Technical Assistance
HYDROLOGY PROJECT

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Training module # WQ - 01

Basic water quality concepts

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DHV Consultants BV & DELFT HYDRAULICS

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HALCROW, TAHAL, CES, ORG & JPS

Table of contents

1 Module context

This module is an introduction to the subject of water quality. It is designed to create awareness of the scope of water quality measurement and related issues. No prior training in other modules is needed to complete this module successfully.

2 Module profile

Title	:	Basic water quality concepts
Target group	:	As per training need
Duration	:	1 session of 60 min
Objectives	:	After the training the participants will be able to: • Discuss the common water quality parameters • List important water quality issues.
Key concepts	:	• Water pollutants • Ambient water quality standards • Monitoring water quality
Training methods	:	Lecture, exercises
Training tools required	:	Board, flipchart, OHS
Handouts	:	As provided in this module
Further reading and references	:	

3 Session plan

No	Activities	Time	Tools
1	**Preparations:** Use your standard ToT checklist		
2	**Introduction:** • Ask participants to state factors influencing changes in water quality • Explain/summarise the factors.	10 min	List on flip chart OHS
3	**Water quality parameters:** • Explain reasons to monitor	5 min	OHS
4	**Types of pollutants:** • Ask participants to categorise the pollutants • Explain / add to their list • Describe each pollutant type and its analysis	25 min	List on flip chart OHS
5	**Monitoring water quality:** • Describe standards and classification. • Enumerate the agencies involved	10 min	OHS OHS
6	**Wrap up:** • Ask participants to write 4 lines on a water quality issues and the related parameter(s) which they think are important. • Summarise main points : various parameters and monitoring objectives	10 min	OHS

4 Overhead/flipchart masters

OHS format guidelines

Type of text	Style	Setting
Headings:	OHS-Title	Arial 30-36, Bold with bottom border line (not: underline)
Text:	OHS-lev1 OHS-lev2	Arial 24-26, maximum two levels
Case:		Sentence case. Avoid full text in UPPERCASE.
Italics:		Use occasionally and in a consistent way
Listings:	OHS-lev1 OHS-lev1-Numbered	Big bullets. Numbers for definite series of steps. Avoid roman numbers and letters.
Colours:		None, as these get lost in photocopying and some colours do not reproduce at all.
Formulas/ Equations	OHS-Equation	Use of a table will ease horizontal alignment over more lines (rows and columns) Use equation editor for advanced formatting only

How water quality changes

- In the hydrological cycle:
  - Rain water interacts with substances in atmosphere
  - Surface water carries & dissolves impurities
  - Percolating water reacts with soil and rocks
- By human activities:
  - Industrial waste
  - Municipal waste
  - Mining
  - Agriculture
  - Nuclear

Water quality parameters

- Parameters define water characteristics
- Large range of water quality parameters are available
- Monitoring objective determines selection of parameters:
  - background or base line study
  - suitability studies for a designated use
  - environmental impact studies

Types of pollutants

1. Pathogenic micro-organisms
2. Organic matter
3. Nutrients
4. Dissolved solids
5. Trace compounds

1. Pathogenic micro-organisms

- Present in large numbers in faeces of sick individuals:

Viruses	-	hepatitis, poliomyelitis
Bacteria	-	cholera, typhoid
Protozoa	-	amoebic dysentery
Helminths	-	hookworm

1. Pathogenic micro-organisms

Analysis: coliform bacteria used as indicator of faecal pollution

- Present in large numbers in faeces of healthy & sick individuals
- Easily determined in laboratories
- Expressed as most probable number: MPN/100mL

2. Organic matter

- Organic matter depletes dissolved oxygen (DO) through microbial decomposition

- Anaerobic conditions change ecological regime: fish kills, unsightly conditions and foul odours

2. Organic matter

Analysis: biochemical oxygen demand (BOD) test

- Measures aggregate organic matter in terms of oxygen equivalence:

Organic matter + O_2 (+ bacteria) = CO_2 + H_2O

Only biochemically degradable organic matter is oxidised

3. Nutrients

- Growth of plants (algae) in water is limited due to absence of nutrients, mainly N & P
- Addition of N & P through wastes results in eutrophication
- Excessive growth & death of algae contributes decomposable organic matter & deterioration of quality

3. Nutrients

Analysis: chemical methods to measure N and P

4. Dissolved Solids

- Major cations: Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}
- Major anions: Cl^{-}, SO_4^{2-}, HCO_3^{-}
- Other ions of interest: B, F^{-}, Fe^{2+}, Mn^{2+},NO_3^{-}

4. Dissolved Solids

Analysis:

- Gravimetric method: aggregate salts are measured as total dissolved solids (TDS)
- Electrical conductivity (EC): ions conduct electricity

TDS, mg/L = A x EC, μS/cm

where A = 0.55 to 0.9

5. Trace compounds

- Heavy metals: Cd, Cu, Cr, Hg, Pb, Ni, Zn,
- As
- Organic compounds: PAH, PCB, pesticides

Small concentrations are toxic

Cumulative poisons

Food chain magnification

Care in sample collection

5. Trace compounds

Analysis: requires advanced instruments (AAS & GC)

Monitoring of water quality

- Ambient water quality standards
- Use related water quality standards
- Waste water effluent standards

Water resources management & planning, requires both water quality standards and water quality assessments.

Ambient water quality criteria

Designated best use	Class	Coliform MPN/100mL	DO mg/L
Drinking water, No conventional treatment, only disinfection	A	<50	**>6**
Outdoor bathing	B	<500	**>5**
Drinking water after conventional treatment	C	<5000	**>4**
Propagation of wildlife & fisheries	D	NH3 <1.2mg/L	**>4**
Irrigation, industrial cooling, controlled waste disposal	E	EC < 2250 μmho/cm B < 2mg/L SAR<26	

Agencies monitoring water quality

- CGWB
- CWC
- Central & State PCBs
- State Departments: irrigation, groundwater, mines, public health, water & sewerage boards

Co-ordination required:

- ***avoid duplication of expensive networks***
- ***exchange & integrate data***

Water Quality

- Parameters: each conveys different meaning
- Monitoring objectives: guides parameters to be measured

5 Evaluation

6 Handouts

How water quality changes

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1. Pathogenic micro-organisms

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Viruses	**-**	**hepatitis, poliomyelitis**
Bacteria	**-**	**cholera, typhoid**
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"Only biochemically degradable organic matter is oxidized"

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- Electrical conductivity (EC): ions conduct electricity

$$TDS, mg/L = A \times EC, \mu S/cm$$

where A = 0.55 to 0.9

5. Trace compounds

- Heavy metals: Cd, Cu, Cr, Hg, Pb, Ni, Zn,
- As
- Organic compounds: PAH, PCB, pesticides
  Small concentrations are toxic
  Cumulative poisons
  Food chain magnification
  Care in sample collection

Analysis: requires advanced instruments (AAS & GC)

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Water Quality

- Parameters: each conveys different meaning

- Monitoring Objectives: guides parameters to be measured

Add copy of Main text in chapter 8, for all participants.

7 Additional handouts

These handouts are distributed during delivery and contain test questions, answers to questions, special worksheets, optional information, and other matters you would not like to be seen in the regular handouts.

It is a good practice to pre-punch these additional handouts, so the participants can easily insert them in the main handout folder.

Insert your additional handouts here.

8 Main text

Basic water quality concepts

1. Introduction

Water in its chemically pure form occurs rarely in nature. In fact, water is commonly found to carry a variety of constituents. When water in its precipitate form reaches the surface of the earth, it has already collected a number of substances and properties that characterise natural water. Gases have been absorbed or dissolved, dust particles have been picked up, and it has obtained a certain temperature. In case of a high radioactive washout or high acidity pickup, atmospheric water may not even be clean in the general sense and may not be suitable for some uses.

Atmospheric water is subject to further changes of quality both upon reaching the earth's surface and during its travel underground. The ability to dissolve salts is gained in the topsoil where carbon dioxide is released by bacterial action on organic matter. The soil water becomes charged with carbon dioxide resulting in formation of carbonic acid. Under the acidic conditions that develop many soil and rock constituents are dissolved.

Man's influence on the quality of water is quite apparent and is now a major concern. Mixing with municipal and industrial waste waters may result in drastic changes in the water quality of natural waters. Agriculturally oriented activities such as irrigation, use of fertiliser, pesticides, herbicides, etc., may lead to diffuse pollution of both surface waters and ground water. Irrigation return waters also tend to increase total salts in the receiving water. Construction schemes, such as those connected with river training, flood control, low flow augmentation, etc., considerably influence the quality regime. Mining activities often cause substantial water quality changes.

There is a great range of water quality parameters that can be used to characterise waters. Largely the water quality measurement objectives and the previous history of the water body will determine selection of parameters. It is true, however, that some parameters are of special importance and deserve frequent attention. The commonly used parameters are discussed in the following sections.

2. Water quality parameters

Pathogenic micro-organisms

Pathogenic or disease producing micro-organisms mostly originate from domestic wastewater. These include micro-organisms, which cause diseases of the intestinal tract. Some of these diseases classified according to their causative agent are given below:

Viruses : infectious hepatitis, poliomyelitis
Bacteria: cholera, bacterial dysentery, typhoid and paratyphoid.
Protozoa: amoebic dysentery, giardiasis
Helminth: hookworm, guinea worm, schistosomiasis.

The intestinal discharges (faeces) of infected individuals contains billions of the pathogen, which, if allowed to mix with a water supply source, may result in an epidemic. These diseases are called *water borne* diseases since their spread is mainly through a water pathway (sick individual-sewage-water supply source-healthy person). In 1960 in Delhi, there were more than 6000 cases of infectious hepatitis in a few months because of contamination of a raw water source with municipal sewage.

The presence or absence of the coliform group of bacteria determines the bacteriological quality of water. *Escherichia coli* is the most widely known member of the group. It is a normal inhabitant of intestines of both healthy and sick persons and therefore it is present in large numbers in domestic and municipal sewage. Its presence in water indicates contamination with sewage and of the possible presence of pathogenic micro-organisms of human origin.

Although tests are available for specific pathogenic micro-organisms, there is no way of knowing which pathogenic organism may be present in a sample of water. The cost of testing for all pathogenic organism is prohibitive. Furthermore, in an aquatic environment the die-off rate of *E. coli* parallels that of pathogenic organisms. For these reasons, *E. coli* has come to be used as an indicator for pathogenic organisms. *E. coli* is exclusively of faecal origin. Some coliform bacteria are normal inhabitants of soil and water. Results of bacteriological analysis therefore may be reported as total coliforms and faecal coliforms. The presence of coliforms in a water sample is determined by observing their growth in special culture media and making a statistical deduction regarding their number. The result is reported as most probable number (MPN) /100 ml.

Organic matter

Most waters contain organic matter. In the environmental field organic matter is classified as that which is biochemically decomposable and that which cannot be decomposed. Common parameters of characterisation are: biochemical oxygen demand (BOD), chemical oxygen demand (COD) and volatile solids. While the BOD test measures biochemically decomposable or degradable organic matter, the other two measure total organics. It may be pointed out that the three parameters reflect the aggregate organic constituents.
The BOD test measures oxygen equivalence of organic matter. A schematic equation for the biochemical decomposition reaction may be written as:

$$\text{Organic matter} + O_2 \xrightarrow{\text{Micro-organisms}} CO_2 + H_2O$$

Micro-organisms, mainly bacteria, utilise various types of waste organic matter as their food to obtain energy. In this process they decompose the organic matter to carbon dioxide and water in presence of oxygen. The amount of oxygen consumed is taken as a measure of the quantity of organic matter. The test is carried out in a laboratory representation of the aquatic environment; a water sample is added to oxygenated water and the loss of oxygen measured over a period of time.

The BOD test is the most important parameter to assess the pollution of water bodies by organic matter and its effect on the oxygen resources of streams and lakes. The BOD reaction, being biochemical in nature, proceeds slowly. The rate of reaction depends on the temperature and the population of bacteria that may be present in the sample or added as seed. The rate of reaction also depends on the amount of organic matter in the sample or its BOD value. The standard BOD test is conducted over a 5 day period at 20 ^{o}C. In India, recently it has been decided to conduct the test over a 3 day period at 27 ^{o}C (BIS: IS 3025 Part 44 : 1993). This has been done in view of the fact that the average ambient indoor temperature in India is around 27 ^{o}C and not 20 ^{o}C as is the case for the UK where the test was originally developed.

Furthermore, the 27 ^{o}C, 3 day value is comparable to the 20 ^{o}C, 5 day value also. A further advantage of using the 27 ^{o}C test in India is that, should power failures occur during the test, their effect will be less pronounced as the incubator containing the samples will be at a similar temperature to the laboratory. As a result little heat exchange will occur and the correct sample temperature will be maintained for longer periods.

Dissolved oxygen

The DO level in a surface water body is an important indicator of its 'health'. The presence of DO in water is necessary for maintaining favourable conditions for growth and reproduction of a normal population of fish and other aquatic life. The absence of a low level of DO in surface waters indicates pollution by organic matter. Under such conditions organic matter is decomposed by anaerobic bacteria resulting in production of obnoxious end-products, such as mercaptans, hydrogen sulphide, ammonia, etc.

Nutrients

Nutrients are chemicals containing elements, such as nitrogen (N), phosphorus (P), carbon (C), sulphur (S), calcium (Ca), potassium (K), iron (Fe), manganese (Mn), boron (B) and cobalt (Co), that are essential for the growth of living things. Some of these are required only in very small quantities and are called micro-nutrients. Plants require relatively large amounts of C, N, and P. They obtain C from carbon dioxide and N and P from soil or water. N and P may be limiting in the aquatic or land environment; that is the concentration of one or other of these species may dictate the biomass of plant species which can survive in a particular water body.

Municipal and some industrial wastewaters contain N and P. Addition of such wastes to water bodies may result in algal blooms or eutrophication (unnaturally accelerated growth of algae). With excess growth of algae the available light becomes limiting and the algal cells begin to die. This increases the decomposable organic matter load on the water body resulting in consumption of oxygen and deterioration of quality of water.

Total dissolved solids

Water as it travels in the atmosphere, through ground or over the land, dissolves a large variety of substances or salts. These substances in solution exist in their ionic form. The major cations (positively charged ions) comprise calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}) and potassium (K^{+}) and the associated anions typically include sulphate ($SO_4^{=}$), bicarbonate (HCO_3^{-}) and chloride (Cl^{-}). The divalent cations (those having two positive charges) are responsible for the hardness of water. Other ions which may be present in smaller concentrations but can nevertheless be of environmental significance are B, fluoride (F^{-}), Fe^{++}, Mn^{++}, and nitrate (NO_3^{-}).

The aggregate salts are measured as total dissolved solids (TDS). As a rough approximation waters having less than 1500 mg/L TDS can be considered fresh waters.

Toxic metals and organic compounds.

A number of toxic metals and organic compounds may be added to water through anthropogenic activity. Some metals which are toxic even in small concentrations are arsenic (As - not a metal), cadmium (Cd), copper (Cu), chromium (Cr), mercury (Hg), lead (Pb), nickel (Ni) and zinc (Zn). Examples of organic compounds which are environmentally significant and important from a water quality viewpoint are polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), pesticides, etc. Since these substances are toxic, even in very small concentrations, special care has to be taken in the collection of samples for analysis. Further, advanced level instruments are needed for their determination.

3. Water quality standards

Water quality standards may be classified as ambient water quality standards, specific water use related standards and effluent water quality standards. In this section only the first named classification, which is of general interest, will be discussed.

The Central Pollution Control Board has classified the inland surface waters into 5 categories - A to E on the basis of the best possible use of the water as shown in Table 1. The classification has been made in such a manner that the water quality requirement becomes progressively lower from class A to class E.

A water body may be subjected to more than one organised use. The use demanding the highest quality is the designated best use. A water body or stretch of river whose existing water quality does not meet the designated best use criteria requires action to mitigate the situation. Based on such analysis river action plans are formulated.

4. Water quality monitoring

There are fourteen major rivers in the country, each with a catchment area of more than 20,000 sq. km, accounting for 85% of the total surface flow. About 50 years ago, most of the rivers maintained their pristine status. But over the decades almost all rivers have become grossly polluted in one stretch or another.

Although water quality studies have been undertaken for many years on some rivers, most regular monitoring networks were begun in the seventies. Central Pollution Control Board (CPCB) is now operating water quality monitoring networks on major rivers under Global Environmental Monitoring System (GEMS) and Monitoring of National Aquatic Resources (MINARS) programmes either directly or through State Pollution Control Boards (SPCB). Some state boards have their own monitoring stations also. In addition, the Central Water Commission (CWC) is monitoring water quality at a number of stations on almost all the major rivers. The National River Conservation Directorate (NRCD) has also started monitoring river water quality under its action plans.

Central Ground Water Board (CGWB) is maintaining a countrywide network of groundwater level and quality stations. Groundwater data are also collected by various state agencies and some pollution control boards.

It can be seen that a number of agencies are collecting water quality data. As maintenance of water quality networks is expensive, there is a need to clearly state the objectives of the programmes and optimise the effort where possible

Table1 *Primary water quality criteria for various uses of fresh water*

Designated best use	Class	Criteria
Drinking water source without conventional treatment but after disinfection	**A**	1. Total coliform organisms MPN/100mL shall be 50 or less. 2. pH between 6.5 and 8.5 3. Dissolved oxygen 6 mg/L or more 4. Biochemical oxygen demand 2 mg/L or less
Outdoor bathing (organised)	**B**	1. Total coliform organisms MPN/100mL shall be 500 or less 2. pH between 6.5 and 8.5 3. Dissolved oxygen 5 mg/L or more 4. Biochemical oxygen demand 3 mg/L or less
Drinking water source with conventional treatment followed by disinfection	**C**	1. Total coliform organisms MPN/ 100mL shall be 5000 or less 2. pH between 6 and 9 3. Dissolved oxygen 4 mg/L or more 4. Biochemical oxygen demand 3 mg/L or less
Propagation of wild life, fisheries	**D**	1. pH between 6.5 and 8.5 2. Dissolved oxygen 4 mg/L or more 3. Free ammonia (as N) 1.2 mg/L or less
Irrigation, industrial cooling, controlled waste disposal	**E**	1. pH between 6.0 and 8.5 2. Electrical conductivity less than 2250 micro mhos/cm 3. Sodium absorption ratio less than 26 4. Boron less than 2mg/L