Civilittee
اللجنة الأكاديمية لقسم الهندسة المدنية
www.Civilittee.com

سلايدات

هندسة البيئة

د. أحمد البدور

www.civilittee.com Civilittee Hashemite Civilittee HU | لجنة المدني

Environmental Engineering
CE456

1st Lecture
Dr. Ahmed Bdour
Fall 2025

Ecological Systems

A typical natural ecosystem is divided into:

1. Biotic components:
   a) Producers: green plants, algae
   b) Consumers: herbivores (an animal that gets its energy from eating plants), carnivores ('meat eater '), omnivores ('all-eater ')
   c) Decomposers: microorganism

2. Abiotic components:
   a) Soil
   b) Water
   c) Nutrients (A *nutrient* msinagro na taht lacimehc a si na ni desu ecnatsbus a ro worg dna evil ot sdeen sti morf ni nekat eb tsum hcihw msilobatem s'msinagro tnemnorivne).
   d) Climate elements: heat, humidity, wind
   e) Physical elements: gravity, radiation, light

Pollutants, in the form of substances &/or physical effects, are foreign components to the natural ecosystem.

Important Definitions

- **Ecology:**

  Branch of biology covering relations among living systems as well as between these and their surroundings – Provides knowledge on ability of natural systems for self-purification.

- **Environment:**
  - Global: Sphere in which the life-sustaining resources of the earth are contained.
  - Local: region or area where a specific problem is being addressed.

What is our environment?

- **Environment**: the total of our surroundings
- All the things around us with which we interact:
  - **Biotic factors - living things**
    - **Examples: Animals, plants, forests, fungi, etc.**
  - **Abiotic factors - nonliving things**
    - **Examples: Continents, oceans, clouds, soil, rocks**
  - **Our built environment**
    - **Buildings, human-created living centers**
  - **Social relationships and institutions**

- **Pollution:**
  - Undesirable change in the physical, chemical and / or biological characteristics of air, water or land that can harmfully affect the health, survival or activities of humans or other living organisms.
- **Environmental Science & Engineering**

(next)

Environmental Science

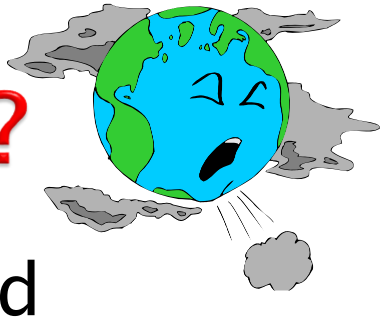
- **Environmental Science** - the study of the air, water, and land surrounding an organism or a community, which ranges from a small area to Earth's entire biosphere.
- It includes the study of the impact of humans on the environment

What is Environmental Science?

- Science can be differentiated into the social sciences and natural sciences.

- Natural sciences include
  - core sciences: chemistry, biology, and physics
  - numerous applied sciences such as geology, meteorology, forestry, and zoology
  - *environmental science* is an integrative applied science that draws upon nearly all of the natural sciences to address environmental quality and health issues

What is Environmental Science?



- We are concerned with the quality and availability of environmental resources and with the waste streams that impact them
- Science…improve our understanding of natural processes
- Engineering…use this understanding to develop and apply technologies that will maintain or improve environmental quality

Environmental science

- Environmental science helps us understand our relationship with the environment and informs our attempts to solve and prevent problems.
- Identifying a problem is the first step in solving it
- Solving environmental problems can move us towards health, longevity, peace and prosperity
    - Environmental science can help us find balanced solutions to environmental problems

What is Environmental Engineering?

- *Environmental engineering* uses environmental science principles, along with engineering concepts and techniques, to assess
  - the impacts of societal activities on the environment,
  - The impact of the environment on people,

  and to protect both human and environmental health.

  (Eng. Techniques involves design, operation and maintenance of engineering units (structures, equipment).

- Environmental engineering requires a sound foundation in the environmental sciences

What is an engineer ?

- Problem solver.
  - Specifically, one who uses science to solve real world problems.

- SO, what about an environmental engineer ?
  - Solves environmental problems using scientific tools

Interdisciplinary Nature of Environmental Science and Engineering: Examples

- Groundwater contamination by leaking gasoline storage tanks – material science, hydrogeology, geochemistry, microbiology, hydraulics AND environmental engineering

- Urban air pollution – chemical/mechanical/ automotive engineering, meteorology, chemistry, AND environmental engineering

Key Elements of Modern Environmental Science and Engineering

- Based on chemistry – environmental quality described by chemical composition of the system

- Quantitative – magnitude of the problem and feasibility of the solution are described numerically

- Driven by government policy, which is increasingly set on the basis of risk

Environmental Systems Overview

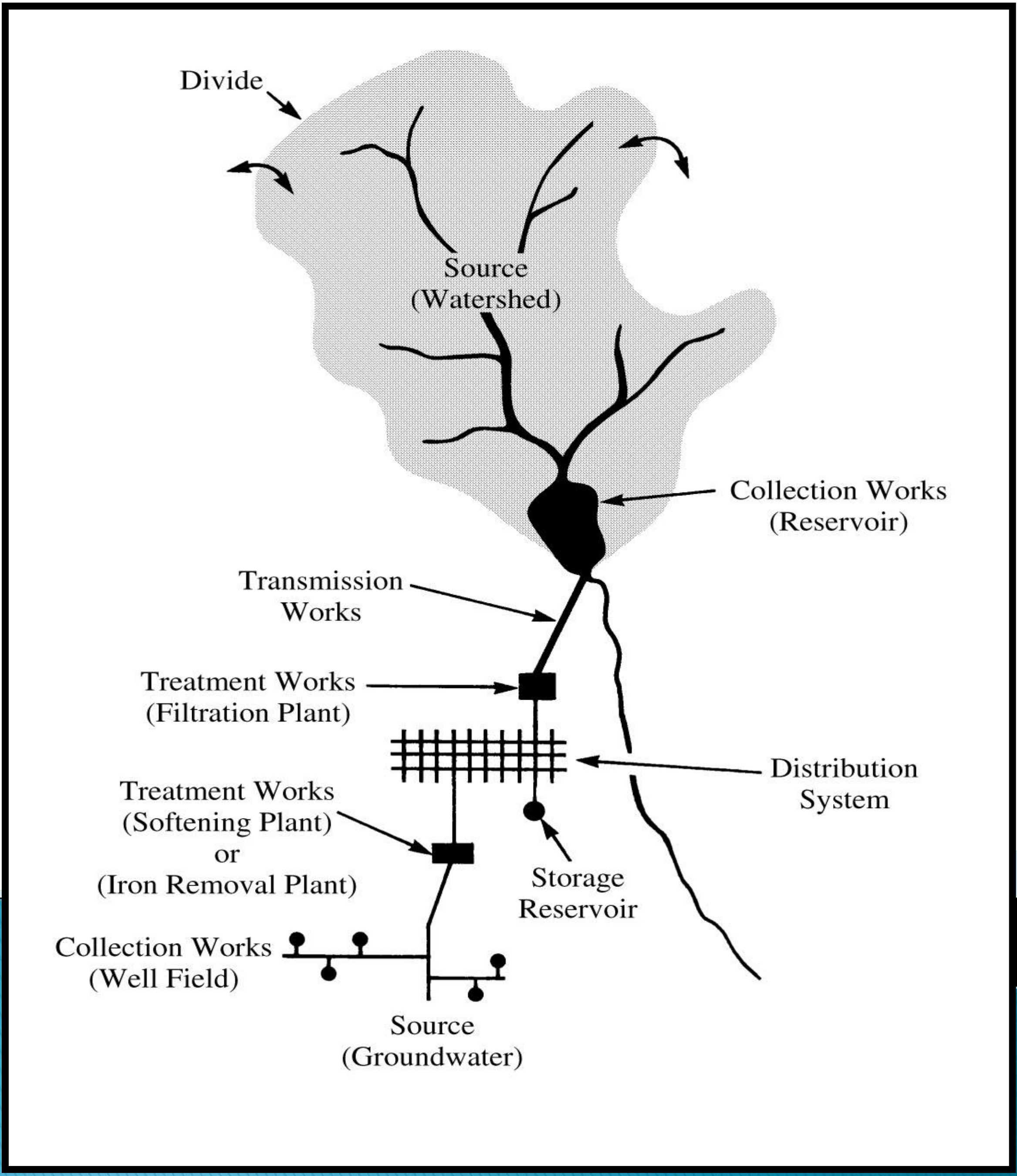
1. Water Resource Management Systems:
    a) Water Supply Sub-system
    b) Wastewater Disposal Sub-system
2. Air Quality Management System
3. Solid Waste Management System
    - ☐ Hazardous Waste Management System

Water Supply Sub-system

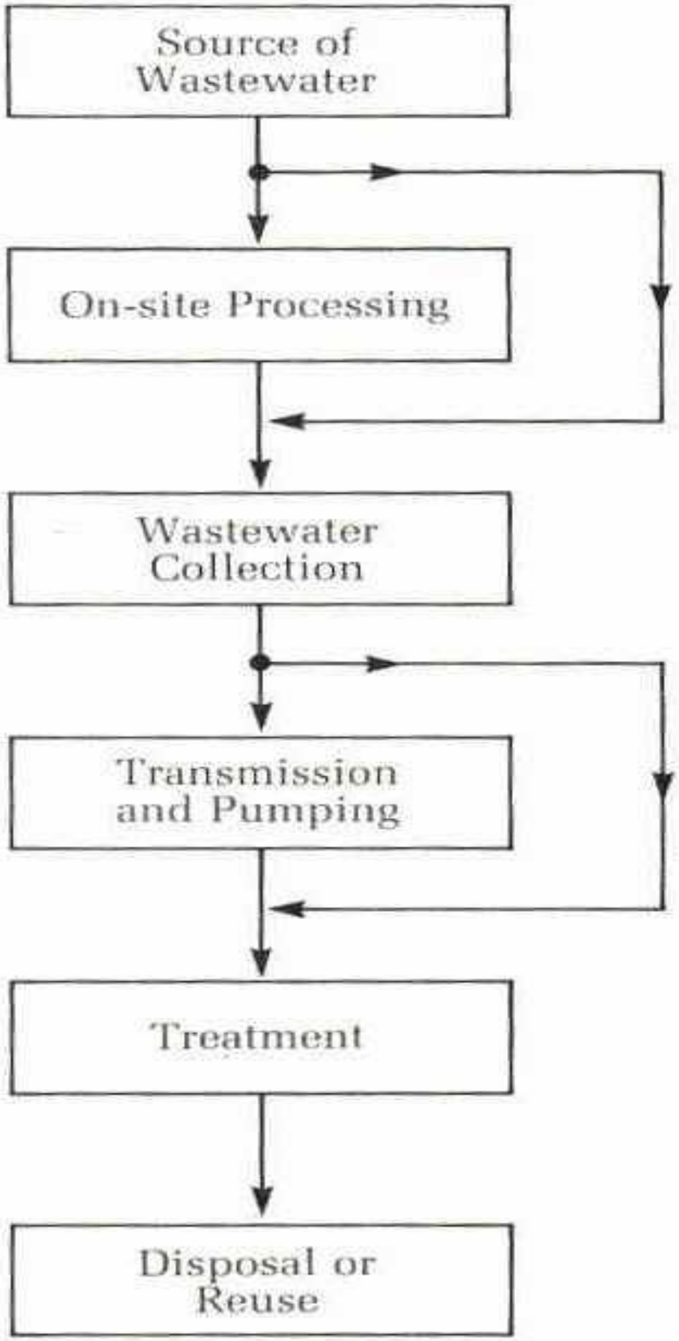
- System Components:
  - Planning
  - Design
  - Operation of processes: collection, treatment (purification), transmission, distribution.

- Water Sources:
  - Meteorological water: rain, snow
  - Ground water: springs, wells
  - Surface water: rivers, lakes, oceans

Water Supply Sub-system



Wastewater Disposal Sub-system



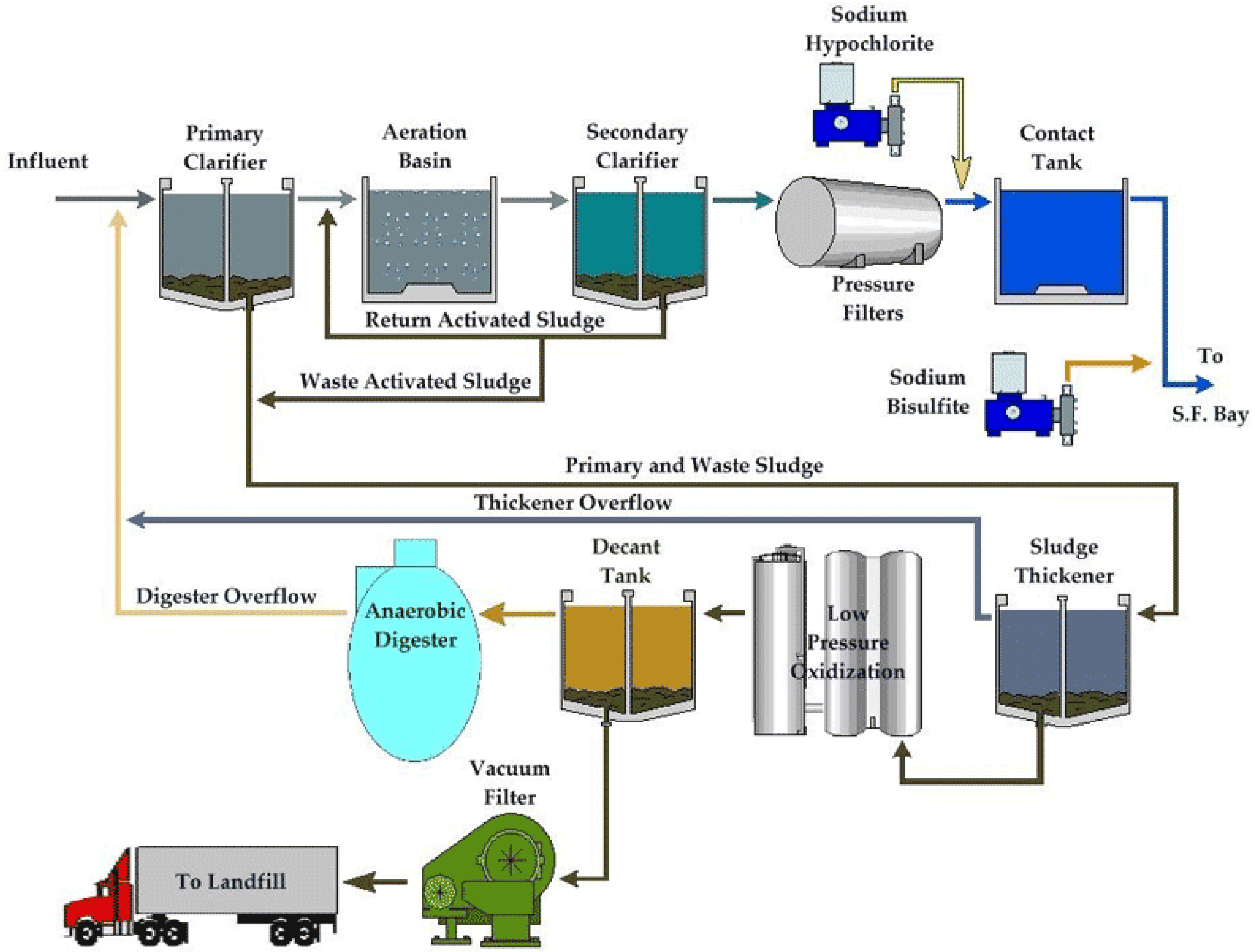
Wastewater Disposal Sub-system

- Wastewater Sources:
  - Domestic sewage
  - Industrial effluents
  - Agricultural runoff
  - Storm runoff
- Collection: 3 types of sewers (sanitary, storm, combined)
- Treatment:
  Stabilization of waste material or pollutant so that it will not be harmful to humans or the environment when disposed of.

Objectives of WW management:

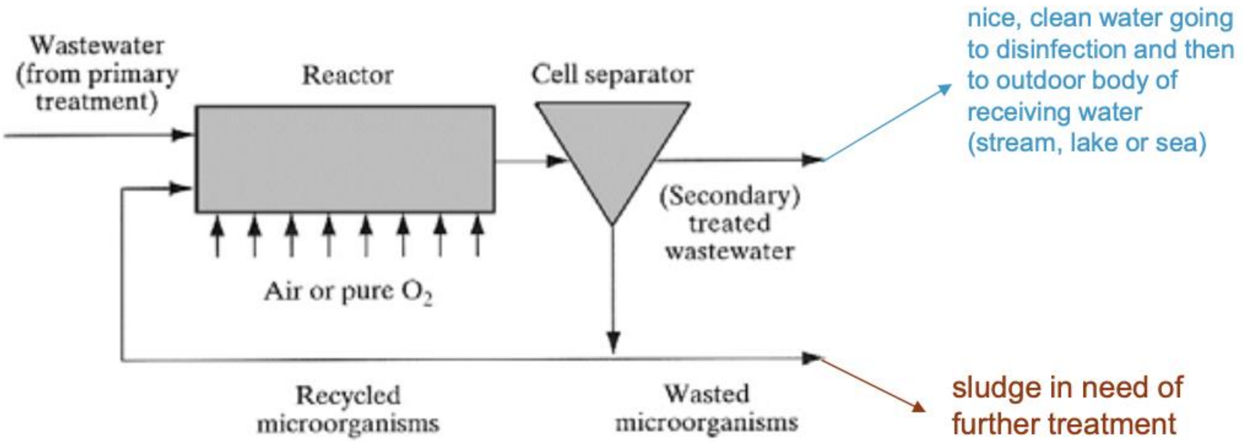
1. Protect drinking water supply; surface & ground.
2. Protect public health hazard: w.w. should not be accessible to insects, rodents, birds or other carriers that may later come into contact with food or drinking water.
3. Protect coastal areas or streams used for recreational purposes.
4. Avoid nuisance due to odor or unsightly appearance.
5. Comply with laws or regulations governing water pollution or sewage disposal.

Wastewater Treatment Plant



Anaerobic Digestion of Wastewater Sludge

(Nazaroff & Alvarez-Cohen, Section 6.E.3)



nice, clean water going to disinfection and then to outdoor body of receiving water (stream, lake or sea)

sludge in need of further treatment

The goal is to reduce the amount of sludge that needs to be disposed.

The most widely employed method for sludge treatment is anaerobic digestion.

In this process, a large fraction of the organic matter (cells) is broken down into carbon dioxide (CO_2) and methane (CH_4), and this is accomplished in the absence of oxygen. About half of the amount is then converted into gases, while the remainder is dried and becomes a residual soil-like material.

What the equipment looks like

The tank is capped
- to prevent oxygen from coming in,
- to prevent odors from escaping, and
- to capture the methane produced.

This methane, a fuel, can be used to meet some of the energy requirements of the wastewater treatment facility (co-generation).

What the sludge looks like after anaerobic digestion and subsequent drying.

It is rich in nitrates and performs well as a fertilizer.

(Photos from http://www.madep-sa.com/english/wwtp.html)

How the system works

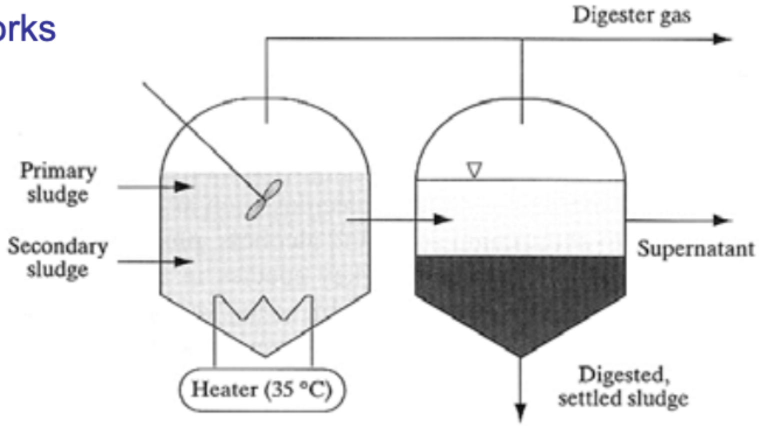


Figure 6.E.7 Schematic of a two-stage, high-rate anaerobic sludge digester (Metcalf & Eddy, 1991).

(Nazaroff & Alvarez-Cohen, Figure 6.E.7)
(Originally from Metcalf & Eddy, 1991)

The treatment of wastewater sludge, from both primary and secondary treatment steps, consists of two main phases.

- In the 1st step, all incoming flows of sludge are combined, and the mixture is heated to a mild temperature (about body temperature) to accelerate biological conversion. The residence time here ranges from 10 to 20 days.
- In the 2nd tank, the mixture is allowed to undergo further digestion. There is no longer active mixing in order to promote separation, and there is no need of heating as the process generates its own heat.
- In further processes (not shown on the diagram) the settled sludge is dewatered and thickened. The goal is to separate as much water as possible to decrease the volume of material. Finally, a phase known as *sludge stabilization* reduces the level of pathogens in the residual solids, eliminates offensive odors, and reduces the potential for putrefaction.

The outcome

Anaerobic digestion of municipal wastewater sludge has been widely practiced since the early 1900s and is the most widely used sludge treatment method.

Overall, the process converts about 40% to 60% of the organic solids to methane (CH_4) and carbon dioxide (CO_2). The chemical composition of the gas is 60-65% methane, 30-35% carbon dioxide, plus small quantities of H_2, N_2, H_2S and H_2O. Of these, methane is the most valuable because it is a hydrocarbon fuel (giving 36.5 MJ/m^3 in combustion).

The residual organic matter is chemically stable, nearly odorless, and contains significantly reduced levels of pathogens.


(Poppendieck, 2008)

Environmental Engineering

The application of science and engineering principles to minimize the adverse effects of human activity on the environment.

Related Sciences

- Philosophy
- Inorganic and Organic Chemistry
- Biological Sciences
- Mathematical and Physical Sciences
- Geophysical Sciences
- Communication Skills
- Social Sciences

Related Topics In C. E.

- Hydrology
- Highway Design
- Material Science
- Construction Management
- Water and Wastewater Transport
- Soil and Foundations Eng..

Causes of Environmental Problems

- Increasing Population
- Greater Consumption of Natural Resources *esp.* **Fossil Fuels**

Pollution: Personal Problem

- air - 7.7 lbs/day/person
- water - 0.2 lbs/day/person
- land - 5 lbs/day/person (collected)
  10 lbs/day/person (total)
- world population - > 6.9×10^9 people

Pollution Sources

- Natural: rivers, precipitation create silt
  - necessary: nothing is 100% efficient
  - increased standard of living increases waste production

Alternatives

- **Pollution can’t be eliminated**
- Control location and conditions
- Reduce the volume - concentration
- Accelerate naturally occurring reactions
- Problematic when nature’s balancing capacity is exceeded

Intro to Treatment Technologies

Role of Environmental Engineering

As pollutants enter air, water and soil, natural processes convert them to more acceptable forms.

Unfortunately, these natural systems have become overwhelmed.

- Environmental Engineering seeks to amplify, optimize and speed operations observed in nature to handle large volumes.

Natural Systems of Purification

In nature self purification mechanisms include Physical; Chemical and Biological

- Physical Processes

- Dilution
- Sedimentation & Re-suspension
- Filtration
- Gas Transfer
- Heat Transfer

Chemical Processes

- Dissolution-precipitation – Nitrogen, phosphorous as well as iron, manganese, copper, zinc etc are important to growth of microorganisms that degrade waste. These are changed to soluble forms that are usable by MO

- Oxidation-Reduction – MO used the above chemicals for growth and reproduction. The reactions require external source of energy for activation, which is supplied by the microorganisms.

Biological Processes

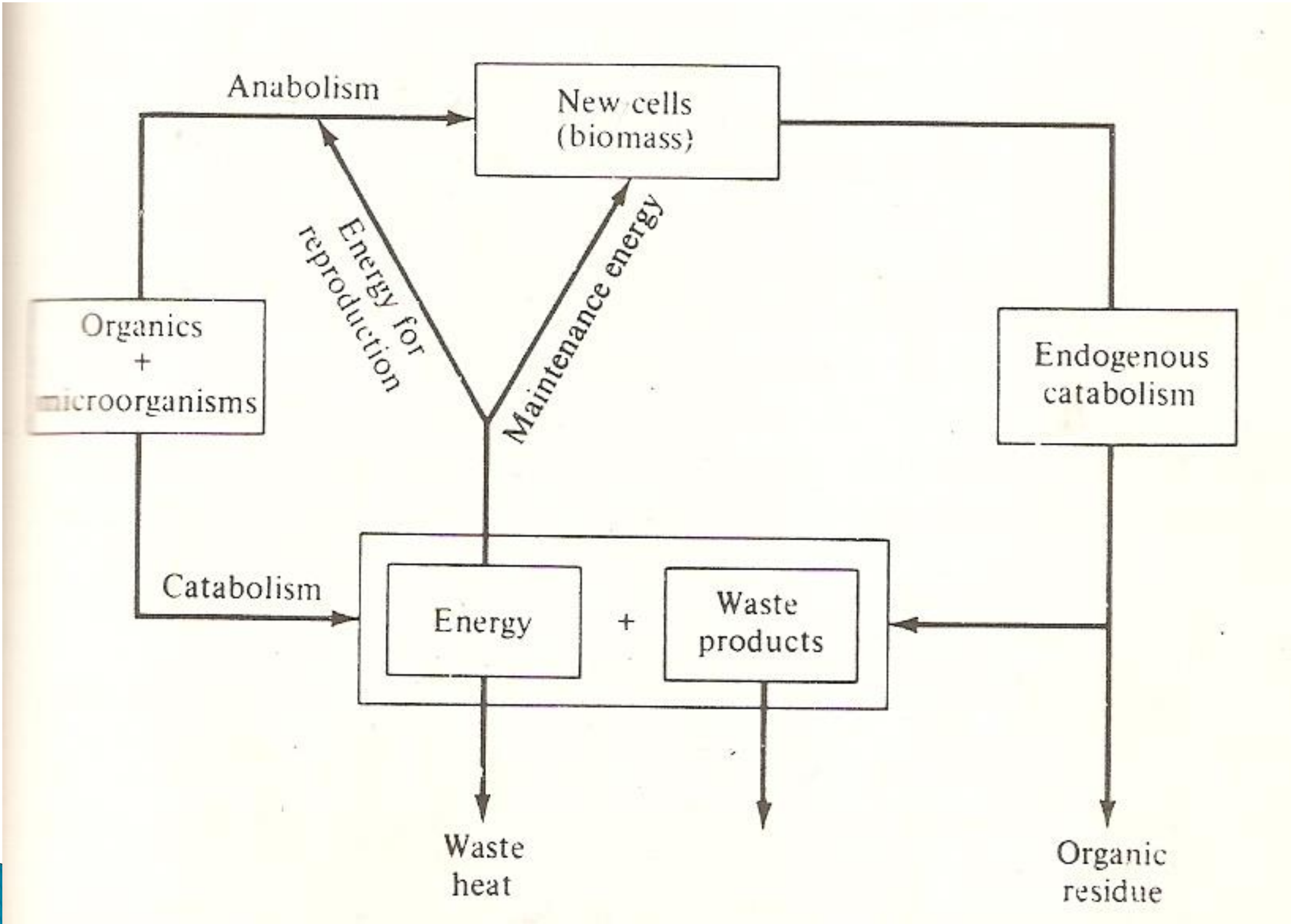
- The total sum of the processes by which living organisms assimilate and use food for subsistence, growth and reproduction is called metabolism

2 types of processes occur

1. Catabolism – provides energy for the synthesis of new cells and energy for maintenance of other cell functions
2. Anabolism – provides material necessary for cell growth

When external food sources are interrupted, organisms will use stored food for maintenance energy – endogenous catabolism

The continued presence of toxic substances will lead to development of a specific bacteria capable of decomposing and utilizing toxic substances – **Many New Technologies are based on this**


Anabolism
New cells (biomass)
Energy for reproduction
Maintenance energy
Organics + microorganisms
Endogenous catabolism
Catabolism
Energy
+
Waste products
Waste heat
Organic residue

Catabolic Processes involve either oxidation or reduction of materials in the substrate (food supply)

If free molecular oxygen is available it will be added to the substrate and the waste products will be oxidized compounds – leads to stable non objectionable end products (H_2O and CO_2)

In the absence of free oxygen, bound oxygen may be removed from oxygen bearing compounds and is hydrogen added to elements of the substrate. The result is a waste product composed of reduced compounds objectionable to streams e.g. methane, H_2S

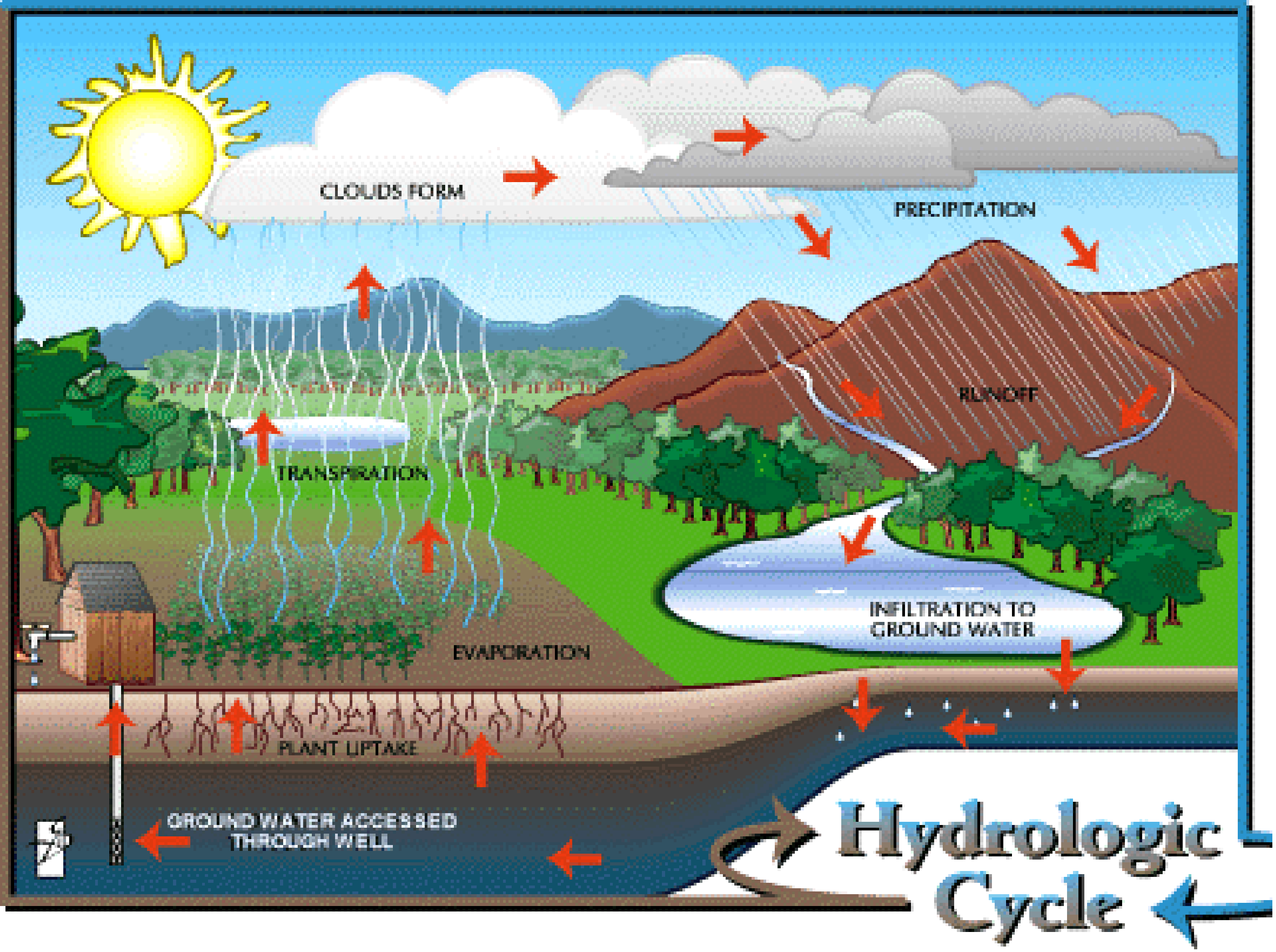
Principles of Waste Treatment

1. Convert objectionable material to less objectionable forms
2. To disperse pollutants so that their concentration is minimal
3. To concentrate them for isolation from the environment

Water-quality parameters

Topics

- Physical water–quality parameters
- Chemical water–quality parameters
- Biological water–quality parameters
- Water quality requirements



Impurities occur
-at point of condensation
-Human activities : Industrial Domestic and Agri chemicals

Form of Impurities
-Suspended
-Dissolved
-Colloids

100% Precipitation; 50% Percolation; 30% Evaporation; 40% Evapotranspiration; 20% Surface Runoff ; 10% Groundwater Flow

Suspended- Larger than molecular size supported by buoyant and viscous forces
Dissolved-molecules or ions held by molecular structure of water
Colloids- Technically suspended but exhibits characteristics of dissolved

Difference Between Dissolved, Suspensions and Colloidal Solutions

Property	Dissolved	Suspensions	Colloidal Solutions
Particle size	Less than 10^{-6} mm	Greater than 10^{-3} mm	Between 10^{-6} and 10^{-3} mm
Visibility of particles	Invisible to naked eye not visible under powerful microscope	Easily visible	Invisible to naked eye. Visible under powerful microscope.
Sedimentation of particles	Do not settle down	Settle down due to gravity	Settle down under high centrifugation
Filtration through filter power	No residue is formed	Residue is formed	No residue is formed

Water Pollution – The presence in water of impurities in such quantity and of such nature as to impair the use of the water for a stated purpose
Water quality is predicted on the intended use

Water Quality Requirements

- Water quality parameters – qualitatively reflect the effect of various impurities on the intended use of water
- *Standard Methods for the Examination of Water and Wastewater*– Standard analytical test procedures which provide quantitative measurements of these parameters

Water Quality Requirements

- **Water quality requirements** vary according to proposed use of the water. Water unsuitable for one use may be satisfactory for another. These are set by the user. It represents a known or assume need and are based on prior experience of the user.
- *Assignment: determine water quality criteria for agriculture; fish and wildlife; recreation uses; some typical industrial use; power generation*
- **Water Quality Standards** are set by a governmental agency and represent a statutory requirement

Water Quality Requirements

- **In-Stream standards** – Streams have minimum quality standards based on its use. Wastewater discharged from human activities together with the geology and natural characteristics of the watershed.
- **Potable-water Standards** – EPA ; WHO addresses turbidity, SS taste, odor, moderate dissolved inorganic; absence of organics, toxic substances and pathogens
- **Wastewater effluent standards**– e.g. EPA standards for the discharge of wastewater. – require secondary treatment. Industrial wastewater must be pretreated to become compatible with receiving domestic WW.

Physical Water-Quality Parameters

Define those characteristics of water that respond to the senses of

- Sight
- Taste
- Touch
- Smell

Parameters:

- Suspended Solids
- Turbidity
- Colour
- Taste
- Odor
- Temperature

1.0 Suspended Solids

Sources of Suspended Solids

Suspended Solids

Inorganic
-Clay
-Silt

Source – Surface Waters; Domestic WW; Industrial WW

Organic
-Plant Fiber
-Biological Solids (Agal Cells; Bacteria;)

Source – Surface Waters; Domestic WW; Industrial WW

Immiscible liquids
-Oils
-Grease

Source– Surface waters; Domestic WW and Industrial WW

Seldom found in groundwaters due to the natural filtering capacity of soils

1.0 Suspended Solids

Impact of Suspended Solids

- Aesthetically Displeasing
- Provide adsorption sites for chemical and biological agents
- May be degraded organically resulting in objectionable by products – e.g. methane
- May include disease causing organisms

1.0 Suspended Solids

Measurement

1. Total Solids Test – quantifies dissolved and suspended including organic and inorganic

- Evaporate a sample to dryness and weigh the residue – mg/L on a dry mass of solids basis
- Temp 104 degree Celsius
- Temp 180 degree Celsius (for occluded water)

1.0 Suspended Solids

2. Filtration –

a. Suspended Solids
- Filter the water sample
- Dry the filter and sample to 104 Degree Celsius
- Determine mass of residue– mg/L

b. Total Dissolved Solids = Total Solids – SS

Note 1 Colloids can be adsorbed unto the filter or pass through the filter. Thus the term filterable and non-filterable solids is used in analytical work

c. Organic Solids – Determine by firing the samples at 600 Deg Cel for 1 hr. Organics are converted to Carbon Dioxide, water and other gases

Work example

EXPERIMENT ON DETERMINATION OF TOTAL SOLIDS IN WATER

14.2 INTRODUCTION

The term “solids” is generally used when referring to any material suspended or dissolved in water or wastewater that can be physically isolated either through filtration or through evaporation.

Solids can be classified as either filterable or non filterable. Filterable solids may either be settleable or non settleable. Solids can also be classified as organic or inorganic.

Total Solids is the term applied to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature.

Measurement of Solids can be made in different water samples (industrial, domestic and drinking water) and it is defined as residue upon evaporation of free water.

Thus, **Total solids are nothing but summation of total dissolved solids and total suspended solids.**

14.2.1 ENVIRONMENTAL SIGNIFICANCE

Total solids measurements can be useful as an indicator of the effects of runoff from construction, agricultural practices, logging activities, sewage treatment plant discharges, and other sources.

Total solids also affect water clarity. Higher solids decrease the passage of light through water, thereby slowing more rapidly and hold more heat; this, in turn, might adversely photosynthesis by aquatic plants. Water will heat up affect aquatic life that has adapted to a lower temperature regime.

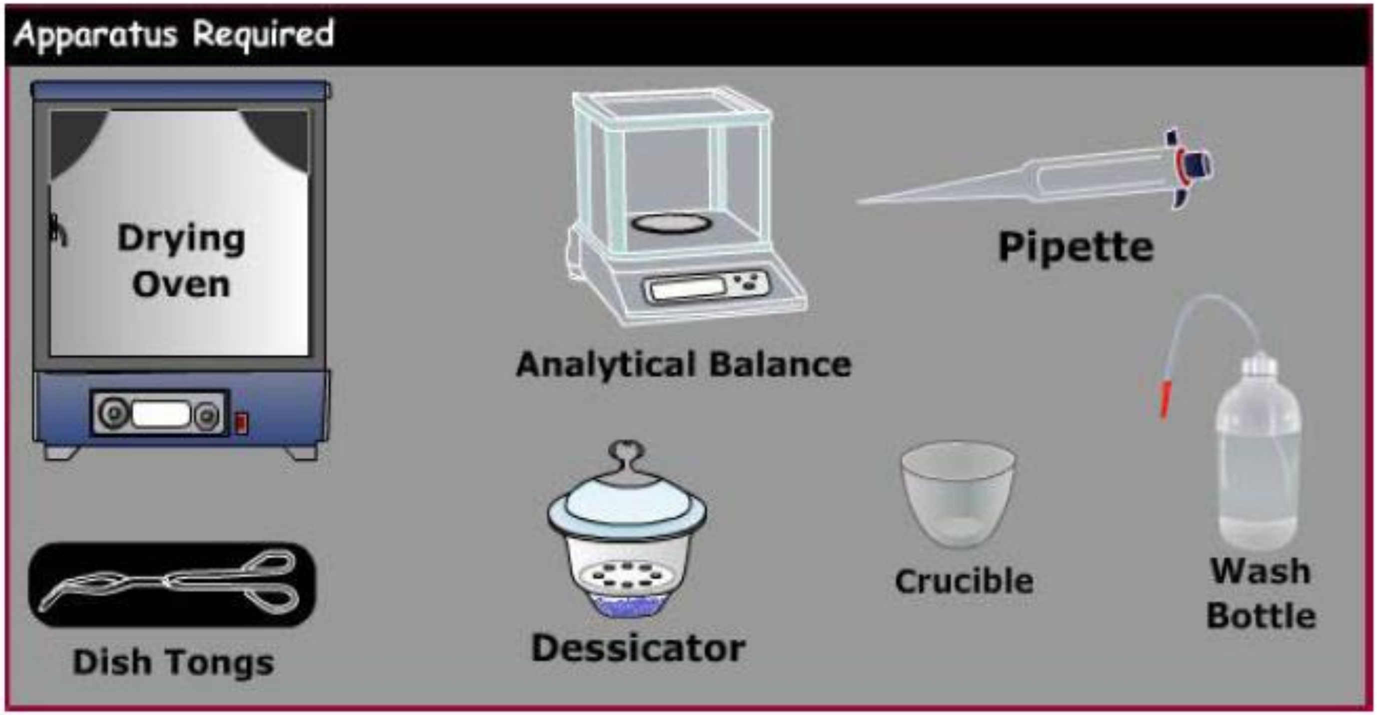
As with turbidity, concentrations often increase sharply during rainfall, especially in developed watersheds. They can also rise sharply during dry weather if earth-disturbing activities are occurring in or near the stream without erosion control practices in place.

Regular monitoring of total solids can help detect trends that might indicate increasing erosion in developing watersheds.

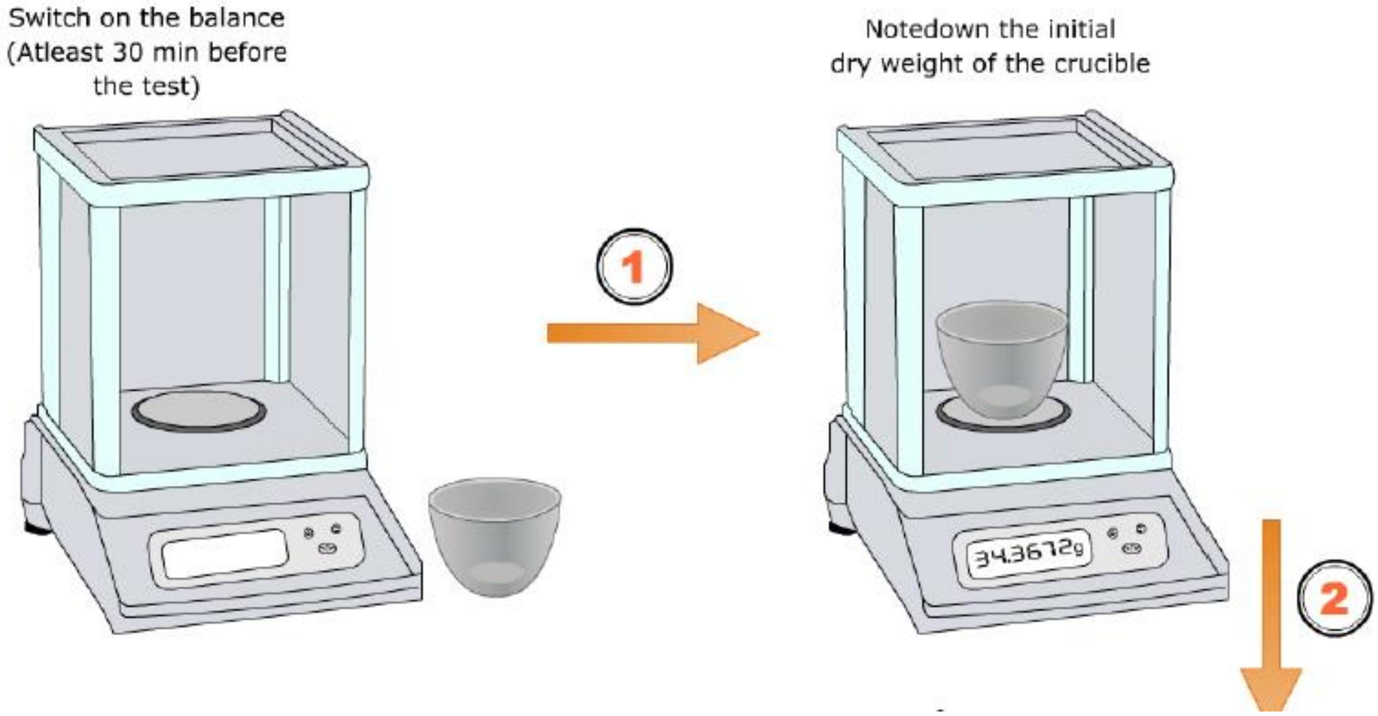
14.4 MATERIALS REQUIRED

14.4.1 APPARATUS REQUIRED

1. Crucible
2. Oven
3. Desiccators
4. Analytical Balance
5. Dish Tongs
6. Magnetic Stirrer
7. Wash Bottle

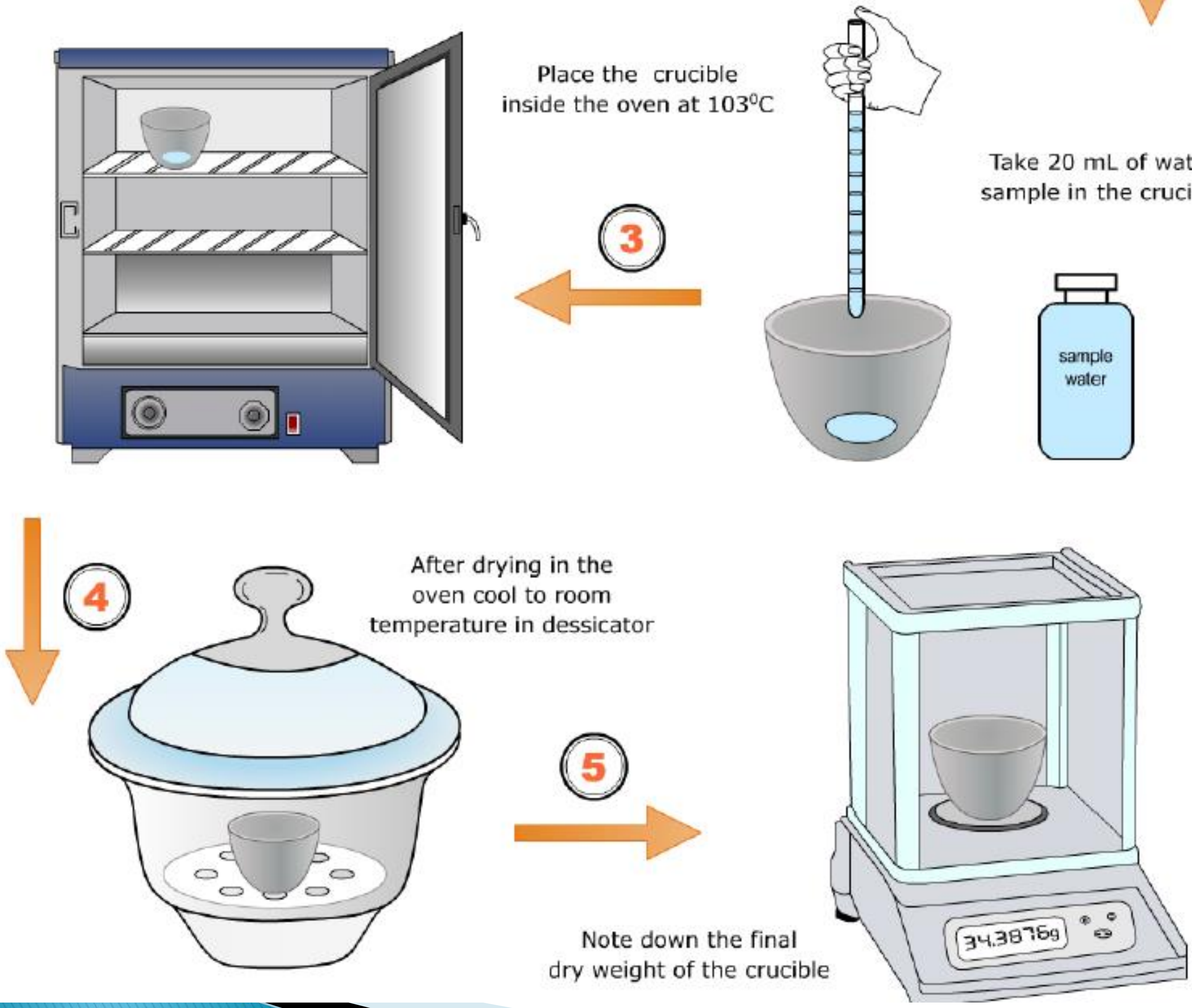


PROCEDURE CHART



Switch on the balance
(Atleast 30 min before
the test)

Notedown the initial
dry weight of the crucible

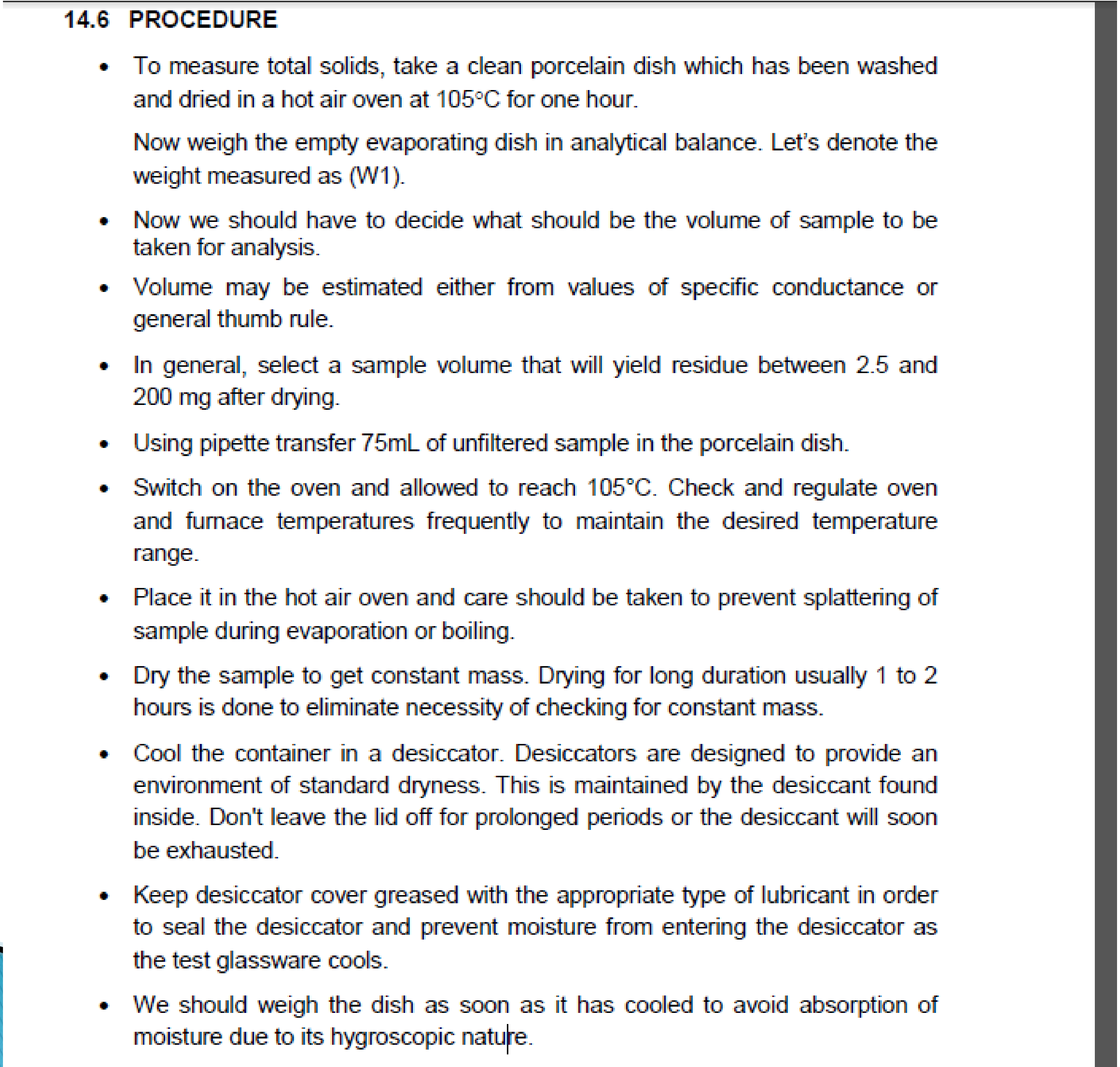


Take 20 mL of water sample in the crucible

Place the crucible inside the oven at 103°C

After drying in the oven cool to room temperature in dessicator

Note down the final dry weight of the crucible



14.6 PROCEDURE

- To measure total solids, take a clean porcelain dish which has been washed and dried in a hot air oven at 105°C for one hour.

  Now weigh the empty evaporating dish in analytical balance. Let's denote the weight measured as (W1).
- Now we should have to decide what should be the volume of sample to be taken for analysis.
- Volume may be estimated either from values of specific conductance or general thumb rule.
- In general, select a sample volume that will yield residue between 2.5 and 200 mg after drying.
- Using pipette transfer 75mL of unfiltered sample in the porcelain dish.
- Switch on the oven and allowed to reach 105°C. Check and regulate oven and furnace temperatures frequently to maintain the desired temperature range.
- Place it in the hot air oven and care should be taken to prevent splattering of sample during evaporation or boiling.
- Dry the sample to get constant mass. Drying for long duration usually 1 to 2 hours is done to eliminate necessity of checking for constant mass.
- Cool the container in a desiccator. Desiccators are designed to provide an environment of standard dryness. This is maintained by the desiccant found inside. Don't leave the lid off for prolonged periods or the desiccant will soon be exhausted.
- Keep desiccator cover greased with the appropriate type of lubricant in order to seal the desiccator and prevent moisture from entering the desiccator as the test glassware cools.
- We should weigh the dish as soon as it has cooled to avoid absorption of moisture due to its hygroscopic nature.

14.7 CALCULATION

Initial weight of the Crucible **(W_1)** = ………… g
Final weight of the Crucible + sample (**W_2**) = ………… g
Weight of residue **(W)** = $W_2 - W_1$ g

Amount of total solids present in the sample = $\frac{1000 * 1000w}{v}$

W = weight of total residue in (mg). (Therefore multiply W with 1000)

V = Volume of the sample (mL)(To convert mL to L)

=…………..mg/L

The readings are required to be tabulated.

14.7.1 TABLE

Description		Weight (g)

Description		Weight (g)
Initial Weight of the Crucible (g)	W_1	35. 4323
Final Weight of the Crucible + sample (g)	W_2	35. 4739
Weight of residue(g)	W	0. 0416
Volume of the Sample (mL)	V	75. 0
Total Solids (mg/L)	**TS**	**555.0**

Specimen Calculation:

W_1 = 35. 4323 g
W_2 = 35. 4739 g
V = 75. 0 mL

Weight of residue (g) W = W_2 - W_1
= 35. 4739 - 35. 4323
= 0. 0416 g

Weight of residue in mg (To convert W (g) to W (mg), multiply W (g) with 1000)
W (mg) = 0.0416 x 1000
= 41.6mg

Multiply the weight of the dry solids (in mg) by 1,000 mL/L to convert the sample size from mL to L.

Total Solids (mg/L)
V = Volume of the sample (mL) (To convert mL to L, multiply by 1000)
=41.6 mg/75 mL = 0.555 mg/mL
= 0.555 mg/mL x 1,000 mL/L
= **555 mg/L**

Evaluation and Quick Problems

The determination of total solids in wastewater gives an idea about

a) the foulness of the sewage
b) pH of the sewage
c) temperature of the sewage
d) colour of the sewage

The evaporating dishes needs to be cleaned and dried at ________ to remove the existing organic content.

a) 100° C
b) 250° C
c) 450° C
d) 550° C

Sewage contains about 99% of ______.

a) water
b) solids
c) clay
d) microbes

The sewage contain

a) suspended and dissolved solids.
b) no solids
c) only dissolved solids
d) only suspended solids

. The major dissolved substances in natural water are comprised of

a) iron, manganese, silica and nitrate
b) calcium, magnesium, sodium, bicarbonate, sulfate and chloride
c) all anions
d) all cations

The hard water

a) is corrosive
b) forms scales
c) is tasteless
d) is costly

The hard water consumes more soap for cleaning purposes.

a) True
b) False

1.0 Suspended Solids

Use

Important parameter in wastewater

Used to measure the quality of wastewater influent and effluent as well as monitor treatment processes

Typical SS Values

- **Marine waters** 5-80mg/L
- **River waters** 0-200mg/L,
- **Stormwaters** 80-100mg/L,
- **Raw sewage** 200-350mg/L,
- **Treated sewage** 100-200mg/L,

2.0 Turbidity

Test for turbidity is often performed of natural bodies and potable water rather than SS. Nature of solids and secondary effect is of greater importance

Turbidity is a measure of the extent to which light is absorbed or scattered by suspended material. f(size and surface characteristics of suspended material)

2.0 Turbidity

1 Sources:

- Erosion of clay, silts, rock fragments and metal oxides
- Vegetable fiber and microorganisms
- Soaps, detergents and emulsifying agents

2 **Impact**

- Aesthetically displeasing
- Creates adsorption sites for chemicals that cause taste and odor
- Shield organisms from disinfection
- Interfere with light penetration in streams and lakes

2.0 Turbidity

Measurement

-Standard electric bulbs produce a light directed through the sample.

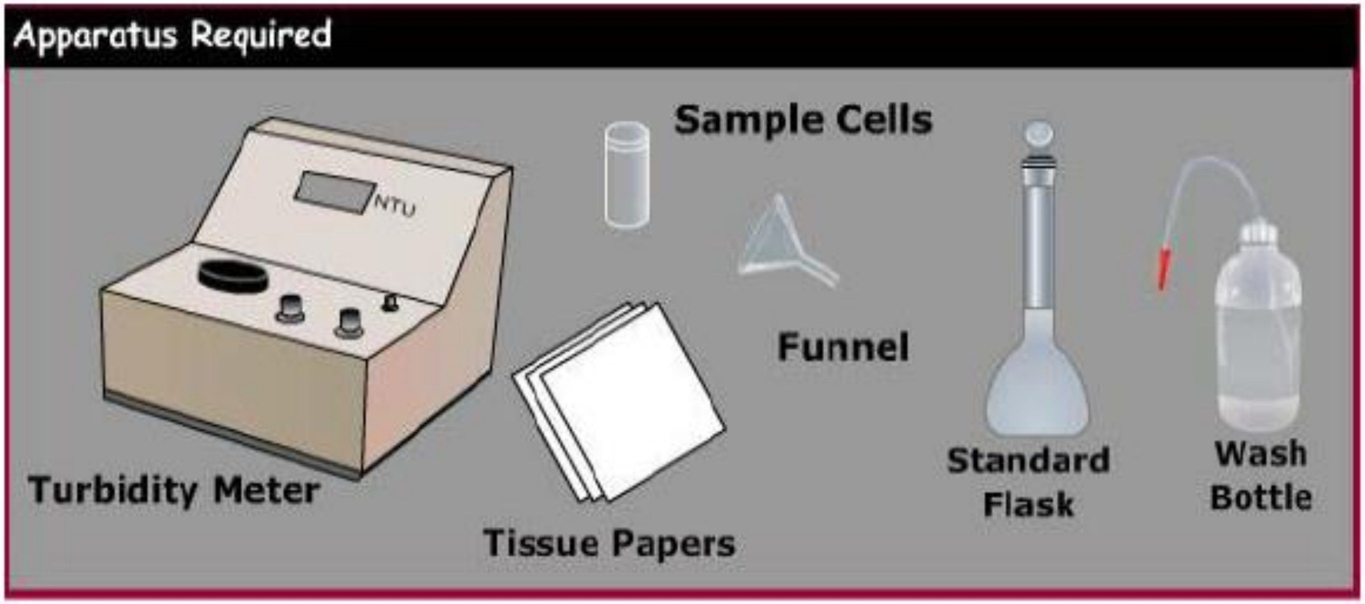
In absorption mode light passing through the sample is measures

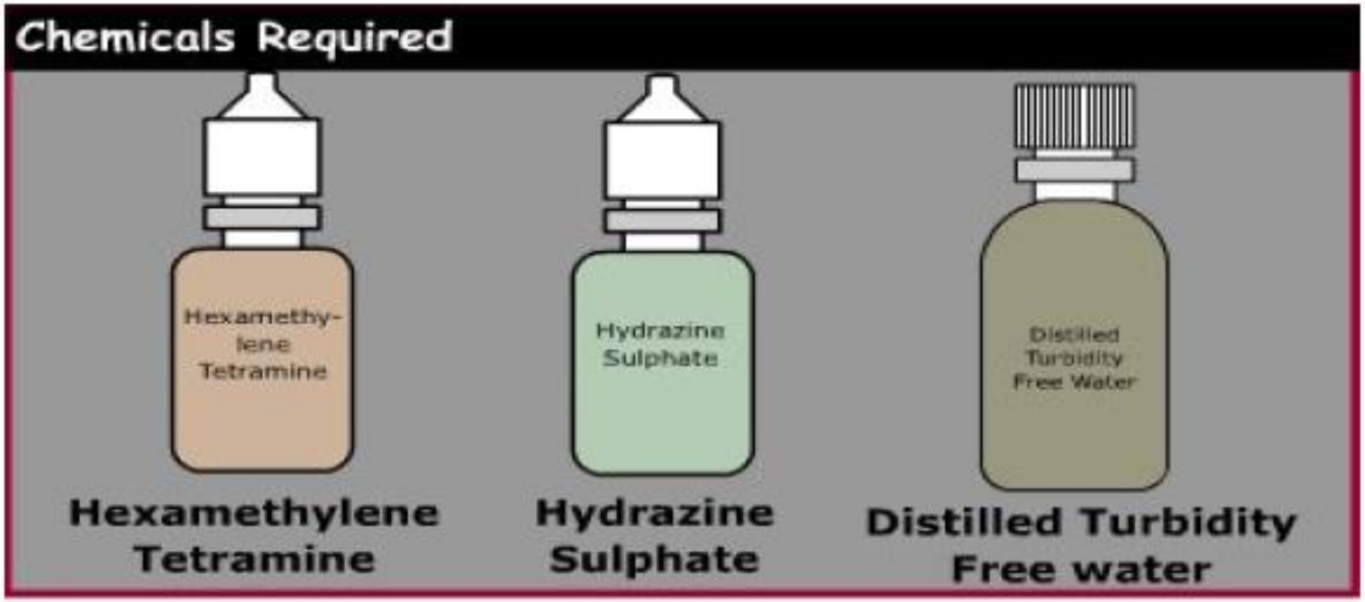
*In scattering mode light a*t 90 degrees is *measured.*

Turbidity readings are measured in FTU where F refers to the standard *Formazin*

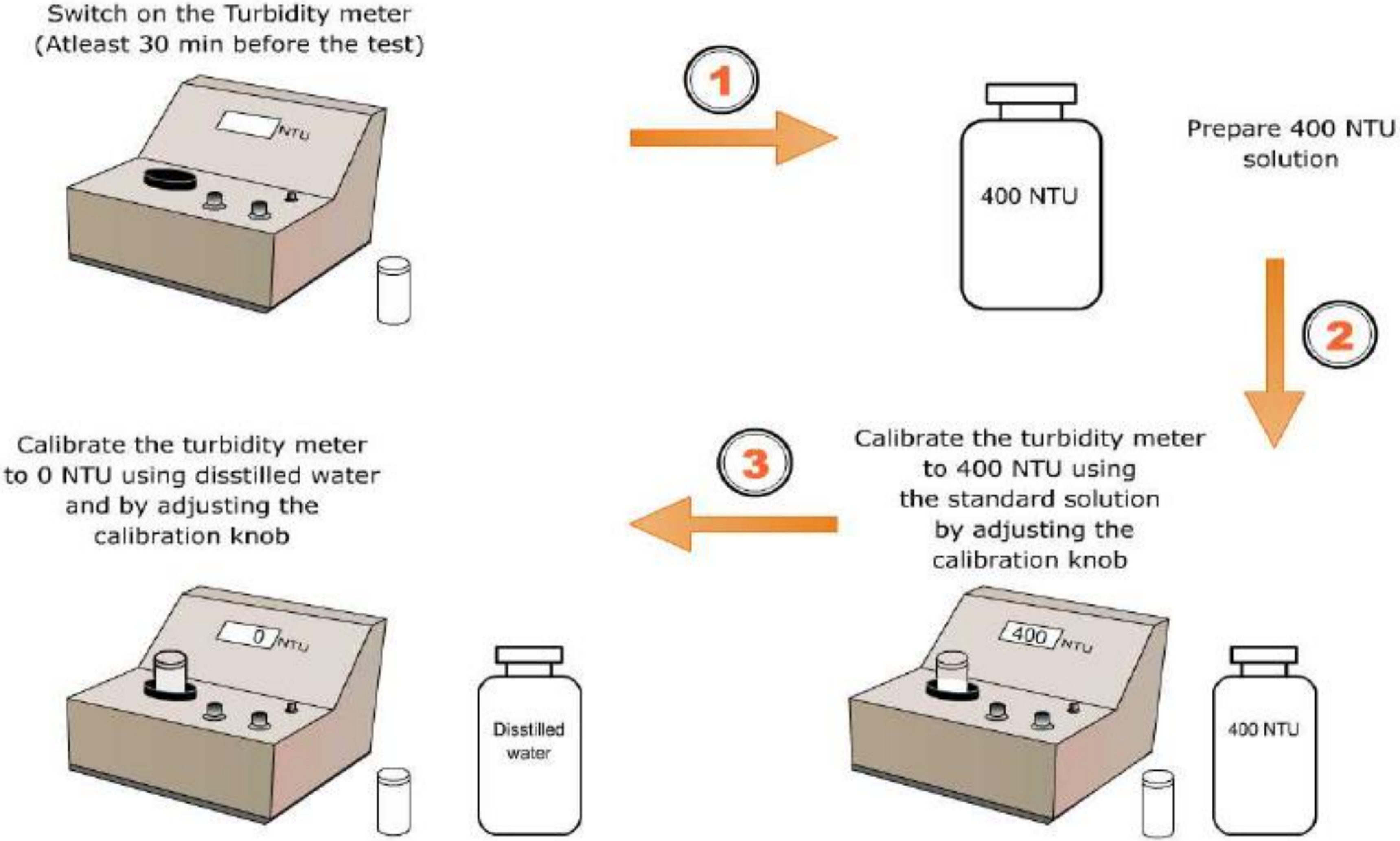
NTU – Nephelometry Turbidity Unit – used to indicate the test is run according to scattering principle

EPA – Standard for drinking water is 1 FTU


Apparatus Required
NTU
Sample Cells
Funnel
Turbidity Meter
Tissue Papers
Standard Flask
Wash Bottle


Chemicals Required
Hexamethy-lene Tetramine
Hydrazine Sulphate
Distilled Turbidity Free Water
Hexamethylene Tetramine
Hydrazine Sulphate
Distilled Turbidity Free water

PROCEDURE CHART

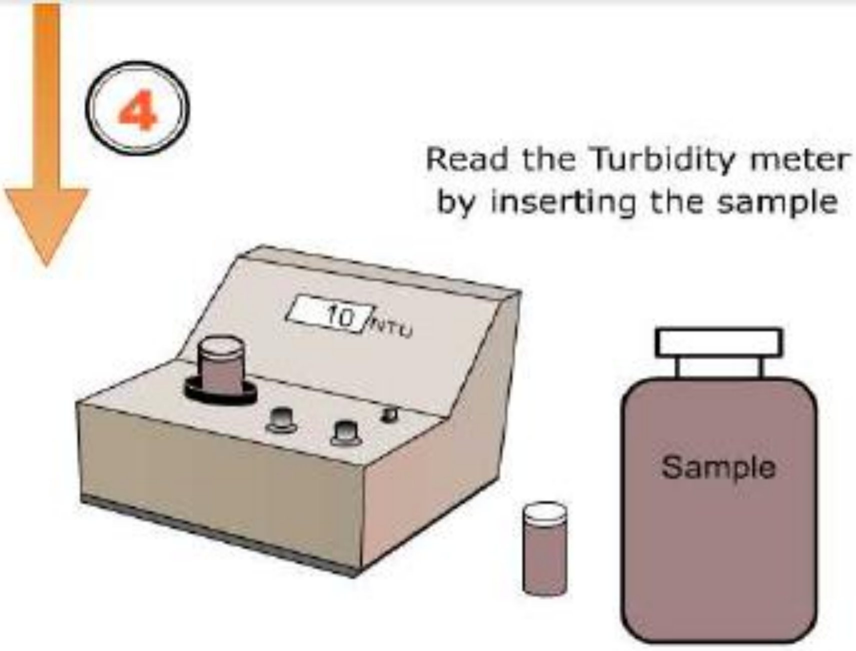


Switch on the Turbidity meter
(Atleast 30 min before the test)

Prepare 400 NTU solution

Calibrate the turbidity meter to 400 NTU using the standard solution by adjusting the calibration knob

Calibrate the turbidity meter to 0 NTU using disstilled water and by adjusting the calibration knob



Read the Turbidity meter
by inserting the sample

2.6.1 PREPARATION OF REAGENTS

1. Hydrazine Sulphate

- Weigh accurately 1 g of hydrazine sulphate and dissolve it in turbidity free distilled water.
- Take 100 mL standard measuring flask and place a funnel over it.
- Transfer it to a 100 mL standard flask and make up to 100 ml using turbidity free distilled water.

2. Hexamethylene Tetramine

- Weigh accurately 10 g of Hexamethylene tetramine and dissolve it in turbidity free distilled water.
- Take 100 mL standard measuring flask and place a funnel over it.
- Transfer it to a 100 mL standard flask and make up to 100 ml using turbidity free distilled water.

3. Standard 4000 NTU Solution

- Mix 5 mL of hydrazine sulphate solution and 5 mL of Hexamethylenetetramine solution in a 100 mL standard measuring flask.
- Allow the mixture to stand for 24 hours.
- After 24 hours, make up the volume to 100 mL using turbidity free distilled water.
- The standard 4000 NTU solution is ready.

3.0 Colour

Colour

Apparent Colour
Colour that is partly due to suspended matter

True Colour (water treatment)
Colour that is contributed by dissolved solids after removal of SS

3.0 Colour

- **Sources**

1. Leaves, wood etc – pick up tannins, humic acid leading to yellowish-brown colour
2. Iron oxides – reddish
3. Manganese Oxides – brown of blackish
4. Industrial Waste – textile and dyeing operations, pulp and paper production, food processing, chemical production, mining, refining and slaughter house operations

3.0 Colour

- **Impact**

\- Aesthetically displeasing

\- Not suitable for many operations as textile and paper production

\- True colour can exert a chlorine demand

- **Measurement**

Colour comparison with a series of standard colour materials after apparent colour is removed.

Units of measurement – TCU (true colour units)

For colours with yellowish-brown hues special spectrophotometric techniques are used

Note: Smaples should be measured within 72 hrs to avoid biological and physical changes

4.0 Taste and Odor

Taste & Odor are closely related. Substances that produce an odor in water often impart taste. The reverse is not often true.

- **Source:**

-Metals, minerals, salts form soil

-End products from biological reactions

-Inorganic produce taste e.g. Alkaline – bitter taste; metallic salts impart salty or bitter taste

-Organics produce taste and odor – e.g. Petroleum-based products; biological decomposition of organics (sulphur – rotten egg smell); Synergistic effect of chlorine and organics

4.0 Taste and Odor

- **Impact**
  - Aesthetically displeasing (associate odor and taste with contamination)

Measurement

Assignment

5.0 Temperature

One of the most important parameters in natural surface waters. It influences the number and type of species present and their rate of activities; effect most chemical reactions; affect solubility of gases e.g oxygen decrease with increase temp. 8mg/L @ 25 degree Celsius

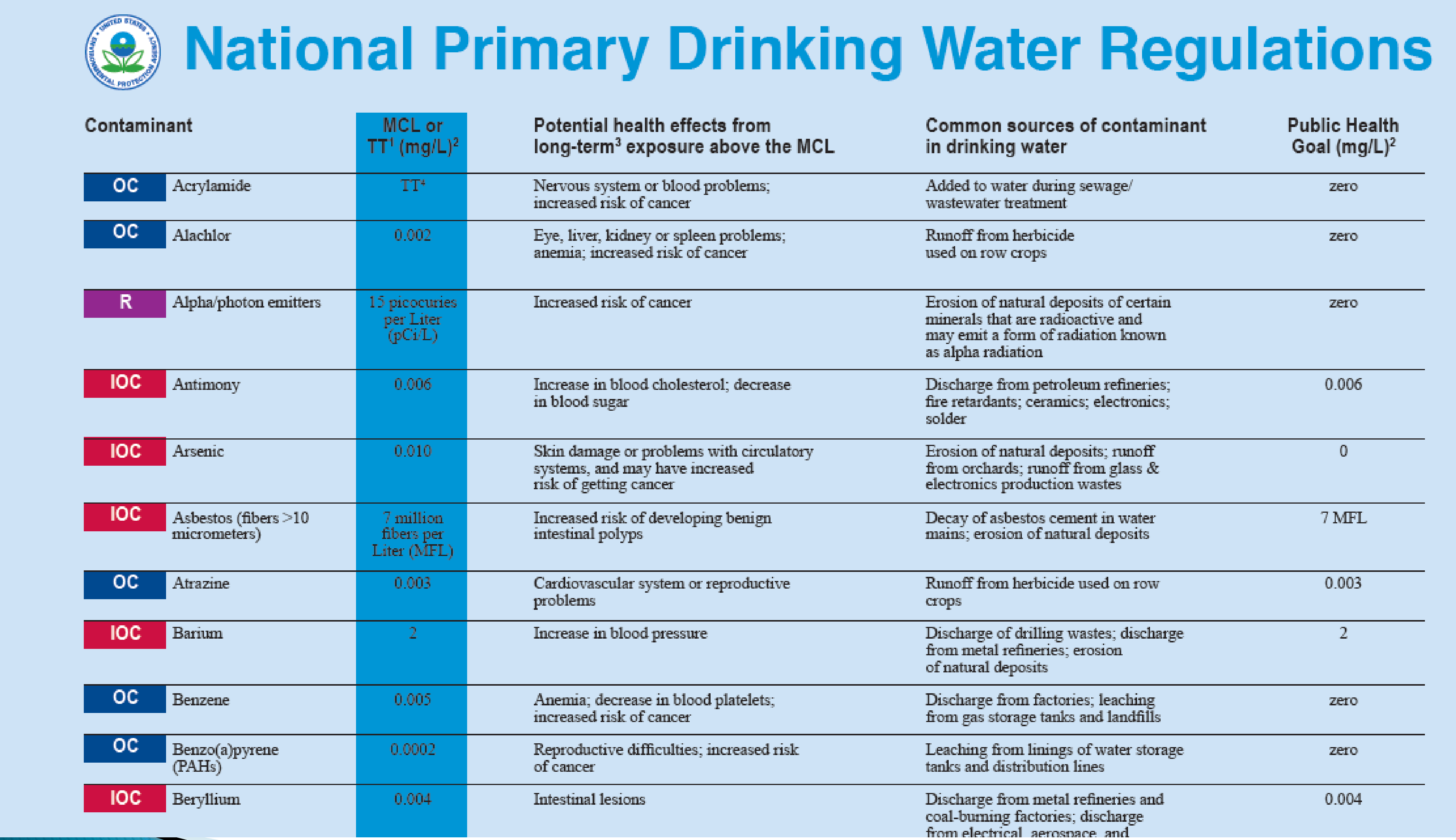
- **Sources**

-Influence by ambient temperatures i.e. surrounding atm. Shallow water bodies experience greater changes

- Dissipation of waste heat by industries
- Removal of forest canopy

5.0 Temperature

- **Impacts**
- Cooler waters have wider diversity of biological species
- Biological activities reduces at lower temperature i.e. utilization of food; growth; reproduction
- Increase of 10 degree Celsius can result in double activities– Accelerated growth of algae leading to cell clusters in mats. Secretion of oils and dead algal cells impart taste and odor
- Reduction in oxygen levels affect fishes
- Increase viscosity with decrease temperature
- Maximum density occur at 4 degree Celsius. – density and temperature affect planktonic MO



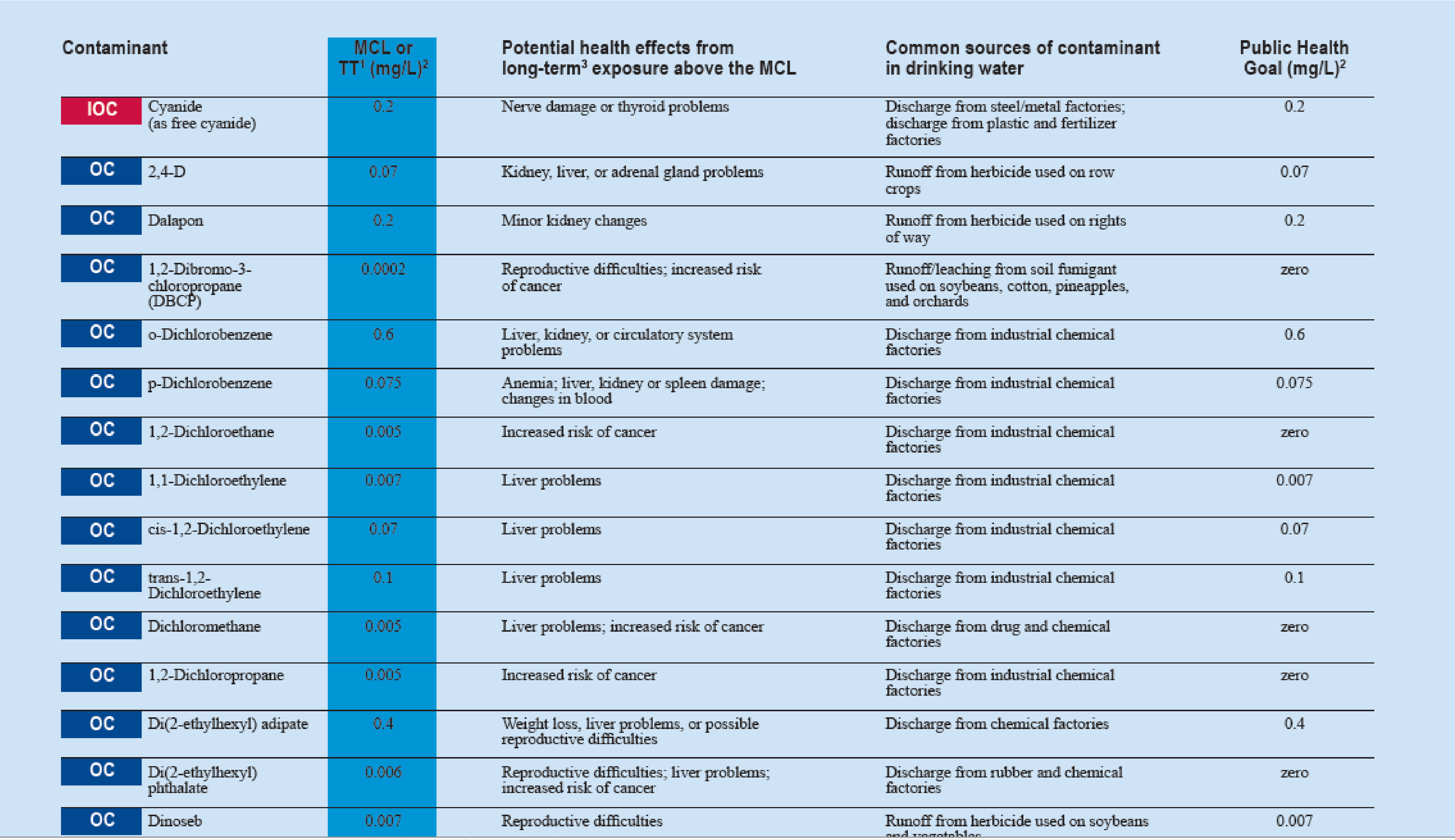
National Primary Drinking Water Regulations

Contaminant		MCL or TT[1] (mg/L)[2]	Potential health effects from long-term[3] exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L)[2]
OC	Acrylamide	TT[4]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/ wastewater treatment	zero
OC	Alachlor	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops	zero
R	Alpha/photon emitters	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	zero
IOC	Antimony	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006
IOC	Arsenic	0.010	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards; runoff from glass & electronics production wastes	0
IOC	Asbestos (fibers >10 micrometers)	7 million fibers per Liter (MFL)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 MFL
OC	Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops	0.003
IOC	Barium	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits	2
OC	Benzene	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills	zero
OC	Benzo(a)pyrene (PAHs)	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines	zero
IOC	Beryllium	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and	0.004

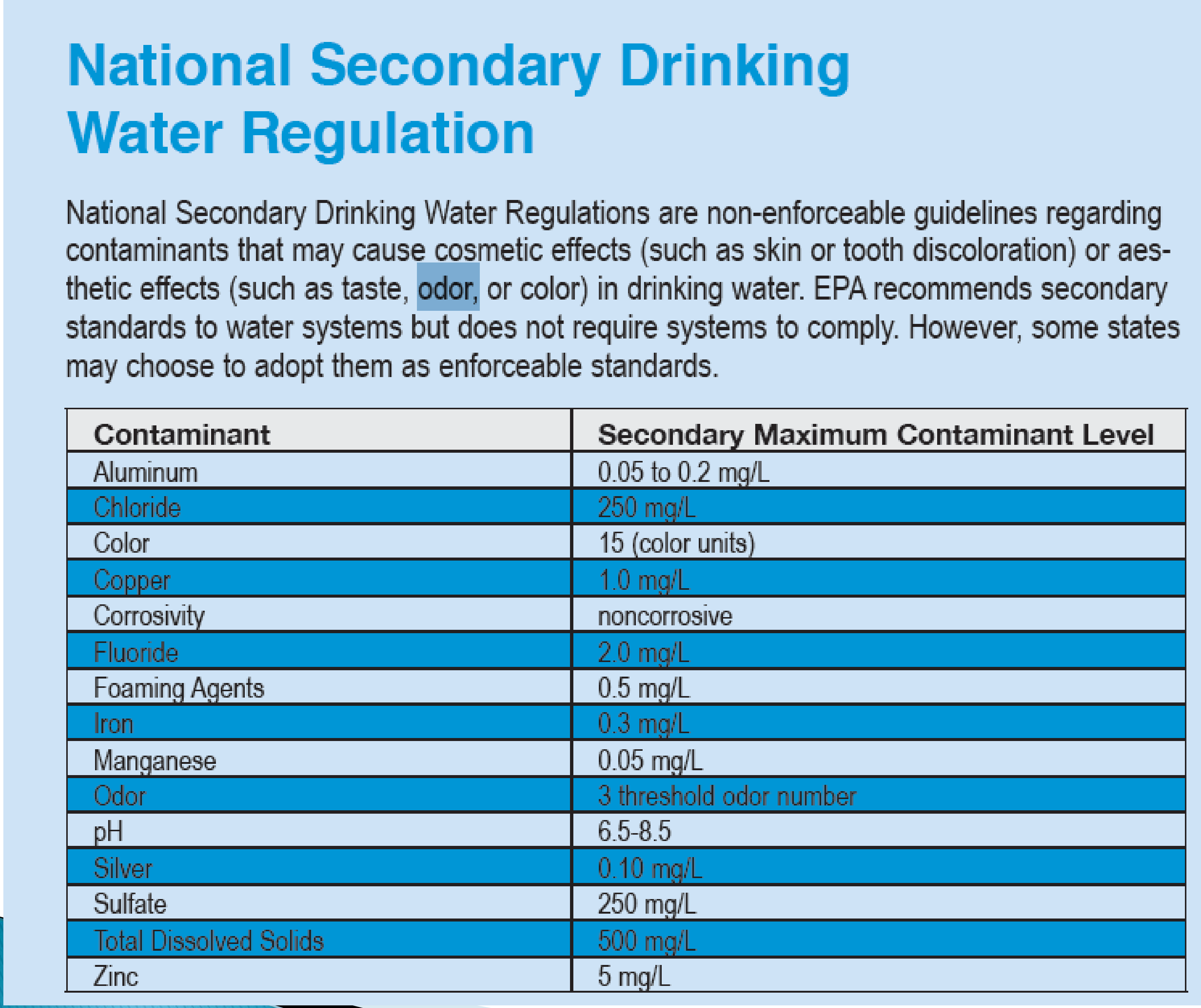
OC	Carbofuran	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa	0.04
OC	Carbon tetrachloride	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities	zero
D	Chloramines (as Cl_2)	MRDL=4.0^1	Eye/nose irritation; stomach discomfort; anemia	Water additive used to control microbes	MRDLG=4^1
OC	Chlordane	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide	zero
D	Chlorine (as Cl_2)	MRDL=4.0^1	Eye/nose irritation; stomach discomfort	Water additive used to control microbes	MRDLG=4^1
D	Chlorine dioxide (as ClO_2)	MRDL=0.8^1	Anemia; infants, young children, and fetuses of pregnant women: nervous system effects	Water additive used to control microbes	MRDLG=0.8^1
DBP	Chlorite	1.0	Anemia; infants, young children, and fetuses of pregnant women: nervous system effects	Byproduct of drinking water disinfection	0.8
OC	Chlorobenzene	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories	0.1
IOC	Chromium (total)	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits	0.1
IOC	Copper	TT^5; Action Level = 1.3	Short-term exposure: Gastrointestinal distress. Long-term exposure: Liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits	1.3
M	*Cryptosporidium*	TT^7	Short-term exposure: Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero

LEGEND

D	**Disinfectant**	IOC	**Inorganic Chemical**	OC	**Organic Chemical**
DBP	**Disinfection Byproduct**	M	**Microorganism**	R	**Radionuclides**



Contaminant		MCL or TT[1] (mg/L)[2]	Potential health effects from long-term[3] exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L)[2]
IOC	Cyanide (as free cyanide)	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories	0.2
OC	2,4-D	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops	0.07
OC	Dalapon	0.2	Minor kidney changes	Runoff from herbicide used on rights of way	0.2
OC	1,2-Dibromo-3-chloropropane (DBCP)	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards	zero
OC	o-Dichlorobenzene	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories	0.6
OC	p-Dichlorobenzene	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories	0.075
OC	1,2-Dichloroethane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC	1,1-Dichloroethylene	0.007	Liver problems	Discharge from industrial chemical factories	0.007
OC	cis-1,2-Dichloroethylene	0.07	Liver problems	Discharge from industrial chemical factories	0.07
OC	trans-1,2-Dichloroethylene	0.1	Liver problems	Discharge from industrial chemical factories	0.1
OC	Dichloromethane	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories	zero
OC	1,2-Dichloropropane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC	Di(2-ethylhexyl) adipate	0.4	Weight loss, liver problems, or possible reproductive difficulties	Discharge from chemical factories	0.4
OC	Di(2-ethylhexyl) phthalate	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories	zero
OC	Dinoseb	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables	0.007



National Secondary Drinking Water Regulation

National Secondary Drinking Water Regulations are non-enforceable guidelines regarding contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems but does not require systems to comply. However, some states may choose to adopt them as enforceable standards.

Contaminant	**Secondary Maximum Contaminant Level**
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

Environmental Engineering

Chemical Water-Quality Parameters

Dr. Ahmed N Bdour

Summary

Chemical Water-Quality Parameters

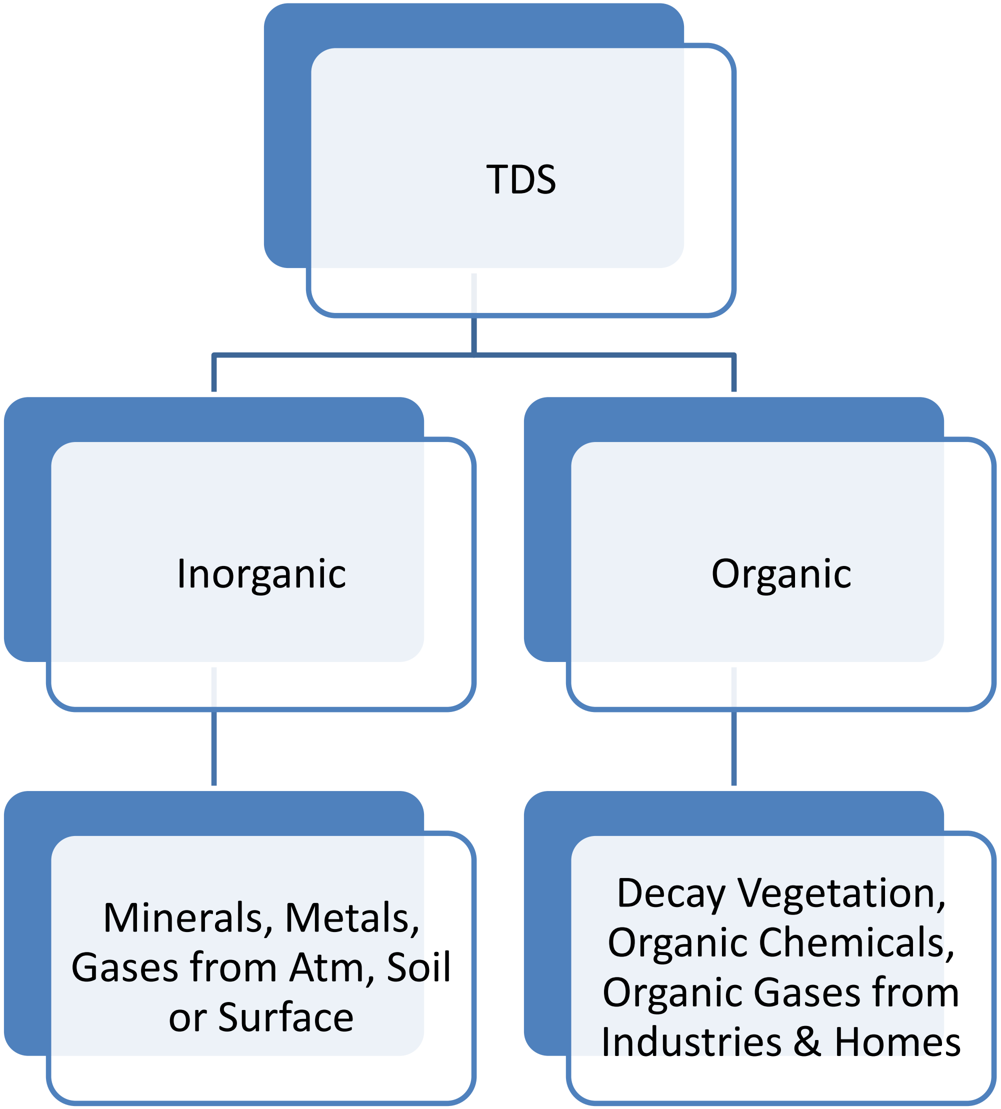
- Total Dissolved Solids
- Alkalinity
- Hardness
- Fluoride
- Metals
    - Nontoxic
    - Toxic

- Organics
    - Biodegradable
    - Nonbiodegradable
- Nutrients
    - Nitrogen
    - Phosphorus

Total Dissolved Solids

- **Sources**
- Impacts
- Measurements
- Use

Solvent action of water on solids, liquids and gases


TDS

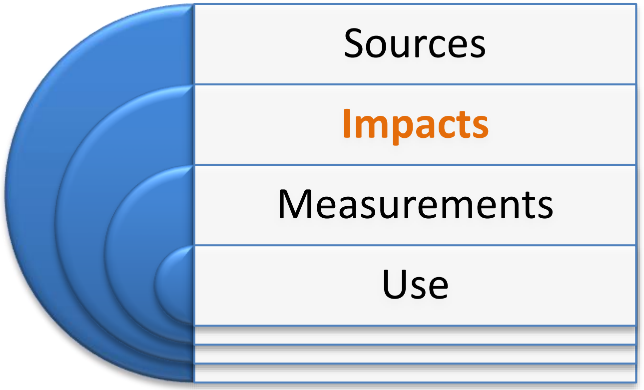
Inorganic

Organic

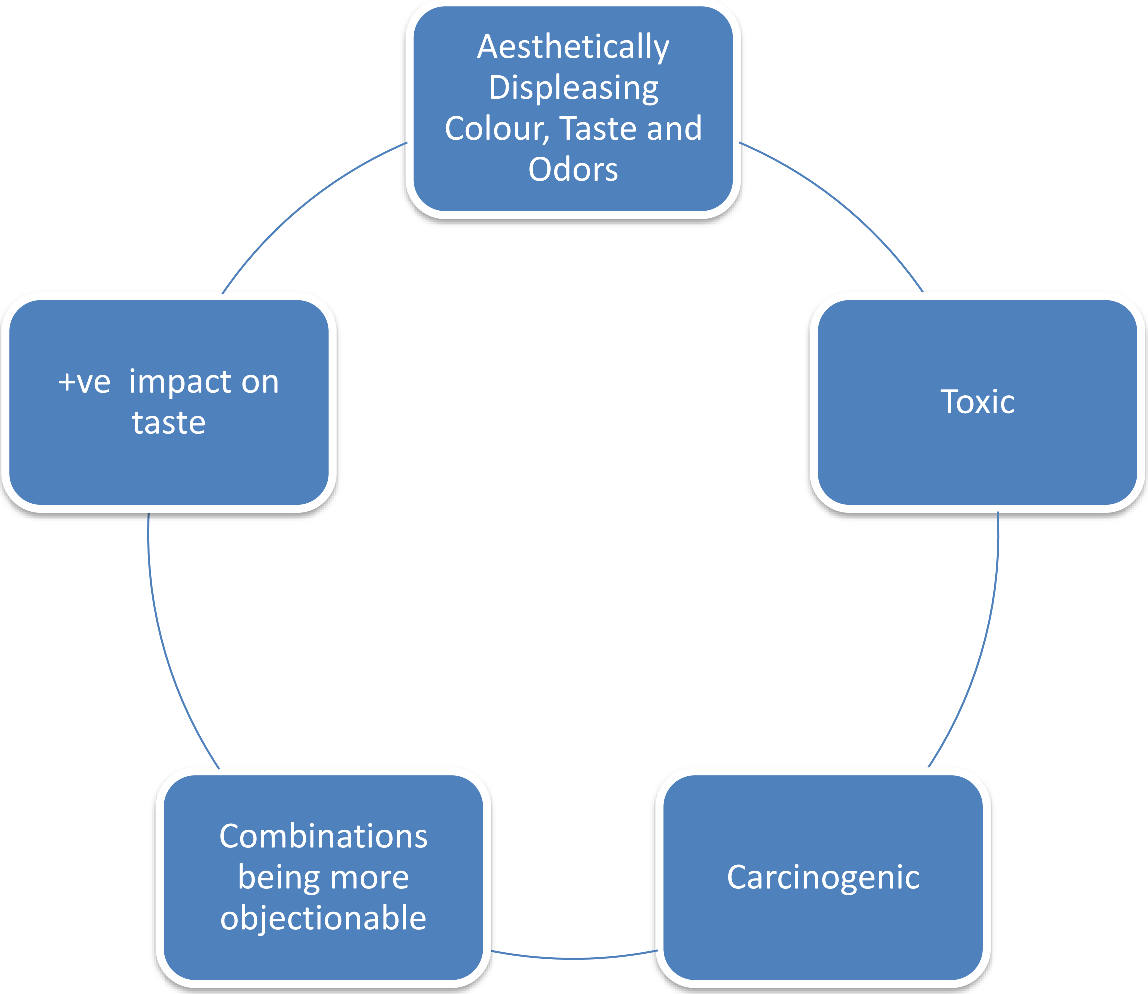
Minerals, Metals, Gases from Atm, Soil or Surface

Decay Vegetation, Organic Chemicals, Organic Gases from Industries & Homes

Total Dissolved Solids



- Sources
- **Impacts**
- Measurements
- Use



Aesthetically Displeasing Colour, Taste and Odors

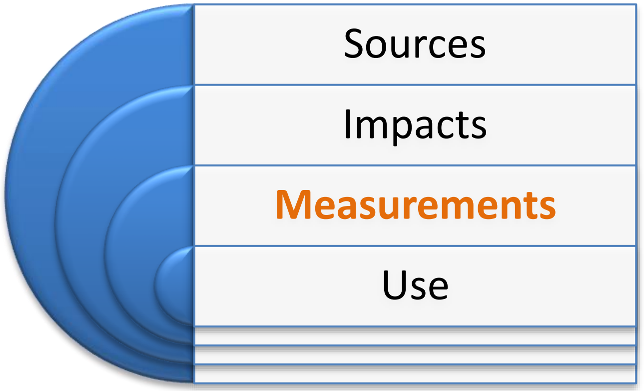
Toxic

Carcinogenic

Combinations being more objectionable

+ve impact on taste

Total Dissolved Solids



Sources

Impacts

Measurements

Use

- Evaporation as discussed earlier
- Approximated by determining the electrical conductivity of the water - specific conductance (SC) *milliSiemens per meter (mS/m)*

SC= *f (valence, mobility, relative number of ions, temperature)*

Specific conductance measures ionized substances ONLY.

Thus, SC and TDS are not related one to one. – Constant – 0.055 to 0.09

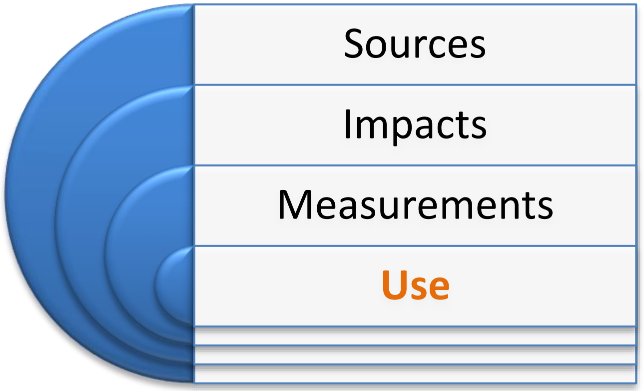
- SC is used qualitatively to monitor changes in streams and treatment processes

Total Dissolved Solids

Total dissolve solids does not make distinction among the constituents

Used in the measurement of water and wastewater as a gross measure of dissolved substances

Not often suitable for water intended for potable supply, agriculture and some industrial processes



pH

- Balance of H and OH ions in water. These ions have an electric charge

- Measuring pH is determining the balance between H and OH

- Most fish tolerate between 5-9
- Most natural lakes are alkaline and becomes acidic with time as organics decay resulting on CO_2 and thus carbonic acid

- Synergy – where two or more substances combine to produce effects greater than their sum
- E.g. 2 + 2 = 4 but synergistically, 2 + 2 is greater than 4. Synergy is mathematically impossible
- Normal pH values in sea water are about 8.1 at the surface and decrease to about 7.7 in deep water.

Alkalinity

Alkalinity – the quantity of ions in water that will react to neutralise hydrogen ions .

Alkalinity is not a pollutant. It is a total measure of the substances in water that have "acid-neutralizing" ability. Don't confuse alkalinity with pH.

Alkalinity is thus a measure of the ability of water to neutralize acids

pH measures the strength of an acid or base; alkalinity indicates a solution's power to react with acid and "buffer" its pH — that is, the power to keep its pH from changing.

To illustrate, we will compare two samples of pure water and buffered water. Absolutely pure water has a pH of exactly 7.0. It contains no acids, no bases, and no (zero) alkalinity. The buffered water, with a pH of 6.0, can have high alkalinity. If you add a small amount of weak acid to both water samples, the pH of the pure water will change instantly (become more acid). But the buffered water's pH won't change easily because the Alka-Seltzer-like buffers absorb the acid and keep it from "expressing itself."

Alkalinity

Sources

Impacts

Measurements

Use

Carbonates, Bicarbonates and Hydroxide compounds, Borates, silicates

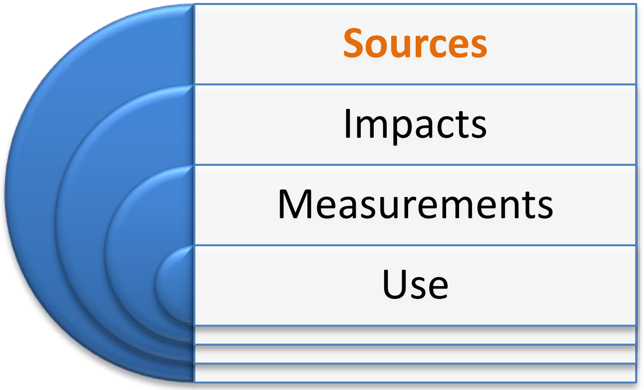
from

Dissolution of minerals from soil and atmosphere

Phosphates *from detergents in WW, fertilizers and insecticides from agricultural land*

Hydrogen Sulfide and ammonia *from microbial decomposition of organics*

Alkalinity



Sources

Impacts

Measurements

Use

Carbonates, Bicarbonates and Hydroxide compounds- most abundant

(1) CO_2 [free carbon dioxide] + H_2O <-----> H_2CO_3 [carbonic acid]

(2) H_2CO_3 <-----> H^+ + HCO_3^- [bicarbonate ion]

(3) HCO_3^- <-----> H^+ + CO_3^{-2} [carbonate ion]

(4) CO_3^{2-} + H_2O<-----> $HCO_3^{\,-}$ + OH^- + [Hydroxide]

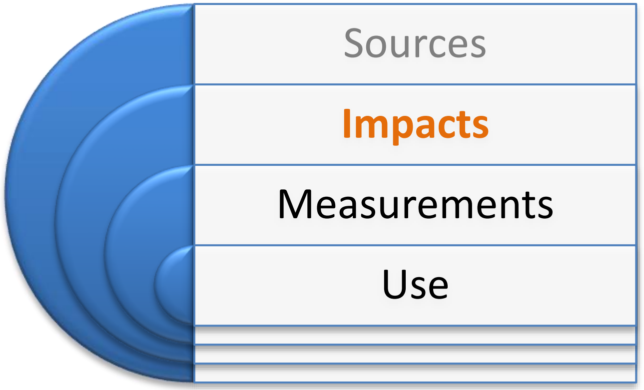
The bicarbonate ion can be used as a source of carbon for algae results in an increase in OH^- *ions = pH 9 to 10*

Relative quantity of alkalinity is pH dependent

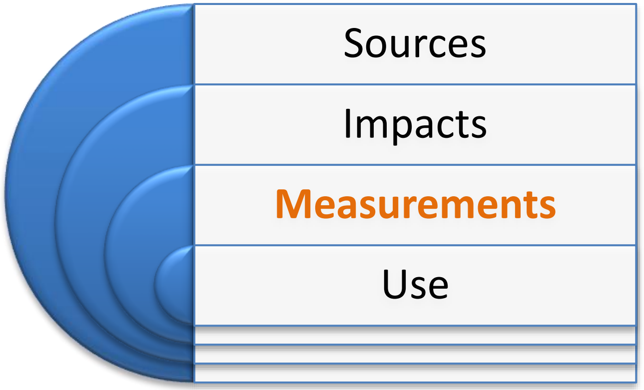
Alkalinity

Alkalinity imparts a bitter taste in large quantities

Reacts with many cations in water resulting in precipitates which foul pipes



Alkalinity



Sources

Impacts

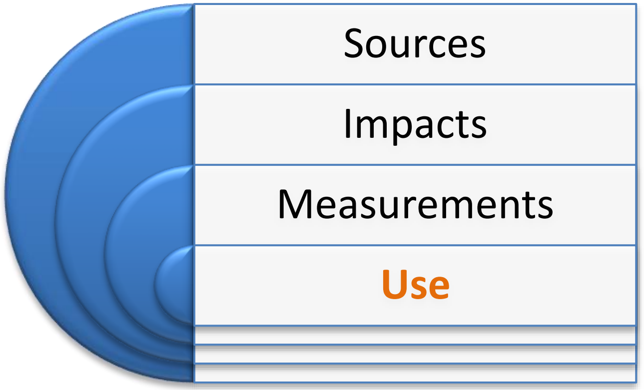
Measurements

Use

Titrating the water with an acid and determining the equivalent

Alkalinity is expressed as mg/L of $CaCO_3$

Every 1mL of 0.02N H_2SO_4 will neutralize 1mg of alkalinity as $CaCO_3$



Sources

Impacts

Measurements

Use

Use

- Alkalinity is important for fish and aquatic life because it protects or buffers against pH changes
- Variable in Water and WW Treatment
- makes water less vulnerable to acid rain

Hardness

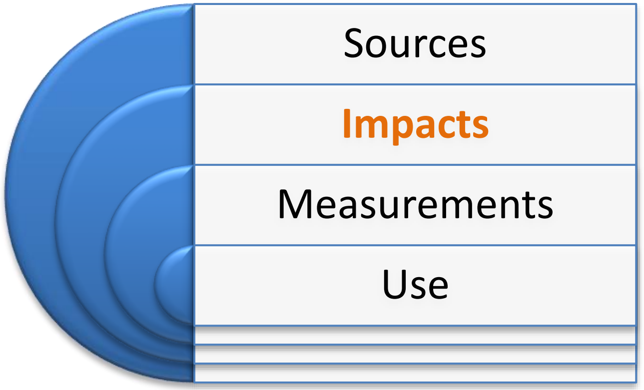
Sources
Impacts
Measurements
Use

- **Hardness is defines as the conc. of multivalent metallic cations in solution**

- **The major divalent cations of most natural waters are calcium (Ca^{+2}) and magnesium (Mg^{+2}).** Hardness is usually a measure of the sum of these two ions. Other divalent cations such as iron, manganese, strontium and aluminum may also contribute to hardness.

- Hardness is classified as Carbonate (equivalent to alkalinity) and non-carbonate hardness

Hardness



Sources

Impacts

Measurements

Use

- Sodium soap reacts with multivalent metallic cations to form a ppt., thereby loosing their surfactant properties. Thus representing an economic loss to water users

- Lathering only occur after all hardness ions have ppt. The water is then soft. The ppt adheres to surfaces. Boiler scales cause fouling of water heaters and hot water pipes.

- Magnesium hardness when associated with magnesium sulphate has a laxative effect

Hardness

- Sources
- Impacts
- **Measurements**
- Use

- Measurements are done by Spectrophotometric techniques or chemical Titration

- Sources
- Impacts
- Measurements
- **Use**

- Analysis for hardness is commonly made on natural waters and waters intended for potable use.

Soft	<50mg/L
Moderately Hard	50 – 150 mg/L
Hard	150 – 300 mg/L
Very Hard	> 300 mg/L

Note values expressed as CaCO3

Fluoride

- Fluoride is seldom found in appreciable quantities in surface water and appear in GW in only few geological regions

- Conc. Of 1.0 mg/L – help to prevent dental cavity
- Conc. >2.0mg/L results in discoloration of teeth
- Conc. > 5mg/L may cause bone fluorosis and skeleton abnormalities

- WHO recommended limit – 1.5 mg/L

Metal

- All Metals are soluble to some extent in water. Only metals that harmful in small quantities are considered toxic.
- Source- dissolution from natural deposits, domestic, industrial and agri discharges
- Measurements – AAS or Titration

Introduction

Non-Toxic Metal

Toxic Metals

- Calcium – *Previously discussed*
- Magnesium - *Previously discussed*
- Sodium – most common – health hazard in excessive amounts, corrosive
- Iron (0.3 mg/L) & Manganese (0.05)- small quantities cause colour problems; energy source for some bacteria
- Aluminum – low quantities natural waters
- Copper & Zinc – synergetic – when both are present in small amts, can be toxic to many biological species

Metal

Harmful to human and other organisms in small quantities

Introduction

Non-Toxic Metal

Toxic Metals

- Arsenic
- Cadmium
- Lead
- Mercury
- Silver
- Barium

Cumulative toxins. Conc. In the food chain thus posing a danger to organisms near the top of the chain

Organics

Many organics are soluble in water

Source of Organics ;

1) natural sources – decay products of organic solids
2) human activity- WW discharge or Agri practices

Dissolved organics are divided into;

1) Biodegradable
2) Non-biodegradable

Introduction

Biodegradable

Non-biodegradable

Biodegradable Organics

Organics that can be utilized for food by naturally occurring MO, within a reasonable length of time. E.g. Starches; fats; protein; alcohols; acids; aldehydes; esters.

Microbial Utilization can be accompanied by–

1. **Oxidation** (Addition of Oxygen or removal of Hydrogen) or

2. Reduction – (Addition of Hydrogen or removal of Oxygen)

NOTE: Both can occur simultaneously, but if Oxygen is present it dominates

Organics

- Introduction
- **Biodegradable**
- Non-biodegradable

Biodegradable Organic Processes
Aerobic – (oxygen present) – end products are stable and acceptable
Anaerobic – (oxygen absent) – end products are unstable and objectionable

The oxygen-demanding nature of biodegradable organics is most important in natural water systems. If oxygen utilization is more rapid than replenishment from say Atm, then anaerobic conditions result.

The amt of oxygen consumed during microbial utilization of organics is called *Biochemical Oxygen Demand (BOD).*

BOD – is measured by determining the oxygen consumed from a sample placed in an air tight 300mL bottle and incubated at 20° C for 5 days
NOTE : light must be excluded to prevent algal growth = production of oxygen

Organics

Introduction

Biodegradable

Non-biodegradable

Sample must be diluted with organic free oxygen saturated water.
Note: Sat conc. For oxygen @ 20 degrees approx. 9mg/L

BOD of Diluted Sample, $BOD = DO_I – DO_F / P$

Where DO_I and DO_F are the initial and final dissolved oxygen conc. (mg/L) and P is the decimal fraction of the sample in the 300 mL bottle.

NOTE: Final DO must not be less than 2 or more than 7 for reliable results

Work example

Organics

Introduction

Biodegradable

Non-biodegradable

Non biodegradable -

Some organic materials are resistant to degradation. Woody plants - E.g. Tannic and lignic acid, cellulose and phenols, They degrade so slowly, that they are considered refractory.

Molecules with exceptionally strong bond – polysaccharides; benzene e.g. Alkayl benzene sulfonate ABS causes frothing and foaming WWTP

Organics that are toxic to MO – organic pesticides (cumulative toxins); industrial chemicals, hydrocarbon that have combined with chlorine.

e.g. -Organic insecticides are usually chlorinated hydrocarbons – aldrin, dieldrin

- Herbicides – 2,4-dichlorophenoxyacetic acid

Organics

Measurement

Non-biodegradable organics is measured by the Chemical Oxygen Demand , COD or the Total Organic Carbon analysis, TOC.

TOC and COD also measures the biodegradable organics therefore, the BOD must be subtracted.

Non -biodegradable Organics = COD or TOC - BOD

Nutrients

Introduction

Nitrogen

Phosphorus

Nutrients are essential to the growth and reproduction of plants and animals and aquatic species. Those required in most abundance by aquatic species is : Carbon; Nitrogen and Phosphorus

Carbon is readily available from many sources e.g. Atm; alkalinity; decay products of organic matter. Nitrogen and Phosphorus are usually limited. Human activity has resulted in excess N and P

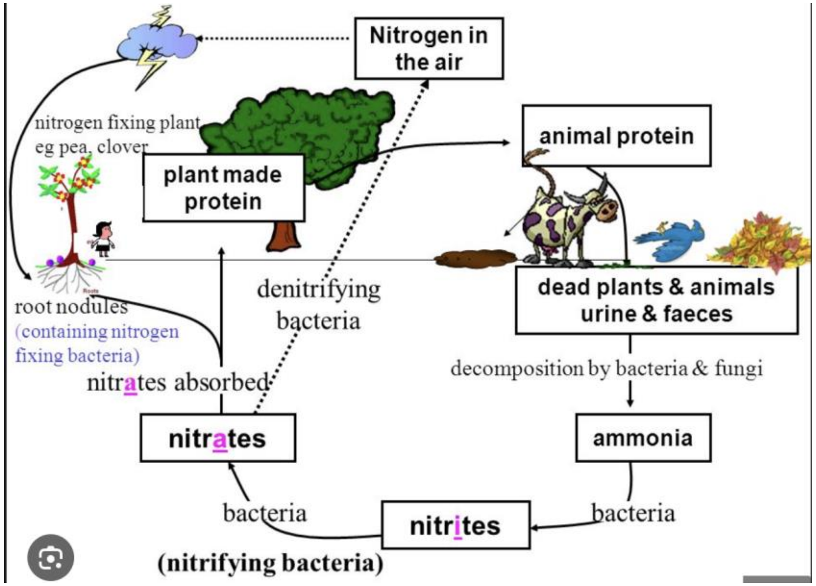
Nitrogen

Sources

1. Nitrogen is a constituent of proteins, chlorophyll and many biological compounds.

These are broken down into simple forms upon death of plants and animals by bacteria. E.g. Protein – amino acid - ammonia (NH3) – Nitrite NO2-(if oxygen is present oxidized) – Nitrate $NO3^{-}$ – reconstituted into living organic matter by photosynthesis.

- This involves two oxidation processes
- The ammonia produced by ammonification is first converted to nitrite (by bacteria):
  - $NH_3 + 1^1/_2O_2 \rightarrow NO_2^- + H_2O$
- The nitrite is then converted to nitrate (by bacteria):
  - $NO_3^- + {}^1/_2O_2 \rightarrow NO_3^-$



Nutrients

2. Other sources include animal waste, chemical fertilizers and WW discharges in the form of ammonia and ammonium

Impact

-These can be oxidized to nitrates by soil bacteria. Oxidation of ammonia and ammonium too nitrite and nitrate results in an increase COD.

-Nitrate poisoning – nitrite causes oxygen starvation

-Algal Bloom

Measurements

Test for ammonia and organic nitrogen is done on WW; Test for nitrate on clean-water samples and treated WW

Nutrients

- Introduction
- Nitrogen
- **Phosphorus**

Sources

Like nitrogen, phosphates pass through the cycle of decomposition and photosynthesis. It is used extensively in fertilizers, a constituent of animal waste. Agri runoff is the major source as well as municipal WW. Phosphates are used in detergents and in industries (boiler water conditioning – removal of calcium)

Impact

-In great quantities, phosphate causes rapid growth of aquatic plants

- Affects WT systems – interfere with chemical coagulation

Chemical concepts

Review

DEFINITIONS

- Atomic Weight: is the weight of an element when compared to Carbon (Carbon atomic weight is 12)
    - Atomic weight of Calcium (Ca) is equal to 40 g or (g/mole)
- Molecular weight of a compound (MW): is the sum of the atomic weights of the combined elements
    - For Calcium Carbonate ($CaCO_3$), MW = 40+12+3(16)=100 g/mole
- Valence: is the combining power of the element when compared to Hydrogen (Hydrogen has a combining power of 1)
    - For example Calcium (Ca^{+2}) has a valence of +2, Na^+ has a valence of +1
- Equivalent Weight of an element = Atomic Weight / Valence
    - Equivalent weight of Ca^{+2} = 40 (g/mole) / 2 (eq/mole) = 20 (g/eq)

      or, Ca^{+2} = 40 g / 2 = 20 g

DEFINITIONS

- Equivalent weight of a compound: is that weight of the compound which contains 1 gram atom of available hydrogen or its chemical equivalent.
  - Equivalent weight = Molecular weight / Z,

    where Z is an number whose value depends on the chemical context (reaction). Usually, it is the number of available protons (H^+) or (OH^-).
  - For Acids: Z is equal to the moles of H^+ obtained from 1 mole of acid.

    for example Z=2 for H_2SO_4 (because this acid contains 2 moles of H^+)

    Its equivalent weight = $(2\times1 + 32 + 4\times16) / 2 = 49$ g or (g/eq)
  - For base: Z is equal to the number of moles of H^+ with which 1 mole of base will react. For $Ca(OH)_2$, $Z = 2$
  - For salts: Z is the oxidation or valence state of the ion.

    for $Al_2(SO_4)_3$, Z=6 because $2Al^{+3}$ is equivalent to 6 moles of H^+.

Concentration Units

- milligram per liter (mg/l)
  - Weight of solute per volume of solution
- part per million (ppm)
  - When the specific gravity is unity, 1 mg/l is equal to ppm.
- kilograms per million liters
  - Chemical doses are usually expressed in kilograms per million liters or pounds per million gallons.
- milliequivalents per liter (meq/l) = [(mg/l) / eq weight]
  - Example: the concentration $CaCO_3$ in a water sample is 76 mg/l. Express the concentration in meq/l.
  - Solution: eq. wt. of $CaCO_3$ = MW/Z = 100/2 = 50 eq

    conc. in (meq/l) = 76/50 = 1.52 meq/l

Concentration Units

- Expressing Hardness, Alkalinity, and others
  - Hardness and Alk are due to different ions, therefore, they are expressed in unit weights of $CaCO_3$ in order to facilitate for computations.
  - The following equation can be used to express concentration as $CaCO_3$:

$$\text{mg/l as CaCO}_3 = [\text{mg/l of substance}] \times \left[\frac{\text{eq. wt. CaCO}_3}{\text{eq. wt of substance}}\right]$$

  - Example: The concentration of $Ca(HCO_3)_2$ was found to be 60 mg/l. Express the concentration in unites as $CaCO_3$.

    Solution: eq. wt. of $Ca(HCO_3)_2$ = MW/Z = 162/2 = 81g.

    conc. as $CaCO_3$ = 60mg/l (50/81) = 37.0 mg/l as $CaCO_3$.

2.38 While visiting Zagreb, Croatia, Mr. Arthur Van de Lay visits the Mimara Art Museum and then takes in the great architecture of the city. He stops at a café in the old town and orders a bottle of mineral water. The reported chemical concentration of this water is: $[Na^+] = 0.65$ mg/L, $[K^+] = 0.4$ mg/L, $[Mg^{2+}] = 19$ mg/L, $[Ca^{2+}] = 35$ mg/L, $[Cl^-] = 0.8$ mg/L, $[SO_4^{2-}] = 14.3$ mg/L, $[HCO_3^-] = 189$ mg/L, $[NO_3^-] = 3.8$ mg/L. The pH of the water is 7.3. (a) What is the hardness of the water in mg/L $CaCO_3$? (b) Is the chemical analysis correct?

Solution:

a) To determine the total hardness of a water sample, identify all the divalent cations, convert to units of mg/L as $CaCO_3$, then sum up to find the total hardness.

$$Ca^{2+} = 35\ mg/L \times \frac{100\ g/2\ eqv}{40.1\ g/2\ eqv} = 87\ mg/L\ as\ CaCO_3$$

$$Mg^{2+} = 19\ mg/L \times \frac{100\ g/2\ eqv}{24.3\ g/2\ eqv} = 78\ mg/L\ as\ CaCO_3$$

Total hardness = 87 + 78 = 165 mg/L as $CaCO_3$

2.43 Reverse osmosis is used to treat brackish groundwater water and requires 1 kWh of energy per 1 m^3 of treated water. In comparison, reverse osmosis of seawater requires 4 kWh of energy per 1 m3 of treated water (this difference is because of the higher TDS concentration of seawater). According to eGRID, the carbon dioxide equivalent emission rate is 1,324.79 lb CO_2e/MWh in Florida and 727.26 lb CO_2e/MWh in California. Estimate the carbon footprint of using reverse osmosis to desalinate 1 m^3 brackish groundwater and 1 m^3 sea water in Florida and California. Ignore line losses in your estimate.

Solution:

FL brackish water

$$\frac{1\ kWh}{1\ m^3} \times \frac{1\ MWh}{10^3 kWh} \times \frac{1{,}324.79\ lb\ \mathbf{CO_{2e}}}{MWh} = \mathbf{1.32}\ \boldsymbol{lb}\frac{\mathbf{CO_{2e}}}{\mathbf{m^3}}$$

CA brackish water

$$\frac{1\ kWh}{1\ m^3} \times \frac{1\ MWh}{10^3 kWh} \times \frac{727.26\ lb\ \mathbf{CO_{2e}}}{MWh} = \mathbf{0.73}\ \boldsymbol{lb}\frac{\mathbf{CO_{2e}}}{\mathbf{m^3}}$$

FL sea water

$$\frac{4\ kWh}{1\ m^3} \times \frac{1\ MWh}{10^3 kWh} \times \frac{1{,}324.79\ lb\ \mathbf{CO_{2e}}}{MWh} = \mathbf{5.28}\ \boldsymbol{lb}\frac{\mathbf{CO_{2e}}}{\mathbf{m^3}}$$

CA sea water

$$\frac{4\ kWh}{1\ m^3} \times \frac{1\ MWh}{10^3 kWh} \times \frac{727.26\ lb\ \mathbf{CO_{2e}}}{MWh} = \mathbf{2.92}\ \boldsymbol{lb}\frac{\mathbf{CO_{2e}}}{\mathbf{m^3}}$$

Acidic or Basic?

- $pH = \log (1/[H^+])$
  - [ ] means molar concentration (mole/l)
- When $[H^+]$ concentration is 10^{-7}, then $pH = 7$, which represents the neutral state.
- If $pH > 7$, then it is basic
- If $pH < 7$, then it is acidic
- Water ionization is represented by:
  - $[H^+][OH^-] = K_w = 10^{-14}$ (K_w is the ionization constant)

    Example: If the concentration of H^+ in water is 10^{-2} mole/l, what is the concentration of OH^- and the pH of the water.

    Solution: $[OH^-] = K_w / [H^+] = 10^{-14} / 10^{-2} = 10^{-12}$

    $pH = \log (1/ 10^{-2}) = 2$

Chemical Equilibria

- $aA + bB \Leftrightarrow cC + dD$
  - A and B are the reactants
  - C and D are the products
  - Most reactions are reversible, an increase of A or B shift the reaction to the right and vice versa. The relationship may be expressed by the mass action equation:

$$\frac{[C]^c[D]^d}{[A]^a[B]^b} = K$$

  - [ ] = molar concentration and K=equilibrium constant

Chemical Equilibria

- In Water Chemistry, the carbonic acid-bicarbonate-carbonate system is very important.

▶

  - The carbonic acid dissociate as the following:
    - $H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$

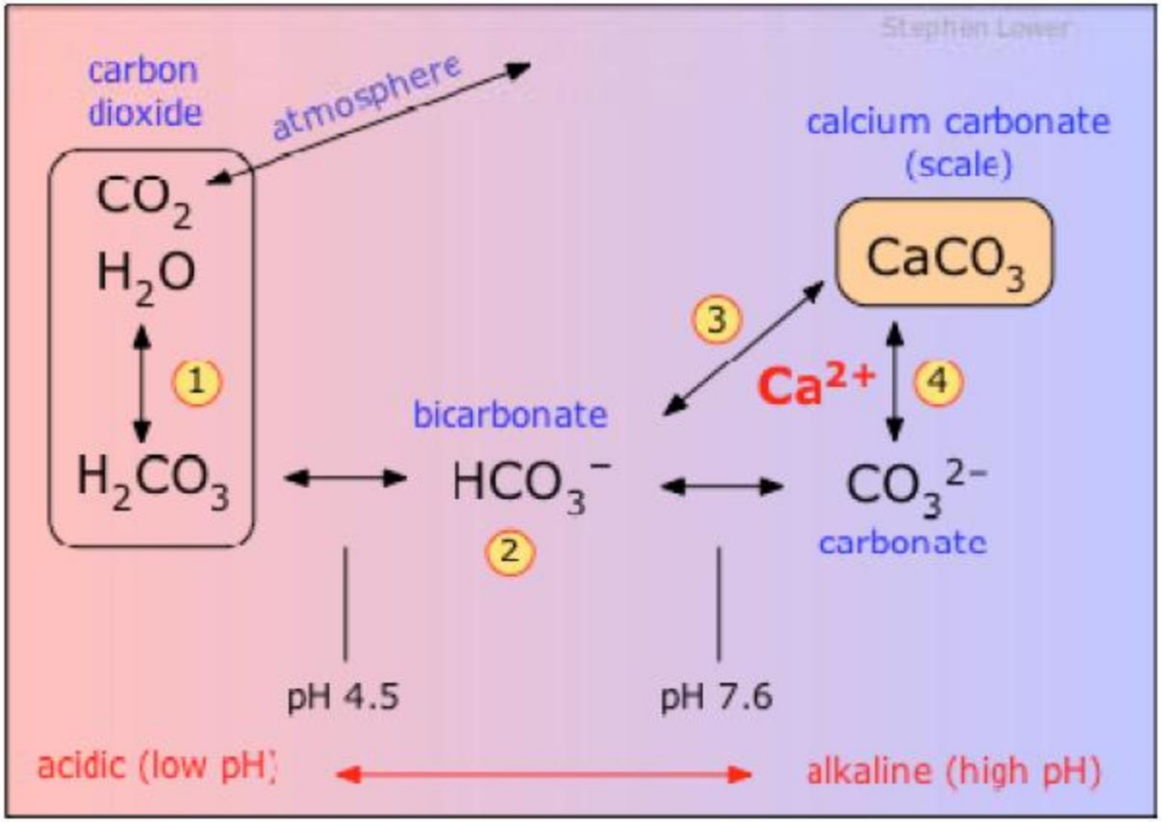
$$\frac{[H^+][HCO_3]}{[H_2CO_3]} = K_1 = 4.45 \times 10^{-7} \, at \, 25^o \, C$$

  - The bicarbonate dissociate as the following:
    - $HCO_3^- \Leftrightarrow H^+ + CO_3^{-2}$

$$\frac{[H^+][CO_3^{-2}]}{[HCO_3]} = K_2 = 4.69 \times 10^{-11} \, at \, 25^o \, C$$

    - These reactions are called Homogenous Chemical Equilibria, because reactants and products occur in the same physical state.

Carbonic acid-bicarbonate-carbonate System



- Heterogeneous equilibria, reactants and products occur in different physical states. Important reaction is the following:
  - $CaCO_3 \Leftrightarrow Ca^{+2} + CO_3^{-}$

$$\frac{[Ca^{+2}][CO_3^{-2}]}{[CaCO_3]} = K$$

  - Since $CaCO_3$ is solid, it can be treated as constant, K_s , then
  - $[Ca^{+2}][CO_3^{-}] = KK_s = K_{sp} = 5 \times 10^{-9}$ @ 25° C
  - K_{sp} = solubility products constant
  - If $[Ca^{+2}][CO_3^{-}] < K_{sp}$, the solution is undersaturated
  - If $[Ca^{+2}][CO_3^{-}] > K_{sp}$, the solution is supersaturated, precipitation will occur.

Shift of Equilibria

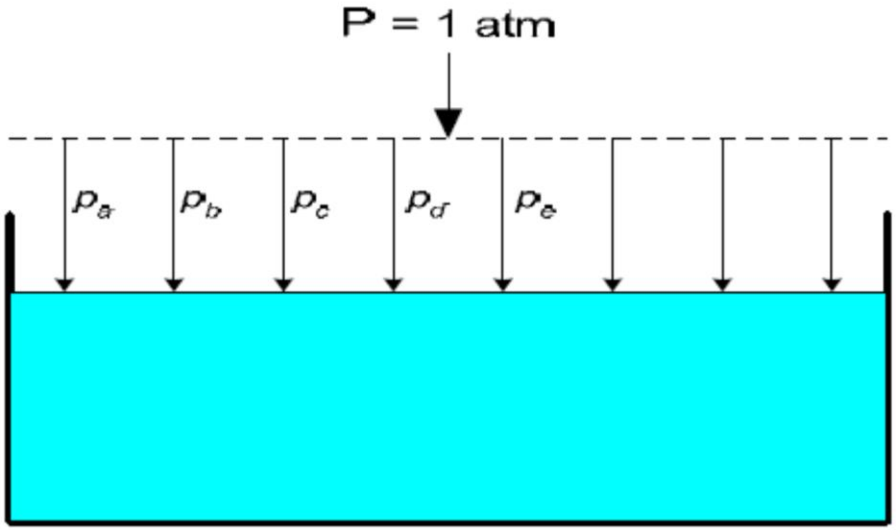
- How to shift equilibria
  - Produce insoluble products
  - Produce gaseous products
  - Produce weakly ionized products
  - Produce oxidation-reduction reaction
- Examples of Equilibria Shift
  - Adding lime ($Ca(OH)_2$) to remove Ca^{+2}
    - $Ca^{+2} + 2HCO_3^- + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2CO_2$
  - Adding Chlorine (Cl_2) to remove Ammonia (NH_3)
    - $3Cl_2 + 2NH_3 \rightarrow N_2 \uparrow + 6H^+ + 6Cl^-$
  - Adding acid or base to produce poorly ionized product
    - $2H^+ + SO_4^{-2} + 2Na^+ + 2OH^- \rightarrow 2H_2O + 2Na^+ + SO_4^{-2}$
  - Adding Chlorine (Cl_2) to Cyanide ion to complete the reaction
    - $5Cl_2 + 2CN^- + 8OH^- \rightarrow 10Cl^- + 2CO_2 + N_2 \uparrow + 4H_2O$

Dalton's law

- In a mixture of gases, such as air, each gas exerts a pressure independent of the others.

- The partial pressure of each gas is proportional to the percent by volume of that gas in the mixture.

Dalton's law



$\mathrm{P} = p_a + p_b + p_c + \text{etc}\ldots.= 1\ \text{atm}$

p_a is proportional to the volume percent of the mixture.

Example: Air contains 20.9% by volume of oxygen. Determine its partial pressure.

Solution: $20.9\% \times 1\ \text{atm} = 0.209\ \text{atm}$

Henry's Law

- The weight of any gas that would dissolve in a given volume of a liquid, at a constant temperature, is directly proportional to the pressure the gas exerts above the liquid. In equation form:
  - $C_s = H\, p_g$

where:

C_s = the concentration of the gas dissolved in the liquid at equilibrium

H = Henry's law constant for the gas at the given temperature

p_g = the partial pressure of the gas above the liquid

Henry's Law

- Example: Calculate the equilibrium concentration of oxygen in water at 20 °C and an elevation of 610 m above sea level, given that Henry's law constant for oxygen in water at 20 °C and 1 atm is 43.8 mg/*l*-atm and that the partial pressure (p_{O2}) is 0.209 atm.

- Solution:

At sea level atmospheric pressure (P) = 1 atm (760 mm Hg)

At 610 m P = 706 mm Hg or = 706/760 = 0.929 atm

$C_s = H\, p_{O2}$

$C_s = 43.8 \text{ mg}/l\text{-atm} \times 0.209 \text{ atm} \times 0.929 = 8.5 \text{ mg}/l$

Applications in Environmental Engineering

- Aeration
  - The rate of transfer of oxygen into solution is proportional to the difference between equilibrium concentration as given by Henry's Law and the actual concentration in the liquid. Therefore:

$$\frac{dC}{dt} \propto (C_s - C_a)$$

Where:

dC/dt = rate of oxygen transfer into solution

C_s = equilibrium concentration of oxygen

C_a = actual concentration of oxygen

3.9 What would be the saturation concentration (mole/L) of oxygen (O_2) in a river in winter when the air temperature is 0°C if the Henry's law constant at this temperature is 2.28×10^{-3} mole/L¯atm? What would the answer be in units of mg/L?

Solution:

$$P_{O_2} = 0.21\ atm$$

$$K_H = 2.28 \times 10^{-3}\ \frac{mole}{L - atm}$$

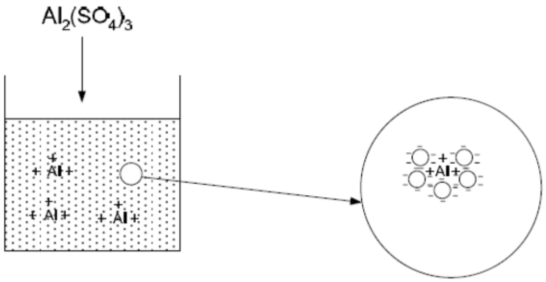
$$(2.28 \times 10^{-3}\ \frac{mole}{L - atm}) \times (0.21\ atm) = 4.79 \times 10^{-4}\ mole\ O_2 / L$$

$$\frac{4.79 \times 10^{-4}\ mole\ O_2}{L} \times \frac{32\ g\ O_2}{1\ mole\ O_2} \times \frac{1000\ mg}{1 g} = \boxed{15.3\ mg / L}$$

Removal of colloids:

- Removal is accomplished by adding a chemical coagulant to suppress the charge, therefore, bringing the particles together so that they grow in size and settle out of solution by gravity.

Removal of colloids



Particles Agglomerate and settle

Environmental Engineering

Biological Water Quality Parameters

Dr. Ahmed N Bdour

Summary

Biological Water Quality Parameters

- Pathogens

    Bacteria

    Viruses

    Protozoa

    Helminths

- Pathogen Indicators

Pathogens

A body of water hosting large numbers of species with well balanced numbers of individuals is considered to be a healthy system.

Based on their known tolerance for a given pollutant, certain organisms can be used as an indicator of pollution

Pathogen – Capable of infecting or transmitting diseases to humans.

They require a host for growth and reproduction. They can be transported in natural waters . Many are able to survive in waters and maintain their infectious capability for long periods. These waterborne pathogens include species of bacteria, viruses, protozoa and helminths (parasitic worms)

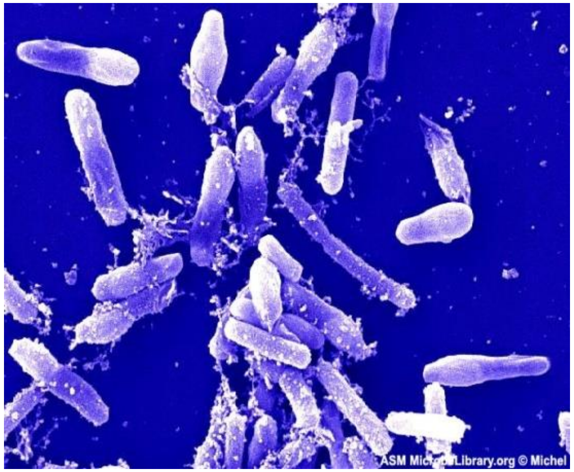
Pathogens

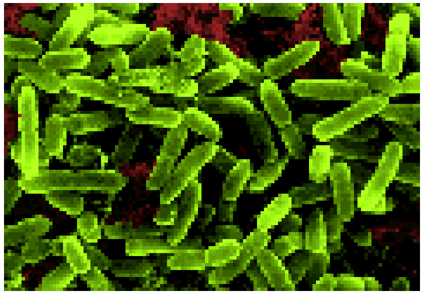
Bacteria – Bacteria are single-cell microorganisms usually colorless. It is a completely self-contained and self-reproducing unit. When the time is right, bacterium will split its DNA and RNA genetic material in two. Separate cell walls will build up around these two new bacteria. Bacteria are rod shape (bacilli); spherical (cocci) or spiral-shaped (spirilli).

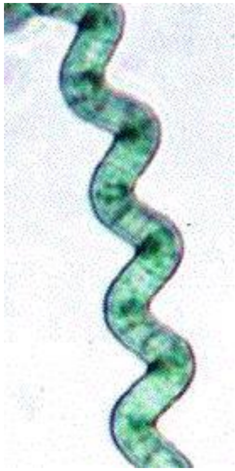
Gastrointestinal disorder are common symptoms of most diseased transmitted by waterborne pathogenic bacteria

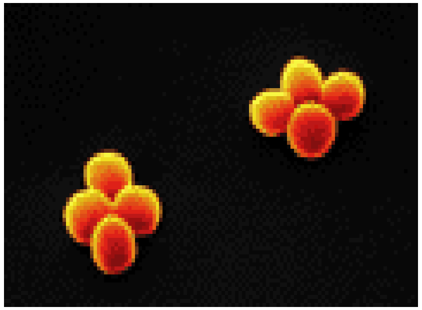
Ninety-nine percent of all known bacteria are considered beneficial to humans, or at least harmless.

Bacteria

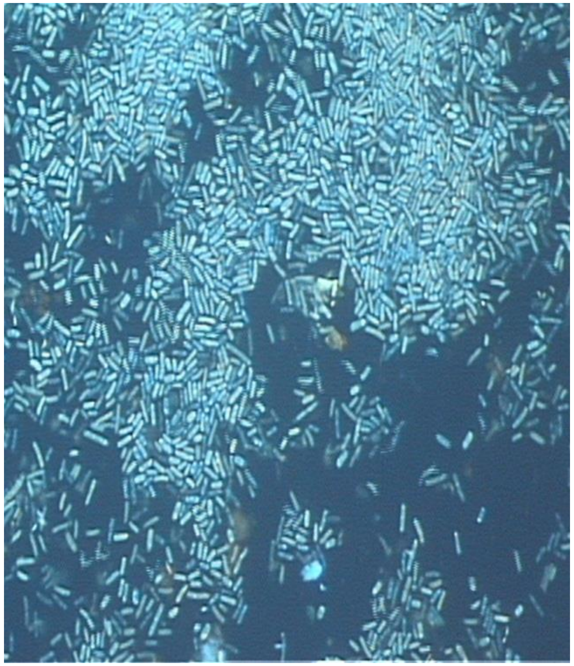

ASM MicrobeLibrary.org © Michel

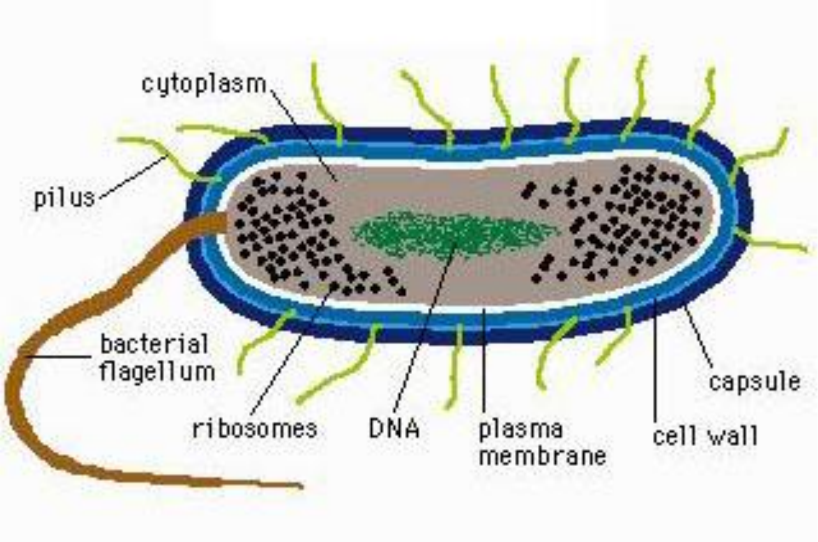






Spherical, rodlike, spiral





Pathogens

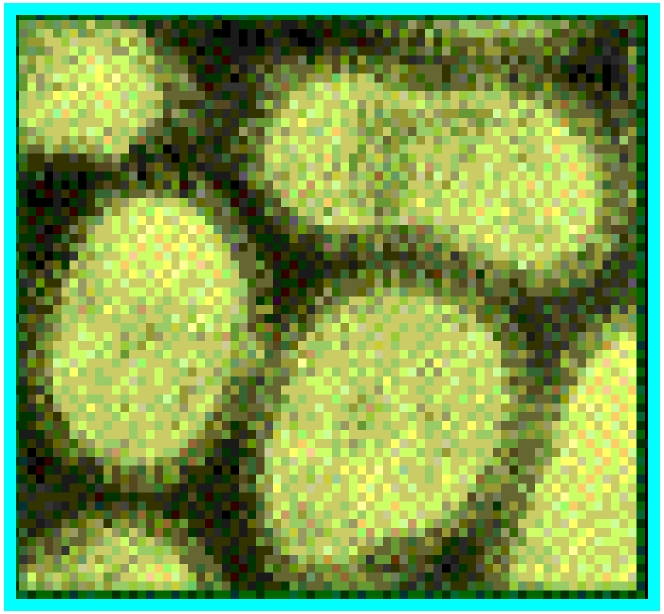
Virus – Smallest biological structure known to contain all the genetic information necessary for their own reproduction. Symptoms associated with waterborne viral infection usually involve disorders of the nervous system rather than the gastrointestinal tract.

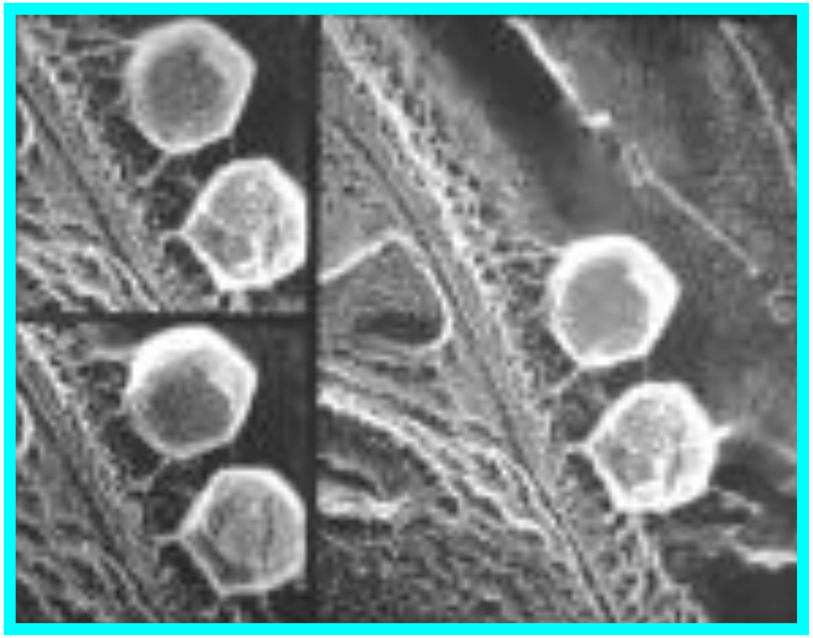
e.g. polio (inflammation of the gray matter of the spinal cord) and hepatitis

Although standard disinfection practices are known to kill viruses, confirmation of effective disinfection is difficult owing to the small size and lack of quick and conclusive test.

This is the major concern with recycling of WW

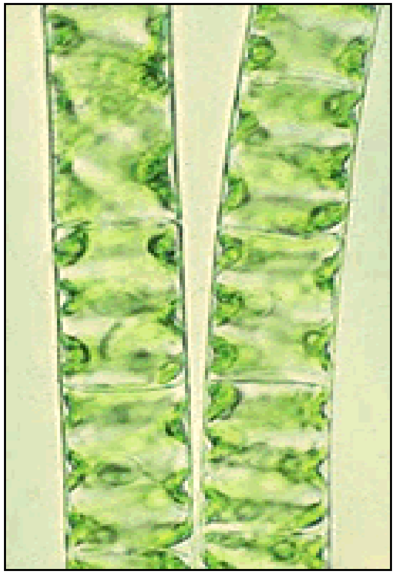
VIRUSES





FUNGI

Algae



Pathogens

Protozoa – The lowest form of animal life. They are unicellular organisms more complex in their functional activity than bacteria or viruses. They are complete, self contained organisms that can be free-living or parasitic, pathogenic or nonpathogenic, microscopic or macroscopic.

They are highly adaptable and widely distributed in natural waters however, only few are pathogenic

Infections are usually characterize by gastrointestinal disorders milder to that of bacteria.

Under adverse environmental circumstances, aquatic protozoa form cysts which are difficult to disinfect. Usually complete treatment is needed including filtration.

Pathogens

Helminths – The life cycles of parasitic worms often involved two or more animal hosts, one of which can be human, and water contamination may result from their waste. Contamination can also be via snails and insects.

Modern WT systems are very effective in destroying helminthal pathogens. They pose hazards primarily to persons expose to untreated water. E.g. sewerage plant operators, swimmers in lakes polluted from cattle feedlots.

Pathogen Indicators

Analysis of water for all the known pathogens would be a time consuming and expensive task. Therefore the purity of water is usually checked using **indicator organisms**.

An indicator organism is one whose presence presumes that contamination has occurred and suggest the nature and extent of the contamination. The ideal indicator organism should have the following characteristics:

- Be applicable to all types of water
- Present when pathogens are present
- Absent when pathogens are absent
- Easily identified and analyzed
- Not be a pathogen for safety of personnel

The fecal coliform group of organisms are best suited as indicator organisms as they

1. Native to the intestinal track of warm blooded animals
2. They are excreted in large numbers
3. They are nonpathogenic
4. Composed of several strains of bacteria principally Escherichia coli, E coli
5. Can survive for longer times outside the host than pathogens

There are other coliform groups which flourish outside intestinal track. Native to soil and decaying vegetation. Their presence can indicate the presence of helminths from soil.

Pathogen Indicators

The quality of drinking water is determined based on the Total Coliform i.e. Fecal Coliform plus Nonfecal Coliform

Test for Fecal Coliform is performed on WW

Measurement

Membrane filter technique – Sample is filtered through a membrane 0.45 microns. Bacteria that remains on the filter is placed in a selective media to promote growth while inhibiting growth of other species. It is incubated for 24hrs. The resulting visible colonies are counted. Results are reported in organisms / 100mL of water.

Waterborne diseases

- Communicable diseases which may be transmitted by water
  - Bacterial infection
    - Typhoid, salmonellosis, dysentery
  - Viral infection
    - Hepatitis, poliomyelitis
  - Protozoal infections
    - Giardia and Cryptants

Waterborne diseases

- Infections are normally caused and spread through the fecal and urinary discharges of sick persons and carriers, also animals and soils may be considered as sources of protozoa and bacteria.

Inorganic contaminants

- Includes both suspended and dissolved materials
- Problems associated, generally are
  - Undesirable for esthetic reasons
  - Ability to shield microorganisms from disinfectants
  - Health effects
- Examples: aluminum, arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, and silver.
- EPA has established the so called Maximum Contaminant Level (MCL) for primary pollutants which are generally toxic

Inorganics

- Aluminum associated with neuropathological disorders such as Alzheimer's disease as well as physiological problems among dialysis patients.
- Radionuclides like radium-226 and others are also included in primary standards.
- Arsenic: well-known poison (fatal at high doses).
- Barium: soluble form and very toxic
- Cadmium and chromium: cause acute or chronic toxicity depending on the concentration.
- Fluoride: high concentration discoloration and loss of teeth and embitterment of bones.
- Lead and mercury: affect the nervous system
- Nitrate: interfere with oxygen transfer in the blood of infants
- Selenium: dental problems

Radionuclides

- Widely distributed in nature
- MCLs range from 20,000 pCi/L for hydrogen-3 (part curies per liter) to 5 pCi/L for radium
- Uranium-238, the commonest isotope of uranium, soluble in mg/L range
- It is more dangerous as a chemical toxin to the liver than a source of radioactivity
- Turbidity is a measure of presence of suspended solid material which can be removed by filtration, coagulation, sedimentation.

Organic contaminants

- Associated with color, taste, or odor, in some cases may be toxic or carcinogenic.
- Chlorinated hydrocarbons: used as pesticides and herbicides,
  - persistent in nature and within human bodies.
  - Many shown to produce carcinogenic effects in laboratory animals.

Organic contaminants

- Trihalomethans:
  - May enter water from industrial processes,
  - The most common source is through chlorination of water
  - Chloroform is the most common occurring of trihalomethans
  - Carcinogenic

Organic contaminants

- Volatile Organic chemicals (VOCs)
  - Industrial chemicals
  - Found in both SW and GW
  - Carcinogenic

Natural waters

- All natural water consists of some dissolved minerals
  - Cations: sodium, potassium, calcium, magnesium, iron, and manganese
  - Anion: bicarbonate, carbonate, sulfate, and chloride.
- EPA has established secondary standard called Recommended Contaminate Level (RCL), usually they are not toxic.

Dissolved Gases

- Nitrogen, oxygen, carbon dioxide, hydrogen sulfide, and methane.
- Hydrogen sulfide: produced by reduction of sulfates, dissolution of pyrites or anaerobic decomposition of organic matter.
- It has a rotten-egg odor in low concentration
- Poisonous in high concentration
- Contribute to corrosion of metal and concrete

Dissolved Gases

- Carbon dioxide is dissolved from the atmosphere and produced by decomposition of organic matter
- Soluble in water form carbonic acid
- Oxygen exists in atmosphere and decreased by biological and chemical reactions.
  - Absent in groundwater and badly contaminated surface water
  - Generally added for treatment processes
  - It contribute to corrosion of metals under some conditions.

Liability for unsafe water

- Producers are required to test the water in their systems to be guaranteed for safe use in any purpose.
- Failure to provide an adequate supply (quantity and quality) is a legal issue.

Characteristics of waterborne epidemics

- Widespread outbreaks of disease are often attributed to water systems
- Exception to this rule may occur if water from several sources is used in the systems and only one source is contaminated
- Outbreaks in the past were attributed to the use of untreated water, particularly cross-connections.

Watershed and reservoir protection

- EPA requires that all public supplies that drawn from surface sources be filtered unless very stringent criteria with regard to quality and protection are met.
- Rules should be applied
  - Recreational use should be permitted only when there is a real need for such use and the need can be supplied by other bodies of water
  - Use should be controlled by caretakers
  - Picnics and camping should be restricted to areas with garbage and toilet facilities
  - Swimming and other water contact sports should be restricted to areas at least 2 km distance from the source
  - Non contact recreation such as fishing, boating, and haunting should be restricted to areas at least 200 m from the intake

Groundwater and well protection

- May be contaminated by surface water during floods and by percolation of waste material through the soil.
- Careful construction of wells can prevent contamination which require that the casting be grouted down to the first impervious stratum.
- Leaking sewers, septic tanks are all potential points of pollution.

Protection within the treatment and distribution systems

- Careful design of treatment system will ensure no mixing of potable and nonpotable water by
  - avoiding bypass around the treatment units
  - Wall construction between treated and untreated waters
  - Plants must have adequate chemical supplies to prevent any interruptions in supply resulting from weather or natural disasters
  - All pipes should be made of iron and be installed above the ground
  - Treated water reservoir must be covered and air inlets must be screened to exclude insects

Protection within the treatment and distribution systems

- Within distribution systems
  - Continuous maintenance of a residual disinfectant concentration in the water supply.
  - Such systems are most likely contaminated by cross-connections which need close inspection and maintenance

SOLID WASTE MANAGEMENT

Fall 2024

Environmental engineering

Prepared by

Ahmed Bdour, PhD

Basel Convention Definition of Wastes

"Substances or objects which

- are disposed of or
- are intended to be disposed of or
- are required to be disposed of by the provisions of the law"

- **Bio-degradable**

  can be degraded (paper, wood, fruits and others); produce biogas, fertilizer, etc…

- **Non-biodegradable**

  cannot be degraded (plastics, bottles, old machines,

  cans, styrofoam containers and others)

AND

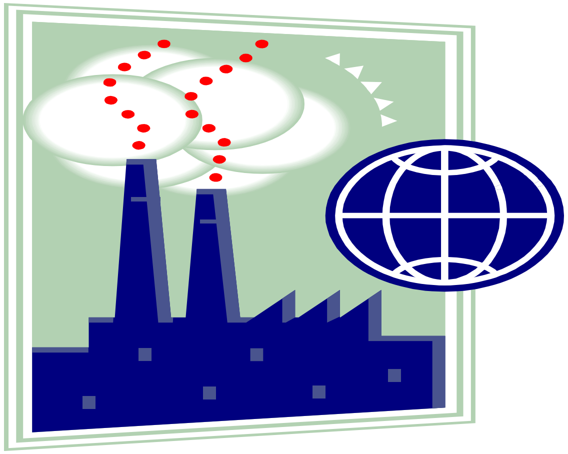
- **Combustible**

  organic (paper, wood, food waste, etc.) ; recover energy

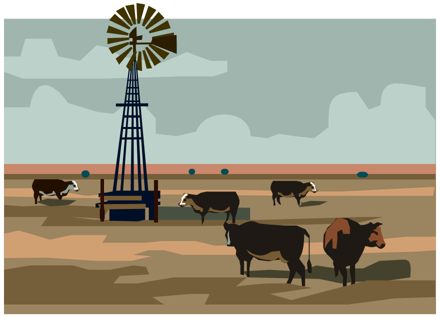
- **Non-combustible**

  inorganic (glass, metal and others)

Households



Commerce and Industry



Agriculture

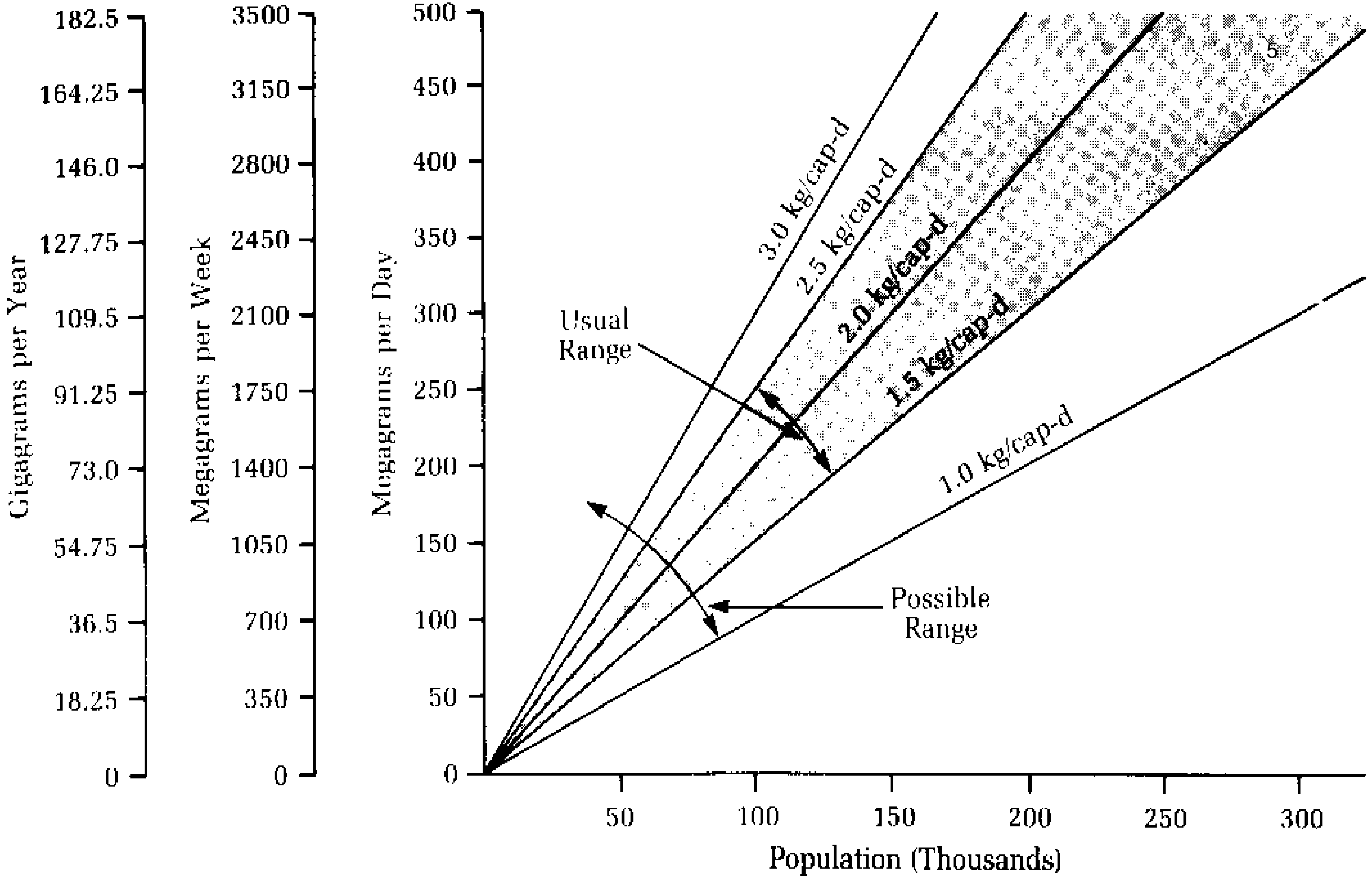


FIGURE 8-1

Solid waste produced: varying per capita figures.

- The first objective of solid waste management is to remove discarded materials from inhabited places in a timely manner:
  - to prevent the spread of disease,
  - to minimize the likelihood of fires, and
  - to reduce aesthetic insults arising from putrefying organic matter.

- The second objective, which is equally important, is to dispose of the discarded materials in a manner that is environmentally acceptable.

Hazardous Waste Management

RCRA .vs. CERCLA

- RCRA (Resource Conservation and Recovery Act,1976), which is enforced by the EPA, manages hazardous waste from its point of origin to its final disposal.
- Before RCRA took effect, sites "known as superfund" that were previously contaminated are funded for cleanup through **CERCLA** (Comprehensive Environmental Response, Compensation, and Liability Act).

Hazardous Waste Management characteristics

- Four Primary Characteristic under RCRA

1) **Ignitability-burns less than 60 C or 140 F**
2) **Reactivity – when mix can explode or form harmful vapors**
3) **Corrosivity – includes strong alkaline or acidic substances [ph<2 or ph>12.5] causes rust in steel**
4) **Toxicity**
    - Carcinogenic .vs. mutagenic – **Carcinogenic** are cancer causing where as **mutagenic** causes biological changes in children or offspring **(a change in the DNA of a cell)**
    - Not allowed in even a traceable amount
    - TCLP (Toxicity Characteristic Leaching Procedure) is used to determine the mobility of organic and inorganic compounds

Additional Type Hazardous Properties

- Infectious or Medical Waste – i.e. human tissue from surgery, used bandages and needles, microbiological materials, etc.
- Radioactive – Nuclear power plants have waste that produce radiation which destroys living organisms. Decay half life extends its activity for thousands of years.

Options for Hazardous Waste Management:

1) Eliminate or reduce waste quantities
2) Reclaim and recycle the waste
3) Stabilize the waste
4) Incinerate the waste
5) Apply modern land disposal methods

- Hazardous waste .vs. Hazardous materials
  - Toxic Substance Control Act (TOSCA) manages hazardous materials so that they won't become hazardous waste
- Toxic .vs. Hazardous
  - Hazardous material/waste must be listed as such by federal regulations
  - Hazardous waste must cause death or serious illnesses
  - Any waste that contains a listed hazardous waste, regardless of the quantity is hazardous

Transportation (HMTA)

- HMTA (**Hazardous Materials Transportation Act**)
  - Requires proper labeling and transport of all hazardous materials and waste.
  - TSDF- Treatment, Storage, and Disposal Facilities are linked together in RCRA legislation.(This has prevented “midnight dumping”)
  - Manifest System – “cradle-to-grave” is a system of accurately keeping track of source, transporters, disposal facility, quantities, emergency response, etc.

Hazardous Waste Treatment Method

- Incineration – Thermal –Chemical process which causes a molecular change due to extreme high temperatures and a reduction in volume.
  - Exceptions would be heavy metal (it just vaporizes)
  - TCLP (Toxicity Characteristic Leaching Procedure test is required for the residual material after burning, and to insure safety in landfills.
  - Equipment includes rotary kiln, fluidized bed incinerator, multiple-hearth furnace, etc

Biological Treatment Process

1. Genetically Engineered Bacteria –useful for breaking down organic waste from the petroleum industry
2. Landfarming or Land treatment – mixing waste in soils that are non-agriculture but have high levels of microorganisms and nutrients for bio-degradation
3. Using plants in contaminated water to absorb contaminants

Physical Treatment Process

- Solidification and Encapsulation by mixing with a concrete, asphalt, or plastic
- Soil Vitrification Process (melting soils at 1600 to 2900 F)
  - Organic contaminants are destroyed by pyrolysis or they are stripped out of the soil with the escaping steam and trapped in the off-gas treatment system.

USTs and Impoundments

- Underground Storage Tanks must comply with the updated RCRA requirements (1984) or be taken out of service
- Surface Impoundments (storage) which are used for liquid hazardous waste must comply with a strict design

Landfills

- Liners- geomembrane or flexible membrane liner (FML) must have a permeability coefficient less that 10^{-6} mm/sec.
- Landfills must have a double-liner, a cap for a cover, and a leachate collection system, as well as a network of monitoring wells to sample groundwater.
- Underground Injection- For disposal of liquid hazardous waste into a deep-well (.25 mi from an underground source of drinking water).
    - The well is cased and cemented to protect drinking water contamination
    - The injection pipe has three concentric pipes
    - Geological formation must be limestone or sandstone layers wedged between impervious layers such as clays or rock

SOLID WASTE MANAGEMENT SYSTEM

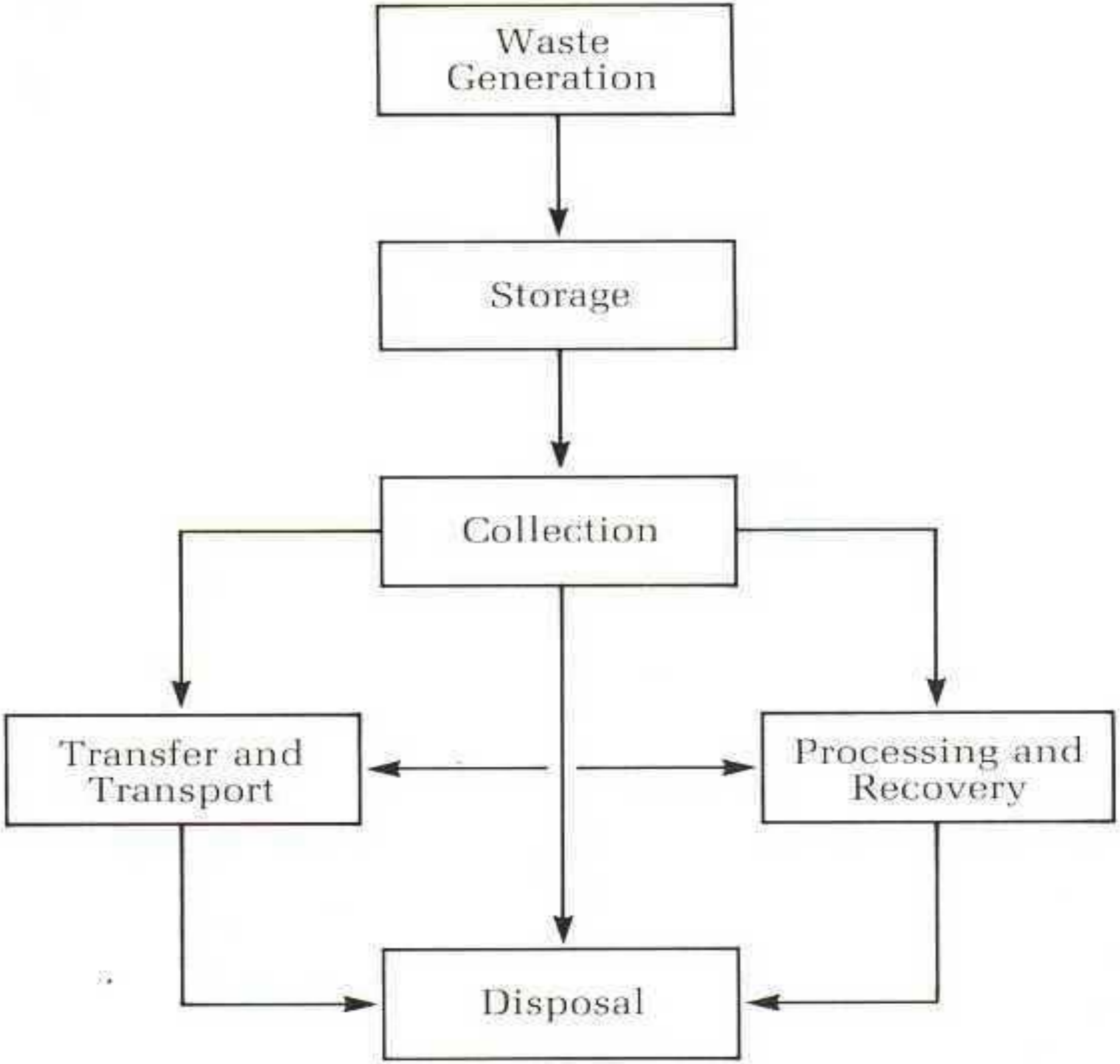
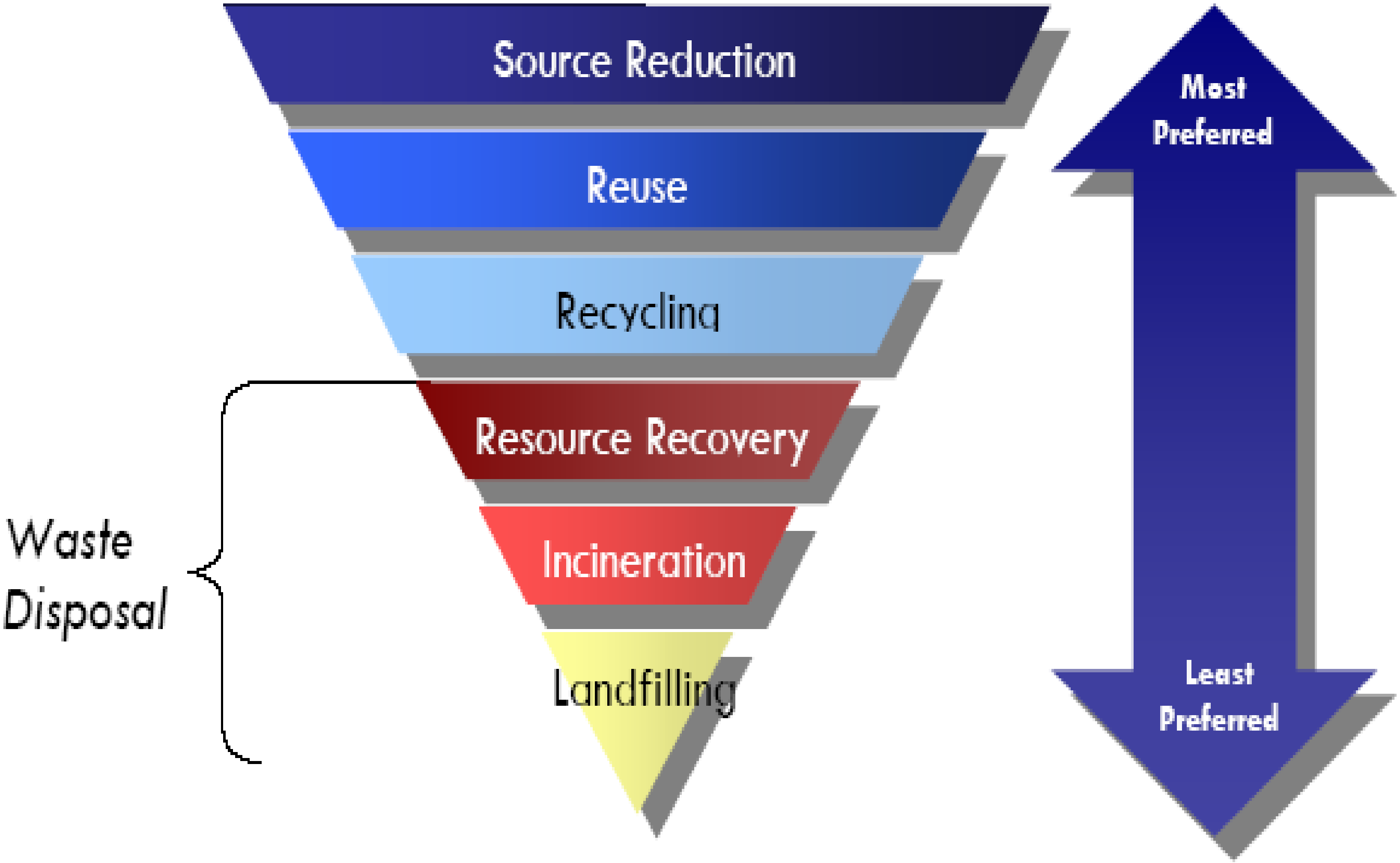


Figure 3-1. The Solid Waste Management Hierarchy



Processing & Recovery

- Classification
- Separation
- Size Reduction
- Moisture Control
- Recycling of Resource Materials
- Recovery of Energy

- Is the reprocessing of wastes to recover an original raw material.
  - At its lowest and most appropriate technological level, the materials are separated at the source by the consumer.
  - This is the most appropriate level because it requires the minimum expenditure of energy.

- Generally, the recycling options available to a municipality for residential use include:

1. drop-off centers
2. curbside collection
3. material processing facility
4. material transfer stations leaf/yard waste compost bulky waste collection and processing
5. tire recovery

Composting

- Composting is nature's way of recycling organics.
- When you compost, you convert vegetable scraps, leaves, grass clippings and other materials into a nutrient rich soil material.
- You can use finished compost in your garden and around shrubs or other plants to help them grow.
- Composting also reduces the amount of materials that need to be disposed of, reducing those related costs.

- Compost is a humus-like material that results from the aerobic biological stabilization of the organic materials in solid waste.
- Compost is useful as a soil conditioner. In this role compost will:
  - 1) improve soil structure,
  - 2) increase moisture-holding capacity,
  - 3) reduce leaching of soluble nitrogen, and
  - 4) increase the buffer capacity of the soil.

- It should be emphasized that compost is not a valuable fertilizer. It contains only 1 percent or less of the major nutrients, such as nitrogen, phosphorus, and potash. Thus, only a limited market exists for compost.

Processing and Beneficial Use

- Processing reduces the volume of materials to be landfilled and can create products such as fuel oils and steam for electricity generation.
- Beneficial use means the reuse of solid waste as a substitute for raw material in manufacturing, as construction material or fill, as a fuel, or as an agronomic soil amendment.

- Incineration has been used to reduce the bulk (size & weight) of the solid waste.

- Although the solid waste may have some heat value, it is normally quite wet and is not self-sustaining in combustion until it is dried.

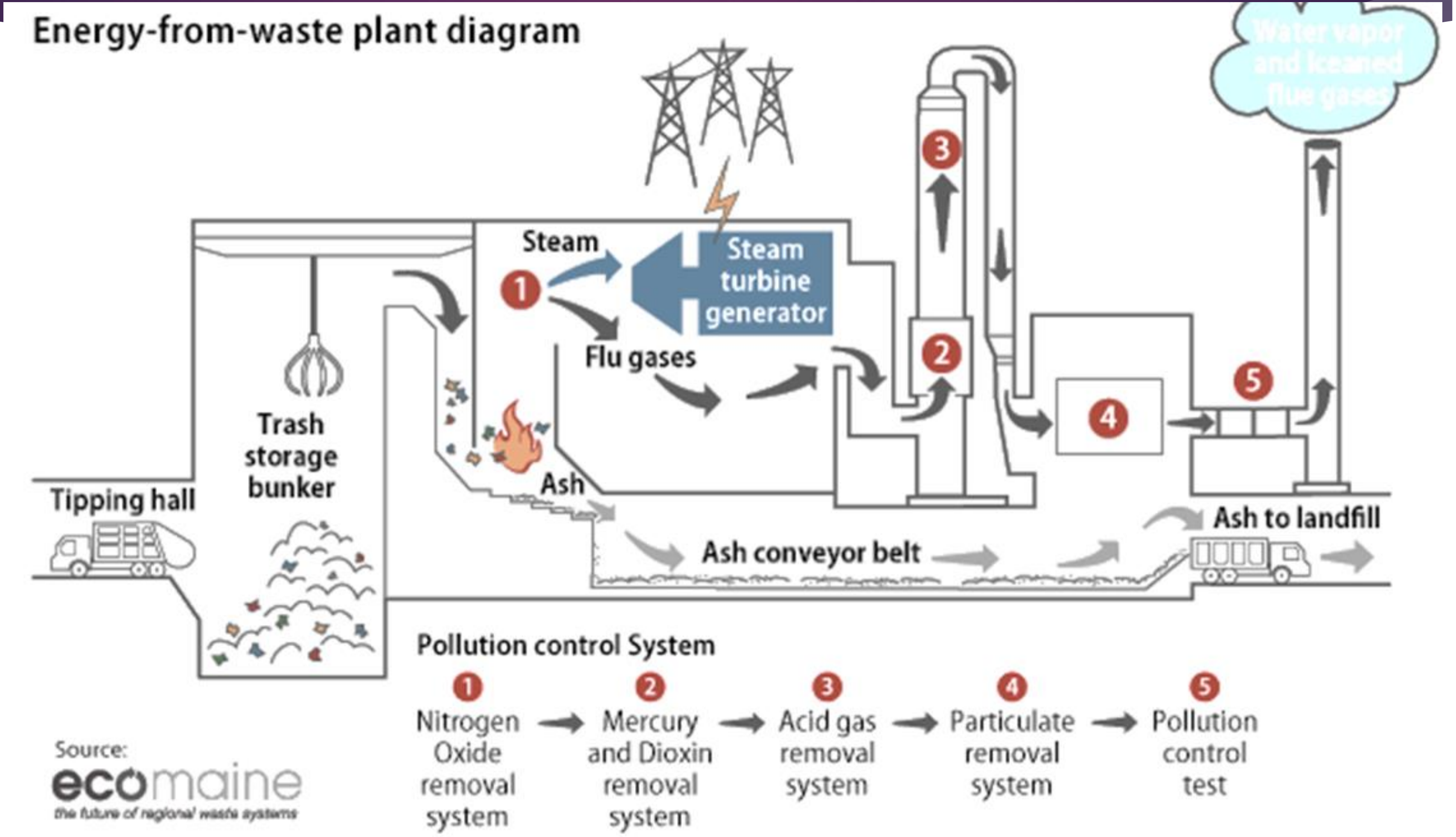
- Conventionally, auxiliary fuel is provided for the initial drying stages.

- Some type of air pollution control device is required because the large amount of particulate matter generated in the combustion process (plus gases).

Waste-To-Energy

- Waste-to-Energy facilities accept our solid waste and combust it at very high temperatures, producing heat that is used to convert water into steam. The steam is used to run turbines that generate electricity.
- Scrubbers, filters, and other pollution control equipment reduce pollutants released during the incineration process. Ash and other residues from this process are landfilled.

Waste-to Energy


Energy-from-waste plant diagram

Source: ecomaine the future of regional waste systems

Sanitary landfill

- The sanitary landfill is defined as
  - a land disposal site employing an engineered method of disposing of solid wastes on land in a manner that minimizes environmental hazards.
- This is achieved by:
  1. spreading the solid wastes to the smallest practical volume, and
  2. applying & compacting *cover material* at the end of each day.

Site Selection

1. Availability of cover material
2. Haul distance and time
3. Hydrology
4. Climate (better dry area)
5. Buffer areas around the site (for example, high trees on the site perimeter)
6. Proximity of major roadways
7. Traffic patterns and congestion
8. Historic buildings. endangered species, wetlands, and similar environmental factors.

Site Preparation

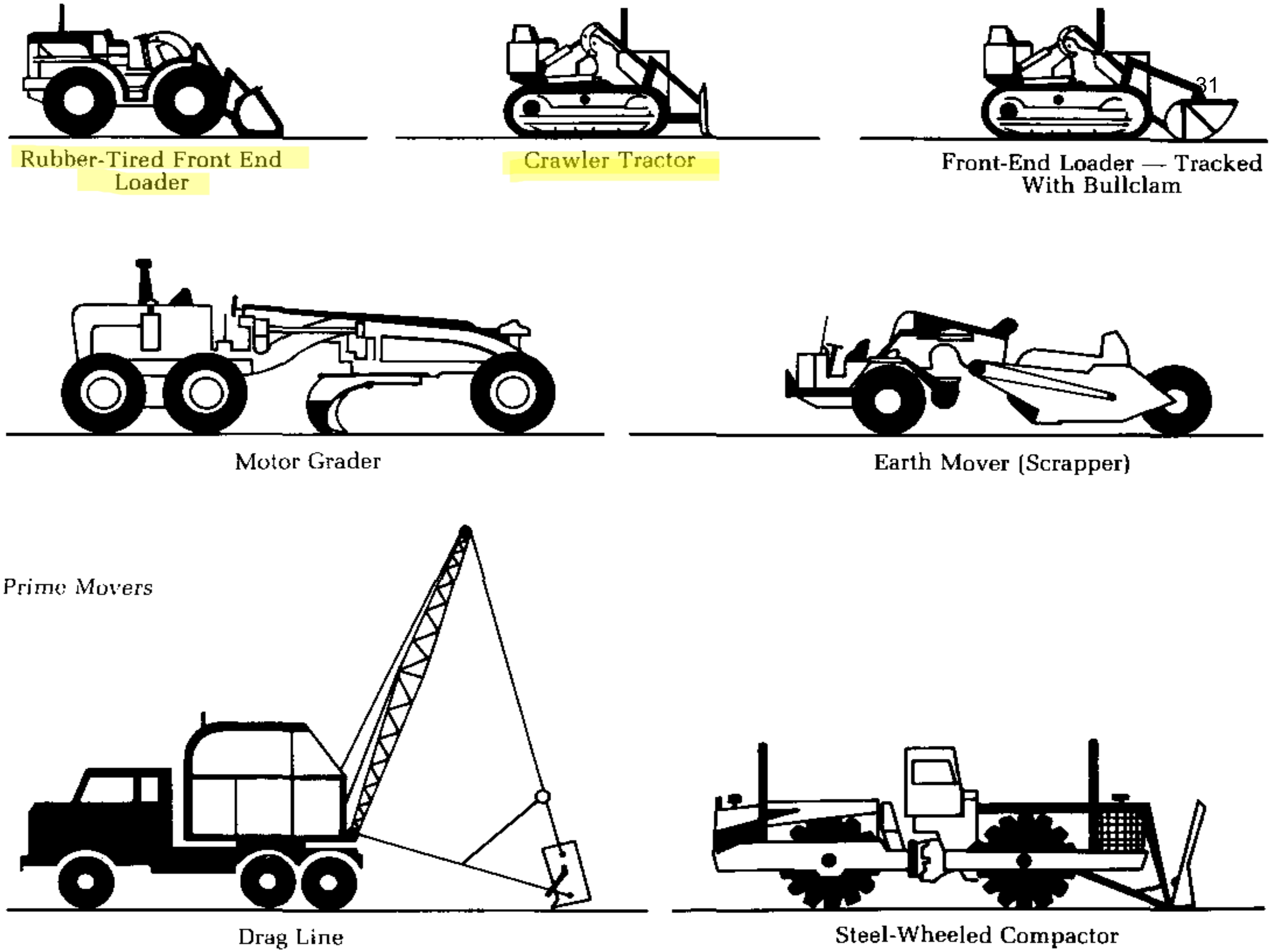
- The plans and specifications
- Operations:
  - grading the site area,
  - constructing access roads and fences, and
  - installing signs, utilities & operating facilities.
- On-site access roads should be of all-weather construction and wide enough to permit two-way truck travel.
- All sanitary landfill sites should have
  - electric, water, and sanitary services.
  - Telephone or radio communications.

Equipment

- A wide variety of equipment is available from which to select the proper type and size needed for an efficient operation.

- The size, type, and amount of equipment required at a sanitary landfill depends on:

1. the size and method of operation,
2. quantities and time of solid waste deliveries, and
3. the experience and preference of the designer and equipment operators.
4. the availability and dependability of service from the equipment.



Rubber-Tired Front End Loader

Crawler Tractor

Front-End Loader — Tracked With Bullclam

Motor Grader

Earth Mover (Scrapper)

Prime Movers

Drag Line

Steel-Wheeled Compactor

FIGURE 8-9
Sanitary landfill equipment.

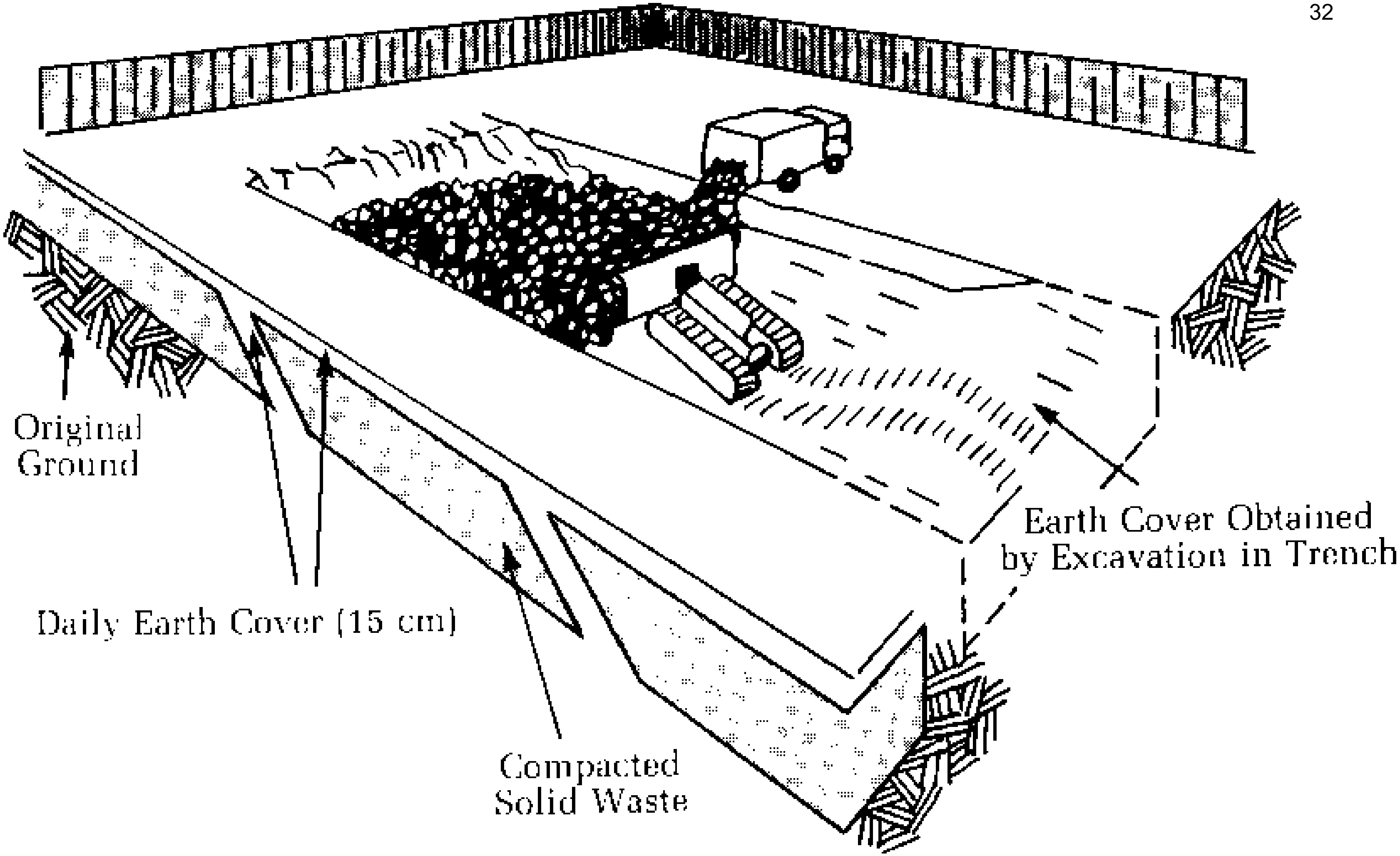


FIGURE 8-11
The trench method.

**Used on slightly sloping land.
Excavation is done.**

- Vectors (carriers of disease),
- Water and air pollution,

should not be a problem in a properly operated and maintained landfill.

Important factors in achieving insect, rodents and fire control:

1. well-compacted solid wastes
2. well-compacted cover material (soil)
3. good housekeeping, and
4. timely (daily) covering of the solid waste.

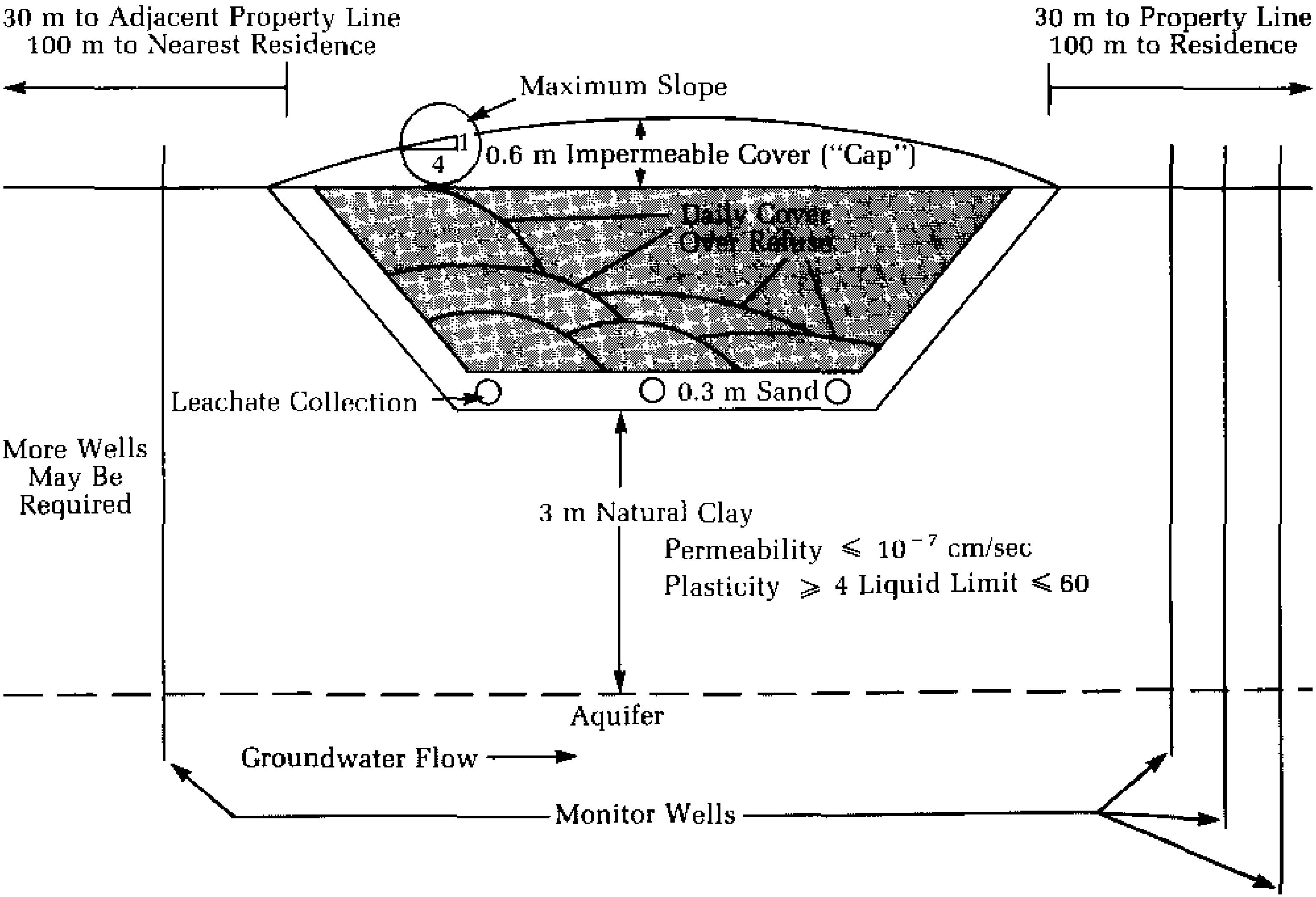
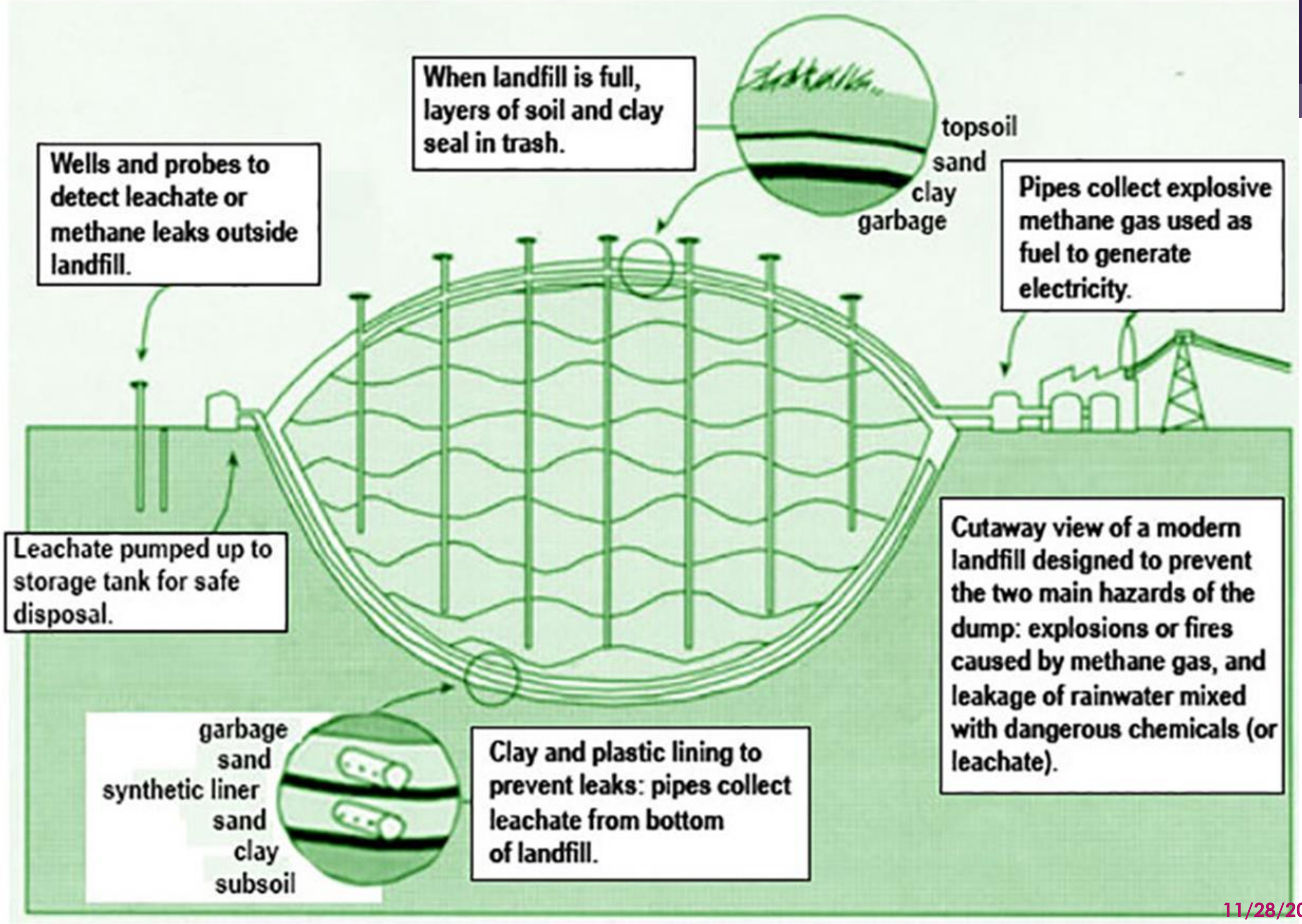


FIGURE 8-12
Municipal solid waste landfill, natural clay site. (*Note:* Drawing is not to scale; size of landfills may vary, and cover slope may exceed limit by approved design.) (*Source:* Michigan Department of Natural Resources.)



When landfill is full, layers of soil and clay seal in trash.

Wells and probes to detect leachate or methane leaks outside landfill.

Pipes collect explosive methane gas used as fuel to generate electricity.

Leachate pumped up to storage tank for safe disposal.

Cutaway view of a modern landfill designed to prevent the two main hazards of the dump: explosions or fires caused by methane gas, and leakage of rainwater mixed with dangerous chemicals (or leachate).

Clay and plastic lining to prevent leaks: pipes collect leachate from bottom of landfill.

Problem 1

Leachate is produced when precipitation infiltrates a sanitary landfill , contacts the waste material, and appears at the bottom of the stored waste. Assume 6 kg of benzene (molecular formula of C6H6) were placed in the landfill and it is all dissolved in the 100,000 gallons of leachate produced during one year. What is the benzene concentration in the leachate during this one year in (a) mg/L; (b) ppbm; and (c) moles/L?

a) $\frac{6\ kg\ C_6H_6}{1.0\times 10^6 gallons} \times \frac{3.7584\ gallons}{L} \times \frac{1000g}{1\ kg} \times \frac{1000\ mg}{1\ g} = \mathbf{23}\ \frac{\mathbf{mg\ C_6H_6}}{\mathbf{L}}$

b) 1 L water = 1 kg water (in water, mg/L = ppm)

$$23\ \frac{mg\ C_6H_6}{L} = 23\ ppm_m\ C_6H_6 * \frac{10^3 \text{ppb}}{1\ \text{ppm}} = \mathbf{2.3\ \times 10^4 ppb_m\ C_6H_6}$$

c) $23\ \frac{mg\ C_6H_6}{L} \times \frac{1\ mole}{78\ g} = \mathbf{3.3 \times 10^{-2}\ \frac{mole}{L}\ \ C_6H_6}$

Problem 2

A new solid waste landfill site is being designed with a projected life of 10 years. The landfill will serve a population of 250,000 that generates 1 kg solid waste/day-person. Assume that yard waste makes up 15% of the total waste (by weight), paper makes up 40% of the total waste (by weight), and metals make up 10% of the waste (by weight). The municipality bans the placement of yardwaste in landfill and has a recycling program that collects one half of all discarded metals. (a) What is the volume of waste that is discarded by the community every day (assume a waste density at the curb of 140 kg/m3).

First calculate the percentage of waste that is discarded (subtract yard and metal waste percentages given in the problem).

$$\text{Percent of waste discarded} = 1 - 0.15 - 0.10(0.5) = 0.80$$

Next, calculate the amount of waste generate by the population per day then use the equation for density to solve for the volume of the waste discarded every day.

$$250{,}000\ people \times \frac{1\ kg\ solid\ waste}{day - person} \times 0.8 = 200{,}000\ kg$$

$$\rho = \frac{m}{V} \therefore V = \frac{\rho}{V} = \frac{200{,}000\ kg/day}{140\ kg/m^3} = \mathbf{1430\ m^3}$$

Problem 3

What is the dry weight percent composition for the following combined waste?

Component	% Composition	% Moisture (wet weight)
Paper	40	6
Yard/Food	30	60
Other	30	3

Solution:

$$Dry\ weight\ \%_{paper} = 100\% - \%moisture = 100\% - 6\% = 94\%$$

$$Dry\ weight\ \%\ of\ total\ weight_{paper} = dry\ weight\ \% \times \%\ composition = 94\% \times 40\% = 38\%$$

Component	% Composition	% Composition (g)	% Moisture (wet weight)	% Moisture (grams)	Dry weight %	Dry weight (g)	**Dry weight % of total weight**
Paper	40	0.4	6	0.02	0.94	0.38	**38**
Yard/Food	30	0.3	60	0.18	0.4	0.12	**12**
Other	30	0.3	3	0.01	0.97	0.30	**30**
Total	100	1		0.21		0.80	

Introduction to
Environmental Chemistry

Part (2)
Chemistry of Pollutants

Dr. Ahmed Bdour

Spring 24-25

Pollution and pollutants

- A pollutant is any *material or energy* that can cause harm to a living thing.
- Pollution is a change to the environment that that produces conditions that harm living things.
- A pollutant may not always cause pollution.
  - Why?

Introducing Chemicals into the Environment: Pollutants

- **Fertilizer application in agriculture:**
  - nitrate, phosphate and potassium are added to soil as fertilizer, and dissolve in water.
  - Some will run off into streams and lakes.
    - Fertilizer labels: **15-30-15** means 15% N, 30% P, 15% K

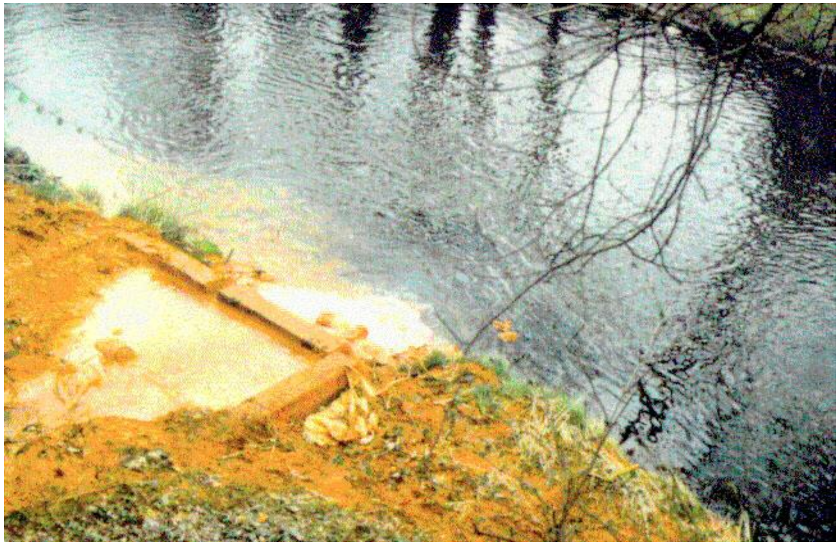
- **Solid Waste:**
  - chemicals can move into the soil when it rains and
  - gases from incinerators can pollute the air.
- *Multi-media pollutant (top 5 outdoor Air pollutants)*
    - Ozone (O3)
    - Nitrogen Oxides (NOx)
    - Carbon Monoxide (CO)
    - Sulfur Dioxide (SO2)
    - Particulate Matter (PM10 and PM2.5)

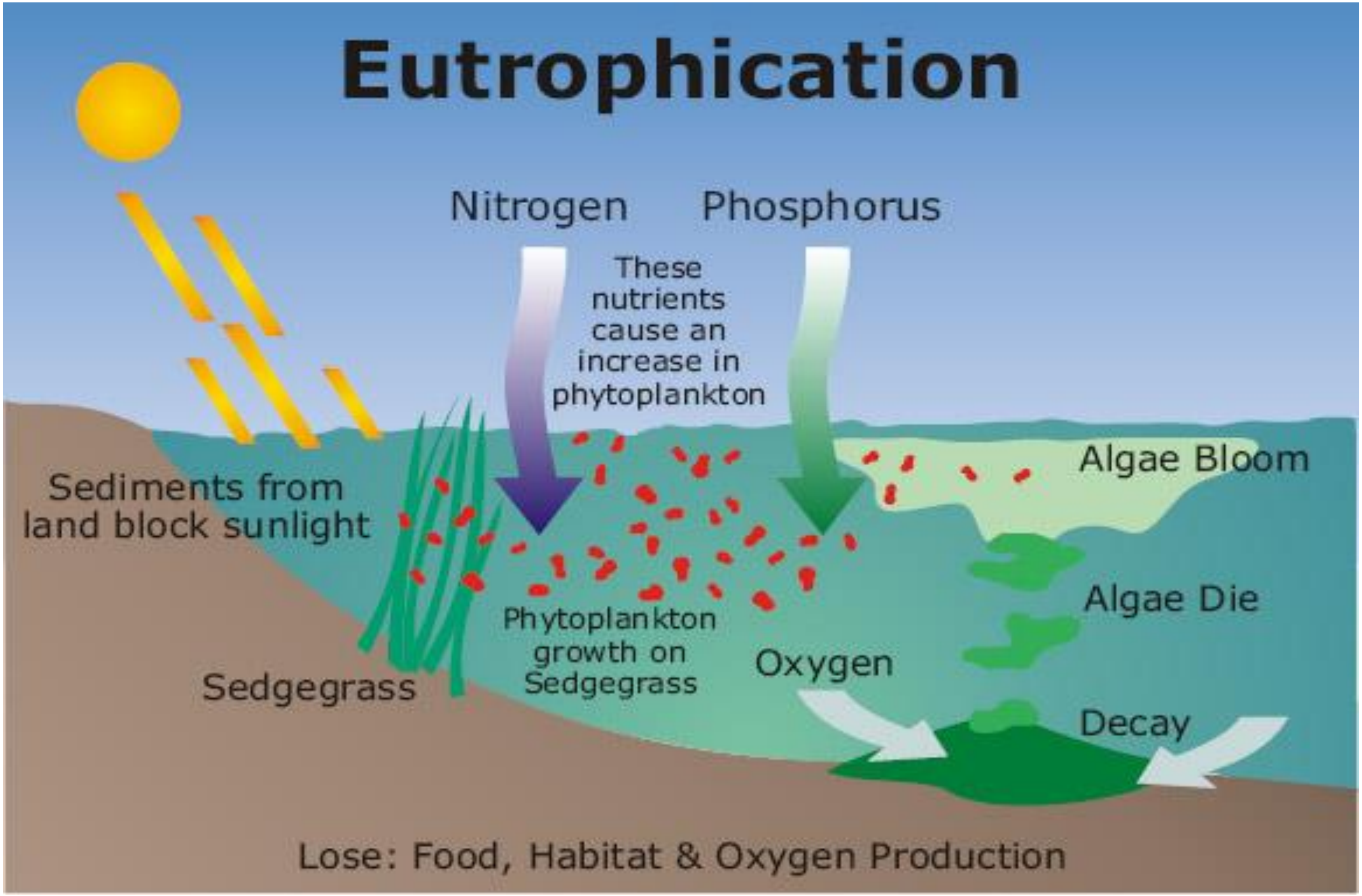
Water Pollutants

- **Wastewater:**
  - dissolved and un-dissolved materials from your house (sewage),
  - both organic and inorganic.
  - Treated water may contain nitrogen or phosphorus from the breakdown of sewage during treatment.
  - Applies to both municipal & industrial wastewater.

Water Pollutants

- With all of the above processes, chemical concentrations are changed.
- In rivers and lakes, nitrate and phosphate levels increase
- Result can be *eutrophication:* over-enrichment of a water body with nutrients, resulting in excessive growth of organisms and depletion of oxygen concentration





Phytoplankton are **microscopic plants**, but they play a huge role in the marine food web. Through photosynthesis, phytoplankton use sunlight, nutrients, carbon dioxide, and water **to produce oxygen and nutrients for other organisms**. With 71% of the Earth covered by the ocean, phytoplankton are responsible for producing up to 50% of the oxygen we breathe.

Pollutants

- **Spraying:**
  - herbicides/fungicides are used to control weeds, and
  - pesticides/insecticides are used to control unwanted insects.
  - Spraying is not very precise, some of these chemicals end up in the atmosphere and our water system
  - Smog (common in cities) can react with water vapour to produce acid rain.

Pollutants

- **Industrial Processes**:
  - electrical power generation,
  - mineral processing and
  - Chemicals (e.g. fertilizer) production.
  - In natural gas processing to remove **sour gas** (hydrogen sulfide), sulphur dioxide is released into the air (causes acid rain).

Chemical pollutants

There are more than 100, 000 synthetic chemicals that are in daily use:

1. solvents
2. detergents
3. dyes and varnishes
4. additives in plastics and textiles
5. chemicals used for construction
6. antifouling agents
7. herbicides, insecticides, fungicides
8. Pharmaceuticals
9. Others …

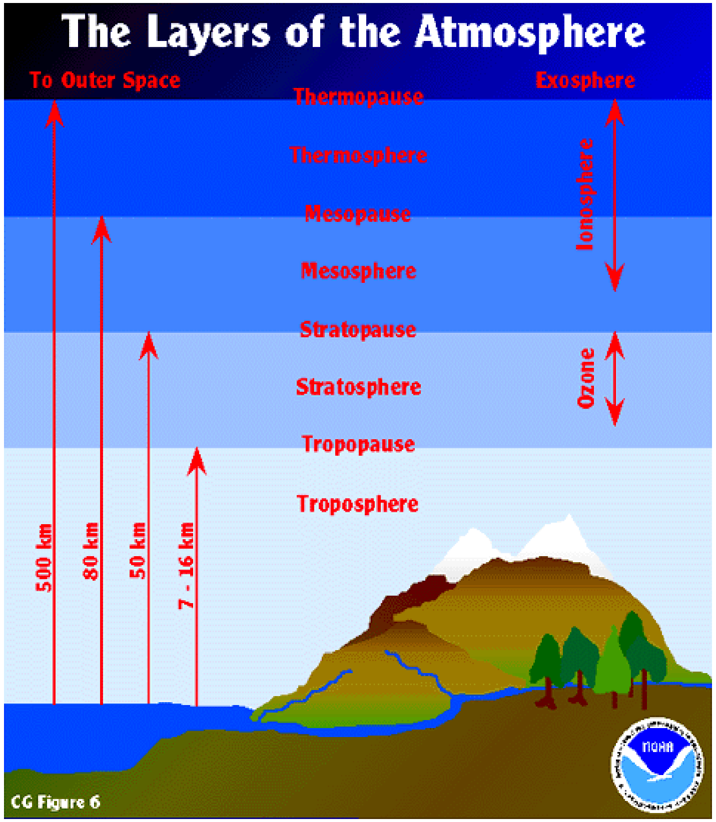
Ozone Layer

Ozone in the Stratosphere

≈ 16 - 50km above the Earth's Surface

acts as a blanket preventing harmful radiation that can marked affect living material from reaching the surface of the Earth.

Most atmospheric ozone is concentrated in a layer in the stratosphere



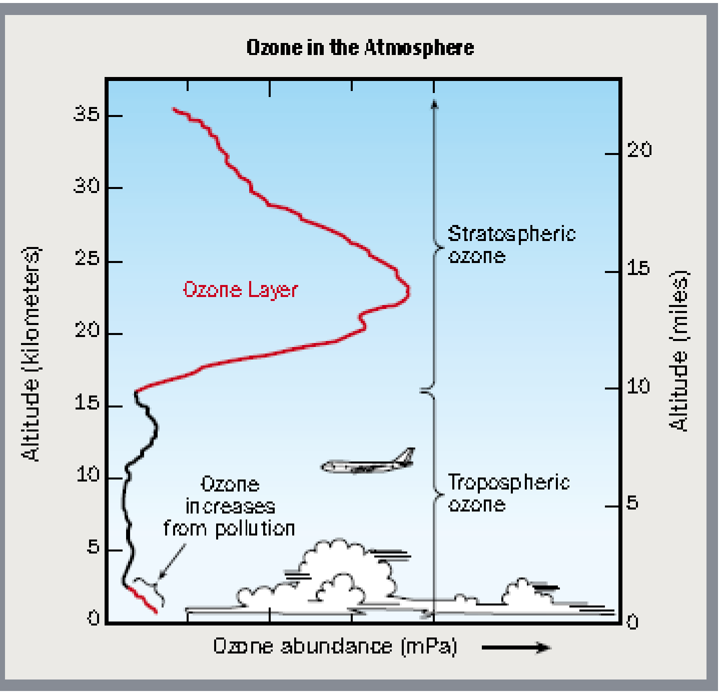


Figure Q1-2 Ozone in the atmosphere. Ozone is present throughout the troposphere and stratosphere. This profile shows schematically how ozone changes with altitude in the tropics. Most ozone resides in the stratospheric "ozone layer." The vertical extent or thickness of this layer varies from region to region and with season over the globe (see Q4). Increases in ozone occur near the surface as a result of pollution from human activities.

ozone layer

- The ozone layer is a natural part of our atmosphere. It acts like a protective sun screen by blocking harmful ultraviolet (UV) rays from the sun.
- Certain chemicals—such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and halons—can damage the ozone layer. These can cause holes to form in the layer and allow more UV rays to reach the earth’s surface. Increased exposure to UV rays is dangerous for people, animals, and plants.
- The ozone hole is not technically a “hole” where no ozone is present, but is actually a region of exceptionally depleted ozone (total column ozone values of less than 220 Dobson Units were not observed prior to 1979) Dobson Unit is the most common unit for measuring ozone concentration

Chemicals that damage the ozone layer

- known as ozone-depleting substances (ODS), are used in:
  - commercial, home and vehicle air conditioners, and refrigerators,
  - foam blowing agents,
  - solvents,
  - aerosol spray propellants,
  - fire extinguishing agents, and
  - chemical reactants

Effects of Reduction in Ozone

- Effects of Reduction

1% Reduction In O_3 ➡ 2% increase in UV-B*

- Skin sunburns, tans, Skin cancer

Absorbed by DNA ➡ DNA damage

- Possible eye cataracts (cloudiness or opacity)
- Interferes with photosynthesis
- Organisms in 1st 5metre of the Oceans at risk (phytoplankton in particular)

*UV-B lamps are lamps that emit a spectrum of ultraviolet light of 290-320 nanometers

Chlorofluorocarbons & Ozone

- CFCs (e.g., Freon) were invented in the 1930s as "miracle" refrigerants and propellant stable, non-toxic, but unreactive in the lower atmosphere.
- Ozone crisis: In the 1970s, scientists found CFCs drift to the stratosphere, where UV light breaks them apart, releasing chlorine radicals that destroy ozone (O_3).
- Result: One chlorine atom can obliterate 100,000+ ozone molecules, creating the ozone hole; leading to the 1987 Montreal Protocol banning CFCs.
- Human ingenuity (CFCs) had unintended global consequences, but swift action helped heal the ozone layer!

- Destruction of the Ozone Layer discovered in 1970's
- Due to CFC's (Chlorofluorocarbons)
  - First synthesized Swartz (1892)

trichlorofluoromethane

$$CCl4 + xHF \rightarrow CCl(4-x)Fx + HCl$$

  - The aliphatic chlorofluoro compounds became the first fluorochemicals to be used commercially after Thomas Midgley and A. L. Henne in 1930, using a modified Swarts reaction, prepared the group of fluorinated methanes and ethanes known as the Freons.
  - Used as refrigerants 1928 (Midgely & Henne)
  - Aerosol Propellants & Air conditioners

Ozone Destruction

Ozone destruction begins when UV light breaks down CFCs, releasing chlorine radicals (Cl^{-}).

1. **Chlorine** from **CFCs** interacts with ozone (**O_3**), forming chlorine monoxide (**ClO**) and **O_2**.
2. Two **ClO** molecules react, forming chlorine peroxide (**Cl_2O_2**).
3. **Sunlight** causes **Cl_2O_2** to break down into **O_2** and free **chlorine** atoms.

The **chlorine** atoms can begin the cycle again.

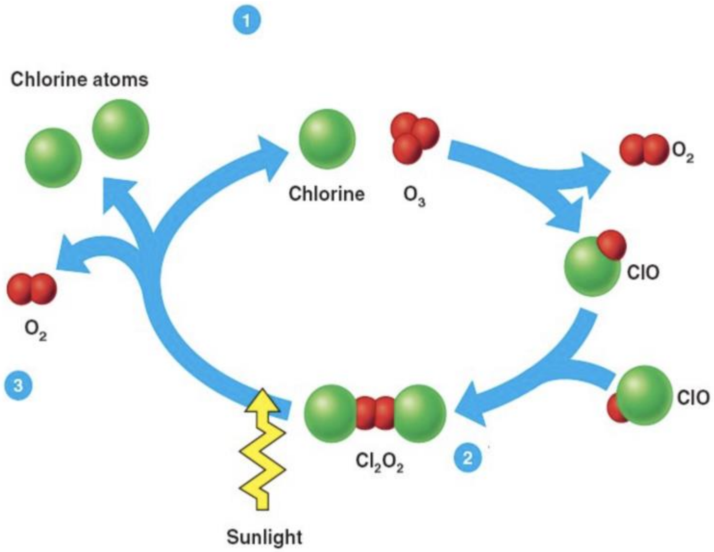
Destruction $CFCl_3 \rightarrow Cl^{\bullet}$ Chlorine

(UV-C, UV-B) Radical

$$Cl^{\bullet} + O_3 \rightarrow O_2 + ClO^{\bullet}$$

$$ClO^{\bullet} + O^{\bullet} \rightarrow Cl^{\bullet} + O_2$$

$$ClO^{\bullet} + ClO^{\bullet} \rightarrow ClOOCl$$ (relatively stable)



Troposphere Contamination by pollutants

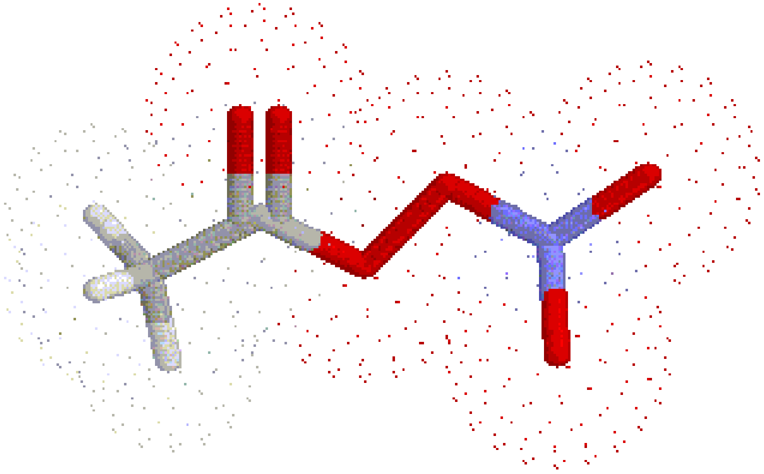
- Air pollution in troposphere (photochemistry)
- chemical processes that occur because of the absorption of light
  - $NO_2 + O_2 + h\nu \rightarrow NO + O_3$
  - $O_3 + h\nu \rightarrow O + O_2$
  - $O + H_2O \rightarrow 2\ OH$ $[OH] \sim 10^6$ molecules/cc
  - OH radical is dominant oxidizer in troposphere!

☐ Tropospheric pollution involves photochemical reactions, where sunlight ($h\nu$) breaks down pollutants like NO_2, forming ozone (O_3) and other reactive species.

☐ Ozone and water vapor further react to produce hydroxyl radicals (OH), the atmosphere's primary "cleaner" (~1 million molecules/cm^3).

☐ OH radicals dominate oxidation in the troposphere, breaking down pollutants but also contributing to smog and health hazards.

Air pollutants: Smog



- "Smoke and fog," a term

  from London episode 1952.
- Engine exhaust components
  1. CO, NO, unburnt hydrocarbons
  2. Lean mix minimizes CO, hc, maximizes NO
  3. Rich mix minimizes NO, maximizes CO, hc
     - Run a little rich and catalytically kill CO to CO_2

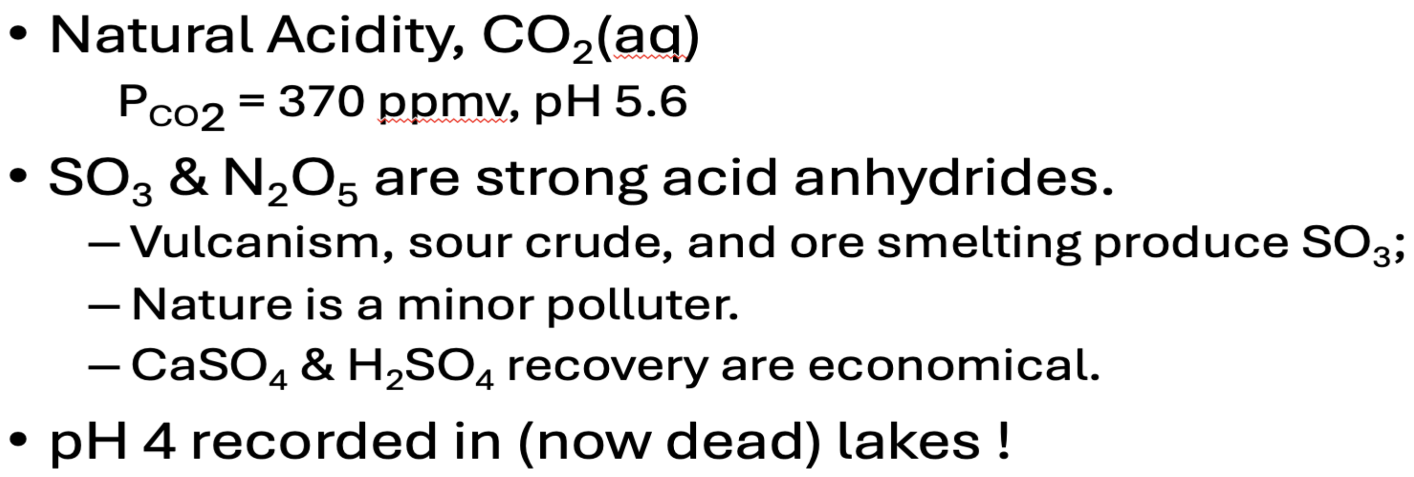
  $OH + CO + O_2 \rightarrow CO_2 + HO_2$

  Hydroxyl radicals (OH) oxidize CO into CO_2, but side reactions produce irritants like PAN, worsening air quality and health impacts.

  Peroxides like **P**eroxy**A**cetyl**N**itrate (PAN) result compound containing an oxygen–oxygen (organic and inorganic),

- Smog (smoke + fog) forms when engine exhaust (CO, NO, unburned hydrocarbons) reacts with sunlight, creating secondary pollutants like ozone and PAN (a harmful peroxide).
- Air-fuel mixtures affect emissions: lean burns reduce CO/hydrocarbons but increase NO, while rich burns do the opposite, catalytic converters help balance this.

Muti-media pollutants: Acid Rain



- Natural Acidity, CO_2(aq)

  P_{CO2} = 370 ppmv, pH 5.6
- SO_3 & N_2O_5 are strong acid anhydrides.
  - Vulcanism, sour crude, and ore smelting produce SO_3;
  - Nature is a minor polluter.
  - $CaSO_4$ & H_2SO_4 recovery are economical.
- pH 4 recorded in (now dead) lakes !

❖ Natural rainwater is slightly acidic(pH ~5.6) due to dissolved CO_2, but human activities (burning fossil fuels, smelting) emit SO_3 and NO_x, forming strong acids like H_2SO_4 and HNO_3.

❖ These pollutants lower rain pH to harmful levels (pH 4 or lower), killing aquatic life and damaging ecosystems; evidenced by "dead" lakes.

❖ Ex. mitigation : Scrubbers recover $CaSO_4$ (gypsum) and H_2SO_4, turning waste into useful products while reducing acid rain.

Greenhouse Effect: Carbon Cycle first

- Natural
  - 2.5×10^{12} ton in atmosphere vs. 1.3×10^{14} in sea.
    - 10^{11} ton yr^{-1} exchange gives ~25 yr residency.
    - So oceans are the perfect sink for excess CO_2.
  - 10^{13} ton in biosphere exchange 6×10^{10} ton yr^{-1}.
- Anthropogenic
  - Fuel burn at 10% of photosynthesis
    - decay exchange increases atmospheric CO_2.
  - Seas *can* absorb but only eventually.

- Natural Balance: Oceans store 50x more CO_2 than the atmosphere, absorbing ~100 billion tons/year, while the biosphere cycles 60 billion tons/year keeping CO_2 levels stable over time.
- Burning fossil fuels (Human Impact) adds CO_2 at 10% of natural photosynthesis rates, overwhelming sinks; oceans absorb excess slowly, but not fast enough to prevent rising atmospheric CO_2.
- Consequence: This imbalance disrupts the carbon cycle, prolonging CO_2's atmospheric residency (~25 years) and intensifying the greenhouse effect, driving climate change.
- Key Idea: Nature's sinks can't keep up with human emissions, causing CO_2 buildup and global warming.

Transfer of Pollutants

- Pollutants are carried through the air by **dispersion**.
- The pollutant is **released** from a source (a factory), is scattered in various directions (dispersion), and then falls to the ground or water (**deposition**).
- Wind direction and speed will influence where the pollution lands.
- When pollution combines with rain or snow it is not usually carried as far.

Transfer of Pollutants

- Pollutants are carried through the soil through the process of **leaching**.
- The pollutant dissolves in water (for example fertilizer, herbicide, pesticide), and then moves downward through the soil.
- The type of soil will affect how much leaching occurs.

Transfer of Pollutants

- Soils with a lot of clay (not porous) do not allow water to soak through (prevents leaching).
- Soils that are very porous (sandy soils) allow water to soak through (allow leaching).
- Some pollutants react with substances in the soil and are neutralized.
- Acid rain can be neutralized by basic soils (soils high in calcium carbonate).

Transfer of Pollutants

- Pollutants that move through the soil can then enter the groundwater.
- Groundwater is water held within porous rock below the soil.
    - If you use water from a well, you are using groundwater.
- The porous nature of the rock allows the groundwater to move great distances, and carry pollutants with it.
- The more porous the rock, the faster the pollutants will move.

Transfer of Pollutants

- Pollutants can also move in surface water (runoff, rivers, streams).
  - Pollutants that dissolve easily in water will be carried a long way.
- Pollutants that don’t dissolve well
  - will *settle* in the river or stream bottom and
  - accumulate causing problems for the organisms.

Transfer of Pollutants

- **Examples** on pollutants which would transfer in the environment (air, water, soil):
  1. minerals in rocks,
  2. organic substances,
  3. leached substances from landfills,
  4. leakage from underground storage and pipelines,
  5. industrial products,
  6. de-icers (salts),
  7. microorganisms from improperly maintained septic tanks,
  8. household chemicals .....

Dilution: reduces the concentration of the pollutant by mixing the polluting substance with large quantities of air or water

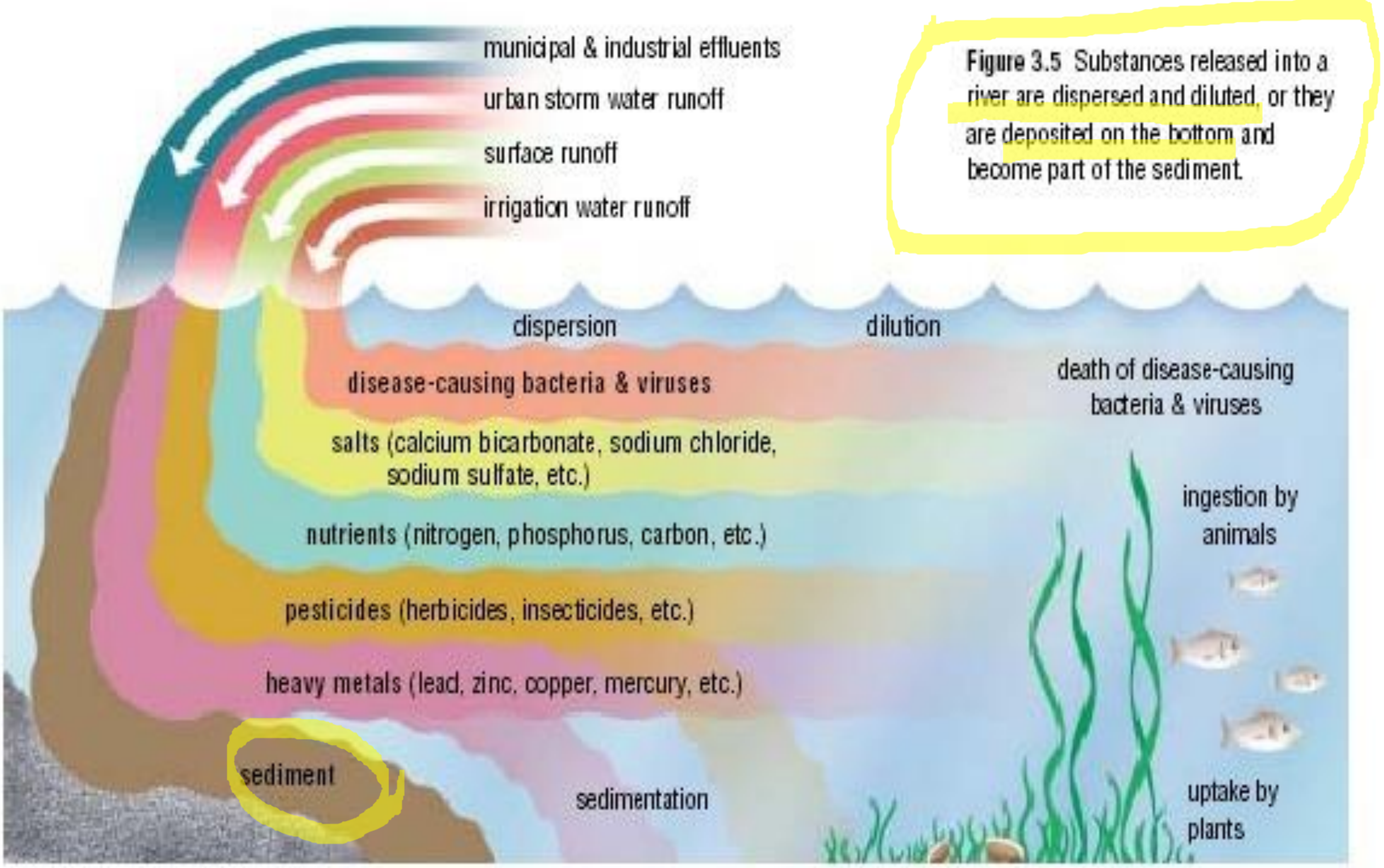


Figure 3.5 Substances released into a river are dispersed and diluted, or they are deposited on the bottom and become part of the sediment.

Environmental Awareness

- As scientists & engineers, we are morally obliged to consider the consequences of our acts.
- We synthesize a molecule for profit but must consider its fate when discarded.
  - E.g., plastic bottles now biodegrade and are no longer immortal.
  - E.g., non-chlorinated refrigerants now cool food without sacrificing the Ozone Layer.

Air Quality Indoor vs Outdoor

Issues and Technologies

Prof. Ahmed Bdour

Spring 2025

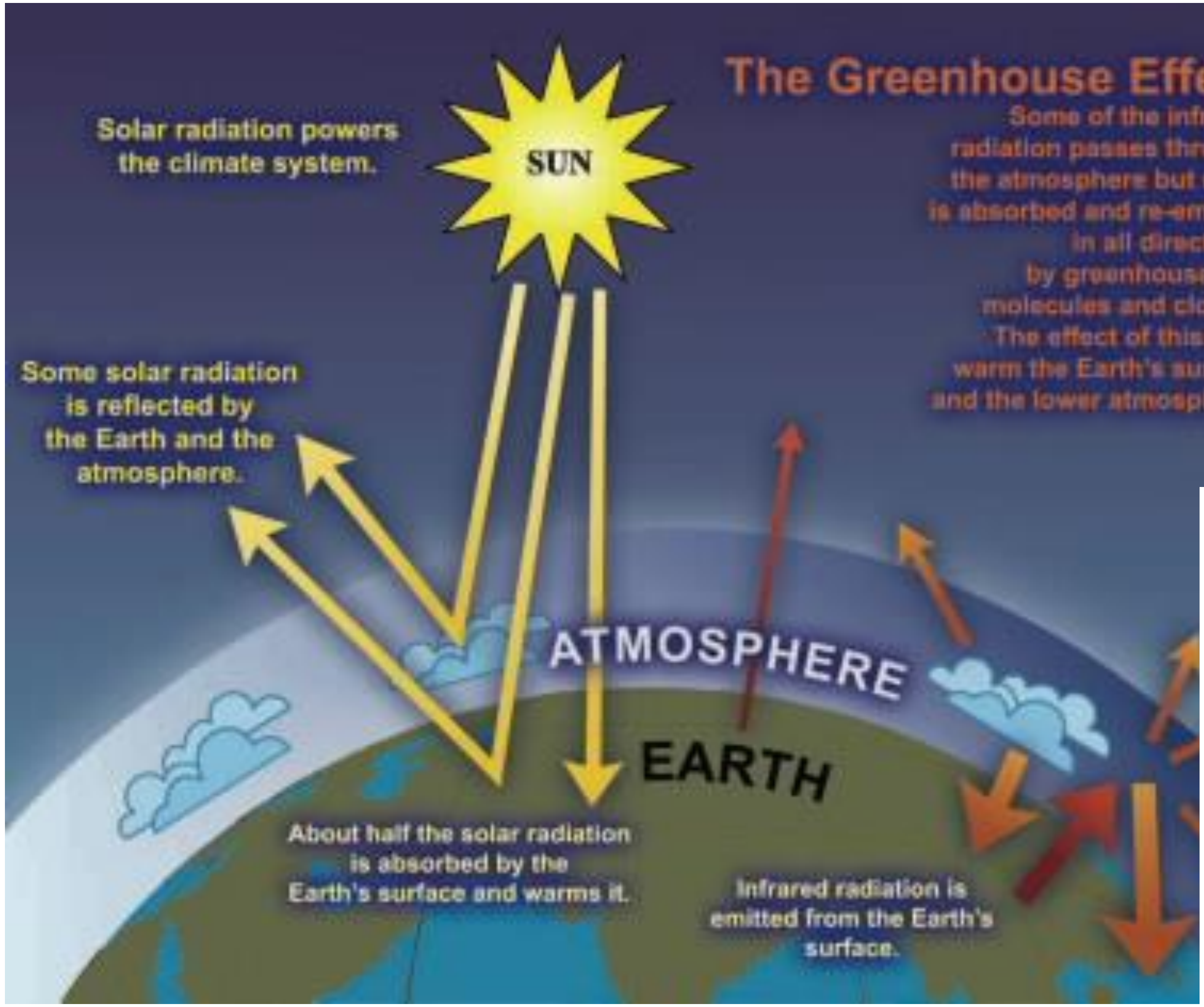
Air Quality Issues and Technologies

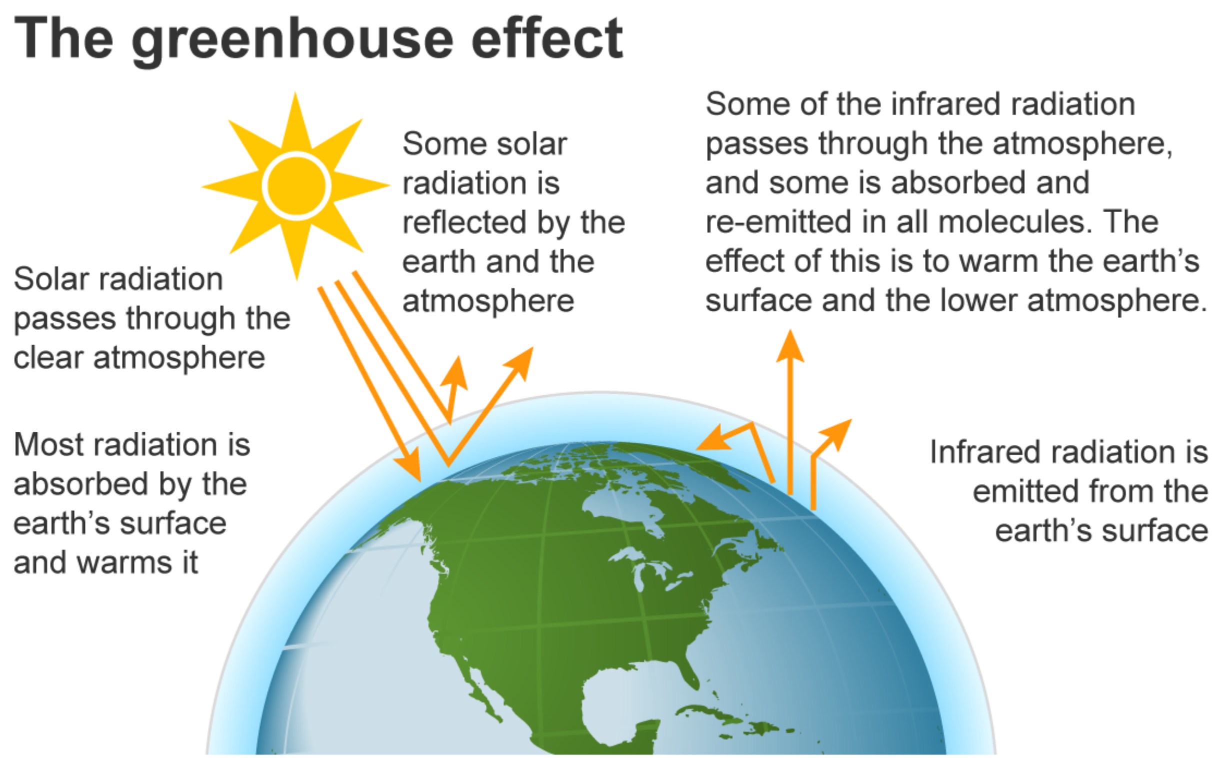
Quality of the air

- Chemicals that humans breathe
  - Toxic, potentially fatal
  - Harmful to lungs
  - Causing cancer
- Chemicals harmful to non-humans
  - Harmful to breathing animals
  - Harmful to vegetation & habitats
  - Impacting water quality
    - Harmful to aquatic life
  - Affecting buildings & monuments
  - Affecting visibility

Climate issues

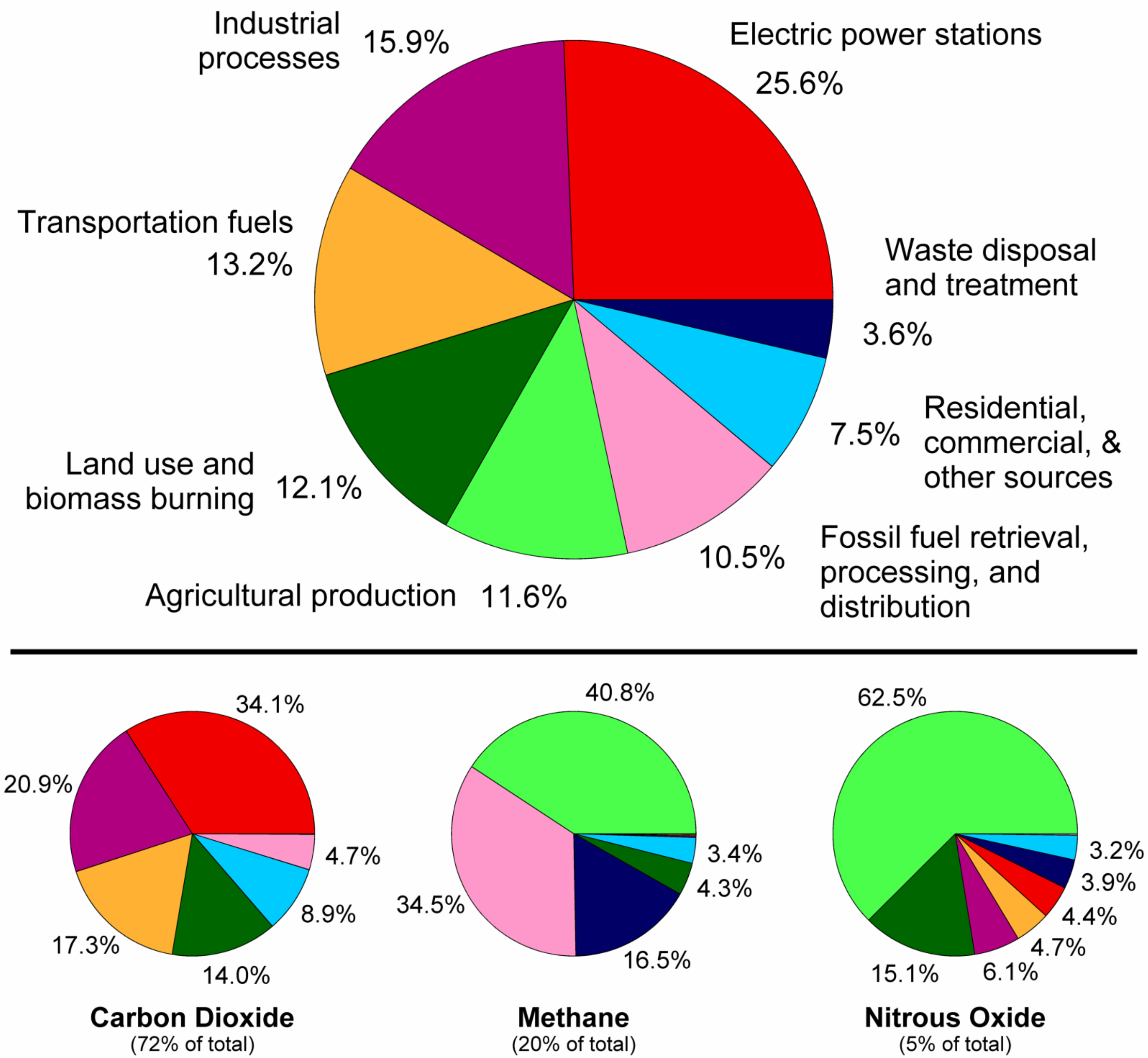
- Excessive greenhouse gases
  - Global warming
    - Change in precipitation patterns
    - Change in vegetation
    - Rising sea level (thermal expansion)
  - Other climatic changes
    - Melting of sea ice (climate feedback)
    - Melting of land ice (glaciers)
      - Rising sea level (added water)
    - More extreme weather





Source: U.S. Environmental Protection Agency (public domain)

Annual Greenhouse Gas Emissions by Sector



A distinction

A distinction needs to be made between indoor and outdoor (personal *vs.* ambient) air quality.

In the United States, indoor, personal air quality is mostly regulated by the Occupational Safety & Health Administration (OSHA) whereas outdoor, ambient air quality is the purview of the Environmental Protection Agency (EPA).

Indoor air quality is addressed, in large parts, at the time of building planning via design of heating and ventilation needs. In industrial settings, air quality is also addressed in relation to the equipment used by workers.

Leaving indoor air quality issues to building planners and ventilation mechanical engineers, the air section of this course is (except for the following few slides) exclusively concerned with outdoor, ambient air pollution and its preventative treatment.

Indoor Air Quality

According to the EPA, people spend on average 90% of their time indoors.
Thus, most of the air they breathe is indoor air, and indoor air quality is of primary importance to human health.

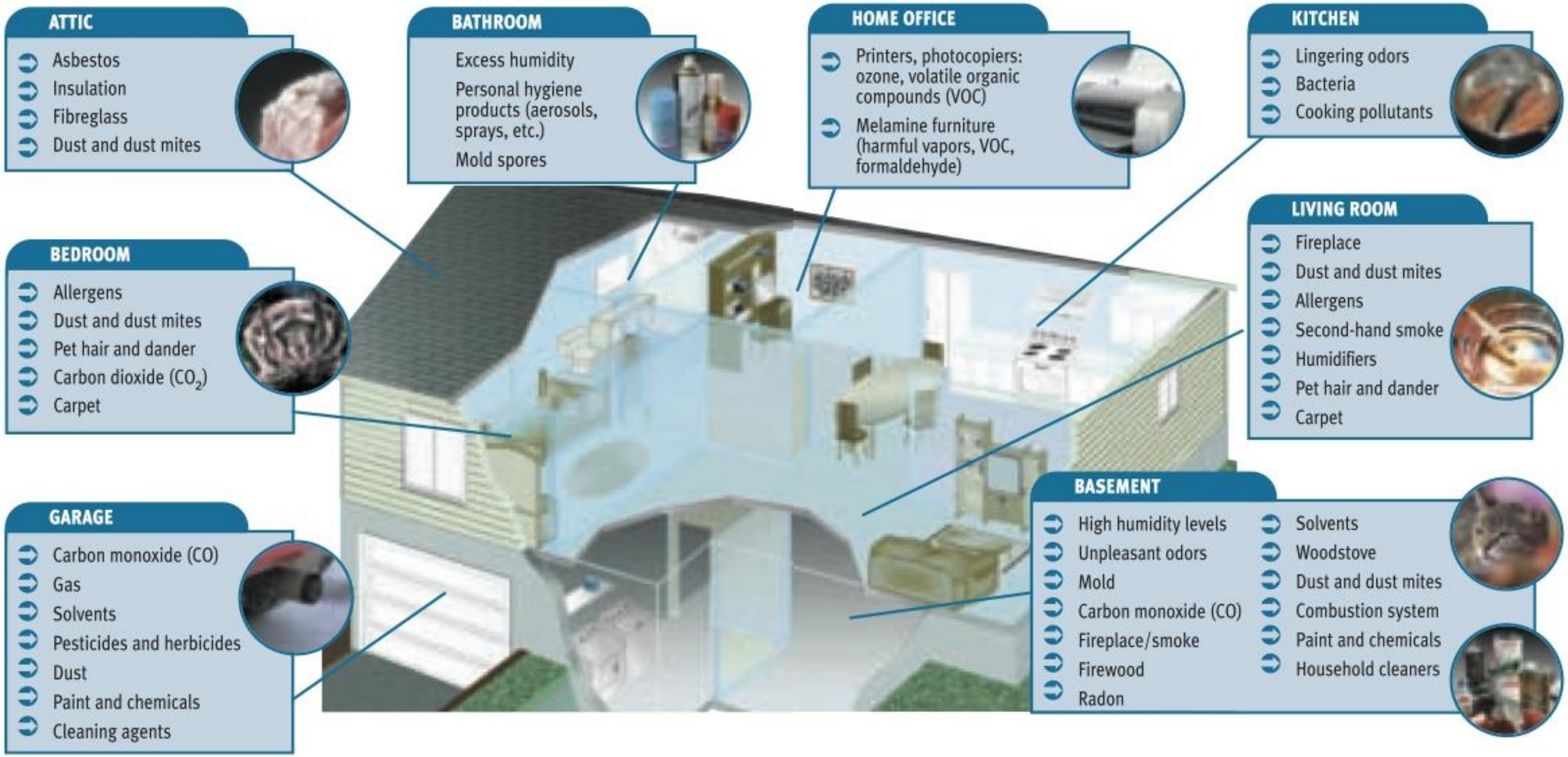
The risks are:

- Disease from airborne bioaerosols (germs in the air; *ex*. after someone sneezing)
- Odors
- Allergic reactions.

www.mtatva.com/en/disease/sick-building-syndrome-meaning-diagnosis-and-overview/

Besides human health, indoor air quality is important in museums for the preservation of valuable pieces of art, and some studies have shown that some indoor air pollutants can affect electronic boards in computers.

PRIMARY SOURCES OF INDOOR AIR POLLUTION



ATTIC

- Asbestos
- Insulation
- Fibreglass
- Dust and dust mites

BATHROOM

Excess humidity

Personal hygiene products (aerosols, sprays, etc.)

Mold spores

HOME OFFICE

- Printers, photocopiers: ozone, volatile organic compounds (VOC)
- Melamine furniture (harmful vapors, VOC, formaldehyde)

KITCHEN

- Lingering odors
- Bacteria
- Cooking pollutants

BEDROOM

- Allergens
- Dust and dust mites
- Pet hair and dander
- Carbon dioxide (CO_2)
- Carpet

LIVING ROOM

- Fireplace
- Dust and dust mites
- Allergens
- Second-hand smoke
- Humidifiers
- Pet hair and dander
- Carpet

GARAGE

- Carbon monoxide (CO)
- Gas
- Solvents
- Pesticides and herbicides
- Dust
- Paint and chemicals
- Cleaning agents

BASEMENT

- High humidity levels
- Unpleasant odors
- Mold
- Carbon monoxide (CO)
- Fireplace/smoke
- Firewood
- Radon
- Solvents
- Woodstove
- Dust and dust mites
- Combustion system
- Paint and chemicals
- Household cleaners

https://onestopcooling.com/residential-services/duct-cleaning/attachment/sources

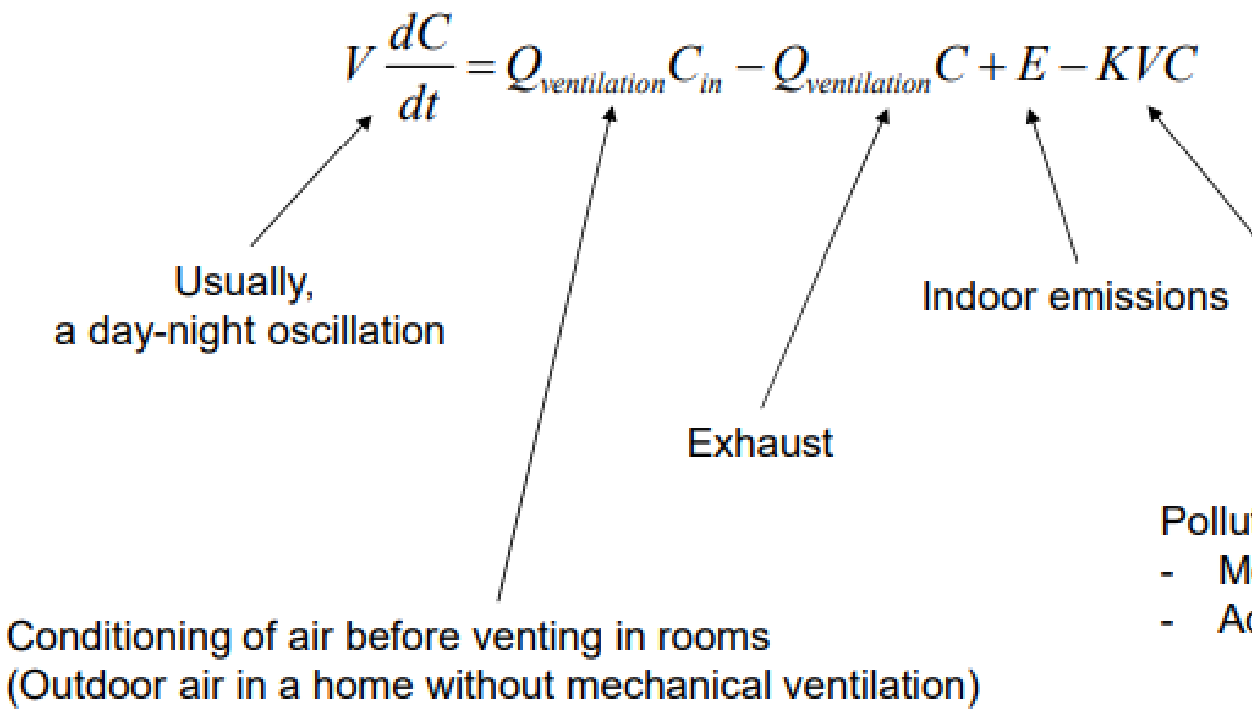
Indoor Air Pollutants

(Mihelcic & Zimmerman, Section 12.4.3)

Pollutant	**Source**	**Permissible Exposure Limit**	**Short-Term Exposure Limit**
Carbon monoxide	Stoves, furnaces	50 ppm	400 ppm
Formaldehyde	Carpets, particle board, finishes	0.75 ppm	2 ppm
Particulate Matter	Cooking, carpets, materials processing	5 mg/m^3	
Volatile Organic Compounds (VOCs)	Solvents, cleaning products, personal-care products	Compound specific	
Radon	Diffusion from underground rocks and soil	100 pCi/L	
Ozone	Photocopiers, printers, air-cleaning devices	0.1 ppm	0.3 ppm
Biological agents (bioaerosols)	Mold, fungi, pets	No exposure	
Tobacco smoke	Cigarettes, cigars, pipes	No exposure	
Asbestos	Wall insulation, floor/ceiling tiles, fireproofing	0.1 fiber/cm^3	

Modeling of indoor air quality is most often performed using a CMFR mass balance, for one room at a time or for the building as a whole.

CMFR: are control volumes for which spatially uniform properties may be assumed



$$V\frac{dC}{dt} = Q_{ventilation}C_{in} - Q_{ventilation}C + E - KVC$$

Usually,
a day-night oscillation

Conditioning of air before venting in rooms
(Outdoor air in a home without mechanical ventilation)

Exhaust

Indoor emissions

Pollutant removal by
- Mechanical equipment, if any
- Adhesion to surfaces

V = volume of control volume (in L)
C = concentration of substance (in g/L)
Q = volumetric flux of fluid (in L/s) S = sum of sources or emissions (in g/s)
K = decay constant (in 1/s)

Air residence time $\theta = \frac{V}{Q_{ventilation}}$ is the primary control parameter.

Worst-case scenario in a modeling study:

Dominance of indoor emission E over import $Q_{ventilation}C_{in}$ and removal KVC

Approximate solution is:

$$V\cancel{\frac{dC}{dt}} = \cancel{Q_{ventilation}C_{in}} - Q_{ventilation}C + E - \cancel{KVC}$$

$$C \approx \frac{E}{Q_{ventilation}} = \frac{E\theta}{V}.$$

Air-quality problems vary with scale

System	Length scale	Time scale	Examples
Indoor environment	10 m	1 hour	Radon in basement Tobacco smoke Airplane cabin air
Industrial plumes	1 km	10 minutes	Toxic organics Mercury and other metals
Urban airshed	10 to 100 km	day-night cycle	Ground-level ozone (smog) Carbon monoxide Particulate matter
Regional / continental	1000 km	several days to a week	Acid deposition
Planetary atmosphere	20,000 km	decades to centuries	Nuclear plant accidents Stratospheric ozone depletion Climate change

It used to be worse a century ago…

Sign of prosperity in Pittsburgh in 1906
(*Source*: Carnegie Library of Pittsburgh)

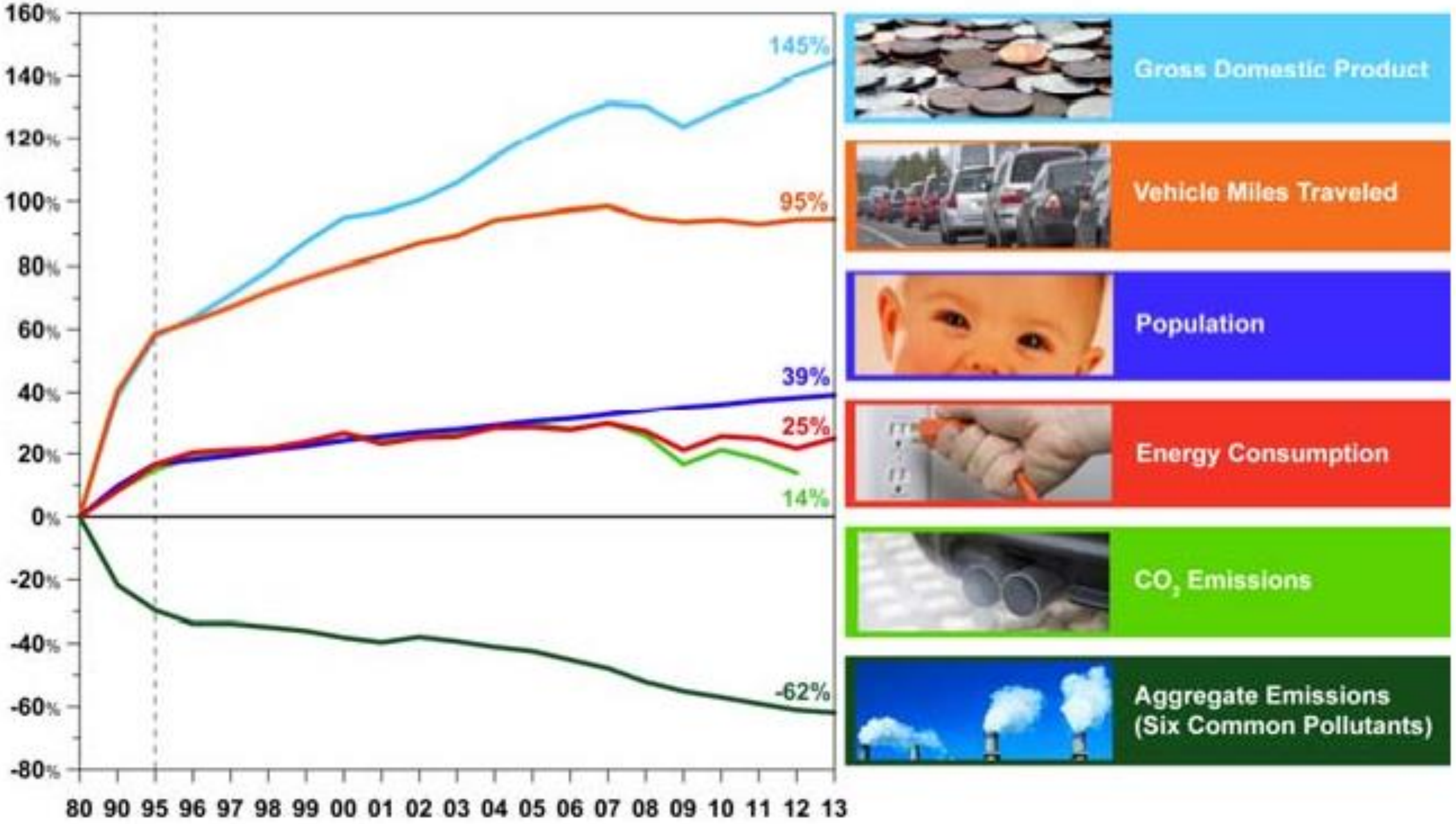
… and still 50 years later …

Riders of a local message delivery company in Los Angeles being outfitted with protective gas masks in the fall of 1955.

At the 1958 Air Pollution Conference,
Dr. James P. Dixon, Health Commissioner of Philadelphia said :

"If gas masks are not to become as common in a hundred years as shoes are today in the civilized world, we should do well to heed our somewhat submerged instincts of self-preservation and remember that – whatever other uses man may devise for it – air is essentially for breathing."

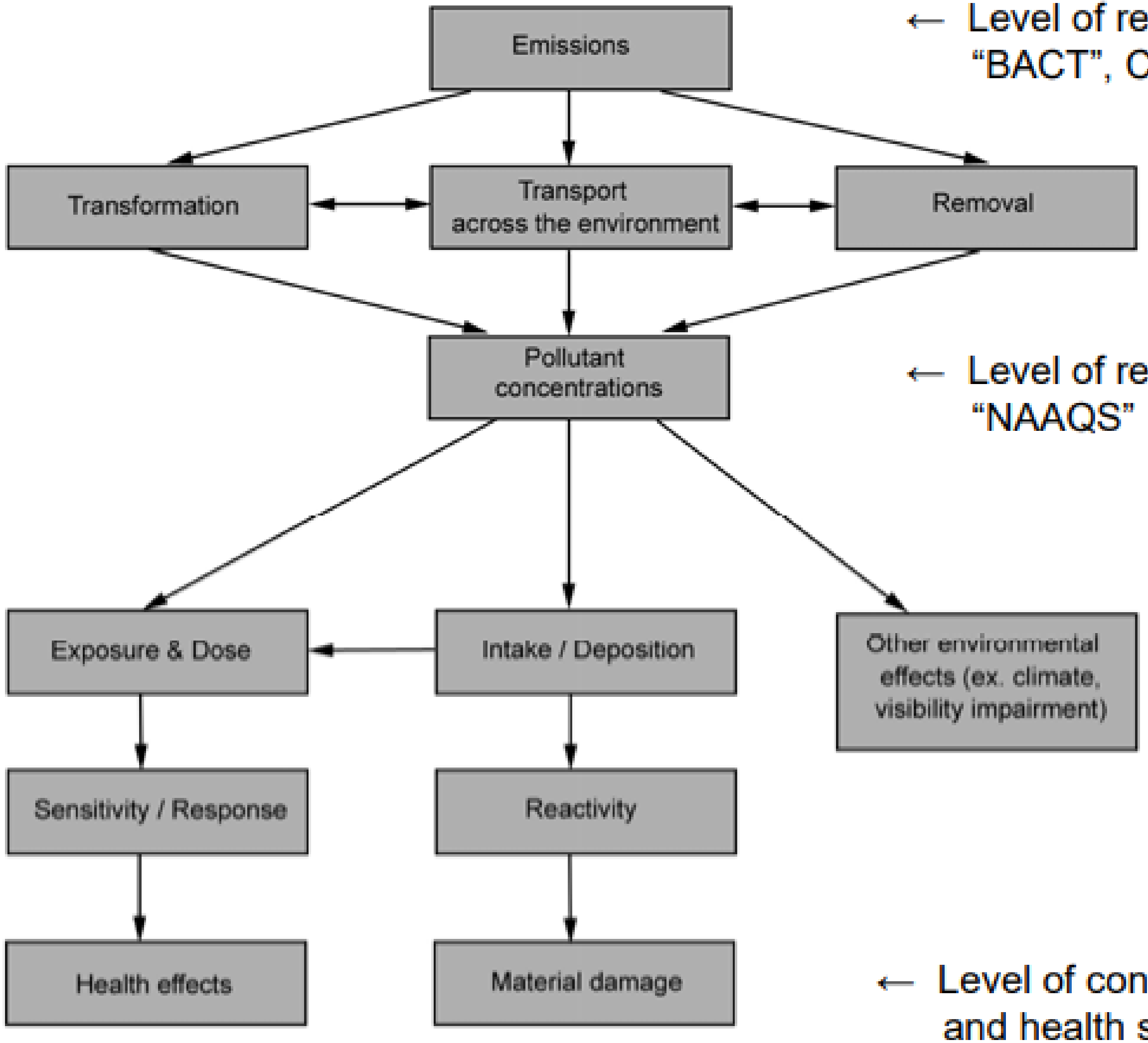
The landmark piece of legislation governing ambient air quality in the U.S. is the **Clean Air Act** (CAA), first enacted in 1970 and subsequently amended several times, with major amendments enacted in 1990.



Great work has been accomplished, especially in the face of a growing population and economy. There is more to be done, however.

For a summary and helpful presentation, see <http://www.epa.gov/oar/caa/>.

Framework for understanding air pollution problems



← Level of regulations
“BACT”, Cap-n-Trade

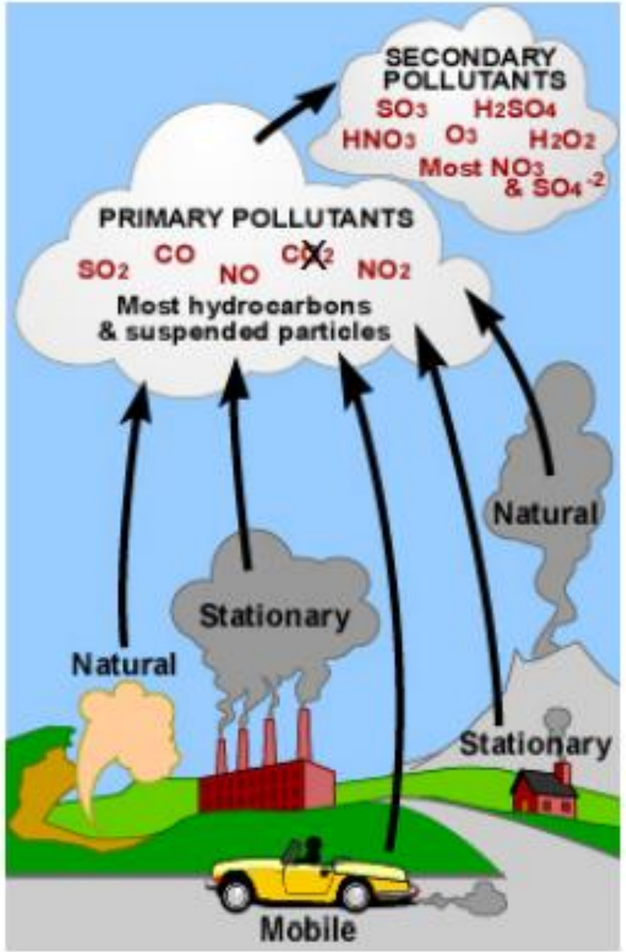
← Level of regulations
“NAAQS”

← Level of concern
and health studies

Distinction: Primary vs. Secondary pollutants

A primary pollutant is one emitted by an identifiable source.

A secondary pollutant is not emitted from a source but formed from precursors through chemical reactions taking place in the atmosphere.



(Formerly found at http://www.epa.gov/apti/course422/ap3.html)

<u>Note</u>:

CO_2 is not to be mentioned here.
It is not a pollutant.
It is a greenhouse gas.

Criteria Pollutants

Criteria Pollutants

In its Title I, the Clean Air Act has identified **six** air pollutants of special concern because of their health and environmental effects.

These six so-called **criteria pollutants** are:

You need to know this list!

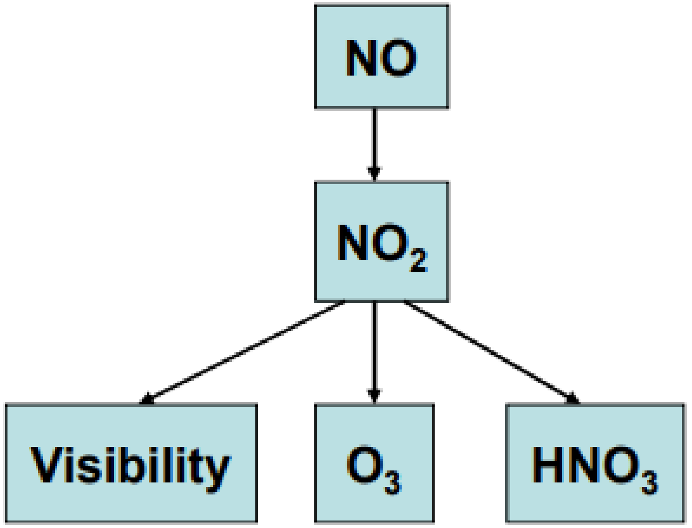
- Carbon Monoxide (CO)
- Nitrogen Dioxide (NO_2)
- Ozone (O_3)
- Sulfur Dioxide (SO_2)
- Particulate Matter (PM)
  subdivision: - Respirable particulate matter (PM_{10}) [size ≤ 10 μm]
  - Fine particulate ($PM_{2.5}$) [size ≤ 2.5 μm]
- Lead (Pb)

Criteria Pollutant	Primary / Secondary	Sources	Effects
CO *Carbon Monoxide*	P	Incomplete combustion	Impairs oxygen-carrying capacity of blood → Asphyxiation & brain damage
NO_2 *Nitrogen Dioxide*	both P and S	From combustion, esp. automobile engines	Respiratory irritant (asthma) Compromised immunity Visibility impairment Acid deposition
O_3 *Ozone*	mostly S	From NO and NO_2	Lung, throat and eye irritant Reduced resistance to infection Damage to vegetation
SO_2 *Sulfur Dioxide*	P	Sulfur in fuels, esp. coal and diesel	Respiratory irritant Heart attack Acid deposition; reduced visibility
PM_{10} and $PM_{2.5}$ *Particulate Matter* (*)	both P and S	Industrial combustion Other industrial activities	Visibility impairment Respiratory impairment
Pb *Lead*	P and S	Industrial processes Lead pipes, solder	Blood poisoning; hypertension Kidney damage; cancer Mental retardation

For added information, see
Mihelcic & Zimmerman, pages 531-537.

(*) also going by name of “aerosols”

Problems caused by nitrogen oxides



NO

NO_2

Visibility

O_3

HNO_3

$$\text{Excitation:} \quad NO_2 + \text{sunlight} \rightarrow NO + O$$

$$\text{Ozone formation:} \quad O + O_2 \rightarrow O_3$$

$$\text{Relaxation:} \quad NO + O_3 \rightarrow NO_2 + O_2$$

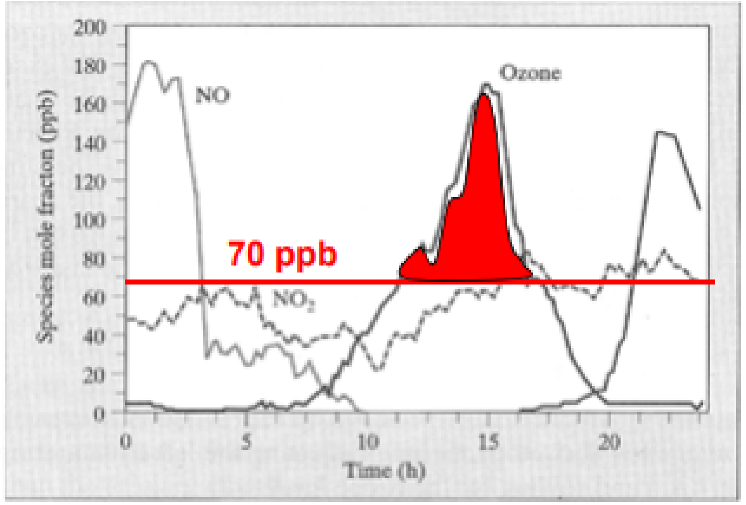
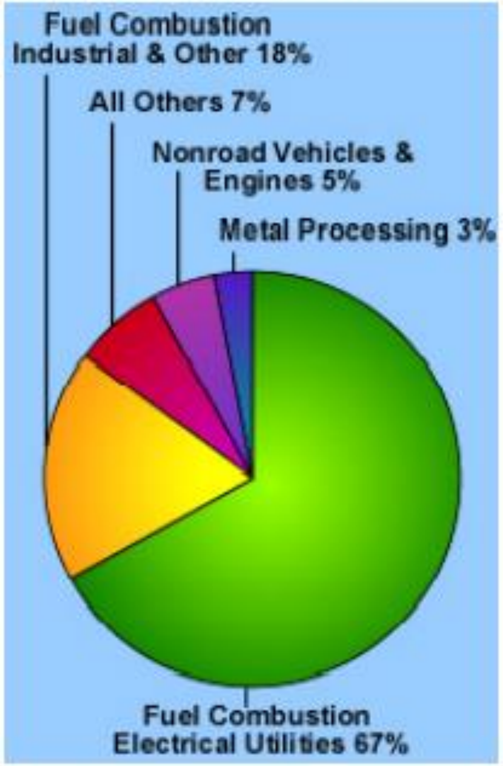


Figure 7.A.4 Ozone, nitric oxide (NO), and nitrogen dioxide (NO_2) mole fractions for a day in the Los Angeles air basin (November 4, 1984). The maximum 8-hour average ozone concentration is 97 ppb, which exceeds the 80 ppb standard. Time 0 corresponds to midnight.

Sources of and problems caused by sulfur oxides



Sources of sulfur oxides according to the EPA

Sulfur in fuel → **SO_x in fumes**

SO_x in fumes → **Respiration irritant**

SO_x in fumes → **H_2SO_4** → **Acid rain**

Acid rain → Damaged buildings & monuments

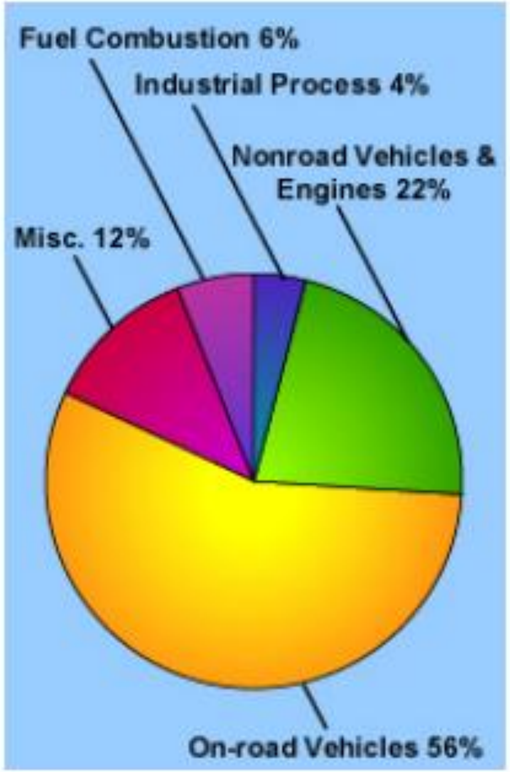
Acid rain → **Tree damage**

Acid rain → **Acid lakes** → **Dead fish**

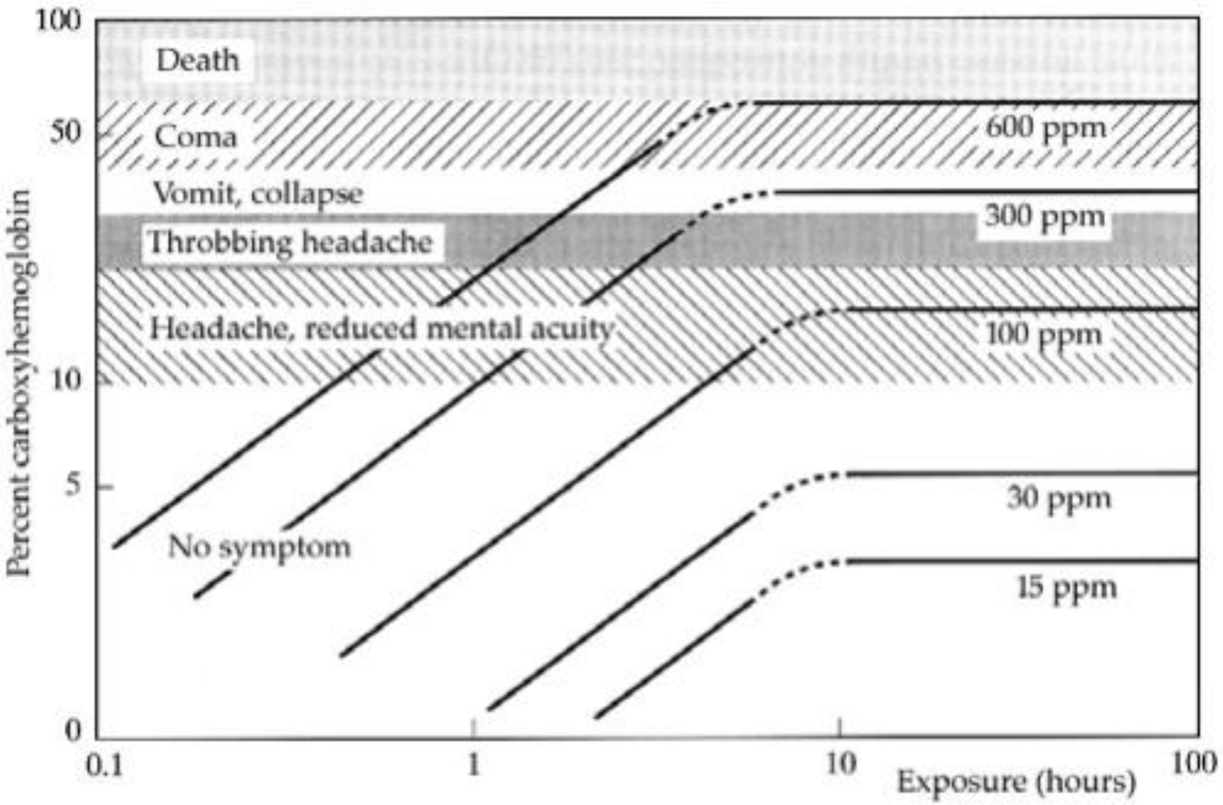
(http://www.merritton.ca/acid55.jpg)

(http://www.robl.w1.com/Pix/I-900991.htm)

Carbon monoxide

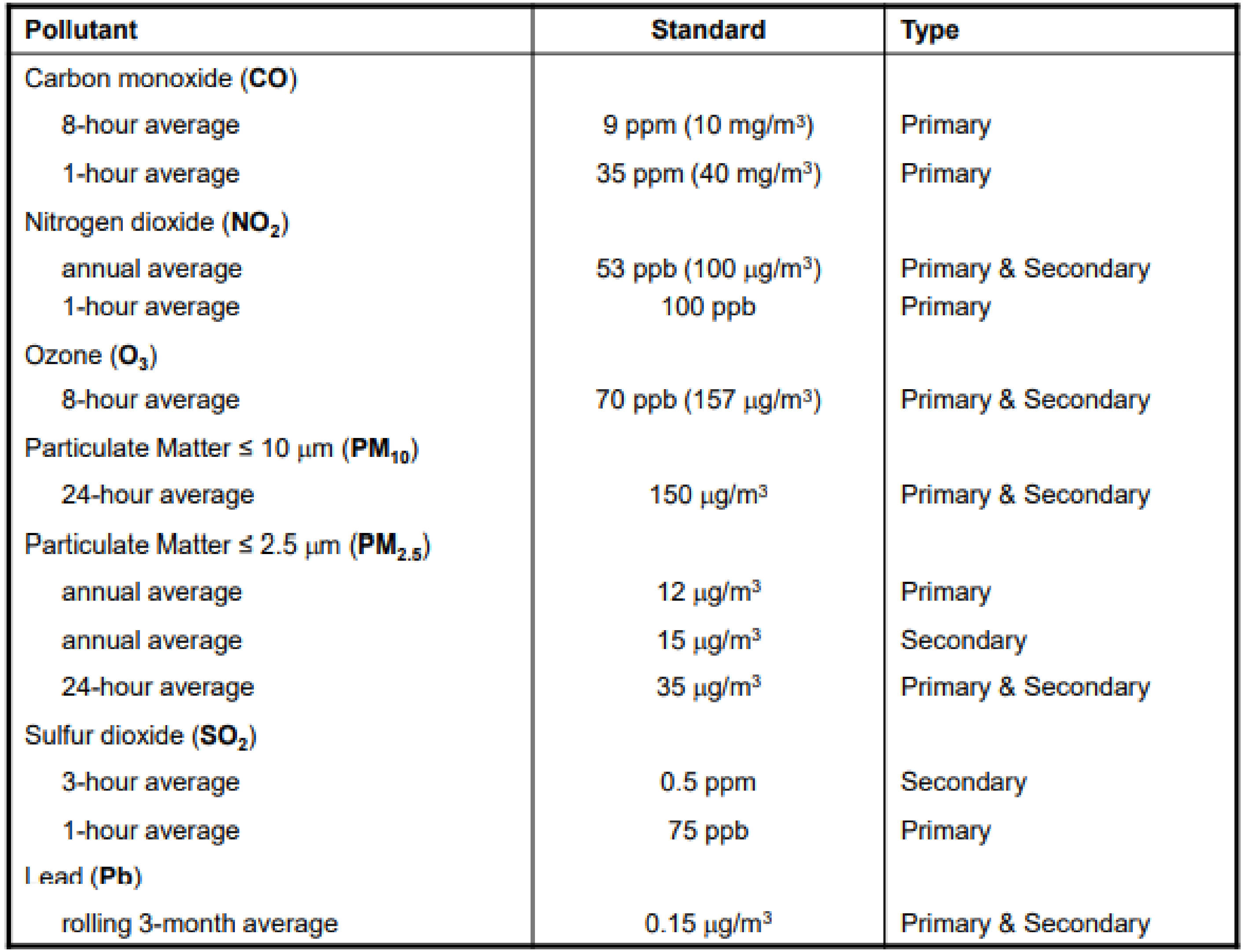


Sources of
carbon monoxide (CO)
according to the EPA



Effects of exposure to carbon monoxide
(From Seinfeld, 1986; Masters, 1998)

The EPA has set National Ambient Air Quality Standards (NAAQS) for these six criteria pollutants.



Pollutant	Standard	Type
Carbon monoxide (**CO**)		
8-hour average	9 ppm (10 mg/m^3)	Primary
1-hour average	35 ppm (40 mg/m^3)	Primary
Nitrogen dioxide (**NO_2**)		
annual average	53 ppb (100 μg/m^3)	Primary & Secondary
1-hour average	100 ppb	Primary
Ozone (**O_3**)		
8-hour average	70 ppb (157 μg/m^3)	Primary & Secondary
Particulate Matter ≤ 10 μm (**PM_{10}**)		
24-hour average	150 μg/m^3	Primary & Secondary
Particulate Matter ≤ 2.5 μm (**$PM_{2.5}$**)		
annual average	12 μg/m^3	Primary
annual average	15 μg/m^3	Secondary
24-hour average	35 μg/m^3	Primary & Secondary
Sulfur dioxide (**SO_2**)		
3-hour average	0.5 ppm	Secondary
1-hour average	75 ppb	Primary
Lead (**Pb**)		
rolling 3-month average	0.15 μg/m^3	Primary & Secondary

www.epa.gov/criteria-air-pollutants/naaqs-table

In some U.S. cities…

Los Angeles, CA

Newark, NJ

Hazardous Air Pollutants

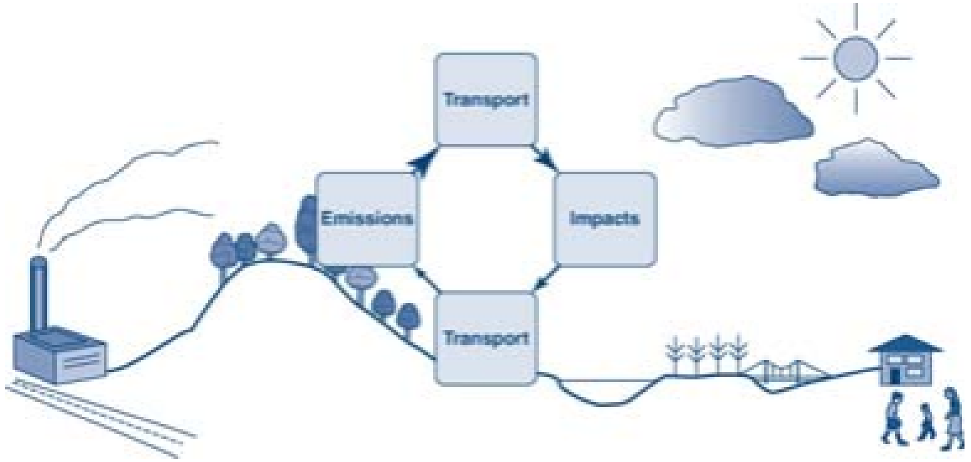
Hazardous air pollutants, also called air toxics, are those pollutants that are known or suspected to cause **cancer** or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.

Examples of air toxic pollutants include *benzene* (from gasoline), *mercury* (from coal combustion and fluorescent lamps), *perchloroethylene* (from dry cleaning facilities), *methylene chloride* (a solvent used in industry).

Some affect humans by direct respiration, others settle and fall in water, affecting people when they drink. On rare occasions, effect is through skin exposure (dermal contact).

Hazardous Air Pollutants (HAPs) are not covered by national ambient air quality standards because they tend not to be uniformly present in the atmosphere but to be in greater concentrations near their sources. Hence, they are not subject to routine monitoring in the air. Instead, emissions are monitored at the source.

Air-Quality Management



Two-prong strategy:

1. Control emissions, with goal of reduction
   - Command & Control – requiring use of *Best-Available ControlTechnology* (BACT)
   - Incentives (cap-n-trade of emissions)

2. Control of ambient concentrations: **Six criteria pollutants**
   - *National Ambient Air Quality Standards* (NAAQS)

Distinction:

Primary pollutant: emitted directly from a source
(source can be regulated)

Secondary pollutant: formed in the air by chemical reactions from precursor species
(no source to be regulated – need to go after chemical precursors)

Emission Factor Modeling

Basic idea

A source emitting a pollutant has a certain level A of activity (action per time).
This activity level leads to a certain amount E of emission (amount emitted per time).
The factor of proportionality is called the
Emission Factor (EF), ratio of amount emitted per action.

Example

An industrial boiler emits 0.6 kg of CO per 1,000 L of oil burned.
EF = 0.6 kg CO/ 1,000 L fuel

So, if the activity level of the boiler is 120,000 L of oil consumed per day,
then A = 120,000 L/day, and
the emission is E = (0.6 kg CO / 1,000 L)x(120,000 L/day) = 72 kg CO per day.

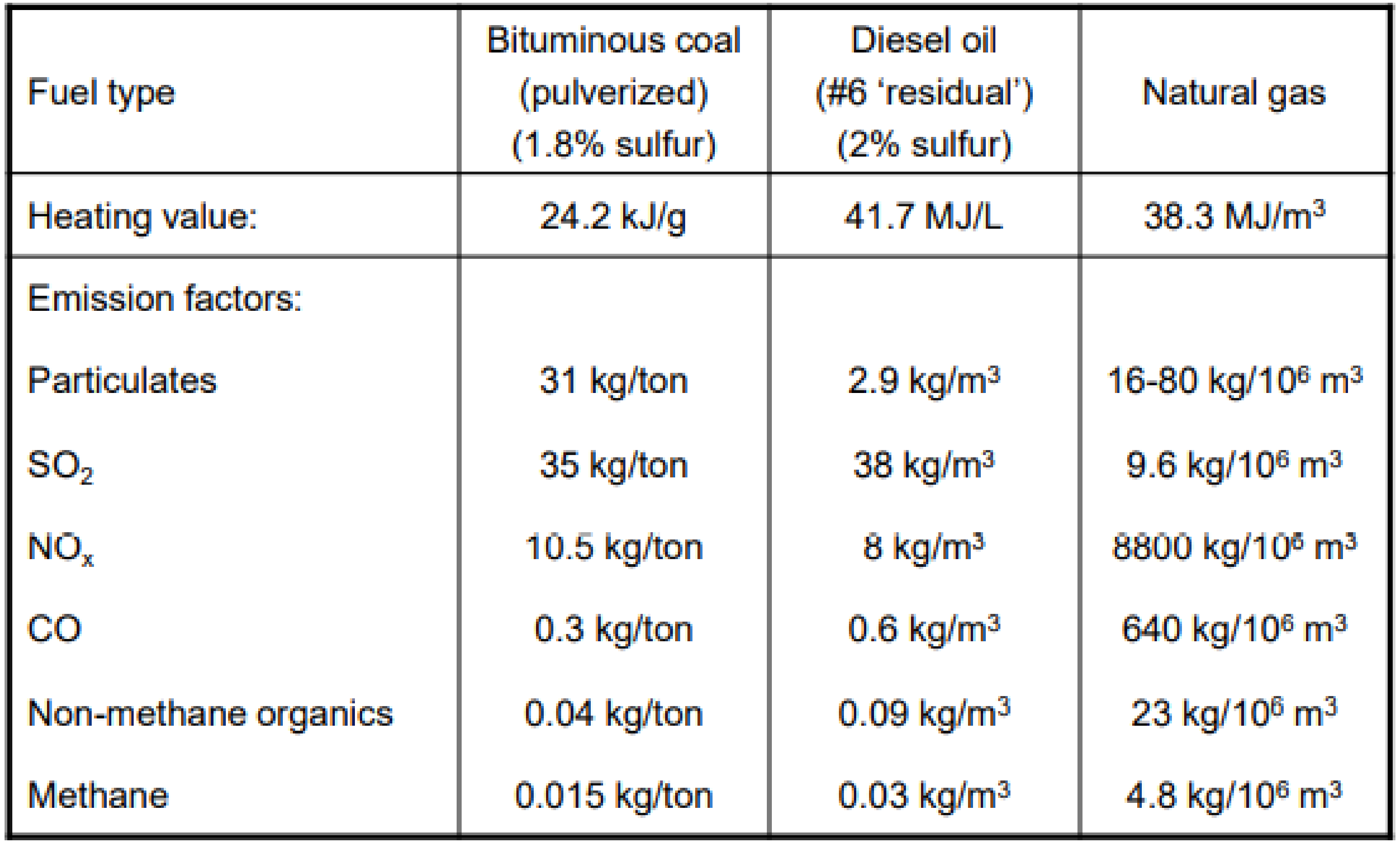
Correction

There may be an emission-control device installed that reduces the outgoing emission by an efficiency factor η (% of emission captured).

→ Formula

$$E = A \times EF \times (1 - \eta)$$

Emission factors for common fuels



Fuel type	Bituminous coal (pulverized) (1.8% sulfur)	Diesel oil (#6 ‘residual’) (2% sulfur)	Natural gas
Heating value:	24.2 kJ/g	41.7 MJ/L	38.3 MJ/m^3
Emission factors:			
Particulates	31 kg/ton	2.9 kg/m^3	16-80 kg/10^6 m^3
SO_2	35 kg/ton	38 kg/m^3	9.6 kg/10^6 m^3
NO_x	10.5 kg/ton	8 kg/m^3	8800 kg/10^6 m^3
CO	0.3 kg/ton	0.6 kg/m^3	640 kg/10^6 m^3
Non-methane organics	0.04 kg/ton	0.09 kg/m^3	23 kg/10^6 m^3
Methane	0.015 kg/ton	0.03 kg/m^3	4.8 kg/10^6 m^3

Example

A coal-fired power plant burns bituminous coal with a 1.8% sulfur content by weight.
To produce 1 MW of electricity, this plant burns 12 tons of coal per day.
The plant is equipped with a wet scrubber that captures 95% of the SO_2 from combustion.

How much SO_2 does the plant release per day when it generates 350 MW of electricity?

Answer

Activity = A = (350 MW) x (12 tons coal / day • MW) = 4,200 tons coal / day

Emission Factor = EF = 35 kg SO_2 / ton of coal (from preceding table)

Emission-control efficiency = η = 95% = 0.95

Emission = $E = A \times EF \times (1 - \eta)$
= (4,200 tons coal / day) x (35 kg SO_2 / ton coal) x (1 – 0.95)
= 7,350 kg SO_2 /day

Best Available Control Technology (BACT)

Most common types of “end-of-pipe” treatment

Particulates: Cyclone

Electrostatic precipitator

Stationary combustion fumes (incl. SO_2): Wet scrubber

Mobile exhaust: Catalytic converter

Figure 1. Top-Inlet Large-Diameter Cyclone

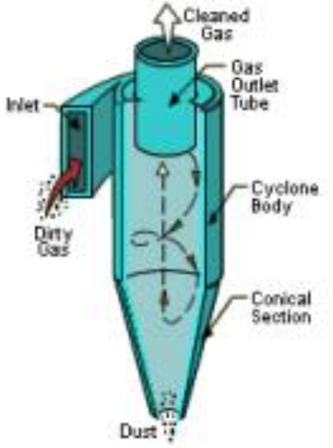


Figure 9. Conventional Electrostatic Precipitator

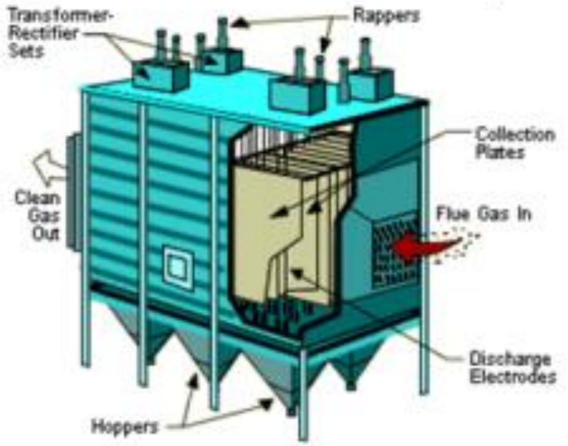
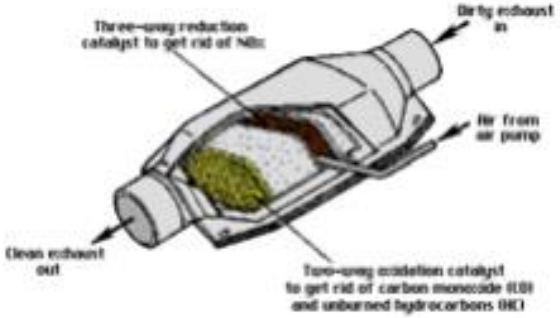


Figure 6. Spray Tower Scrubber



(http://www.aa1car.com/library/p0420_dtc.htm)

(sketches from an earlier http://www.epa.gov/ site)

Gaseous Emission-Control Technologies (Air-Quality Technology)

Two different approaches:

- Pollution Prevention at the source – the better alternative
- Treatment of fumes as they are formed – the classical approach

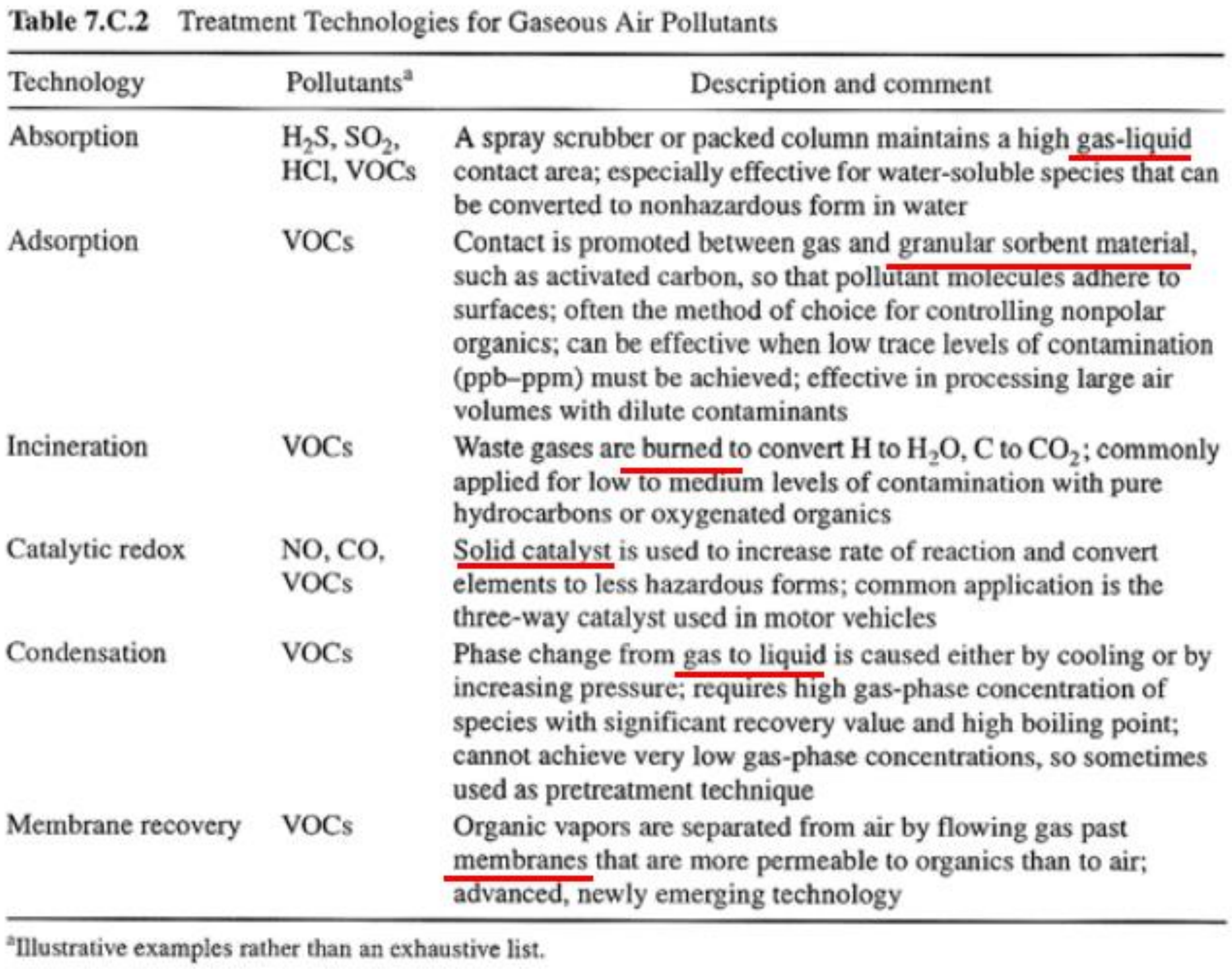
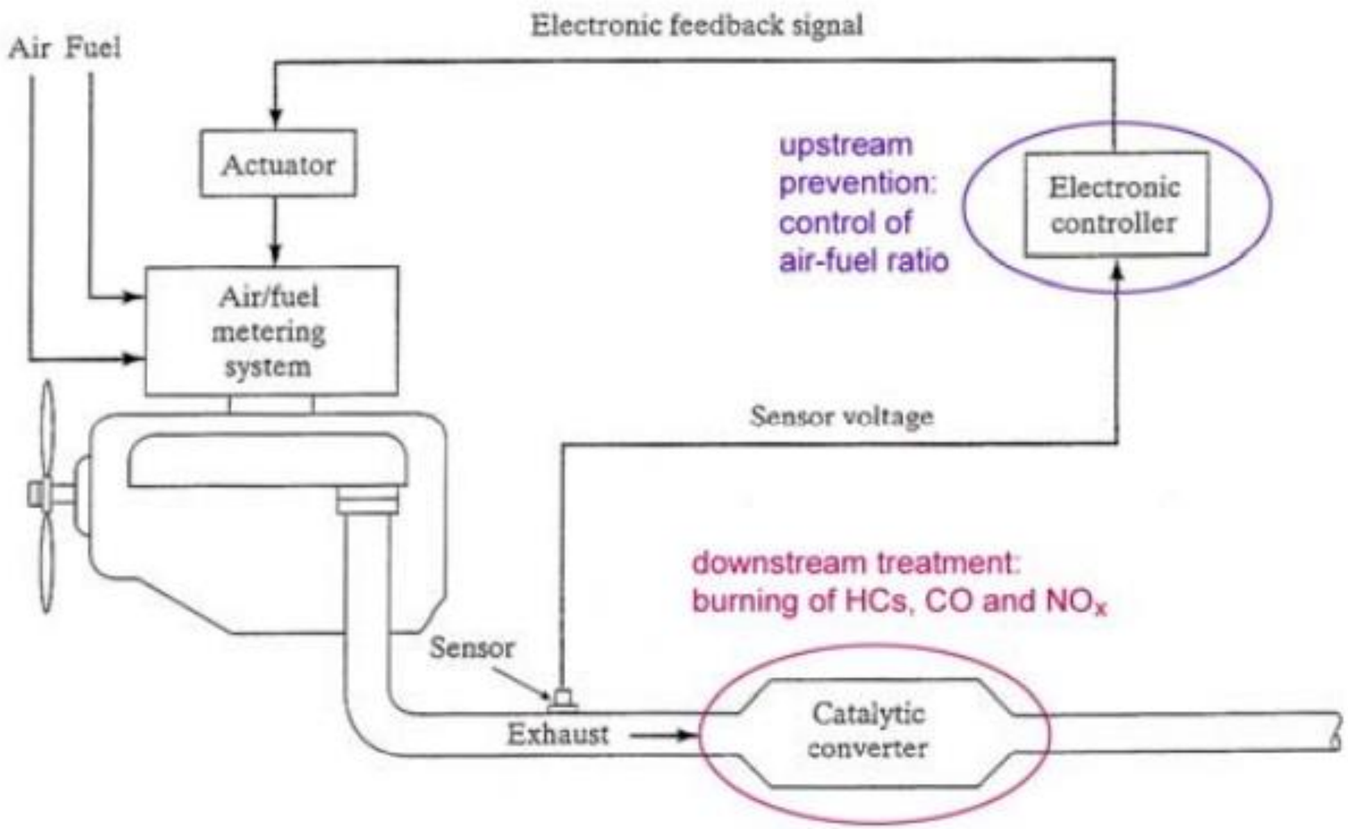


Table 7.C.2 Treatment Technologies for Gaseous Air Pollutants

Technology	Pollutants[a]	Description and comment
Absorption	H_2S, SO_2, HCl, VOCs	A spray scrubber or packed column maintains a high gas-liquid contact area; especially effective for water-soluble species that can be converted to nonhazardous form in water
Adsorption	VOCs	Contact is promoted between gas and granular sorbent material, such as activated carbon, so that pollutant molecules adhere to surfaces; often the method of choice for controlling nonpolar organics; can be effective when low trace levels of contamination (ppb–ppm) must be achieved; effective in processing large air volumes with dilute contaminants
Incineration	VOCs	Waste gases are burned to convert H to H_2O, C to CO_2; commonly applied for low to medium levels of contamination with pure hydrocarbons or oxygenated organics
Catalytic redox	NO, CO, VOCs	Solid catalyst is used to increase rate of reaction and convert elements to less hazardous forms; common application is the three-way catalyst used in motor vehicles
Condensation	VOCs	Phase change from gas to liquid is caused either by cooling or by increasing pressure; requires high gas-phase concentration of species with significant recovery value and high boiling point; cannot achieve very low gas-phase concentrations, so sometimes used as pretreatment technique
Membrane recovery	VOCs	Organic vapors are separated from air by flowing gas past membranes that are more permeable to organics than to air; advanced, newly emerging technology

[a] Illustrative examples rather than an exhaustive list.

(Nazaroff & Alvarez-Cohen, Table 7.C.2, page 444)



upstream prevention: control of air-fuel ratio

downstream treatment: burning of HCs, CO and NO_x

For a three-way catalyst to function correctly, the air-to-fuel ratio must be maintained within a very narrow band. To maintain that ratio, a closed-loop control system monitors the composition of exhaust gases and sends corrective signals to the air-to-fuel metering system. (After Powell and Brennan, 1988)

A three-way catalytic converter performs three simultaneous tasks:

1. Oxidation of carbon monoxide (CO) to carbon dioxide

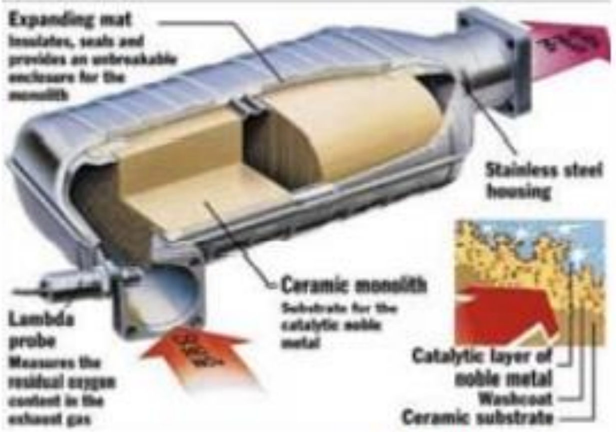
   $2\,CO + O_2 \rightarrow 2\,CO_2$

2. Oxidation of unburned hydrocarbons (HC) to carbon dioxide and water

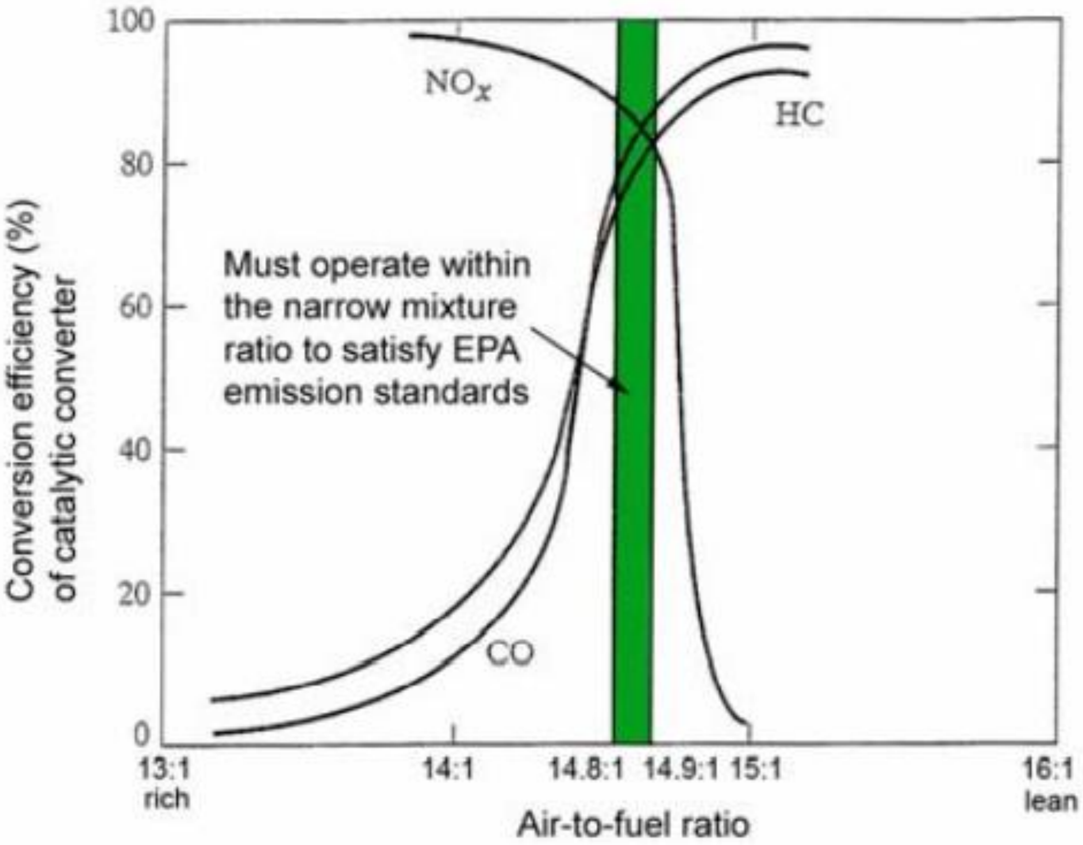
   $C_xH_{2y} + [(2x+y)/2]O_2 \rightarrow x\,CO_2 + y\,H_2O$

3. Reduction of nitrogen oxides to nitrogen and oxygen

   $2NO_x \rightarrow N_2 + x\,O_2$



www.youtube.com/watch?v=E4tk3IgVVgk



Must operate within the narrow mixture ratio to satisfy EPA emission standards

In other words: Choose your pollutant!

Techniques to remove particles from an air stream

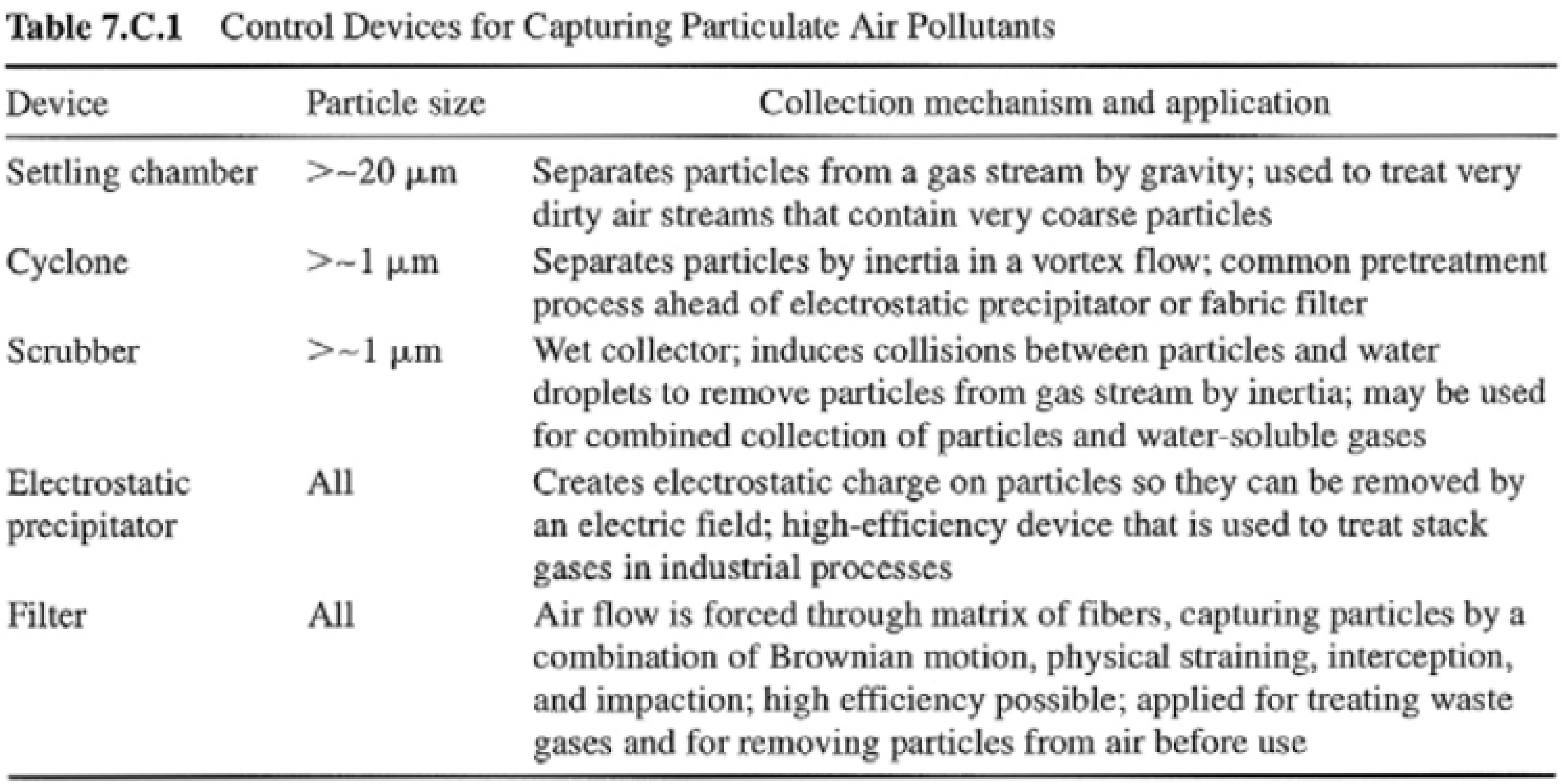


Table 7.C.1 Control Devices for Capturing Particulate Air Pollutants

Device	Particle size	Collection mechanism and application
Settling chamber	>~20 μm	Separates particles from a gas stream by gravity; used to treat very dirty air streams that contain very coarse particles
Cyclone	>~1 μm	Separates particles by inertia in a vortex flow; common pretreatment process ahead of electrostatic precipitator or fabric filter
Scrubber	>~1 μm	Wet collector; induces collisions between particles and water droplets to remove particles from gas stream by inertia; may be used for combined collection of particles and water-soluble gases
Electrostatic precipitator	All	Creates electrostatic charge on particles so they can be removed by an electric field; high-efficiency device that is used to treat stack gases in industrial processes
Filter	All	Air flow is forced through matrix of fibers, capturing particles by a combination of Brownian motion, physical straining, interception, and impaction; high efficiency possible; applied for treating waste gases and for removing particles from air before use

(Nazaroff & Alvarez-Cohen, Table 7.C.1, page 443)

Cyclone Separators and their Design

(Nazaroff & Alvarez-Cohen, pages 445-447 augmented)
(Mihelcic & Zimmerman, Section 12.8.1)

Low-pressure drop cyclone
at Rochester Asphalt Plant
(Victor, NY)

http://www.jtsystemsinc.com/

A cyclone used in a woodshop
(Lebanon, NH)

Cyclone separators have been used in the United States for about 100 years, and are still one of the most widely used of all industrial gas-cleaning devices. The main reasons for the wide-spread use of cyclones are that they are inexpensive to purchase, they have no moving parts, and they can be constructed to withstand harsh operating conditions.

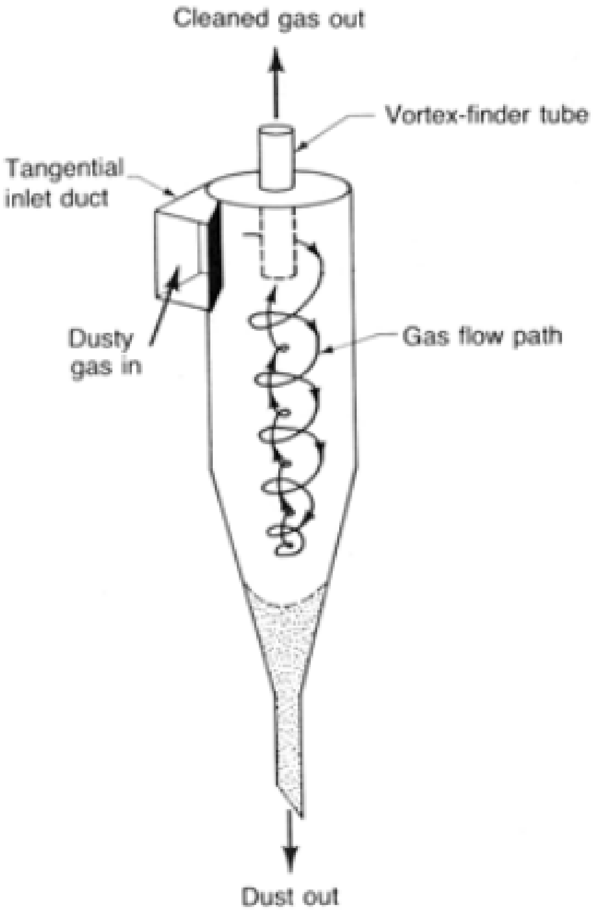
Cyclone Design

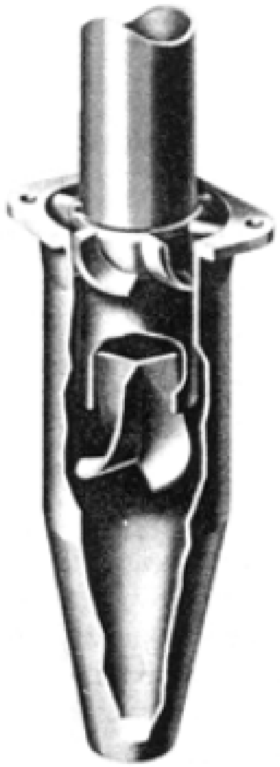
(Adapted from *Air Pollution Control* by C. D. Cooper & F.C . Alley, 1986)

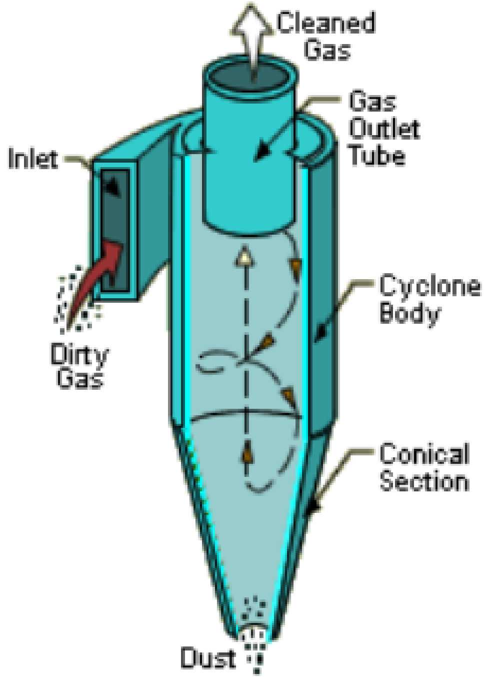
Typically, a particulate-laden gas enters tangentially near the top of the cyclone, as shown schematically in the left figure. The gas flow is forced into a downward spiral simply because of the cyclone's shape and the tangential entry.

Another type of cyclone (a vane-axial cyclone – see right figure) employs an axial inlet with fixed turning vanes to achieve a spiraling flow.

Centrifugal force and inertia cause the particles to move outward, collide with the outer wall, and then slide downward to the bottom of the device. Near the bottom of the cyclone, the gas reverses its downward spiral and moves upward in a smaller inner spiral. The cleaned gas exits from the top through a "vortex-finder" tube, and the particles exit from the bottom of the cyclone through a pipe sealed by a spring-loaded flapper valve or rotary valve.







Advantages of cyclones:

- Low capital cost (few parts, easy to assemble)
- Ability to operate at high temperatures (all metal parts)
- Low maintenance requirements (no moving parts).

Disadvantages of cyclones:

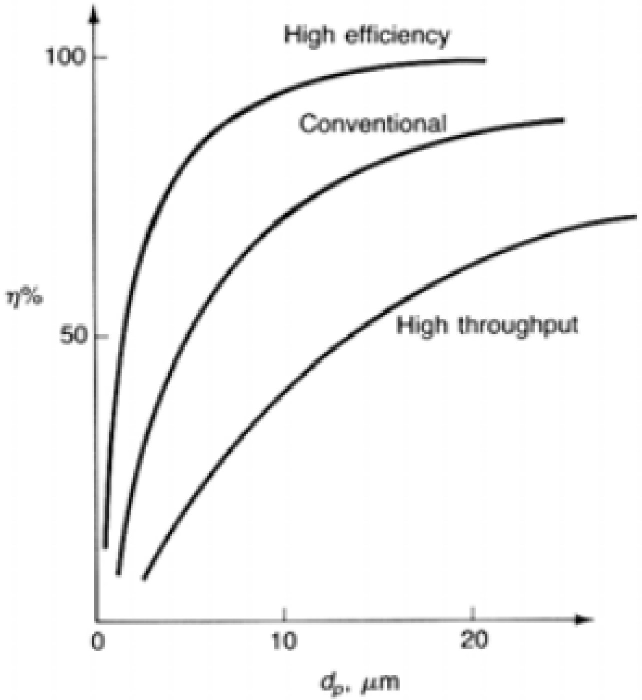
- Low collection efficiencies (especially for very small particles)
  - → cyclones used almost exclusively for particles > 5 μm.
- High operating costs (power required to overcome large pressure drop).

Cyclones by themselves are generally not adequate to meet stringent air pollution regulations, but they serve an important purpose. Their low capital cost and their maintenance-free operation make them ideal for use as pre-cleaners for more expensive final control devices such as baghouses or electrostatic precipitators. In addition to use for pollution control, cyclones are used extensively in process industries. For example, they are used for recovering and recycling certain catalysts in petroleum refineries, for recovering freeze-dried coffee in food processing plants, and for capturing saw dust in a lumber shop.

Cyclones have often been regarded as low-efficiency collectors. However, efficiency varies greatly with particle size and cyclone design. Advanced design work has greatly improved cyclone performance. Some cyclone manufacturers advertise cyclones that have efficiencies greater than 98% for particles larger than 5 microns, and others that routinely achieve efficiencies of 90% for particles larger than 15 – 20 microns.

In general, operating costs increase with efficiency (higher efficiency requires higher inflow pressure), and three categories of cyclones are available: high efficiency, conventional, and high throughput.

Typical efficiency curves for these three types of cyclones are presented in the figure.



Standard Cyclone Dimensions

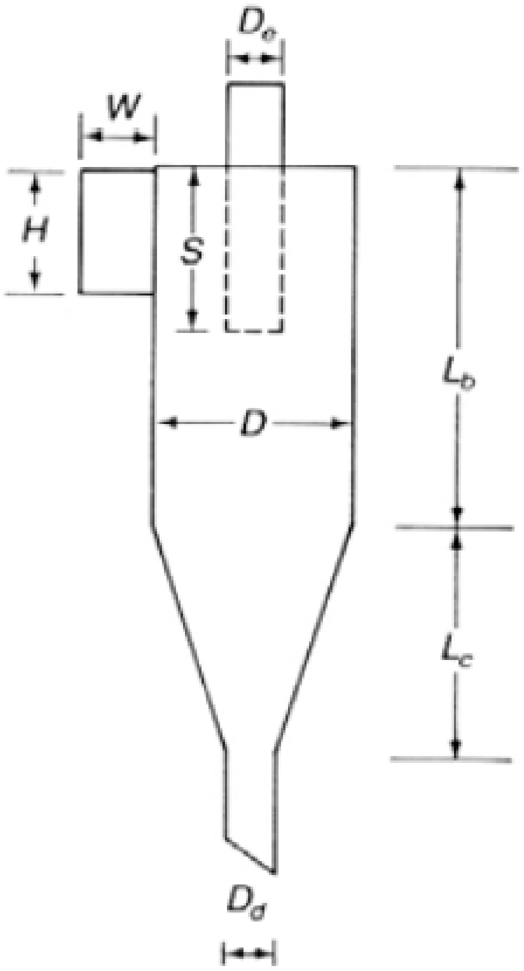
Extensive work has been done to determine in what manner dimensions of cyclones affect performance. In some classic work that is still used today, Shepherd and Lapple (1939, 1940) determined “optimal” dimensions for cyclones. Subsequent investigators reported similar work, and the so-called “standard” cyclones were born.

All dimensions are related to the body diameter of the cyclone so that the results can be applied generally.

The table on the next slide summarizes the dimensions of standard cyclones of the three types mentioned in the previous figure. The side figure illustrates the various dimensions used in the table.

Standard cyclone dimensions

	Cyclone Type					
	High Efficiency		Conventional		High Throughput	
	(1)	(2)	(3)	(4)	(5)	(6)
Body Diameter, D/D	1.0	1.0	1.0	1.0	1.0	1.0
Height of Inlet, H/D	0.5	0.44	0.5	0.5	0.75	0.8
Width of Inlet, W/D	0.2	0.21	0.25	0.25	0.375	0.35
Diameter of Gas Exit, D_e/D	0.5	0.4	0.5	0.5	0.75	0.75
Length of Vortex Finder, S/D	0.5	0.5	0.625	0.6	0.875	0.85
Length of Body, L_b/D	1.5	1.4	2.0	1.75	1.5	1.7
Length of Cone, L_c/D	2.5	2.5	2.0	2.0	2.5	2.0
Diameter of Dust Outlet, D_d/D	0.375	0.4	0.25	0.4	0.375	0.4



SOURCES:
Columns (1) and (5) = Stairmand, 1951; columns (2), (4) and (6) = Swift, 1969; column (3) and sketch = Lapple, 1951.

To be collected, particles must strike the wall within the amount of time that the gas travels in the outer vortex. The *gas residence time* in the outer vortex is

$$\Delta t = \text{path length} / \text{speed} = \pi\, D\, N / V_i$$

$$N = \frac{1}{H}\left(L_b + \frac{L_c}{2}\right)$$

NUMBER OF EFFECTIVE TURNS

where

Δt = time spent by gas during spiraling descent (sec)
D = cyclone body diameter (m or ft)
V_i = gas inlet velocity (m/s or ft/s) = Q/WH
Q = volumetric inflow (m^3/s or ft^3/s)
H = height of inlet (m or ft)
W = width of inlet (m or ft).

$$\boxed{V_i = \frac{Q}{WH}}$$

The maximum radial distance traveled by any particle is the width of the inlet duct W. The centrifugal force quickly accelerates the particle to its terminal velocity in the outward (radial) direction, with the opposing drag force equaling the centrifugal force. The terminal velocity that will just allow a particle initially at distance W away from the wall to be collected in time is

$$V_t = W / \Delta t$$

where V_t = particle drift velocity in the radial direction (m/s or ft/s).

The particle drift velocity is a function of particle size.

Assuming Stokes regime flow (drag force = $3\pi\mu d_p V_t$) and spherical particles subjected to a centrifugal force mv^2/r , with m = mass of particle in excess of mass of air displaced, $v = V_i$ of inlet flow, and $r = D/2$,
we obtain

$$V_t = \frac{(\rho_p - \rho_a) d_p^2 V_i^2}{9 \mu D}$$

where

V_t = terminal drift transverse velocity (m/s or ft/s)
d_p = diameter of the particle (m or ft)
ρ_p = density of the particle (kg/m^3)
ρ_a = air density (kg/m^3)
μ = air viscosity (kg/m.s).

Substitution of the 2nd equation into the 3rd eliminates Δt. Then, setting the two expressions for V_t equal to each other and rearranging to solve for particle diameter, we obtain

$$d_p = \left[\frac{9\,\mu W}{\pi\, N V_i\,(\rho_p - \rho_a)} \right]^{1/2}$$

It is worth noting that in this expression, d_p is the size of the smallest particle that will be collected if it starts at the inside edge of the inlet duct. Thus, in theory, all particles of size d_p or larger should be collected with 100% efficiency.

Note that the units must be consistent in all equations.
One consistent set is m for d_p, R and W; m/s for V_i and V_t; kg/m.s for μ; and kg/m^3 for ρ_p and ρ_a.
An equivalent set in English units is ft for d_p, R and W; ft/sec for V_i and V_t; lbm/ft.sec for μ; and lbm/ft^3 for ρ_p and ρ_a.

The preceding equation shows that, in theory, the smallest diameter of particles collected with 100% efficiency is directly related to gas viscosity and inlet duct width, and inversely related to the number of effective turns, inlet gas velocity, and density difference between the particles and the gas.

In practice, collection efficiency does, in fact, depend on these parameters. However, the model has a major flaw: It predicts that ***all*** particles larger than d_p will be collected with 100% efficiency, which is incorrect. This discrepancy is the result of all our approximations.

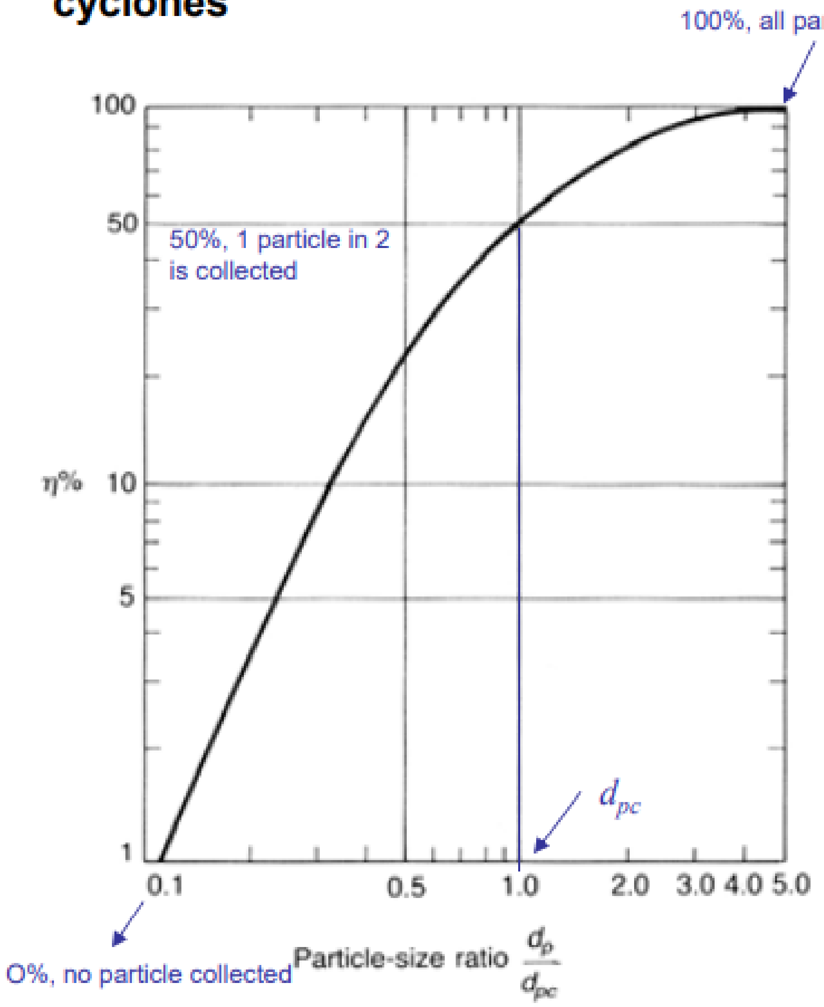
Lapple (1951) developed a semi-empirical relationship to calculate a "50% cut diameter" d_{pc}, which is the diameter of particles collected with 50% efficiency. The expression is

$$\boxed{d_{pc} = \left[\frac{9\,\mu W}{2\pi N V_i (\rho_p - \rho_a)} \right]^{1/2}}$$

where d_{pc} = diameter of particle collected with 50% efficiency.

Note the similarity between the last two equations. The only difference is a factor 2 in the denominator.

Particle collection efficiency versus particle size ratio for standard conventional cyclones



100%, all particles collected

50%, 1 particle in 2 is collected

0%, no particle collected

Lapple then developed a general curve for standard conventional cyclones to predict the collection efficiency for any particle size (see side figure).

If the size distribution of particles is known, the overall collection efficiency of a cyclone can be predicted by using the figure.

Theodore and DePaola (1980) then fitted an algebraic equation to the curve, which makes Lapple's approach more precise and more convenient for application to computers. The efficiency of collection of any size of particle is given by

$$\eta_j = \frac{1}{1+\left(d_{pc}/d_{pj}\right)^2}$$

where

η_j = collection efficiency of particles in the jth size range ($0 < \eta_j < 1$)
d_{pj} = characteristic diameter of the jth particle size range (in μm).

The overall efficiency, called performance, of the cyclone is a weighted average of the collection efficiencies for the various size ranges, namely

$$\boxed{\eta = \frac{\sum \eta_j m_j}{M}}$$

where

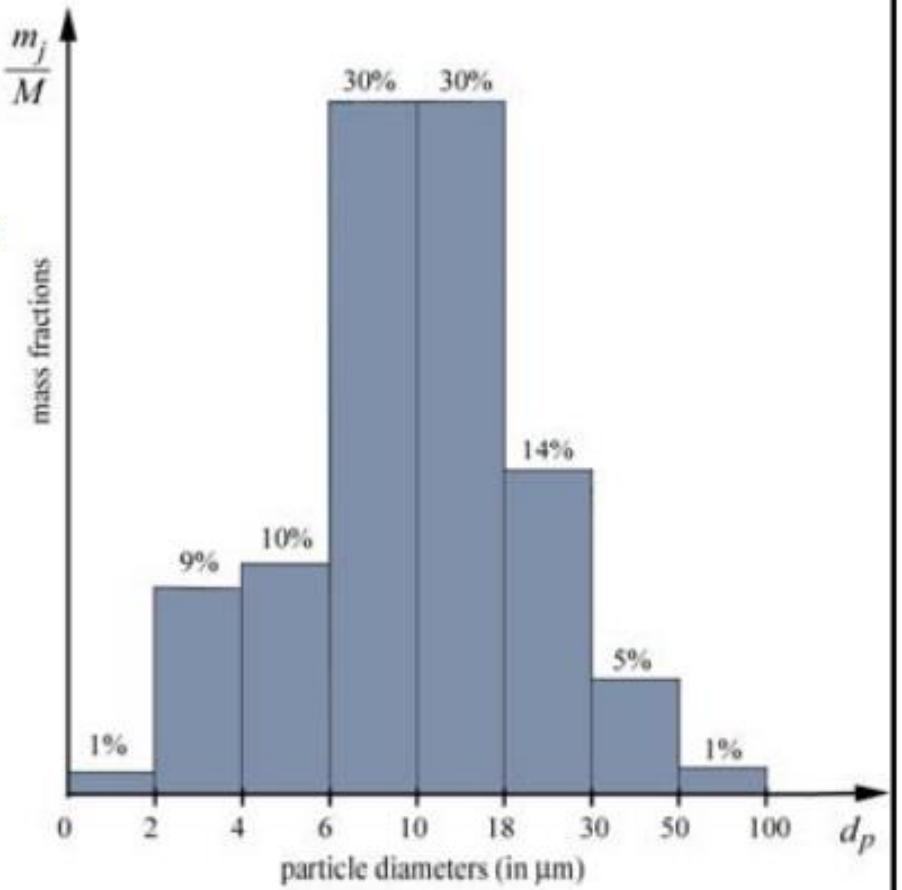
η = overall collection efficiency ($0 < \eta < 1$)
m_j = mass of particles in the jth size range
M = total mass of particles.

Example of Cyclone Analysis

Given:

Conventional type (standard proportions)
D = 1.0 m
Flow rate = Q = 150 m^3/min
Particle density = ρ_p = 1600 kg/m^3
Particle size distribution as follows:

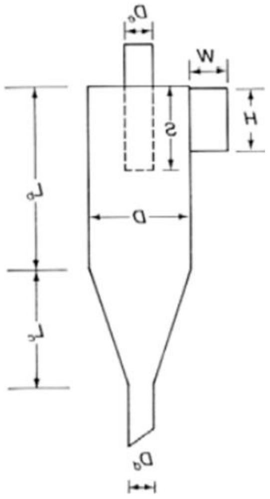
Particle size (d_p)	% mass in that size (m/M)
0-2 μm	1.0%
2-4 μm	9.0%
4-6 μm	10.0%
6-10 μm	30.0%
10-18 μm	30.0%
18-30 μm	14.0%
30-50 μm	5.0%
50-100 μm	1.0%
	100%



Question:

What is the collection efficiency? Use Lapple, 1951 approach

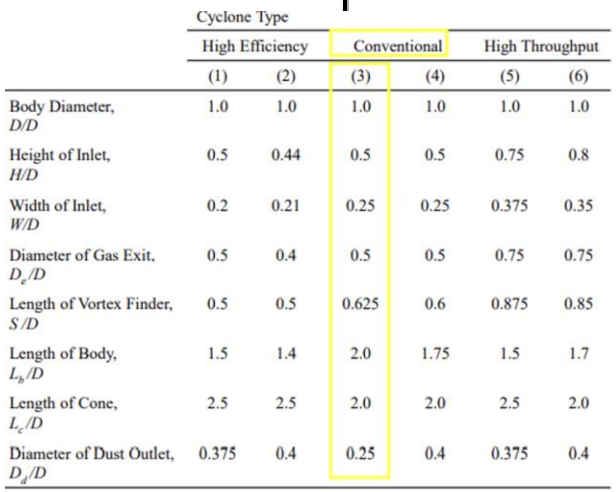
Solution



$$N = \frac{1}{H}\left(L_b + \frac{L_c}{2}\right) = 6$$

$$V_i = \frac{Q}{WH} = \frac{Q}{0.125\,D^2} = 1200\ \text{m/min} = 20\ \text{m/s}$$

$$d_{pc} = \sqrt{\frac{9}{2\pi}\,\frac{\mu W}{NV_i(\rho_p - \rho_a)}} = \sqrt{\frac{9}{2\pi}\,\frac{0.25\,\mu D}{6V_i(\rho_p - \rho_a)}} = 5.79\times10^{-6}\,\text{m} = 5.79\ \mu\text{m}$$



	Cyclone Type					
	High Efficiency		Conventional		High Throughput	
	(1)	(2)	(3)	(4)	(5)	(6)
Body Diameter, *D/D*	1.0	1.0	1.0	1.0	1.0	1.0
Height of Inlet, *H/D*	0.5	0.44	0.5	0.5	0.75	0.8
Width of Inlet, *W/D*	0.2	0.21	0.25	0.25	0.375	0.35
Diameter of Gas Exit, D_e/D	0.5	0.4	0.5	0.5	0.75	0.75
Length of Vortex Finder, *S/D*	0.5	0.5	0.625	0.6	0.875	0.85
Length of Body, L_b/D	1.5	1.4	2.0	1.75	1.5	1.7
Length of Cone, L_c/D	2.5	2.5	2.0	2.0	2.5	2.0
Diameter of Dust Outlet, D_d/D	0.375	0.4	0.25	0.4	0.375	0.4

Size range (in μm)	Average size d_p (in μm)	Collection efficiency η	Mass fraction m/M	Contribution to performance $\eta \times m/M$
0 – 2	1	2.9%	0.01	0.029%
2 – 4	3	21.1%	0.09	1.903%
4 – 6	5	42.7%	0.10	4.268%
6 – 10	8	65.6%	0.30	19.678%
10 – 18	14	85.4%	0.30	25.613%
18 – 30	24	94.5%	0.14	11.953%
30 – 50	40	97.9%	0.05	4.897%
50 - 100	75	99.4%	0.01	0.994%
			1.00	**70.6%**

$$\eta_j = \frac{1}{1 + \left(d_{pc}/d_{pj}\right)^2}$$

$$\eta = \frac{\sum \eta_j m_j}{M}$$

Two distinct approaches in cyclone analysis

1. *Performance analysis*

The cyclone exists – All dimensions and characteristics are known.
The engineer calculates its collection efficiency (η).

2. *Design analysis*

The cyclone needs to be chosen for a given task.
A target performance (η) is imposed.
Typically, the engineer knows the amount of air flow (Q),
& characteristics of particles (range of d_p's, mass fractions m_j/M).
The engineer needs to determine
the type of cyclone needed (conventional, high-throughput, …)
the required size of the device (diameter D).

Note: Design analysis usually necessitates an iterative approach.
(Successive guesses until the required performance is achieved.)

Environmental Risk Assessment (ERA)

HU-Spring Semester, 2025

What is ERA?

- **Qualitative and quantitative valuation of environmental status**

- Components of ERA
  - ☐ human health risk assessment;
  - ☐ ecological risk assessment.

When to conduct risk assessment

- ERA should be conducted when
  - it is determined that a management decision, project or activity
    - may have consequences to either
      - humans or
      - the environment.

ERA addresses 3 questions

1. What can go wrong with the project?
2. What is the range of magnitude of these adverse consequences?
3. What can be done and at what cost to reduce unacceptable risk and damage?

Purpose of performing ERA

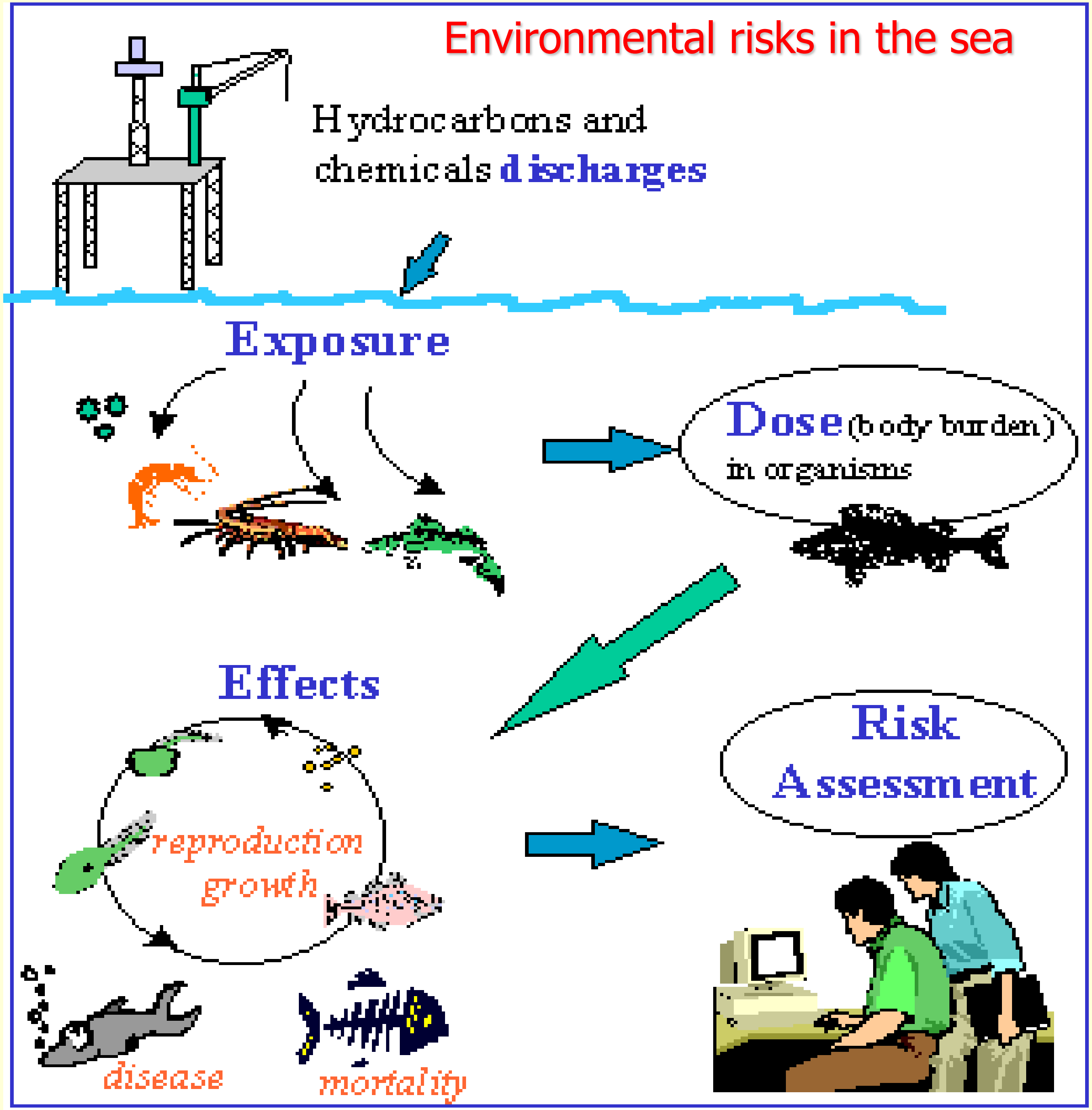
- to learn about the risks
  - To determine the likelihood of the occurrence / non-occurrence of adverse ecological effects as a result of exposure to hazard/ pollution sources

- to reduce the risk
  - take actions: e.g. …………..

What do we mean by Hazards

1. chemicals toxic to humans, animals, and plants;
2. materials that are highly flammable or explosive;
3. mechanical equipment, the failure of which would endanger persons and property;
4. structural failure (e.g., dam or containment vessel);
5. natural disasters leading to technological hazards;
6. ecosystem damage (e.g., eutrophication, soil erosion).

Framework for Environmental Risk Assessment



Team work in ERA

- Interaction among risk assessors, risk managers, and interested parties all phases of an ERA is critical to ensure that the results can be used to support a management decision.

- Because of the diverse expertise required (especially in complex ecological risk assessments), risk assessors and risk managers frequently work in multidisciplinary teams.

Impact characteristics

- Can be biological, physical, chemical
- Characterized by
  - intensity (conc. or dose)
  - duration
  - frequency
  - timing
  - scale — Spatial aspect

Temporal aspects

Risk (Impact) Classification

1 → Type	biophysical, social, health or economic
2 → Nature	direct or indirect, cumulative, etc.
3 → Magnitude or severity	high, moderate, low
4 → Extent	local, regional, trans-boundary or global
5 → Timing	immediate/long term
6 → Duration	temporary/permanent
7 → Uncertainty	low likelihood/high probability
8 → Reversibility	reversible/irreversible 
9 → Significance	unimportant/important

Impact Prediction

- Forecast of the potential effects in terms of-
    1. Magnitude,
    2. The affected feature/resource/population,
    3. Action causing the effect,
    4. Timescale and duration of the effect,
    5. Level of uncertainty in the forecast,
    6. Proposed mitigation/enhancement measures,
    7. Significance
- The effects must be recorded in terms of-
    1. Short term /Long term
    2. Direct/Indirect/Synergistic
    3. Cumulative/Increase or Reduce with time

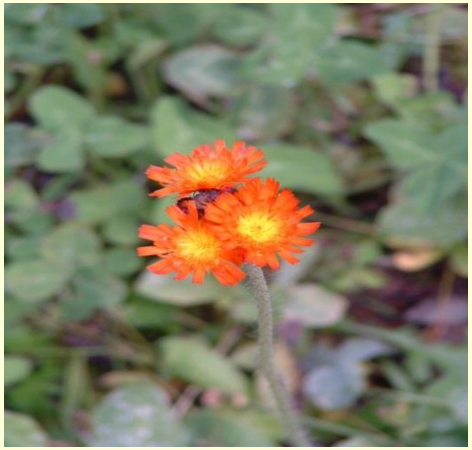
Environmental Affected Components

Physical components:

- Land
- Air
- Water
- Energy

Bio-components:

- Nature
- Culture
- People
- Access



Exposure analysis

- Determine environmental concentration
  - end of pipe
  - how much toxic stuff is there?
  - Non-point sources can be more difficult
    - Where to measure?
    - When to measure?

1. Risk estimation:

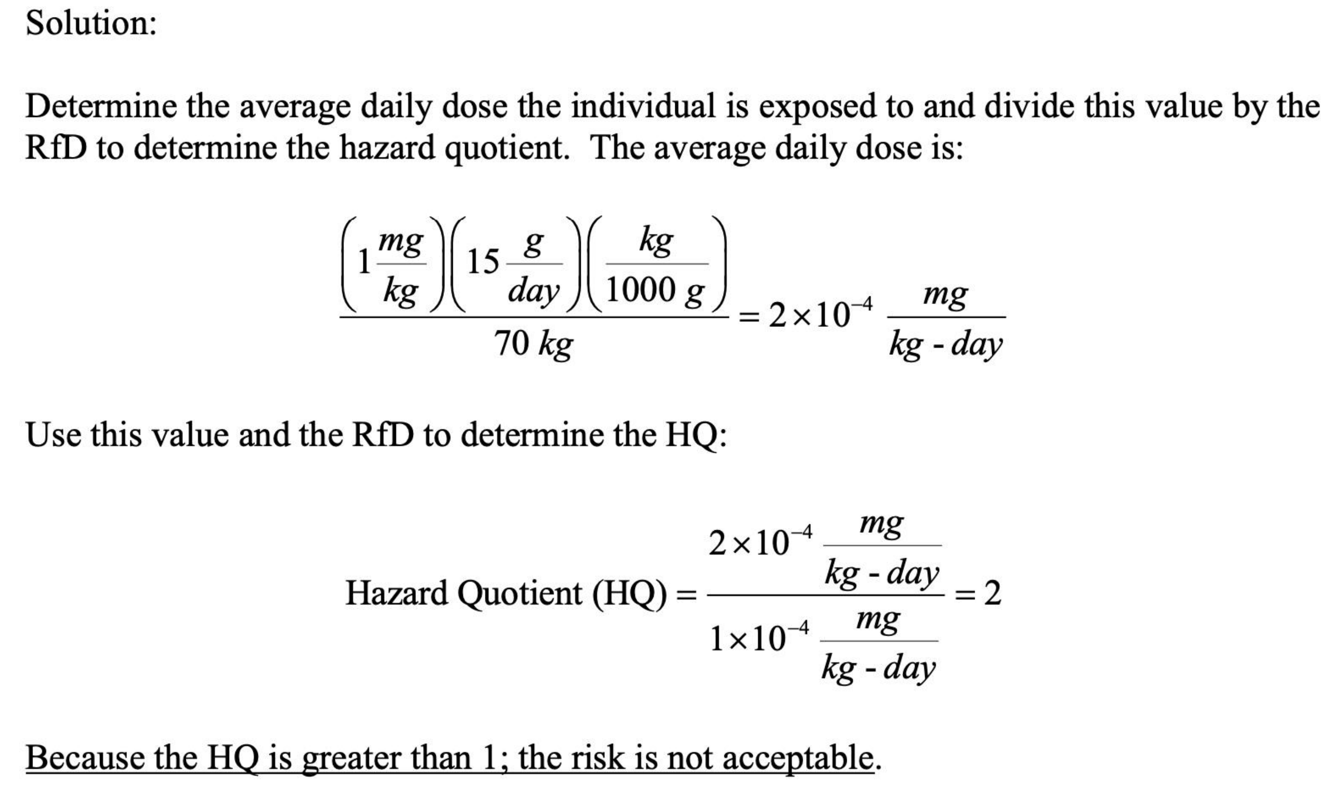
The Quotient Method

$$\text{Quotient} = \frac{\text{Expected environmental concentration}}{\text{Concentration producing an unacceptable environmental effect } \mathbf{(RfD)}}$$

RfD: Reference Dose

Quotient	Risk
>1	Potential of high risk
~1	Potential risk
<< 1	Low risk

<u>Example</u>: Is there an unsafe risk associated with a 70 kg adult eating 15 g fish every day that contains 1 mg/kg of methylmercury? Methylmercury has been shown to cause developmental neuropsychological impairment in human beings. The RfD for methylmercury is 1 × 10-4 mg/kg-day.



Solution:

Determine the average daily dose the individual is exposed to and divide this value by the RfD to determine the hazard quotient. The average daily dose is:

$$\frac{\left(1\frac{mg}{kg}\right)\left(15\frac{g}{day}\right)\left(\frac{kg}{1000\ g}\right)}{70\ kg} = 2\times10^{-4}\ \frac{mg}{kg\text{ - }day}$$

Use this value and the RfD to determine the HQ:

$$\text{Hazard Quotient (HQ)} = \frac{2\times10^{-4}\ \frac{mg}{kg\text{ - }day}}{1\times10^{-4}\ \frac{mg}{kg\text{ - }day}} = 2$$

<u>Because the HQ is greater than 1; the risk is not acceptable</u>.

Examples of information about hazards

1. potential release of hazardous chemicals (rate and amount);
2. accidental fires and explosions;
3. transport and fate of pollutants in the environment;
4. exposure to toxins (who, how many, how much);
5. dose-response predictions based on animal tests;
6. failure of mechanical equipment or structures;
7. human behavior (errors by workers, public reaction);
8. natural hazards (earthquake, tsunami, typhoon);
9. alterations in drainage patterns, water table, vegetation, microclimate.

Uncertainties

1. lack of understanding of important cause-effect relationships, lack of scientific theory;
2. weaknesses in available data; data gaps;
3. natural variation in environmental parameters;
4. assumptions on which estimates are based;
5. novelty of the project.

Membrane Processes

Environmental Engineering
110401457

Dr. Ahmed Bdour
Spring 2023/2023

Membrane Processes - Overview

What is a Membrane?

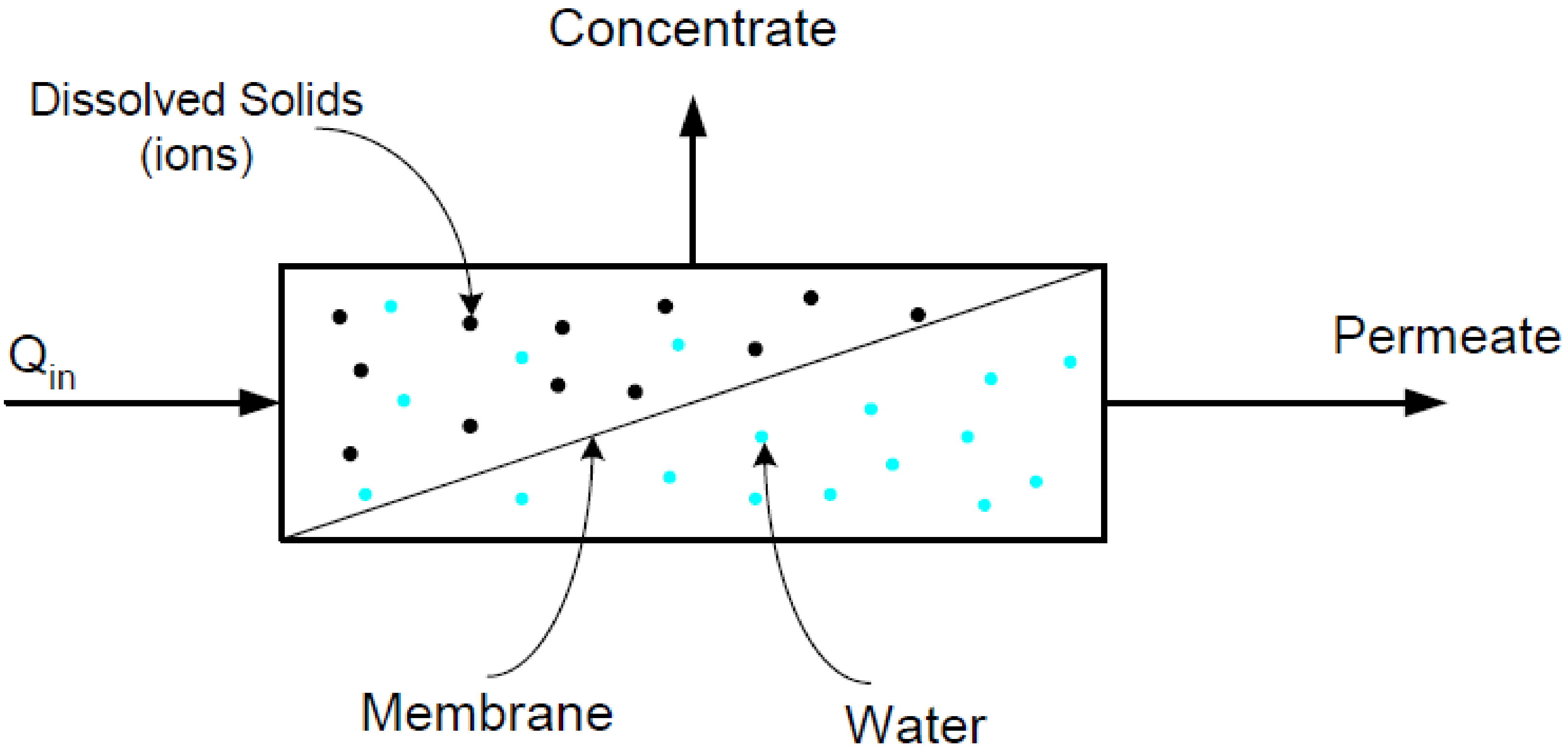
- The membrane can be defined essentially as a barrier, which separates two phases and restricts transport of various chemicals in a selective manner.

Membrane Separation Technology

- A membrane separation system separates an influent stream into two effluent streams known as the permeate and the concentrate.
- The permeate is the portion of the fluid that has passed through the semi-permeable membrane.
- The concentrate stream contains the constituents that have been rejected by the membrane.

Prepared by: Dr. AN Bdour

Membrane Processes - Overview



Membrane Processes - Overview

- **The main membrane processes are**
  - Dialysis
  - Electro-dialysis
  - Reverse osmosis
- **Driving forces that cause mass transfer of solutes are:**
  - Difference in concentration (dialysis)
  - Difference in electric potential (electro-dialysis)
  - Difference in pressure (reverse osmosis)

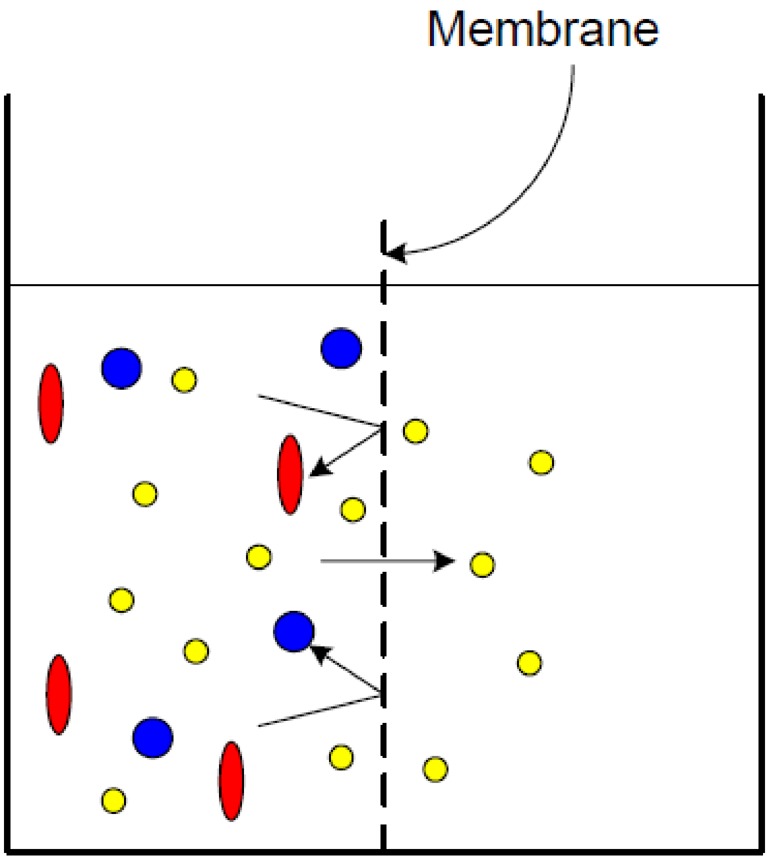
Dialysis

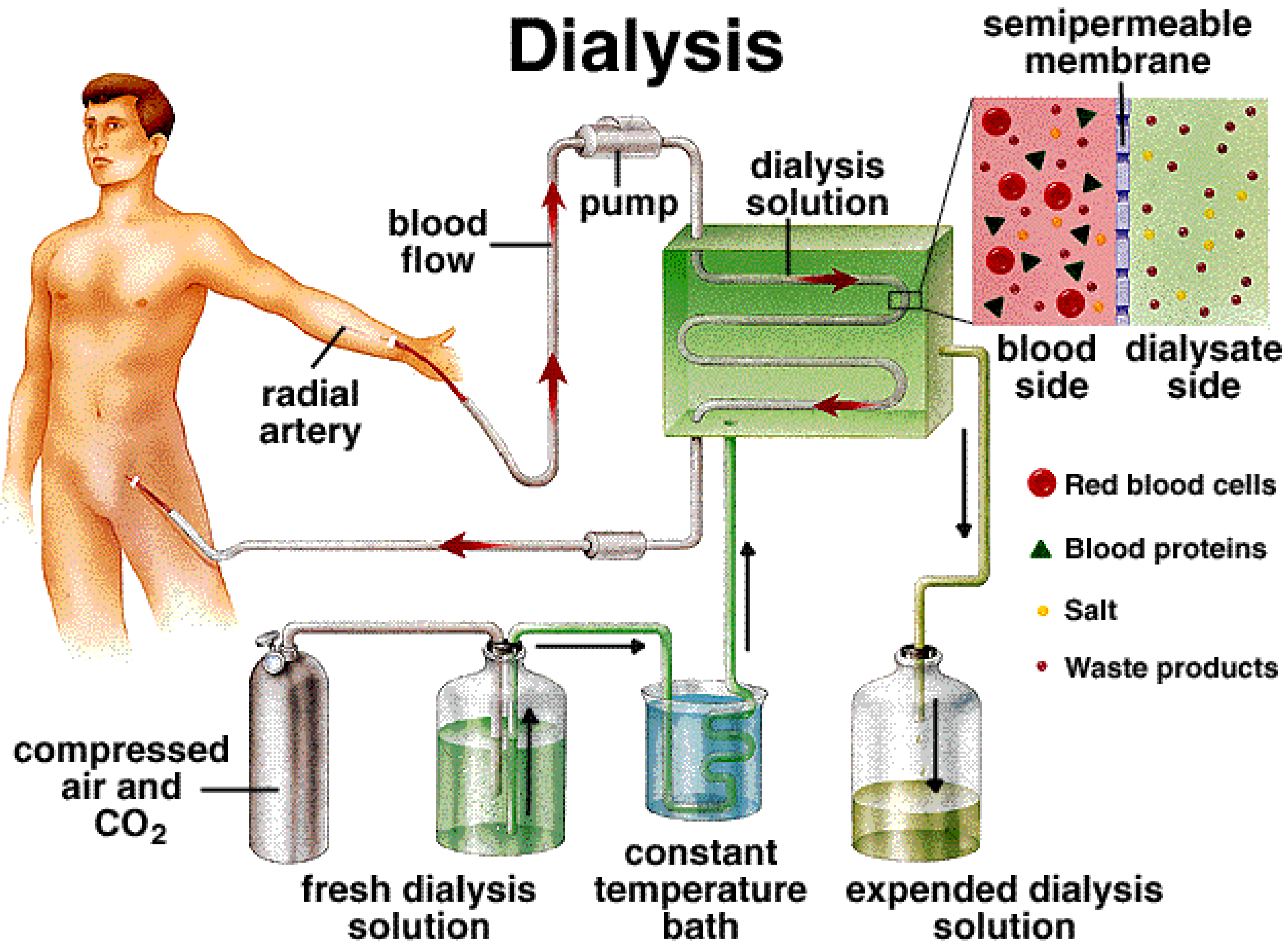
- Theory
  - Dialysis depends on separating solutes of different ionic or molecular size in a solution by means of a selectively permeable membrane.
  - The driving force for dialysis is the difference in the solute concentration across the membrane
- The mass transfer of solute through the membrane is given by

$$M = KA\Delta C$$

- M = mass transferred per unit time (gram/hour)
- K = mass transfer coefficient [gram/(hr-cm^2)(gram/cm^3)]
- A = membrane area (cm^2)
- ΔC = difference in concentration of solute passing through the membrane (gram/cm^3)

Dialysis




Dialysis
semipermeable membrane
pump
dialysis solution
blood flow
radial artery
blood side
dialysate side
● Red blood cells
▲ Blood proteins
● Salt
● Waste products
compressed air and CO_2
fresh dialysis solution
constant temperature bath
expended dialysis solution

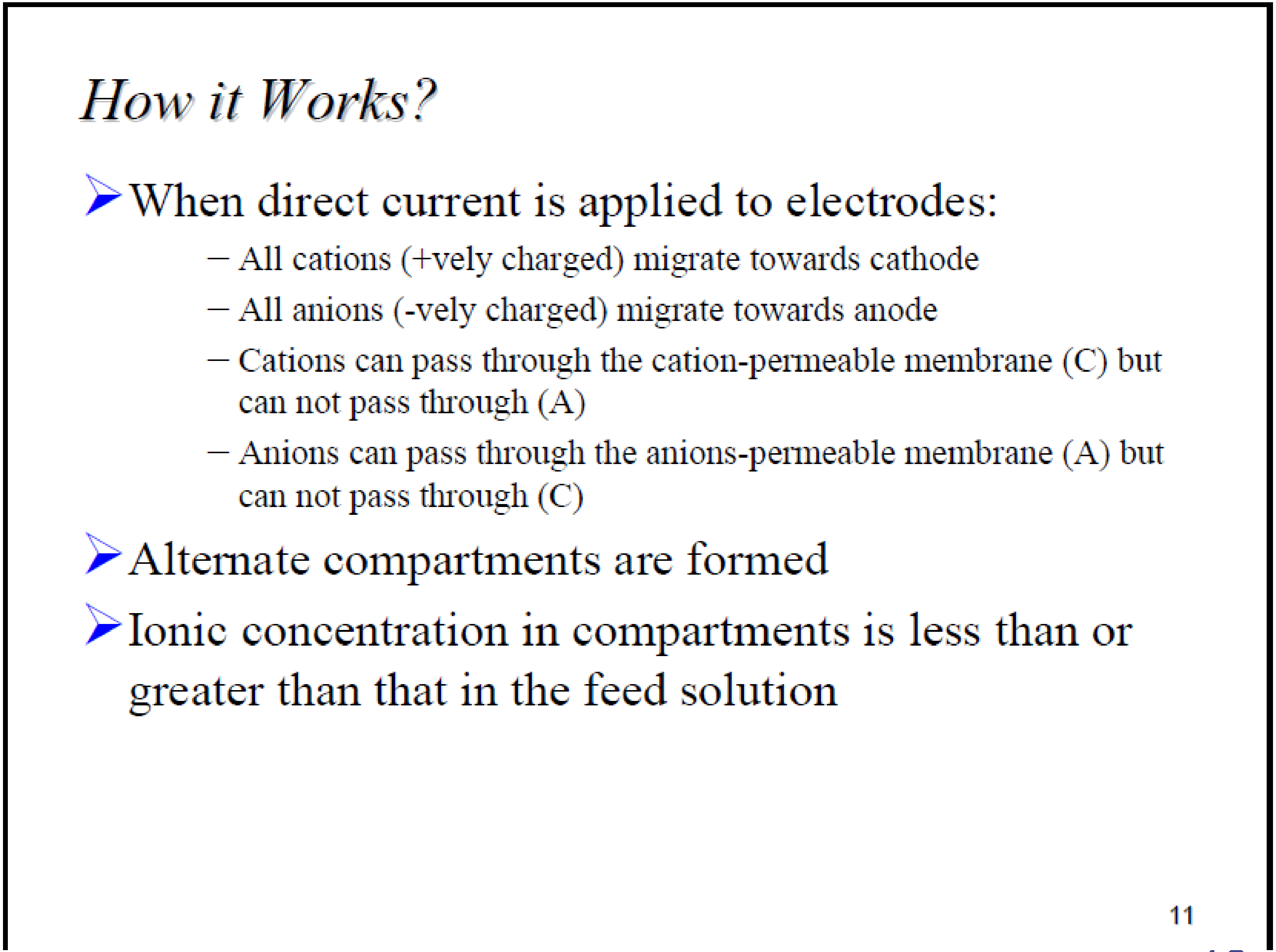
Applications of Dialysis

- In environmental engineering, Dialysis is not used to an appreciable extent.
- In industrial applications, Dialysis can be used to recover Sodium Hydroxide from textile wastewater.
- Dialysis is limited to small flows due to small mass transfer coefficient (K)

Electro-Dialysis

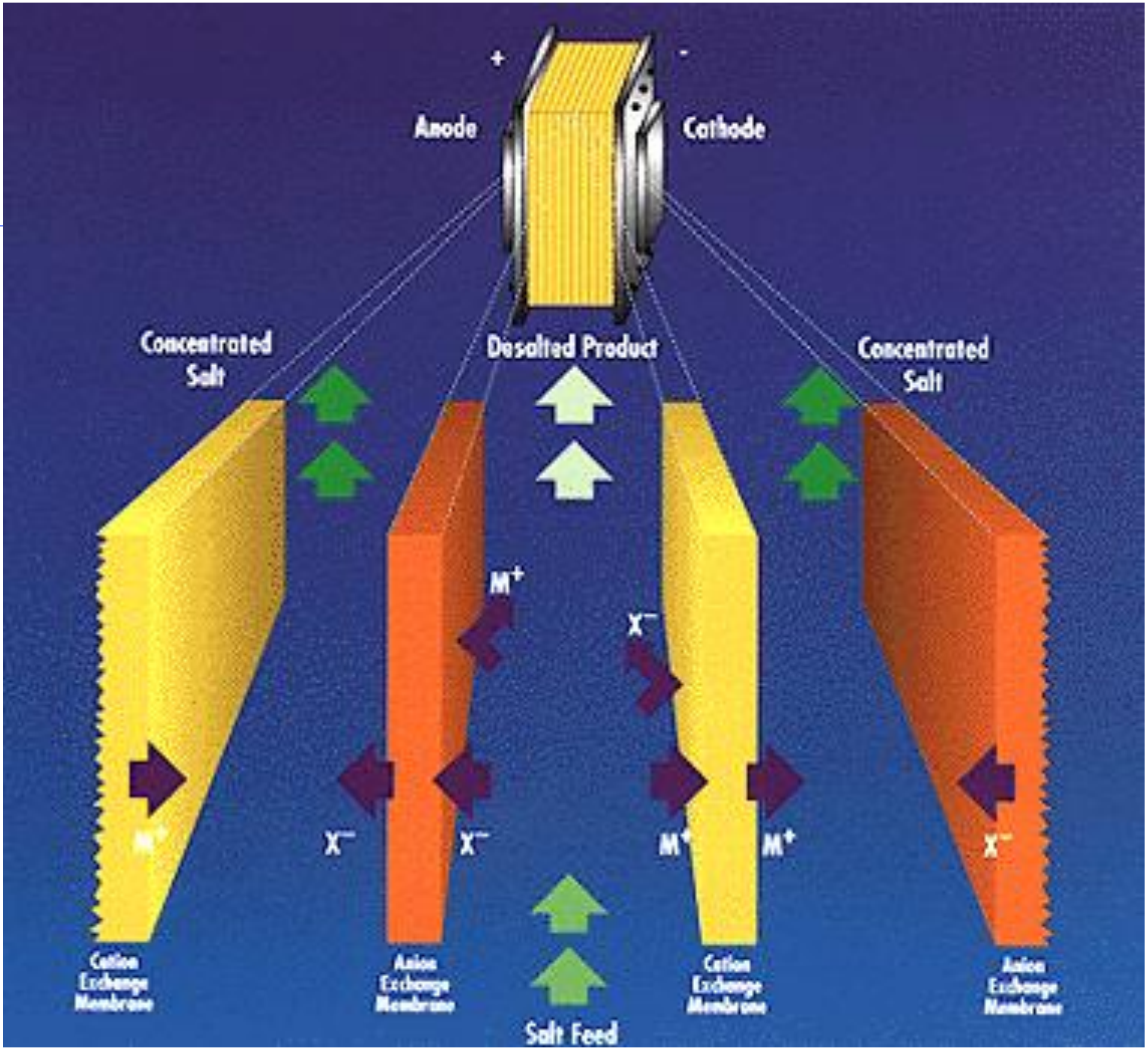
➢ Theory

- This process depends on the presence of an electrical filed across the selectively permeable membrane.
- The driving force is an electromotive force (electrical potential)
- When electromotive force is applied across the permeable membrane:
  - An increased rate of ion transfer will occur
  - This results in decrease in the salt concentration of the treated solution
- The process demineralizes (removes dissolved solids)
  - Brackish water and seawater to produce fresh water
  - Tertiary effluents



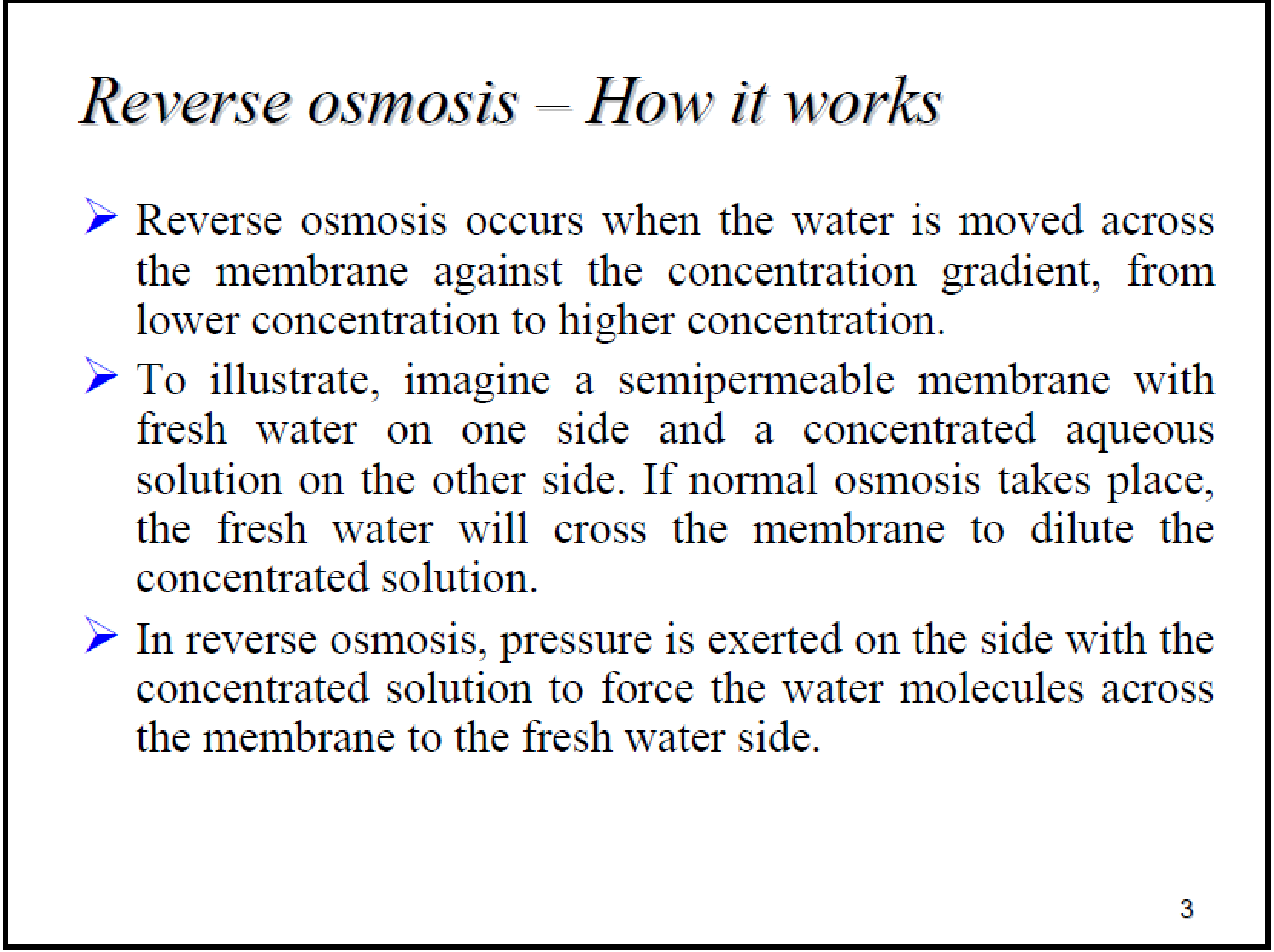
How it Works?

- When direct current is applied to electrodes:
  - All cations (+vely charged) migrate towards cathode
  - All anions (-vely charged) migrate towards anode
  - Cations can pass through the cation-permeable membrane (C) but can not pass through (A)
  - Anions can pass through the anions-permeable membrane (A) but can not pass through (C)
- Alternate compartments are formed
- Ionic concentration in compartments is less than or greater than that in the feed solution


+
-
Anode
Cathode
Concentrated Salt
Desalted Product
Concentrated Salt
M^+
X^-
M^+
X^-
X^-
M^+
M^+
X^-
Cation Exchange Membrane
Anion Exchange Membrane
Salt Feed
Cation Exchange Membrane
Anion Exchange Membrane

Reverse osmosis - Defenition

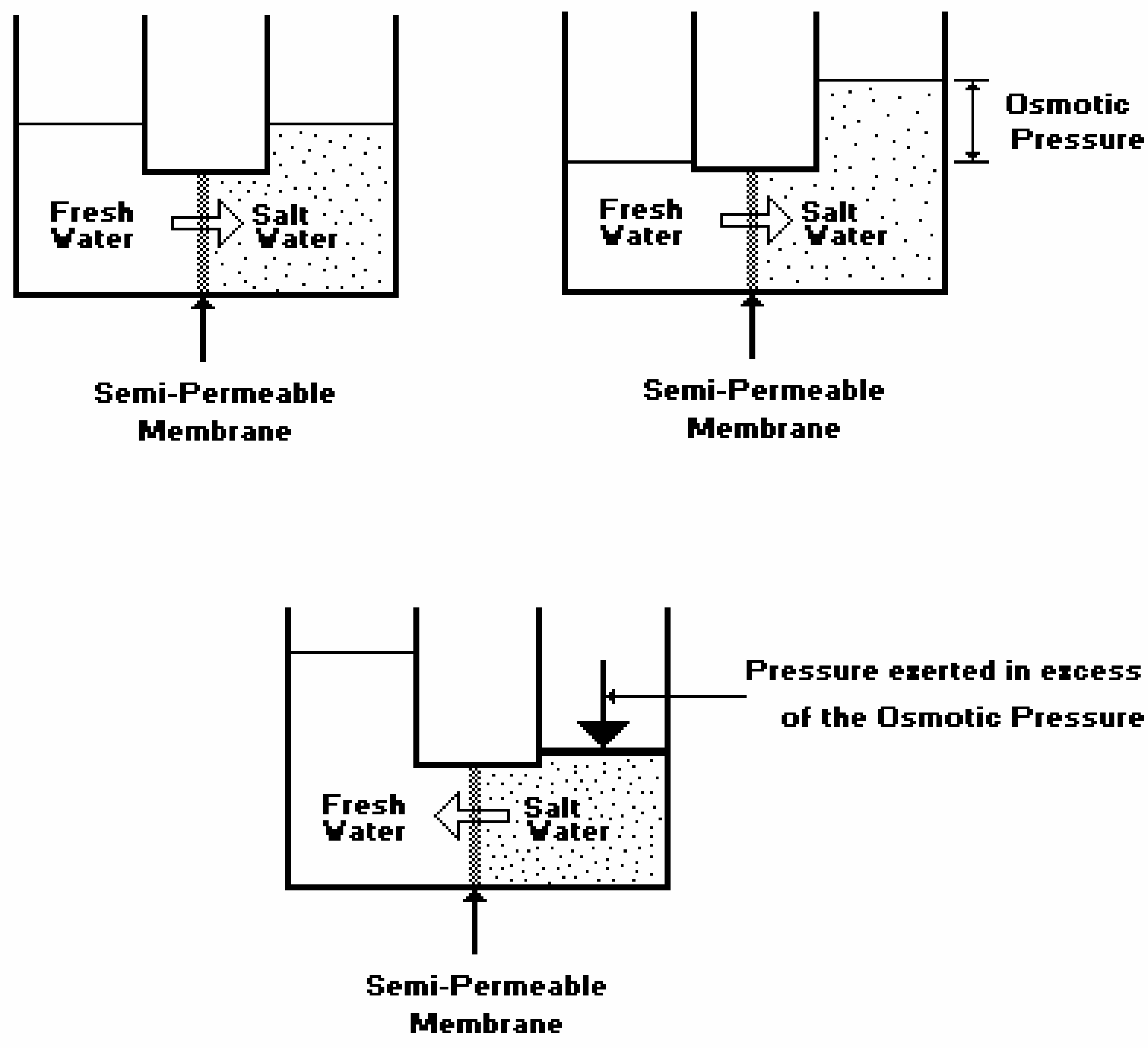
- It is the process of forcing a solvent (like water) from a region of high solute (such as salts of Soudium, Potasium, etc…) concentration through a membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure.
- It is the reverse of the normal osmosis process, which is the natural movement of solvent from an area of low solute concentration, through a membrane, to an area of high solute concentration when no external pressure is applied.
- The membrane here is semipermeable, meaning it allows the passage of solvent but not of solute.

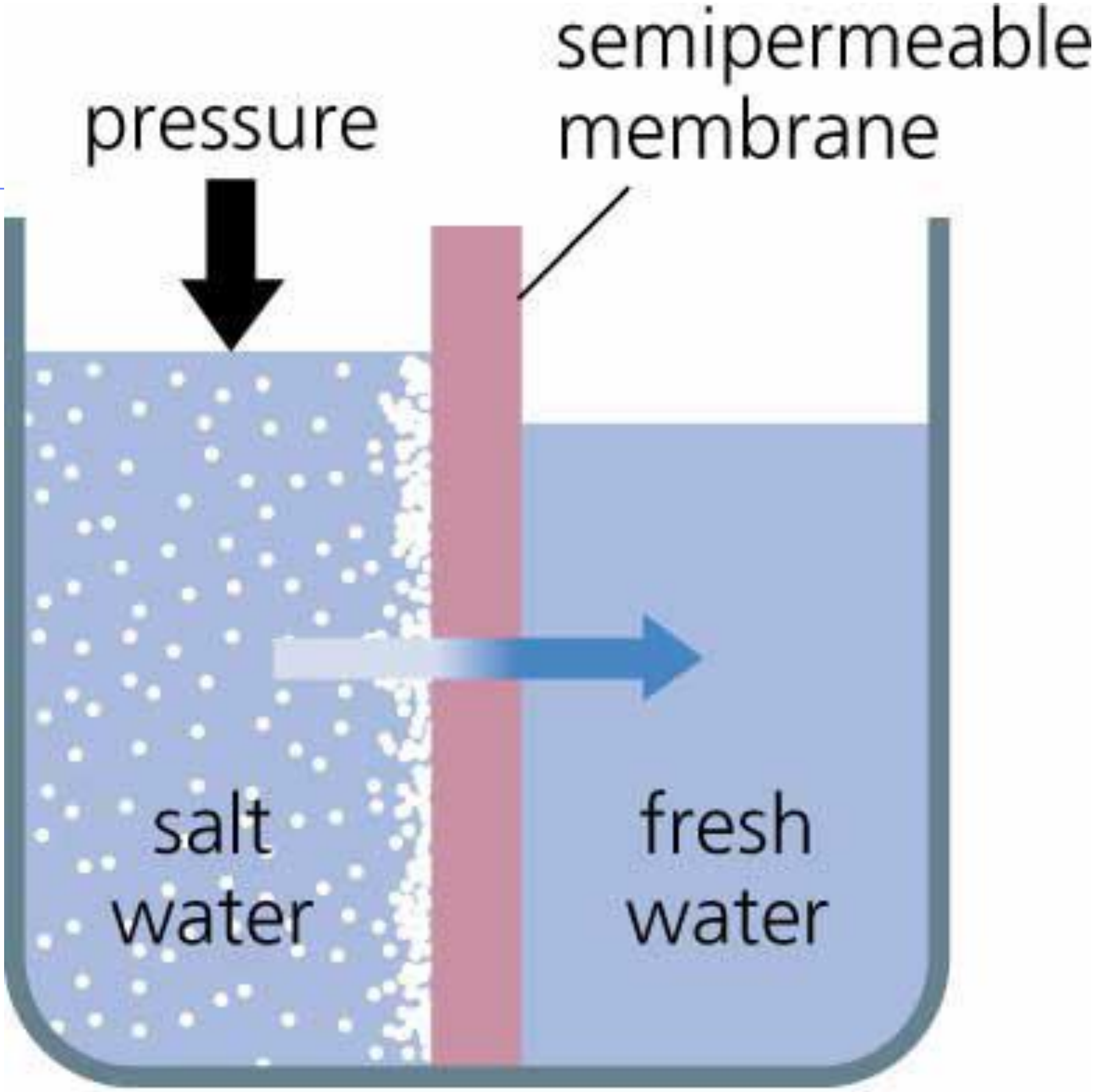


Reverse osmosis – How it works

- Reverse osmosis occurs when the water is moved across the membrane against the concentration gradient, from lower concentration to higher concentration.
- To illustrate, imagine a semipermeable membrane with fresh water on one side and a concentrated aqueous solution on the other side. If normal osmosis takes place, the fresh water will cross the membrane to dilute the concentrated solution.
- In reverse osmosis, pressure is exerted on the side with the concentrated solution to force the water molecules across the membrane to the fresh water side.

Reverse osmosis – How it works





Precision Graphics

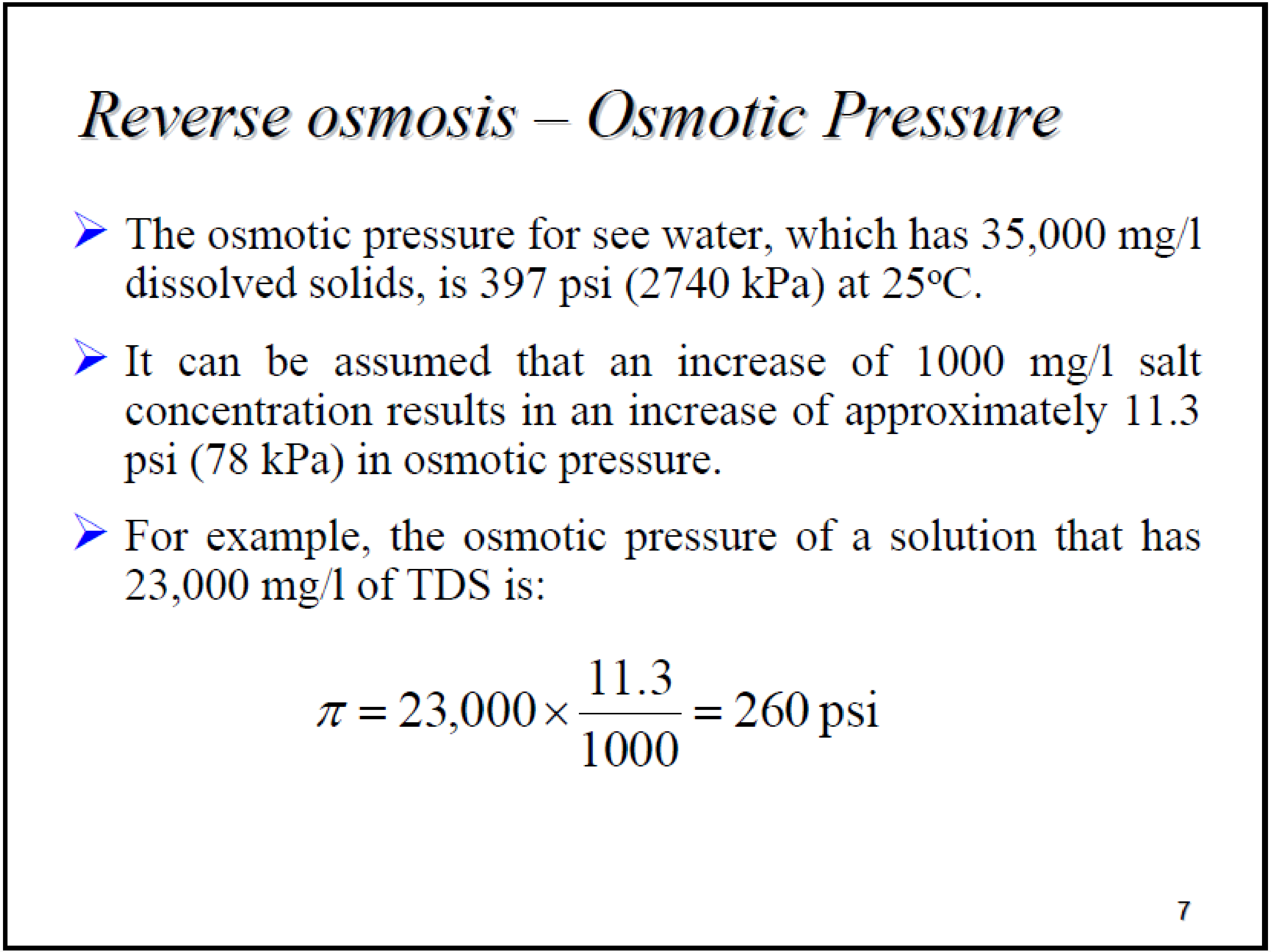
Reverse osmosis – Osmotic Pressure

- The osmotic pressure of solutions of electrolytes may be determined by the following equation:

$$\pi = \phi \nu \frac{n}{V} RT$$

Where;

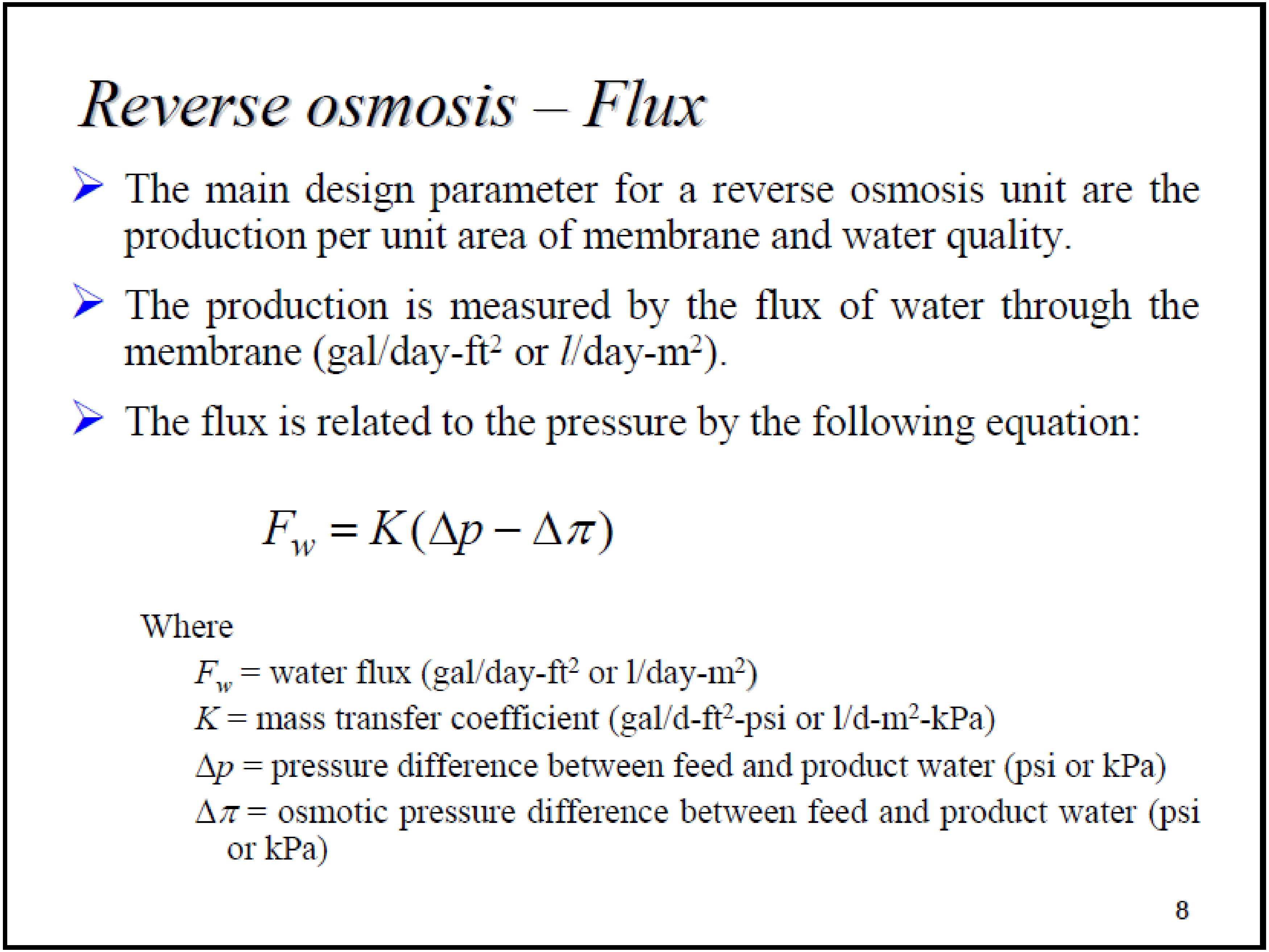
- π = osmotic pressure
- ϕ = osmotic coefficient
- ν = number of ions formed from one molecule of electrolyte
- n = number of moles of electrolyte
- V = volume of solvent
- R = universal gas constant
- T = absolute temperature



Reverse osmosis – Osmotic Pressure

- The osmotic pressure for see water, which has 35,000 mg/l dissolved solids, is 397 psi (2740 kPa) at 25°C.
- It can be assumed that an increase of 1000 mg/l salt concentration results in an increase of approximately 11.3 psi (78 kPa) in osmotic pressure.
- For example, the osmotic pressure of a solution that has 23,000 mg/l of TDS is:

$$\pi = 23{,}000 \times \frac{11.3}{1000} = 260 \text{ psi}$$



Reverse osmosis – Flux

- The main design parameter for a reverse osmosis unit are the production per unit area of membrane and water quality.
- The production is measured by the flux of water through the membrane (gal/day-ft² or *l*/day-m²).
- The flux is related to the pressure by the following equation:

$$F_w = K(\Delta p - \Delta \pi)$$

Where

F_w = water flux (gal/day-ft² or l/day-m²)

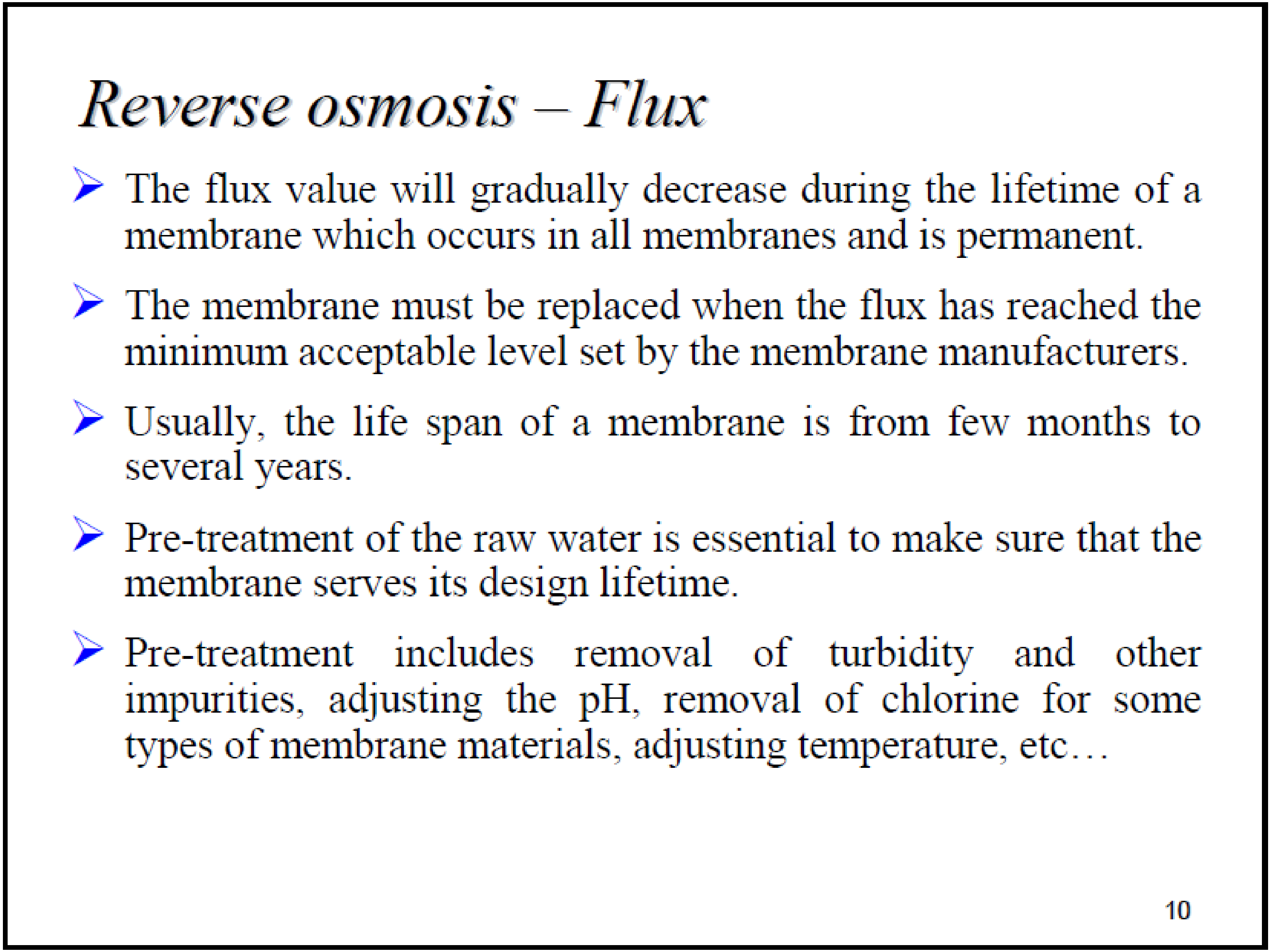
K = mass transfer coefficient (gal/d-ft²-psi or l/d-m²-kPa)

Δp = pressure difference between feed and product water (psi or kPa)

$\Delta \pi$ = osmotic pressure difference between feed and product water (psi or kPa)

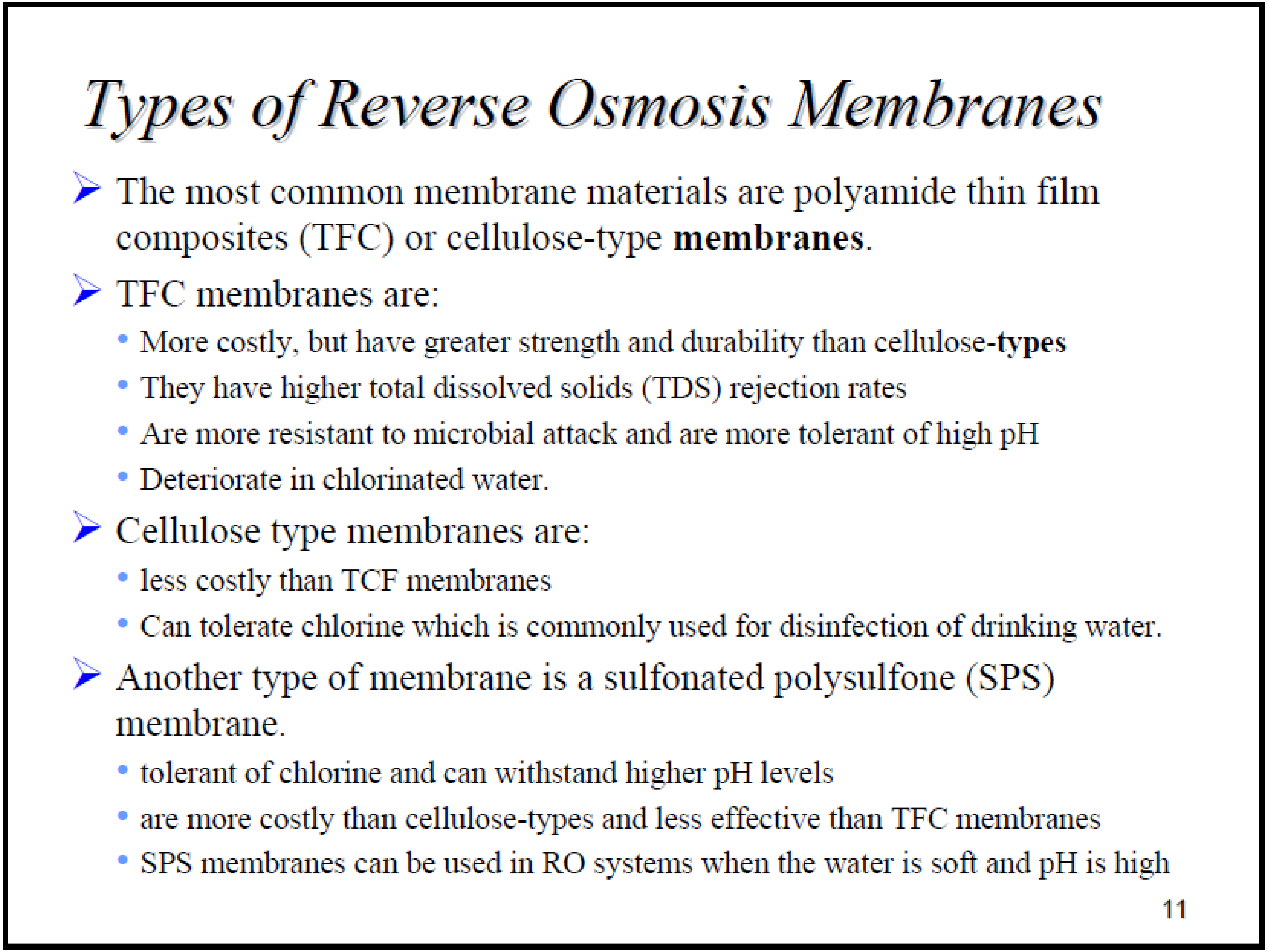
Reverse osmosis – Flux

- The membrane flux value furnished by manufacturer is usually for 25°C. Temperature variations causes the flux to vary. Therefore, membrane area correction (A_T/A_{25}) should be considered as the following:
  - For 10°C,1.58; 15°C, 1.34; 20°C, 1.15; 25°C, 1.00; 30°C, 0.84
- The term (A_T/A_{25}) is the ratio of the areas required for temperatures of T°C and 25°C.



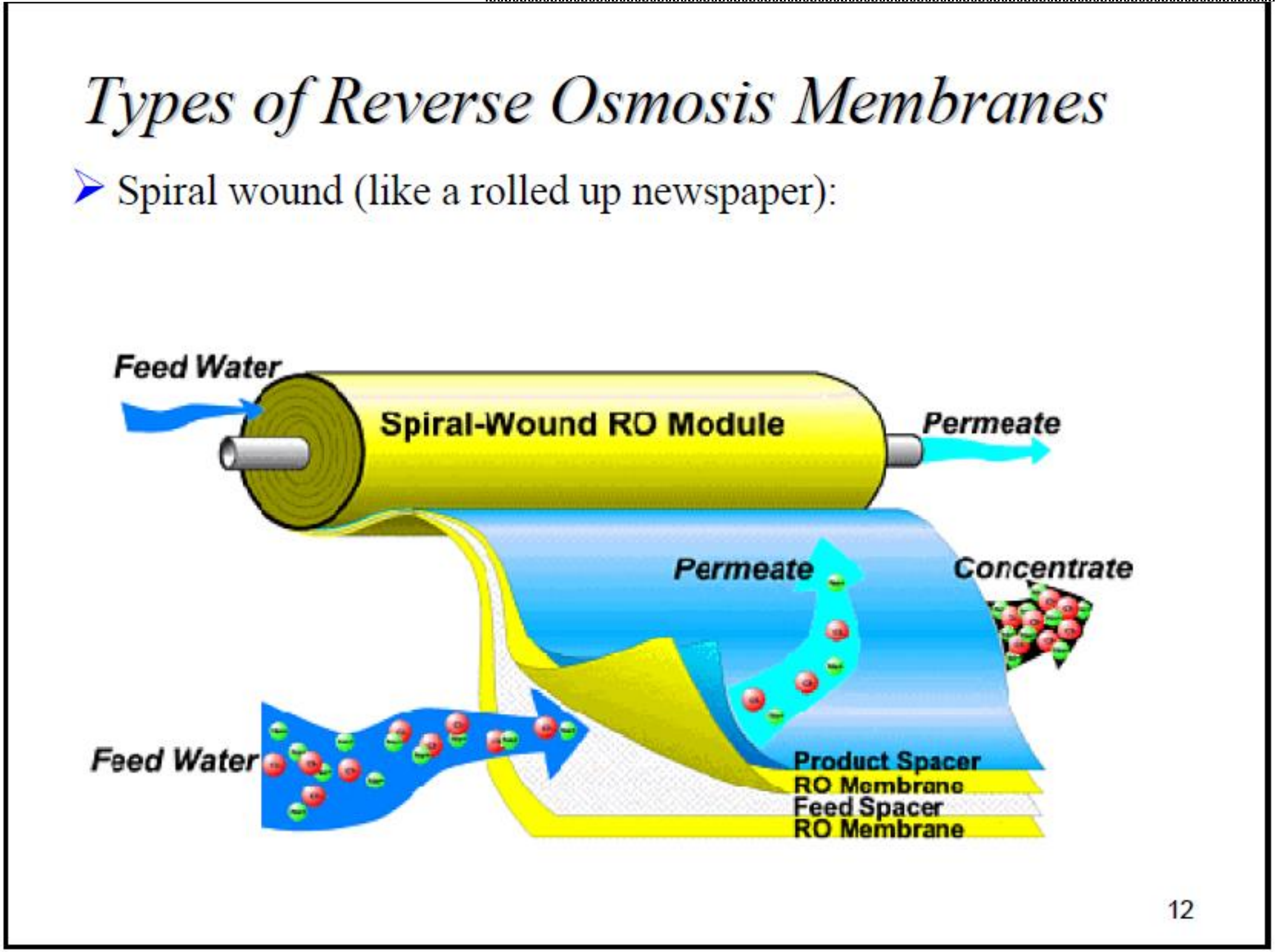
Reverse osmosis – Flux

- The flux value will gradually decrease during the lifetime of a membrane which occurs in all membranes and is permanent.
- The membrane must be replaced when the flux has reached the minimum acceptable level set by the membrane manufacturers.
- Usually, the life span of a membrane is from few months to several years.
- Pre-treatment of the raw water is essential to make sure that the membrane serves its design lifetime.
- Pre-treatment includes removal of turbidity and other impurities, adjusting the pH, removal of chlorine for some types of membrane materials, adjusting temperature, etc…



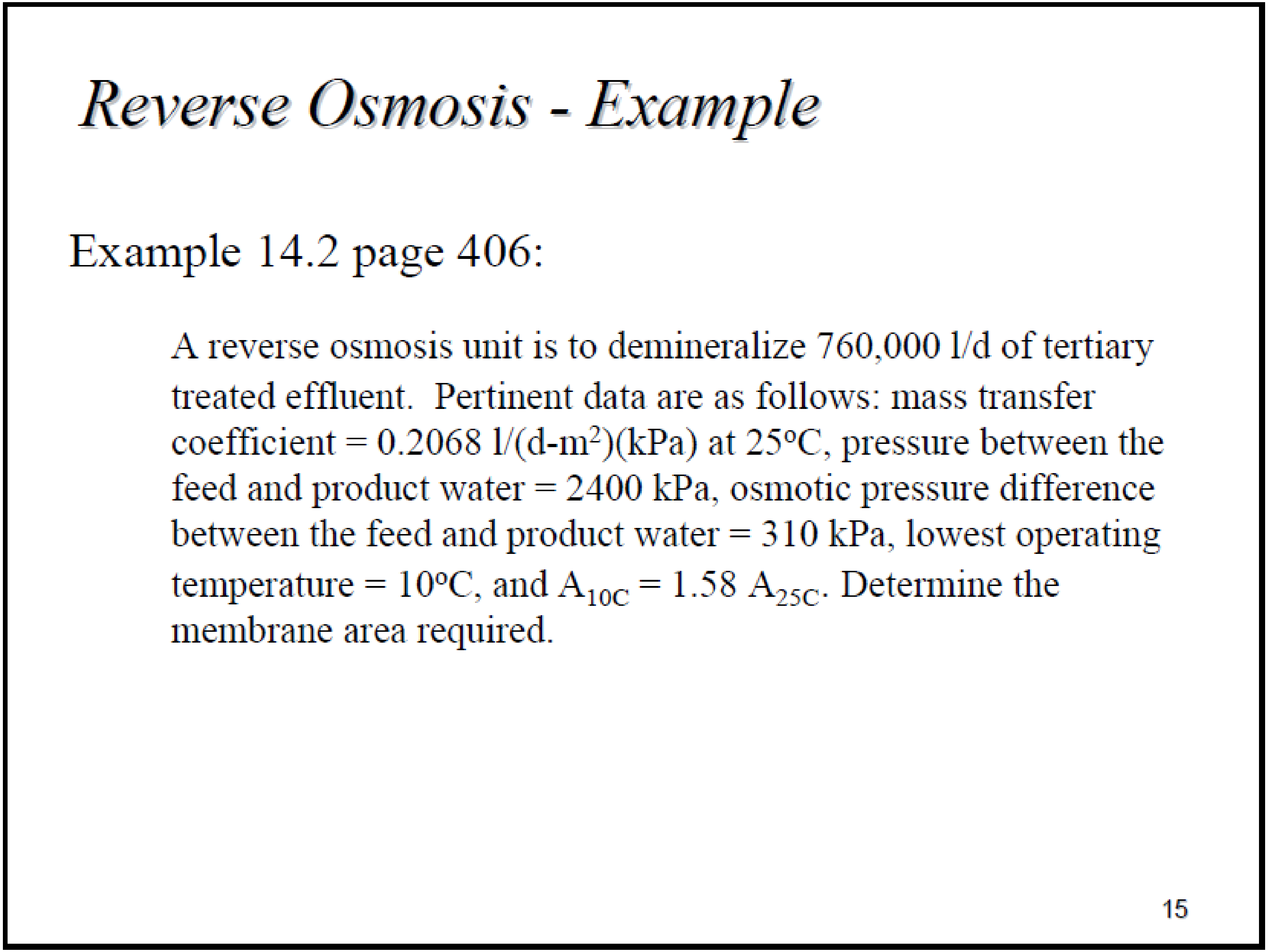
Types of Reverse Osmosis Membranes

- The most common membrane materials are polyamide thin film composites (TFC) or cellulose-type **membranes**.
- TFC membranes are:
  - More costly, but have greater strength and durability than cellulose-**types**
  - They have higher total dissolved solids (TDS) rejection rates
  - Are more resistant to microbial attack and are more tolerant of high pH
  - Deteriorate in chlorinated water.
- Cellulose type membranes are:
  - less costly than TCF membranes
  - Can tolerate chlorine which is commonly used for disinfection of drinking water.
- Another type of membrane is a sulfonated polysulfone (SPS) membrane.
  - tolerant of chlorine and can withstand higher pH levels
  - are more costly than cellulose-types and less effective than TFC membranes
  - SPS membranes can be used in RO systems when the water is soft and pH is high



Types of Reverse Osmosis Membranes

- Spiral wound (like a rolled up newspaper):



Reverse Osmosis - Example

Example 14.2 page 406:

A reverse osmosis unit is to demineralize 760,000 l/d of tertiary treated effluent. Pertinent data are as follows: mass transfer coefficient = 0.2068 l/(d-m^2)(kPa) at 25°C, pressure between the feed and product water = 2400 kPa, osmotic pressure difference between the feed and product water = 310 kPa, lowest operating temperature = 10°C, and $A_{10C} = 1.58\ A_{25C}$. Determine the membrane area required.

Reverse Osmosis - Example

Solution:

The water flux is given by equation (14.6):

$$F_w = K(\Delta p - \Delta \pi)$$

F_w = [0.2068 l/(d-m^2)(kPa)]×(2400 kPa – 310 kPa)
= 432.21 l/(d-m^2) at 25°C

The area is given by:
A = (760,000 l/d)/(432.21 l/(d-m^2) = 1758.4 m^2 at 25°C

The area at 10°C is given by:
A_T/A_{25} = 1.58, therefore:
A (at T=10°C) = $A_{25\ C} \times 1.58 = 1758.4 \times 1.58 = 2780$ m^2