water quality standards.
  - How the quality of water in a water body is affected by natural processes in the catchment.
  - The capacity of the water body to assimilate an increase in waste discharges without causing unacceptable levels of pollution.
  - Whether or not existing waste discharges conform to existing standards and regulations.
  - The appropriateness and effectiveness of control strategies and management actions for pollution control.
  - The trends of changes in water quality with respect to time as a result of changing human activities in the catchment area.

## The need for information for management

- Control measures that should be implemented to improve or prevent further deterioration of water quality.
- The chemical or biological variables in the water that render it unsuitable for beneficial uses
- The hazards to human health that result, or may result, from poor water quality in the water body.
- How developments in the catchment area have affected or will affect water quality.
- The effects that deteriorating water quality have on plant and animal life in, or near, the water body.

## 3.5. Objectives of water quality monitoring

- help to avoid misunderstandings by project participants
- an effective way of communicating with sponsors
- provide assurance that the monitoring program has been systematically planned.
- important when the program is evaluated to determine whether or not the objectives are being met.
- The following questions help to establish monitoring objectives
  - Why is monitoring going to be conducted? Is it for basic information, planning and policy information, management and operational information, regulation and compliance, resource assessment, or other purposes?
  - What information is required on water quality for various uses? Which variables should be measured, at what frequency and in response to which natural or man-made events?

## Cont..

- What is practical in terms of the human and financial resources available for monitoring?
  - There is little point in setting unrealistic objectives.
  - Who is responsible for the different elements of monitoring?
  - Who is going to use the monitoring data and what are they intending to do with the information?
- The following is a list of typical monitoring objectives that might be used as the basis for design of sampling networks.
- Identification of baseline conditions in the water-course system.
  - Detection of any signs of deterioration in water quality.
  - Identification of any water bodies in the water-course system that do not meet the desired water quality standards.
  - Identification of any contaminated areas.
  - Determination of the extent and effects of specific waste discharges.
  - Estimation of the pollution load carried by a water-course system or subsystem.

**Cont..**

- Evaluation of the effectiveness of a water quality management intervention.
- Development of water quality guidelines and/or standards for specific water uses.
- Development of regulations covering the quantity and quality of waste discharges.
- Development of a water pollution control program.



## 3.6. Preliminary surveys

- When a new program is being started, or a lapsed program is being reinstated, it is useful to begin with a small-scale pilot project.
  
- **This provides an opportunity to**
  - gain hands-on experience to new trained staff
  - confirm whether components of the program can be implemented as planned.
  - assess the sampling network
  - provide indications of whether more samples are needed in order to gain knowledge of the water quality at various points throughout a water body
  - refine the logistical aspects of monitoring

## 3.7. Description of the monitoring area

- ❑ The description of a monitoring area should consider as a minimum:
  - definition of the extent of the area
  - a summary of the environmental conditions and processes (including human activities) that may affect water quality
  - meteorological and hydrological information
  - a description of the water bodies and
  - a summary of actual and potential uses of water.
  
- ❑ A monitoring program commonly covers the water-course system of a catchment area
- ❑ The catchment area is defined as the area from which all water flows to the water-course.
- ❑ A description of the catchment area includes its size (in km<sup>2</sup>), its geographical location and the identification of each water body in the water-course system.

## □ **Description of water quality monitoring area include**

- Conditions and processes
- Meteorological and hydrological information
- Water bodies
- Water uses

## 3.8. Sampling Sites and stations

- ❑ A sampling site is the general area of a water body from which samples are to be taken and is sometimes called a “macrolocation”
- ❑ The exact place at which the sample is taken is commonly referred to as a sampling station or, sometimes, a “microlocation”.
- ❑ Selection requires consideration of the monitoring objectives, knowledge of the geography of the water-course system and the uses of the water and of any discharges of wastes into it
  
- ❑ The choice of sampling station depends on several factors
  - ✓ The type of the water body
  - ✓ Important morphological features of the water bodies
  - ✓ The magnitude of human impact
  - ✓ Hydrological conditions
  - ✓ Physical and chemical conditions

## 3.9. Resources for monitoring programs

- Laboratory facilities
- Transport
- Staffing
- Human resource development and training
- Communication
- Inventory of sampling stations
- Schedules for sampling expeditions
- Source literature and readings

## 3.10. Field work and sampling

- Sample containers
- Types of sample
- Water samplers
- Manual sampling procedures
- Recording field observations
- Sample preservation
- Transportation and storage of samples
- Reception of samples by the laboratory
- Safety during field work
- Source literature and further reading

## 3.11. Water quality Parameters

- ❑ Parameter selection depends on the purpose of the monitoring or the assessment.
- ❑ The parameters can be categorized as in situ and parameters measured in the laboratory (ex situ parameters).
- ❑ **Most important water quality parameters are**
  - physical parameters
  - chemical parameters
  - biological parameters
  - microbiological analysis
  - meteorological and hydrological analysis are also supplementary parameters

□ The common parameters measured in the field include:

- Temperature
- Transparency
- pH
- Conductivity (or specific conductance)
- Dissolved oxygen

□ Testing procedures and parameters may be grouped into physical, chemical, bacteriological and microscopic categories.

- Physical tests indicate properties detectable by the senses
- Chemical tests determine the amounts of mineral and organic substances that affect water quality
- Bacteriological tests show the presence of bacteria, characteristic of fecal pollution



## 3.12 Physical Parameters

- ❑ Colour, turbidity, total solids, dissolved solids, suspended solids, odor and taste are recorded.
- ✓ Colour 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. Color tests indicate the efficacy of the water treatment system.
- ✓ Turbidity in water is because of suspended solids and colloidal matter. It may be due to eroded soil caused by dredging or due to the growth of microorganisms. High turbidity makes filtration expensive. If sewage solids are present, pathogens may be encased in the particles and escape the action of chlorine during disinfection.
- ✓ Odor 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. While chlorination dilutes odor and taste caused by some contaminants, it generates a foul odor itself when added to waters polluted with detergents, algae and some other wastes.

## a. Odor

- Water odor is usually the result of labile, volatile organic compounds and may be produced by phytoplankton and aquatic plants or decaying organic matter.
- Industrial and human wastes can also create odors, either directly or as a result of stimulating biological activity.
- Organic compounds, inorganic chemicals, oil and gas can all impart odor to water although an odor does not automatically indicate the presence of harmful substances.
- Usually, the presence of an odor suggests higher than normal biological activity and is a simple test for the suitability of drinking water, since the human sense of smell is far more sensitive to low concentrations of substances than human taste.

- Odor can be measured in terms of the greatest dilution of a sample, or the number of times a sample has to be halved with odor-free water, that yields the least definitely perceptible odor.
- The former method is known as the Threshold Odor Number (TON) and the latter method as the Odor Intensity Index (OII). Both methods suffer from the subjective variability of different human judges.

## b. Temperature

- The temperature of a body of water influences its overall quality as it can harm aquatic organisms if it is outside the normal range.
- Temperature should be measured at different locations and a change in temperature determined.
- Temperature changes could indicate thermal pollution eg. industrial pollution, Runoff from parking lots and rooftops, contributing to increase in overall temperature.

Temperature of the air above the water body may affect water temperature depending on the depth of the water. Shallow water bodies are more susceptible to temperature changes than deep water.

- Temperature must be measured in situ because a water sample will gradually reach the same temperature as the surrounding air.
- If it is not possible to measure the temperature in situ, a sample must be taken from the correct location and depth of the sampling station and its temperature measured immediately it is brought to the surface.

■ Temperature: can determine the rate of biochemical reactions in the aquatic environment or whether they Can occur at all.

- Temperature is measured with a glass thermometer, either alcohol or toluene-filled or mercury-filled, with 0.1 °C graduations, or an electronic thermometer of the type that is usually an integral part of a dissolved oxygen meter or a conductivity meter.

## **Factors affecting water temperature:**

- Air temperature
- Amount of shade
- Soil erosion increasing turbidity
- Thermal pollution from human activities
- Unknown chemical reactions that weren't previously occurring in the water

## **Effects of water temperature:**

- Solubility of dissolved oxygen
- Rate of plant growth
- Metabolic rate of organisms
- Resistance in organisms

## c. Suspended matters

- Suspended matter consists of silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton and other microscopic organisms
- The type and concentration of suspended matter controls the turbidity and transparency of the water.
- Such particles vary in size from approximately 10 nm in diameter to 0.1 mm in diameter, although it is usually accepted that suspended matter is the fraction that will not pass through a 0.45  $\mu\text{m}$  pore diameter filter.

- Turbidity results from the scattering and absorption of incident light by the particles, and the transparency is the limit of visibility in the water



## d. Turbidity /Transparency

- A measure of the water's lack of clarity.
- Highly turbid water reduces light penetration therefore affecting levels of photosynthesis, warming is increased. due to absorption of sunlight, and it is generally
- Stormwater contributes to increased turbidity because of sediments and phytoplankton suspended in it
- High turbidity decreases the amount of sunlight able to penetrate the water, there by decreasing the rate of photosynthesis.
- Reduced clarity also makes the water less aesthetically pleasing, making it less desirable for many water uses eg. drinking

- ✓ It is a water quality characteristic of lakes and reservoirs and can be measured quickly and easily using simple equipment.
- ✓ This characteristic varies with the combined effects of color and turbidity. Some variation may also occur with light intensity and with the apparatus used.
- ✓ The apparatus used for transparency measurement is called a Secchi disc - named after Secchi
- ✓ The disc is made of rigid plastic or metal, but the details of its design are variable. It may be 20 to 30 cm or even larger in diameter and is usually painted white. Alternatively, it may be painted with black and white quadrants.

- When water is cloudy, sunlight will warm it more efficiently because suspended particles absorb the sunlight, warming the water. This can lead to problems associated with increased water temperature.
- Sources of  $\text{Fe}^{3+}$  and  $\text{Al}^{3+}$  can be used as flocculation agents to clear turbid water

#### **Causes of Turbidity:**

- Soil erosion – silt and clay deposition
- Urban runoff – road grime; rooftops; parking areas
- Industrial waste – sewage treatment effluent; particulates
- Abundant bottom-dwelling organisms eg catfish stirring up the sediment built up on the bottom of the lake.
- Organic matter – microorganisms; decaying plants and animals; petrol, diesel or oil from roads

#### **Effects of Turbidity:**

- Reduces water clarity
- Aesthetically unpleasant
- Decreases rate of photosynthesis
- Increases water temperature

## e. Total dissolved solids

- The substances remaining after evaporation and drying of a water sample are termed the “residue”.
- The residue is approximately equivalent to the total content of the dissolved and suspended matter in the water sample.
- Non- filterable residue corresponds to the total suspended solids (see section 7.25) and the filterable residue is the total dissolved solids (TDS).
  
- The results of a determination of total dissolved solids (TDS) can be used to check the accuracy of analyses when relatively complete analyses have been made on a water sample.
- This is accomplished by comparing the value of calculated TDS with the measured value. Ion concentrations in  $\text{mg l}^{-1}$  of constituents required to calculate the TDS are as follows:

$$1.0 < \frac{\text{measured TDS}}{\text{calculated TDS}} < 1.2$$

## 3.13. Chemical parameters

### i. pH

- Determination of the pH of water should, if possible, be made in situ. If this is not possible, for example with well water or when access to a lake or river is very difficult, the measurement should be made immediately after the sample has been obtained.
- pH: scale used to measure the acidity of water most aquatic organisms have a limited pH range with most surface water between 6 and 8 units
- **There are three different methods of pH measurement:**
  - pH indicator paper, liquid colorimetric indicators and electronic meters.
  - ✓ The use of pH indicator paper is simple and inexpensive, but the method is not very accurate and requires a subjective assessment of color by the user.

- Liquid colorimetric indicators change color in accordance with the pH of the water with which they are mixed.
- Colorimetric methods are reasonably simple and accurate to about 0.2 pH units.
- Their main disadvantage is that standards for comparison or a comparator instrument must be transported to the sampling station.
- Moreover, physical or chemical characteristics of the water may interfere with the colour developed by the indicator and lead to an incorrect measurement.

- The third method, electrometric pH measurement, is accurate and free from interferences.
- Pocket-sized, battery-powered, portable meters that give readings with an accuracy of  $\pm 0.05$  pH units are suitable for field use. Larger, more sophisticated models of portable meter can attain an accuracy of  $\pm 0.01$  pH units.
- Measurement of pH using colour indicators

Indicator	pH range
Universal	4.0-11.0
Bromocresol green	3.6-5.2
Methyl red	4.4-6.0
Bromocresol purple	5.2-6.8
Bromothymol blue	6.0-7.6
Phenol red	6.8-8.4
Thymol blue	8.0-9.6
Phenolphthalein	8.6-10.2

# Factors affecting pH

- Acidic rainfall
- Algal blooms – generally cause water to be more basic
- Level of hard-water minerals
- Releases from industrial processes—depends on whether acids or bases are released
- Release of detergents into water
- Carbonic acid from respiration or decomposition
- Oxidation of sulphides in sediments – generally more acidic



## Expected levels:

- Between pH7 and 8 for lakes and streams
- Levels between 6.5 and 8.5 are acceptable for most drinking water standards
- Areas with higher levels of water hardness (higher concentrations  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ , and  $\text{HCO}_3^-$  have higher pH values between 7.5 and 8.5 (often detergent damage is present as well).

## ii. Conductivity (or specific conductance)

- The ability of water to conduct an electric current is known as conductivity or specific conductance and depends on the concentration of ions in solution.
- Conductivity is measured in millisiemens per metre ( $1 \text{ mS m}^{-1} = 10 \text{ } \mu\text{S cm}^{-1} = 10 \text{ } \mu\text{mhos cm}^{-1}$ )
- The measurement should be made in situ, or in the field immediately after a water sample has been obtained, because conductivity changes with storage time.
- Conductivity is also temperature-dependent; thus, if the meter used for measuring conductivity is not equipped with automatic temperature correction, the temperature of the sample should be measured and recorded.

- Many manufacturers of scientific equipment produce conductivity meters.
- The apparatus consists of a conductivity cell containing two rigidly attached electrodes, which are connected by cables to the body of the meter.
- Electrolytic conductivity increases with temperature at a rate of 1.9 per cent per °C. Conductivity measurements will therefore be the most accurate when made at the same temperature as that at which the cell constant is determined.

When *conductivity* of the sample has been measured, the calculation is:

$$\text{Conductivity} = \frac{C_m \times K_c}{[0.019(t - 20) + 1]} \mu\text{mhos cm}^{-1}$$

When *resistance* of the sample has been measured, the calculation is:

$$\text{Conductivity} = \frac{10^6 \times K_c}{R_m [0.019(t - 20) + 1]} \mu\text{mhos cm}^{-1}$$

where

$K_c$  = cell constant ( $\text{cm}^{-1}$ )

$C_m$  = measured conductivity of sample at  $t$  °C ( $\mu\text{mhos cm}^{-1}$ )

$R_m$  = measured resistance of sample at  $t$  °C (ohms)

$T$  = temperature of sample (°C).

*Note:* The value for  $[0.019(t - 20) + 1]$  may be taken from the graph in Figure 6.2.

*Reporting*

Record the meter reading, the units of measurement, and the temperature of the sample at the time of reading. Report conductivity at 20 °C.

### iii. Dissolved oxygen

- The dissolved oxygen concentration depends on the physical, chemical and biochemical activities in the water body, and its measurement provides a good indication of water quality.
- Changes in dissolved oxygen concentrations can be an early indication of changing conditions in the water body.
- Two main methods are available for the determination of dissolved oxygen: the Winkler method and the electrometric method using membrane electrodes.
- Use of the Winkler method requires the addition of three chemical reagents to the sample very soon after it is obtained. The dissolved oxygen concentration (in  $\text{mg l}^{-1}$ ) is then determined by titration with sodium thiosulphate solution, which may be done in the field or up to 6 hours later in a laboratory.

- The electrometric method is suitable for the field determination of dissolved oxygen and is simple to perform.
- It requires an electrically powered meter and an appropriate electrode. The result it gives requires the application of correction factors to compensate for salinity and temperature; some meters have built in temperature compensation.

$$\text{Dissolved oxygen} = \frac{\text{ml titrant} \times \text{mol l}^{-1} \text{ titrant} \times 8,000}{\text{volume of sample titrated}} \text{ mg l}^{-1}$$

Sources of dissolved oxygen are:

- Diffusion from the atmosphere and water at the surface
- Aeration as water flows over rocks and uneven surfaces
- Aeration through churning action of wind and waves
- Photosynthesis from aquatic plants

The concentration of dissolved oxygen is affected by

- Plant activity
- Amount of decaying organic matter in the water
- Temperature
- Water condition – flowing, calm, turbulence
- Altitude/atmospheric pressure

## iv. Nitrate

Nitrate ions ( $\text{NO}_3^-$ ) found in freshwater samples result from a variety of natural and manmade sources. Nitrates are an important source of nitrogen necessary for plants and animals to synthesize amino acids and proteins.

Through the process called the Nitrogen Cycle, nitrogen ( $\text{N}_2$ ) from air is converted to useable forms for plants and animals. These conversions include industrial production of fertilisers, as well as natural processes such as nitrogen fixation by legumes plants, plant and animal decomposition, and animal waste.

Sources of Nitrate ions:

- Agricultural runoff
- Urban runoff
- Animal feedlots and stock yards
- Municipal and industrial wastewater
- Automobile and industrial emissions
- Decomposition of plants and animals



Nitrate levels in freshwater are usually less than 1 mg/L but manmade sources of nitrate may elevate levels above 3 mg/L. Levels above 10 mg/L in drinking water can cause a potentially fatal disease in infants called *methemoglobinemia*, or Blue-baby Syndrome (nitrate converts haemoglobin into a form that can no longer transport oxygen).

High nitrate concentrations (and phosphates from grey water/sewage) also contribute to *eutrophication*, ie excessive growth of aquatic plants and algae. Unpleasant odour and taste of water, as well as reduced clarity often accompany this

process. Eventually dead biomass accumulates at the bottom of the lake where it decays, compounding the problem by recycling nutrients. If other nutrients are present, algal blooms can occur with as little as 0.5 mg/L  $\text{NO}_3^- \text{N}$ .

### **Expected Levels:**

Nitrate level in freshwater is usually found in the range of 0.1 to 4 mg/L  $\text{NO}_3^- \text{N}$ . Unpolluted waters generally have nitrate levels below 1 mg/L. The effluent of some sewage treatment plants may have levels in excess of 20 mg/L.

## v. Water Hardness - Ca And Mg Ions

- Hardness can be measured as Calcium hardness or total hardness.
  - Excess Calcium ( $\text{Ca}^{2+}$ ) and Magnesium ( $\text{Mg}^{2+}$ ) ions contribute to water hardness. An obvious sign of water hardness is a layer of white film deposited on surfaces.
  - Total hardness is the sum of Mg (1/3) and Ca (2/3) hardness.
  - Other ions that can cause hardness are  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$  and  $\text{Sr}^{+}$  but they are not included in total hardness measurement
- 
- The concentration of  $\text{Ca}^{2+}$  in freshwater is generally in the range of 0 to 100mg/L.
  - The recommended upper level for drinking water is 50mg/ but higher levels do not cause health risks.

- **Seawater contains  $\text{Ca}^{2+}$  ions at levels of about 400mg/L**

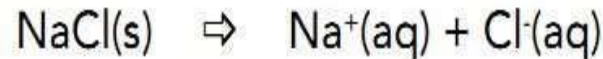
Calcium hardness ( $\text{CaCO}_3$ ):

- Soft 0-20mg/L
- Moderately soft 20-40 mg/L
- Moderately hard 40-80 mg/L
- Hard 80-120 mg/L
- Very hard >120 mg/L

# Chloride and Salinity

## Chloride:

Chloride, in the form of the  $\text{Cl}^-$  ion is one of the major inorganic anions (negative ions) in saltwater and freshwater



In drinking water, the salty taste produced by chloride depends on the concentration of the chloride ion. Water containing 250mg/L of chloride May have a detectable salty taste if the chloride can from sodium chloride.

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## Sources of Chloride ions:

- River or lake beds with salt-containing minerals
- Irrigation water returned to lakes / rivers
- Mixing of seawater with freshwater
- Chlorinated drinking water – often increases chloride levels
- Water softener regeneration - often increases chloride levels

# Chloride and salinity

## Salinity

- Salinity is a measure of the total salt concentration, comprising mostly Na and Cl ions as well as a small quantities of other ions such as K, Mg<sup>2+</sup> or SO<sub>4</sub>.
- It is the total carbonate salts dissolved in water, was expressed in thousands (1ppm = 100mg/l) but is now generally expressed in parts per millions.

The salinity of seawater is fairly constant, at about 35000 ppm.

- Highly saline water ranges from 10000ppm to 35000ppm.
- Moderately saline water ranges from 3000ppm to 10000ppm
- Slightly saline water ranges from 1000ppm to 3000ppm
- Freshwater is less than 1000ppm

## Chloride and salinity

- Freshwater has lower levels of ions such as Na and Cl, and these are often lower in concentration than hard water ions such as Ca and Bicarbonate.
- Saltwater organisms can survive in salinity levels up to 40000 ppm but many freshwater organisms cannot live in salinity levels above 1000 ppm.

# Biochemical Oxygen Demand (BOD)

- ✓ BOD is a measure of the oxygen used by microorganisms to decompose the organic waste dissolved in water.
- ✓ BOD is affected by temperature, the content of nitrates and phosphates dissolved in the water.

➤ In the presence of free oxygen, aerobic bacteria use the organic matter found in wastewater as “food”.

➤ The BOD test is an estimate of the “food” available in the sample. The more “food” present in the waste, the more Dissolved Oxygen (DO) will be required

➤ The BOD test measures the strength of the wastewater by measuring the amount of oxygen used by the bacteria as they stabilize the organic matter under controlled conditions of time and temperature.



## **The BOD test is used to**

- measure waste loads to treatment plants,
- determine plant efficiency (in terms of BOD removal)
- control plant processes.
- determine the effects of discharges on receiving waters.

A major disadvantage of the BOD test is the amount of time (5 days) required to obtain the results.

When a measurement is made of all oxygen consuming materials in a sample, the result is termed “Total Biochemical Oxygen Demand” (TBOD), or often just simply “Biochemical Oxygen Demand” (BOD).

Because the test is performed over a five day period, it is often referred to as a “Five Day BOD”, or a BOD<sub>5</sub>.

## Biochemical Oxygen Demand (BOD)

<b>BOD Level</b> <i>(in ppm)</i>	<b>Water Quality</b>
<b>1 - 2</b>	<b>Very Good</b> There will not be much organic waste present in the water supply.
<b>3 - 5</b>	<b>Fair: Moderately Clean</b>
<b>6 - 9</b>	<b>Poor: Somewhat Polluted</b> Usually indicates organic matter is present and bacteria are decomposing this waste.
<b>100 or greater</b>	<b>Very Poor: Very Polluted</b> Contains organic waste.

## Two methods of measurement

- Dilution method
- Manometric method

### Dilution method

A very small amount of micro-organism seed is added to each sample being tested

**BOD can be calculated by:**

**Undiluted:** Initial DO - Final DO = BOD

**Diluted:** (Initial DO – Final DO) x Dilution Factor

$$\mathbf{B O D}_t = \frac{\mathbf{D O}_i - \mathbf{D O}_f}{\left( \frac{\mathbf{V}_s}{\mathbf{V}_b} \right)}$$

Where

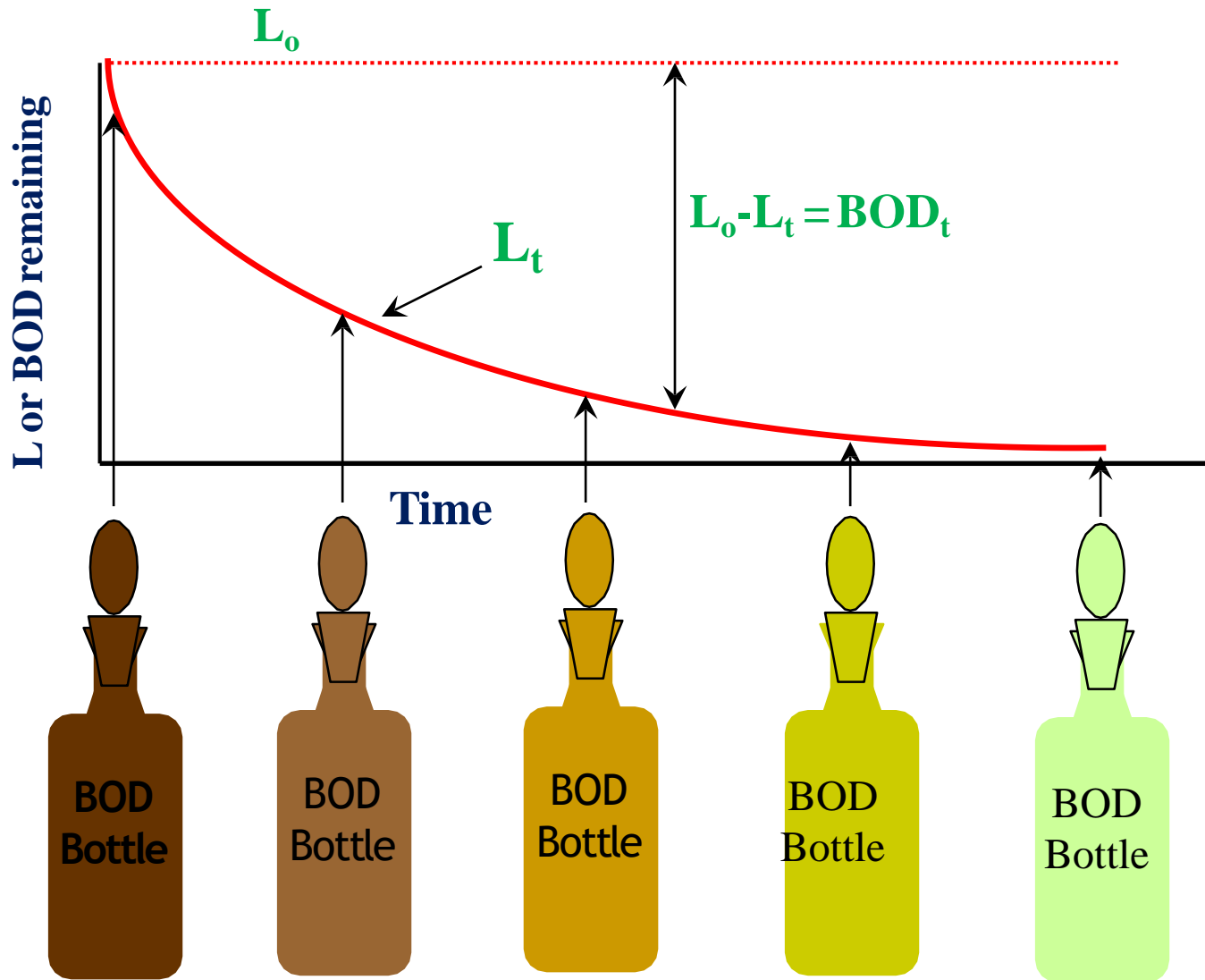
- $\mathbf{BOD}_t$  = biochemical oxygen demand at t days, [mg/L]
- $\mathbf{DO}_i$  = initial dissolved oxygen in the sample bottle, [mg/L]
- $\mathbf{DO}_f$  = final dissolved oxygen in the sample bottle, [mg/L]
- $\mathbf{V}_b$  = sample bottle volume, usually 300 or 250 mL, [mL]
- $\mathbf{V}_s$  = sample volume, [mL]

## Manometric method

Manometric method for measuring Biochemical Oxygen Demand (BOD) is a test done at 20 °C in a controlled environment.

The test period can be 5, 7 or 10 days, depending on the analysis or protocol. The BOD test measures the quantity of oxygen consumed by bacteria that oxidize organic matter in a water sample.

# BOD - loss of biodegradable organic matter



## Working procedure

Table 4 Simplified sample volumes

BOD range mg/L	Sample volume mL
0 to 35	420
0 to 70	355
0 to 350	160
0 to 700	95

### Required apparatus:

BOD bottles  
Spatula scoop  
BOD incubator  
Seal cup, stir bar

### Reagents

2 potassium hydroxide pellets



1. Put a BODTrak II stir bar into the bottle.



2. Put a seal cup into the neck of the bottle.



3. Use a spatula scoop to add 2 potassium hydroxide pellets to the seal cup. Repeat steps 1 to 3 for each sample bottle.



## Working procedure

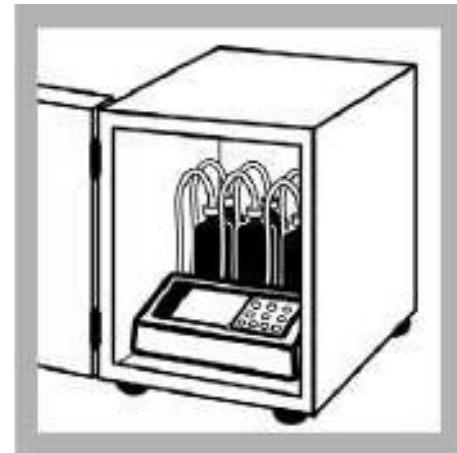


**4.** Put the bottles on the BODTrak II chassis. Connect the applicable tube to the sample bottle and tighten the cap.



**5.** Put the instrument in the incubator. The incubator temperature must be  $20 \pm 1$  °C ( $68 \pm 1$  °F).

*Note: Instrument performance has not been tested at other temperatures.*



**6.** Plug in and power on the instrument. Make sure all stir bars are rotating. If not, lift the bottle up and set down again.

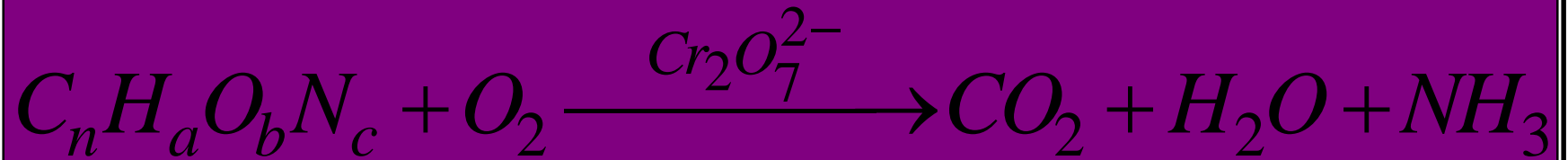
## **The main advantages of this method compared to the dilution method are:**

- simplicity: no dilution of sample required, no seeding, no blank sample
- direct reading of BOD value
- continuous display of BOD value at the current incubation time.

# Chemical Oxygen Demand

## Basic Principles

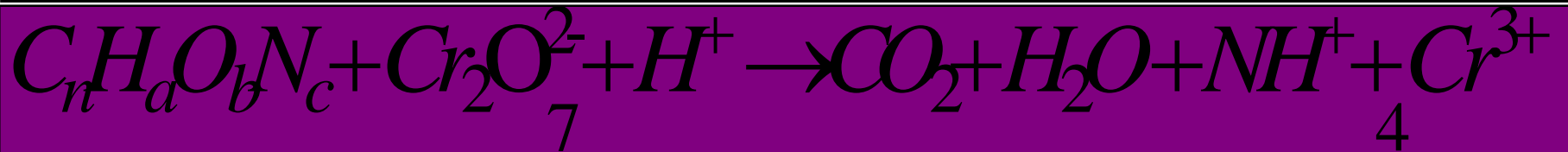
The Chemical Oxygen Demand (COD) test measures the oxygen required to oxidize organic matter in water and wastewater samples by the action of strong oxidizing agents under acid conditions.



- COD is often used as a quality parameter to assess the extent of organic pollutants in municipal and industrial wastewaters.
- If discharged untreated, organic compounds will result in microorganism blooms, resulting in oxygen depletion and fish kills.
- COD measurement provides a rapid means of monitoring the organic pollutants within the wastewater treatment plant, allowing for control of the treatment process to maintain optimum plant operation.

## COD Measurement

COD is measured by **the oxidation of organic pollutants using a strong oxidizing agent** (Potassium dichromate) under acidic conditions. The reaction of potassium dichromate with organic compounds is given by:



- In the process of oxidation, potassium dichromate is reduced forming  $\text{Cr}^{3+}$ .
- The amount of  $\text{Cr}^{3+}$  is determined after oxidization is completed, and is used as an indirect measure of the organic contents of the water sample.
- For all organic matter to be completely oxidized, an excess amount of potassium dichromate must be present.

# Biological Parameters



# Pros & Cons

## Biological

- Organisms integrate effects of stressors overtime
  - Indicate real ecological issues
  - Status of biological communities of direct public interest
  - May be inexpensive relative to complex chemical tests
- 
- High variability may make detection of change or trends difficult
  - Specific pollutants or sources causing impacts may not be revealed
  - Complex relationships with habitat, bioregion
  - Collection may be inexpensive, but analysis may be expensive and time-consuming



# Biological Monitoring

- Fish
- Habitat
- Algae
- Benthic macroinvertebrates
  - insects in their larval or nymph form, crayfish, clams, snails, and worms)



# Biological Monitoring

- **Determine support of aquatic life uses**
  - **Biological criteria**
    - Benthic macroinvertebrate diversity and abundance impacted by stream biological, chemical, and physical conditions
    - Varying tolerance
      - Stonefly nymphs are very sensitive to DO
      - If no stoneflies, check DO
  - **Biological surveys**

# Biological Monitoring

- **Determine the severity of the pollution problem and to rank stream sites**
  - Monitored stream data compared to data from reference site
- **Characterize the impact of pollution and of pollution control activities**
  - Identify problem sites along a stream

# Fecal Contamination

- **Coliforms and fecal streptococci used as indicators of possible sewage contamination because they are commonly found in human and animal feces**
  - **Generally not harmful themselves**
  - **Cheaper and easier to test than other pathogens**
  - **Indicate the possible presence of pathogenic (disease-causing) bacteria, viruses, and protozoans**
    - **Impaired swimming**
    - **Unsafe shellfish**
    - **Unpleasant odors**
    - **Increased BOD**

# Fecal Bacteria Indicators

- The most commonly tested fecal bacteria indicators are
  - Total coliforms
  - Fecal coliforms
  - *Escherichia coli*
  - Fecal streptococci
  - Enterococci



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# Total Coliform

- A widespread group of bacteria
- Human feces, animal manure, soil, and submerged wood, etc.
- Utility as an indicator of fecal contamination depends on extent to which the bacteria species found are fecal and human in origin
- Not recommended for recreational waters
- Still standard test for drinking water

# Fecal Coliforms

- A more fecal-specific subset of total coliform bacteria
  - Contains a genus, *Klebsiella*, with species that are not necessarily fecal in origin
    - Commonly associated with textile and pulp and paper mill wastes
  - Recently replaced by *E. coli* and enterococci as the primary bacteria indicator for recreational waters in many states

# *Escherichia coli*

- ***E. coli* is a single species in the fecal coliform group**
  - Specific to fecal material from humans and other warm-blooded animals
- **Best indicator of health risk in fresh water contact recreation along with enterococci**
- **Indiana uses *E. coli* for determining recreational use support (swimming)**



# Fecal Streptococci

- Digestive systems of humans and other warm-blooded animals
- FS were monitored with FC
  - FC/FS ratio was used to determine whether the contamination was of human or nonhuman origin
  - No longer recommended as a reliable test

# Enterococci

- **A subgroup of FS**
- **Can survive in salt water**
  - **More closely mimic many pathogens**
  - **Typically more human-specific than the larger fecal streptococcus group**
  - **EPA recommends enterococci as the best indicator of health risk in salt water used for recreation and as a useful indicator in fresh water as well**

# Sources of Fecal Contamination

- Sources of fecal contamination to surface waters include wastewater treatment plants, on-site septic systems, domestic and wild animal manure, and storm runoff



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