GE 302 - Industry and the Environment

Chapter II

WATER POLLUTION

(Review Chapters 9, 10, and 11 of the textbook for more information)

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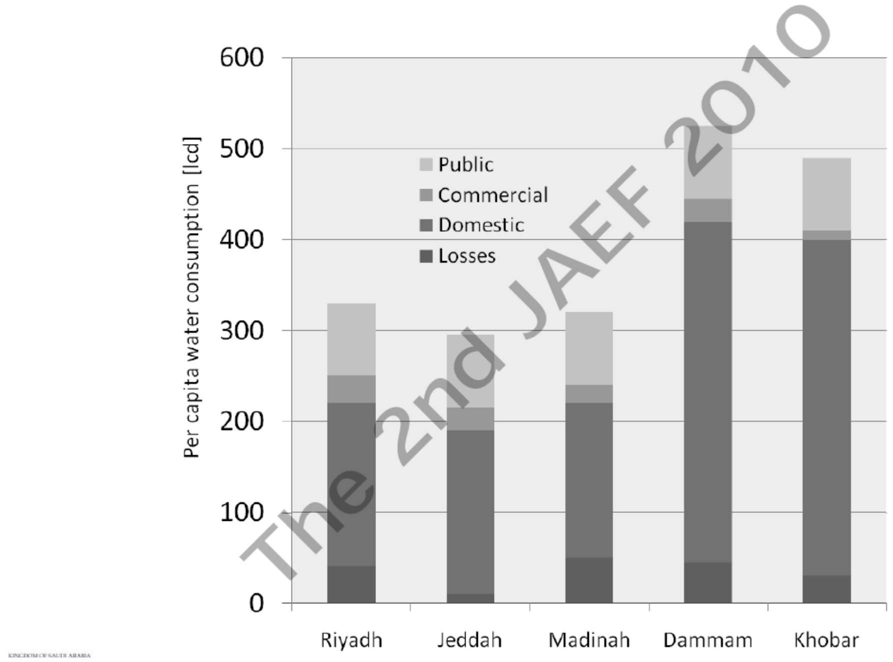
Water Quantity

Average water consumption rate in Saudi Arabia = 275 l/p.d
USA: 575 l/p.d UK: 150 l/p.d Rwanda: 20 l/p.d

Per Capita Water Consumption in Major Cities



Factors affecting the water consumption rate per person

- Standard of living (car wash, swimming pools, gardening)
- Environmental awareness
- Weather conditions and season of the year
- Availability of water conservation programs
- Metering and pricing
- Social and cultural habits (bathing and showering frequency, ablution, food festivals)

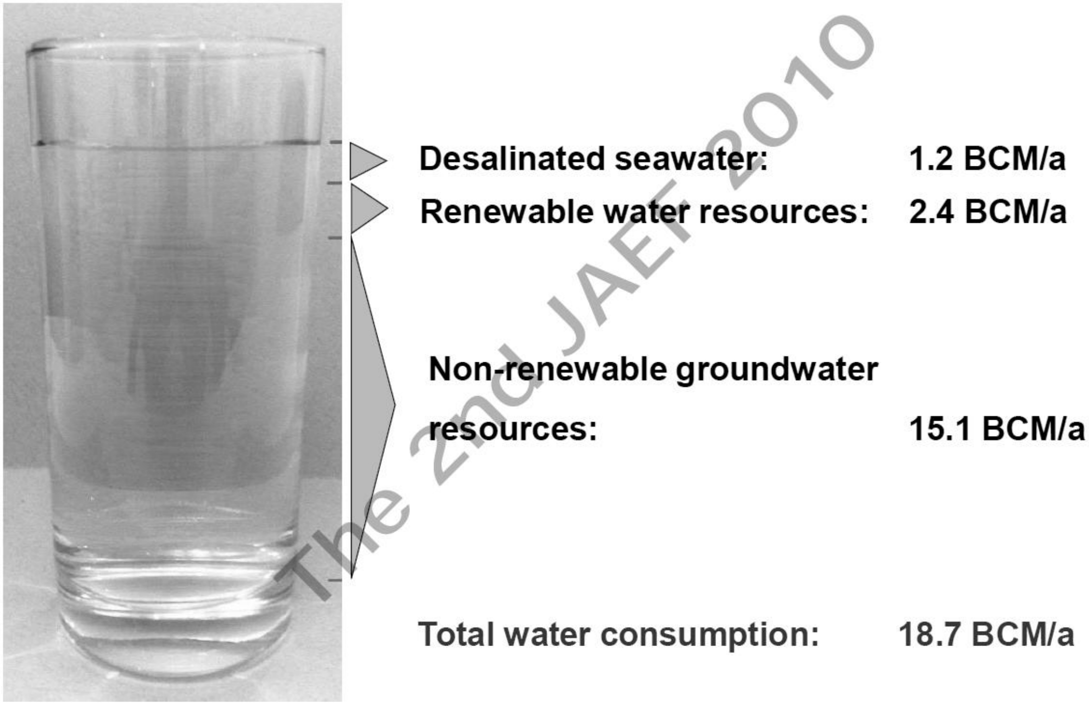
Important Facts

- Water surfaces constitute 70% of the earth's surface
- Seas and oceans (saltwater) forms approximately 97% of the earth's water; i.e. only 3% is fresh water (sweet water)
- 78% of the fresh water is in glaciers, groundwater and the atmosphere, and 22% is in rivers, lakes and springs.

Water Resources

Facts & figures for the Kingdom of Saudi Arabia

Water consumption 2009



- Surface water (rivers, lakes, springs)
- Groundwater (difficult to obtain)
- Desalinized Water (not that economic to produce)
- Treated Wastewater (not used for drinking and cooking)

Water Sectors

- Domestic
- Agricultural
- Industrial

After water is consumed (used), it is disposed back into the environment (streams, seas, oceans, deserts) through point or non-point sources.

Point sources: Domestic sewage (municipal sewage) and industrial wastes.

Nonpoint sources (multiple discharge points): Urban and agricultural runoff.

Water Pollutants and Their Sources

(Sec. 9-2 Textbook)

Water Pollutants Sources

A- Oxygen-demanding materials Dissolved oxygen (DO)
Food waste and dead Plant and animal tissue that consume oxygen dissolved in water during its degradation thus depleting oxygen required for survival of fish, other marine animals and marine plants.

B- Nutrients: are considered pollutants when they become too much of a good thing. Nutrients of primary concern: **Nitrogen and Phosphorus**

Effect of nitrogen:
Nitrogen is harmful to a receiving body for four reasons:

1- In high concentrations, ammonia in its unionized form is toxic to fish.
2- Ammonia, NH_3, in low concentrations, and nitrate, NO_3^-, serve as nutrients for excessive growth of algae.
3- The conversion of NH_4^+ to NO_3^- consumes large quantities of dissolved oxygen.
4- Formation of chloramines, during chlorination, which are more toxic.

Effect of Phosphorous:
Serves as a vital nutrient for the growth of algae; resulting in excess growth of algae. When algae die, become an oxygen-demanding organic material as bacteria seek to degrade those causing fish to die.

C- Pathogenic organisms: include bacteria, viruses, and protozoa.

- They are excreted by diseased persons or animals.
- They make the water unfit for drinking (i.e., non-potable).
- If the concentration of pathogens is sufficiently high, water may also be unsafe for swimming.

D- Suspended solids

E- Salts: the salts and other matter that don't evaporate are called total dissolved solids (TDS)

F- Pesticides; chemicals used by farmers, households, or industry to regulate and control various types of pets or weeds.

Major types of Pesticides: <u>herbicides</u> (used to kill unwanted plants), <u>insecticides</u> (used to kill unwanted insects that would otherwise destroy crops, gardens, or structures), <u>fungicides</u> used to control the growth of fungi, many of which cause plant diseases).

G- Toxic metals: heavy metals (arsenic, cadmium, chromium, copper, nickel, lead, and mercury).

H- Heat

I- Nanoparticles: are those particles that have a dimension less than 100 nm

Contaminant Migration in Groundwater

Sec. 9-7(Textbook)

Contaminants can result from a variety of sources, including:

1- Discharge from improperly operated or located septic systems (Pathogens)
2- Leaking underground storage tanks, dumps and landfills
3- Improper disposal of hazardous and other chemical wastes
4- Spills from pipelines or transportation accidents
5- Recharge of groundwater with contaminated surface water
6- Salts from various chemical processes
7- Fertilizers and pesticides from agricultural operations (followed by agricultural runoff or drainage and infiltration of irrigation water)
8- Acidification of lakes

Categories used to describe Drinking-Water Quality

1- Physical: physical characteristics relate to the quality of water for domestic use and are usually associated with the appearance of water, its taste and odor. Physical parameters include: color, odor, temperature, and turbidity. Insoluble contents; such as solids, oil and grease, also fall in this category.
   Solids may be further subdivided into suspended and dissolved solids as well as organic (volatile) and inorganic (fixed) fractions.

2- Chemical: The chemical characterization of drinking water includes the identification of its components and their concentrations.
   Organic chemical parameters of water include: biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and total oxygen demand (TOD). **Inorganic chemical parameters** include: salinity, hardness, pH, acidity and alkalinity, as well as concentrations of ionized metals such as iron and manganese, and anionic entities such as chlorides, sulfates, sulfides, nitrates and phosphates.

3- Microbiological: Microbiological agents are important to public health and may also be significant in modifying the physical and chemical characteristics of water.
   Bacteriological parameters include: coliforms, fecal coliforms, specific pathogens, and viruses.

4- Radiological: Radiological factors must be considered in areas where the water may have come in contact with radioactive substances. The radioactivity of the water is of public health concern.

Physical Characteristics of Water

1. Total Suspended Solids

Total Suspended Solids (TSS) is comprised of organic and mineral particles. In most rivers TSS is primarily composed of small mineral particles. TSS is often referred to as 'turbidity'. Higher TSS (>1000 mg L^{-1} may greatly affect water use by limiting light penetration.

Turbidity is a measure of the clarity of the water. It is the amount of solids suspended in the water. It can be in the form of minerals or organic matter. It is a measure of the light scattering properties of water, thus an increase in the amount of suspended solid particles in the water may be visually described as cloudiness or muddiness. Turbidity is measured in Nephelometric Turbidity Units (NTU).

2. Temperature

Temperature is a measure of how cool or how warm the water is, expressed in degrees Celsius (C). Temperature is a critical water quality parameter, since it directly influences the amount of dissolved oxygen that is available to aquatic organisms.

3. Color

The presence of color in water does not necessarily indicate that the water is not potable. Color-causing substances may be harmless. Color is not removed by typical water filters; however, slow sand filters can remove color, and the use of chemicals may also succeed in trapping the color-causing compounds. Dissolved and particulate material in water can cause discoloration. Slight discoloration is measured in **Hazen Units** (HU). Impurities can be deeply colored as well, for instance dissolved organic molecules can result in dark brown colors, or algae floating in the water (particles) can impart a green color. Certain inorganic components like iron or manganese can also impart color.

The color of a water sample can be reported as:

- *Apparent color* is the color of the whole water sample, and consists of color from both dissolved and suspended components.
- *True color* is measured after filtering the water sample to remove all suspended material.

Chemical Characteristics of Water

1. Total dissolved solids (TDS)

Total dissolved solids is a measure of the amount of particulate solids that are in solution. This is an indicator of nonpoint source pollution problems associated with various land use practices. The TDS measurement should be obtained with the conductivity meter and is expressed in (mg/L).

2. Conductivity

Conductivity is the ability of the water to conduct an electrical current, and is an indirect measure of the dissolved salts (ion) concentration. The more ions present, the more electricity can be conducted by the water. This measurement is expressed in microsiemens per centimeter (uS/cm) at 25 degrees Celsius.

3. pH

pH, or the "potential of hydrogen", is a measure of the concentration of hydrogen ions in the water. This measurement indicates the acidity or alkalinity of the water. On the pH scale of 0-14, a reading of 7 is considered to be "neutral". Readings below 7 indicate acidic conditions, while readings above 7 indicate the water is alkaline, or basic. Naturally occurring fresh waters have a pH range between 6 and 8. The pH of the water is important because it affects the solubility and availability of nutrients, and how they can be utilized by aquatic organisms.

4. Dissolved Oxygen

Dissolved oxygen is the amount of oxygen dissolved in water, measured in milligrams per liter (mg/L). This component in water is critical to the survival of various aquatic life in streams, such as fish. The ability of water to hold oxygen in solution is inversely proportional to the temperature of the water. For example, the cooler the water temperature, the more dissolved oxygen it can hold.

5. Biological Oxygen Demand (BOD)

Biological Oxygen Demand is a measure of how much oxygen is used by microorganisms in the aerobic oxidation, or breakdown of organic matter in the streams. Usually, the higher the amount of organic material found in the stream, the more oxygen is used for aerobic oxidation. This depletes the amount of dissolved oxygen available to other aquatic life. This measurement is obtained over a period of five days, and is expressed in mg/L.

Microbiological Characteristics of Water

1. Fecal Coliform Bacteria

Fecal coliform bacteria are microscopic organisms that live in the intestines of all warm blooded animals, and in animal wastes or feces eliminated from the intestinal tract. Fecal coliform bacteria may indicate the presence of disease carrying organisms which live in the same environment as the fecal coliform bacteria. The measurement is expressed as the number of organisms per 100 mL sample of water (#/100mL).

Water Quality Standards

(p. 409 textbook)

Includes maximum contaminants levels (MCLs)

Examples of some national/international standards and institutions:

- Saudi Water Quality Standards
- US Water Quality Standards
- Environmental Protection Agency (EPA)
- World Health Organization (WHO)

Water Treatment

(p. 410 textbook)

Raw water and wastewater need to be treated before consumption of the first or disposal of the second. In some regions; e.g. Jordan, water may be so scarce that treated wastewater may be used as water resource. The degree to which water is treated depends upon the sector use.

Palatable water: is water that does not impart a taste or odor and is, therefore, pleasant to drink.

Potable water: is water that is free of chemicals, microorganisms, and other contaminants, and is, therefore, safe to drink, is called potable water.

Groundwater and Surface water (rivers, lakes, and reservoirs)

Water treatment facilities come in one of three general acceptable variations:

1) Limited treatment plants, generally have a high-quality water source.
2) Coagulation plants (Figure 10-2) (used to treat surface water).
3) Softening plants (Figure 10-3) (used to treat waters having a high hardness level, typically groundwater)

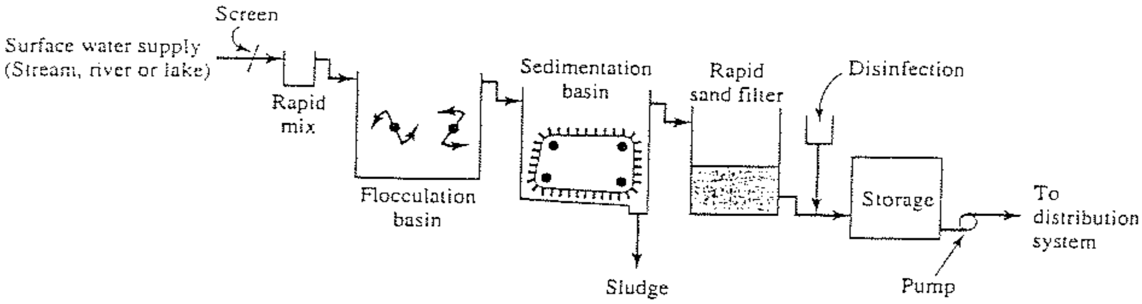


Figure10-2 Flow diagram of a Surface water plant

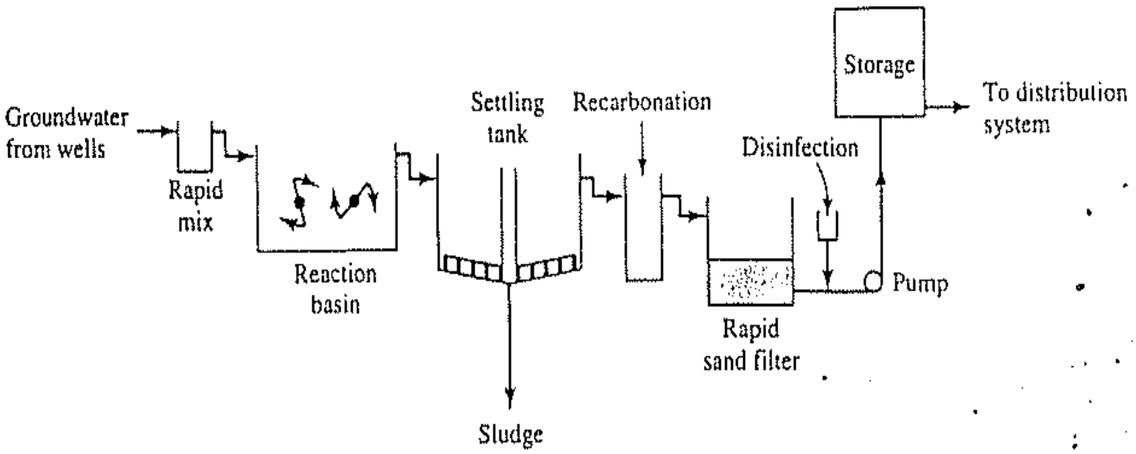


Figure10-3 Flow diagram of a water-softening plant

A combination selected from the following processes is used for municipal drinking water treatment worldwide:

- Pre-chlorination - for algae control and arresting any biological growth
- Aeration - along with pre-chlorination for removal of dissolved iron and manganese
- Coagulation – chemical addition
- Coagulant aids, also known as polyelectrolytes - to improve coagulation and for thicker floc formation
- Flocculation – gentle mixing, increases the particle size to visible suspended particles
- Sedimentation - for solids separation, that is, removal of suspended solids trapped in the floc
- Filtration - removing particles from water
- Disinfection - for killing bacteria.

Disinfection, corrosion control, fluoridation, iron/manganese removal and softening are used for treatment of ground water as a raw water source.

More contamination means more extensive and expensive treatment.

Wastewater

Wastewater flow: Wastewater and water flows about equal when:
– there is no lawn sprinkling
– Infiltration and exfiltration are not large
Generally 70% to 120 % of water becomes wastewater

Residential flows

- ✓ 40 - 100 gpcd (150 – 380 l/p.d) (depends on type apartment or home)
- ✓ Where possible use flow data from similar areas

Commercial

- ✓ 800 - 1500 gal/acre-day (748.32- 1403.1 m^3/km^2.d), typical

Industrial

- ✓ 1000 - 1500 gal/acre-day (935.4-1403.1m^3/km^2.d) (light industries)
- ✓ 1500 - 3000 gal/acre-day (1403.1 – 2806.2m^3/km^2.d) (medium industries)

Characteristics of Domestic Wastewater

(Sec 11-2 in textbook)

A- Physical characteristics: Temperature and TDS

B- Chemical characteristics: BOD, COD, TKN, pH and P.

1. **BOD (Biochemical Oxygen Demand) test:** refer to pervious definition **(110-350 mg/l)**

2. **COD (Chemical Oxygen Demand) test:**

is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water (250-800 mg/l)

3. **Total Kjeldahl nitrogen (TKN)**

(pronounced "total kell dall nitrogen"): is a measure of total organic and ammonia nitrogen. TKN gives a measure the availability of nitrogen for building cells, as well as the potential nitrogenous demand that will have to be satisfied (20 – 70 mg/l).

4. **Phosphorous (4 – 12 mg/l).**

5. **pH**

Typical composition of untreated domestic wastewater (Table 11-1 Textbook): Weak – medium – strong

Wastewater characteristics and per capita loading of most countries in the West Asia region

Parameter	Unit	Avg.	Range	US Avg.
BOD_5	mg/L	530	280-750	192
TSS	mg/L	453	300-700	181
NH_4-N	mg/L	75	45-110	13
Total N	mg/L	100	80-120	34
Total P	mg/L	15	10-20	9.4
TDS	mg/L	1000	620-1300	-
Cl	mg/L	260	125-350	-
Na	mg/L	180	95-240	-
S	mg/L	70	12-115	-
Br	mg/L	0.43	0.15-0.6	-

The characteristics and levels of pollutants in industrial wastewater vary significantly from industry to industry.

Wastewater Treatment Standards

(Sec. 11-3 Textbook)

municipalities and industries are required to provide secondary treatment before discharging wastewater into natural water bodies.

On-Site Disposal Systems (Sec 11-4 Textbook)

are used where municipal sewers are not available.

Examples: Septic tanks and constructed wetlands

Municipal Wastewater Treatment

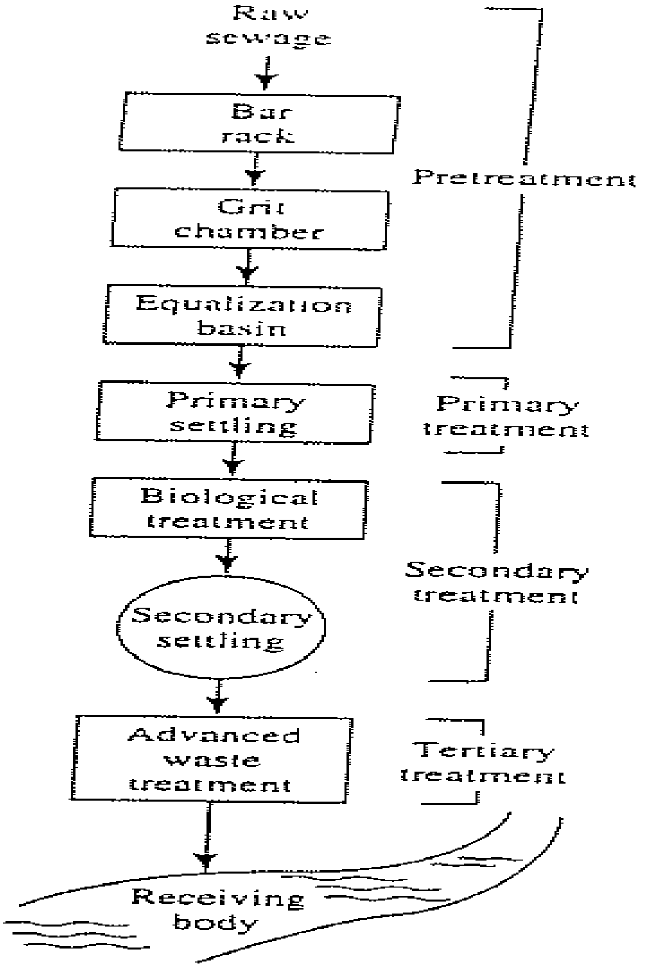
(Sec. 11-5 Textbook)

Sewage treatment, or **domestic wastewater treatment**, is the process of removing contaminants from wastewater and household sewage, both runoff (effluents) and domestic. It includes physical, chemical, and biological processes to remove physical, chemical and biological contaminants. Its objective is to produce a waste stream (or treated effluent) and a solid waste or sludge suitable for discharge or reuse back into the environment.

Pretreatment – Primary – Secondary – Tertiary – Disposal (See Figure 11-9)

FIGURE 11–9

Degrees of treatment.



1. Primary Treatment Processes (Clarification)

Clarification consists in removing all kind of particles, sediments, oil, natural organic matter and color from the water to make it clear.

A clarification step is the first part of conventional treatment for waste and surface water treatment. Usually, it consists in:

- Screening
- Physical and chemical treatment is a generic term for Coagulation-Flocculation
- Sedimentation or Flotation, upon particles properties and water type
- Fine filtration

For industrial effluents, Centrifugation is applied for heavy particles removal.

2. Secondary Treatment (Sec 11-8 Textbook)

Biological treatment of waste water and (domestic) sewage water is used to lower the organic load of organic compounds. There are two main categories:

- Aerobic treatment
- Anaerobic treatment

In aerobic systems the water is aerated with compressed air (in some cases oxygen). Anaerobic systems run under oxygen free conditions.

The majority of municipal plants treat the settled sewage liquor using aerobic biological processes.

In aerobic treatment a variety of approaches is used. The most common approaches for municipalities are: Trickling filter and the Activated sludge process. Lagoons are employed when wastewater flows are not large and land space is available.

Secondary treatment systems include

Fixed-film (attached growth system) treatment process including trickling filter and rotating biological contactors where the biomass grows on media and the sewage passes over its surface.

In **suspended-growth** systems, such as activated sludge, the biomass is well mixed with the sewage and can be operated in a smaller space than fixed-film systems that treat the same amount of water. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal rates for organic material and suspended solids than suspended growth systems.

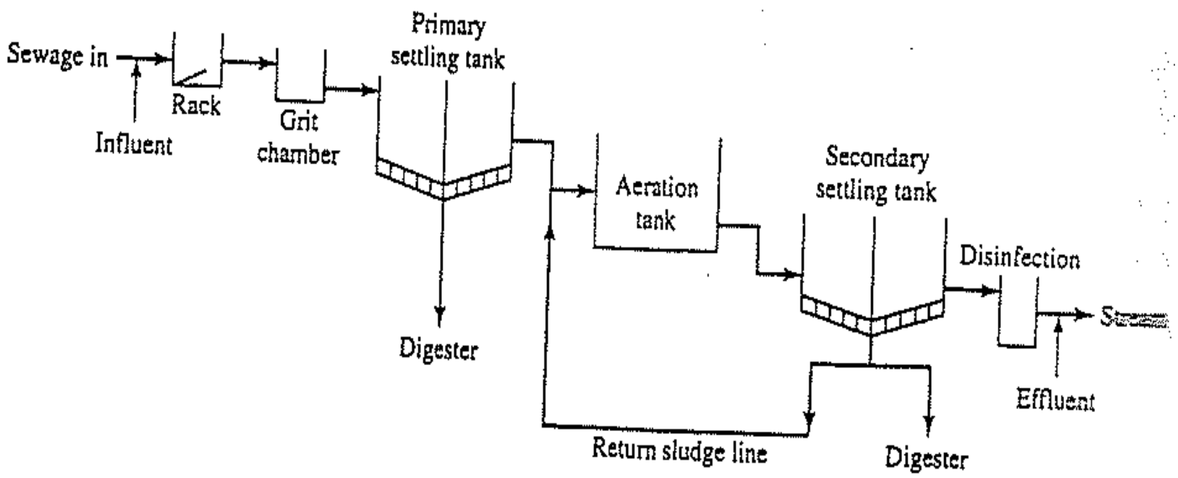
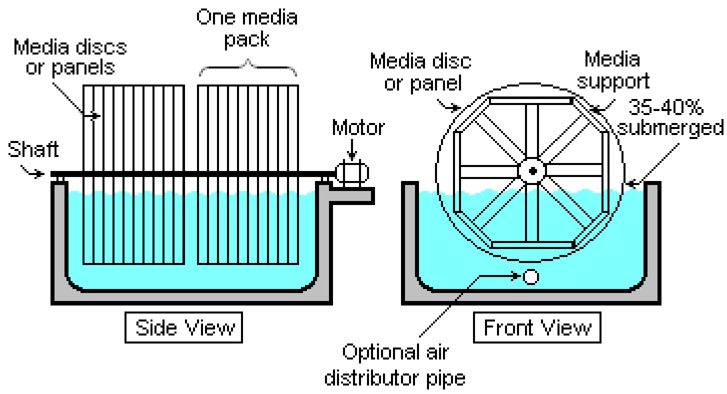


Figure 11-12: Conventional Activated Sludge Treatment Plant



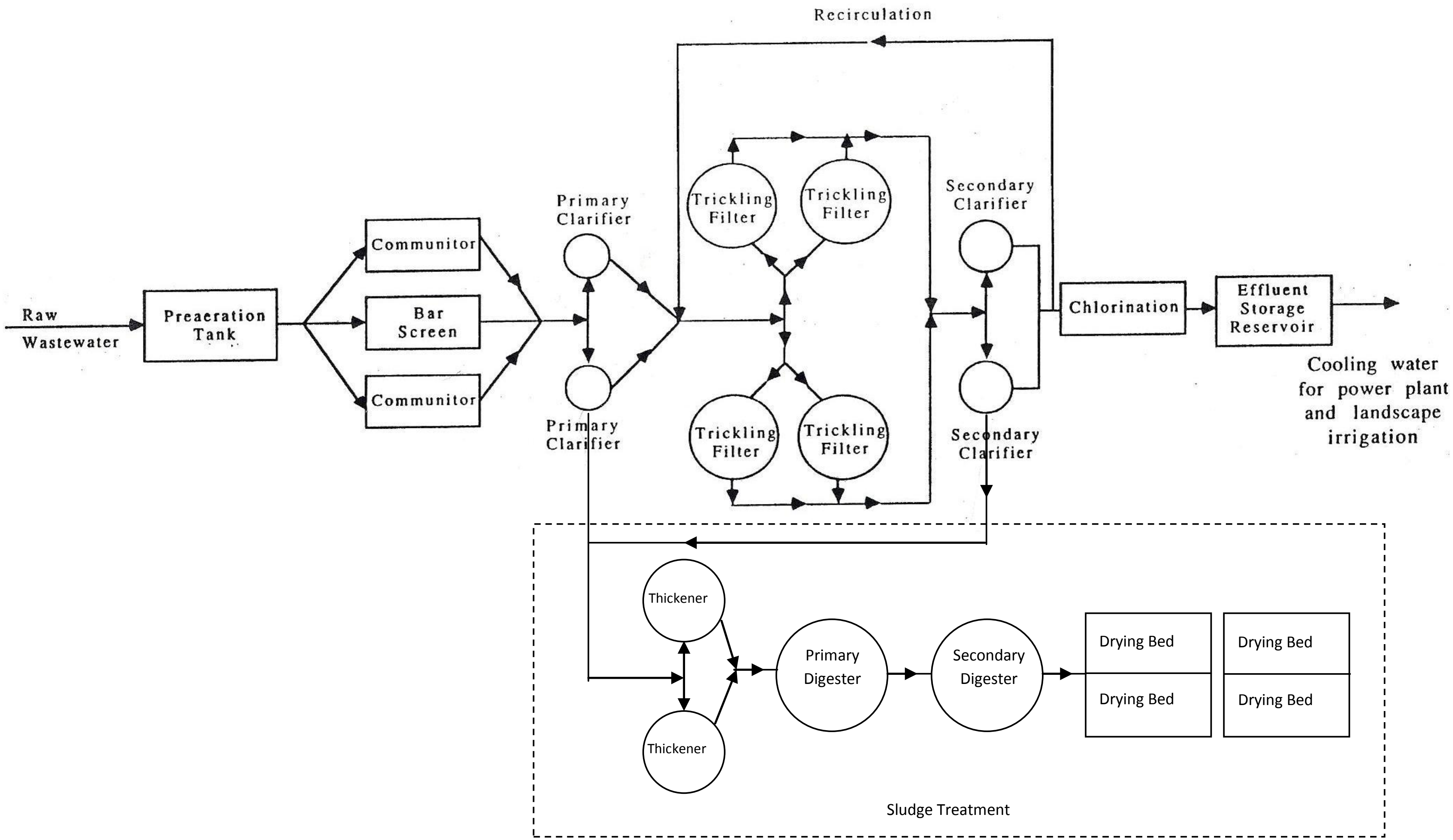
Schematic diagram of a typical rotating biological contactor (RBC). The treated effluent clarifier/settler is not included in the diagram (refer to Figure 11-18 in the textbook)

Disinfection: (Sec 11-9 Textbook)
It is the process that eliminates many or all pathogenic microorganisms with the exception of bacterial endospores.

Sterilization is the complete elimination or destruction of all forms of microbial life (i.e., involves killing 100% of vegetative microorganisms, including associated endospores).

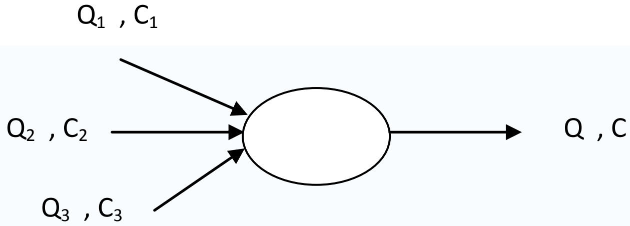
3. Advanced wastewater Treatment (Sec 11-10 Textbook)

A- Filtration
B- Carbon adsorption
C- Phosphorus removal



Schematic diagram of King Saud University Wastewater Treatment Plant.

Pollution of Stream Lines



$Q = Q_1 + Q_2 + Q_3$

$C = \sum(QC) / \sum Q = (Q_1 C_1 + Q_2 C_2 + Q_3 C_3) / (Q_1 + Q_2 + Q_3)$

Example:

A wastewater treatment plant is discharging its effluents to a river. Water flow rates and characteristics are as follow:

	River (before mixing point)	Wastewater Treatment Plant
Flow rate (m^3/h)	20,000	3100 (24 h/day)
TDS (mg/L)	360	420

At the point of discharge (assuming complete mixing), determine the concentration of TDS.

Solution:

TDS=[(20,000x360)+(3100x420)] / [20,000+3100]= 368 mg/L

Note: If a factory is discharging its wastewater during certain hours every day, the factory can reduce the flow rate by using an equalization tank. The new flow rate could be calculated as follows:

Equalized flow rate = Total volume discharged daily / 24

= (original flow rate × factory working hours) / 24

Example

A wastewater treatment plant and a factory are discharging their effluents to a river at the same point. Water flow rates and characteristics are as follows:

	River (before mixing point)	Wastewater Treatment Plant	Factory
Flow rate (m^3/h)	20,000	3100	800 (during the working hours)
Working hours daily		24	6
COD (mg/L)	14	70	420
TDS (mg/L)	360	420	2600

At the point of discharge (assuming complete mixing), determine the concentration of TDS for the following conditions:

A. Within and off (out) the working hours of the factory.
B. The use of the factory for an equalization tank.

Solution:

A.

Within the working hours of the factory, TDS=[(20,000x360)+(3100x420)+(800x2600)] / [20,000+3100+800]=442.8 mg/L

Off the working hours of the factory, TDS=[(20,000x360)+(3100x420)] / [20,000+3100]=368.1 mg/L

B. If the factory utilize an equalization tank:
Flow rate from the factory will be=800x(6/24)= 200 m^3/h

TDS=[(20,000x360)+(3100x420)+(200x2600)] / [20,000+3100+200]=387.2 mg/L

Water Pollution with Oil Spill

1. Oil Spill

An **oil spill** is the release of a liquid petroleum hydrocarbon into the environment due to human activity, and is a form of pollution. The term often refers to marine oil spills, where oil is released into the ocean or coastal waters. The oil may be a variety of materials, including crude oil, refined petroleum products (such as gasoline or diesel fuel) or by-products, ships' bunkers, oily refuse or oil mixed in waste. Spills take months or even years to clean up.

Photo showing an oil ship wreck in the open ocean. The damage caused the formation of the shown oil spill.

Environmental Effects

A- Damage to Fisheries:

Oil spills present the potential for enormous harm to deep ocean and coastal fishing and fisheries. Harms include: fish mass mortality and contamination, poisoning ocean organic substrate and shutting down fishing enterprises.

B- Damage to Wildlife:

Wildlife other than fish and sea creatures; including mammals, reptiles, amphibians, and birds that live in or near the ocean, are also poisoned by oil waste.

C- Damage to Recreation:

Coastal areas are usually thickly populated and attract many recreational activities; for example fishing, boating, diving, swimming, natural parks and preserves, beaches, …etc.

Clean Up an Oil Spill

The techniques used to clean up an oil spill depend on oil characteristics and the type of environment involved; for example, open ocean, coastal, or wetland**.**

Pollution-control measures include:

a) containment and removal of the oil (either by skimming, filtering, or *in situ* combustion),

b) dispersing it into smaller droplets to limit immediate surficial and wildlife damage,

c) biodegradation (either natural or assisted), and

d) normal weathering processes.

Photo: Workers clean up an oil refinery spill that polluted Anacortes Bay, Washington. The floating ring of absorbent pads trailing behind the boat is being used to contain some of the oil that has spilled.

Methods for Cleaning up

1) Booms

Oil boom is a floating barrier, which is used in cleaning up oil on the surface of the water. Boom is used to contain oil, to collect oil, as a barricade to exclude oil from a certain area; to absorb oil; and to deflect oil. Floating booms are mechanical barriers that extend above and below the surface of the water to stop the flow of oil.

2) Oil Spill Skimmers

Skimming is a process of removing oil from the top of the water surface. This is achieved by the use of various mechanical devices such as pumps, vacuum systems etc. The efficiency of a skimmer depends upon the sea and weather conditions. As the water conditions become rougher the skimmer starts to pull in more water along with oil.

3) Sorbents

Sorbent booms and barriers are used to absorb a moving oil slick. They only work well when a slick is thin, because once their surfaces are saturated, they cannot absorb anymore.

4) In-situ Burning

Through controlled burning of the oil can effectively remove the oil slick. This method is called in-situ burning. In-situ burning can approximately remove around 100-gallons/day/square foot of surface area under excellent weather conditions. In this way, bird, marine mammals, turtles and sensitive coast areas are being spared from the effects of the spill.

5) Bioremediation

Oil, like many natural substances, will biodegrade over a period of time into simple compounds such as carbon dioxide, water and biomass. Bioremediation is the term used to describe a range of processes, which can be used to accelerate natural biodegradation.

6) Manual Cleanup

The other best way to clean up oil once it has hit the shore is by manual cleanup. Since oil has chances of spreading and getting mixed with the soil or sand on the shore, the best method to contain oil spread is by manual methods.

7) Dispersants

Dispersants are chemicals, which have components of surface-active agents called surfactants. The dispersants aids in the breaking up of the oil slick into smaller droplets.

Marine Oil Spill Prevention

Preventing and preparing for spills

Spill prevention and preparedness is an essential part of the program. Preparedness tools include geographic response plans, drills and exercises, and vessel and facility plans.

a) Geographic response plans

Geographic response plans detail geographic information, equipment requirements and locations, as well as preferred response activities for particular sections of the Willamette and Columbia rivers and coast. Each plan focuses on a specific river segment and includes identification of aquatic and wildlife habitats and water withdrawal points and uses, resource protection and spill containment strategies, maps, locations of necessary materials, and other information. Government agencies, river users and response providers collaborate to develop these plans.

b) Drills and exercises

Regulatory agencies often require participation in and attend response and cleanup exercises as an observer or active participant. Incident management teams, emergency responders and relevant staff all gain valuable training and insights from drills and exercises as well as actual incidents.

c) Vessel and facility plans

Vessels traveling through navigable waters and oil handling facilities must have oil spill response plans. These plans provide clear instructions for responding to oil spills. Regulatory agencies review and approve each of the plans.

2. Produced Oily Water Disposal during Oil Production

Produced water is a term used in the oil industry to describe water that is produced as a byproduct along with the oil and gas. Oil and gas reservoirs often have water as well as hydrocarbons, sometimes in a zone that lies under the hydrocarbons, and sometimes in the same zone with the oil and gas.

Oil wells sometimes produce large volumes of water with the oil, while gas wells tend to produce water in smaller proportion.

To achieve maximum oil recovery, waterflooding is often implemented, in which water is injected into the reservoirs to help force the oil to the production wells. The injected water eventually reaches the production wells, and so in the later stages of waterflooding, the produced water proportion ("cut") of the total production increases.

Historically, produced water was disposed of in large evaporation ponds. However, this has become an increasingly unacceptable disposal method from both environmental and social perspectives. Produced water is considered an industrial waste and coal seam gas (CSG) producers are now required to employ beneficial re-uses for produced water.