Training Workshop on Water Monitoring Network and Early Warning System

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Water Quality Assessment

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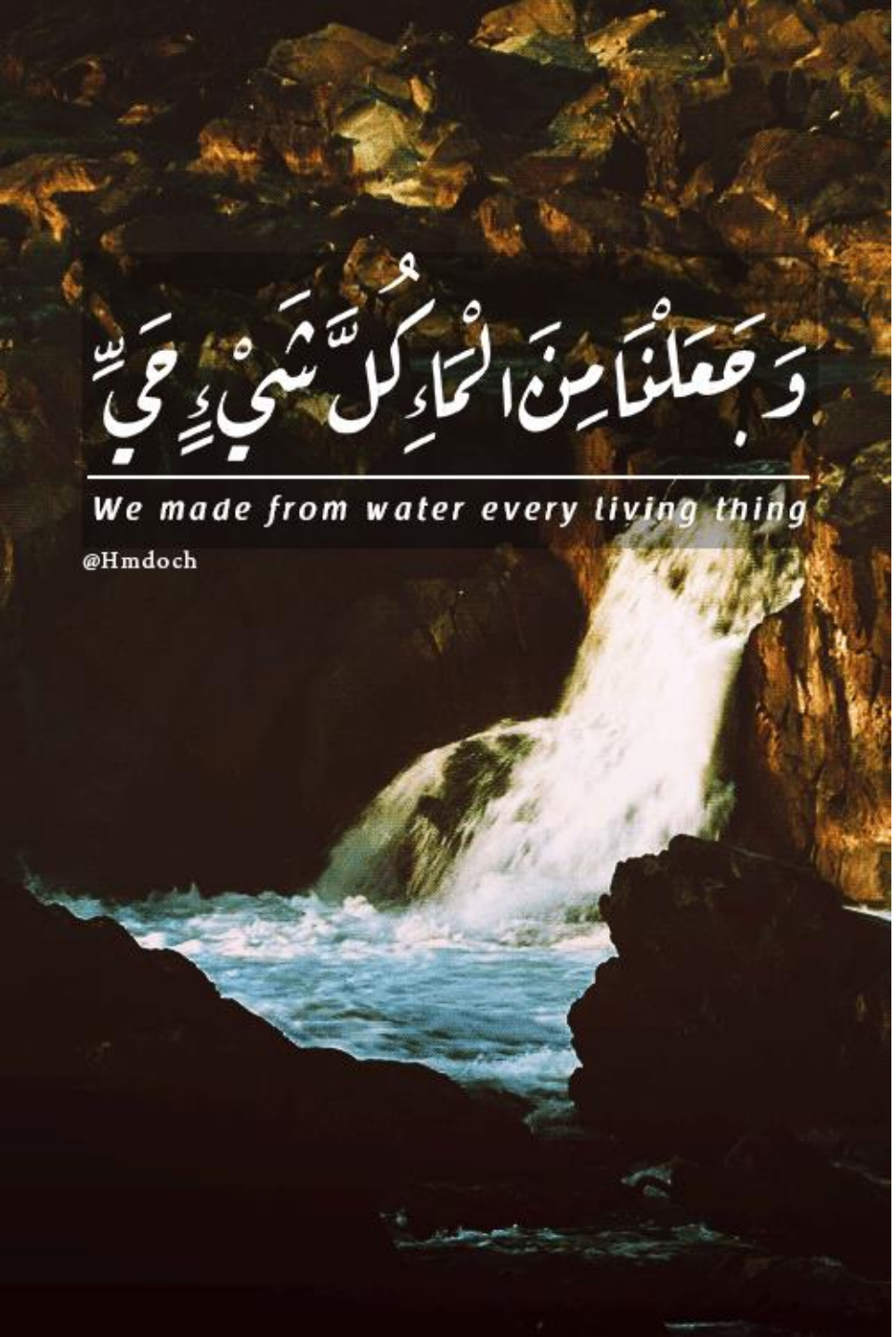

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

قال الله تعالى :

أَوَلَمْ يَرَ ٱلَّذِينَ كَفَرُوٓاْ أَنَّ ٱلسَّمَٰوَٰتِ وَٱلْأَرْضَ
كَانَتَا رَتْقًا فَفَتَقْنَٰهُمَا ۖ وَجَعَلْنَا مِنَ ٱلْمَآءِ كُلَّ
شَىْءٍ حَىٍّ ۖ أَفَلَا يُؤْمِنُونَ ﴿٣٠﴾

سورة الأنبياء

PREFACE

- The most important compound found in nature is water. Water is not only necessary for living but to run our everyday life smoothly. In fact, it will totally be absurd to think our life without water. Since water is so important in our life we must be careful of its quality. In fact, our body is made up of nearly seventy percent of water.
- Water is not just important for drinking but its various range of use makes it the most commonly used substance by humans. Besides drinking it is used for agriculture and industrialization. They are used in steam engines, to produce hydro-electricity and many more. They also have entertainment values such as swimming. Thus we can understand the role of water in life.

- The quality of water means various characteristics of water which includes chemical features, biological features, and radiological features. Proper quality of water is a relative term as the term “proper quality” for water can be different for different purposes.
- For example, the quality of water that is proper for irrigation may not necessarily be proper for drinking purpose. Hence the standard of water required varies according to the use. The quality of water is generally assessed in relation to ecosystems, safety of human and animal contact as well as drinking water.
- The majority part of the surface water on earth is neither toxic nor potable. A majority portion of surface water is sea water which is not generally used for drinking, agriculture or industries. Other major sources of surface water are lakes, rivers, waterfall etc. The qualities of water in these water body vary according to the environment and human intervention.

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6. **Organic matter in water**

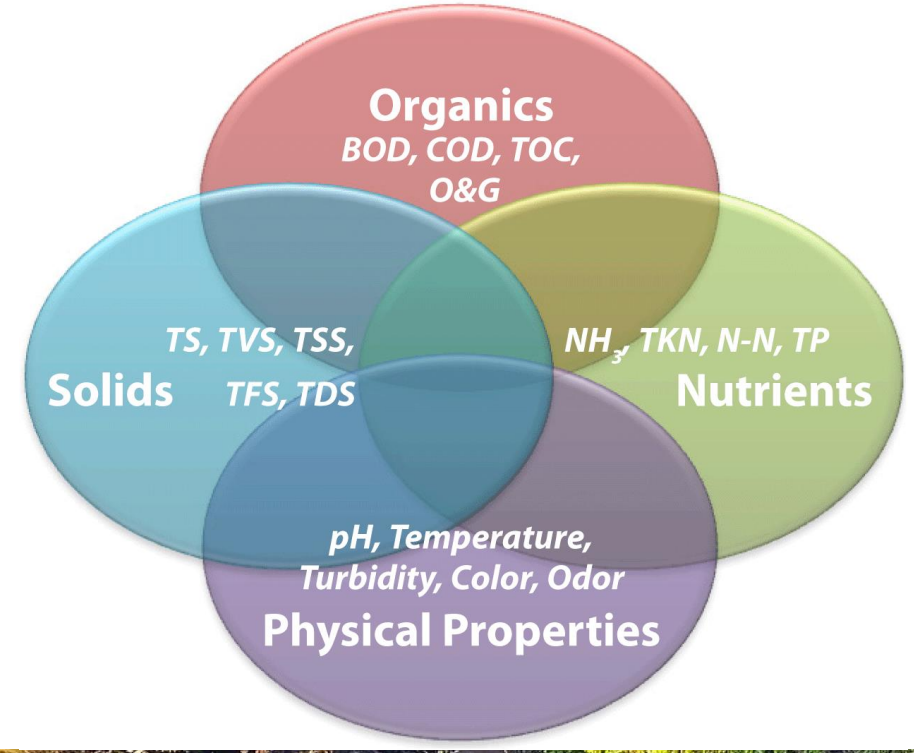
INTRODUCTION

- Over large parts of the world, rivers and lakes show increasing trends of water pollution. This holds especially for developing countries under economic expansion and increasing population sizes. Evaluation of the physical, chemical and biological water quality is essential for the abatement of freshwater pollution.
- For this, sound and sustainable water quality assessment programmes should be aimed at integrating the different steps in the monitoring cycle, from the information needs, monitoring network design, field and laboratory procedures up to data collection and processing.
- The resulting water quality data can then be evaluated together with the natural water quality, human effects and water quality usages.
- Optimization of the water quality monitoring programmes, amongst others with respect to cost, should ensure that these programmes are sound and sustainable, also in future.

DEFINITION

- **Water Quality Assessment:**

The overall process of evaluation of the physical, chemical and biological nature of the water



- **Water Quality Monitoring:**

The collection of the relevant information on water quality

1- Water uses and functions

Water quality expresses the suitability of water for various uses or processes: drinking water; irrigation water; nature conservation, …

Different water quality requirements:

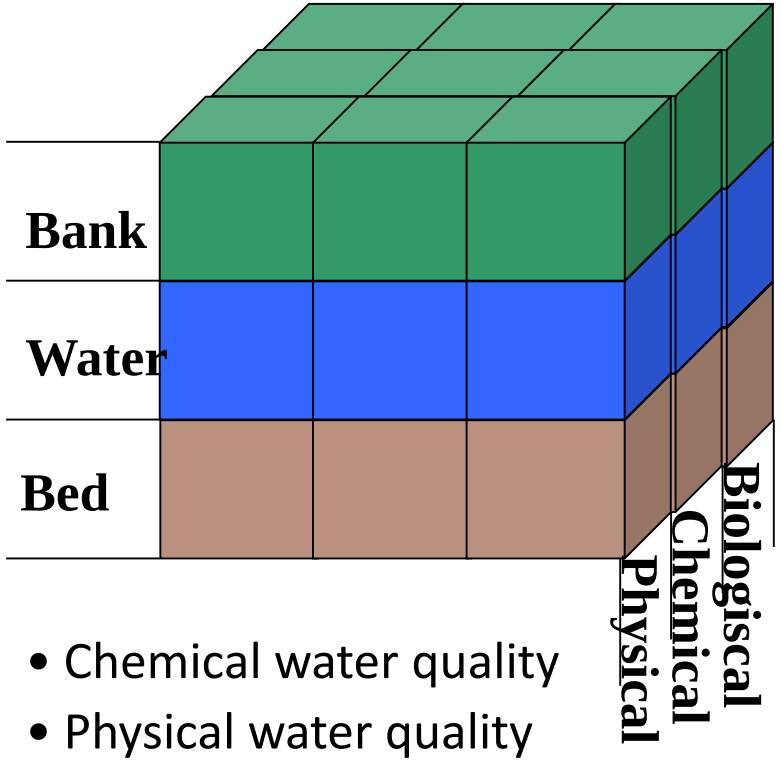
a) No or hardly any specific requirements:
Example: navigation water or power generation

b) Defined "minimum standards"
Examples: irrigation water or recreation water,

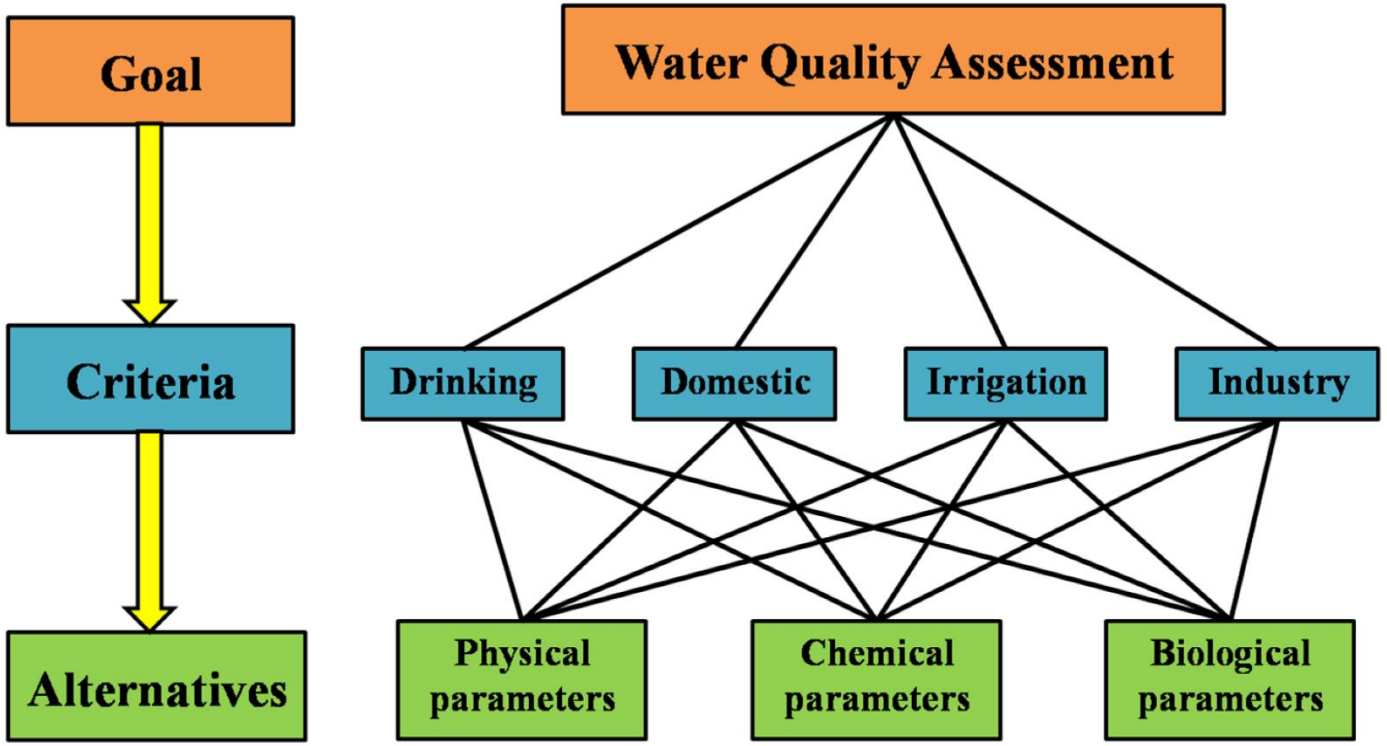
c) "Undisturbed quality": ecosystem functioning.

2- Water quality standards

An aquatic ecosystem is more than just water: all compartments of the water system must be looked at as a whole.



- Chemical water quality
- Physical water quality
- (Micro)biological water quality



WATER QUALITY ASSESSMENT

01 Water quality is determined by assessing three classes of parameters: biological, chemical, and physical.

02 Biological parameters: Biological attributes refer to the number and types of organisms that inhabit a waterway.

03 Chemical parameters: include DO, COD, BOD, HARNESS, Salinity, pH etc.

04 Physical parameters : includes TSS, TDS, Temp, color, odour, etc.

05 Assessment of water quality by its chemistry includes measures of many elements and molecules dissolved or suspended.

Standards for different uses

Water fit for ecosystems needs virtually undisturbed water quality.

To achieve this, there is nowadays also much emphasis on the micropollutants (heavy metals, pesticides, PCBs, *etc.*), which are mainly originating from industrial sources.

➔ Industries should use "Best Available Technologies" **(BAT)** ➔ **"zero" discharges**

For the other (non-ecosystem) water uses, often the **"ALARA principle"** holds: "As low as reasonably achievable".

Standards for different uses

Examples of maximum allowable concentrations of selected water quality variables for different uses

Use	Drinking water					Fisheries and aquatic life		
Variable	WHO[1]	EU	Canada	USA	Russia[2]	EU	Canada[1]	Russia
Colour (TCU)	15	20 mg l^{-1} Pt-Co	15	15	20			
Total dissolved solids (mg l^{-1})	1,000		500	500	1,000			
Total suspended solids (mg l^{-1})						25	inc. of 10 or 10%[3]	
Turbidity (NTU)	5	4 JTU	5	0.5-1.0				
pH	< 8.0[4]	6.5[1]-8.5[1]	6.5-8.5	6.5-8.5	6.0-9.0	6.0-9.0	6.5-9.0	
Dissolved oxygen (mg l^{-1})					4.0	5.0-9.0	5.0-9.5	4.0[5]-6.0
Ammoniacal nitrogen					2.0	0.005-	1.37-2.2[6,7]	0.05

(For complete table and meaning of the symbols, see pages 92-94 in Chapman,1996)

Chapman, Deborah V, World Health Organization, UNESCO & United Nations Environment Programme. (1996). Water quality assessments : a guide to the use of biota, sediments and water in environmental monitoring / edited by Deborah Chapman, 2nd ed. London : E & FN Spon. https://apps.who.int/iris/handle/10665/41850

3- Natural water quality : “background” concentrations

Depends on the following environmental factors:

- occurrence of highly soluble or easily weathered minerals
- distance to the coastline,
- precipitation/river run-off ratio, and
- occurrence of peat bogs, wetlands and marshes which release large quantities of dissolved organic matter.

Other factors include the ambient temperature, thickness of weathered rocks, organic soil cover, etc.

➔ *No “average” natural water quality can be given, high variation throughout the world exists!*

(Page 258 Chapman, 1996)

Chemical & Biological Variables

- Measure in water, particulate matter and/or in living organisms
- Physico-chemical variables
- Biological water quality monitoring

Choice of variables: dependent on objectives, occurrence, impacts, resources. Also: water use (for irrigation? recreation?,..) determines variables' choice.

Water Quality Assessment Methods

- Numeric criteria (Dissolved Oxygen)
- Biological criteria (benthos community diversity)
- Pathogen criteria (fecal coliform bacteria)
- Shellfish Harvesting criteria (growing area classifications)
- Fish Consumption criteria (DHHS advisories)Assessment Period

Water Quality Assessment with Water Quality Indices

- A water quality index provides a single number that expresses overall water quality at a certain location and time based on several water quality parameters.
- Water quality index (WQI) is valuable and unique rating to depict the overall water quality status in a single term that is helpful for the selection of appropriate treatment technique to meet the concerned issues.
- These indices utilize various physico-chemical and biological parameters and have been resulted as an outcome of efforts and research and development carried out by different government agencies and experts in this area globally.

Different water quality indices

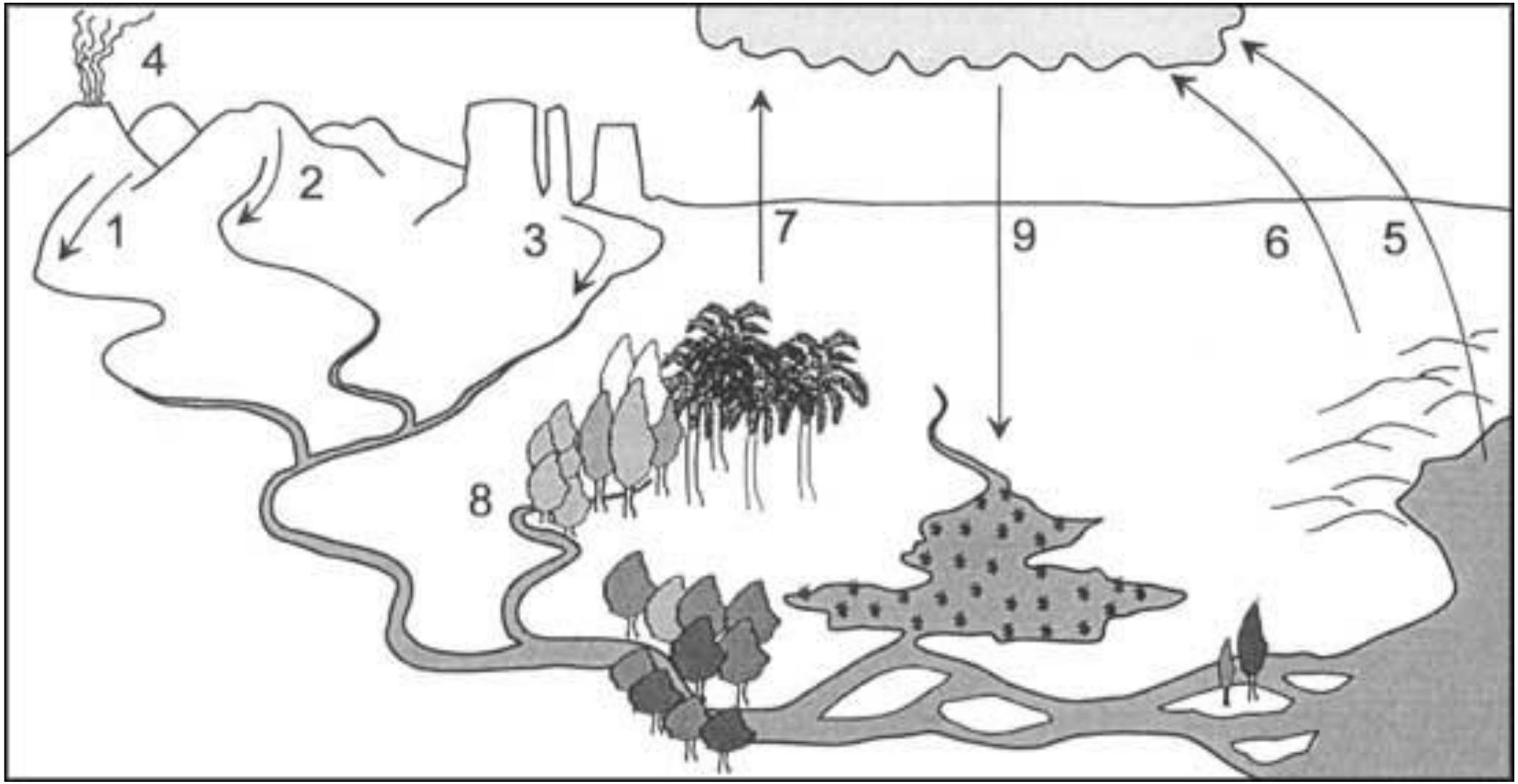
Water quality index	Parameters involved	purpose
Multimetric Benthic Macroinvertebrae Index	DO, BOD, pH, EC, TN, TP, Turbidity, Altitude,	Assessment of Stream Biotic Integrity
Fuzzy Logic Water Quality Index	DO, BOD, COD, AN, SS and pH.	Water quality of a river
W Q M - W a t e r Quality Index	pH, EC, DO, BOD, Total Coliform, FC,	Water Quality Monitoring
Dairy cattle drinking water quality index	DO, BOD, Temp, TDS, Turbidity, Fecal Coliforms, Heterotrophic plate count, Hardness, Alkalinity, Arsenic, Lead, Mercury, Nickel, Cadmium, Chromium, Total phosphorous, H2S, Nitrate, and Fluoride,	Water quality
Drinking water quality index	pH, Total dissolved solids, Electrical conductivity, Turbidity, Total hardness, Suspended solids,	Ascertain the quality of water for domestic purposes

Water Quality Index Legend

Concentration	Quality	E.I.A.
90 – 100	Excellent	Excellent
80 – 90	Good	Healthy
50 – 80	Medium	Alarming
25 – 50	Bad	Badly Affected
0 – 25	Very bad	Very Badly Affected

Essentially the WQI is calculated by comparing the water

Natural sources of elements to rivers. 1, 2 and 3: Chemical weathering of surficial rocks; 4: Volcanic fallout; 5: Recycled oceanic aerosols; 6: Continental aeolian erosion; 7: Decay of vegetation; 8: Leaching of organic soils; 9: Atmospheric inputs

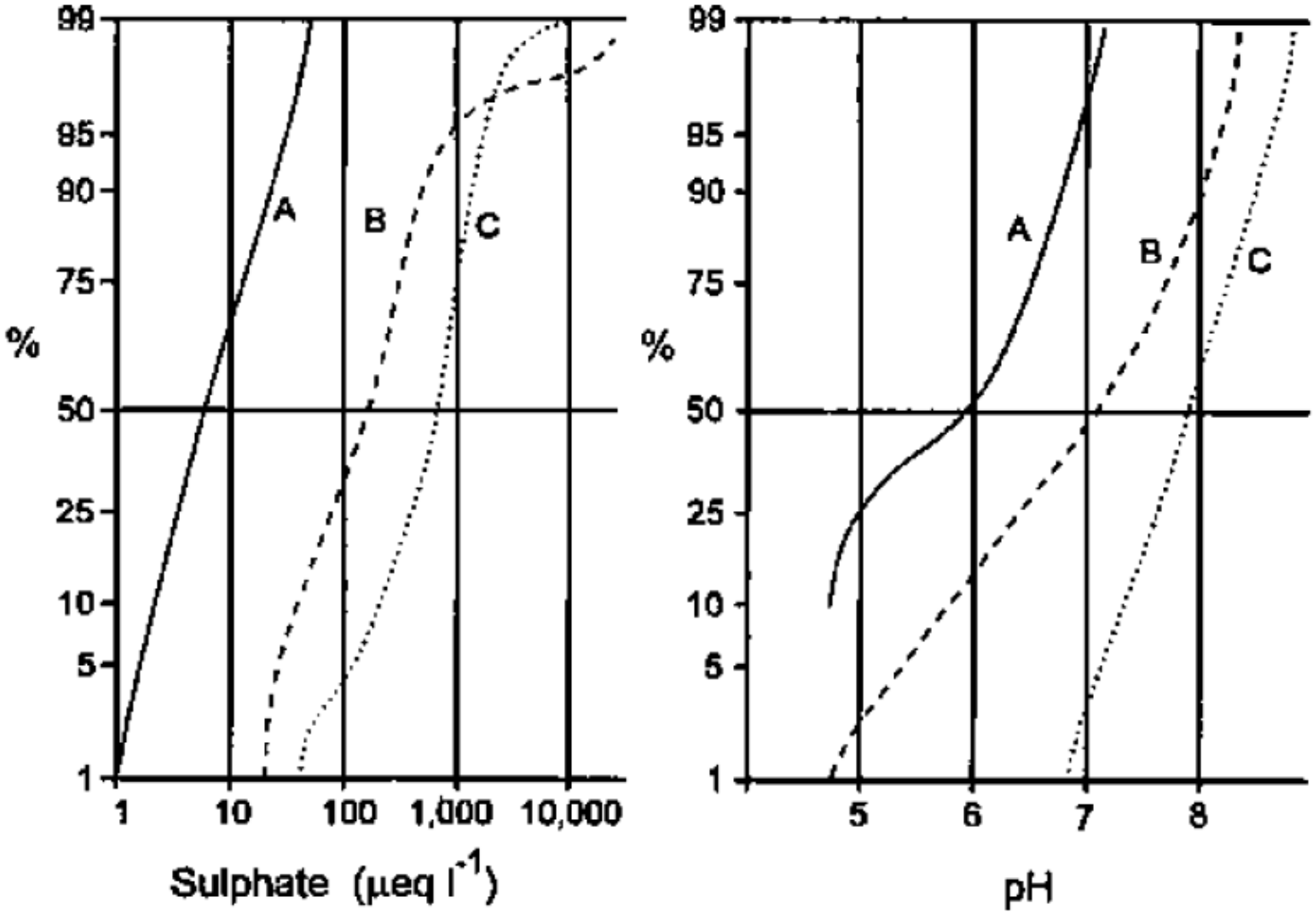


(For more details , see pages 256-258 in Chapman,1996)

Natural water quality - examples

Cumulative distribution of Sulphate and pH in unpolluted rivers and streams: A. Lower Amazon tributaries; B. Unpolluted French streams; C. Mackenzie river tributaries

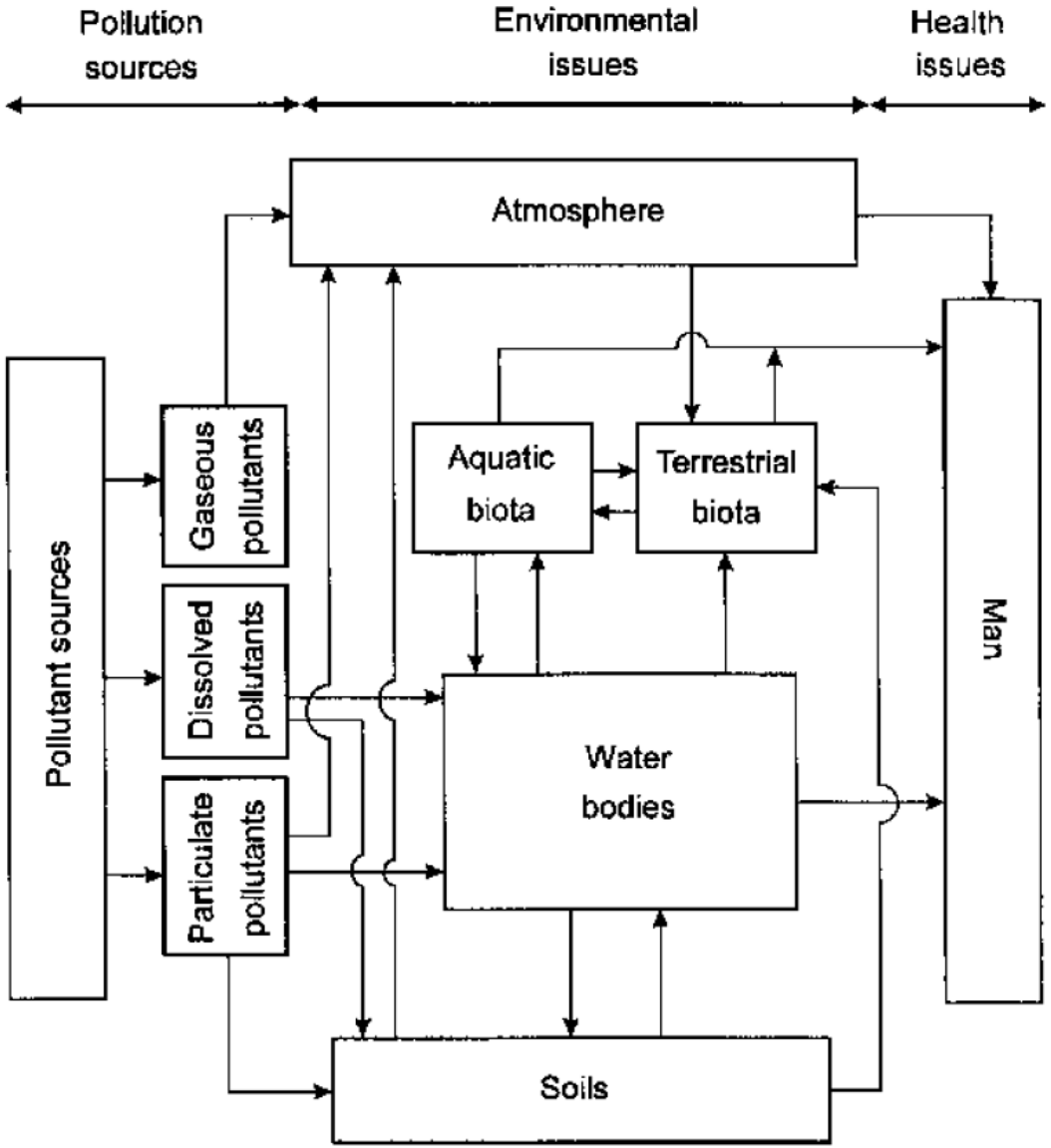
(Page 261 Chapman, 1996)



4- Sources of pollution & environmental compartments

Potential pollutant pathways related to the aquatic environment

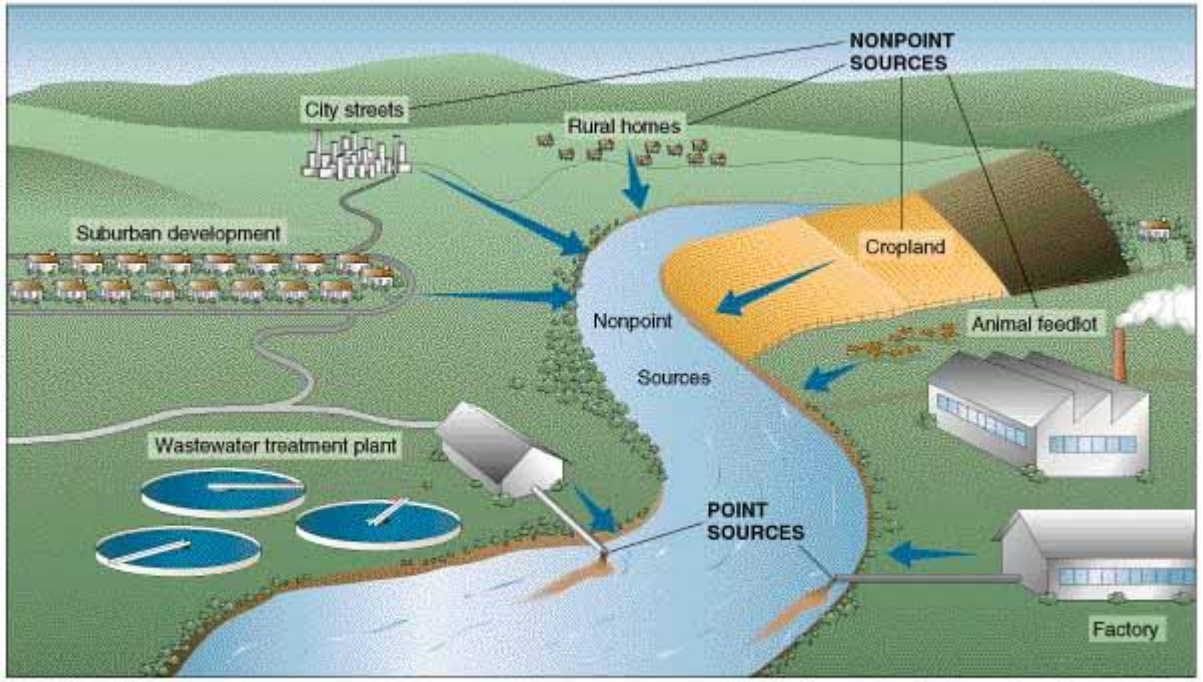
In general, pollutants can be released into the environment as gases, dissolved substances or in the particulate form. Ultimately pollutants reach the aquatic environment through a variety of pathways, including the atmosphere and the soil.



(Page 31 Chapman, 1996)

- Pollution may result from point sources or diffuse sources (non-point sources). There is no clear-cut distinction between the two, because a diffuse source on a regional or even local scale may result from a large number of individual point sources, such as automobile exhausts.
- An important difference between a point and a diffuse source is that a point source may be collected, treated, or controlled.

Type	Definition	Management
Point Source	Pollution released from a single source e.g. Chernobyl	-Easy to monitor and control emission at source -Reasonability easily established and managed by law
Non-Point Source	Pollution release from diffuse sources e.g. car	-Monitoring requires extensive survey techniques Emissions control requires widespread changes -Responsibility shared amongst many requiring greater effort to enforce



- The major point sources of pollution to freshwaters originate from the collection and discharge of domestic wastewaters, industrial wastes, or certain agricultural activities, such as animal husbandry.
- Most other agricultural activities, such as pesticide spraying or fertilizer application, are considered as diffuse sources. The atmospheric fall-out of pollutants also leads to diffuse pollution of the aquatic environment.

Point-source pollution

- Point source pollution as any contaminant that enters the environment from an easily identified and confined place. Examples include smokestacks, discharge pipes, and drainage ditches.
- Factories and power plants can be a source of point-source pollution, affecting both air and water. Smokestacks may spew carbon monoxide, heavy metal, sulfur dioxide, nitrogen dioxide, or “particulate matter” (small particles) into the air. Oil refineries, paper mills, and auto plants that use water as part of their manufacturing processes can discharge effluent—wastewater containing harmful chemical pollutants—into rivers, lakes, or the ocean.
- Municipal wastewater treatment plants are another common source of point-source pollution. Effluent from a treatment plant can introduce nutrients and harmful microbes into waterways. Nutrients can cause a rampant growth of algae in water.

Waste filled water is dumped into a river, polluting it for the people
and animals who use it as a source for eating and drinking

Nonpoint-source pollution

- Nonpoint-source pollution is the opposite of point-source pollution, with pollutants released in a wide area. As an example, picture a city street during a thunderstorm. As rainwater flows over asphalt, it washes away drops of oil that leaked from car engines, dog waste, and trash. The runoff goes into a storm sewer and ends up in a nearby river. Runoff is a major cause of nonpoint-source pollution, It is a big problem in cities. The amount of pollutants washed from a single city block might be small, but when you add up the miles and miles of pavement in a big city you get a big problem.
- In rural areas, runoff can wash sediment from the roads. It can also carry chemicals from abandoned factories and flush pesticides and fertilizer from farm fields. All of this pollution is likely to wind up in streams, rivers, and lakes.
- Airborne pollutants are major contributors to acid rain. It forms in the atmosphere when sulfur dioxide and nitrogen oxides combine with water. Because acid rain results from the long-range movement of those pollutants from many factories and power plants, it is considered nonpoint-source pollution.

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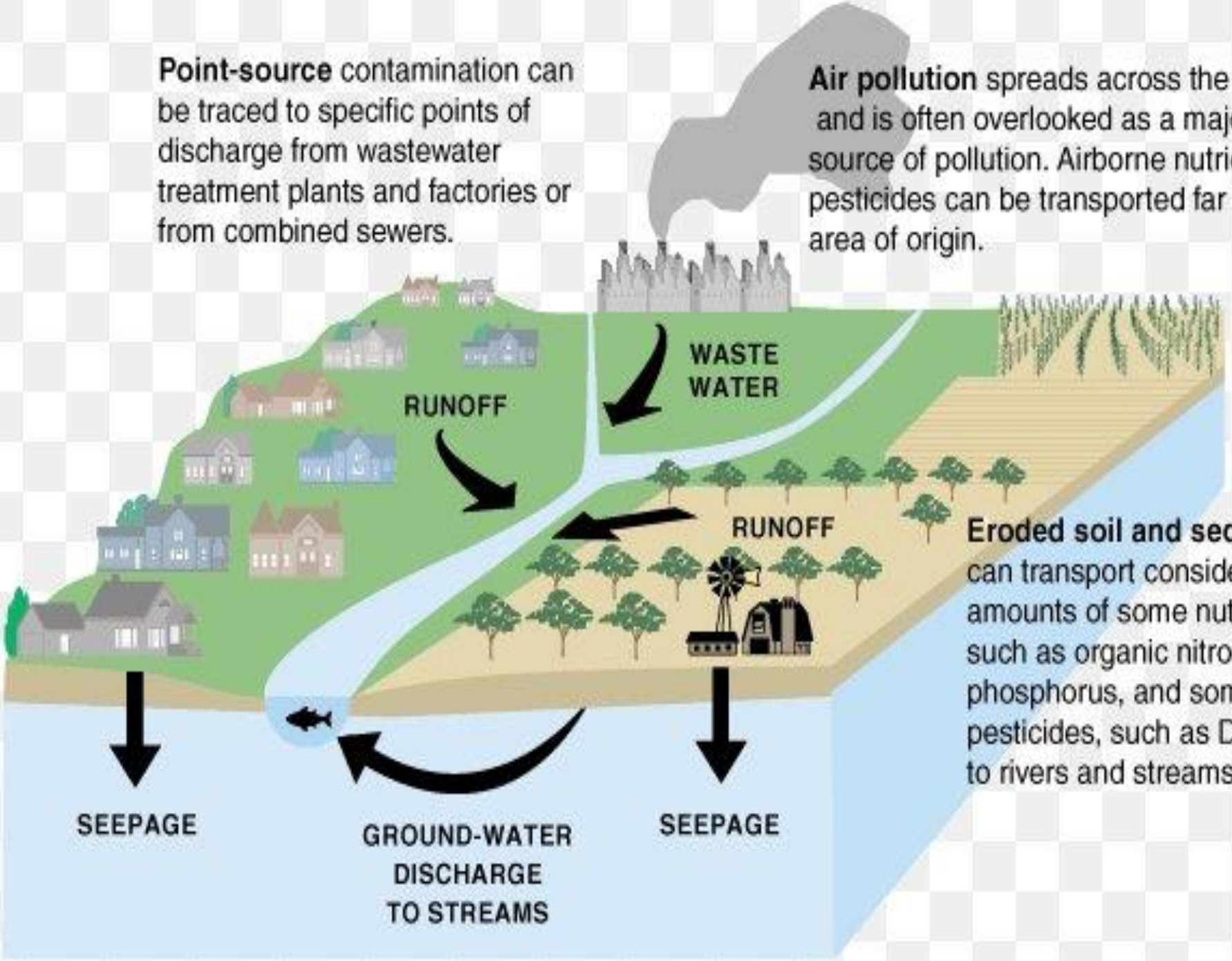
Anthropogenic sources of pollutants in the aquatic environment

Source	Bacteria	Nutrients	Trace elements	Pesticides/herbicides	Industrial organic micro pollutants	Oils and greases
Atmosphere		x	xxxG	xxxG	xxxG	
Point sources						
Sewage	xxx	xxx	xxx	x	xxx	
Industrial effluents		x	xxxG		xxxG	xx
Diffuse sources						
Agriculture	xx	xxx	x	xxxG		
Dredging		x	xxx	xx	xxx	x
Navigation and harbours	x	x	xx		x	xxx
Mixed sources						
Urban run-off and waste disposal	xx	xxx	xxx	xx	xx	xx
Industrial waste disposal sites		x	xxx	x	xxx	x

x Low local significance
xx Moderate local/regional significance
xxx High local/regional significance
G Globally significant

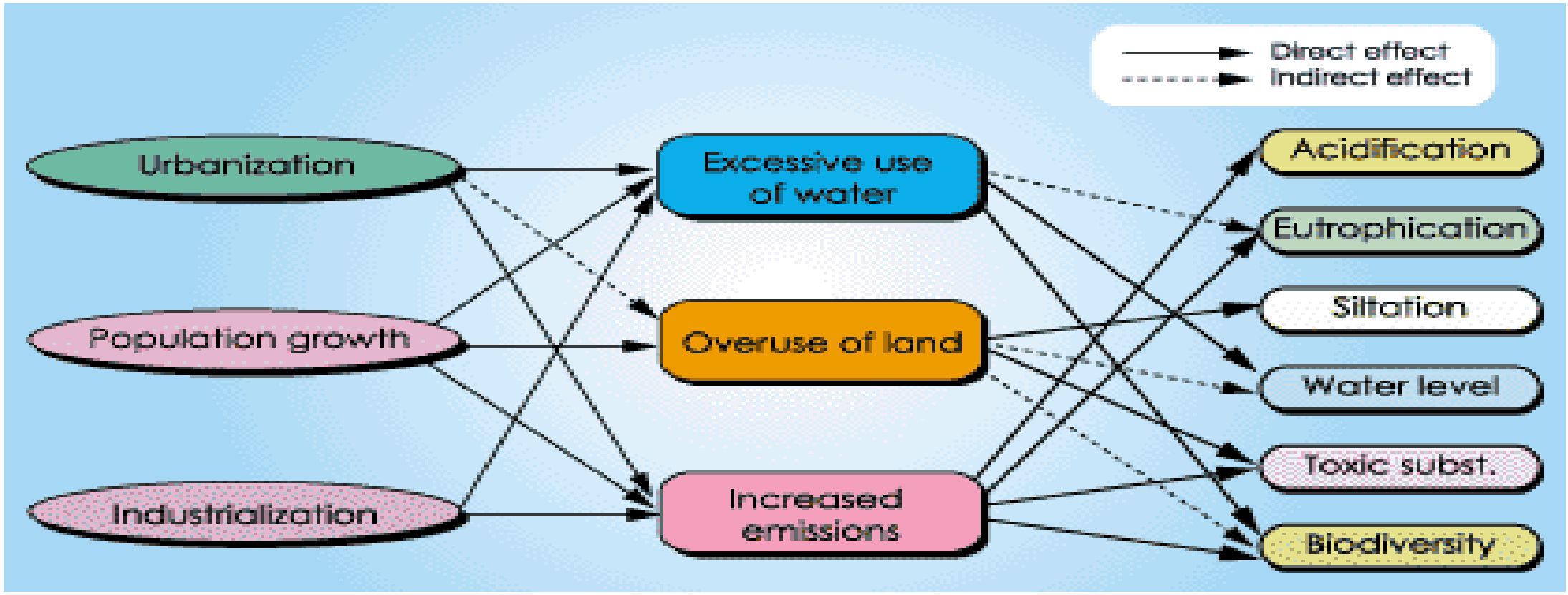
Point-source contamination can be traced to specific points of discharge from wastewater treatment plants and factories or from combined sewers.

Air pollution spreads across the landscape and is often overlooked as a major nonpoint source of pollution. Airborne nutrients and pesticides can be transported far from their area of origin.



Eroded soil and sediment can transport considerable amounts of some nutrients, such as organic nitrogen and phosphorus, and some pesticides, such as DDT, to rivers and streams.

Pollution causes & consequences



Urbanization, population growth and industrialization are amongst the basic factors which cause environmental problems in lakes and reservoirs.

5-Spatial and temporal variations

Rivers and lakes have different water quality

Spatially: source and mouth or inlet and outlet
surface layer and deepest layer
banks and middle

Temporally: day/night
seasons
years
centuries

→ **Importance of designing good monitoring network !**

For rivers, a good understanding of the discharge regime is important for interpretation of water quality measurements.

The discharge of a river determines in many cases the concentration of dissolved substances, via dilution.

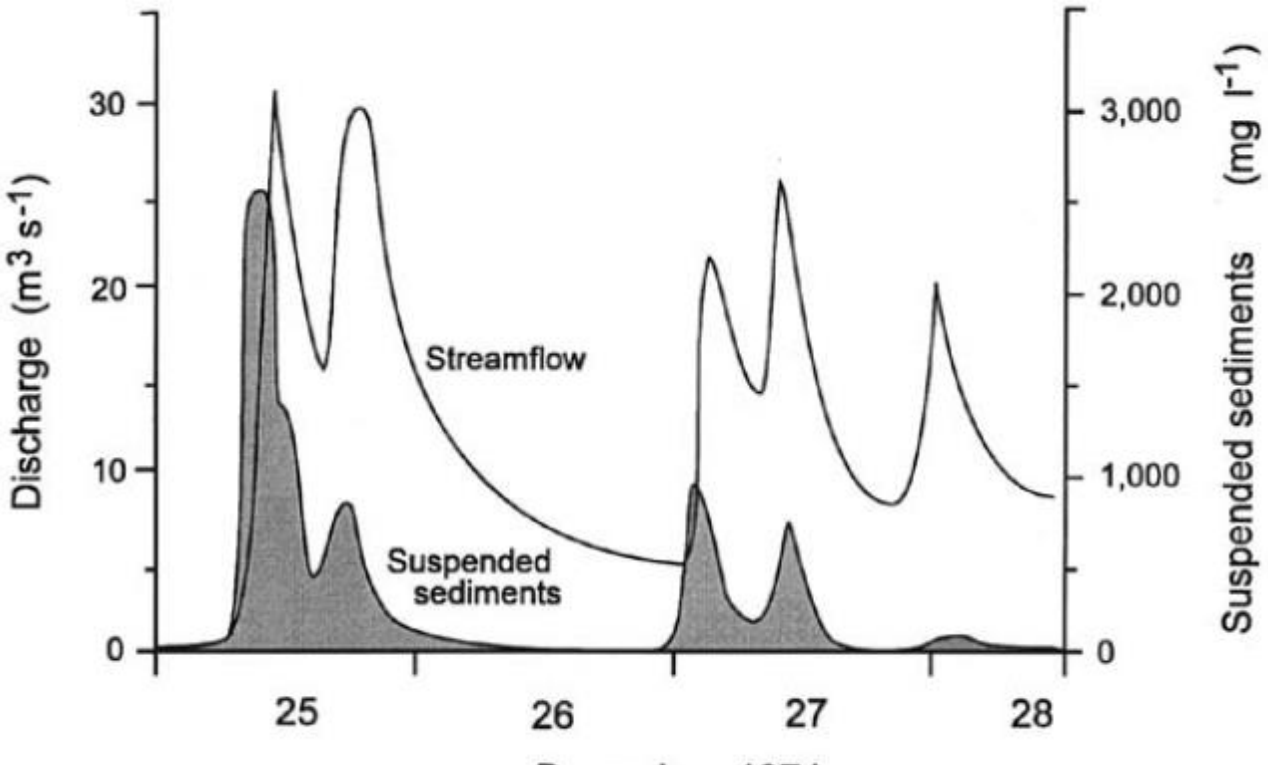
Load L (g/s) = Discharge Q (m^3/s) *Concentration C (g/m^3)

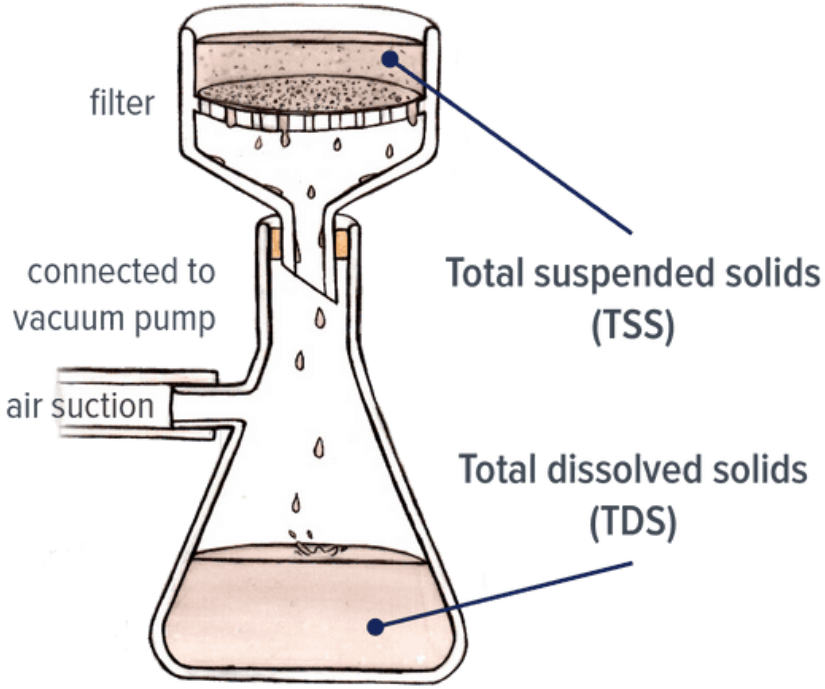
E.g. assuming a constant load shows you that for increasing discharges the concentration will go down and *vice versa*.

Water quality can thus depend much on the **season**.

However, **total suspended solids** (TSS) often show increase with higher Q (more erosion during rain storms)

Example : The temporal relationship of total suspended solids to the hydrography of the River Exe, UK (After Walling, 1977)





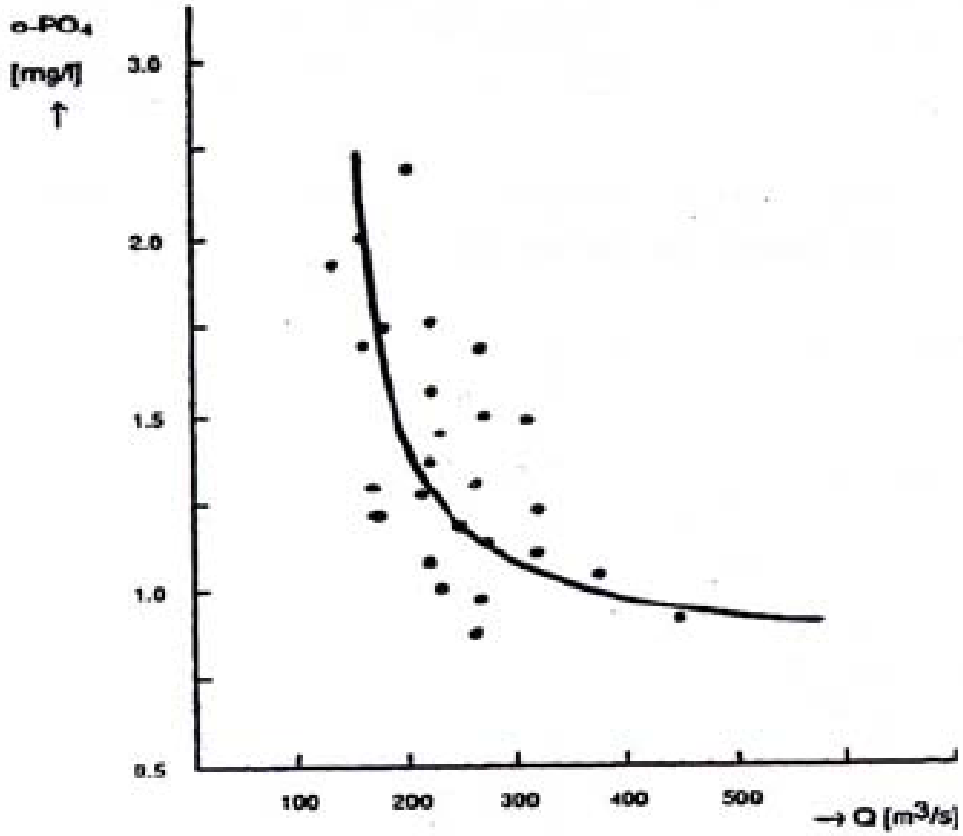


Fig.2.1. Ortho-phosphate vs. discharge in the river Rhine at Kampen (the Netherlands)

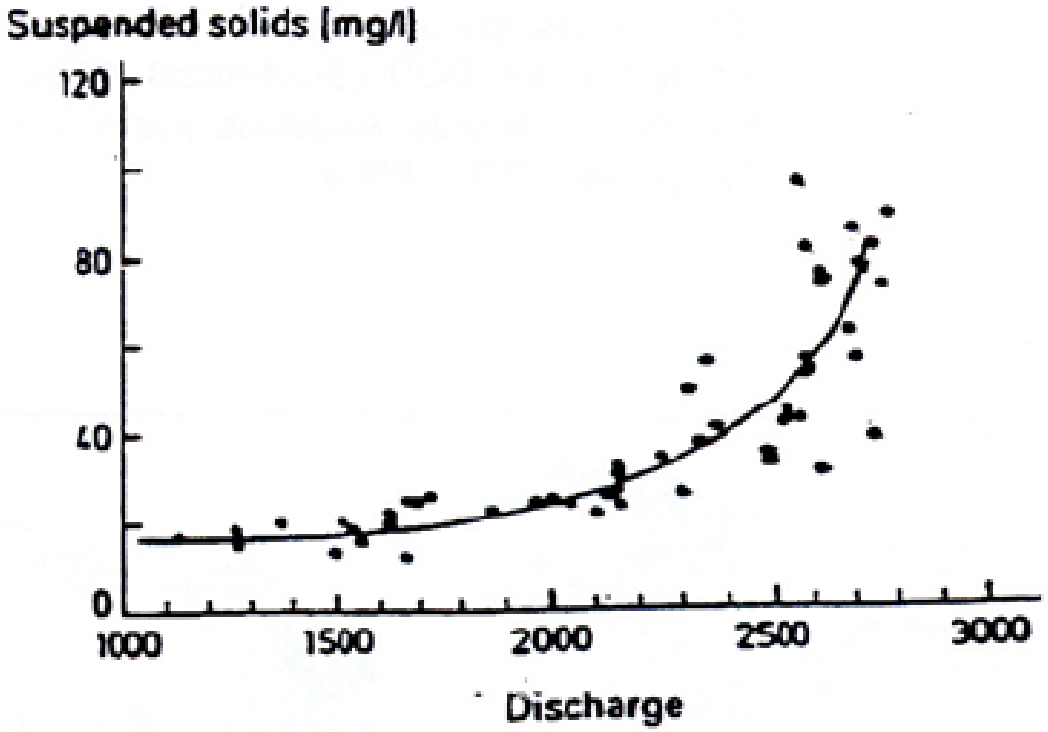
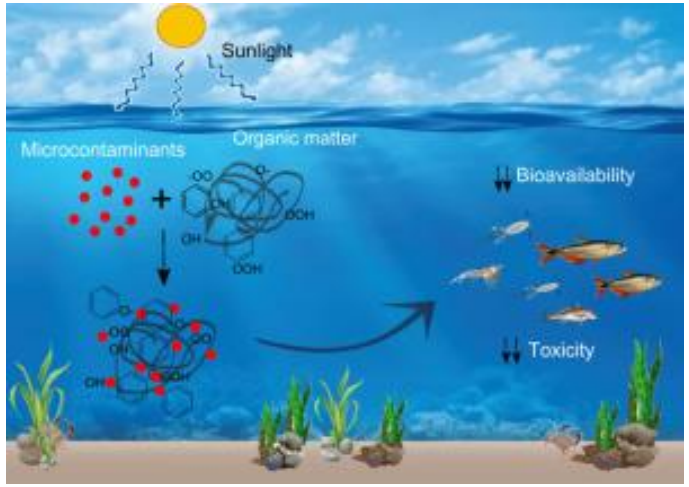


Fig. 2.2. Total suspended solids(mg/L) and discharges (m^3/sec.) for the river Rhine at Koblenz, Germany

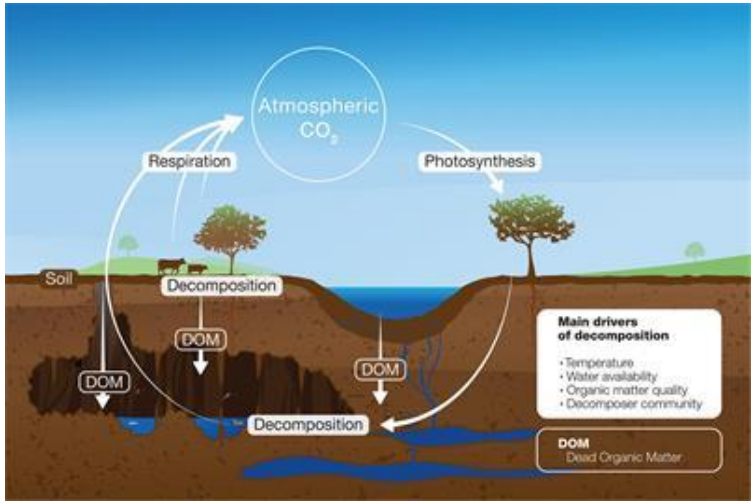
6- Organic matter in Water



Degradable organic matter is broken down by **microbes**, usually with the help of **oxygen,** although in the absence of oxygen also anaerobic reactions (fermentation and methanogenesis) are possible.

- Amount of organic waste load expressed as **"Oxygen Demand"**:

- Theoretical oxygen demand, **ThOD**, from reaction with O_2, *e.g.* :



$C_2H_5OH + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$ (M.W.* of ethanol = 46)

$\rightarrow$ ThOD of C_2H_5OH = $3*\left(\frac{32}{46}\right)$ = <u>2.08 mg O_2/mg ethanol</u>

(M.W. = molecular weight; M.W. of C_2H_5OH = (2*12)+(5*1)+16 +1= 46)

Biochemical Oxygen Demand (BOD)

- **Biochemical oxygen demand (BOD)** is the amount of dissolved oxygen (DO) needed (i.e. demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. The BOD value is most commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days of incubation at 20 °C and is often used as a surrogate of the degree of organic pollution of water.
- BOD reduction is used as a gauge of the effectiveness of wastewater treatment plants. BOD of wastewater effluents is used to indicate the short-term impact on the oxygen levels of the receiving water.
- BOD analysis is similar in function to chemical oxygen demand (COD) analysis, in that both measure the amount of organic compounds in water. However, COD analysis is less specific, since it measures everything that can be chemically oxidized, rather than just levels of biologically oxidized organic matter.

Biochemical Oxygen Demand determination

BOD_5^{20}: by microbial decomposition in the lab, under standardised conditions:

- during 5 days
- at 20 º Celsius
- in the dark (to prevent algae growth and photosynthesis of O_2)

Surface water and wastewater normally contain sufficient quantities of bacteria for the analysis.

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

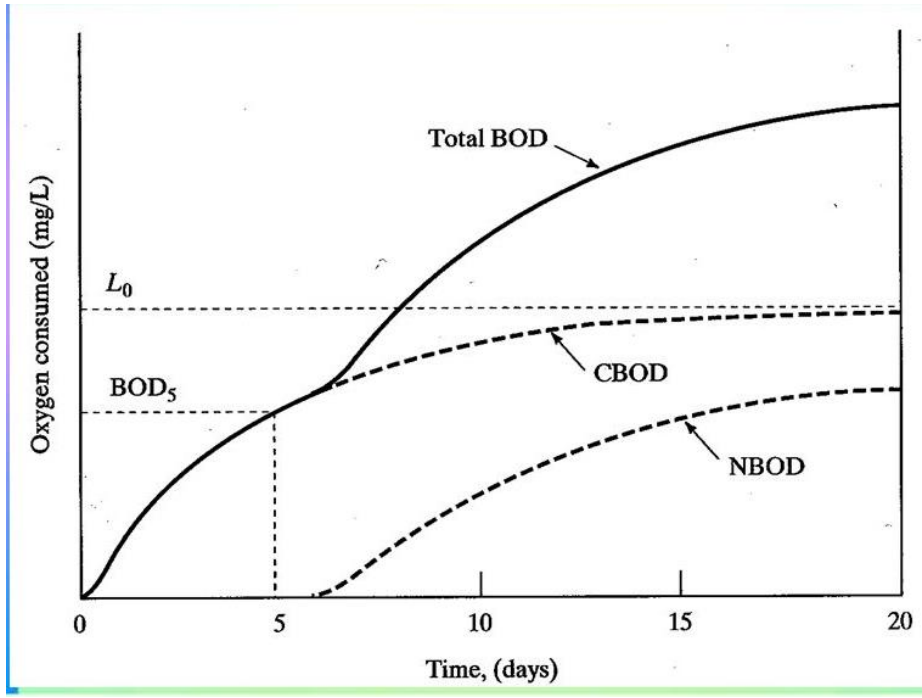
Warning: other compounds (than organic matter) can also be converted by microbes while using oxygen. Most common one is **NH_4^+**:

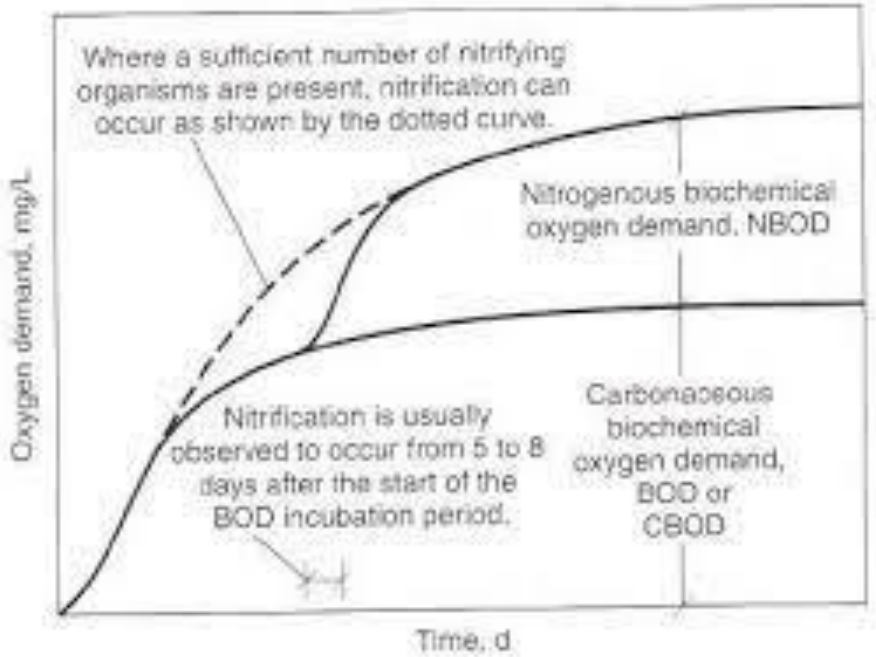
Theoretically: $NH_4^+ + \mathbf{2\ O_2} \rightarrow NO_3^- + 2H^+ + H_2O$

Nitrogen Oxygen Demand (nBOD) = 4.57 g O_2 / g NH_4-N !

When no measures are taken to prevent this, the analysis result is called TBOD (total BOD).

When a so-called nitrification inhibitor is added (prevents conversion of NH_4^+), then it is called CBOD (carbon-BOD).





INTERMEZZO: NH_4-N or NH_4?

In water quality monitoring we can express concentration as:

- Based on the **molecule,** so mg NH_4/L (M.W. = 14 + 4 =18) (rounded off)
- Based on the **atom(s),** so mg NH_4-N/L (Atomic weight A.W. = 14)

So a water quality of 1.0 mg NH_4/L corresponds to 0.78 mg NH_4- N/L .

Similarly: the Worlds Health Organization, WHO, guideline for nitrate in drinking water = 50 mg NO_3/L, equivalent to (14/62)*50 = 11.3 mg NO_3-N/L .

It is highly recommendable to use the "Atoms system" (*e.g.* to make mass balances)

Be very aware, in water quality data interpretation as well as in your own data reporting, of the way the results are expressed ! It's a big source of errors!

Chemical Oxygen Demand (COD)

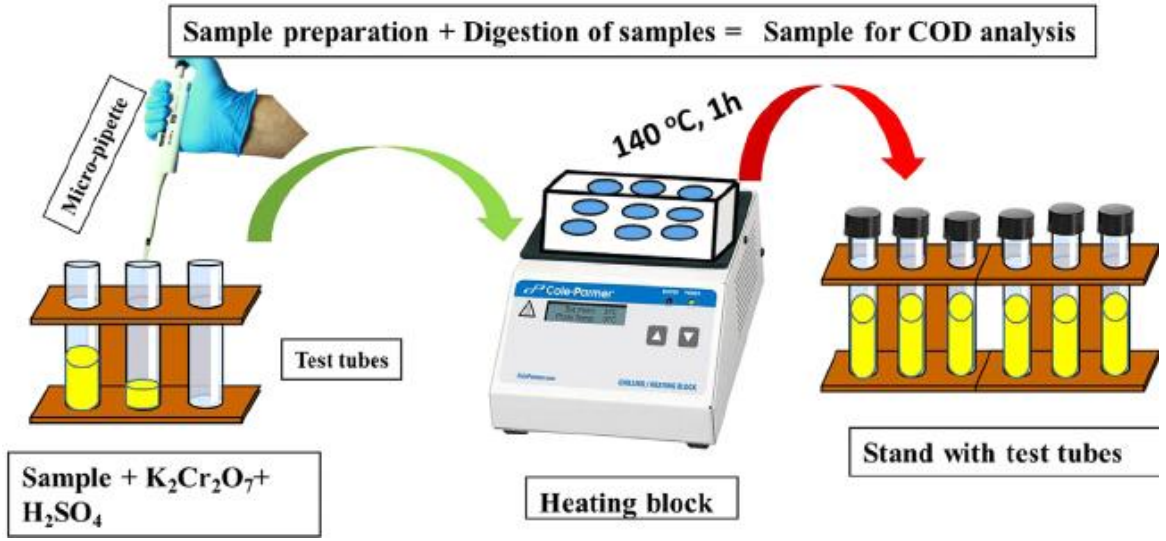
In practice, to avoid 5 days delay between sampling and obtaining result:

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:

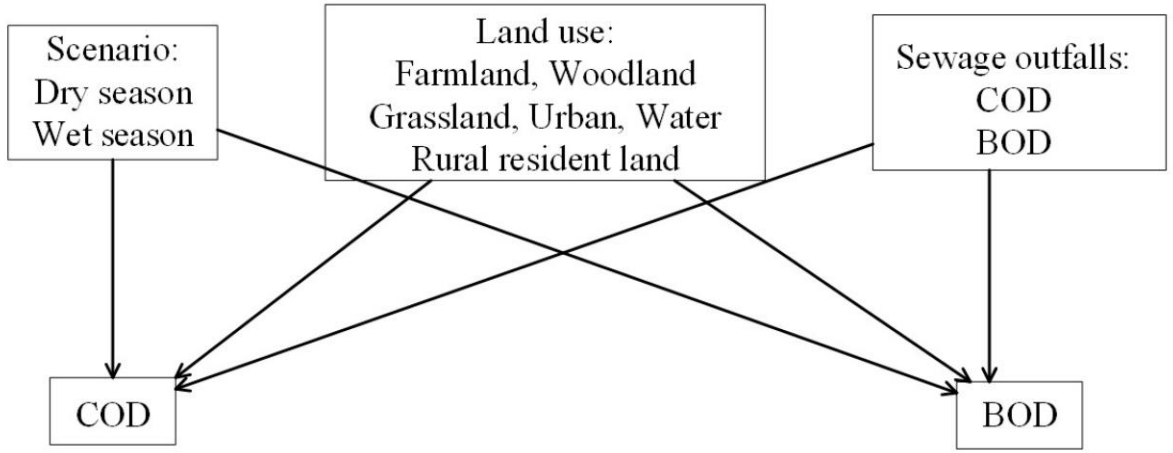
- domestic wastewater: BOD/COD = 0.65
- surface water: BOD/COD = 0.40



Sources of BOD and COD

Mainly from domestic and industrial sources.

Some examples are given below:

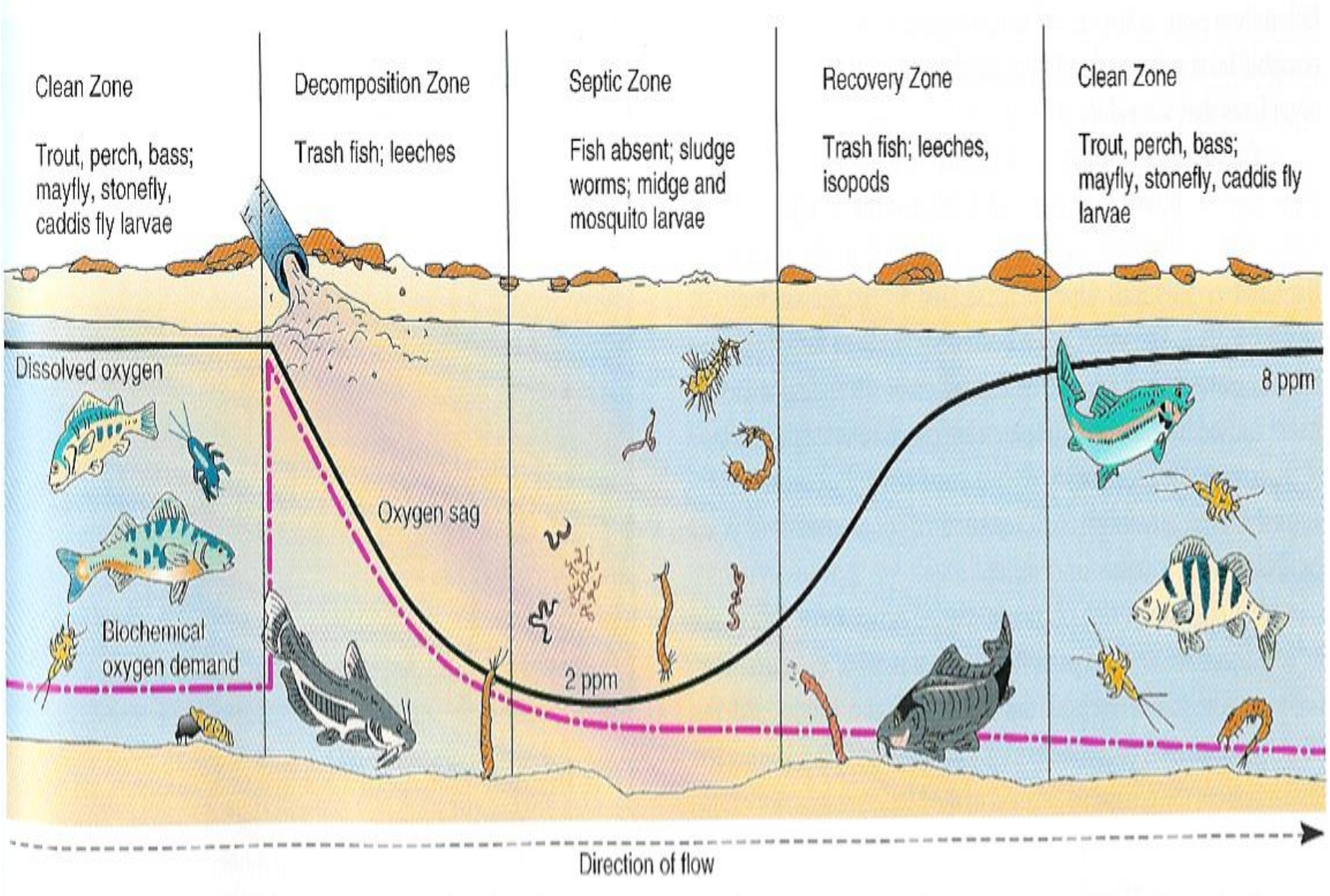


	BOD (mg/L)	COD (mg/L)
Medium-strength domestic wastewater	190	430
Textile wastewater	197	2497
Paper mill wastewater	93 - 633	571 – 3085
Landfill leachate	20 – 57,000	140 – 152,000

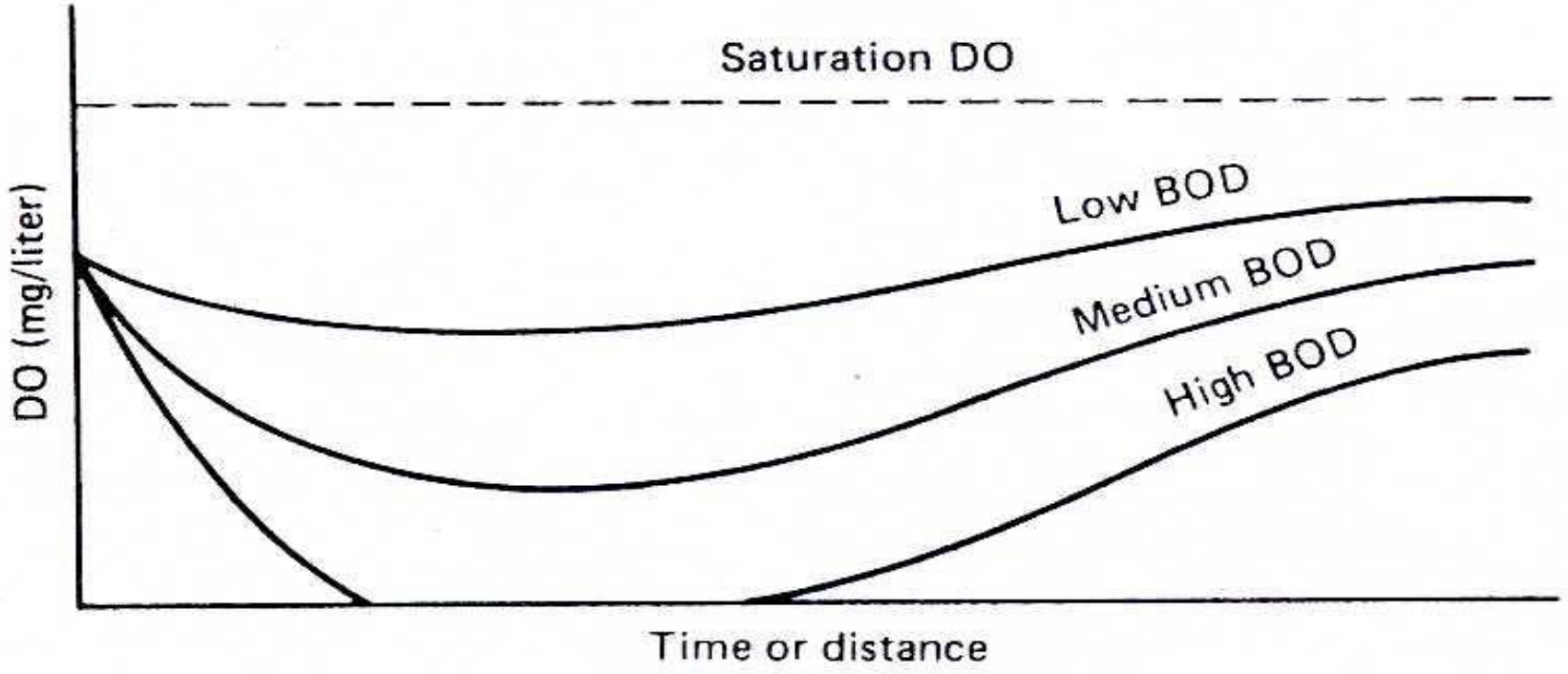
Assignment

- Have a look at the BOD / COD data for your own country at: http://www.gemstat.org/
- The Global Freshwater Quality Database GEMStat provides scientifically-sound data and information on the state and trend of global inland water quality. As operational part of the GEMS/Water Programme of the United Nations Environment Programme (UNEP), GEMStat is hosted by the GEMS/Water Data Centre (GWDC) within the International Centre for Water Resources and Global Change (ICWRGC) in Koblenz, Germany.

Impact of BOD on dissolved oxygen in a river



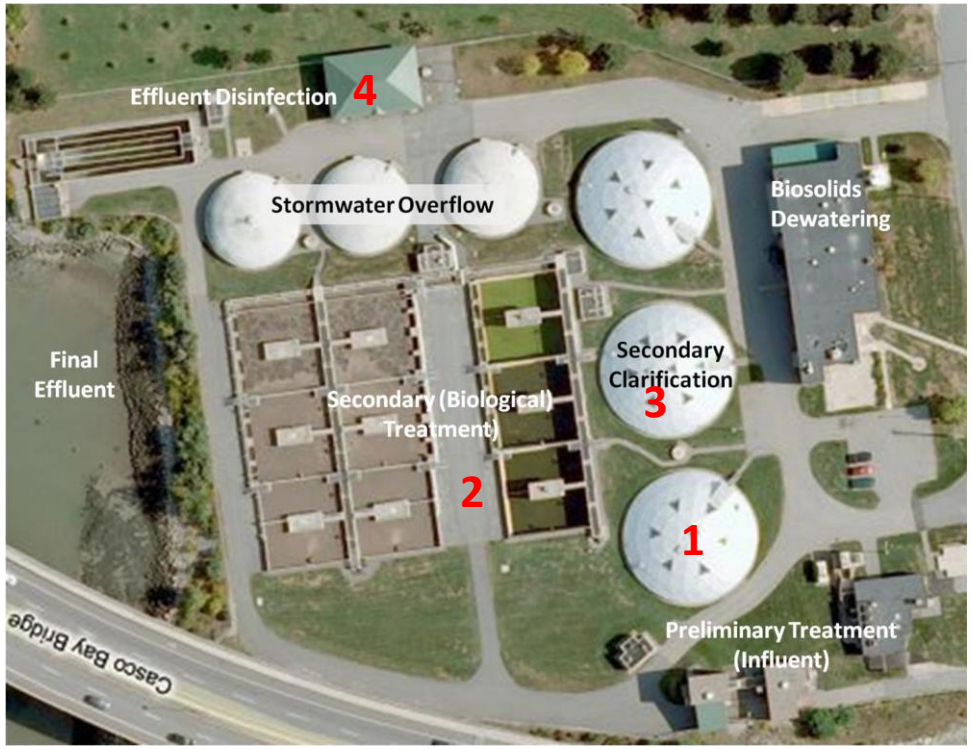
Impact of BOD on dissolved oxygen in a river



Modelling, for the general formula of the oxygen sag curve, for the minimum DO ("depth of oxygen sag is roughly proportional to BOD load"), and for the distance to reach the minimum

Wastewater treatment for removing of :

Suspended solids in sewage (1)
- CBOD, NBOD by microbes, under strong aeration (2)
- Bacterial “sludge” (3)
- Extra: Pathogens (4), *e.g.* by U.V. radiation
- Also as extra (expensive!): nutrients (phosphate, nitrate, …



Cost recovery often: “the polluter pays” (households, factories, …)

European countries: BOD reduction from > 90% !

CONCLUSION

- Water is a precious resource. We can’t live without it.

- To protect our environment, health, economic well-being and community quality of life, we must protect our Water resources from Pollution.

- The water quality assessment is an evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses.

- **Water Quality** Is Everyone's **Responsibility**

Thanks for your attention