UNE

DEPARTMENT OF RESOURCE ENGINEERING

Resource Engineering 422-1/622-1

Water Quality Management

Notes - Volume I

The University of New England, Armidale, NSW, 2351

THE UNIVERSITY OF NEW ENGLAND

RESOURCE ENGINEERING 422-1/622-1

Water Quality Management

1992 ASSIGNMENT SUMMARY

Assignment No.	Date (to be posted by	Description
1	Friday, 14th August 1992	2000 Word Essay
2	Friday, 11th September 1992	Problem Exercises

This Assignment Summary can be detached for your notice-board.

ASSIGNMENT 1

You should write a paper of about 2000 words on **ONE** of the following topics.

1 Small Community Water Supply Systems.

2. Land uses and associated water quality problems.

3. A brief history of Sewage Treatment in Australia.

ASSIGNMENT 2

1. Name the physical, chemical and bacteriological parameters of concern in water quality management.

2. The results of the chemical analysis of a sample of well water were as follows:

Carbon dioxide	=	0.8 $meqL^{-1}$
Calcium	=	4.0 $meqL^{-1}$
Magnesium	=	2.4 $meqL^{-1}$
Sodium	=	1.2 $meqL^{-1}$
(HCO_3^-) Alkalinity	=	5.4 $meqL^{-1}$
Sulphate	=	1.2 $meqL^{-1}$
Chloride	=	1.0 $meqL^{-1}$

Draw a $meqL^{-1}$ bar diagram and calculate the total hardness, carbonate hardness and non-carbonate hardness expressed as mgL^{-1} of calcium carbonate ($CaCO_3$).

Also calculate amount of lime (CaO) and Soda Ash (Na_2CO_3) required to treat this water.

Atomic weights: Ca = 40, Mg = 24, C = 12, O = 16
Na = 23, S = 32, H = 1.

3. A water supply of 55,000 m^3d^{-1} is to be chlorinated so as to ensure a free residue chlorine of 0.4 mgL^{-1}. The results of the chlorine demand test showed that a minimum chlorine residual of 0.25 mgL^{-1} occurred when the dosage was 1.30 mgL^{-1}. Calculate

(i) the maximum chlorine demand.

(ii) the required dosage expressed in kgd^{-1} of dry calcium hypochlorite containing 70% available chlorine.

4. The disinfecting efficiency of water containing Escherichia Coli [E. Coli] is given by the empirical equation:

$$C^{0.86}t_{99} = 0.24$$

where C = concentration of HOCl in mgL^{-1}

t_{99} = time in minutes for 99% kill.

Raw water with an E. Coli concentration of 100 per 100ml at a pH of 7.6 is disinfected in a treatment plant to the required bacteriological standard of less than 1 coliform per 100ml. If Chick's Law applies with a rate constant of 9 per minute (base e value); determine

(a) minimum contact time.

(b) the corresponding concentration of free available chlorine.

Assume that the hypochlorite ion (OCl^-) has negligible disinfecting ability and that the ionisation constant for Hypochlorous acid is 2.7 x 10^{-8} moles per litre.

5. Laboratory determination of an industrial waste indicate that its ultimate BOD is 750 mgL^{-1} and the K_1 value at 20°C is 0.20 per day.

   (a) Calculate the 5-day BOD.

   (b) What would be the 5-day BOD of the K_1 value dropped to 0.1 per day.

   (c) What will be the value of BOD_3 at 28°C.

6. A town of 25,000 people is to discharge treated domestic wastewater to a river with a minimum flow of 0.14 m^3s^{-1} and BOD_5 $2mgL^{-1}$. The wastewater dry weather flow is 140 litres per person per day and the per capita BOD contribution is 0.05 kgd^{-1}. If the BOD_5 in the river downstream of the discharge is not to exceed 4 mgL^{-1}, determine the maximum permissible effluent BOD_5 and the percentage purification required in the treatment plant.

7. What is the importance of dissolved oxygen in rivers and streams? Explain why some pollutants affect the amount of dissolved oxygen.

8. Explain the objectives of flocculation in water treatment, and the methods used to achieve them.

9. Draw a labelled line diagram of a raw water treatment plant, indicating the different units, and briefly explain their purpose.

10. Show in diagrammatic form all the processes that occur in a facultative stabilization pond.

Note: This assignment covers both Volumes I and II.

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CHAPTER 1: INTRODUCTION AND TYPES OF WATER SOURCES

1.1 INTRODUCTION

Water is a valuable natural resource that is shared by everyone. Water is colourless, odourless and tasteless and it is all around us. Water determines the climate of a region. Nearly 80% of the surface of the earth is water and 97% of all the water on earth is salt water leaving the remaining 3% as glacier ice and fresh water. Water is essential to humans, animals and plants and without water life on earth would not exist. From early days, people have settled close to water sources, along rivers and streams, besides lakes or near natural springs. Water is used for drinking, cooking, transportation, heating and cooling, farming, power generation, recreation, fire fighting, bathing and industrial purposes. The human body is made up of about 70% water. Each day humans must replace about 2.5 litres of water. Drinking returns only part of it and the rest of the water is taken by the body from the food. Thus water can be considered as the most important raw material of civilisation because of the fact that without water, humans cannot live and industry cannot function. With increasing population and industrial developments, the demand for water is also increasing daily and hence, every country has to take preventive measures to avoid pollution and contamination of the available water resources. Safe drinking water is important in the control of many diseases. This is particularly well-established for diseases such as diarrhoea, cholera, typhoid and paratyphoid fever, infectious hepatitis, amoebic and bacillary dysentery. It has been estimated that as many as 80 percent of all diseases in the world are associated with unsafe water. This association can take a number of different forms, and diseases may be grouped accordingly. (Table 1.1)

Diseases related to deficiencies in water supply and/or sanitation

GROUP	DISEASES
Diseases transmitted by water (water-borne diseases) Water acts only as a passive vehicle for the infecting agent. All of these diseases depend also on poor sanitation	Cholera Typhoid Bacillary dysentery Infectious hepatitis Leptospirosis Giardiasis Gastro enteritis

Diseases due to lack of water (water-washed diseases) Lack of adequate quantity of water and poor personal hygiene create conditions favourable for their spread. The intestinal infections in this group also depend on lack of proper human waste disposal.	Scabies Skin sepsis and ulcers Yaws Leprosy Lice and typhus Trachoma Conjunctivitis Bacillary dysentery Amoebic dysentery Salmonellosis Entervirus diarrhoeas Paratyphoid fever Ascariasis Trihcurisasis Whipworm (Enerobius) Hookworm (Ankylostoma)
Diseases caused by infecting agents spread by contact with or ingestion of water. (Water-based diseases) An essential part of the life cycle of the infecting agent takes place in an aquatic animal. Some are also affected by waste disposal.	Schistosmiasis(urinary & rectal) Dracunculosis (guinea worm) Bilharziosis Philariosis Oncholersosis Treadworm
Diseases transmitted by insects which live close to water (water-related vectors) Infections are spread by mosquitoes, flies, insects that breed in water or bite near it. These are especially active and aggressive near stagnant open water. Unaffected by disposal.	Yellow fever mosquito Dengue & dengue hemorrhagic fever mosquito West-Nile and Rift Valley fever mosquito Arbovirus Encephalitides mosquito Bancroftian Filariasis mosquito Malaria (diarrhoea)* mosquito Onchocerciasis* Simulium fly Sleeping sickness* Tsetse fly
Diseases caused by infecting agents. Mostly contracted by eating uncooked fish and other food (Faecal-disposal diseases)	Clonorchiasis Fish Diphyllobothriasis Fish Fasciolopsiasis Edible plant Paragonimiasis Crayfish

* Unusual for domestic water to affect these much

Source: Sauders. J., Warford, J. *Village Water Supply: Economics and policy in the Developing World*. Published for the World Bank by the Johns Hopkins University Press, Baltimore, 1976 Adapted from Small Community Water Supplies. IRC, Netherland.

The availability of a water resource over time is subject to considerable fluctuation and, particularly in Australia, is largely unpredictable. For example, it will be of interest to know how widely streamflows fluctuate in this country by comparison with other countries. A useful index of the extent of variation is the ratio of maximum annual streamflow to minimum annual streamflow as given below:

Country	**$\frac{Qmax}{Qmin.}$**
Australia	10-10,000
Europe	3-10
U.S.A	3-15

The solution to this problem of fluctuation in streamflow is to build a reservoir and it is an established fact that proper maintenance and conservation of water resources will eliminate water shortages at present and in the future.

The basic objective of Water Quality Management is the application of the environmental controls that are necessary to achieve a specific environmental quality objective.

ie. Water Quality Management not only deals with the water quality of an area, but further deals with the management framework and interrelationships necessary to solve the problems identified in water quality control.

1.2 CONCEPTS OF WATER QUALITY MANAGEMENT

In the context of these notes we can distinguish several different categories of water with which the engineer may be concerned. 'Raw water', in which any pollutants present are likely to be in comparatively dilute concentrations, is naturally-occurring fresh water which is intended to be transported from its source and used, with or without pollution control treatment, for some engineering purpose. Raw waters may occur in streams, lakes, reservoirs or underground aquifers; various hydraulic engineering structures and devices such as pumps, dams, canals and pipelines will be needed to transport it to its point of use. If pollution control measures are taken, the resulting product is known as 'treated water' and the pollution control process is known as 'water treatment'.

'Receiving waters' are also naturally-occurring waters, which may be fresh, saline or sea water and may occur in streams, lakes, aquifers, estuaries or the ocean, into which contaminated waters and many other forms of pollutants may be discharged. Receiving waters are inhabited by fish, birds and many other forms of life and may be used by humans for a variety of recreational and other purposes. We are concerned, in particular, with the fact that receiving waters may subsequently become a source of raw water for some purpose downstream. Along the Murray River, for example, what constitutes the 'receiving water' for one township becomes the 'raw water' for the next township along the river, and so on all the way from Albury to Adelaide.

Treated water, after use by man, becomes 'waste water', which is water that has been through an engineering system and contaminated in the process to an extent that renders it unsuitable for the purpose for which it was originally intended. Waste waters are generally disposed of by discharging them into receiving waters, and here again a variety of engineering structures and devices will be needed to transport the waster water from its point of use, undertake such pollution control measures as 'wastewater treatment' as is necessary, and discharge it at an appropriate point into a body of receiving water.

It cannot be too strongly emphasised that all these forms of water are inter-related; the same water molecules may exist successively in all four states. Domestic water doesn't appear magically out of a tap and then disappear, just as magically, when you pull the plug. What is originally raw water will be transported and treated, to become treated water, and then reticulated through an urban community. After use by that community, most of it appears in the sewerage system as waste water, and will again need to be treated and transported to a point of discharge, where it comes part of the body of receiving water. Further downstream it becomes raw water once more and the whole cycle is repeated; perhaps many times, in the case of a river system like the Murray, until it is eventually discharged into the sea. Within any single cycle, the engineer is concerned with the design and operation of the many devices and structures, including water transport and distribution systems and raw and wastewater treatment plants, that constitute the overall water-supply-and-disposal system.

The design of the various components of this system is interconnected: for example, the volume and rate of flow of wastewater from a city is a direct function of the volume and rate of flow of the raw water previously delivered to the city from its original source.

1.3 WATER SUPPLY SYSTEMS

Objectives

1. To provide water of a quality consistent with the use to which it is to be put according to World Health Organisation (WHO) standards or other approved standards.
2. To provide water in sufficient quantity and at a sufficient rate of flow to satisfy the demand.

Design of a Water Supply System involves

1. Establishment of water quality standards for its different uses - Domestic, industrial, agricultural, recreational, fire fighting etc.
2. Estimation of demand.

3. Location of a convenient source of water.
4. Assessment of the quality of water source.
5. Identification of the treatment needed to improve the quality to the required standard.

A water supply may provide water for domestic, commercial, industrial, agriculture and public use. The size of the system may be specified by the total volume delivered in a given period, for example, a number of cubic metres per day. Or the size may be given by the daily flow per capita, that is the total daily flow divided by the number of residents receiving water from the supply system. The latter method is useful for estimating the size of the supply system required by a community.

Assessment of the quantity and quality of water available from a particular source is of vital importance and depends upon knowledge of the hydrological cycle and the ability to measure the amounts of water in the various components of the cycle.

1.4 HYDROLOGICAL CYCLE - THE WATER CYCLE (FIG 1.1)

The movement of water from the atmosphere to the earth and its return to the atmosphere through condensation, precipitation, evaporation and transpiration is termed the hydrological cycle.

About 2/3 of the precipitation which reaches the land surface is returned to the atmosphere by evaporation from water surfaces and soil, and through transpiration by plants.

A water source must be capable of supplying enough water for the community and normally water can be abstracted as

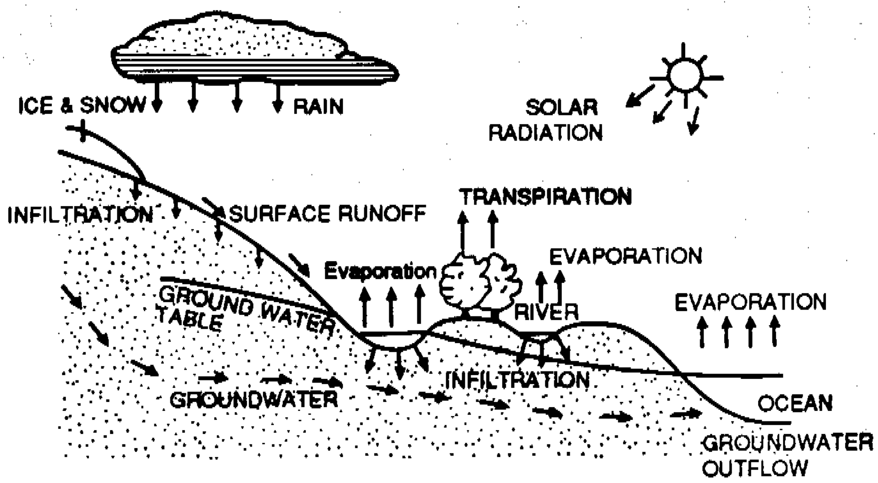


Fig. 1.1. Hydrological cycle.

1. Rain water
2. Ground water
3. Spring water
4. Lake water
5. River water
6. Ocean.

Quantity and Quality of various water sources

Source	*Quantity*	*Quality*
Rain water	variable	good, but post contamination may affect the quality.
Ground water	excellent	bacteriologically good but chemically doubtful.
Spring water	excellent	bacteriologically good but chemically doubtful.
Lake water	good	doubtful but easily treatable.
River	variable	usually bad, but improved by artificial treatment.

The process of selecting the most suitable source of water for a public water supply largely depends on the local conditions. If groundwater is not available, it will be necessary to consider surface water from sources such as rivers, stream or lakes. Surface water will always require some treatment to render it safe for human consumption and use. The costs and difficulties associated with the treatment of water, particularly the day-to-day problems of operation and maintenance of water treatment plants, need to be carefully examined.

FURTHER READING

Linsley R.K. and Franzini J.B. *Water Resources Engineering.* McGraw Hill. 1979.

REFERENCES

International Reference Centre (TRC) "Small Community Water Supplies", Technical paper 12, The Hague, The Netherlands, 1981

CHAPTER 2: CHARACTERISTICS OF FRESH WATER BODIES

The water required for public water supply schemes should be fit for drinking purposes. During precipitation and runoff water acquires many kinds of suspended and dissolved impurities. The rain water as it drops down to the surface of earth absorbs dust and gases from the atmosphere. It is further exposed to organic matter on the surface of the earth and by the time it reaches the source of water supply it is found to contain various other impurities as well. Therefore a vast array of potentially harmful materials may be transported by water.

2.1 SOURCES OF POLLUTION

Water pollution occurs when undesirable effluents and matter enter water bodies and so change water quality that the water is unfit for human use without treatment. Water pollution comes from five primary sources:-

- nature
- domestic wastewater
- industrial wastewater
- agricultural runoff
- urban runoff

Natural sources of water pollution include thermal and acid effluents from volcanic activities as well as wind induced dust particles. Domestic sources are mainly sewage which comes from toilets, bathrooms and kitchens and are generated in houses, apartments and other dwellings. Industrial wastes are those wastes discharged by industries and these wastes vary greatly from industry to industry and from place to place. As domestic and industrial wastewaters are gradually receiving improved treatment methods, the present day pollution problem is mainly based on the effects of urban and agricultural runoff. Agricultural runoff is a major contributor to eutrophication in rivers, lakes and other surface water bodies. Table 2.1 gives some examples of side-effects on water quality associated with different types of engineering activities.

Table 2.1

1. Effects of extractive mining schemes:
    - increased heavy metal ions,
    - increased sedimentation and turbidity,
    - changes in water courses and drainage systems,
    - changes in flora and fauna,
    - cumulative addition of pollutants to water,
    - waste disposal problems;

2. Effects of river basin development schemes:
    - increase in water-related diseases, especially associated with population movements,
    - weed invasion of irrigation systems,
    - increased water loss (higher evapo-transpiration),
    - fishery losses due to competition for light, energy, nutrients;

3. Effects of communication and transportation routes:
    - waste disposal problems,
    - cumulative addition of pollutants to water.

Source: "Effects on man and his environment of major engineering works", Project 10 of the Programme on Man and the Biosphere (MAB), Final Report series No. 37, UNESCO, Paris, 1976.

2.3 TYPES OF POLLUTANTS

There are a number of general categories of pollutants and these include:

1. Oxygen-demanding wastes such as domestic and industrial wastewaters.

2. Disease-causing micro-organisms such as bacteria and viruses from sewage and from some food processing plants.

3. Organic chemicals such as petroleum wastes, soap and industrial matter.

4. Inorganic chemicals such as metal salts and acids from manufacturing processes.

5. Plant nutrients such as nitrogen and phosphorus compounds from sewage and from agricultural activities.

6. Sediments that are washed from land into rivers and streams from rainfall runoff.

7. Radioactive substances arising from natural sources and from industrial activities.

Pure water is a tasteless, colourless and odourless liquid made up of hydrogen and oxygen. Impurities present in water may be divided into 3 groups:-

1. Physical impurities

2. Chemical impurities

3. Bacteriological impurities

These can be present in water in the form of suspended solids, colloidal solids or dissolved solids. Normally these impurities are measured in milligrams per litre (mgL^{-1}) which is also equal to grams per cubic metre (gm^{-3}). Concentration can also be expressed as parts per million (ppm) on a weight basis where:

$$\text{ppm} = \frac{mgL^{-1}}{\text{specific gravity of the liquid}}$$

For dilute solutions, ppm = mgL^{-1}.

2.3.1 The main physical impurities of water are

1. colour
2. Taste and odour
3. Turbidity
4. Suspended matter
5. Temperature
6. Conductivity
7. Foam

Colour

Even pure water is not colourless. It has a pale green-blue tint in large volumes. It imparts a bluish colour in depth. Any modification in colour is due to pollutants. The decay of large quantities of organic matter introduces appreciable colour into the water. Intense colour occurs in water draining from swamps and areas of forests. Industrial wastes may contain many colouring substances. Tannins may cause a yellowish brown colour. It should be noted that the impurity caused by colour is mainly an aesthetic one. Coloured waters may not be acceptable for certain industrial uses such as in the production of high-grade art paper. Removal of some types of colour increases the cost of treated water. Colour is determined by visual comparison with standard solutions of the chloroplatinate ion which are similar in colour to the natural colours in waters.

The unit of colour is Hazen units and one Hazen is equal to the colour produced by $1mgL^{-1}$ of platinum in the form of potassium chloroplatinate.

Taste and Odour

An objective of a water supply system is to provide water which is not objectionable to the consumer. Taste and odour make water unpleasant for drinking. Some of the chemicals producing taste and odour in water are salts, iron, manganese, free chlorine, hydrogen sulphide, phenols and ammonia. It may also be due to algae. The basis of estimation is called the threshold method and the threshold number is the dilution ratio at which taste or odour is most detectable.

Turbidity

The term turbid is applied to water containing suspended matter that interferes with the passage of light through water. Water may become turbid due to the presence of the following:-

a) Colloidal matter

b) salts of iron and manganese which are oxidised to their hydroxides.

c) sewage

d) industrial wastes of certain origin.

Turbidity measure the resistance of the passage of light through water.

The turbidity of a sample will depend upon the number, size, shape and refractive index of the particles in suspension. Therefore, there is no universal relationship between measured turbidity and the amount of material suspended in the water, although for specific samples there may be proportionality between turbidity and suspended solids concentration. Turbidity is measured on a turbidity scale of units established for a standard suspension under defined conditions of illumination. It is expressed in Nephelometry turbidity units (NTU).

Turbidity measurements:-

1. indicate the quality of treatment required.
2. determine the dosage of chemicals necessary in a treatment plant.
3. control the loadings to the filters. Water that goes into the filters must not have a turbidity greater than 10-15 NTU. After filtration the turbidity should be 2 to 5 NTU.

Suspended matter

The insoluble suspended matter present in water may be inorganic or organic. The presence may be due to contamination either by sewage, organic matter or some industrial wastes. To determine the amount of suspended matter, the sample is centrifuged or filtered and the dried residue weighed. The determination of suspended matter indicates the material which might be removed by sedimentation.

Temperature

Temperature of water is important in terms of its intended use and its effect on other properties. Temperature pollution is objectionable because:-

a) activity of biological life is more at higher temperatures, speeding up chemical reactions and as temperature of water rises more demand for dissolved oxygen.

b) oxygen solubility is inversely proportional to temperature. Thus at higher temperatures quantity of dissolved oxygen decreases.

Conductivity

The conductivity of a water sample is a measure of the ability of the sample to carry an electric current. The conductivity is the reciprocal of the resistivity of a sample, so any meter which can determine the resistance can be used to determine the conductivity of a sample. It is determined by the number of ions in solution, hence it is a measure of the dissolved inorganic material in a sample. However, the relationship between the conductivity and the amount of dissolved material depends on the nature of the dissolved material, temperature and pH of the sample. Regular measurements of conductivity for a given water body provide a method of monitoring the dissolved solids in the water. Conductivity results are usually reported in millisiemens per centimetre ($mscm^{-1}$).

Foam

Foam or froth indicates suspension of gas in water. Foam may develop in water either by fall from height or by the presence of some chemical matter. Foam formed by fall from a height lasts only a few minutes but it can be persistent when it is due to some chemical matter.

2.3.2 Chemical Impurities

Chemical substances that may be discharged to the receiving waters may be broadly classified into organic and inorganic pollutants.

The major consideration with respect to organic substances is the depletion of dissolved oxygen and its resultant effect on the aquatic biota. Other organic substances and effects of concern to water quality control include oils with their tendency to form surface films, taste and odour producing substances such as phenols, and compounds of a toxic nature such as pesticides and cyanides. Of particular concern are the refractory (non biodegradable) organics that are known to restrict growth or cause the death of fish and other aquatic life.

Undesirable results from the discharge of inorganic materials include changes in the pH of the waters caused by strong acids or bases, an increase in water corrosivity caused by soluble salts and toxicity due to heavy metals.

pH

Water is only weakly ionised and at 25°C the equilibrium constant for the reaction:

$$H_2O \rightleftharpoons H^+ + OH^-$$

is 1.10×10^{-14}. This relationship must be satisfied for all dilute aqueous solutions and the basic or acidic nature of solutions can be specified by one parameter - the concentration of hydrogen ions. Given the smallness of this concentration and the range of variation, this concentration is conveniently expressed on a logarithmic scale, this is the function pH,

$$pH = -\log_{10} [H^+]$$

The values of the pH can range from 0 to 14 with 7 for neutral solution, more than 7 is basic and less than 7 acidic.

Many chemical reactions are controlled by pH and biological activity is usually restricted to a fairly narrow pH range of 7 to 8. Highly acidic or highly alkaline waters are undesirable because of corrosion hazards and possible difficulty of treatment in water and wastewater plants.

The pH of a solution is normally measured potentiometrically using a glass electrode. The electrode consists of a glass bulb containing a standard solution of hydrochloric acid in which there is a silver/silver chloride electrode. The outside surface of the glass bulb is sensitised by the concentration of hydrogen ions in the sample, the inside by the standard concentration of hydrogenions, any difference in the two concentrations establishes a potential difference across the glass membrane which is measured and displayed on a pH scale. The response depends on the condition of the membrane and the electrode requires frequent calibration with buffer solutions of known pH.

Acids

Acids are contained in wastes of certain industries such as factories producing explosives, batteries and certain chemical compounds. Water containing acids is harmful to aquatic life and leads to corrosion of metal and concrete structures. The usual causes of acidity are free carbon dioxide in the water and organic acids. Also, sulphuric acid from a polluted industrial atmosphere.

Alkalies

Alkalies are contained in certain industrial wastes. The presence of alkalies in water has the same effects as that of acids. Usually the cause is the presence of bicarbonates, carbonates and hydroxides of calcium, magnesium, potassium and sodium. Calcium bicarbonate is the usual constituent causing alkalinity.

Aluminium

Found in some natural waters in a detectable amount. It can enter a water source from the use of aluminium cooking utensils, tanks or pipes. Also, through incorrect dosing of aluminium sulphate as a coagulant at the water treatment works. Although there is evidence of harm caused by traces of aluminium in water, research studies are in progress to see whether there is a link between aluminium and Alzheimer's disease.

Arsenic

Arsenic should be absent from water supplies as severe poisoning can result from the ingestion of as little as 100 mg. Chronic effects can also appear from its accumulation in the body at low intake levels. It is reported that arsenic is a possible cause of cancer. The arsenical concentration of drinking water should not exceed 0.05 mgL^{-1}. The element may be present in some natural waters or may gain access to shallow wells from surface washings or percolation where arsenical weed-killers or tree-sprays have been used in the vicinity of the well. Sheep-dipping may contaminate surface runoff waters and lakes and reservoirs may also be affected in this way. Arsenic can also come from natural sources through volcanic activities. The US Environmental Protection Agency (EPA) has recommended in 1976, 0.10 mg As/L for irrigation waters for crops.

Barium

Barium should be absent in municipal waters or must not exceed 1.0 mg/L^{-1}. The fatal oral dose of barium for adult humans is reported to be 550-600 milligrams. Barium salts are considered to be muscle stimulants, especially for the heart muscle and may cause an increase in blood pressure. On the other hand, there is no evidence that barium accumulates in the bone, muscle, kidney, or other tissue. It is excreted more rapidly than calcium and there is, therefore, no danger from a cumulative effect (J.McKee & H. Wolf: "Water Quality Criteria", 2nd ed., State Water Quality Control Board, Sacramento, California, Publ. No.3-A, 1963). Many of the Ba-salts are soluble, but the carbonate and sulfate are highly insoluble. Consequently, it is to be expected that any barium ions discharged into natural waters will be precipitated and absorbed in the bottom mud. Barium ions have been detected in a few springs and in effluents from areas where baryte ($BaSO_4$) and whitherite ($BaCO_3$) are mined.

Boron

The boron content of drinking waters is considered satisfactory if it is less than 1 mgL^{-1} ("Water Quality and Treatment", 3rd ed., AWWA, McGraw Hill Book Co., 1971).

The ingestion of excessive dosages of borates may cause nausea, cramps, convulsions, coma, and other symptoms of distress. The fatal dose for adult humans is reported between 5 and 45 gms. The big difference between the lower and upper magnitudes of a fatal dose is probably because boron, in most humans, is promptly excreted in urine.

US EPA has recommended in 1976, 0.75 mg B/L for long term irrigation on sensitive crops.

Beryllium

Beryllium and its compounds are believed to be exceedingly poisonous and capable of causing death in high concentrations. Inhalation of Be dust can cause a serious affliction called berylliosis. Beryllium disease can also take the following forms: dermatitis, conjunctivitis (eye disease), acute pneumonitis (lung disease) and chronic pulmonary berylliosis.

In 1976, the US EPA had recommended, 11 micrograms Be/L for the protection of aquatic life in soft fresh water, and 1.1 mg Be/L in hard fresh water. It is also recommended as the maximum permissible limit for continuous irrigation on all soils 0.10 mg Be/L, except 0.5 mg Be/L for the irrigation on neutral to alkaline fine-textured soil. In drinking water the upper limit of concentration for Be is 0.0002 mg/L^{-1}.

In the form of the element, compounds or alloys, Be is used in atomic reactors, aircraft, rockets and missile fuels. Entry into a water supply can result from the discharges of such industries. Beryllium has been reported to occur in U.S. drinking waters with the mean value of 0.013 micrograms Be/Litre.

Cadmium

Ideally cadmium should not be detected in drinking waters. The maximum permissible limit (MPL) should not exceed 0.005 mg Cd/L (NHMRC). Cadmium is used in metallurgy to alloy with copper, lead, silver, aluminium and nickel. It is also used in electroplating, ceramics pigmentation and photography. Consumption of cadmium salt causes cramps, nausea and tends to accumulate in liver, kidneys and thyroids of humans and animals.

Chromium

Chromium ions can be present in two principal forms, trivalent and hexavalent. The ingestion of trivalent chromium is reported to have no physiological effects in the quantities normally associated with drinking waters, but hexavalent chromium should not exceed 0.05 mg/L for domestic water supply (NHMRC, 1987). There is no evidence that Cr-salts are essential or beneficial to human nutrition. When administered orally, Cr-salts are not retained in the body, but are rapidly excreted. Although the salts of trivalent chromium are not considered to be physiologically harmful, there is evidence that large doses of hexavalent chromium lead to ulcerations in the intestinal tract. For the purpose of protecting freshwater aquatic life the US EPA recommends that Cr-content of 0.10 mg/L should not be exceeded.

Cr-salts are used extensively in industrial processes and may enter a water supply through the discharge of wastes. Chromate compounds are frequently added to cooling water for corrosion control. Chromium may exist in water supplies in both valence states, although the trivalent form rarely occurs in potable water supplies.

Cyanide

Cyanide is a chemical compound, not an element. It is reported that most of the cyanide in water supplies is in the form of HCN which is largely undissociated at pH values of 8 or less, and it is therefore the HCN rather than the CN^- which is the major toxic chemical.

Cyanides occur in the effluents from coal-gas works and coke ovens, from the scrubbing of gases in steel plants, from metal cleaning and electroplating processes, and from chemical industries. Hence they are found in river waters receiving industrial wastes.

Cyanides in waters are usually decomposed by bacteria. The percolation of wastewaters through soil columns rich in organic matter will materially reduce the cyanide content. The biological degradation process is temperature sensitive and is most effective between 10-35°C, proceeding at a slower rate at temperatures both above and below these limits. Cyanides and their related compounds, the cyanates, can be oxidised to non-toxic chemicals by the action of chlorine.

Drinking water standards for cyanide will usually accept 0.01 mg/L. However, the odour threshold for HCN in water is 0.0001.

Lead

Ideally, lead in drinking water supplies should not be detectable. The MPL value should not exceed 0.05 mg Pb/L.

Lead is a serious cumulative body poison and is to be avoided. Natural waters seldom contain more than 0.02 mg/L, although values as high as 0.40 mg Pb/L have been reported where mountain limestone and galena are present. The presence of lead in a water supply may arise from industrial, mine and smelter discharges, or from the dissolution of old lead plumbing. Tap waters which are soft, acid, and not suitably treated may contain lead resulting from an attack on the lead service pipes. Lime-softened waters are said to be safe with regard to lead pipes in home plumbing installations. Well waters have been recorded as high as 15 mg Pb/L.

In advanced stages of lead accumulation in humans, lead poisoning results in constipation, anemia, abdominal pains and gradual paralysis, particularly in the arm muscles. Lead can, of course, enter the body through food, air and tobacco smoke as well as from water and other beverages.

Mercury

The Japanese people have a special concern for environmental pollution related to mercury compounds since they have had experience with the Minamata disease which was caused by the consumption of sea foods contaminated with methylmercury compounds discharged from a chemical plant which had been synthesising acetaldehyde from acetylene with inorganic mercury compounds as the catalysts.

With regard to the medical aspects of the disease, various combinations of neuropsychiatric symptoms, such as a type of polyneuritis, mental deterioration, a type of symptom combined with apoplexy and a type combined with hypertension, are now included in the enlarged concept of the Minamata disease. During the period from 1954 to 1968, 2500 tons of phenylmercury pesticides were consumed. This amount corresponds to the application of 500 to 700 g/ha (100 times the consumption in Europe). The use of phenylmercury pesticides was officially prohibited in 1968, but even today, the residues of this toxic substance are detectable in Japan in a considerably large amount of the harvested rice grain.

The USEPA (1987) recommendation is a maximum limit of 0.14×10^{-3} mgL^{-1}.

Nitrogen

This is an important element in biological systems. Biological treatment of wastes can only proceed if sufficient nitrogen is present. Nitrogen exists in four main forms from the viewpoint of the environmental technologist:

(i) Organic nitrogen - nitrogen in the form of proteins, amino acids and urea.

(ii) Ammonia nitrogen - nitrogen as ammonium salts, eg ammonium carbonate, $(NH_4)_2CO_3$, or as free ammonia.

(iii) Nitrite nitrogen - an intermediate oxidation stage not normally present in large amounts.

(iv) Nitrate nitrogen - the final oxidation product of nitrogen.

Oxidation of organic nitrogen compounds, termed nitrification, occurs in the following steps:

$$\text{Org-N} + O_2 \rightarrow \text{Amm-N}$$
$$\text{Amm-N} + O_2 \rightarrow NO_2\text{-N}$$
$$NO_2\text{-N} + O_2 \rightarrow NO_3$$

Reduction of nitrogen, termed denitrification, may reverse the process:

$$NO_3^- \rightarrow NO_2^- \rightarrow NH_3 + N_2$$

The appropriate bacteria must be present for both these processes to occur, additionally, the denitrification process requires an adequate supply of organic matter to serve as an energy source. The relative concentrations of the different forms of nitrogen give a useful guide to the degree of pollution of a water sample. Before the availability of bacteriological analysis, the quality of waters was often assessed by considering the nitrogen content. A water containing high organic and ammonia nitrogen would be considered unsafe because of recent pollution. On the other hand, a sample with only organic or ammonia nitrogen and some nitrate nitrogen would be considered safe as nitrification had occurred and thus the pollution could not have been recent.

Nitrogen enters the water system from many sources, primarily from the decomposition of nitrogenous organic matter, sewage, surface water runoff and use of nitrogenous fertilisers.

Ammonia

Ammonia is the natural product of the bacterial decomposition of organic matter. When dissolved in water ammonia is lethal to many species of fish at concentrations above two milligrams per litre. The toxicity increases sharply with the pH.

Nitrates

Nitrates may attain high levels in some ground waters (up to 1000 mg/L^{-1} as N). The nitrate ion, NO_3^- is toxic to babies of less than six months. At this age the stomach is not fully developed and cannot detoxify the nitrite ions, NO_2^-, formed in the stomach. The nitrite ions interfere with the transfer of oxygen to the haemoglobin.

The condition known as methemoglobinemia or 'blue baby disease' develops, which can be fatal.

Phosphates

The levels of phosphorus-containing compounds in water bodies are important because of the role of phosphorus as a nutrient in biological processes. Aquatic flora require an adequate level of phosphorus to maintain a healthy environment for aquatic fauna. However, excessive levels of the nutrient may lead to excessive algal growth and oxygen demand, culminating in eutrophication of the water body.

Sodium

Drinking water contributes about 10% of total intake of sodium. There has been an increase of sodium content in water during the last few decades. Sodium pollution may be caused by Lime Soda Ash process in water treatment, industries and mineral water. It can cause hypertension and cardio vascular diseases in humans.

Pesticides

These are usually extremely toxic organic chemicals used by fruit growers and farmers to control diseases common to orchards and crops. One of the major problems with the determination of biocides in waters is the sampling procedure that must be adapted if reasonably accurate results are to be obtained.

With the use of degradable biocides the problems in water supply systems should not become too severe providing a monitoring program is maintained. It is necessary, however, that a water engineer be aware of this problem when designing intakes and waterworks in areas where pesticides and biocides may become a problem, and to orient the intake with the intention of avoiding surface and storm water runoff as much as possible.

polychlorinated Biphenyls (PCB)

The coastal areas around Japan are highly polluted with PCB. Its accumulation is found not only in marine fish, but also in fish-eating birds. PCBs are used: a) as dielectrics in transformers and large capacitors, b) in heat transfer and hydraulic systems, c) in the formulation of lubricating and cutting oils, in pesticides and as plasticisers in paints, copying paper, adhesives, sealants and plastics.

Selenium

Selenium has a toxic effect upon man and animals comparable with that of Arsenic, and giving rise to similar symptoms. Selenium has also been suspected of causing dental caries in man, and has been cited as a potential carcinogenic agent. Therefore the MPL in drinking waters is set at 0.01 mg Se/L, but preferably should not be detectable.

Concentrations of Selenium in natural waters exceeding 0.5 mg/L are limited to seepage from seleniferous soils. The sudden appearance of Se in a water supply might indicate industrial pollution. Little is known regarding the valence state of selenium in natural waters, but because selenate and selenite are both found in soils, it is reasonable to expect that both may be present in seleniferous water. Water contaminated with wastes may contain selenium in any of its four valence states. Many organic compounds of selenium are known. Selenium is used in many manufacturing processes such as pigmentation of paints, dyes and glass production, as a component of rectifiers, semi-conductors and photoelectric cells, and can therefore be expected to be present in their industrial wastes.

Copper and Zinc

Copper and zinc are found in some natural waters, particularly in the vicinity of ore deposits. They can be toxic to fish at concentrations above a milligram per litre; copper is some ten times more toxic than zinc. At these levels copper and zinc are not considered detrimental to human health, however, they would give an undesirable taste to drinking water.

Fluorides

In some areas water sources contain natural fluorides. Where the concentrations approach optimum levels the incidence of dental cavities has been found to be less than that in areas without natural fluorides. The optimum fluoride level for a given area is dependent on the air temperature, since temperature has a pronounced effect on the amount of water consumed by an individual. Optimum concentrations from 0.7 to 1.2 mg/L are recommended. Excessive fluoride in drinking water may produce fluorosis, that is mottling, of the teeth. This effect increases with concentration above the optimum levels, at large excess levels, the teeth may become brittle.

Iron

Small amounts of iron frequently are present in water because of the large amount of iron in the soil. The presence of iron in water is considered objectionable because it imparts a brownish colour to laundered goods and affects the taste of beverages such as tea and coffee. Recent studies indicate that eggs spoil faster when washed in water containing iron in excess of 10 mg/L.

Trihalomethanes

Chlorine used for the disinfection of water can react with some of the organic substances present to form Trihalomethane (Chloroform) and other chlorinated hydrocarbon. These are of concern because they are suspected carcinogens.

Hardness of Water

Hardness is a measure of the concentration of calcium and magnesium ions in a water sample, expressed as milligrams of calcium carbonate per litre. The salts of these ions cause scaling in pipes and reduce the lather produced by soaps and detergents. There are no adverse health effects, but the economic disadvantages of hard water include increased soap consumption and higher fuel costs.

For many uses the extent to which water will dissolve calcium ions or precipitate calcium salts is extremely important. This property is determined by a complex interaction of the total concentration of calcium, magnesium and sodium ions. A number of indices have been defined to give a measure of the tendency to dissolve or precipitate calcium, these include the Calcium Carbonate Saturation Index, the Residual Alkali and the Sodium Adsorption Ratio. Details of the parameters measured and the method to calculate these indices can be found in appropriate reference books on water quality.

Normally water hardness is classified as follows:

Soft = hardness < 50 mg/L
Moderately Hard = Hardness 50-150 mg/L
Hard = Hardness 150-300 mg/L
Very Hard = Hardness > 300 mg/L

Hardness in water is of two types:

1. Temporary Hardness

2. Permanent Hardness

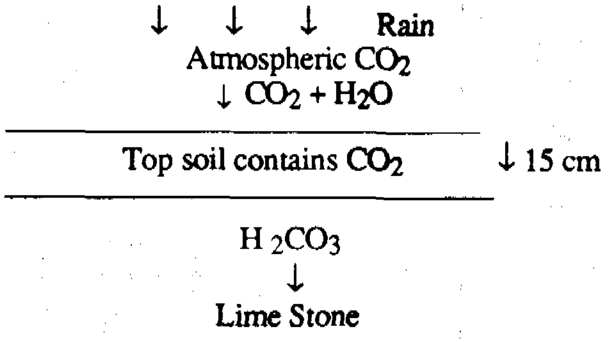
Temporary hardness is also called carbonate hardness and it is mainly due to the presence of bicarbonates of calcium and magnesium. It can be removed by boiling or by adding lime to the water.

Permanent hardness is also known as non-carbonate hardness and it is due to the presence of sulphates, chlorides and nitrates of calcium and magnesium. It cannot be removed by boiling the water.

The cause of alkalinity is the presence of bicarbonates, carbonates and hydroxides of calcium, magnesium, potassium and sodium. Of these calcium bicarbonate is the most usual constituent causing alkalinity.

When alkalinity and hardness figures are equal all the hardness is temporary. If the total hardness is greater than the alkalinity then the excess represents permanent hardness. Sometimes the total hardness is less than the alkalinity, then the difference indicates the presence of sodium bicarbonate which adds to the alkalinity but does not increase the hardness.

Source of Hardness



$$\underset{\text{Insoluble}}{\overset{\substack{\text{(Lime Stone)}\\ \downarrow}}{CaCo_3}} + H_2CO_3 \longrightarrow \underset{\text{Soluble}}{\overset{\substack{\text{(Calcium bicarbonate)}\\ \downarrow}}{Ca\,(HCO_3)_2}}$$

PRESENTATION OF ANALYTICAL RESULTS

When the analysis of a water sample is completed, an environmental engineer must interpret these results. This is frequently done by converting the results for each analysis to the equivalent concentration of C_aCO_3 or milli equivalents per litre. These values may be plotted on a bar chart to show the relationship between the various components. A bar chart for the results in Table 2.2 is shown in Figure 2.1. The concentration of each ion is converted to milliequivalents per litre by dividing the concentration of ion by its equivalent weight. The values of the ions in milliequivalents per litre (m eq/L) are given in the third column of Table 2.2.

Table 2.2

Ion	Concentration of ion mg/L	Equivalent Weight	M eq/L
Ca^{++}	103	20.0	5.15
Mg^{++}	5.5	12.2	0.45
Na^{+}	16	23.0	0.69
HCO_3-	255	61.0	4.18
SO_4--	49	48.0	1.02
Cl-	37	35.0	1.05

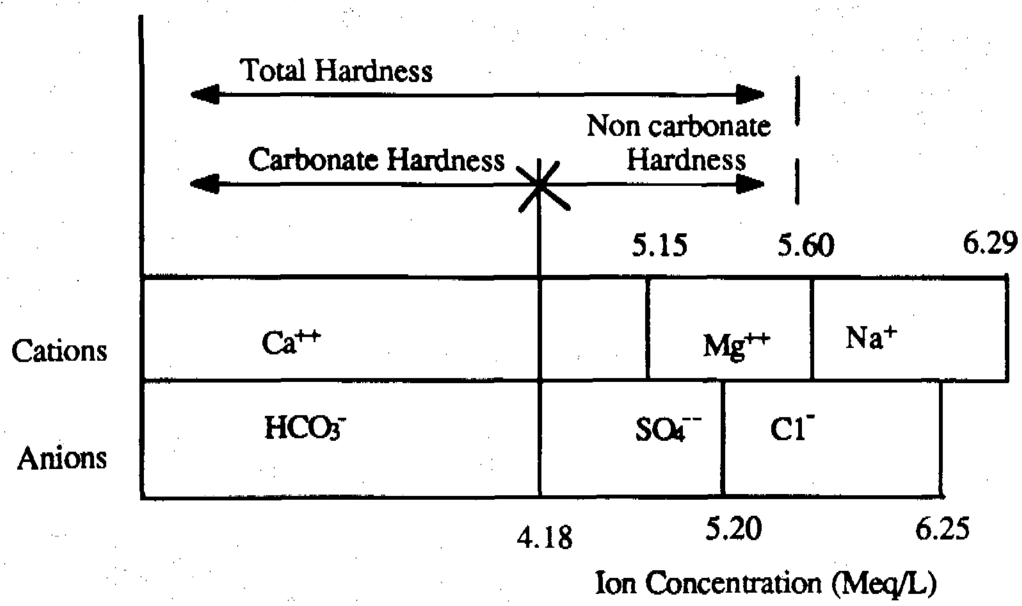


Fig. 2.1

As can be seen from the bar chart, where the concentrations of the cations are plotted on one bar and the anions on another bar, the total concentrations of the cations is 6.29 meq/L and of the anions 6.25 meq/L. The discrepancy between the values arises from the presence of some anions not included in the analysis such as nitrate or phosphate. For a complete analysis the total concentrations of the cation and anions must be equal. The diagram shows the total hardness to be 281 mg/L and the carbonate hardness 209 mg/L of calcium carbonate. This water would be unsuitable for domestic use without softening to reduce the hardness. Water with hardness in excess of 150 mg/L is unsuitable for domestic use; supply authorities usually treat water supplies to reduce the hardness below 120 mg/L. (Hardness ing/L of $CaCCO_3$ = meq/L X Equivalent Weight of $CaCO_3$.)

2.3.3 Bacteriological Impurities

Micro-organisms are commonly present in surface waters, but they are usually absent from most groundwaters because of the filtering action of the aquifer. Bacteriological impurities may be present in the water, usually by sewage contamination. These impurities are in the form of micro-organisms and organisms.

1. Bacteria - The most common water-borne bacteria are typhoid fever and cholera.
2. Protozoa - Protozoa caused infections are usually limited to amoebic dysentery.

3. Worms - Intestinal worms, eggs and larvae cause helminthic diseases.

4. Viruses - Yellow Jaundice (hepatitis), poliomyelitis, influenza are caused by viruses in water.

5. Fungi - Skin rashes and eye disorders.

As water falls through the atmosphere, rainwater picks up airborne micro-organisms and may also pick up soil particles as it flows through the ground. Neither of these sources of contamination is particularly important because of the dilution in large bodies or streams of water or filtration through the soil. These natural safeguards do not protect water from microbial pollution by human or domestic wastes.

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2. Tebbutt, T. H. "Principles of Water Quality Control". Pergamon Press. 3rd edition

CHAPTER 3: WATER QUALITY CRITERIA AND TESTING PROCEDURES

3.1 INTRODUCTION TO BASIC MICROBIOLOGY

Micro-organisms are of considerable importance in water quality control. The stabilisation of organic wastes is largely achieved by micro-organisms and the assimilation of effluents into rivers is aided by biological self-purification. On the other hand, micro-organisms are responsible for diseases such as typhoid, taste and odour in water supplies, corrosion of concrete and metal structures and the prolific microbial growth which can lead to eutrophication of enclosed water bodies.

3.1.1 Types of metabolism

A basic classification of micro-organisms depends on the type of metabolism the organism requires to survive. This classification is shown schematically in Figure 3.1 and described in the following paragraphs.

Autotrophes are organisms which are capable of synthesising their organic requirements from inorganic sources and therefore can grow independently of an external source of organic matter. This can be achieved by two methods:

(i) **Photosynthesis** - plants of most species use light energy to produce organic matter and oxygen; these organisms are described as phototrophes.

(ii) **Chemosynthesis** - the chemical energy of inorganic chemicals is used to synthesise organic matter, for example denitrifying bacteria; these organisms are described as chemotrophes.

Heterotrophes are organisms which require an external source of organic matter and are of three main types:

(i) **Saprophobes** - organisms which obtain soluble organic matter from the environment directly or by the extra-cellular digestion of insoluble material.

(ii) **Paratrophes** - organisms which obtain soluble organic material from the tissues of other living organisms and are thus frequently pathogenic.

(iii) **Phagotrophes** - organisms which utilise solid organic matter.

Organisms also differ in their requirements for oxygen; aerobes must have free oxygen present, whereas anaerobes exist in the absence of free oxygen. Facilitative forms can operate in either system, but perform more efficiently in an aerobic environment.

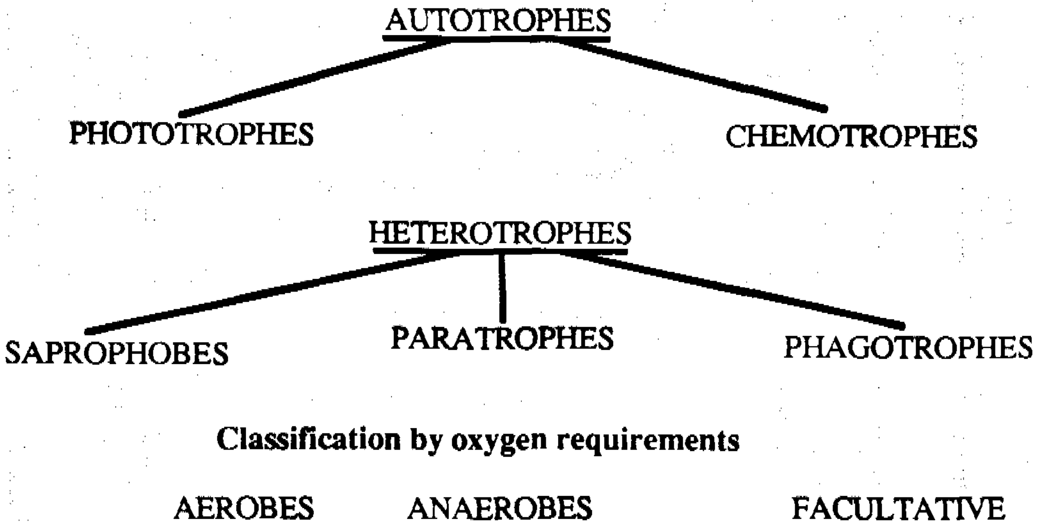

Fig. 3.1. Classification of micro-organisms by type of metabolism.

3.1.2 Types of Micro-organisms

Micro-organisms are too small to be visible to the naked eye and there are a large number of organisms in this category. The basic division is between plants and animals, but the dividing lines between different types of micro-organisms are often indistinct so that the classification may sometimes be difficult. The various types of plants and animals are shown in Figure 3.2 and discussed in the following paragraphs.

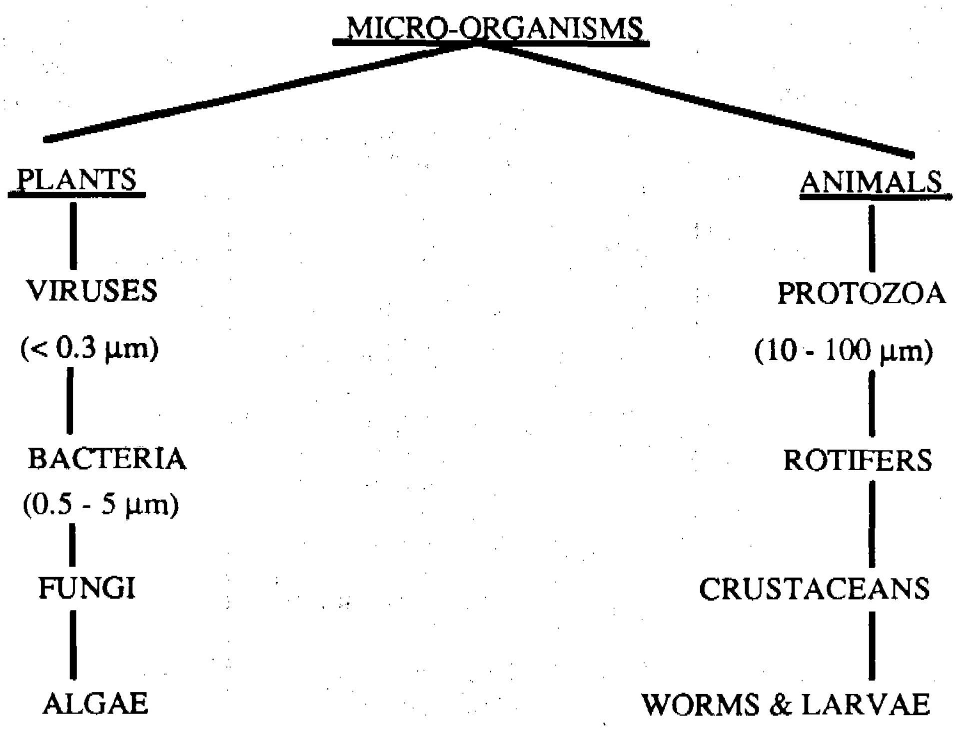

Fig. 3.2. Types of Micro-organisms

3.1.2.1 Plants

Plants require soluble food which may be either organic or inorganic, although specific organisms will utilise one form or the other.

(i) **Viruses** - These are the smallest plants, less than 0.3 microns in diameter, and can reproduce only within a specific host cell.

They are all parasitic and lack normal metabolic functions, lying on the borderline between living organisms and chemical compounds. Many diseases; for example, influenza and poliomiolitis; are caused by virus infections. Viruses are commonly found in sewage effluents and are present in most polluted waters. Due to their small size they are difficult to remove from water and are frequently resistant to disinfection methods.

(ii) **Bacteria** - The basic unit of plant life: single cell organisms which utilise soluble food, normally organic although there are many chemotrophic types.

They range in size from 0.5 to 5 microns in a variety of shapes. Reproduction is by binary fission and the generation time may be as short as 20 minutes. Some types form resistant spores which lie dormant in unsuitable environmental conditions and become reactivated if more acceptable conditions return. Most bacteria are sensitive to pH, preferring more or less neutral conditions, although some species, for example, the sulphur bacteria, can exist in a highly acidic environment. They are sensitive to temperature and have an optimum growth temperature. Bacteria are either aerobic, facultative or anaerobic. They are of vital importance in wastewater stabilisation as well as being responsible for many waterborne diseases.

(iii) **Fungi** - Mainly multicellular plants which are more tolerant of acid conditions and a drier environment than the bacteria.

There are over 100,000 different species and all are chemosynthetic aerobic organisms. The fungi have four or five different life phases as distinct from bacteria which have only one. Reproduction is by means of asexual spores or seeds. Fungi are found in biological treatment plants and in polluted rivers and they are responsible for tastes and odours in water.

(iv) **Algae** - Photosynthetic plants usually multicellular, incorporating chlorophyll. They utilise Co_2, NH_3 and PO_4^{3-} to produce new cells and oxygen.

In the absence of sunlight, some species can exist with a chemosynthetic mechanism in which case they exert an oxygen demand. The photosynthetic activity is controlled by pigments which give algae characteristic colours. They have no definite stems or leaves as do higher plants and may exist as single cells or colonies. Freshwater forms are usually microscopic, but saltwater forms can be very large, for example seaweed. Algae and bacteria growing in the same solution do not compete for food but operate in a synergistic manner. The algae utilise the end products of the bacterial decomposition of organic matter and produce oxygen which helps to maintain an aerobic environment to optimise the activity of the bacteria. In the absence of organic material the growth of algae depends on the mineral content from the water. Thus in hard water, algae obtain carbon dioxide from bicarbonates, reducing the hardness and usually increasing the pH. Algae are important in water quality control because of their effect on the DO balance and also because of their property of producing severe taste and odour problems which are best solved by preventing the growth of large algal blooms in reservoirs.

3.1.2.2 Animals

Animals utilise organic foods only, that is they cannot synthesise protoplasm from inorganic matter. The food is usually in solid form, but some species can utilise high concentrations of soluble organic material. All types require oxygen, although some forms can live at low DO levels.

(i) **Protozoa** - Single cells 10 to 100 microns long which reproduce by binary fission and live mainly by eating bacteria.

A single protozoa can consume many bacteria because of its relatively large size and energy requirements. Protozoa cannot synthesise all the essential growth factors and must depend on bacterial food to provide these items. They play an important role in biological waste treatment.

(ii) **Rotifers** - The simplest multicellular animal.

They have a flexuous body and cilia on the head catch food and provide mobility. They are sensitive to changes in their environment and are thus good indicator organisms, predominating in stable conditions with high DO.

(iii) **Crustaceans** - Hard-shelled multicellular animals.

They have a flexuous body inside a shell and are an important fish food. They are relatively large and some can be seen with the naked eye. Crustaceans are only found in stable conditions.

(iv) **Worms and Larvae** - Similar to rotifers these animals are multicellular with a flexuous body found mainly in bottom deposits where they are important scavengers. They can metabolise organics not readily broken down by other micro-organisms.

3.2 WATER QUALITY PROBLEMS IN N.S.W.

The eastern river basins of NSW support most of the State's population and urban and industrial centres, while the western basins support most of the rural and agricultural activities. This difference in human activity has, in part, caused different water quality problems.

Traditionally, the emphasis in water quality management has been to treat specific water problems rather than seeking to eliminate their cause. Today, however, growing public concern over the health of the environment, coupled with the high cost of water treatment, have underscored the pressing need for coordinated land and water management practices to control the causes of degraded water, particularly from diffuse-source pollution.

When the quality of water is badly managed it can:

- significantly lower the quality of life for many people
- reduce economic outputs

- irreparably harm sections of the natural environment.

In 1989 a survey of various water user groups across the State, conducted on behalf of the NSW Department of Water Resources, identified the issues in Table 1 as being most significant.

Table 3.1

ISSUE	EXTENT	CONSEQUENCES
Eutrophication	Most storages and in many streams	Stock deaths, sickness, recreational loss, low flow due to water weeds
Turbidity	Predominantly in western NSW streams and domestic supplies	Alteration to ecosystems, water unsuitable for stock
Salinisation	Areas in south-western NSW	Loss of farm productivity, damage to land users and ecosystems
Toxicity	Intensive cropping and horticulture areas, abandoned mine sites	Contamination of stock and crop, fish kills, danger to people and ecosystems
Bacterial pollution	Water bodies near major towns	Risks to human life and health

While these issues are not universal, they are widespread across the State and their most common causes are discussed below. The discussion also indicates some control measures which might be adopted to control the various problems.

Eutrophication

"Eutrophication" is the build-up in water of excessive amounts of nutrients, particularly nitrogen and phosphorus. Increases in nutrient concentrations are caused by discharges of treated sewage effluent and the widespread and excessive use of chemical fertilisers in agriculture. High nutrient concentrations can lead to the rapid growth of algae and aquatic weeds. Some algae may be toxic, causing fish and stock deaths. Eutrophication of water supplies may cause complaints about taste and odour, and problems such as clogged filters and poor settlement of flocs in treatment plants. Large and excessive doses of chlorine are sometimes needed for disinfection.

Turbidity

Turbidity is a widespread water quality problem, particularly in the western basins draining to the Darling and Murray rivers. Increases in turbidity are caused by soil erosion due to the combined effects of poor land management, widespread rainfall and flooding. To some extent, however, turbidity in these western rivers is a natural phenomenon caused by the dispersive clays present in the area.

Salinity

Water impregnated with salts can become unsuitable for humans and livestock. If saline water is used for irrigation, crop yields may drop and some plants may become totally unproductive or even die. Salts usually have a geological source but their rate of release to surface water may be accentuated by irrigation, surface and sub-surface drainage water disposal, and groundwater seeping into surface watercourses, usually after the clearance of native vegetation.

Pollution from Toxic Chemicals

Water pollution from chemicals such as pesticides and fertilisers may present long or short-term hazards to humans, animals and aquatic ecosystems. Chlorinated hydrocarbon compounds cause the greatest concern because they remain unchanged in the environment for long periods and can accumulate in plants and animals, often to toxic levels.

Metals such as arsenic, cadmium, chromium, copper, lead, manganese, mercury and zinc are often found in water near abandoned mining sites. They may accumulate in plants and animals and can be toxic at certain concentrations. Unlike many of the newer pesticides, they are not necessarily converted to less toxic forms by bacteria. Both the chemicals and the metals can accumulate in sediment.

Bacterial Contamination

Water may become contaminated by bacterial micro-organisms which are pathogenic, ie organisms which can transmit communicable disease and which therefore pose a health hazard to humans or animals.

Safe guidelines for bacterial contamination are usually based on indicator organisms rather than on pathogenic organisms. One common indicator organism is faecal coliforms. These generally indicate pollution caused by the faeces of warm-blooded animals.

3.3 WATER QUALITY INDICATORS

Any contaminant or property of water can be used to indicate quality. In developing criteria, it must be decided which indicators are relevant to the Protection Category. Indicators generally adopted in other documents are used here. Nevertheless, this does not mean that other indicators may not be adopted in the future. Water quality indicators can be categorised as follows:-

Biological Indicators:

- Bacteria
- Algae.

Physical Indicators:

- Temperature
- Turbidity, light penetration
- Colour
- Electrical conductivity (salinity)
- Suspended solids
- Dissolved solids.

Aesthetic Indicators:

- Odours
- Taints
- Colour
- Floating matter.

Chemical Indicators:

- pH
- Dissolved oxygen
- Biochemical oxygen demand
- Nutrients (nitrogen and phosphorus compounds)
- Inorganic ions and compounds*
- Organic ions and compounds.

* These can include toxicants and genetically active materials.

Radioactive Indicators:

Alpha, beta and gamma radiation emitters.

3.4 WATER QUALITY CRITERIA

Water quality criteria are guidelines for establishing the desirable quality of water for a variety of beneficial uses, or for establishing the quality of wastewaters and effluents to be discharged into receiving waters. The Environmental Protection Authority of NSW has developed water quality criteria for different protection categories of water. The thirteen protection categories identified include:

1. Potable water supply
2. Agricultural water supply
3. Industrial water supply
4. Recreation and
5. Aquatic Ecosystems.

3.4.1 Potable Water Supply

Traditionally three categories of criteria have been applied to potable waters. These are:

(i) Health Criteria: where water is to be used for human consumption, minimum risk levels for toxicants and pathogens must be satisfied.

(ii) Palatability and Aesthetic Criteria: water should be free of objectionable taste, odour, colour and turbidity.

(iii) User Convenience Criteria: potable water is normally supplied through a reticulation system from which only a small percentage is used for human consumption. The bulk is primarily used for washing and accordingly, should not contain corrosive or scale forming agents or be excessively hard.

3.4.2 Agricultural Water Supply

Water used in agriculture can be grouped into the categories of farmstead, stock and irrigation. These categories can be further broken up to give "use sub-sets" each requiring its own set of water quality criteria.

Farmstead Supplies

Under this category, water can be used for:

(i) domestic use, including potable, for such things as washing and laundering

(ii) dairy use, washing, cooling etc, where generally potable criteria would apply but in addition low hardness is also preferred

(iii) produce preparation, cooling and washing of vegetables and other farm produce.

To protect people living on farms and the consumers of farm produce, waters used for the above applications should be free of pathogenic organisms, toxicants, undesirable taints, odours and colours as well as corrosive and scale forming substances.

Stock Water Supplies

The acceptable level of any given water quality indicator for stock supplies will depend upon a number of factors including:

(i) the particular tolerance of the animal species, which may be age-dependent and influenced by pregnancy or lactation

(ii) the amount of water the animal consumes

(iii) the level of a particular indicator in food consumed by the animal.

Irrigation Water

Quality criteria for irrigation waters are designed to ensure high crop yields while preserving the structure and quality of soils. The specific criteria depend not only upon the crop type but also soil type, drainage characteristics and the methods of irrigation (ie flood, furrow, sprinkler or drip).

In the long term, crop yields will not be sustained if the quality of the irrigation waters adversely affects the soil's physical and chemical properties. Different species of plants are susceptible to salinity, pH and concentrations of specific ions, eg chloride, boron, etc. Irrigation as a classified use has been divided into six sub-groups, primarily on the basis of salinity. Crop sensitivity to certain elements must also be considered when setting water quality criteria aimed at preserving irrigation as a classified use.

Generally, those properties of waters which determine their suitability for irrigation can be summarised as follows:

(i) salinity
(ii) the ratio of sodium to other cations
(iii) the solubility relationship between the ions of bicarbonate, carbonate, calcium and magnesium
(iv) the concentrations of toxic ions and compounds
(v) the concentration of oxygen demanding substances
(vi) pH
(vii) suspended solids
(viii) bacterial levels.

3.4.3 Industrial Water Supply

Industrial uses of water are extremely varied and often require very different levels of water quality, even within a single industry. Three broad classes of industrial water are generally recognised:

(i) heat transfer (cooling and heating)
(ii) power generation
(iii) processing.

Based on US findings (NCWQ 1968), the relative quantities of water accounted for by these classes of use is as follows:

- 90% for heat transfer
- 2% for power generation
- 8% for processing.

Water quality concerns industry through its effects on products, equipment and plant efficiency or capacity. Such effects include the following (IWBE 1972):

Effects on Products:

(i) decay (biological action)
(ii) staining
(iii) corrosion
(iv) chemical reaction and contamination

Effects on Equipment:

(i) corrosion
(ii) erosion
(iii) scale deposition

Effects on Plant Efficiency or Capacity:

(i) tuberculation
(ii) sludge formation
(iii) scale formation
(iv) foaming
(v) organic growths.

Since the cost incurred through the use of poor quality water may be high, some form of treatment of raw waters is common in industry.

3.4.4 Recreation

Four levels of recreational activity are recognised, with different water quality requirements.

Level 1: Passive Recreation in a Pristine Environment

There is increasing demand for passive recreation in pristine environments. This is characterised by people travelling to observe pristine areas. Water quality criteria for such areas would be set at the background levels.

Level 2: Primary Contact Recreation

This is characterised by bodily immersion or submersion where there is direct contact with the water. It includes swimming, diving, water skiing and surfing. Water quality criteria for the protection of these uses fall into three categories.

(i) health criteria
(ii) safety criteria
(iii) aesthetics.

Level 3: Secondary Contact Recreation

This includes activities such as wading, boating, fishing, etc, in which some contact with the water may occur but in which the probability of bodily immersion or the intake of significant amounts of water is minimal. The following categories of criteria are relevant:

(i) health criteria
(ii) safety, including protection of vessels
(iii) aesthetics
(iv) recreational fisheries criteria.

Level 4: Passive Recreation - Non-Pristine Environment

Aesthetic enjoyment is the primary consideration for this type of recreation.

3.4.5 Aquatic Ecosystems

The protection of aquatic ecosystems is in many ways more fundamental than the protection of other waters. Aquatic ecosystems are important in a number of ways:

- Aquatic ecosystems are valuable resources in themselves. In many parts of the world aquatic life represents a major source of protein for humans. In most countries, including Australia, commercial and sport fisheries are economically important.
- Aquatic communities are essential to the efficient assimilation of organic matter and recycling of nutrients in the aquatic environment. Such processes are important in maintaining water quality.
- Aquatic ecosystems are an integral part of the biosphere. They must remain functional if the biosphere is to continue to support people and their various classified uses of the environment. The world's conservation strategy stresses the importance of maintaining healthy ecosystems and genetic diversity.
- Not only do aquatic communities play an important role in maintaining water quality, they also are a valuable indicator of

the quality, and of the water's suitability for many other classified uses.

- Aquatic ecosystems also provide enjoyment to people, and a subject for educational and scientific pursuits.

3.5 PHYSICAL AND CHEMICAL EXAMINATION OF WATER AND WASTEWATER

The methods of analysis used to define the physical and chemical characteristics of water and wastewater samples can be classified as:

- Gravimetric
- Volumetric
- Physicochemical

3.5.1 Gravimetric Methods

Gravimetric analysis is made through a weighing operation. Suspended solids content is the most common parameter determined gravimetrically.

3.5.2 Volumetric Methods

In volumetric methods, the volume of a solution is computed using the following expression which is based on the principle of conservation of Mass, ie

$$V_1C_1 = V_2C_2$$

where V_1 = volume of solution of known concentration
C_1 = concentration of known solution
V_2 = volume of solution of unknown concentration
C_2 = concentration of unknown solution.

3.5.3 Physicochemical Methods

In physicochemical methods, physical properties other than mass and volume are measured. Instrumental methods of analysis such as turbidimetry, colourimetry, potentiometry, adsorption spectrometry, spectroscopy and nuclear radiation are representative of the physicochemical methods.

3.6 PURPOSES OF EXAMINATION

Water and wastewater are examined to evaluate their treatability, treatment effectiveness, and quality.

Sewage is analysed to determine those constituents that may cause difficulties in treatment or disposal, as an aid in plant operation, and in selecting the correct degree and type of treatment. Plant effluents are investigated to measure their strength and to determine the constituents of the final waste. Receiving waters are tested to evaluate their ability to accept a pollutional load and to indicate the degree of self-purification which occurs in a given reach. The strength of sewage is usually measured by its nuisance-producing potentialities — odour, solids content, and appearance. The yardstick that measures much of the nuisance potential is the biochemical oxygen demand or BOD. This is the amount of oxygen required by the bacteria to reduce some of the organic matter in a waste under standard conditions.

Water to be used for a public supply must be potable (drinkable), ie not contain pollution. Pollution can be defined as the presence of any foreign substance which tends to degrade the water quality and constitute a hazard or impair the usefulness of the water. Routine analyses of developed water sources are made usually to determine acceptability of the water for domestic and industrial uses. Results of these analyses also indicate the kind of corrective treatment which should be considered for specific applications of the water. The complete analysis of a potential water source should include a sanitary survey and physical, chemical, and biological analysis.

Methods of collection and analysis must be standardised if results obtained by different laboratories are to be comparable. In the United States, *Standard Methods for the Examination of Water and Wastewater* has been published jointly by the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation. These methods have also been accepted by the American Chemical Society. No attempt will be made here to describe the various analytical procedures. The reader can acquaint himself with the techniques involved by reading Standard Methods.

3.7 IMPORTANCE OF QUALITY CONTROL

3.7.1 General

The analytical laboratory provides qualitative and quantitative data for use in decision-making. To be valuable, the data must accurately describe the characteristics and concentrations of constituents in the samples submitted to the laboratory. In many cases, because they lead to faulty interpretations, approximate or incorrect results are worse than no result at all.

Ambient water quality standards for pH, dissolved oxygen, heavy metals, and pesticides are set to establish satisfactory conditions for drinking water, fishing, irrigation, power generation, or other water uses. The laboratory data define whether conditions are being met and whether the water can be used for its intended purposes. In wastewater analyses, the laboratory data identify the characteristics of the treatment plant influent and the final load imposed upon receiving water resources, as well as the effectiveness of steps in the treatment process. Decisions on process changes, plant modifications, or the construction of new facilities may be based upon the results of water laboratory analyses. The financial implications of such decisions suggest that extreme care be taken in analysis.

Effective research in water pollution control also depends upon a valid laboratory data base, which in turn may contribute to sound evaluations of both the progress of the research itself and the viability of available water pollution-control alternatives.

The analytical data from water and wastewater laboratories may also be used to determine the extent of compliance of a polluting industry with discharge or surface water standards. If the laboratory results indicate a violation of a standard, remedial action is required by the responsible parties. Both legal and social pressures can be brought to bear to protect the environment. The analyst should realise not only that he has considerable responsibility for providing reliable laboratory descriptions of the samples at issue, but also that his professional competence, the validity of the procedures used, and the resulting values reported may be challenged (perhaps in court). For the analyst to meet such challenges, he should support the laboratory data with an adequate documentation program that provides valid records of the control measures applied to all factors bearing on the final results of investigations.

3.7.2 Quality Assurance Programs

Because of the importance of laboratory analyses in determining practical courses of action that may be followed, quality assurance programs to insure the reliability of the water and wastewater data are essential. Although all analysts practice quality control (QC) in amounts depending upon their training, professional pride, and the importance of their particular projects, under actual working conditions sufficiently detailed QC may be neglected. An established, routine quality assurance program applied to each analytical test can relieve analysts of the necessity of originating individual QC efforts.

Quality assurance programs have two primary functions in the laboratory. First, the programs should continually monitor the reliability (accuracy and precision) of the results reported; ie they should continually provide answers to the question "How good (accurate and precise) are the results obtained?" This function is the *determination* of quality. The second function is the *control* of quality (to meet the program requirements for reliability). As an example of the distinction between the two functions, the processing of spiked samples may be a determination of measurement quality, but the use of analytical grade reagents is a control measure.

Each analytical method has a rigid protocol. Similarly, QC associated with a test must include definite required steps for monitoring the test and insuring that its results are correct. The steps in QC vary with the type of analysis. For example, in a titration, standardisation of the titrant on a frequent basis is an element of QC. In any instrumental method, calibration and checking out of instrumental response are also QC functions. All of the experimental variables that affect the final results should be considered, evaluated, and controlled.

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In summary, laboratory data, in quantitative terms, eg in milligrams per litre, are reported by the analyst. These values are interpreted by environmental engineers to show compliance or noncompliance with permits for discharge, by state pollution control agencies to define the need for additional sampling and analysis to confirm violations, or by Environmental Protection Authority to demonstrate that prescribed waste treatment was sufficient to protect the surface waters affected by the discharge.

3.7.3 Analytical Methods

Physical and chemical measurement methods used in water or wastewater laboratories should be selected by the following criteria:

a) The selected methods should measure desired constituents of water samples in the presence of normal interferences with sufficient precision and accuracy to meet the water data needs.

b) The selected procedures should use equipment and skills ordinarily available in the average water pollution control laboratory or water quality laboratory.

c) The selected methods should be sufficiently tested to have established their validity.

d) The selected methods should be sufficiently rapid to permit repetitive routine use in the examination of large numbers of water samples.

Regardless of which analytical methods are used in a laboratory, the methodology should be carefully documented. In some reports it is stated that a standard method from an authorative reference (such as ref. 1) was used throughout an investigation, when close examination has indicated, however, that this was not strictly true. Standard methods may be modified or entirely replaced because of recent advances in the state of the art or personal preferences of the laboratory staff. Documentation of measurement procedures used in arriving at laboratory data should be clear, honest, and adequately referenced; and the procedures should be applied exactly as documented.

Reviewers can apply the associated precision and accuracy of each specific method when interpreting the laboratory results. If the accuracy and precision of the analytical methodology are unknown or uncertain, the data user may have to establish the reliability of the result he or she is interpreting before proceeding with the interpretation.

The necessarily strict adherence to accepted methods in water and wastewater analyses should not stifle investigations leading to improvements in analytical procedures. Even with accepted and documented procedures, occasions arise when the procedures must be modified; eg to eliminate unusual interferences, or to yield increased sensitivities. When a modification of a procedure is necessary, it should be carefully formulated. Data should then be assembled using both the original and the modified procedures to show the superiority of the latter. Such results can be brought to the attention of the organisations responsible for standardisation of procedures. To increase the benefit, the modified procedures should be written in a standard format for routine use as applicable. The standard format usually includes scope and application, principle, equipment, reagents, procedure, calculation of results, and expected precision and accuracy.

In field operations, because it may be difficult to transport samples to the laboratory, or to examine large numbers of samples (eg for gross characteristics), the use of rapid field methods yielding approximate answers is sometimes required. Such methods should be used only with a clear understanding that the results obtained are not as reliable as those obtained from standard laboratory procedures. The fact that such methods have been used should be documented, and the results should not be reported in the same context with more reliable analytical information. When only approximate values are available, perhaps obtained for screening purposes in the field only, the data user would then be so informed.

3.8 IMPORTANCE AND PURPOSES OF PHYSICAL AND CHEMICAL ANALYSIS

The purposes of physical and chemical analyses are:

1. to classify a water with respect to the general level of mineral constituents;
2. to demonstrate the absence of an excess of any particular constituent as affecting potable quality and general use;
3. to demonstrate the level of organic impurities;
4. to investigate the behaviour, for example, corrosion-potential towards metals and structures;
5. to determine the degree of clarity and ascertain the nature of matter in suspension; and
6. to assess palatability.

Thus the general character of a water as regards its suitability for domestic and industrial use is determined, having due regard to bacterial quality and to the topographical features of the source.

3.9 BACTERIOLOGICAL EXAMINATION OF WATER SUPPLIES

3.9.1 Purposes

1. To detect and assess the degree of sewage pollution in new and existing water supplies.
2. To estimate the kind of treatment required to use a new source of supply for safe consumption.
3. To check the efficiency of purification at various stages of treatment.
4. To establish the bacterial purity of the final water as it leaves the treatment works.

3.9.2 Indicator Organisms for Water Quality

Testing a water for pathogenic bacteria might at first glance be considered a feasible method for determining bacteriological quality. However, on closer examination, this technique has a number of shortcomings that precludes its application. Laboratory analyses for pathogenic bacteria are difficult to perform and generally are not quantitatively reproducible. Furthermore the demonstrated absence of *Salmonella,* for example, does not exclude the possible presence of *Shigella, Vibrio,* or disease-producing viruses. Finally, since few pathogens are present in polluted waters, the high frequency of negative results would lead to questioning the validity of the test procedures. It is far more reassuring to an analyst if a few tests yield positive results. For these reasons, the bacteriological quality of water is based on testing for nonpathogenic indicator organisms, principally the coliform group.

Coliform bacteria, as typified by *Escherichia coli,* and fecal streptococci (enterococci) residing in the intestinal tract of man, are excreted in large numbers in feces of man and other warm-blooded animals, averaging about 50 million coliforms per gram. Untreated domestic waste water generally contains more than 3 million coliforms per 100 ml. Pathogenic bacteria and viruses causing enteric diseases in man originate from the same source, namely, fecal discharges of diseased persons. Consequently, water contaminated by fecal pollution is identified as being potentially dangerous by the presence of coliform bacteria.

Drinking water standards generally specify that a water is safe provided that testing in a specified manner does not reveal more than an average of one coliform organism per 100 ml. This criterion is supported by the following arguments. The number of pathogenic bacteria, such as *Salmonella typhosa,* in domestic waste water is generally less than one per million coliforms, and the average density of enteric viruses has been measured as a virus to coliform ratio of 1:100 000. The die-off rate of pathogenic bacteria is greater than the death rate of coliforms outside of the intestinal tract of animals; thus, exposure to treatment and residence in surface waters reduces the number of pathogens relative to coliforms. Based on these premises, water that meets a standard of less than one coliform per 100 ml is, statistically speaking, safe for human consumption because of the improbability of ingesting any pathogens.

Extension of coliform criteria to water quality for purposes other than drinking is poorly defined. Since these bacteria can originate from warm-blooded animals, soil, and cold-blooded animals in addition to feces of man, presence of coliforms in surface waters indicates any one or a combination of three sources: wastes of man, farm animals, or soil erosion. Although a special test can be run to separate fecal coliforms from soil types, there is no way of distinguishing between the human bacteria and those of animals. The significance of coliform testing in pollution surveys then depends on a knowledge of the river basin and the most probably source of the observed coliforms.

Streptococci could be used as indicator organisms rather than coliforms. But the use of coliforms was established first, and there does not appear to be any distinct advantage to warrant shifting to a fecal streptococcus system.

In almost all water supply systems faecal bacteria are likely to be found. It would be pointless to condemn all supplies that contain some faecal contamination, especially when the alternative source of water is much more polluted. Rather, testing of the bacteriological

Water samples should be collected in sterile bottles according to standard procedure. They should be shaded and kept as cool as possible. It is necessary to carry out bacteriological examination of samples within a few hours after sampling, otherwise the results will be quite unreliable.

There are two methods for conducting tests on the levels of faecal coli and faecal streptococci in water: the multiple tube method for establishing the most probable number (M.P.N.), and the membrane filtration method.

In the multiple tube method, small measured quantities of the water sample are incubated in 5 or 10 small flasks containing a selective nutrient broth. The most probable number of bacteria in the sample (M.P.N.) can be estimated on the basis of the number of bottles which show signs of bacterial growth.

In the membrane filtration method, water is filtered through a membrane of special paper which retains the bacteria. The membrane is then placed on a selective nutrient medium and incubated. The bacteria multiply forming visible colonies which can be counted. The result is expressed as number of bacteria per 100 ml of water. Direct counts of faecal coli and faecal streptococci can be made in 24 and 48 hours respectively. There is no need for confirmatory tests to check the species of bacteria as in the multiple tube method.

The equipment and materials necessary in the multiple tube method for faecal coli are cheaper and generally more readily available in developing countries, than is the case for the membrane filtration method. The problem with using the multiple tube method for faecal streptococci is that the required 5 days' incubation time is not so practical. The membrane filtration method is applicable both for faecal coli and faecal streptococci. It gives rapid results which are easy to interpret and quite accurate. The membrane tests can be carried out on site in the back of the vehicle. The multiple tube equipment is fragile and requires special provisions during transport. Taking all factors into consideration, the membrane filtration method is to be recommended.

For more details of the above two methods please refer to "Standard Methods". In summary, Table 3.2 shows the criteria surface water should meet in the United States for use as a source for public water supply. The criteria are also applicable to groundwater sources. Table 3.3 gives the drinking water standards recommended by the World Health Organisation in 1971.

Table 3.2: Surface-Water Criteria for Public Water Supplies-Sources

Constituent or Characteristic	Permissible Criteria	Desirable Criteria
Physical		
Colour (colour units)	75	<10
Odour	*b*	Virtually absent
Temperature^a	Do	*b*
Turbidity	Do	Virtually absent
Microbiological		
Coliform organisms	20,000/100 ml^c	<100/100 ml^c
Fecal coliforms	2,000/100 ml^c	<20/100 ml^c
Inorganic chemicals	(mg/l)	(mg/l)
Alkalinity	*b*	*b*
Ammonia	0.5(as N)	0.01
Arsenic^a	0.05^d	Absent
Barium^a	1.0^d	Do
Boron^a	1.0	Do
Cadmium^a	0.01^d	Do
Chloride^a	250	<25
Chromium,^{a}hexavalent	0.05^d	Absent
Copper^a	1.0	Virtually absent
Dissolved oxygen	≥4 (monthly mean) ≥3 (individual sample)	Near saturation
Fluoride^a	*b*	*b*
Hardness^a	Do	Do
Iron (filterable)	0.3	Virtually absent
Lead^a	0.05^d	Absent
Manganese^a (filterable)	0.05	Do
Nitrates plus nitrites^a	10 (as N)^d	Virtually absent
pH (range)	6.0-8.5	*b*
Phosphorus^a	*b*	Do
Selenium^a	0.01^d	Absent
Silver^a	0.05^d	Do
Sulfate^a	250	<50
Total dissolved solids^a (filterable residue)	500	<200
Uranyl ion^a	5	Absent
Zinc^a	5	Virtually absent
Organic chemicals		
Carbon chloroform extract^a (CCE)	0.15	<0.04
Cyanide^a	0.20	Absent
Methylene blue active substances^a	0.5	Virtually absent
Oil and grease^a	Virtually absent	Absent
Pesticides		
Aldrin^a	0.017	Do

Chlordane[a]	0.003	Do
DDT[a]	0.042	Do
Dieldrin[a]	0.017	Do
Endrin[a]	0.001 (0.0002)[d]	Do
Heptachlor[a]	0.018	Do
Heptachlorpoxide[a]	0.018	Do
Lindane[a]	0.056 (0.004)[d]	
Methoxychlor[a]	0.035 (0.01)[d]	Do
Organic phosphates plus carbamates[a]	0.1[c]	Do
Toxaphene[a]	0.005	Do
Herbicides		
2,4-D plus 2,4,5-T, plus 2,4,5,-TP[a]	0.1[e]	Do
Phenols[a]	0.001	Do
Radioactivity	(pc/1)	(pc/1)
Gross beta[a] (Beta and photon)	1,000 (15, ≥3 mr/yr)[d]	<100
Radium-226[a] (and radium-228)	3 (5)[d]	<1
Strontium-90[a]	10	<2

Source: *Water Quality Criteria*, Report of the National Technical Advisory Committee to the Secretary of the Interior, Washington, D.C., April 1968, p. 20.

[a] The defined treatment process has little effect on this constituent. (Conventional coagulation, sedimentation, rapid sand filtration, and chlorination.)

[b] No consensus on a single numerical value that is applicable throughout the country. See Report and text.

[c] Microbiological limits are monthly arithmetic averages based on an adequate number of samples. Total coliform limit may be relaxed if fecal coliform concentration does not exceed the specified limit.

[d] National Interim Primary Drinking Water Standards maximum for public water supplies at consumer's tap. The *total* mercury shall not exceed 0.002 mg/1.

[e] As parathion in cholinesterase inhibition. It may be necessary to resort to even lower concentrations for some compounds or mixtures. Permissible levels are based on the recommendations of the Public Health Service Advisory Committee on Use of the PHS Drinking Water Standards.)

Table 3.3: World Health Organisation Drinking Water Standards

Characteristic	Highest Desirable Level	Maximum Permissible level
Total Solids	500	1500
Colour (^{0}H)	5	50
Taste	Unobjectionable	-
Odour	Unobjectionable	-
Turbidity (Formazin units)	5	25
Chloride	200	600
Iron	0.1	1
Manganese	0.05	0.5
Copper	0.5	1.5
Zinc	5	15
Calcium	75	200
Magnesium	30	150
Sulphate	200	400
Total Hardness (as $CaCO_3$)	100	500
Nitrate (as NO_3)	45	-
Phenol	0.001	0.002
Anionic detergent	0.02	1.0
Fluoride	0.9 - 1.7 (mean temp 12°C) 0.6 - 0.8 (mean temp 32°C)	
pH (units)	7 - 8	min 6.5 max 9.2
Arsenic	-	0.05
Cadmium	-	0.01
Chromium (6+)	-	0.05
Cyanide	-	0.05
Lead	-	0.10
Mercury	-	0.001
Selenium	-	0.01
Polynuclear aromatic hydrocarbons	-	0.0002
Gross alpha radioactivity (pC/1)	-	3
Gross beta radioactivity (pC/1)	-	30

Concentration in mg/L except where noted

Bacteriological standard for water in the distribution system:

(i) in 95% of samples examined throughout a year coliform bacteria should be absent in 100 ml.

(ii) No sample should contain *E. Coli* in 100 ml.

(iii) No sample should contain more than 10 coliform organisms per 100 ml.

(iv) Coliform organisms should not be detectable in 100 ml of any two consecutive samples.

* *International Standards for Drinking-Water, 3rd ed., WHO, Geneva, 1971.*

CHAPTER 4: LEGAL AND ADMINISTRATIVE ASPECTS

4.1 PURPOSE

Throughout the world, a variety of legal and administrative strategies has been established to achieve the objectives of water quality management.

The New South Wales Clean Waters Act was enacted in December, 1970, to provide the machinery for a rational approach to the problem of reducing and preventing the pollution of waters. The Clean Waters Regulations, together with the Act, were brought into operation in November, 1972.

The Act is designed to control pollution in rivers, streams, lakes, lagoons, natural or artificial watercourses, dams, tidal waters (including estuaries, oceans, beaches and the sea), and underground waters.

Its principal control provisions are:

- To authorise the EPA to classify or to re-classify the waters of the State.
- To enable any person to object to any proposed classification of waters, and to provide for such objection to be determined by the Clean Waters Appeal Board.
- To prohibit any person from polluting waters other than under the conditions contained in a licence granted to him.
- To require any person who is responsible for land on which there is a drain to hold a licence issued by the EPA, if the drain discharges or is likely to be used for discharging pollutants into classified waters.
- To prohibit any person from installing or constructing any apparatus, equipment or works for the discharge of pollutants into waters, unless he holds the approval in writing of the Authority.
- To empower the EPA to require an applicant for a licence or an approval to furnish such information and plans as may be required by the EPA.
- To enable an applicant for, or holder of, a licence who is aggrieved by any decision of the EPA in relation to his

application or licence, and an applicant for an approval who is aggrieved by any decision of the EPA in relation to his application, to appeal against the Authority's decision to the Clean Waters Appeals Board.

- To empower the Minister in cases of emergency.
- To authorise the discharge of pollutants into waters.
- To prohibit the discharge of pollutants into waters.

The diversity of ways by which the quality and usefulness of waters may be impaired is well recognised, and has been adequately provided for the definition of 'pollution' under the Clean Waters Act.

In essence, 'pollution' means placing in or on waters any matter which changes the physical, chemical or biological condition of the waters, or introducing any matter which is likely to make the waters unclean noxious, poisonous or impure or detrimental to the health, safety, welfare or property of person, or harmful to animals, aquatic life, birds or fish.

While the implications of this broad definition are clear, it would not be suitable for use in legal proceedings because of the burden of proof that it places on the prosecutor. For this reason an important dimension is added to the definition to allow specific materials, or even broad classes of materials, to be declared as pollutants under the Clean Waters Regulations.

The strength of the Clean Waters Act largely depends upon the definition of 'pollution', and is considerably enhanced, in a practical sense, by the prescription of materials declared to be pollutants. Additionally, the meaning of pollution is substantially extended by Section 16 of the Act, which provides that a person shall be deemed to pollute waters if:

> *he places any matter, whether solid, liquid or gaseous, in a position where it falls, descends, is washed, is blown, or percolates, or is likely to fall, descend, he washed, be blown or percolate into any waters, or onto the bed of any waters when dry, or causes or permits any such matter to be placed in such a position.*

This Section makes it an offence for any person to discharge wastes on to land from which it may drain into underground waters, or from which it may run into surface waters, unless the discharge complies with the terms of a licence issued under the Clean Waters Act.

In its administration of the Clean Waters Act, the EPA seeks to achieve standards of purity of waters consistent with their existing and likely future desirable uses. These uses may be for agricultural and pastoral purposes, for the protection and propagation of fish, aquatic life and wildlife, and for recreational and other legitimate uses, including aesthetic enjoyment.

While applying the principle that no waters will be classified to allow their use as open sewers, the EPA recognises that reasonable use of waters must be permitted in the final distribution of the waterborne wastes of the community, provided these wastes are given the treatment required to prevent unnecessary or unreasonable impairment of natural water quality.

Within the EPA engineers, scientific officers and technicians implement the provisions of the legislation, carry out research into water pollution, and undertake monitoring of pollution and studies of water quality.

Section 16 of the Act makes it an offence for a person to pollute any waters, or to cause or permit any waters to be polluted, unless he holds a licence and does not contravene any condition of the licence.

To ascertain the nature of a discharge, if the information is not otherwise available, the EPA issues a notice under Section 28 of the Act, requiring the occupier to furnish information as to any manufacturing, industrial or trade process carried on, or as to any wastes discharged from his premises. The information obtained in response to this notice provides the basis from which a pollution control plan for the particular premises is formulated.

As long as the discharge meets the standard specified in the licence, it may continue. The licence must be renewed annually, and a licence fee of up to $3,000 may be charged. During the currency of the licence the EPA may vary the conditions imposed, or may impose new conditions if the circumstances so warrant.

When reviewing an application for a licence, the EPA has regard to the classification of the waters and to the pollution likely to be caused by the discharge. It may impose such conditions on the licence as are necessary to achieve and maintain the desired quality in the receiving waters. If aggrieved by a licensing decision, the Licencee may appeal to the Clean Waters Appeals Board.

Under Section 19 of the Act, the approval of the Commission must be obtained for the installation, construction or modification of any apparatus, equipment or works for the discharge of pollutants into waters or on to land from whence it might drain or percolate into surface or underground waters. A penalty of $20,000 may be imposed in any case where works are built, modified or installed without such an approval.

Any person who proposes to commence works for the discharge of wastes directly or indirectly into waters, whether the waters are classified or not, must apply to the EPA for permission to install, construct, or modify the works. In issuing an approval, it is the

EPA's practice to indicate to the applicant standards that must be met following completion of the works.

A fundamental concept of the Clean Waters Act is the system of classifying waters on the basis of existing and likely future beneficial uses. Details of the classification system have already been given in Section 3.3.3 of these notes.

Before any waters are classified, a study is made to establish the existing and likely future uses of the waters. On the basis of the study, an appropriate classification is proposed and advertised in local newspapers and the Government Gazette. Any person may lodge an objection in writing to the proposed classification, and the objections are heard and determined by the Clean Water Appeals Board constituted under the Act.

After objections have been determined, or if no objections have been lodged within one month after the date of advertisement, the final classification notice is published in the Government Gazette and the water is then classified. However, the EPA may reclassify waters at some future time by carrying out the formal procedures again, if a change of circumstances so warrants.

When a classification has been prescribed for any waters, all drains that discharge or are likely to be used for discharging pollutants into those waters, must be licensed. However, if a licence is already held for the discharge of pollutants by means of any such drain, that licence is deemed to be a licence in respect of that drain.

In cases of emergency, the Minister may authorise the discharge of pollutants into waters, or may prohibit the discharge of pollutants into waters. Use of these provisions is unlikely, but catastrophes could arise which would make such authorisation or prohibition necessary.

A further provision of the Act allows the EPA to direct a statutory authority or local authority to remove, disperse, destroy or mitigate the pollution of waters. Where an authority has performed work of this kind, it may take certain steps to recover the costs and expenses so incurred.

Penalties up to $120,000 for single offences and additional penalties up to $20,000 per day may be imposed by the Courts for offences against the Act. Penalties of $60,000 and $10,000 per day may be imposed for offences against the regulation. Companies face fines of up to $1 million plus all clean-up costs. Company directors and managers can be fined up to $150,000 with a maximum seven years' goal.

4.2 TOTAL CATCHMENT MANAGEMENT

The Catchment Management Act 1989 defines Total Catchment Management (TCM) as the coordinated and sustainable use and management of soil, water, vegetation and other natural resources on a water catchment basis in order to balance resource use and conservation.

Section 5.1 of the Act sets out the legislation's objectives as:

- to coordinate policies, programs and activities as they relate to TCM
- to achieve active community participation in natural resource management
- to identify and rectify natural resource degradation
- to promote the sustainable use of natural resources
- to provide stable and productive soil, high quality water, and protective and productive vegetative cover within each of the State's water catchments.

In order to give effect to these objectives, Section 5.2 of the Act provides for:

- a network of Catchment Management Committees, coordinated by a State Coordinating Committee, as a link between Government and the community to achieve the objectives of TCM.
- Catchment Management Trusts to raise funds for particular total catchment purposes.

The development of TCM provides a sound framework for environmental management, including the management of water quality. The EPA's role in water quality management is twofold:

- Under the proposed revised water classification system, the EPA will establish water quality goals for catchment management. The catchment community will make appropriate contributions to this process.
- The EPA will continue to control point-source discharges within catchments through the licensing and approvals provisions of the Pollution Control Act (1970).

4.2.1 Catchment Management and Classification

For the purposes of catchment management, "broad-brush" water quality goals will be provided through Stage I Classification of all

NSW waters based on geographic, zonal characteristics. This will provide a precursor for Stage 11 Classification, which will be more closely tailored to the needs of specific catchments.

Stage II will assess and balance the views of all interests within the catchment, using the mechanisms provided by catchment management committees, local government and community structures.

Classifying waters in this way will set goals and objectives for water quality within each catchment although large stretches of NSW waters will probably not meet them. However setting goals will provide an incentive for the development of catchment strategies, and give increased control over proposed developments that have the potential to degrade water in the area. This approach is common in other countries.

4.3 POLLUTION CONTROL

Point Sources

Under the provisions of the Clean Waters Act and the Pollution Control Act, any point source of discharge (such as a sewage treatment plant, a factory or an abattoir) must be licensed. Under Stage I of the revised water classification system, Zonal Water Quality Goals and Objectives (ZWQO) will be set for all waters in the State, including those already classified under the existing system (which will continue to stand until Stage II Classification has been completed). Point-source effluent quality requirements will continue to be determined on a case-by-case basis, taking account of the factors below.

Where receiving waters have already been classified under the existing system, discharges will have to satisfy at least the specific effluent quality limitations of the prescribed class. In addition, licence discharge limits will be determined, taking account of ZWQO. Practicable limits will be set such that ZWQO is met under specified flow conditions (usually 50 per cent) at a designated point downstream of the proposed discharge. Where existing background water quality is considerably better than the ZWQO, the licence limits will generally be set at a level which ensures that water quality is not degraded.

Where receiving waters are not classified under the existing system, the same principles will apply except that discharges will be required to satisfy at least some basic effluent quality requirements (see below) in lieu of restrictions imposed under existing classifications.

The section of the receiving waters between the discharge point and a designated point downstream will be identified as the approved "mixing zone" on the licence. Where the receiving waters are stored waters or oceanic waters, the approved mixing zone will be defined as a volume adjacent to the discharge point where initial dilution of the wastes takes place. The mixing zone will be determined by the EPA in consultation with other parties. Factors to be considered will include minimising the extent, strength and volume of the proposed discharge; the likely impacts on migratory species; upstream (or background) water quality; and ZWQO.

In addition to any discharge limitations imposed as a result of ZWQO, existing classifications or the above general requirements, the EPA may impose further restrictions as a result of specific investigations or research findings. Published EPA guidelines, design manuals, policies or codes of practice, may also have a bearing on effluent quality requirements. Generally speaking, the EPA will require effluent levels of a standard that would result from the use of wastewater treatment or pollution control equipment which is "best available technology economically achievable" (BATEA). A licence may also specify a discharge and/or an environmental monitoring program to determine the extent to which effluent quality standards and/or water quality objectives are being achieved.

Stage II classification will see the gradual replacement of existing and zonal classifications by classifications of whole catchments. Point-source effluent quality requirements will continue to be determined case-by-case as described above, except that the requirements imposed as a result of classifications under the existing and zonal systems will not apply.

After Stage II classification, it will be generally expected that all statutory managers will ensure that water quality will not deteriorate as the result of granting approvals or licences or agreeing to changes in land use.

Diffuse Sources

The overall objective of the new classification system is to provide a statutory framework for the long-term management of surface and groundwater quality to protect existing and likely future uses from both point and diffuse-source pollution. The Zonal and Catchment Water Quality Goals defined as a result of the proposed modifications should provide the necessary targets for TCM and similar water quality management strategies.

Following the implementation of Stage I, the ZWQO should be interpreted as the general target level of water quality in each zone. Catchment managers will need to take them into account in approving or regulating all activities within catchments which could affect water quality.

Where Stage II has occurred, it will be incumbent on all catchment managers to demonstrate that existing water quality will not be degraded by any new development to a level below that specified by the objectives. Alternatively, revised Stage II Objectives may need to be developed. The Water Quality Policy should be incorporated into catchment management strategies.

4.4 ENFORCEMENT

Point Sources

The EPA licenses all point sources of pollution in the State. A system which combines self-regulation and self-monitoring, backed up by EPA audits, is being introduced. All licence holders will be required to submit a Certificate of Compliance, declaring that they have met the monitoring requirements of their licence and indicating the effectiveness and efficiency of operation and maintenance of approved pollution control equipment. There will be severe penalties for both companies and individual office-bearers within companies if:

- there is a breach of licence conditions as revealed by the Certificate of Compliance or by the EPA audits
- no Certificate of Compliance is provided by the due date
- false information is supplied on the Certificate of Compliance as detected by EPA audit
- a discharge occurs where no licence is held.

Diffuse Sources

The control of diffuse sources of pollution rests with the structures established under the Catchment Management Act. While there are no formal enforcement structures set up under the Act, the monitoring and reporting aspects of the State Policy will make it apparent where catchment managers are failing in their responsibilities.

In this case, the enforcement is effectively based on the moral persuasion of public expectation and by regular performance reporting.

4.5 ROLES OF STATE AND INTERSTATE AGENCIES

Department of Water Resources

Under the Water Administration Act 1986, the Water Act 1912 and other related Acts, the Minister for Natural Resources has the statutory power to determine Statewide water policies and to assist in determining priorities for water authorities. The Minister is supported by the Department of Water Resources, which replaced the Water Resources Commission on 1 January 1987. The Broken

Hill and Cobar Water Boards are also part of the Minister's portfolio responsibilities.

The Department of Water Resources has two major functions. It is responsible for advising the Minister in his water resource management role. This includes:

- managing the State's surface and underground water resources
- developing and administering policies for the allocation of water resources
- providing policy guidelines for water authorities
- developing policies to manage water-related environments
- monitoring the quantity of available water resources
- coordinating research to improve the efficiency of water supply and use
- representing NSW in interstate water resource matters.

The department also has a service role in rural areas, including supplying water on a commercial basis. The main services provided are:

- operating and maintaining the network major storages that supply water
- operating and maintaining the water supply and drainage systems in the established Irrigation Areas and Irrigation Districts
- licensing and surveillance of the supply of water allocated from the State's rivers, streams and underground
- undertaking flood protection in rural and urban areas, and work to prevent erosion of river channels.

The Director of the department is responsible to the Minister for Natural Resources for the overall administration of the organisation and for ensuring that the Government's water policies are carried out effectively. Management of water quality in surface and ground waters is therefore a key part of its function. In achieving this, the department is committed to the use of Total Catchment Management and other cooperative resource management strategies.

Water Board (Sydney)

The Water Board is a statutory authority which was established initially under the Metropolitan Water Sewerage and Drainage Act 1924. However in 1987, the Government simplified the legislation by enacting the Water Board Act which is now the board's prime legislation.

The Board provides services to an estimated population of over 3.5 million. Its area of operations, totalling almost 13,000 square kilometres, extends from the Hawkesbury River in the north to Gerroa in the south, and from the Pacific Ocean west to Mt Victoria in the Blue Mountains. Some of the Board's water catchment areas are, however, outside its area of operations.

Under its Act the Board is responsible for:

- ensuring that the water and related resources within its area of operations are allocated and used in ways which are consistent with environmental requirements and which provide the maximum long-term benefit for the area and the State

- providing water and related services to meet the needs of users in a commercial manner, consistent with the overall policies of the Government.

The Board is subject to the direction and control of the Minister for Housing through whom it reports annually to the NSW Parliament.

Environmental Protection Authority (EPA)

The Environment Protection Authority replaced the State Pollution Control Commission in 1991. It is constituted under the Protection of the Environment Administration Act 1991, which details its functions and powers and *interalia* gives it responisibility for the administrative of the Clean Waters Act.

In general terms, the Environmental Protection Control Authority's role is to control pollution and the disposal of waste, to protect the environment and to advise the Government on these matters.

Since the introduction of the Clean Waters Act in 1970, the EPA and former SPCC, with the support of industry and the public, has concentrated on controlling the many and varied point sources of pollution discharging into NSW waterways. Today, most of these point sources have either been eliminated or controlled, or programs are being implemented to control them.

The EPA is now focusing on what may be called "second-generation" water pollution control problems: diffuse or non-point sources of pollution. Diffuse-source pollution occurs when contaminated surface runout waters from urban and rural areas discharge into watercourses, mainly during wet weather.

For several reasons, diffuse-source pollution is more difficult to control. The processes of pollutant pick-up, transportation and deposition are highly variable and difficult to quantify. In turn, this makes it difficult to assess the effectiveness of various control options. The control of diffuse-source pollution is considerably more complex than point-source control; there must be coordination of the many planning, advisory and statutory authorities at all tiers of government, often in conjunction with several land holders or developers.

The conversion of land to urban use modifies the natural environment, disturbs the soil, alters the land surface and its hydrologic character, and changes drainage patterns. The urban runoff generated in built-up areas across the State is now the major source of pollutants to waterways and the most important determinant of receiving water quality in these areas. Total Catchment Management seeks to balance the catchment's economic production with protection of its resources by minimising land degradation and soil erosion and maintaining both the quantity and the quality of water.

The EPA is also involved in beach protection programs and environmental monitoring, as well as the licensing of primary treatment plant discharges. The Authority is also working on a new system of classifying waterways by setting goals and objectives which, if achieved, will allow them to be used for certain desirable activities.

The EPA is subject to the direction and control of the Minister for the Environment through whom it reports annually to the NSW Parliament.

Public Works Department

The Public Works Department is a specialist manager in the development, procurement and conservation of public assets and the management of specific government programs. Its charter is to ensure that its clients' objectives are met in the most cost-effective way.

Specific government water management programs overseen by the department include:

- country town water supply and sewerage schemes
- coastline hazards
- flood plain management
- estuary management
- fishing and Government facilities.

In managing these programs, the department optimises the social, environmental and economic benefits to the communities served.

The functions performed by the department are:

- the development of effective policies and strategies for the management and use of the coastal zone, river estuaries and flood plains and for the management of water and sewerage services serving country councils
- management of the design and construction of civil engineering works such as dams, water supply, sewerage, port and harbour facilities
- management of the design, construction and maintenance of public buildings such as schools, hospitals, police facilities, court houses, prisons and office buildings and their surrounding environment.

As far as the State Water Quality Policy is concerned, the Public Works Department:

- exercises management responsibilities in respect of water quality in coastal zones and estuaries
- assists country councils to protect water quality by managing waste products with the provision of sewerage schemes
- is concerned to ensure that water quality is acceptable for use in town water supplies.

The department reports to the Minister for Public Works who tables an annual report to the NSW Parliament.

Soil Conservation Service (Department of Conservation and Land Management)

The Soil Conservation Service was formed after the enactment of the Soil Conservation Act in 1938. In 1991 it was in corporated into the Department of Conservation and Land Management (CALM). The SCS has long been involved in the protection of the State's catchment areas. It has adopted a holistic approach to natural resources management and has acted to control indiscriminate clearing of protected lands on behalf of the Catchment Areas Protection Board.

The SCS undertakes the following principal activities:

- advises the NSW Government on land and water conservation
- develops and promotes land-use practices which conserve the State's land and farm water resources

- protects the catchment areas of the State's river systems, water storages and proclaimed works
- develops and coordinates TCM policies and activities
- organises "whole-valley" soil conservation projects
- operates a scheme for the hire of specialised earthmoving services and equipment
- manages environmentally sensitive parcels of land
- undertakes land resource surveys
- carries out research into land conservation and rehabilitation
- conducts investigations into land degradation problems
- undertakes specific technical studies
- offers detailed technical and practical advice and assistance to landholders
- produces and distributes technical and non-technical information
- offers a consultancy service.

The SCS is subject to the direction and control of the Minister for Conservation and Land Management through whom it reports annually to the NSW Parliament.

Murray-Darling Basin Commission

The Murray-Darling Basin Agreement requires that the Murray-Darling Basin Commission (formerly the River Murray Commission) "shall establish, operate and maintain an effective and uniform system for measuring and monitoring the quality of the waters of the River Murray".

The agreement also empowers the commission to formulate water quality objectives and standards and recommend action necessary to maintain or improve the water quality of the river.

The commission has the following water quality policy:

- In the case of those parameters such as salinity and nutrients which are already recognised as causing problems in certain sections of the river, the policy is to improve existing water quality.

- Where there are other parameters which currently may be easily meeting recognised standards, the policy is to endeavour to ensure that existing quality is not allowed to deteriorate.

The best practical means of waste treatment and disposal should be adopted.

- For salinity, the specific objective is to reduce the levels of river salinity.

The Murray-Darling Basin Commission commenced monitoring water quality in July 1978, although operational salinity data had been recorded for some years prior to this.

Hunter Water Board

The Hunter Water Board operates under the Hunter Water Board Act 1988. Under the legislation the Board is required to allocate and use the water and related resources within its area in an environmentally responsible manner to provide the maximum long-term benefits for the area and the State.

The Board serves a population of some 410,000 over an area of 5366 square kilometres. This area includes the local government areas of Newcastle, Lake Macquarie, Maitland, Cessnock and Port Stephens.

The board aims to provide the community it serves with a continuous and adequate supply of water which represents value for money and conforms to National Health and Medical Research Council/Australian Water Resources Council guidelines. The Board also encourages the conservation of water as a limited resource.

In addition to its responsibility for providing a safe and reliable water supply, the Board is responsible for the collection, transport and disposal of community wastewater, and the operation and maintenance of major stormwater channels.

The Board is subject to the direction and control of the Minister for Housing through whom it reports annually to the NSW Parliament.

National Parks and Wildlife Service

The National Parks and Wildlife Service has responsibility for:

- the conservation of native flora throughout the State
- the conservation of native fauna throughout the State
- the protection of all relics and Aboriginal places throughout the State

- the acquisition, establishment and management of national parks and nature reserves
- the preservation of historic sites within NPWS areas
- the investigation of areas suitable for acquisition as state recreation areas.

While the NPWS has no statutory role in water quality protection and monitoring, it certainly has an interest in protecting and monitoring water quality in national parks and other reserves. In particular, the NPWS is very concerned about water pollution associated with urban development and its impact on streams in national parks and other reserves. Streams in national parks such as the Blue Mountains, Ku-ring-gai Chase and Royal national parks are known to be polluted from surrounding urban and industrial development.

Development and recreational use in reserves is also of concern. For example, intensive recreational use of Kosciusko National Park for ski resorts has led to an increase in pathogens, nutrients and turbidity in streams.

Nutrients and pesticides, eg phosphorus, herbicides and insecticides, have been introduced into wetlands and they need to be controlled. Increased nutrients in wetlands and streams assist in the introduction and spread of weeds which, in turn, affects native vegetation.

The NPWS is willing to cooperate with Government agencies responsible for the protection of water quality to ensure the protection of catchments and wetlands in areas of high conservation value.

The NPWS is subject to the direction and control of the Minister for the Environment through whom it reports annually to the. NSW Parliament

Forestry Commission of New South Wales

The Forestry Commission of New South Wales is a corporation sole established under the Forestry Act 1916. The commission's primary objective is the multi-purpose management of State Forests. However, implicit in such management is a responsibility to preserve and improve water catchment capabilities.

To ensure water quality is maintained in streams which originate in forest areas, the Commission exercises strict controls on forest management activities, such as the location, design and drainage of road systems, the maintenance of undisturbed forest cover along permanent watercourses and the limitation of works on steeper slopes.

The Commission carries out research into the effects of forest management practices, natural cycles and events on changes in water quality and quantity in State Forests. Th research indicates that the establishment of pine plantations on grasslands may be improving the water quality, an outcome which could be significant in catchments such as the Murray.

The Commission is subject to the direction and control of the Minister for Conservation and Land Management through whom it reports annually to the NSW Parliament.

NSW Agriculture

NSW Agriculture has a responsibility to protect agriculture and the environment generally. The department must ensure that all measures are taken to protect and maintain water quality necessary for the long-term sustainability of agricultural and fisheries enterprises.

The States' major land use is agriculture and the major water use is irrigation. The department is primarily involved in research and extension in the agricultural sphere as well as research and control in fisheries. The growth of agricultural products can affect water quality. There are therefore a number of specific issues which the department must address:

- land-use management
- irrigation management
- agricultural chemicals management
- soil degradation

The Department's effective input into land-based agricultural issues will result in in-stream issues being dealt with more effectively.

The department is subject to the direction and control of the Minister for Agriculture through whom it reports annually to the NSW Parliament.

Maritime Services Board

The Maritime Services Board was established in 1936 as a statutory authority responsible for administering maritime matters within its jurisdiction.

One of the MSB's corporate goals is "to ensure the protection of the unique marine environment in NSW ports and waterways". Marine environmental protection matters within the charter of the MSB are primarily managed and coordinated by the recently established Marine Environment Protection Branch. Implementation of environmental policy is achieved through liaison with the MSB Port and Waterways Authorities and other agencies.

The MSB functions and responsibilities below have the objective of protecting the marine environment and maintaining water quality.

- The MSB administers the Marine Pollution Act 1987 (NSW), which repealed the Protection of Navigable Waters Act 1960 and came into operation in May 1990. The Act imposes liability with penalties on a range of persons for offences involving the discharge of oil or oily mixtures of noxious liquid substances from a ship or pipeline into prescribed waters. It requires the reporting of such incidents to the MSB and the keeping of records on ships carrying and transferring oil and noxious liquid substances. The MSB has powers under the Act to prevent, control and remove pollution of this kind, to prosecute offenders and to recover costs.

- The MSB consults and reviews the policy of the international conventions and protocols of the International Maritime Organisation such as the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), which deals with five groups of ship-generated pollutants (oil, noxious liquid substances, harmful substances carried in tankers/containers, sewage and garbage [including plastic waste]).

- The MSB has the State responsibility under the National Plan to Combat Pollution of the Sea by Oil to provide oil spill control, clean-up and recovery equipment around Australia.

- It operates a laboratory where staff have expertise in the identification of oils ("fingerprinting") and the ability to interpret results.

- The MSB fulfils the State's obligations regarding the London Dumping Convention, which involves multiple-agency input on ocean dumping of dredge spoil and other materials.

- The MSB coordinates the planning, implementation and monitoring of water quality and pollution control measures for waterway developments and operations, and operations in the ports and areas of its jurisdiction, in matters such as control of vessel sewage pollution (lead role), dredging impacts, litter, stormwater pollution and tributyltin (TBT) anti-fouling paints.

- It ensures there is compliance with section 13TA of the Maritime Services Act 1935, which provides that excavation associated with waterfront development or lands vested in the MSB should not result in siltation or erosion.

- The MSB develops and coordinates contingency plans for potential environmental hazards and pollution incidents and carries out environmental audits to assess the effectiveness of environmental protection strategies and procedures.

The Board is subject to the direction and control of the Minister for Transport through whom it reports annually to the NSW Parliament.

REFERENCES

1. New South Wales Water Resources Council "State Water Quality Policy" Discussion Paper, June 1991.

CHAPTER 5: WATER TREATMENT

5.1 TREATMENT METHODS

The purpose of water treatment is to convert the water taken from a ground or surface source, the 'raw water', into a drinking water suitable for domestic use. Most important is the removal of pathogenic organisms and toxic substances such as heavy metals causing health hazards. Other substances may also need to be removed or at least considerably reduced. These include: suspended matter causing turbidity, iron and manganese compounds imparting a bitter taste or staining laundry, and excessive carbon dioxide corroding concrete and metal parts.

Urban reticulated water supplies generally rely upon surface catchments and storage in large reservoirs. Contamination by animal matter, vegetable matter and suspended matter creates problems which must be treated before human consumption can be guaranteed with reasonable safety. The treatment of raw water acts upon the suspended matter, excess minerals and pathogenic organisms.

Groundwater supplies used for urban reticulation are usually free from pathogenic contamination and need only treatment for excess mineral salts. The particular minerals depend upon the aquifer characteristics and vary from location to location.

The processes of raw water treatment are:

Sedimentation	remove suspended matter
Coagulation	remove flocculated material
Disinfection	destroy pathogens
Softening	remove minerals such as calcium and magnesium
Aeration	remove gases, add oxygen

Treatment plants can be designed along three types depending upon the level of treatment given to the raw water. This depends upon the source of the water and the consumer requirements.

Type 1	Chlorination and screening only. Applied to water from catchments restricted from any other use. Applies also to some groundwater sources.
Type 2	Full treatment. Chlorination, sedimentation and filtration. Armidale's water treatment is in this category.
Type 3	As for type 2, but with the additional removal of special minerals depending upon the source of the raw water. The removal of excess iron may involve special treatment.

As stated earlier, common water sources for public supplies are deep wells, shallow wells, lakes, rivers and reservoirs. Well and bores normally yield cool, uncontaminated water of uniform quality that is easily processed for municipal use. Processing may be required to remove dissolved gases and undesirable minerals. The simplest treatment illustrated in Figure 5.1a is disinfection and fluoridation. Deep well supplies are chlorinated to provide residual protection against potential contamination in the water distribution system. In the case of shallow wells recharged by surface waters, chlorine both disinfects the groundwater and provides residual protection. Fluoride is added to reduce the incidence of dental caries. Dissolved iron and manganese in well water oxidises when contacted with air, forming tiny rust particles that discolour the water. Removal is performed by oxidising the iron and manganese with chlorine or potassium permanganate, and removing the precipitates by filtration (Figure 5.1b). Excessive hardness is commonly removed by precipitation softening, shown schematically in Figure 5.1c. Lime and, if necessary, soda ash are mixed with raw water, and settleable precipitate is removed. Carbon dioxide is applied to stabilise the water prior to final filtration. Aeration is a common first step in treatment of most groundwaters to strip out dissolved gases and add oxygen.

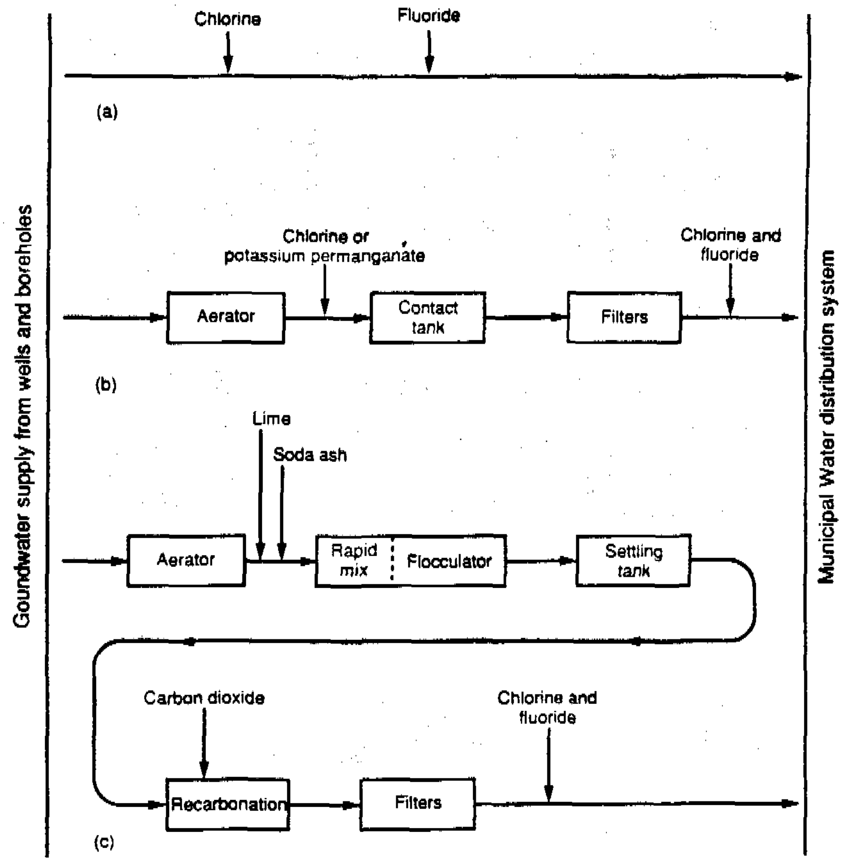

Fig. 5.1 Flow diagrams of typical groundwater treatment systems. (a) Disinfection and fluoridation. (b) Iron and manganese removal. (c) Precipitation softening.

(Source: Hammer, M.J. *Water and Wastewater Technology*. Wiley, 1972.)

The primary process in surface water treatment is chemical clarification by coagulation, sedimentation, and filtration, as illustrated in Figure 5.2. Lake and reservoir water has a more uniform year-round quality and requires a lesser degree of treatment than river water. Natural purification results in reduction of turbidity, coliform bacteria, colour, and elimination of day-to-day variations. On the other hand, growths of algae may cause increased turbidity and may produce difficult-to-remove tastes and odours during the summer and autumn.

Chlorination is commonly the first and last steps in treatment, providing disinfection of the raw water and establishing a chlorine residual in the treated water. Excess prechlorination and activated carbon are used to remove taste- and odour-producing compounds. The specific chemicals used in coagulation depend on the character of the water and economic considerations. River supplies normally require the most extensive treatment facilities with greatest operational flexibility to handle the day-to-day variations in raw water quality. The preliminary step is often presedimentation to reduce silt and settleable organic matter prior to chemical treatment. As is illustrated in Figure 5.2, many river water treatment plants have two stages of chemical coagulation and sedimentation to provide greater depth and flexibility of treatment. The units may be operated in series, or by split treatment with softening in one stage and coagulation in the other. As many as a dozen different chemicals may be used under varying operating conditions to provide a satisfactory finished water.

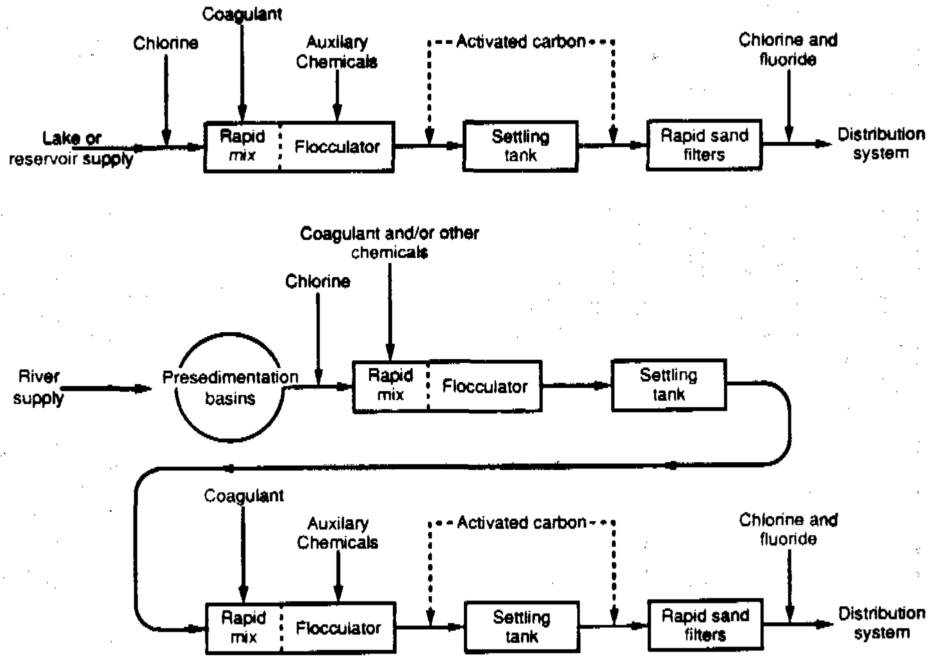

Fig 5.2 Schematic patterns of typical surface-water treatment systems.
(Source: Hammer, M.J. *Water and Wastewater Technology*. Wiley, 1972.)

5.2 AERATION

In water treatment the term aeration applies to the process which brings the water into contact with the air. Aeration of water has many benefits which include:

1. dissipation of free carbon dioxide
2. the introduction of oxygen
3. precipitation of iron and manganese
4. removal of odours.

The rate at which gas will move from surrounding air to water or vice versa, depends on the difference between the quantity of gas in the water and the equilibrium solubility of the gas in the water. Where a gas obeys Henry's Law the equilibrium solubility will be proportional to the concentration of the gas in the surrounding air. The equilibrium solubility can, therefore be raised or lowered by raising or lowering the concentration of the gas in contact with the water. The rate of exchange will also be affected by the area and the nature of the surface of water in contact with the air.

To reduce the amount of a gas in water it is necessary:

1. to reduce the concentration of that gas in the surrounding air. (provide adequate ventilation)
2. to increase the area of water in contact with air. (smaller droplets)
3. to keep the surface of the liquid constantly agitated so as to prevent the formation of a "liquid film" which would reduce the rate of exchange of the gas.
4. to increase the time during which the water is in the form of droplets.

On the other hand, to increase the amount of gas in the water, it is necessary to increase the concentration of that gas in contact with the water and also to maintain conditions 2 and 4 above.

Now, read pages 309 to 322 from the prescribed text book 'Water Quality' by G. Tchobanoglous and E. Schroeder.

5.2.1 Types of Aerators

Four types of aerators in common use.

1. Free fall aerators or gravity aerators.
2. Diffused air aerators.

3. Spray aerators.
4. Mechanical aerators.

1. Free Fall Aerators

(a) Cascades
(b) Multiple trays
(c) Vertical stacks

(a) Cascades

A simple cascade consists of a flight of three or four concrete or metal steps over which the water falls in thin sheets. This creates turbulance and brings larger surface areas of water to be in contact with air.

(b) Multiple tray aerators

These consist of a series of trays which are perforated or wire-meshed. Usually 3 to 5 trays are used. Sometimes stones are placed in the trays to increase the efficiency.

(c) Vertical stacks

Water in the form of droplets is allowed to fall and an upward flow of air is sent in a countercurrent flow.

2. Diffused Air Aerators

In this method compressed air is bubbled into water through orifices or nozzles in air piping or by diffusers. It is used in water as well as wastewater treatment.

3. Spray Aerators

When water is under a pressure head of about 7m or more, it can be sprayed into basins through nozzles. The nozzles are usually 25-40mm in diameter. The water rises either vertically or at an angle and falls into a collecting basin.

4. Mechanical Aerators

Aeration is carried out by splashing or by disturbance caused by some form of stirring. There are many kinds of mechanical aerators. These are usually employed in wastewater treatment.

For more information and diagrams on different aeration methods please refer to text book 'Water Quality' by G. Tchobanoglous and E. Schroeder from page 470 to 478.

5.3 COAGULATION AND FLOCCULATION

Prior to filtration, water may be treated by means of processes known as coagulation and flocculation. The purpose of these processes, which are often used in conjunction with sedimentation, is to remove colloidal suspensions, eg turbidity and colour.

A colloidal suspension in raw water is a heterogeneous mixture of particles that vary in size, shape and chemical composition — dissolved inorganic and organic, microscopic organisms and suspended inorganic material such as clay minerals.

Colloids are discrete particles which can remain in suspension in a dispersion medium. To remove them from suspension, it is necessary to coagulate small particles into larger areas. Coagulation reduces the net electrical repulsive forces at particle surface by electrolytes in solution.

There are two types of colloids — hydrophilic and hydrophobic. *Hydrophilic* colloids are readily dispersed in water, and their stability (lack of tendency to agglomerate) depends upon a marked affinity for water rather than upon the slight charge (usually negative) that they possess. Examples of hydrophilic colloidal materials are soaps, soluble starch, soluble proteins, and synthetic detergents.

Hydrophobic colloids possess no affinity for water and owe their stability to the electric charge they possess. Metal oxide colloids, most of which are positively charged, are samples of hydrophobic sols. A charge on the colloid is gained by adsorbing positive ions from the water solution. Electrostatic repulsion between the charged colloidal particles produces a stable sol.

Colloids encountered in water and wastewater are not purely hydrophobic.

5.3.1 Coagulation Mechanisms

Four major coagulation mechanisms can be identified.

1. Double layer compression

2. Charge neutralisation

3. Interparticle bridging

4. Precipitate enmeshment.

For a detailed explanation of these mechanisms read textbook 'Water Quality' by G. Tchobanoglous and E. Schroeder from page 577 to page 580.

In destabilising colloids, two basic mechanisms have been described as helping form sufficiently large aggregates to facilitate settling from suspension. The first, referred to as *coagulation,* reduces the net electrical repulsive forces at particle surfaces by electrolytes in solution. The second mechanism, known as *flocculation,* is aggregation by chemical bridging between particles.

The electrostatic repulsion between colloidal particles effectively cancels out the mass attraction forces (van der Waal's forces) that would bring the particles together. Certain chemicals (called coagulating agents, coagulants) have the capacity to compress the double layer of ions around the colloidal particles. They check the electrostatic repulsion, and thus enable the particles to flocculate, ie to form flocs. These flocs can grow to a sufficient size and specific weight to allow their removal by settling or filtration.

Generally, water treatment processes involving the use of chemicals are not so suitable for small community water supplies. They should be avoided whenever possible. Chemical coagulation and flocculation should only be used when the needed treatment result cannot be achieved with another treatment process using no chemicals. If the turbidity and colour of the raw water are not much higher than is permissible for drinking water, it should be possible to avoid chemical coagulation in the treatment of the water. A process such as slow sand filtration would serve both to reduce the turbidity and colour to acceptable levels, and to improve the other water quality characteristics, in a single unit. A roughing filter can serve to reduce the turbidity load on the slow sand filter, if necessary.

5.3.2 Coagulants

Alum ($Al_2(SO_4)_3.nH_20$; aluminium sulphate) is by far the most widely used coagulant but iron salts (eg ferric chloride; $FeCl_3$) can be used as well, and in some instances have advantages over alum. A significant advantage of iron salts over aluminium is the broader pH range for good coagulation. Thus, in the treatment of soft coloured waters where colour removal is best obtained at low pH's, iron salts may be preferred as coagulants. Iron salts should also be considered for coagulation at high pH's, since ferric hydroxide is highly insoluble in contrast to aluminium salts which form soluble aluminate ions at high pH's. Sodium aluminate is mostly used for coagulation at medium pH's. Synthetic organic polyelectrolytes have become available as coagulants but are generally not economical for small water supply systems, nor are they readily available.

Coagulants such as soluble aluminium and iron salts react with the alkalinity of the water, and hydrolyze in it. For example, alum reacts to form aluminium-hydroxide floc, $Al(OH_3)$, a gelatinous precipitate. The required alkalinity may be naturally present in the water or it has to be added through dosage of lime, $Ca(OH_2)$ or sodium carbonate, Na_2Co_3 (also called: soda ash).

Aluminium sulphate is called Filter Alum $[Al_2(SO_4)_3.14H_2O]$ which is a dehydrated form of $Al_2(SO_4)_3.18H_2O$. The chemical reaction as:

$$Al_2(SO_4)_3.14H_2O + Ca\,(HCO_3)_2 \rightarrow 2Al(OH)_3 \downarrow + 3CaSO_4 + 14H_2O + 6CO_2$$

If water does not contain sufficient alkalinity to react with alum, the chemical reaction with the addition of lime is:

$$Al_2(SO_4)_3.14H_2O + 3Ca(OH)_2 \rightarrow 2Al(OH)_3 \downarrow + 3CaSO_4 + 14H_2O$$

An advantage of using Soda Ash instead of lime is that unlike lime, it does not increase water hardness. Lime is less expensive than Soda Ash.

With very low concentrations of colloidal matter floc formation is difficult and coagulant aids may be required. Normally polyelectrolytes are used as coagulant aids. Control of pH is also very important for the precipitation of colloids.

For good coagulation, the optimal dose of coagulant should be fed into the water and properly mixed with it. The optimal dose will vary depending upon the nature of the raw water and its overall composition. It is not possible to compute the optimal coagulant dose for a particular raw water. A laboratory experiment called the 'jar test' is generally used for the periodic determination of the optimal dose. The 'jar test' may be briefly described as follows:

> *A series of samples of water are placed on a special multiple stirrer and the samples are dosed with a range of coagulant, eg 10, 20, 30, 40 and 50 mg/l; they are stirred vigorously for about one minute. Then follows a gentle stirring (10 minutes), after which the samples are allowed to stand and settle for 30 to 60 minutes. The samples are then examined for colour and turbidity and the lowest dose of coagulant which gives satisfactory clarification of the water is noted.*
>
> *A second test involves the preparation of samples with the pH adjusted so that the samples cover a range (eg pH = 5; 6; 7 and 8). The coagulant dose determined previously is added to each beaker. Then follows stirring, flocculation and settlement as before. After this, the samples are examined and the optimum pH is determined. If necessary, a re-check of the minimum coagulant dose can be done.*

The most common method of dosing the alum or ferric sulphate is in the form of a solution. Such a solution (usually of 3 to 7% strength) is prepared in special tanks with a holding capacity of 10 or more hours coagulant feeding requirements. Two tanks are required, one in operation, while the solution is being prepared in the other.

When using alum, one should keep in mind that in solutions of less than 1 percent strength, the chemical is hydrolysed (ie forms agglomerates with the chemical feed water) before it is dosed into the raw water. To prevent this, the solution should always have a strength of more than 1.5 percent. Different chemical feed arrangements can be used and a typical example is shown in Figure 5.3.

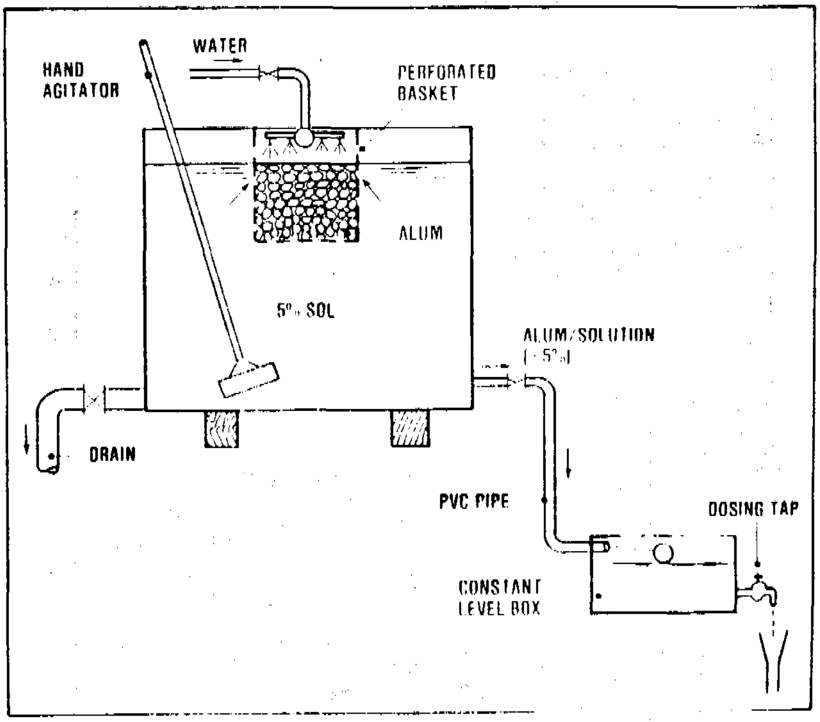

Fig. 5.3 Chemical feed arrangement for alum. (Source: IRC Small Community Water Supplies.)

5.3.3 Rapid Mixing

Rapid mixing aims at the immediate dispersal of the entire dose of chemicals throughout the mass of the raw water. To achieve this, it is necessary to agitate the water violently and to inject the chemical in the most turbulent zone, in order to ensure its uniform and rapid dispersal.

The mixing has to be rapid, because the hydrolysis of the coagulant is almost instantaneous (within a few seconds). The destabilisation of colloids also takes very little time.

The location of the rapid mixer should be near to the 'chemical house' where solutions of chemicals are prepared. The feeding pipes then will be of short length. It is also desirable to place the rapid mixing device close to the flocculators. To combine both these requirements in the layout of a treatment plant is often quite difficult.

Many devices are used to provide rapid mixing for the dispersal of chemicals in water. Basically, there are two groups:

1. Hydraulic rapid mixing.
2. Mechanical rapid mixing.

Hydraulic Rapid Mixing

For hydraulic rapid mixing, arrangements are used such as: channels or chambers with baffles producing turbulent flow conditions, overflow weirs, and hydraulic jumps.

Mechanical Rapid Mixing

With mechanical mixing the power required for agitation of the water is imparted by impellers, propellors or turbines ('Rapid Mixers', 'Flash Mixers', 'Turbo Mixers'). See Figure 5.4.

Generally, mechanical rapid mixers are less suitable for small treatment plants than hydraulic ones since they require a reliable and continuous supply of power.

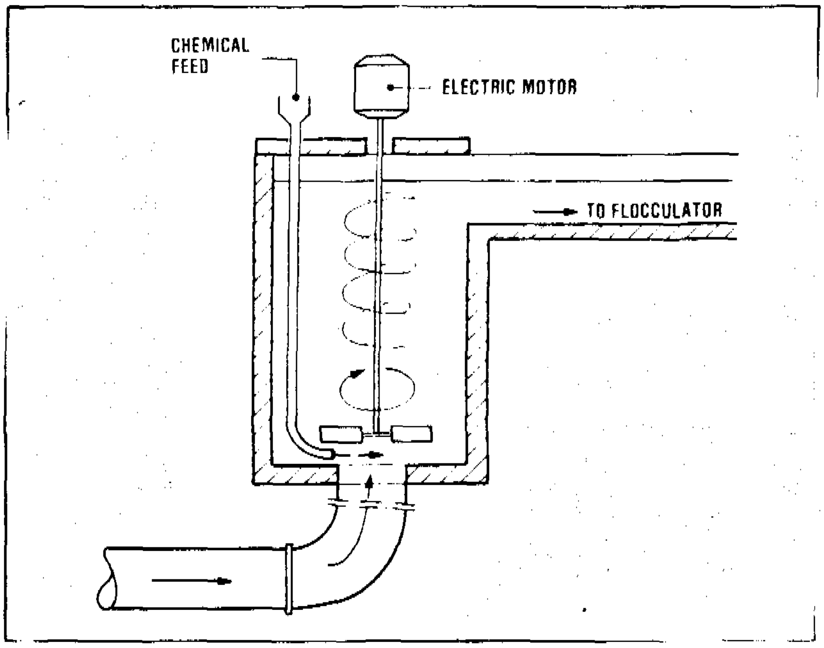

Fig. 5.4 Mechanical Mixer.

5.3.4 Flocculation

Flocculation is the process of gentle and continuous stirring of coagulated water for the purpose of forming flocs through the aggregation of the minute particles present in the water. It is thus the conditioning of water to form flocs that can be readily removed by settling or filtration. The efficiency of the flocculation process is largely determined by the number of collisions between the minute coagulated particles per unit of time. During flocculation which lasts 20 to 40 minutes agglomeration of colloidal particles is completed. Flocculation is due to two causes:

1. Differences in the settling velocities of the particles whereby faster settling particles overtake those which settle more slowly and coalesce with them.
2. Velocity gradients in the liquid which cause particles in a region of higher velocity to overtake those in adjacent stream paths moving at a slower velocity.

Flocculation can be accomplished in a number of ways including the use of baffled basins or paddles. In the design of flocculators not only the velocity gradient should be taken into account, but also the retention time. The product of the velocity gradient and retention time gives a measure for the number of particle collisions, and thus for the floc formation action. The formula for computing velocity gradient is given by:

$$G = \sqrt{\frac{P}{\mu}} \qquad 5.1$$

where G = velocity gradient (sec^{-1})
P = Power consumed by unit volume of water (kw)

μ = dynamic viscosity of water (Nsm^{-2})

Power input in a mechanical paddle can be related to the drag on flocculator paddle and therefore to motor output.

By dimensional analysis it can be shown that

$$F_D = C_D . A\rho \frac{U^2}{2} \qquad 5.2$$

where A = total cross-sectional area of flocculator paddles (m^2)

F_D = drag force, (N)

C_D = drag coefficient

ρ = density of water

u = water velocity (ms^{-1})

$$\therefore \quad G = \sqrt{\frac{C_D A \rho u^3}{2V\mu}} \qquad 5.3$$

where V = volume of the flocculating basin (m^3)

5.4 SEDIMENTATION

Sedimentation is the separation of solid particles from a suspension by the force of gravity and the suspension is separated into clarified liquid and sludge. The sedimentation process is used to remove from the water discrete particles, flocculated matter and precipitates formed during various operations. The factors that influence the sedimentation process are:

1. Size, shape and weight of the particles whether they are discrete or flocculant.
2. Viscosity and hence temperature of water.
3. Time available for sedimentation.
4. Depth of the tanks.
5. Velocity of flow.
6. Overflow rate or surface loading rate $m^3m^{-2}d^{-1}$.
7. Inlet and outlet design of tanks.
8. Effect of wind induced currents.

The theory of sedimentation is applicable to both water and wastewater treatment and it will be dealt in volume two of the notes.

5.4.1 Types of Sedimentation Tanks

1. Horizontal flow tanks.

These fall into two groups identified by their plan shapes; some are rectangular and some are circular.

Rectangular horizontal flow tanks have the form shown in Figure 5.5. They are suitable for small or large works and are easy and cheap to build. Length is usually about 2.5 to 4 times the breadth. The depth is of the order 2m to 4m. Flow enters either through pipes, ports, inlet weirs or a combination of these, and exit is commonly over outlet weirs at a mean velocity of about $5mms^{-1}$.

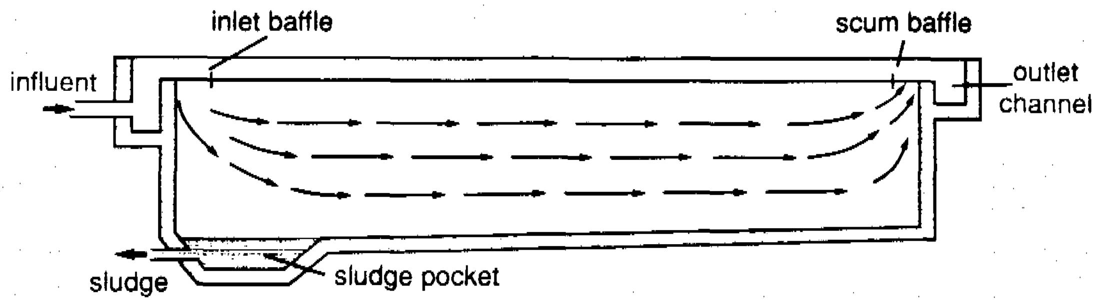

Fig. 5.5 **Rectangular Horizontal Flow Tank.**

Horizontal flow tanks which are circular in plan are often referred to as "radial flow tanks".

Their general form is indicated in Figure 5.6, and again, the flow is continuous. The diameter commonly lies between 15 and 30m, though both smaller and larger tanks have been built. The depths are similar to those of rectangular tanks. The flow enters via an inlet pipe which passes under the tank flow and rises vertically at the centre. The flow is radial towards the outward direction. Water flows toward the perimeter of the tank, then over an outlet weir into a peripheral channel. The floors of these tanks are normally swept by blades supported from a rotating radial arm or bridge.

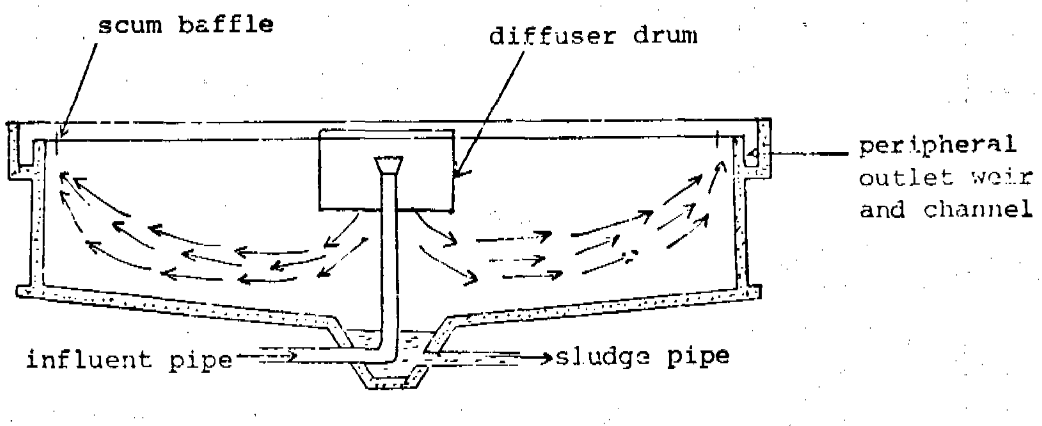

Fig. 5.6 **Circular Horizontal Flow Tank**

2. Upward Flow Tanks.

These are usually square in plan though some circular versions exist. As shown in Figure 5.7 the upper part of the tank has vertical walls while the lower part is of inverted pyramid form, with sides sloping at 60° to the horizontal; the direction of flow is upwards, which causes the particles to rise, and upward velocity is critical with a value of about 1m/h to 2m/h at maximum flow. The weight of the particles reduces their velocity until they are virtually stationary. So a sludge 'blanket' forms across the tanks and acts as a filter and coagulating agent forming larger particles.

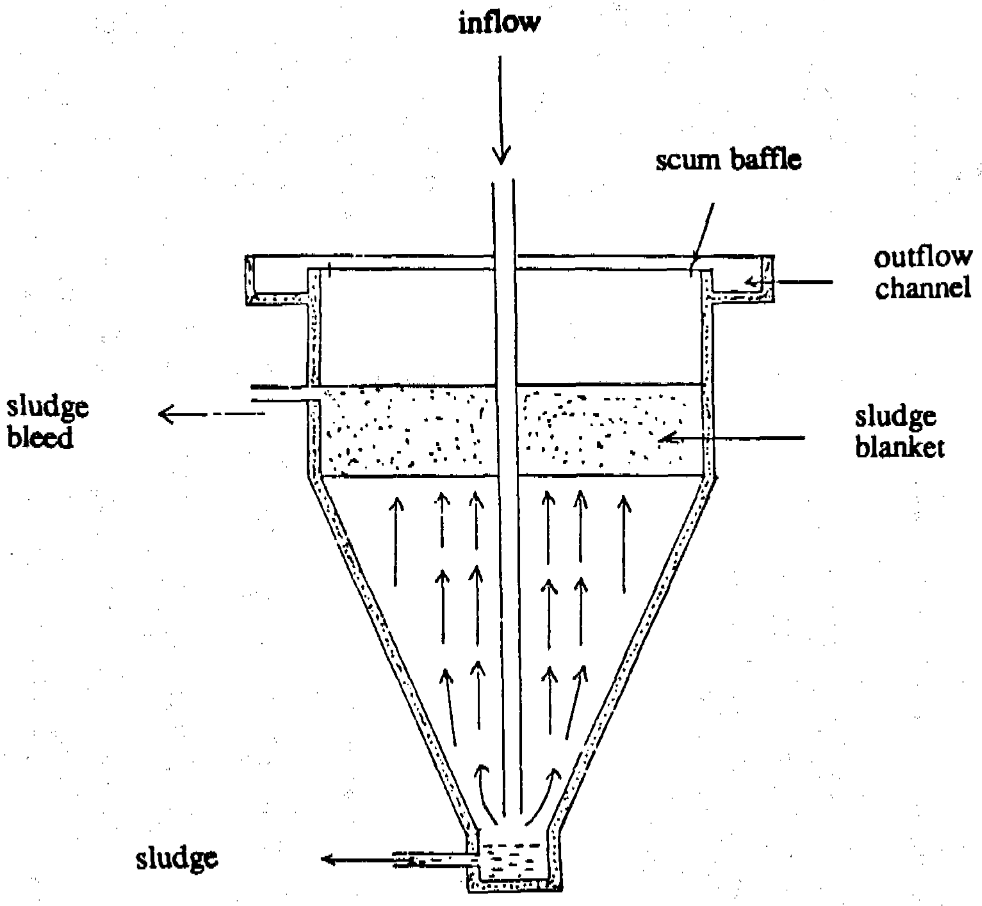

Fig. 5.7 Upward Flow Tank.

5.5 FILTRATION

Filtration is the process in which suspended and colloidal particles, bacteria and other micro-organisms are removed or reduced by passing the water through a porous medium. Though the porous medium may be of any substance, sand is the one commonly used in water treatment.

5.5.1 Mechanisms of Filtration

A number of complex mechanisms contribute towards the filtration process. Some of the factors which contribute to removal are:

1. Straining action taking place at the surface of filter bed.
2. Sedimentation inside the filter bed.
3. Contact of the floc particles with the surface of grains or with already deposited flocs.
4. Electrostatic attraction.
5. Adherence.
6. Biological activity.

A detailed description of the above mechanisms can be found in he text book 'Water Quality' from page 507 to 512.

5.5.2 Types of Filters in Water Treatment

Two general types of filters are in common use.

1. Slow sand filters.
2. Rapid sand filters.

The above classification is based on rate of filtration.

1. Slow sand filters

It has been claimed that no other single process can effect such an improvement in the physical, chemical and bacteriological quality of normal water. For country areas and developing countries, there are advantages:

1. Cost of construction is low.
2. Simplicity of design and operation.
3. Easy maintenance by unskilled labour.
4. No chemicals needed.
5. Suitable for small communities.

The greatest disadvantage of a slow sand filter is that a large area of land is required. Basically, a slow sand filter consists of a box, containing a supernatant raw water layer, a bed of filter medium and a system of underdrains. Percolation of water into the ground is very similar to slow sand filtration. The velocity of water in the filter is between 0.1 and 0.4 m/h. The thickness of sand bed may be 1.0m to 1.5m supported on a layer of gravel 0.3 to 0.5m thick. The supporting layer of gravel prevents the penetration of fine particles along with the filtered water (see Figure 5.8). The treated water is collected in open jointed laterals placed beneath the gravel.

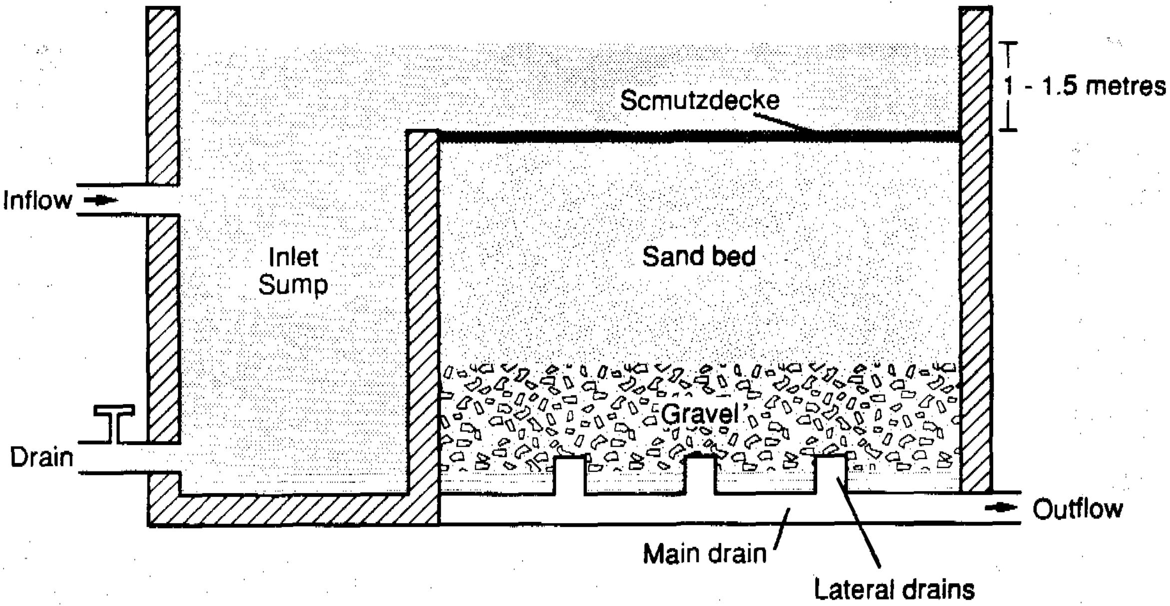

Fig. 5.8 Diagrammatic section of a slow sand filter.

Substances retained during filtration are collected on the surface of the filter medium and form a mesh structure which functions as a porous layer and helps the cleaning action. Organisms begin to grow on the surface of the filter and form a "zoogleal" mass known as schmutzdecke. Since the sand bed cannot be backwashed the operation of the filter must be stopped when head loss increases to about 1m so that the bed can be cleaned. A few centimetres (1 to 2.5cm) of sand from top is removed and replaced with clean sand.

2. Rapid sand filters

In water purification the rapid sand filter has achieved much greater importance than the slow sand filter. It can be operated about 30 times faster than the slow sand filter. The distinguished features of rapid sand filters are their relatively small size and the ways in which they must be cleaned because they accumulate impurities at nearly all depths. The velocity of flow in the filters is very high and the rate of filtration may be between 4 and 5 cubic metres per square metre per hour. The bed is stratified due to backwash, the finer being at the top and the heavier at the bottom. Raw water is treated with chemicals for removal of turbidity. The process of cleaning a rapid sand filter is different from that of a slow sand filter. Backwashing or a reversal of the direction of flow is performed as soon as the designed head loss is attained. A relatively complicated system of underdrains is required in a rapid sand filter to collect filtered water and evenly distribute the backwash water throughout the bed. Wash-water troughs are placed above the sand to remove soiled water during backwashing. (See Figure 5.9).

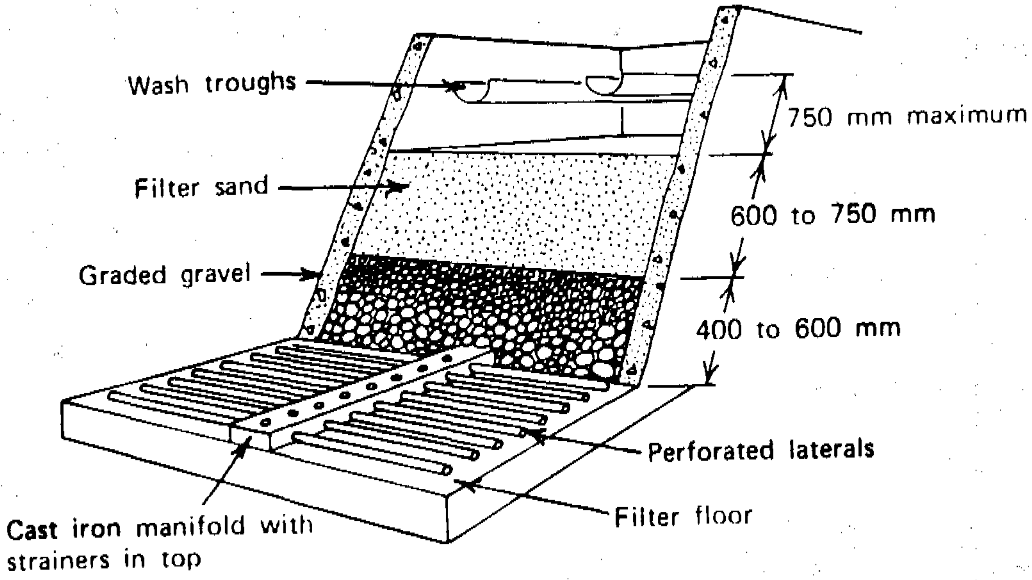

Fig. 5.9 Cross section of a typical sand filter. (From *Water Supply and Treatment*, National Lime Association, 1962).

5.5.3 Filter Troubles

The following two troubles are generally encountered in operating rapid sand filters.

1. Mud balls.
2. Cracking of filters.

1. Mud balls

Mud balls are formed near the top of the filter media. They may even be formed and distributed throughout the filter. The mud balls are caused due to insufficient washing of sand grains. The gelatinous film formed during filtration is not separated out from sand grains during washing. The mud balls interfere with the normal washing of the filter and their size in about 25mm to 50mm.

2. Cracking of filters

The fine material contained in the top layer of the filter shrinks and this shrinkage tends to form cracks in the filter. These cracks are permanent near wall junctions.

FURTHER READING

Water Quality by G. Tchobanoglous and E. Schroeder, pages 506 to 529.

5.6 WATER SOFTENING

The removal of hardness from water is not essential to making water safe. The advantage lies chiefly in reducing soap consumption and scale formation in pipes. The two basic methods used are:

1. Lime-Soda Ash Process.
2. Ion-Exchange Process.

In these notes we will only discuss the Lime-Soda Ash process and details of Ion-Exchange process can be found in any standard water treatment book or in the prescribed text from page 584 to page 589.

Lime-Soda Ash Process

Process is based on chemical precipitation. Aim is to make the calcium and magnesium content of hard water take their insoluble forms so that they can precipitate out.

The insoluble forms of calcium and magnesium are calcium carbonate and magnesium hydroxide respectively.

Carbon dioxide and carbonate hardness are complexed by Lime. Non-carbonate hardness requires addition of soda ash for precipitation.

1. When Lime is added to water, it reacts first with any free carbon dioxide present which does not contribute any hardness

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + H_2O$$

2. To Remove Temporary Hardness

(a) To remove calcium temporary hardness add Lime:

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2\ \underset{\text{insoluble}}{CaCO_3 \downarrow} + 2\ HO_2$$

ie, for each equivalent of $Ca(HCO_3)_2$ add one equivalent of $Ca(OH)_2$

(b) To remove magnesium temporary hardness add Lime:

$$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow + \underset{\text{soluble}}{MgCO_3} + 2\ H_2O$$

∴ Add further molecule,

$$MgCO_3 + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow + CaCO_3$$

Therefore, adding these two equations gives

$$Mg(HCO_3)_2 + 2\ Ca(OH)_2 \rightarrow Mg(OH)_2 + 2\ CaCO_3 + 2\ H_2O$$

ie for each equivalent of $Mg(HCO_3)_2$ removal add 2 equivalent of $Ca(OH)_2$

3. To Remove Permanent Hardness

(a) To remove calcium permanent hardness addition of soda ash is required.

$$\left.\begin{matrix} CaSO_4 \\ CaCl_2 \end{matrix}\right\} + Na_2CO_3 \rightarrow CaCO_3 \downarrow + \left.\begin{matrix} Na_2SO_4 \\ 2\ NaCl \end{matrix}\right\}$$

(b) To remove magnesium permanent hardness both Lime and soda ash are required.

$$\left.\begin{matrix} MgSO_4 \\ CaCl_2 \end{matrix}\right\} + Ca(OH)_2 \rightarrow Mg(OH)_2 + \left.\begin{matrix} CaSO_4 \\ CaCl_2 \end{matrix}\right\}$$

$$\left.\begin{matrix} CaSO_4 \\ CaCl_2 \end{matrix}\right\} + Na_2CO_3 \rightarrow CaCO_3 + \left.\begin{matrix} Na_2SO_4 \\ 2\ NaCl \end{matrix}\right\}$$

The calcium ion can be effectively reduced by the lime additions shown in the equations that raise the pH of water to about 10.3 but precipitation of magnesium ion demands a higher pH and the presence of excess lime in the amount of about 35 mg/L of CaO (1.25 meq/L) above the stoichiometric requirements.

5.7 DISINFECTION

This is the process in which water borne pathogenic organisms are destroyed by physical or chemical means, ie inactivation or killing of pathogenic organisms. The complete destruction of all organisms is termed sterilisation. Disinfection in water and wastewater treatment involves the exposure of the disease-causing organisms in water to some destructive agent. This destructive agent is called disinfectant and it should be harmless, unobjectionable, economical and be able to give a residual sterilising effect for a long time. The disinfectants can be classified into two groups:

1.	Physical agents	-	Heat, light, ultraviolet rays and radiation.
2.	Chemical agents	-	Halogens (chlorine, bromine and iodine), ozone, potassium permanganate, hydrogen peroxide, sulphur dioxide.

Due to the small size of bacteria, it is not possible to ensure their complete removal from water either by physical or chemical means above. Therefore the efficiency is stated in terms of 99%, 99.9% or 99.99% kills.

5.7.1 Rate of Disinfection

This is governed by Chick's law which states that the rate of kill of bacteria is directly proportional to the number of living organisms remaining at any specific time.

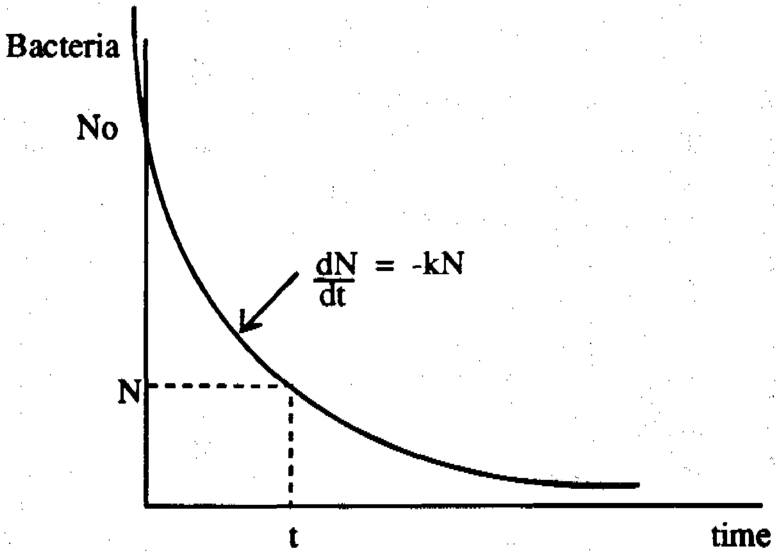

Fig. 5.10 Number of Bacteria vs Time.

The rate of kill is often postulated as a first-order reaction.

$$\therefore \frac{dN}{dt} = -KN \qquad 5.4$$

where K = Rate constant for a particular disinfectant and the system. (temp, pH, bacteria etc.)

N = Number of organisms/unit volume surviving at any given time t.

$$\therefore \int_{N_o}^{N} \frac{dN}{dt} = -\int_{o}^{t} Kdt \qquad 5.5$$

where N_o = Number of organisms/unit volume at time t = o

Integrating equation 5.5, we get

$$N = N_o e^{-Kt} \qquad 5.6$$

In practice, the rate of kill has been found generally to decrease or increase with time. Whether the rate increases or decreases depends on the type of organisms and the disinfectants used.

Factors Affecting Disinfection

1. Disinfectant concentration

The relationship between the disinfectant concentration and the time required to kill a given percentage of organisms is given by the model:

$$c^n t_p = \text{constant (= time concentration factor)} \qquad 5.7$$

where c = concentration of disinfectant in mgL^{-1}

t = time required to kill a certain percentage 'p' in water

n = constant depending on the characteristics of the disinfectant. For Hypochlorous acid (HOCl), n = 0.86.

The time concentration factor for HOCl for 99% kill of E - coli = 0.24 and for Polio virus = 1.2.

2. Contact time

In general it has been observed that, for a given concentration of disinfectant, the longer the contact time, the greater the kill.

In practice the rate of kill may decrease or increase depending on the organism and the disinfectant.

3. Effect of temperature

Disinfection rates may be affected in two ways by temperature.

(a) Bactericidal action may be affected directly by extreme temperature conditions.

(b) Temperature can affect the rates of certain reaction steps involved in the disinfection process, ie diffusion of the disinfectant through the cell walls or its chemical reaction with the cellular enzymes is temperature dependent.

The rate constant K governs the rate of kill and varies with temperature and it is given by:

$$K_T = K_{20}\,\beta^{(T-20)} \qquad 5.8$$

where K_T = rate constant at T°C

K_{20} = rate constant at 20°C

β = an empirical constant >1

ie rate of kill increases with temperature

4. Effect of pH

Under extreme pH conditions (<3 or >11) most micro-organisms are destroyed. Under moderate conditions (pH ≡ 4 - 10), pH will affect the reactivity of the micro-organisms or disinfectant or both.

5. Effect of organic matter

The presence of organic matter may cause the following effects:

(a) Certain organic compounds may adhere to the cell surface and may prevent or retard the action of disinfectant.

(b) The disinfectant may react with dissolved organic matter to form compounds which are less effective.

(c) The disinfectant may react with organic matter to chemically oxidise it. This may reduce the effect of the disinfectant.

5.7.3 Methods of Disinfection

1. **Temperature**

   Boiling water is the most effective method of disinfection. But it is not practical for water supply systems.

2. **Using chemical agents**

   There are many chemical agents. They should have the following features:

   (a) Toxicity to the micro-organisms — should be effective to a very wide spectrum of micro-organisms rather than to a particular species.

   (b) Solubility - preferably in water.

   (c) Stability - no change should occur during storage.

   (d) Non-toxicity to human and animals.

   (e) Capacity to penetrate the cells of organisms.

   (f) Should be active at normal temperature.

   (g) Non-corrosive and non-staining.

5.7.4 Ozone Treatment

The atmospheric oxygen is in molecular form containing two atoms of oxygen. But when a high strength electrical field is passed through a stream of air in a closed chamber ozone (O_3) is formed. Ozone is a very powerful oxidising agent. The third atom is very loosely bound and the ozone easily breaks down into oxygen and releases nascent oxygen which is very powerful in killing bacteria. It is an efficient disinfectant independent of pH and useful in bleaching colour and removing tastes and odours. It is also effective against some chlorine resistent pathogens. The difficulties of using ozone are:

1. It cannot be stored and hence has to be produced at site.
2. Cost of equipment is high.
3. Does not provide for residual protection against recontamination.

5.7.4 Chlorination

It has the following advantages to be used as a disinfectant in water supplies.

1. It is readily available as a gas, liquid or powder or it could be easily produced.
2. It is cheap.
3. High solubility.
4. It leaves a residual in solution not harmful to humans.
5. It is very toxic to micro-organisms.

5.7.5.1 Chemistry of Chlorination

Chlorine is a powerful oxidising agent which will rapidly combine with reducing agents and unsaturated organic compounds. After this chlorine demand has been satisfied, the following equilibrium reaction takes place when elemental chlorine is dissolved in water.

Hydrolysis

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^- \qquad 5.9$$

Hydrochloric acid is neutralised by the alkalinity and Hypochlorous acid becomes dissociated.

Ionisation

$$HOCl \rightleftharpoons H^+ + OCl^- \qquad 5.10$$

The quantities of HOCl and OCl^- ions depend upon the pH value. Hypochlorous acid (HOCl) formed during hydrolysis is more effective disinfectant than the chlorite ion (OCl^-)· Most waters have a pH value between 6 and 7.5 and therefore 40 to 95% of the free residual chlorine is in the form of HOCl (see Figure 5.11).

The HOCl and OCl^- are termed as 'Free Available Chlorine' or 'Free Residual Chlorine'. Softened water with high pH value must be treated with higher doses of Cl_2 to compensate for the low disinfecting power of OCl^-.

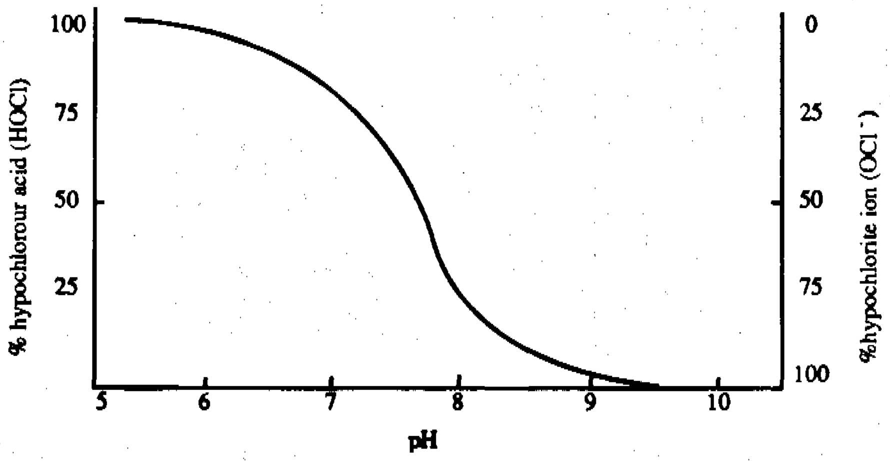

Fig. 5.11. Variation of hypochlorous acid/chlorite ion system with pH.

For equation (5.10) the ionisation constant is given as:

$$K_i = \frac{[H^+]\ [OCl^-]}{[HOCl]} \qquad 5.11$$

$$\text{or} \quad \frac{OCl^-}{[HOCl]} = \frac{K_i}{[H^+]} \qquad 5.12$$

$$\therefore \frac{K_i}{[H^+]} = \frac{100 - \%\ [HOCl]}{\%\ [HOCl]}$$

$$\therefore \frac{K_i}{[H^+]} = \frac{100}{\%\ [HOCl]} - 1$$

$$\frac{100}{\%\ [HOCl]} = 1 + \frac{K_i}{[H^+]}$$

$$\therefore \%\ [HOCl] = \frac{100}{1 + \frac{K_i}{[H^+]}} \qquad 5.13$$

$\therefore$ % [HOCl] is dependent on pH.

FREE Available Chlorine = $[HOCl] + [OCl^-]$

5.7.5.2 Chloramination

Chlorine-ammonia treatment first came into general use to limit tastes and odours resulting from chlorination of water containing phenolic substances. Subsequently it has been found effective at times for reducing tastes and odours due to other substances as well. So ammonia was added prior to chlorination if no ammonia was present in water. Recently it is claimed that these advantages can be obtained by using much higher doses of chlorine.

Free chlorine in solution will react with ammonia in water to form chloramines. The chloramines also serve as disinfectants although they are extremely slow reacting. The bacterial effect of the dose would be maintained over a longer period. The chemical reactions are:

$$NH_3 + HOCl \rightleftharpoons \underset{\text{monochloramine}}{\underset{\downarrow}{NH_2Cl}} + H_2O \qquad 5.14$$

$$NH_2Cl + HOCl \rightleftharpoons \underset{\text{Dichloramine}}{\underset{\downarrow}{NHCl_2}} + H_2O \qquad 5.15$$

$$NHCl_2 + HOCl \rightleftharpoons \underset{\text{Nitrogen Trichloride or Trichloramine}}{\underset{\downarrow}{NCl_3}} + H_2O \qquad 5.16$$

Combined Available Chlorine or
Combined Residual Chlorine = $[NH_2Cl] + [NHCl_2]$

Combined residuals are more stable than free residuals but less effective as a disinfectant. For a given kill with constant residual the combined form requires a hundred times the contact time required by free residual.

5.7.5.3 Break-Point Chlorination

Breakpoint chlorination involves the addition of sufficient chlorine to result in a free chlorine residual.

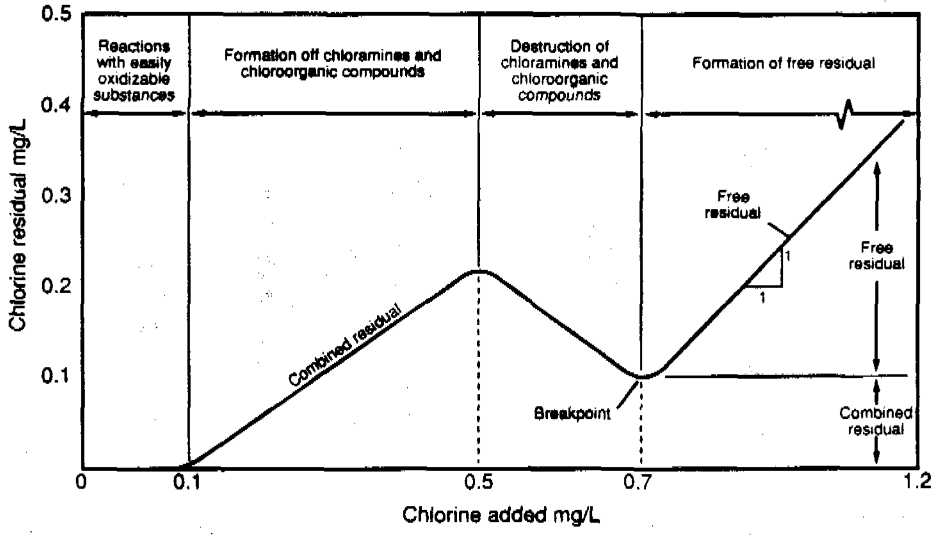

Fig. 5.12. Schematic representation of the breakpoint chlorination curve.

Figure 5.12 illustrates

1. Break-point curve when water containing NH_3 and organic matter is chlorinated.

2. Chlorine Demand = Dose - residual chlorine.

Four zones are observed in Figure 5.12.

In the first zone, with the low doses of 0 to about 0.12 mg/l represents a condition in which all the chlorine is removed by reactors with organic matter, Fe^{++}, My^{++} and H_2S so that no residual chlorine remains. (No disinfection occurs in the absence of residual chlorine.)

In the second zone, with doses of 0.12-0.53 mg/l represents the results with moderate doses of chlorine which form chloramines with the ammonia in water and also chloro-organic compounds. (This zone represents the earlier chlorination practice in which residual chlorine of 0.1-0.2 mg/l was considered ample regardless of combined or free chlorine.)

The third zone with doses of 0.53-0.7 mg/l illustrates the 'Break-Point' at which these higher doses of Cl_2 lead to increased chemical activity which in turn leads to the oxidation or alteration of the chloramines and chloro-organic compounds, ie increased chemical activity of higher chlorine doses in this zone leads more chemical changes which increase the removal of Cl_2 (or Cl_2 demand) so that higher doses produce lower concentrations of residual Cl_2.

The fourth zone represents the conditions that prevail when the reactions in the third zone have been completed, ie continued addition of chlorine past the break-point will result in a directly proportional increase in the free available chlorine.

Therefore, the principle of free-residual chlorine is to add sufficient chlorine to oxidise all organic matter, iron, manganese and other, reduced substances in the water being treated and also to oxidise free ammonia in the raw water, so that the remaining residual chlorine will be present as active free-residual chlorine rather than the less active combined residual chlorine.

5.7.5.4 Super Chlorination and Dechlorination

The process of super chlorination followed by dechlorination is the application of Cl_2 to water to produce free residual chlorination, in which the free available chlorine residual is so large that dechlorination is required before the water is used.

Dechlorination is accomplished by the addition of SO_2, sodium thio sulphate or sodium bisulphite ($NaHSO_3$) $Cl_2 + NaHSO_3 + H_2O \rightarrow NaHSO_1 + 2HCl$.

1 mole of $NaHSO_3$ reduces 1 mole of Cl_2.

ie 71 mg of Cl_2 is reduced by 104 mg of $NaHSO_3$.

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Water Quality Management

Volume 2

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BIO-KINETICS AND STREAM PROCESSES

1.1 INTRODUCTION

The organic matter present in water or wastewater is normally rendered inert either by aerobic and/or anaerobic processes. In water quality management it is important that the amount of organic matter present in the system be known and the quantity of oxygen required for its stabilisation be determined. Over the years, a number of tests have been developed to measure the organic content of water and wastewater and the laboratory tests commonly used to measure gross amounts of organic matter include

* chemical oxygen demand (COD)
* total organic carbon (TOC)
* biochemical oxygen demand (BOD).

The COD test is a chemical test, the TOC test is an instrumental test and the BOD test is a biochemical test involving the use of micro-organisms. Additional information on COD and TOC may be found on pages 101 and 102 of Tchobanoglous & Schroeder (1985) and on BOD in American Public Health Association (1985), often referred to as 'Standard Methods'.

1.2 BIOCHEMICAL OXYGEN DEMAND

The most widely used parameter of organic pollution applied to both wastewaters and surface waters is the five-day BOD (i.e. BOD_5). If oxygen is supplied to a sample of wastewater containing organic matter, aerobic micro-organisms oxidise organic matter until the process is complete (i.e. the water is stabilised). The magnitude of the biochemical oxygen demand depends upon the organic matter present while the rate of demand depends upon the temperature and remaining organic matter.

Oxygen demand is exerted by three classes of matter

* carbonaceous materials
* oxidisable nitrogen
* certain reducing compounds.

Complete stabilisation may require too long a time for practical measurement purposes so a distinction is made between the oxygen demand of the carbonaceous material in waste and the nitrogenous oxygen demanding component of the waste. Fig. 1.1 shows a typical oxygen demand curve of untreated waste that contains nitrogenous material.

The carbonaceous biological oxygen demand (CBOD) is usually exerted first due to a 8 to 10 day lag in the growth of the nitrifying bacteria which exert the nitrogenous biochemical oxygen demand (NBOD). The CBOD is exerted by heterotrophic organisms that are capable of deriving their energy for oxidation from an organic carbon substrate. First a portion of the waste is oxidised to end products to obtain energy for cell maintenance and the syntheses of new cell tissue. Second, some of the waste is converted into new cell tissue using part of the energy released during oxidation. Finally, when the organic matter is used, the new cells begin to consume their own cell tissue to obtain energy for cell maintenance. This third process is called endogeneous respiration.

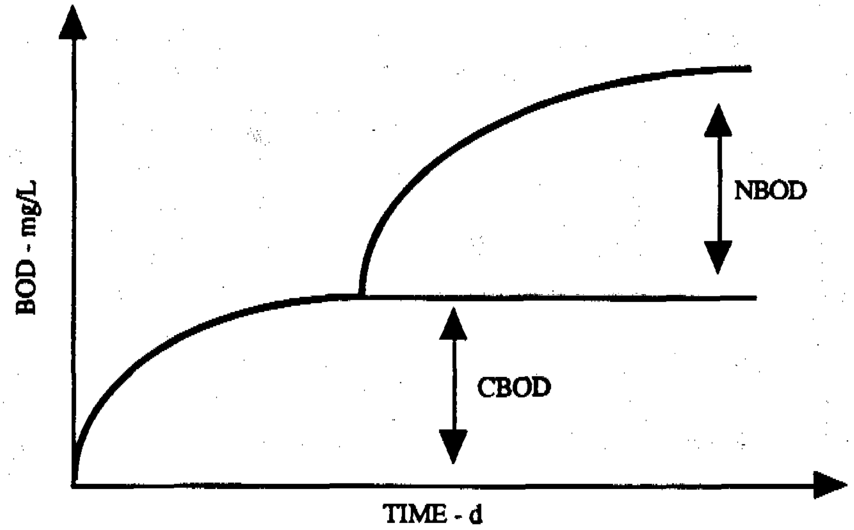

Fig. 1.1 Wastewater carbonaceous and nitrogenous biochemical oxygen demands

If the term COHNS (carbon, oxygen, hydrogen, nitrogen and sulfur) is used to represent the organic waste and the term $C_5H_7NO_2$ is used to represent cell tissue, these process can be defined by the following generalised chemical reactions

Oxidation

$$\text{COHNS} + O_2 + \text{bacteria} \rightarrow CO_2 + H_20 + NH_3 + \text{other end products} + \text{energy} \quad \ldots 1.1$$

Synthesis

$$\text{COHNS} + O_2 + \text{bacteria} + \text{energy} \rightarrow C_5H_7NO_2 + \text{cell tissues} \quad \ldots 1.2$$

Endogeneous respiration

$$C_5H_7NO_2 + 50_2 \rightarrow 5CO_2 + NH_3 + 2H_20 \quad \ldots 1.3$$

The oxygen demand from the biological oxidation of ammonia results in the nitrification process as described by the following equations

Conversion of ammonia to nitrite

$$NH_3 + \frac{3}{2}O_2 \rightarrow HNO_2 + H_20 \qquad \dots\ 1.4$$

Conversion of nitrite to nitrate

$$HNO_2 + \frac{1}{2}O_2 \rightarrow HNO_3 \qquad \dots\ 1.5$$

$\therefore$ the final reaction will be $NH_3 + 2O_2 \rightarrow HNO_3 + H_2O$ ... 1.6

In a standard test for BOD, a sample is diluted with water containing a known amount of dissolved oxygen and the nutrients required for biological growth; the loss in oxygen after the sample has been incubated for 5 days at 20°C is known as the BOD^5_{20}.

1.2.1 The First-Order Kinetics Model for BOD

The rate at which organic matter is oxidised by bacteria is a fundamental parameter in the rational design of biological waste treatment processes. It has been found that BOD removal often approximates first-order kinetics. That is to say, the rate of BOD removal (= rate of oxidation of organic matter) at any time is proportional to the amount of BOD (= organic matter) present in the system at that time. In more mathematical terms, the rate of BOD removal is an exponential decay process.

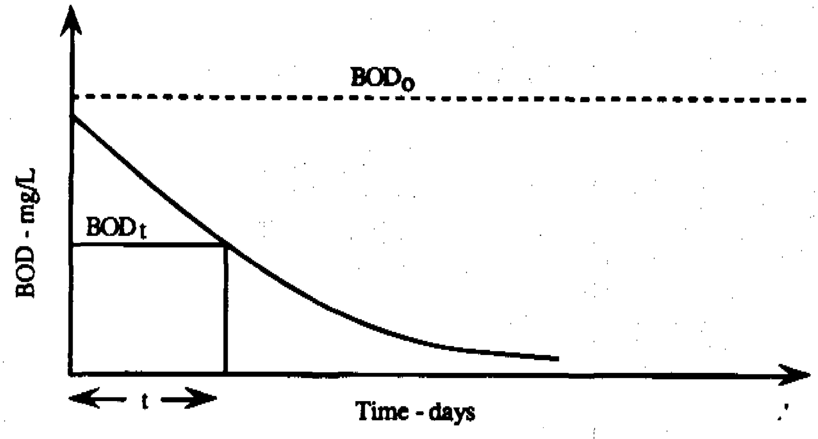

Fig. 1.2 BOD versus time

The rate at which organic matter is being oxidised is

$$\frac{d(BOD_t)}{dt} = -K_1.BOD_t \qquad \dots\ 1.7$$

where K_1 = rate constant (d^{-1}).

Integrating Eqn 1.7 we get

$$\frac{BOD_t}{BOD_0} = e^{-K_1.t} \qquad \ldots\ 1.8$$

$$\text{so } BOD_t = BOD_0[1 - e^{-K_1.t}] \qquad \ldots\ 1.9$$

$$\text{or } BOD_t = BOD_0[1 - 10^{-K.t}] \qquad \ldots\ 1.10$$

where $K = 0.4343K_1$

The rate of reaction, described by the constant K_1, will depend on the nature of the organic waste. Clearly, this constant can have a marked effect on the observed BOD_5 for various wastes and the dissolved oxygen levels in the receiving waters into which the waste is released. Fig. 1.3 shows the BOD versus time curves for three rate constants, 0.5, 0.1 and 0.01 d^{-1}, all with an ultimate BOD of 400 mg/L. The BOD_5 represents 99.7%, 68% and 10% respectively of the ultimate oxygen demand.

The constant K_1 varies with temperature as follows

$$(K_1)_T = (K_1)_{20} \times 1.047^{(T-20)} \qquad \ldots\ 1.11$$

where $(K_1)_T$ = rate constant at T°C
$(K_1)_{20}$ = rate constant at 20°C.

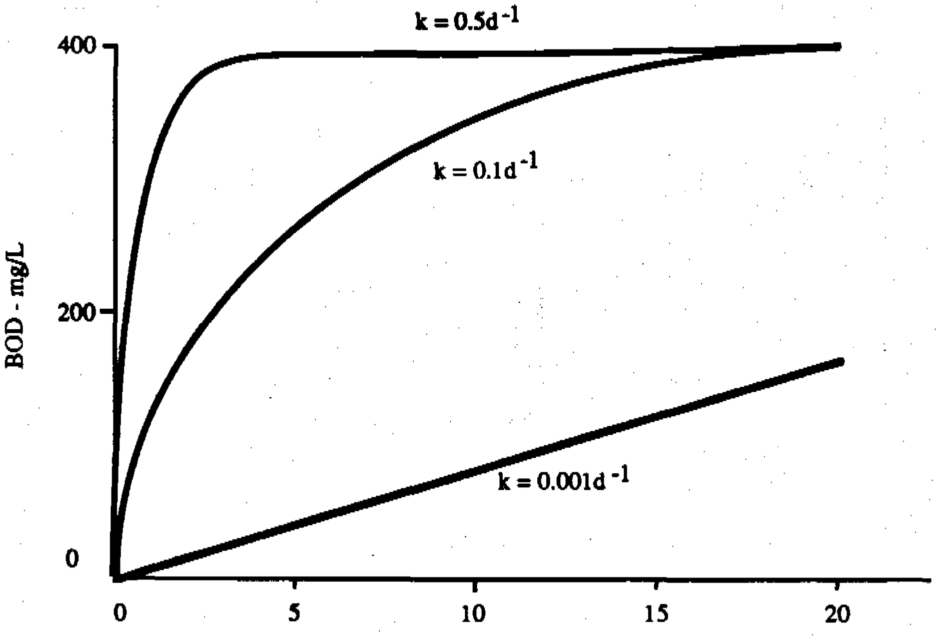

Fig. 1.3 BOD versus time for various rate constants

The initial BOD varies with temperature as follows

$$BOD_0^T = BOD_0^{20}(0.02T + 0.6) \qquad \text{... 1.12}$$

When a wastewater is discharged into a river or stream, the concentration of a pollutant below the mixing zone can be calculated from the equation

$$C = \frac{C_1.Q_1 + C_2.Q_2}{Q_1 + Q_2} \qquad \text{... 1.13}$$

where C = concentration in the combined flow,
Q_1 = quantity of flow in the receiving stream
C_1 = concentration of constituent in Q_1
Q_2 = quantity of wastewater discharge
C_2 = concentration of constituent in Q_2.

The polluting constituent can be of any type (BOD, DO, temperature, chemical, turbidity etc.)

1.3 DISSOLVED OXYGEN

When wastewaters are discharged into a watercourse, lake or sea, there will be a change in the quality of the receiving water. Waters of high organic content are not favourable for animals and plants so bacteria predominate. To prevent serious bacterial pollution it is essential that aerobic conditions be established or maintained. DO in the water, therefore, becomes of vital importance.

Oxygen is dissolved from the atmosphere at a rate which depends upon the saturation deficit, the agitation at the surface and the water temperature. Saturation concentration of DO reduces with increased temperature. Since the reaction rate varies directly with the oxygen deficit,

$$\frac{d(D_t)}{dt} = -K_2.D_t \qquad \text{... 1.14}$$

where D_t = the DO (or saturation) deficit at any time t
K_2 = reaeration constant (d^{-1}).

Integrating Eqn 1.14 we get

$$\frac{D_t}{D_0} = e^{-K_2.t} \qquad \text{... 1.15}$$

where D_0 = DO deficit at t = 0.

If C_0 = concentration of DO at time 0
C_s = saturation concentration of DO
C_t = concentration of DO at time t

then Eqn 1.15 can be written as

$$\log_e \frac{C_s - C_t}{C_s - C_0} = -K_2.t \qquad \text{...1.16}$$

1.4 DISSOLVED OXYGEN SAG CURVE

One of the earliest mathematical water quality models for rivers was developed by Streeter and Phelps (1925). This model is used to predict oxygen deficit in a river resulting from the input of a pollution load and is represented in Fig. 1.4. As soon as the BOD begins to be exerted, the DO falls below saturation and reaeration starts. With increasing saturation deficit, the rate of reaeration increases until a critical point is reached where the maximum DO deficit is reached and, as further time passes, the oxygen deficit will decrease.

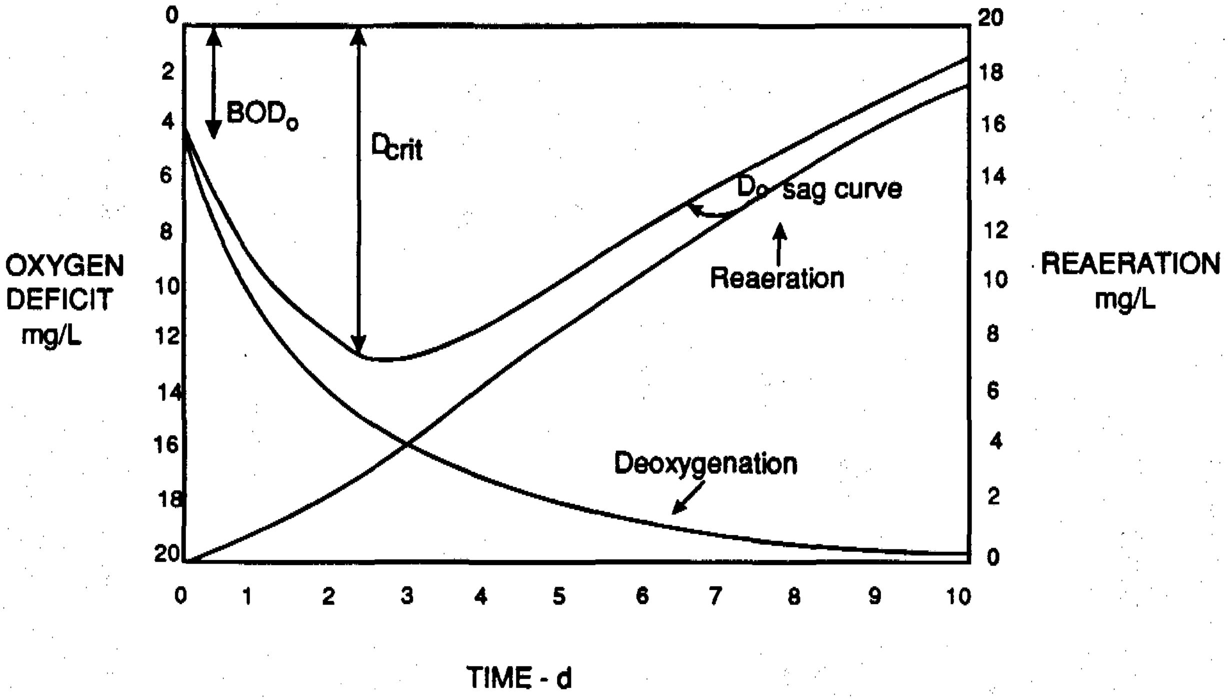

Fig. 1.4 Dissolved oxygen sag curve

Streeter and Phelps stated that the rate of change of DO deficit, D, is the difference between the rate of oxygen utilisation in the oxidation of organic matter and the rate of reaeration which replenishes oxygen from the atmosphere,

$$\text{i.e. } \frac{d(D_t)}{dt} = -K_1.BOD_t - (-K_2.D_t) \qquad \ldots 1.17$$

$$\text{but } \frac{BOD_t}{BOD_0} = e^{-K_1.t} \qquad \ldots 1.8$$

$$\text{so } \frac{d(D_t)}{dt} + K_2.D_t = K_1.BOD_0.e^{-K_1.t} \qquad \ldots 1.18$$

Solving Eqn 1.18 with appropriate boundary conditions results in

$$D_t = \frac{K_1.BOD_0}{K_2 - K_1}\left[e^{-K_1.t} - e^{-K_2.t}\right] + D_0.e^{-K_2.t} \qquad \ldots 1.19$$

where D_t and D_0 = DO deficits
K_1 and K_2= BOD and aeration rate constants
and the subscripts 0 and t are the days after contamination occurs.

At the critical point, $\frac{d(D_t)}{dt} = 0$

$$\text{so } D_{crit} = \frac{K_1}{K_2}.BOD_0.e^{-K_1.t_{crit}} \qquad \ldots 1.20$$

where t_{crit} is the critical time.

Substituting Eqn 1.20 in Eqn 1.19 we get

$$t_{crit} = \frac{1}{K_2 - K_1} \log_e\left\{\frac{K_2}{K_1}\left[1 - D_0 \frac{K_2 - K_1}{BOD_0.K_1}\right]\right\} \qquad \ldots 1.21$$

Eqns 1.19 and 1.21 are theoretically valid only when there is no change in dilution or pollution load in the reach between the point of input and the point of interest. This original Streeter-Phelps model is now considered over-simplified because it does not take into account the following phenomena

- dispersion of material making it less concentrated
- bottom deposits exerting an oxygen demand
- sedimentation of solid material lowering the oxygen demand
- addition of runoff material adding to the oxygen demand
- respiration and photosynthesis of green plants
- effects of ultra-violet radiation
- dilution by inflow or concentration by evaporation
- riffles, waterfalls etc. increasing oxygenation potential
- nitrification of ammonia resulting in an increased oxygen demand.

For a model to be complete, all the factors must be incorporated into the formulation unless specific conditions prevail whereby one or some factors may be neglected.

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WASTEWATER TREATMENT METHODS

2.1 WATER NEEDS

After air, a human's most basic physical need is potable water. If we supply water to a community, it follows that we must dispose of wastewater in a controlled manner to provide a healthy environment in which to live. Excretal contamination of drinking water leads to intestinal and other diseases such as cholera, typhoid and gastro-enteritis. These diseases are still prevalent in parts of South East Asia, Africa and Latin America. Today, gastro-enteritis is also common in developed countries like Australia, but this is mainly due to food contamination.

2.2 COMPOSITION OF SEWAGE

Sewage is the wastewater of a community. It may be purely domestic in origin or it may contain some industrial or agricultural wastewater. In combined sewers, washings from streets, roofs and yards are added. Some of the wastes are carried in suspension, others go into solution, others exist in the colloidal state.

Sewage contains

* faecal and urinous matter
* wash waters
* inorganic grits
* organisms
* trade effluents
* extraneous matter.

The specific gravity of sewage is very nearly equal to that of water since 99.9% of sewage is water so no modifications to hydraulic formulae are necessary in engineering calculations.

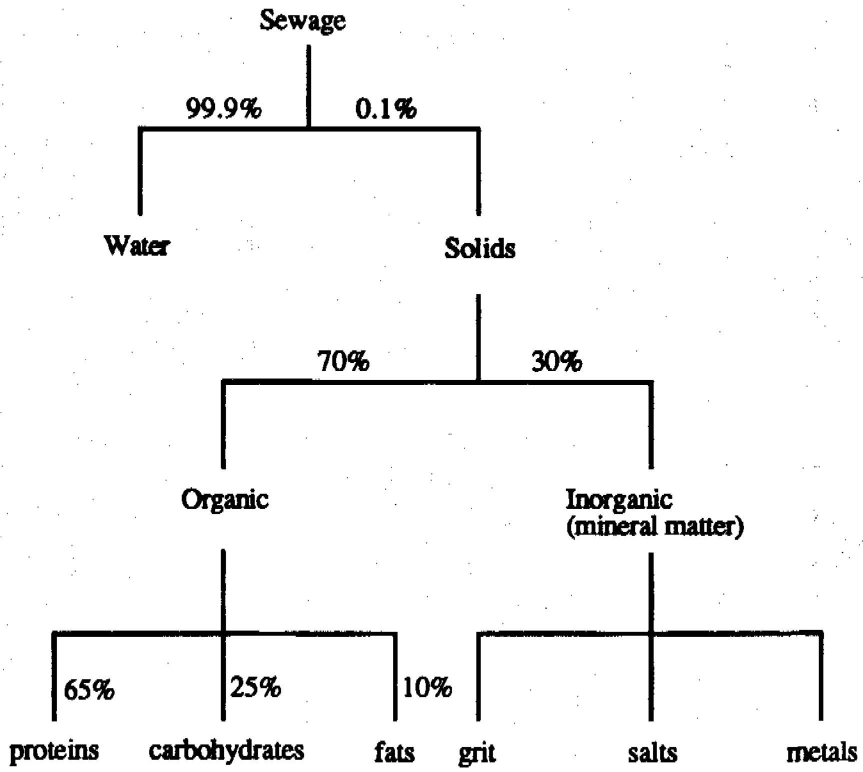


Fig. 2.1 Composition of sewage

The compounds, particularly proteins and carbohydrates, form an excellent diet for bacteria whose voracious appetite for food is exploited by environmental engineers in the biological treatment of sewage. Faeces (and sometimes urine) are a dangerous component of wastewater, not so much because of the items in Table 2.1, but because of the many millions of intestinal bacteria and smaller numbers of other organisms. The majority of these organisms are harmless – indeed some are beneficial – but an important minority is able to cause a wide range of human diseases.

Table 2.1 Composition of human excreta

ITEM	FAECES	URINE
Quantity (wet) - g/cap.d	135 - 270	1000 - 1300
Quantity (dry solids) - g/cap.d	35 - 70	50 - 70
Approximate composition	%	%
Moisture	66 - 80	93 - 96
Organic matter	88 - 97	65 - 85
Nitrogen	5.0 - 7.0	15 - 19
Phosphorus (as P_2O_5)	3.0 - 5.4	2.5 - 5.0
Potassium (as K_2O)	1.0 - 2.5	3.0 - 4.5
Carbon	44 - 55	11 - 17
Calcium (as CaO)	4.5	4.5 - 6.0

Sewage usually contains a wide variety of chemicals: detergents, soaps, fats and greases of various kinds, pesticides, anything in fact that goes down the kitchen sink and that includes such diverse items as

- sour milk
- vegetable peelings
- tea leaves and coffee grounds
- soil (arising from the preparation of vegetables)
- sand (used to clean cooking utensils)

Industrial wastewaters vary in composition with industrial operations. They can be heavily laden with organic or mineral matter, or with corrosive, poisonous, flammable or explosive substances. Some are so objectionable that they should not be admitted to the public sewerage system.

- Fats, lime, hair and fibres adhere to sewers and clog them.
- Acids and hydrogen sulfide destroy cement, concrete and metals.
- Hot wastes crack tile and masonry conduits.
- Poisonous chemicals disrupt biological treatment, kill useful aquatic life and endanger water supplies.
- Fertilising elements add to the eutrophication.
- Flammable or explosive liquors imperil the structures through which they flow.
- Toxic gases or vapours are hazardous to workmen and operators of sewage works, and occasionally also to householders.

If the concentration of waste matter in sewage is high, then it is said to be a strong sewage as judged by the 5-d biochemical oxygen demand. The strength of the sewage from a community is governed to a very large degree by its water consumption. In Australia where the water consumption is a high 350 to 450 L/cap.d, sewage strength is weak (BOD_5^{20} =140 to 200 mg/L); in tropical countries where the water consumption could be 40 to 100 L/cap.d, the sewage strength is likely to be strong (BOD_5^{20} =400 to 700 mg/L). The normal classification is

STRENGTH	BOD_5^{20} (mg/L)
Weak	<200
Medium	350
Strong	500
Very strong	>750

The other factor determining the strength of domestic sewage is the BOD produced per person per day; this also varies from country to country as a result of differences in wealth, diet and habits of the population.

Some figures which have been obtained for the daily per capita BOD_5^{20} contributions are

Kenya	23 g
Zambia	36 g
S.E. Asia	43 g
Rural France	24 - 34 g
India	30 - 45 g
Holland	45 - 54 g
U.S.A.	45 - 78 g
U.K.	50 - 59 g
Germany	60 - 70 g
Australia	50 - 100 g

A suitable design value for tropical developing countries is probably about 40 g/cap and for Australian conditions is about 70 g/cap.

Sewage should be treated before its ultimate disposal to a receiving water in order to

- reduce the spread of communicable diseases caused by pathogenic organisms in the sewage and
- to prevent the pollution of surface and ground water for other uses and users.

Sewage is conveyed in pipes, known as sewers, from places of production to its place of treatment and disposal. Except when sewage is treated in a septic tank which are situated close to the house from where the sewage originates, the pipework is usually considerable in quantity and cost.

In general, wastewater flow rates are quite similar to water demand rates, with two exceptions

- water used for lawns, shrubs, and gardens generally does not enter the sanitary sewer and
- when sewer pipes are located below the water table, substantial infiltration may occur resulting in a wet weather flow rate much higher than the dry weather flow.

Domestic dry weather flow is composed of the wastes from sinks, baths, showers, toilets, and other sources found in houses. Approximately 80% of the domestic water use becomes wastewater, but other sources (industrial discharges, infiltration etc.) often produce wastewater flow rates that are greater than the water use rates. The mean rate of flow in a sewer measured over a normal 24 hour period is termed the 'dry weather flow'.

Example

A population of 50 000 people using 400 L/cap.d in their dwellings and contributing an average BOD of 80 g/cap.d

Volume of sewage = $50\,000 \times 400 \times 10^{-3} = 20\,000\ m^3/d$

BOD = $50\,000 \times 80 = 4 \times 10^6$ g/d

Industrial wastewater, 150 m^3/d with BOD = 3000 g/m^3

BOD = $150 \times 3000 = 0.45 \times 10^6$ g/d

$$\text{BOD of mixture} = \frac{4 \times 10^6 + 0.45 \times 10^6}{20\,000 + 150} = 221\ mg/L$$

Typical wastewater flows from residential areas are given in Table 1.10 on page 23 of Tchobanoglous & Schroeder (1985).

2.3 SEWAGE TREATMENT METHODS

Conventional treatment is the term used to describe the standard method of sewage treatment used in many places, especially in temperate climates. It comprises of five different sections of treatment.

* preliminary treatment (i.e. removal of coarse material and grit)
* primary treatment (i.e. sedimentation)
* secondary treatment (i.e. biological)
* tertiary treatment (i.e. effluent polishing)
* sludge treatment and disposal.

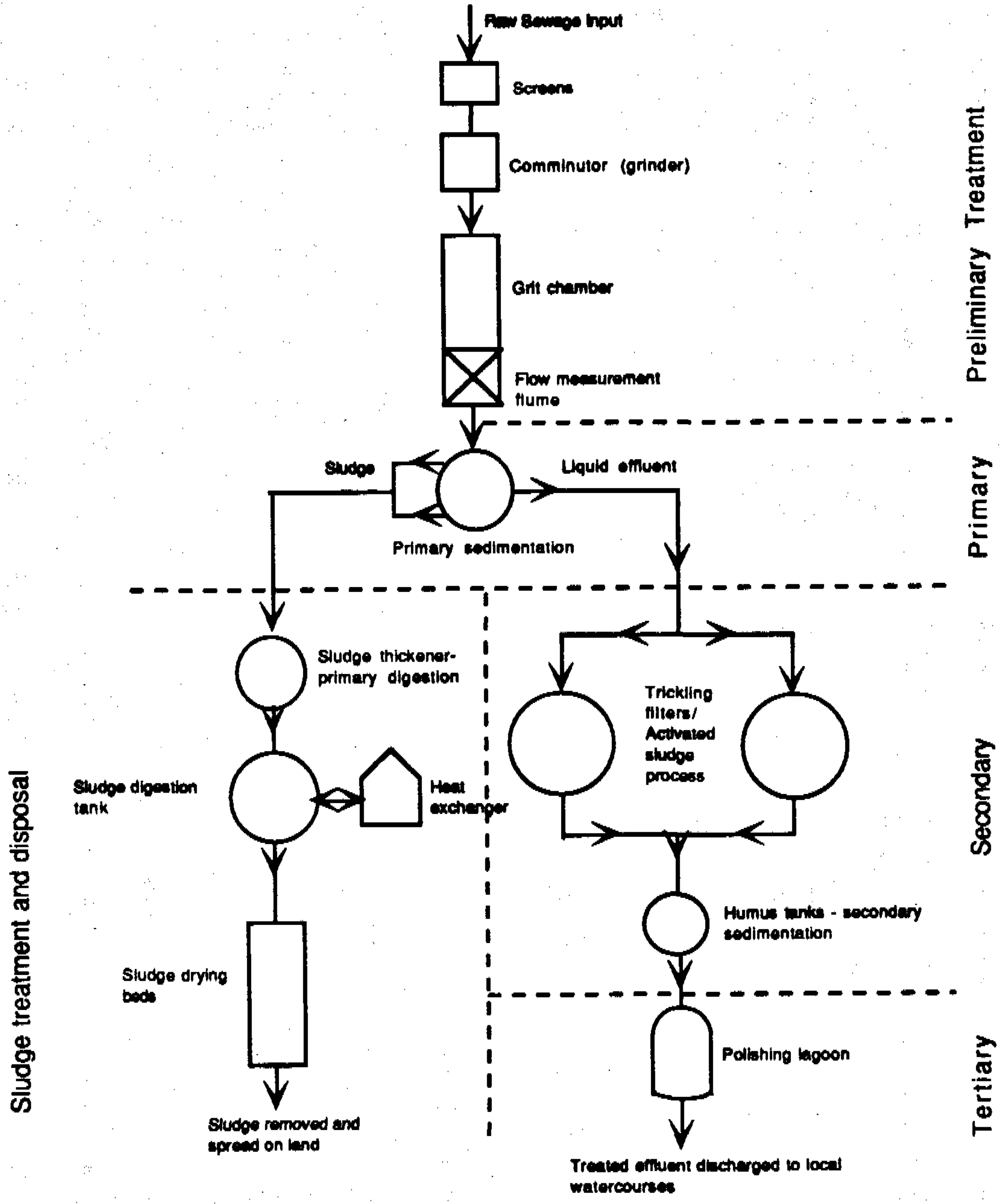


Fig. 2.2 Flow chart for typical sewage treatment plant

2.3.1 Screening

Raw wastewaters may contain gross extraneous suspended and floating matter which may damage or interfere with the operation of pumps and treatment plant equipment as well as choke small diameter pipes. Screens are usually installed at the inlets to wastewater treatment plants.

Coarse solids are removed by a series of closely spaced, mild steel bars placed across the flow. The velocity through the screen should be greater than 0.3 m/s in order to prevent deposition of grit but less than 1.0 m/s so that solids already trapped on the screen are not dislodged. The spacing between the bars is usually 20 to 50 mm and the can be of a number of shapes in cross-section.

At small works, screens are raked by hand and, in order to facilitate this, the screens are usually inclined at 60° to the horizontal. The submerged area of hand-raked screens is calculated on an empirical basis of 0.15 to 0.20 m^2 per 1000 people and this assumes that the screens are raked at least twice each day. A typical simple hand-raked screen is shown in Fig. 2.3 (a).

For flows greater than 200 m^3/d, mechanically cleaned screens are preferred since they can be cleaned more frequently. When the difference in water levels upstream and downstream of the screens (head loss) reaches a predetermined value, the automatic cleaning device is activated and screenings are removed. Screenings are disposed of either by burial or are macerated and returned to the sewage flow downstream of the screens. See Fig. 2.3(b).

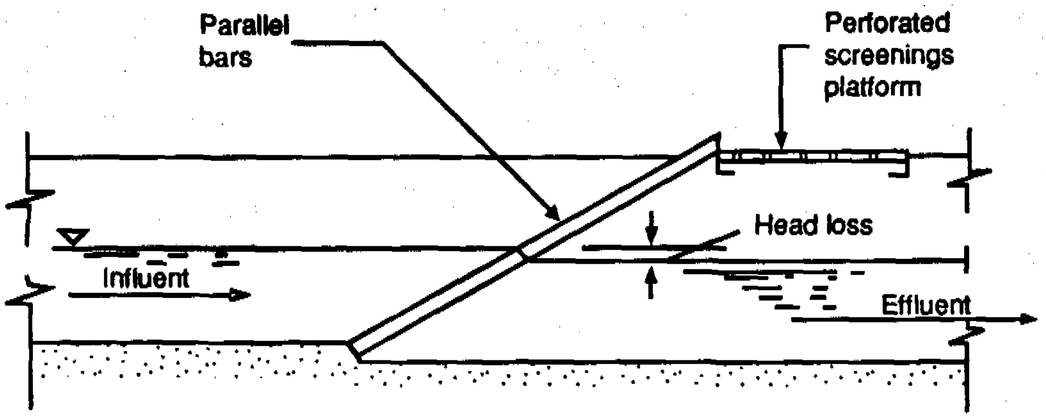


Fig. 2.3(a) Manually-raked bar screen
(from Barnes et al, 1981)

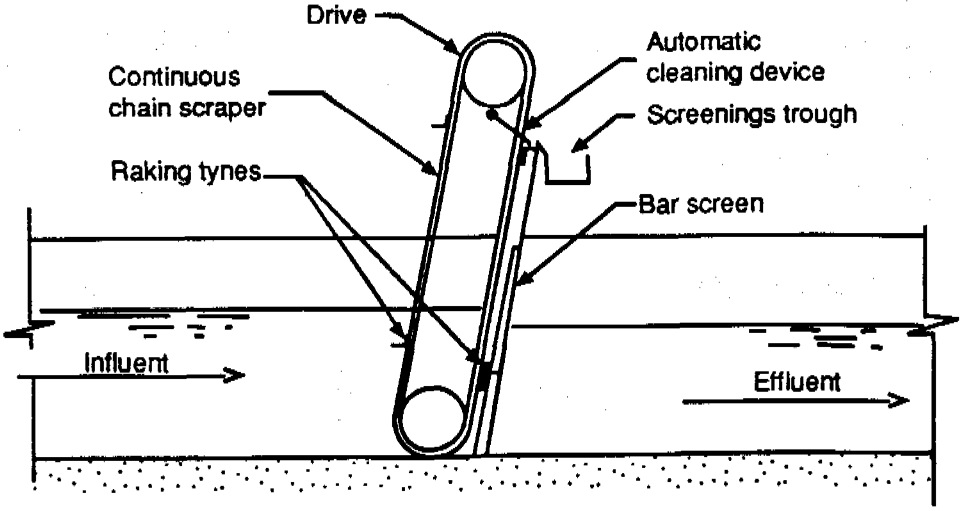


Fig. 2.3(b) Mechanically-raked bar screen
(from Barnes et al, 1981)

2.3.2 Comminution

An alternative to a mechanically-cleaned bar screen is the comminutor. It is a shredding machine which cuts up sewage solids as they pass. It consists of a hollow, cast iron drum which is continuously rotated about its vertical axis. The wastewater passes into the drum through slots and is discharged from the bottom of the unit. Comminutors are not suitable for fibrous sewage.

2.3.3 Grit Removal

Grit (detritus) is the heavy inorganic fraction of sewage solids consisting of sand, gravel and other solid materials that have specific gravities substantially greater than those of the putrescible organic solids. Grit removal is usually achieved by differential settlement in grit chambers, in which the flow velocity is controlled to 0.3 m/s (± 25%) so that the grit particles are removed while organic solids are retained in suspension. On the basis of the method used to control velocity, three main types of grit chamber may be identified

* constant velocity grit channels, in which longitudinal flow velocity is controlled hydraulically

* aerated grit chambers, in which a helical rolling motion is induced by the controlled introduction of air along one side of the chamber

* mechanically-stirred tanks in which rotary motion is produced by a system of paddles mounted on a vertical shaft in a cylindrical chamber.

2.3.4 Sedimentation

Basically sedimentation is the influence of gravity on suspended particles heavier than water, moving them downwards with a velocity which depends upon their size, shape, weight and frictional resistance, and the viscosity of water.

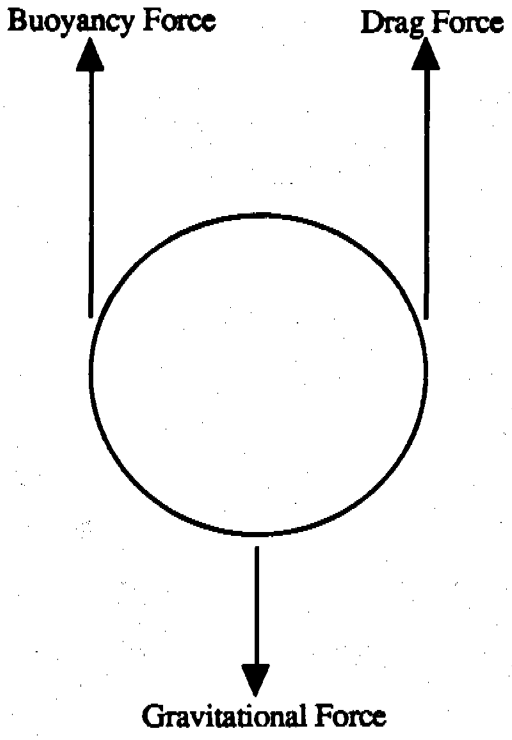


Fig. 2.4 Forces on a body falling through a fluid

Consider a spherical particle released just below the surface of a static body of water. As it is starting from rest, its initial velocity is zero, so the drag forces are initially zero. Once released, the particle will accelerate due to the dominance of the gravity force. As it accelerates, the drag force increases until it becomes equal to the gravity force less buoyancy force. The sum of the forces acting is now zero and, under these conditions, the particle will continue to fall at a constant (i.e. terminal) velocity,.

The resistance to motion of an idealised spherical particle in an infinite medium of liquid depends on diameter d, its settling velocity v_o, viscosity of the liquid η, the density of the liquid ρ_o and the shape which may be described by a dimensionless parameter S_p.

i.e. $R = f(d, v_p, \mu, \rho_o, S_p)$ ... 2.1

By dimensional analysis, Eqn 2.1 can be written as

$$f\left(\frac{R}{v_p^2 . \rho_o . d^2}, \frac{v_p . d}{\eta}, S_p\right) = 0 \qquad \text{... 2.2}$$

where $\eta = \dfrac{\mu}{\rho_o}$ = kinematic viscosity.

If $\frac{R}{v_p^2.\rho_o.d^2} = C_D$ = drag coefficient

and $\frac{v_p.d}{\eta} = R_e$ = Reynold's number.

then $R = f(C_D, R_e, S_p)$

The relationship between C_D and R_e is shown in Fig. 2.4. Values of C_D for non-spherical particles are higher than those for spheres. At low values of R_e, the graph gives a straight line and at higher values, the drag coefficient is almost independent of R_e.

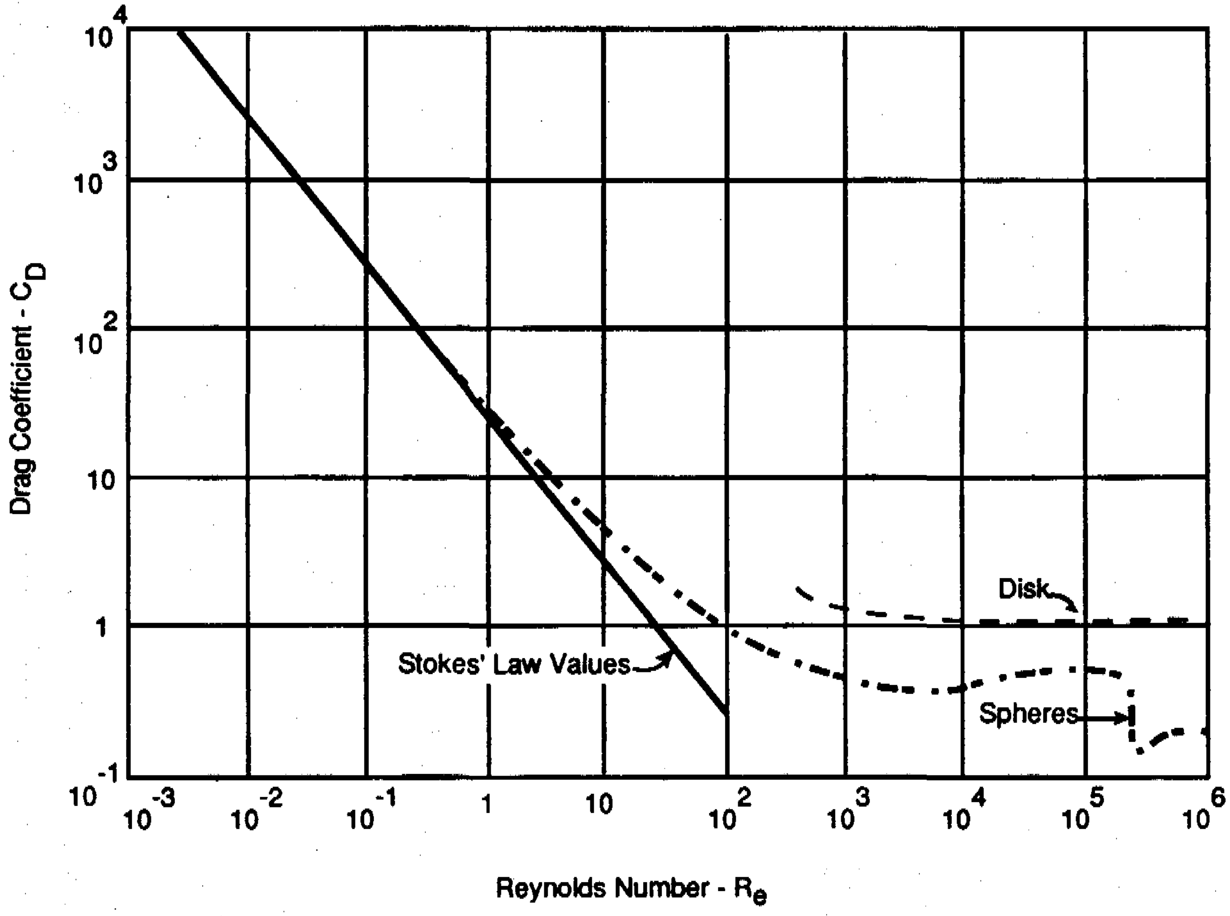


Fig. 2.4 Drag coefficient versus Reynold's number

From Fig. 2.4 it is seen that

$$\frac{R}{v_p^2.\rho.d^2} \propto \left[\frac{v_p.d}{\eta}\right]^{-1}$$

i.e. $R \propto \eta . v_p . d$

According to Stokes' law for spherical particles

$$R = 3\pi \, \mu . v_p . d \qquad \ldots 2.3$$

Gravitational force of attraction

$$(\rho_s - \rho_o) \, V.g \qquad \ldots 2.4$$

where ρ_s = density of the solid particle
V = volume of spherical particle

∴ from Eqns 2.3 and 2.4

$$v_p = \frac{1}{18\mu} (\rho_s - \rho) \, d^2 \qquad \ldots 2.5$$

Eqn 2.5 is a statement of Stokes' law for a sphere falling through an infinite viscous fluid ($R_e < 1.0$) and $C_D = \frac{24}{R_e}$

2.3.4.1 Classes of Suspended Solids

Suspended solids entering a sedimentation tank may be divided into two classes of particles (or floccules)

* those which maintain their individuality, hence terminal velocity, throughout the settling period
* those which continue to coagulate or flocculate during settling so that their terminal velocities vary during sedimentation.

2.3.4.2 Settling in an Ideal Sedimentation Tank.

The following assumptions are applicable

* the direction of flow is horizontal
* the velocity is uniform in all parts of the settling zone
* the concentration of suspended particles of each size is uniform in all parts of the settling zone
* solids entering the sludge zone are not re-suspended.

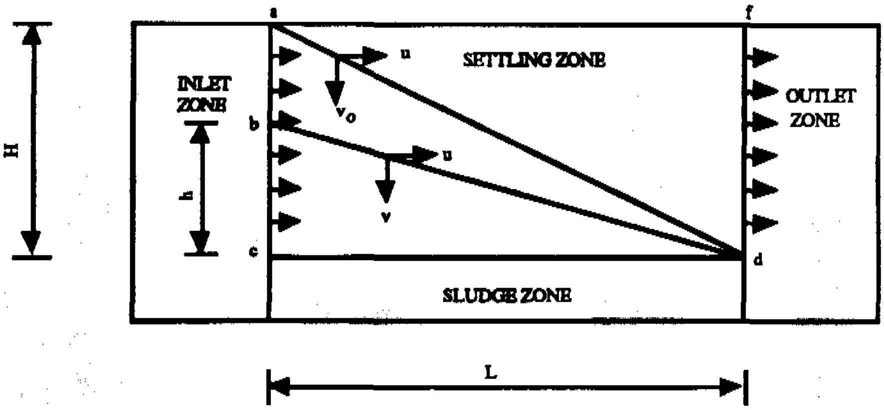


Fig. 2.5 The ideal sedimentation basin (longitudinal section)

Consider a discrete particle with settling velocity v_0 which just enters the sludge zone at the downstream end of the tank.
v_0 = settling velocity of particle which strikes the base of the tank in a time equal to the retention period of the tank.

This particle falls through a depth H in a retention time T of the tank

$$\text{so } v_p = \frac{H}{T} \qquad \text{... 2.6}$$

$$\text{but } T = \frac{\text{volume of tank}}{\text{flow per unit time}} = \frac{V}{Q} \qquad \text{... 2.7}$$

and, where A = surface area of the tank,

$$v_p = \frac{H.Q}{V} = \frac{H.Q}{A.H} = \frac{Q}{A} \qquad \text{... 2.8}$$

which is the surface overflow rate. Settling, therefore, is theoretically independent of depth.

The paths traced by discrete particles entering the settling zone is the line 'ad' in Fig. 2.5 and which is determined by the vector sum of the settling velocity of the particle and the mean velocity of flow. Any particles having a settling velocity greater than or equal to v_0 are completely removed but particles having a velocity less than v will not settle to the bottom if they enter the tank above the point 'b'.

The removal ratio of particles with settling velocity v is given by

$$\frac{v}{v_0} = \frac{bc}{ac} = \frac{h}{H} = \frac{v}{\frac{Q}{A}} = \frac{BLV}{Q} \qquad \text{... 2.9}$$

where B = breadth of the tank and L = its length.

Camp (1946) showed that size-weight composition of a suspension could be expressed in terms of frequency distribution of the settling velocities of the particles. A sample is mixed to have an initially uniform concentration then the concentration of particles is measured before and during quiescent settling in a tall cylinder from which samples are drawn at different time intervals from different depths. The settling velocity of the particles in each sample is calculated by dividing the depth of the sampling point by the time elapsed from the beginning of the test. The concentration of each sample is recorded as the ratio of the measured concentration to the initial concentration.

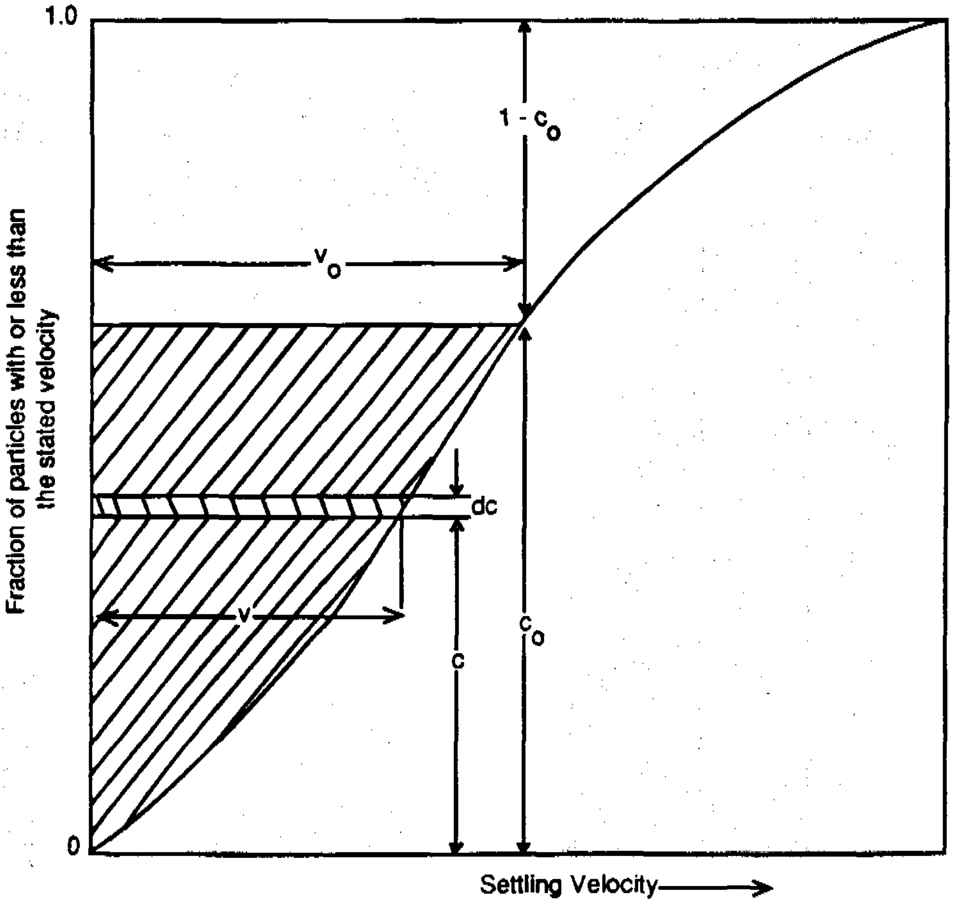


Fig. 2.6 Settling velocity curve of suspension of discrete particles

v_o = surface overflow rate
c_o = fraction of particles settling at v_o or less
$1 - c_o$ = fraction of particles with velocities $\geq v_o$ which are completely removed
c = fraction of particles settling at v or less
r = removal ratio
v = settling velocity of particle

$\therefore$ removal ratio of particles having settling velocity $v < v_o$ is given by

$$r = \frac{v}{v_0} \qquad \text{... 2.10}$$

If the fraction representing these particles is dc, then removal in terms of total suspension is

$$r.dc = \frac{v}{v_0}dc \qquad \text{... 2.11}$$

∴ total removal of all particles is given by

$$R = (1 - c_0) + \frac{1}{v_0} \int_0^{c_0} v.dc \qquad \text{... 2.12}$$

where $\int_0^{c_0} v.dc$ = shaded area to the left of curve in Fig. 2.6.

Primary clarification involves a relatively long period of quiescence in a 2.5 to 4.5 m deep tank where most of the settleable solids are removed by gravity. The primary sedimentation tank is designed according to surface loading and retention time. Efficiently designed and operated primary classifiers should remove 50 to 60 % of total suspended solids and 25 to 40 % of BOD_5.

2.3.4.3 Tilted Plates or Tube Settlers

Tube and plate settlers are sedimentation units designed to follow ideal theory more closely. If the tank is designed to remove all particles with settling velocity $\geq v_0$, particles with settling velocity $v<v_0$ will only be removed if they enter the tank at a distance from the bottom not greater than h as shown before in 2.3.4.2. By inserting a series of trays in the tank, it would be theoretically possible to remove all particles with settling velocities $\leq v_0$. Constructed of bundles of tubes or plates set at selected angles to the horizontal, these settlers have a very short settling distance, and circulation is damped because of the small size of the tubes. Typical tube sizes are 25 to 50 mm diameter.

2.3.5 Biological Treatment

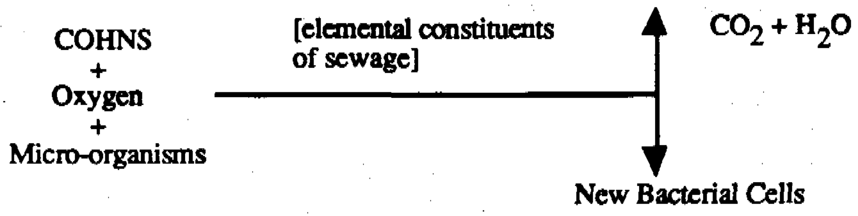
Biological processes are used to convert the finely divided and dissolved organic matter in wastewater into flocculent, settleable solids that can be removed in secondary sedimentation tanks. Bacteria are the primary degraders of organic wastes so aerobic biological oxidation and anaerobic digestion are two microbiological treatment processes used in one form or another. Biological purification of sewage is a natural process in the presence of air and bacteria. The changes associated with the process are

* Coagulation – coagulation and flocculation of colloidal solids into larger particles

* Oxidation – the following subsidiary actions take place

  - carbon to carbon dioxide, carbonates and bicarbonates.
  - hydrogen to water
  - nitrogen to ammonia, nitrous and nitric acids
  - sulphur to sulphuric acid
  - phosphorus to phosphoric acid.

To summarise in diagrammatic form



* Nitrification – ammonia is oxidised to nitrite and eventually to nitrate.

Successful biological treatment depends on the development and maintenance of an appropriate, active, mixed microbial population in the system. This microbial population may be present either as a fixed film attached to some form of support medium (in the trickling filter and rotating biological filter processes) or as a suspended growth (in activated sludge processes and anaerobic digestion). In each of these treatment systems, organic waste matter is used as a food source by the microbial population, In their life processes, these micro-organisms use some of the organic matter in order to synthesise new cell material, and they obtain the energy for their synthesis and cell maintenance functions by degrading some of the organic matter to simple compounds. Biological growth, therefore, involves both cell synthesis and biodegradation processes.

2.3.5.1 The Biological Growth Curve

The growth of a batch culture of micro-organisms utilising a substrate such as organic carbon is shown in Fig. 2.7. Initially, when the food supply is present in excess, the organisms grow at a rate controlled by their inherent metabolic rate, and the organisms increase logarithmically.

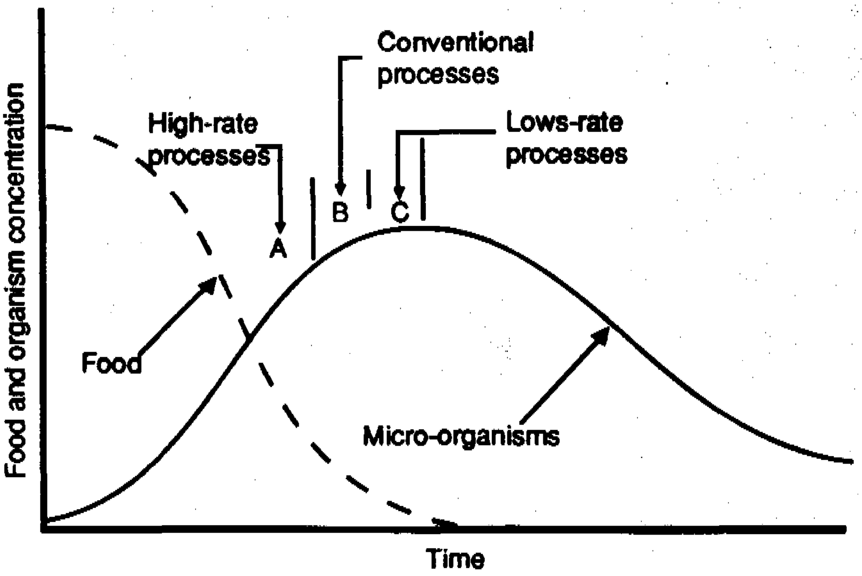


Fig. 2.7 The batch biological growth curve showing typical ranges of operating points for continuous biological treatment processes

The rapid growth phase is followed by a declining growth phase during which shortage of available food begins to limit the rate of organism growth until at some point, approaching depletion of the food supply, the mass of organisms present reaches a maximum. Thereafter, as cells die and are used as a food source by those which remain, the total cell mass declines in the process of endogenous respiration.

One implication of the growth curve in Fig 2.7 is that, in the declining growth phase, the rate of organism growth at any time is a function of the food concentration. It should be noted, however, that practical biological wastewater treatment processes are continuous rather than batch operations, and may be represented, on average, as a single point on the batch growth curve. Each of these operating points is evidently characterised by a particular value of both micro-organism concentration and food concentration. A convenient measure of the organic loading rate in a biological process can be expressed as a ratio, known as the food-to-micro-organism ratio (F/M) which is defined as

$$F/M = \frac{\text{mass of substrate consumed in reactor per day}}{\text{mass of micro-organisms in reactor}}$$

Another very important observation, not readily apparent from Fig. 2.7, is that not only does the rate of organism growth decline as food supply becomes growth limiting, but the net yield of organism mass per unit mass of substrate utilised also declines. Hence the lower the F/M ratio, the greater will be the proportion of the substrate degraded to supply the energy requirements of the cell, and the lower the rate of accumulation of biological solids in the system. It is not feasible to operate practical biological processes to produce zero net growth of biological solids, because a certain proportion of cell material is always relatively resistant to further degradation. This means that as cells grow and in turn die and are used as food by other organisms, these poorly-degradable cell residues will accumulate. Consequently, practical biological treatment systems must be provided with means for withdrawing and disposing of the net mass increase in biological solids.

From these observations, it is possible to develop another process parameter which is of value in the design and operation of many biological treatment systems – sludge age (θ_c), also known as mean cell residence time (MCRT) or solids retention time (SRT). This may be defined as the average time a mass of cells remains in a biological treatment system before being withdrawn in the waste solids stream. If the total mass of biological solids in the system is represented by $[X]_T$, and the daily increase in solids mass which occurs as a result of growth by $[\Delta X]_T$, then θ_c is given by

$$\theta_c = \frac{[X]_T}{[\Delta X]_T} \text{ d}$$

if $[X]_T$ is in kg and $[\Delta X]_T$ is in kg/d.

Practical biological treatment processes are often conveniently divided into high-rate, conventional and low-rate processes on the basis of their F/M ratio, shown qualitatively on the batch growth curve in Fig 2.7 as regions A, B and C respectively. High rate processes are characterised by high growth rates and high values of F (1.0 or more). Conversely, low rate processes have low values of F (less than 0.1), low growth rates and relatively low rates of solids accumulation. Conventional processes usually fall in the range of F = 0.2 to 0.5 and have moderate rates of growth and solids accumulation.

2.3.5.2 Trickling Filters

The trickling filter (also known as the percolating filter, the biological filter or the bacteria bed) is a circular or rectangular bed of coarse aggregate (40 to 100 mm grading) usually 1.8 to 2.5 m deep.

In principle, the trickling filter process is one in which the biological growth is attached to a non-moving medium. Sludge recycling is generally not required. Soon after a filter is placed into operation the surface of the media becomes coated with a jelly-likesubstance (called zoogleal slime) containing bacteria, protozoa and fungi. Organic removal occurs by absorption and assimilation by the biota of soluble and suspended constituents. Oxygen for the aerobic biological metabolism is supplied from the circulation of air and from the dissolved oxygen in the wastewater.

Influent is pumped up a vertical riser to the rotary distributor for spreading uniformly over the filter surface. Bed under-drains carry away the effluent and permit circulation of air. In the filter bed

top layer	–	flocculation under the influence of aerobic bacteria
middle layer	–	the organisms oxidise the organic matter
bottom layer	–	nitrification.

For a photographic description of trickling filter, see page 622 of Tchobanoglous & Schroeder (1985).

Recirculation

Recirculation of the final effluent can increase the capacity of a filter and makes it possible to dose a filter about 2 to 3 times the rate of simple primary sedimentation tank effluent. Usually the rate of recirculation is adjusted so that the strength of the mixture when applied to the filter is well below the normal BOD of settled sewage.

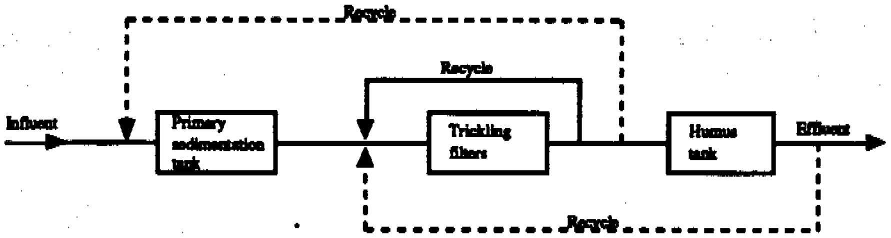


Fig. 2.8 Different recirculation arrangements for a single-stage filter

BOD loading on a trickling filter is calculated using the raw BOD in the primary effluent applied to the filter, without regard to any BOD contribution in the recirculated flow from the final clarifier.

$$\text{BOD load} = \frac{\text{Q x settled wastewater BOD}}{\text{volume of the filter media}} \qquad \text{... 2.13}$$

where BOD load = applied BOD (g/m^3.d)
settled BOD = wastewater BOD remaining after primary settling (mg/L)

volume of filter media = volume of rack material (m^3)

$$\text{Recirculation ratio } R = \frac{Q_R}{Q} \qquad \text{... 2.14}$$

where Q = raw wastewater flow (m^3/d)
Q_R = recirculation flow (m^3/d)

$$\text{Hydraulic load} = \frac{Q + Q_R}{A} \ m^3/m^2.d \qquad \text{... 2.15}$$

where A = surface area of the filters (m^2)

BOD Removal Efficiency

Several mathematical models have been developed for calculating BOD removal efficiency of biological filters based on factors such as depth of bed, type of medium, temperature and recirculation. The National Research Council, U.S.A. (NRC) models for trickling filter performance are empirical expressions developed from an extensive study of the operating records of trickling filter plants at military installations. The formula is applicable to single stage and multi-stage systems with different recirculation rates.

For a single stage (filter) or first stage filter the model is given by

$$E_1 = \frac{100}{1 + 0.014\sqrt{\frac{BOD_{load\ 1}}{F}}} \quad \text{... 2.16}$$

where $F = \frac{1 + R}{(1 + 0.1R)^2}$ = recirculation factor.

$BOD_{load\ 1}$ = BOD loading to 1st stage filter in $g/m^3.d$
R = recirculation ratio
E_1 = percentage efficiency of BOD removal including recirculation and sedimentation.

For a second stage filter,

$$E_2 = \frac{100}{1 + \frac{0.014}{1 - E_1}\sqrt{\frac{BOD_{load\ 2}}{F}}} \quad \text{... 2.17}$$

where E_2 = percentage efficiency of BOD removal for 2nd stage filter including recirculation and settling
$BOD_{load\ 2}$ = BOD loading to 2nd stage filter in $g/m^3.d$

2.3.5.3 Activated Sludge Process

Whenever a wastewater is aerated for a period of time, the mass of organic matter is reduced and a flocculent sludge is simultaneously formed. This sludge is micro-organisms, both active and dead, suspended in a colloid with dissolved organic and inorganic materials. 75 years ago it was found that introducing this (activated) sludge into untreated or settled wastewater accelerated the breakdown process.

The wastewater plus 20 to 50 percent of its own volume of activated sludge enters an aeration tank where the organisms and wastewater are mixed together with a large quantity of air. The organisms oxidise a portion of the waste organic matter to carbon dioxide and water and convert the other portion to new cells. The mixture then enters a settling tank where the flocculated matter settles and is removed, some to be recycled to the inlet of the aeration tank and the majority to be disposed with the sedimentation tank sludge.

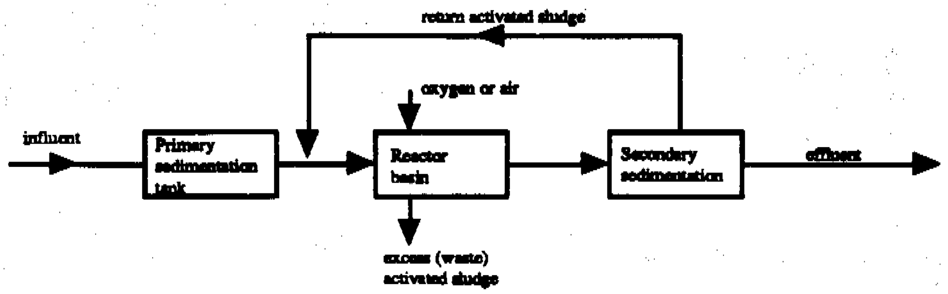


Fig. 2.9 Typical activated sludge process

Aeration chambers are commonly 3 to 5 m deep, and about 6 m wide. Length depends on retention period, usually 4 to 8 hours. Mixed liquor (ML) is the concentration of micro-organisms in a reactor basin and the suspended solids in the mixed liquor (MLSS) vary from 2000 to 8000 mg/L. There are two basic methods of introducing air to the aeration tanks

* compressed air - aeration and mixing of the sludge and sewage are effected by injecting air into the bottom of the tank

* mechanical means - aeration of the sewage is effected by splashing at the surface, and disturbance of the sludge is produced by stirring.

Dissolved oxygen is usually maintained in the range 1 to 2 mg/L. The use of oxygen rather than air can increase treatment plant throughput cheaper than simple duplication of aeration tanks.

For sludge age calculations in this process, the solids in the sedimentation tank and effluent solids losses are dropped from the calculation for convenience and θ_c is taken as the length of the time micro-organisms are retained in the reactor basin.

Operation and Control

The operation of an activated sludge treatment plant involves regulating the

* rate of air supplied
* rate of activated sludge returned
* rate of sludge removed from the system.

The following tests are used to monitor the operation

* DO concentration in the mixed liquor
* influent and effluent BOD_5
* concentration of MLSS in the tank
* sludge volume index (SVI) and settleability of mixed liquor.

One of the common tests for monitoring the operations is the SVI and it is the volume (mL) occupied by 1 g of suspended solids after 30 mins of settling.

$$\mathrm{SVI} = \frac{\text{sludge volume after settling (mL/L)}}{\text{MLSS (mg/L)}} \times 1000$$

For good sludges, SVI is below 100. One with poor settling characteristics may have an SVI in the region 200. Greater than 200 indicates bulking of sludge and it is very light and difficult to settle.

Table 2.1 Activated Sludge Process Types and Loadings

Process Types	Loading		BOD_5 Removal	Aeration Time	MLSS
	F/M BOD kg/d / MLSS kg	SRT d	%	h	mg/L
Extended aeration	0.05	≥ 30	90+	16 - 24	2000 - 6000
Conventional	0.15 - 0.4	4 - 8	90 - 95	4 - 8	1500 - 4000
High rate	0.4 - 1.0	2 - 4	85 - 90	2 - 4	3000 - 5000
Modified aeration	1.5 - 3.0	< 1	60 - 75	0.5 - 2	500 - 1500

(from Water Pollution Control Federation)

- Extended aeration activated sludge plants serve populations generally of less than 20 000 people. Often no primary settling is provided.
- Conventional activated sludge plants are designed to remove CBOD. This system follows primary settling and is used on large plants for 100 000 persons or more.
- High rate activated sludge plants have short aeration times. Plant can produce high BOD removal but are more difficult to operate, being sensitive to wash-out of micro-organisms from the reactor basin.
- Modified aeration activated sludge plants are normally only used on a first stage in a multi-stage process.

Comparison of activated sludge process and trickling filter

The trickling filter has the following

* Advantages
  - low operating costs
  - little technical control needed
  - suitable for strong and difficult industrial wastes and fluctuation loading
  - produce small quantities of secondary sludge

* Disadvantages
  - high initial cost
  - large land area required
  - considerable nuisance from flies and odour
  - less efficient in cold weather

Activated sludge process has the following

* Advantages
  - low initial cost
  - works well in cold and wet weather
  - small areas of land adequate
  - no fly or odour nuisance
  - suspended solids low in final effluent

* Disadvantage
  - high operating costs
  - requires good standard of technical control
  - sensitive to shock loads of trade wastes
  - large quantities of secondary sludge

For BOD removal efficiencies of about 60%, it is usually found that the trickling filters are more economical than activated sludge process, in particular for small flow rates of wastewater. For higher BOD removal efficiencies (90% or more) the activated sludge process is more economical.

Supplement these notes with Chapter 14 of Tchobanoglous & Schroeder (1985).

2.3.6 Waste Stabilisation Ponds

Waste stabilisation by lagoons or oxidation ponds is most suitable for locations where land is inexpensive, organic loadings fluctuate, or there is a shortage of trained personnel. A stabilisation pond is a relatively shallow earthen basin open to air and sun. The decomposable organic wastes are stabilised by micro-organisms and the number of pathogens are reduced considerably, primarily due for the long retention period required for stabilisation. Treatment occurs through natural, physical, chemical and biological processes and no machinery or energy input is required.

Ponds may be designed to operate in single, in series or in parallel but it has been frequently observed that the effluent from a series of ponds is of better quality than that from a single pond of the same size. Aerobic conditions are maintained near the surface and sometimes throughout most of the depth of the pond. An anaerobic environment persists near the bottom where there will be always some settled organic matter.

2.3.6.1 General Principles

- Topography – For the sake of economy, advantage should be taken of topographical features to reduce the cost of constructing ponds. Investigations should, therefore, start with the selection of the most suitable site.
- Environmental factors – The choice of the type of pond and the location should be made in the light of possible environmental repercussions such as odour, mosquito breeding, flies etc.
- Pond arrangement – Since a single pond will generally not produce a satisfactory effluent, 3 or 4 ponds in series are normally recommended, depending on the quality of the waste to be treated and the quality of the effluent specified.

Operating water depths differ from 0.6 to 1.5 m with 0.9 m of freeboard. The minimum of 0.6 m depth is needed to prevent growth of rooted aquatic weeds but exceeding a depth of 1.5 m may cause excessive odours due to anaerobic conditions.

Usually the stabilisation ponds are facultative because of aerobic and anaerobic processes. Algae play an important role in the functioning of stabilisation ponds. The association between algae and bacteria in a facultative pond is shown in Fig. 2.10.

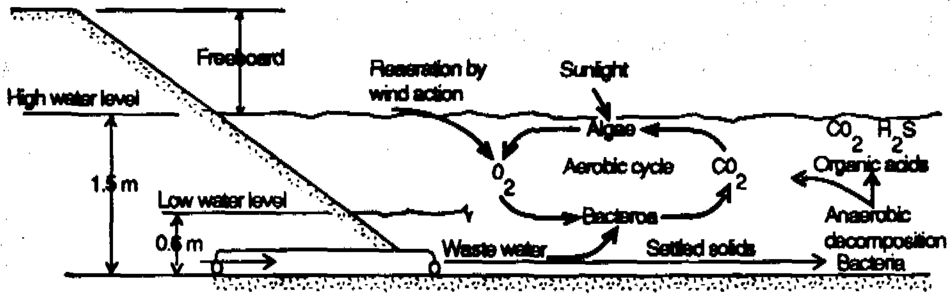


Fig. 2.10 Schematic of a facultative stabilisation pond

Organics in the wastewater are decomposed by bacteria yielding ammonia, phosphates and carbon dioxide. Algae use these compounds along with the energy from sunlight in photosynthesis, releasing oxygen into solution. This oxygen is then taken up by the bacteria thus closing the cycle.

2.3.6.2 Types Of Ponds

- Facultative ponds – depths 1 to 1.5 m.
- Maturation ponds – a second stage to facultative ponds and depth is taken as the same as that of associated facultative pond; mainly aerobic and their main function is the destruction of pathogens.
- Anaerobic ponds – a pre-treatment operation designed to receive such a high organic loading that they are completely devoid of oxygen; tremendous economies of land are achieved by the use of anaerobic ponds depths vary from 2 to 4 m.
- High-rate algal ponds – the basic design is a shallow channel with a water depth of 200 to 600 mm arranged in a race-rack configuration to minimise land use, and stirred by a paddle to keep algae and bacteria in suspension over retention periods from 2 to 6 d; these ponds are vulnerable to shock loads.
- Macrophyte ponds – A macrophyte pond is normally the same depth as a facultative pond and it can simultaneously facilitate secondary treatment and advanced treatment through the removal of organics, suspended solids, nitrogen, phosphorus and heavy metals.

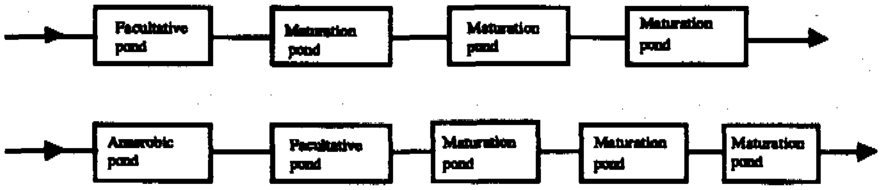


Fig. 2.11 Typical pond layouts

If the pond has vertical sides

$$Q = \frac{A \times D}{t}$$

where Q = volumetric flow rate (m^3/d)
A = surface area (m^2)
D = depth of the pond (m)
t = retention time (d)

$$\text{so } A = \frac{Q \times t}{D} \qquad \dots 2.18$$

Volumetric loading ($g/m^3.d$) is given by

$$\lambda_v = \frac{Q \times BOD_i}{D \times A} \qquad \ldots 2.19$$

where BOD_i is the influent BOD loading (g/m^3)

$$\lambda_v = \frac{BOD_i}{t} \qquad \ldots 2.20$$

$$\text{where } t = \frac{V}{Q} \qquad \ldots 2.21$$

In facultative ponds, λ_v is usually in the range 15 to 30 $g/m^3.d$ whereas in anaerobic ponds λ_v is greater than 100 $g/m^3.d$.

2.3.6.3 Design Of Facultative Ponds

It is assumed that these are completely-mixed reactors in which BOD_5 removal follows first-order kinetics.

The surface area

$$A = \frac{Q}{D.K_1}\left(\frac{BOD_i}{BOD_e} - 1\right) \qquad \ldots 2.22$$

For the pond contents to be aerobic, effluent BOD_e should be in the range 50 to 70 mg/L for pond depths of 1 to 1.5 m. The value of K_1 at any temperature T°C is given by

$$K_T = 0.3 \times 1.05^{T-20} \qquad \ldots 2.23$$

2.3.6.4 Design Of Maturation Ponds

The reduction of faecal bacteria in a pond has been found to follow first-order kinetics and for 'n' ponds in series

$$Ce = \frac{Ci}{(1 + K_T.t_1)\,(1 + K_T.t_2)\,\ldots(1 + K_T.t_n)} \qquad \ldots 2.24$$

where t_n = retention time in the n^{th} pond (d)
Ce = effluent faecal coliform concentration (no/100 mL)
Ci = influent faecal coliform concentration (no/100 mL)
K_T = first-order rate constant for faecal coliform removal
$= 2.6 \times 1.19^{T-20}$ (d^{-1})
n = number of ponds in series ... 2.25

2.3.7 Septic Tanks

A septic tank provides a primary stage of sewage purification and is intended to overflow. It is a watertight settling tank to which wastes are carried by water flushing down a short sewer. A septic tank does not dispose of wastes; it only helps to separate and digest the solid matter. The liquid effluent flowing out of the tank remains to be disposed of, normally by a soakage pit or drain field, and the sludge accumulation in the tank must be periodically removed.

Septic tanks may be a single-compartment receiving the effluent from cistern-flush toilets and all the household sullage. In double-compartment tanks the first compartment, which receives both types of wastewater, has twice the volume of the second. The total volume of the tank should be at least three times the average volume of water used daily. The conventionally designed septic tank works well in low-density areas (less than 100 cap/ha) where soil conditions are suitable, but at higher densities there is often insufficient space for adequate drain fields.

Experience has shown that in order to provide sufficiently quiescent conditions for effective sedimentation of the sewage solids, the liquid retention time should be at least 24 h and 'c' should be 40% of liquid depth.

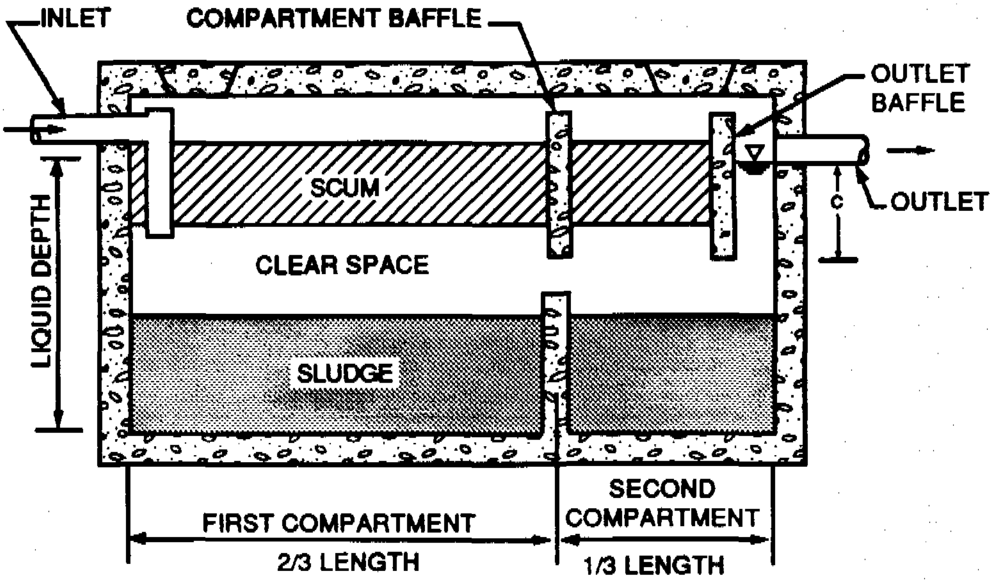


Fig. 2.12 Two compartment septic tank
(from Cotteral & Norris, 1969)

2.3.8 Sludge Treatment and Disposal

The principal end products of wastewater treatment are

- treatment plant effluents discharged to waters or soils
- sludges; because of their origin, water content and putrescibility most of them need to be processed prior to disposal to sea or land.

2.3.8.1 Characteristics and Types of Sludges

The characteristics of a sludge depend on

- its origin
- ageing that has taken place
- type of processing to which it has been subjected.

Sludge from primary sedimentation tanks is usually grey and slimy and in most cases has an offensive odour. It is not easily dried and contains pathogenic organisms but it can be readily digested under suitable conditions of operation.

Sludge from chemical precipitation tanks is usually black, has an objectionable odour but is not as bad as sludge from a primary sedimentation tank.

Activated sludge generally has a brown flocculent appearance. It is fresh, well aerated has a high water content and is gelatinous. It has a tendency to become septic rapidly.

Trickling filter humus is a brownish flocculent and relatively inoffensive when fresh. It generally undergoes decomposition more slowly than other undigested sludges.

Digested sludge is dark brown to black and contains exceptionally large quantities of gas. When thoroughly digested it is not offensive.

Grit is not offensive in spite of containing organic material.

Table 2.2 Solids generated from 580 ML/d inflow

TYPE	DRY SOLIDS t/d
Screenings	0.4
Grit	2.9
Scum	4.1
Primary sludge	128.0
Waste activated sludge	75.0

The problems of dealing with sludge are complicated because

- it is composed largely of the substances responsible for the offensive character of untreated sewage
- only a small part of the sludge is solid matter.

In disposing of sludge the aim is to reduce the water and organic content in it. It should be noted that a change of moisture content from 97 to 95% or from 95 to 90%, halves the quantity of sludge because it is the quantity of dry matter which remains constant.

2.3.8.2 Sludge Digestion

This is generally an anaerobic fermentation process. Anaerobic treatment involves the decomposition of organic and/or inorganic matter in the absence of molecular oxygen. The micro-organisms responsible of the decomposition of the organic matter are commonly divided into two groups.

The first group hydrolyses and ferments complex organic compounds to simple organic acids such as acetic and propionic acid. This group of micro-organisms consists of facultative and anaerobic bacteria, collectively called the acid formers.

The second group converts the organic acids formed by the first group to methane gas and carbon dioxide. The bacteria responsible for this conversion and strict anaerobes and are called methane formers.

The usual mode of operation of an anaerobic digestion unit is by the use of a complete-mix reactor system. During the anaerobic digestion process the organic matter is converted into CH_4 (65 to 70%), CO_2 (25 to 30%) and traces of N_2, H_2, H_2S and NH_3. Digestion is usually carried out within the mesophilic range between 33°C and 35°C. The high temperature thermophilic range (55 to 60°C) necessary to achieve adequate treatment is often listed as a disadvantage of the anaerobic digestion process but high temperatures are necessary only when sufficiently long mean cell residence times cannot be obtained at normal temperatures.

Conventional Design

Conventional (standard rate) sludge digestion is carried out as either a single-stage or two-stage process as shown in Figs 2.13 and 2.14 respectively.

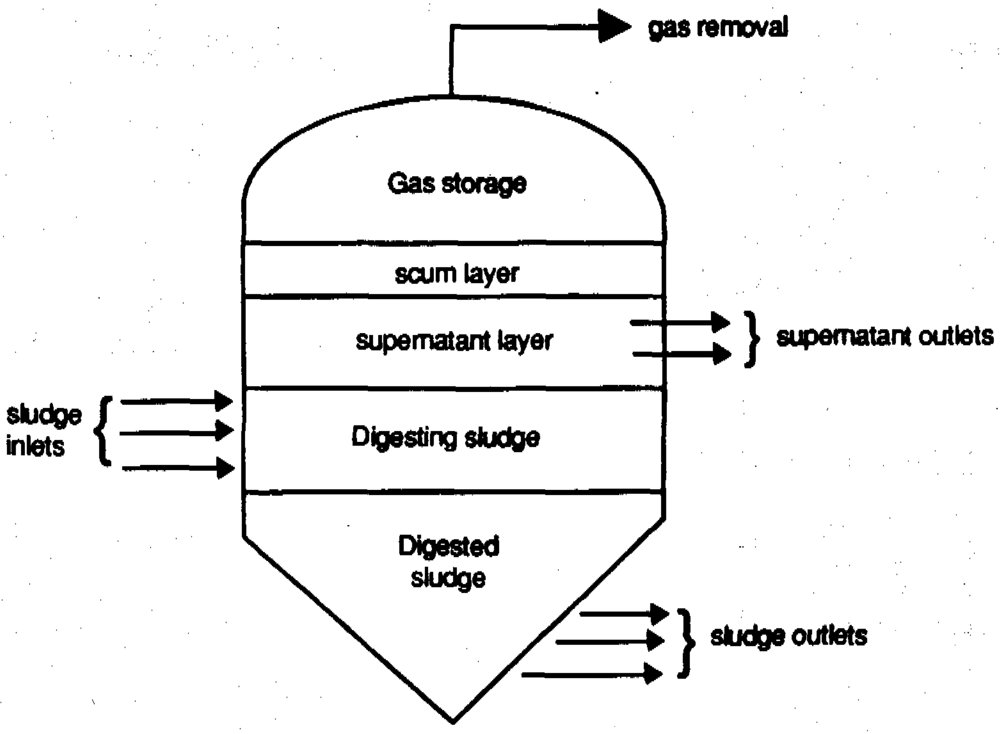


Fig. 2.13 Schematic diagram of a single-stage digester

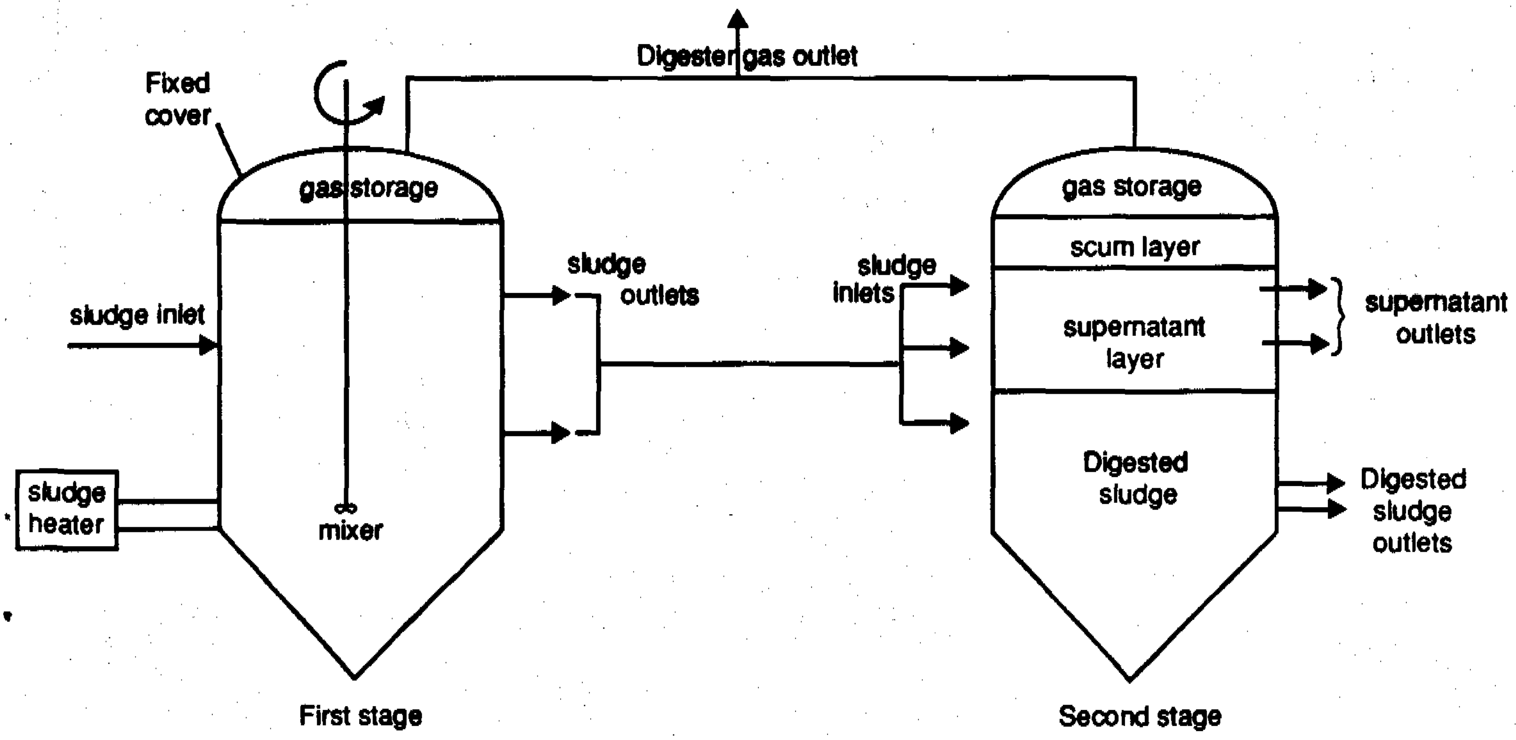


Fig. 2.14 Schematic diagram of a two-stage digester

The sludge is normally heated by means of coils located within the tanks or by an external heat exchanger. In the two-stage process the first tank is used for digestion. It is heated and equipped with mixing facilities. The most common method is to pre-heat the sludge and continuously circulate digester liquid from the digester to an external heat exchanger. The second tank is used for storage and concentration of digested sludge and for formation of a relatively clear supernatant.

2.3.8.3 Methods Of Disposal

- Land disposal – Formerly raw sewage was spread onto open land and allowed to dry; suitable for rural areas with scattered populations and no danger of water pollution.
- Trenching – Sludge poured into trenches which are then back-filled as new trenches are dug; simplest method for small works.
- Lagoons – Natural depressions improved by building up side banks simply to store sludge (and evaporate water).
- To sea – Normally digested sludge is transported in purpose-built vessels and dumped usually outside territorial waters.

Sludge Dewatering and Drying

Dewatering and drying are physical operations used to reduce the moisture content of sludge so that it can be handled as a semi-solid instead of a liquid. Methods commonly used for dewatering sludge include spreading on drying beds, vacuum filtration, centrifugation and pressure filtration. The choice of method depends on the characteristics of the sludge, the method of final disposal, the availability of land and economics.

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INTRODUCTION TO WATER QUALITY MODELLING AND SYSTEMS APPROACH TO MANAGEMENT

3.1 INTRODUCTION TO WATER QUALITY MODELLING

Basically modelling is a way of using some form of mathematical function to describe the relationships between a set of variables or natural processes. A model is only a tool which can be used to help in the solution of a problem. The ability of a model to represent a given phenomenon depends on how well the mathematical functions in the model describe the processes which control the event being predicted.

Under actual conditions, the physical, chemical and biological processes to be simulated by water quality models are generally subject to unexplainable, random variations. Models which incorporate this variability into their structure are termed **stochastic models**.

Because few data are available to describe the probability distributions associated with variations in water quality parameters, most models currently used are based on mean parameter values. These are termed **deterministic models**, and should be considered as producing results approximating average conditions.

In using a model of any type, one should have a thorough understanding of the process or processes to be simulated. A lack of understanding can result in arriving at a solution which has no real meaning. Because of the complex situation of the many relationships in water quality management studies, the models must generally be calibrated or verified using actual data. Calibration means testing a model against real data for a small number of events and verification generally means testing the model over the entire range of events or processes which the model might be designed to simulate.

Most of the systems of concern in water quality management have significant flow through. The actual systems vary from lakes, rivers and estuaries to treatment process units, but with few exceptions, all have continuous flow inputs and outputs and the material balance equation applies.

Rate of accumulation of mass within the system boundary = Rate of flow of mass into system boundary – Rate of flow of mass out of the system boundary + Rate of mass generation within the system boundary i.e. Accumulation = Inflow - Outflow + Generation

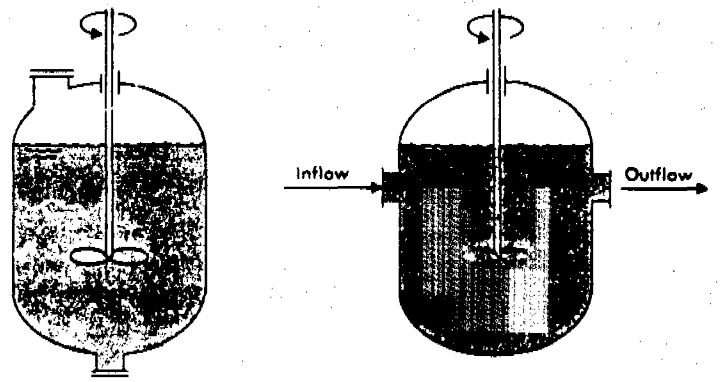
A number of approaches to the analysis of the systems are in use. Most of the approaches begin with two basic assumptions about the hydraulic characteristics of the systems.

- complete-mix model
- plug-flow model

These two ideal models are used to define a shell within which other models fall. In predicting hydraulic performance it is necessary to use models that have been developed to describe the hydraulic characteristics of reactors used to carry out chemical and biological reactions. The five principal reactor models used in water quality modelling are

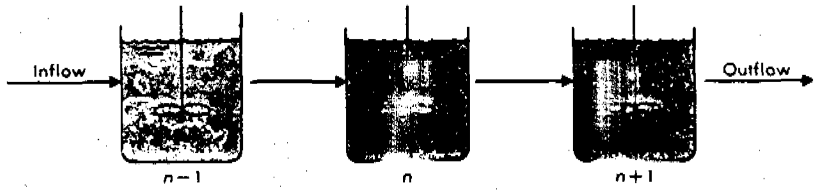
- batch reactor in which flow is neither entering nor leaving; sometimes used to model shallow lakes that are mixed completely.
- complete-mix reactor in which fluid particles that enter the reactor are instantaneously dispersed throughout the reactor volume; used to study lakes and reservoirs with continuous inputs and outputs. Also known as the continuous-flow stirred tank reactor (CFSTR).
- plug-flow reactor (PFR) in which fluid particles pass through the reactor and are discharged in the same sequence in which they entered the reactor after a time period equal to the theoretical retention time; used to study river and estuary systems.
- cascade of complete-mix reactors is used to model flow regimes between the complete-mix and plug-low types. If the cascade is composed of one reactor, the complete-mix flow regime results; if the cascade consists of an infinite number of reactors in series, the plug-flow regime results.

- packed-bed reactor which are filled with some type of packing medium; used to study the movement of water and contaminants in groundwater systems.



(a) Batch (b) CFSTR

(c) PFR



(d) Cascade

(e) Packed bed

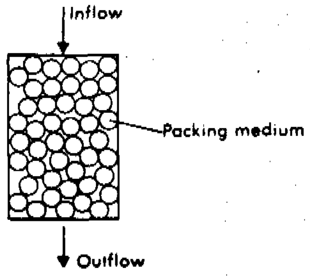


Fig. 3.1 The five reactor types
(from Tchobanoglous & Schroeder, 1985)

3.1.1 Dissolved Oxygen as a Parameter for Modelling

Dissolved oxygen is considered as the most significant parameter in water quality standards. In surface waters, presence of DO is desirable for

* aesthetic reasons
* reactions with other chemical constituents.

Sources of DO in surface waters are

* Atmospheric reaeration by transfer of oxygen from the gaseous phase in the atmosphere to the solution phase in water in contact with the atmosphere.

The rate of DO deficit is given by

$$\frac{dD}{dt} = -K_2.D \qquad \ldots 3.1$$

where D = saturation deficit
K_2 = reaeration constant

$$\text{Also, } D = C_s - C_t \qquad \ldots 3.2$$

where C_s = saturation concentration
C_t = concentration at any time t

* Photosynthesis by aquatic plants represents a significant source of DO to surface waters. Although many many types of aquatic plants contribute DO, algae are generally the most important in DO modelling applications. The photosynthesis reaction can be written

$$6CO_2 + 6H_2O \xrightarrow{\text{photosynthesis}} C_6H_{12}O_6 + 6O_2 \qquad \ldots 3.3$$

* DO from incoming tributaries or influents

Sinks of DO in surface waters are

* Carbonaceous biochemical oxygen demand (CBOD) from the oxidation of organic materials by micro-organisms.

The reaction is given by

$$\frac{d(C_t)}{dt} = -K_1.C_t \qquad \ldots 3.4$$

where C_t = oxygen demand at end of time t
K_1 = CBOD rate constant.

- Nitrogenous biochemical oxygen demand (NBOD) from the oxidation of reduced forms of nitrogen by micro-organisms.

$$\frac{d(N_t)}{dt} = - K_n.N_t$$

where N_t = NBOD demand at time t
K_n = NBOD deoxygenation rate constant

- Algal respiration consumes oxygen and produces carbon dioxide assumed to be a constant for a particular water body during the dark period and zero during the light period of the day.

- Benthic deposits contain organic matter, the decomposition of which depletes oxygen in the overlying water.

- Oxidation of reduced inorganic substances in addition to the biochemical oxidation of nitrogen. The ferous iron, while highly resistant to oxidation at low pH values, readily oxidised chemically to ferric at pH values typical of surface waters.

3.1.2 Modelling of Other Water Quality Parameters.

Model calibration and verification for water quality parameters other than DO is not easy. For example, modelling the behaviour of substances serving as biological nutrients (e.g. nitrogen and phosphorus compounds) requires expressions describing the chemical behaviour of the substances, the growth, synthesis, decay and other biological phenomena, and expressions describing physical phenomena such as the movement of the organisms. As another example, some factors affecting the concentration of various forms of nitrogen in a lake are

- extent of stratification
- oxygen availability
- algal photosynthesis
- bacterial nitrification
- settling rate of microbes.

3.1.3 Categories Of Water Quality Models

- Stream model
- Estuary model
- Lake/reservoir model

} These are for simulating the instream effects of constituents affecting water quality

- Diffuse source pollution model - used to describe the generation of pollutants washed off a given watershed into a receiving water system.

- Multiple function models - used to describe models which overlap in category. For example, by changing certain coefficients, some models can be used to simulate pollutant transport in several types of receiving water systems.

3.2 A SYSTEMS APPROACH TO WATER QUALITY MANAGEMENT

Water quality management planning requires a vast amount of data. For example, to determine the size of wastewater disposal facilities, existing and projected populations and land use patterns must be known. When dealing with a diffuse source of pollution or urban runoff, natural and artificial drainage patterns must be defined. Other information which may be useful is soil type, depth to bedrock and housing patterns. These data should be readily available for good water quality management.

3.2.1 Geographical Data

For a typical water quality management study dealing with point and diffuse sources of pollution, the following data would be needed

* land use
* soils data
* population
* elevation
* stream boundaries
* drainage basin boundaries
* streamflow data
* sewer service boundaries
* location of water supply intakes.

3.2.2 Potential Applications Of Systems Approach

The potential applications of the system approach lie in the data/model linkages and subsequent output. If the problem to be solved were the design of alternative sewer locations, data such as soil type, depth to bedrock and groundwater, population data, land use data, and elevation contours would be input to the model for a given route. Several routes could be evaluated with relative ease until the least cost or most feasible route were determined. If the problem to be solved were the impacts on water quality from non-point sources of pollution, land use patterns and their pollution generation potential could be easily varied for input to the proper model to give the decision maker an idea of the pollution impact of a decision he might make. The list of possible applications of the systems approach could go on, but the numerous possibilities should be obvious in light of the foregoing discussions. The point is that if large amounts of data must be manipulated and displayed in a water quality management study, the systems approach can simplify the process and can easily provide adequate information to the decision maker.

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WATER QUALITY MANAGEMENT AND LAND USE

4.1 INTRODUCTION

For a long time it was thought that rural areas were safe from the ill of water pollution, but it is evident that this is not the case. It is now well known that land use profoundly affects the quality of water in rivers, streams, lakes, reservoirs and shallow aquifers in both urban and country areas. Land use is one of the most basic and sensitive areas of resource management, and water quality problems are closely associated with the misuse of natural land resources. The main land uses which affect water quality are urban development, industries, agricultural activities, mining and quarrying. These contribute to point sources of pollution as well as diffuse sources of pollution and are shown in Fig. 4.1.

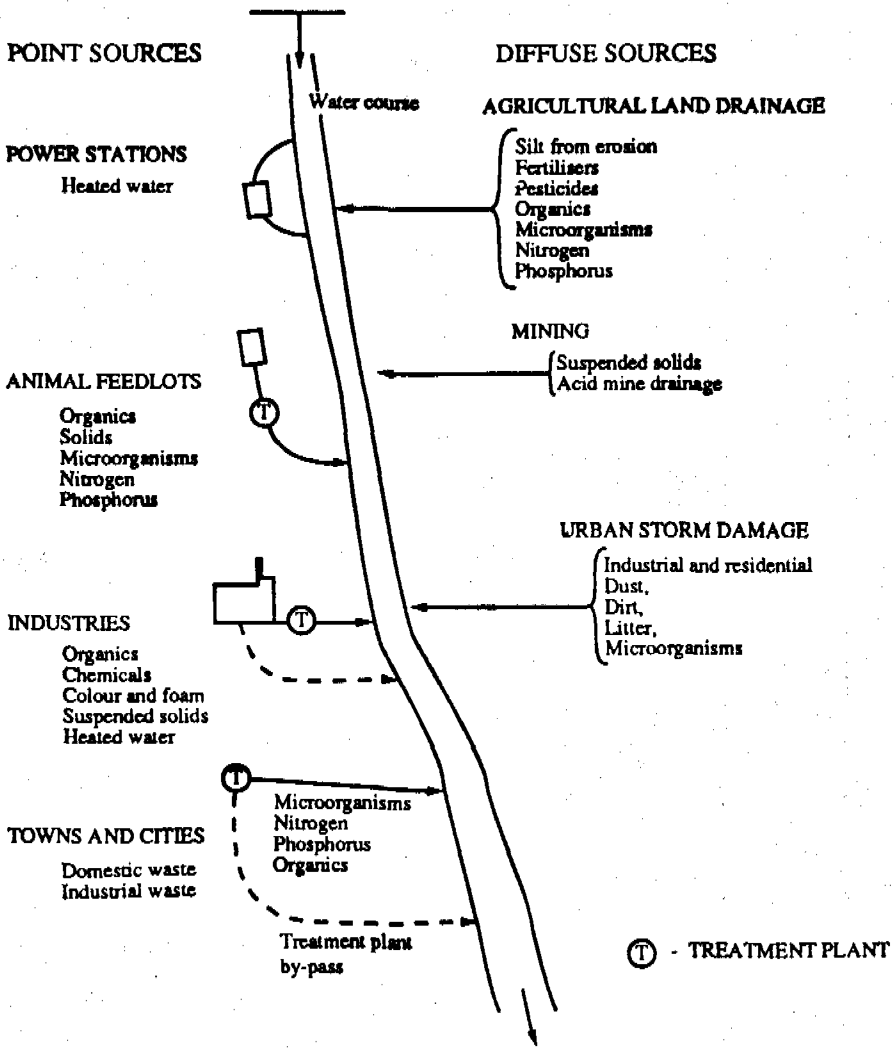

Fig 4.1 **Main sources of water pollution**

Point sources are those pollution inputs that are considered to have a specific point of discharge which is continuous or intermittent. Sewage outfalls and industrial discharges come under this category.

Surface runoff, on the other hand, causes diffuse sources of pollution whereby animal wastes, vegetable matter, residual herbicides, fungicides, insecticides, and nutrients such as nitrates and phosphates are collected from large areas of land and deposited into watercourses over long distances. Many large dams in country areas of New South Wales have catchments which contain agricultural and pastoral activities which contain diffuse sources of pollution.

The primary water quality problem of the organic loads is that they generate large biochemical oxygen demands when they enter the water bodies through surface runoff. High nutrient levels of water bodies stimulate the growth of algae and thereby accelerate this eutrophication process. Further, nitrates and other chemical residues can be toxic to human and other organisms at or above critical concentration. The characteristics of different wastes are give in Table 4.1.

Table 4.1 Waste Water Characteristics

Source	BOD mg/L	Total Nitrogen mg/L	Total Phosphorus mg/L
Untreated domestic sewage	100 - 400	30 - 40	5 - 15
Piggery liquid waste	2000 - 20 000	90 - 270	50 - 150
Dairy liquid waste	2000 - 4500	100 - 325	10 - 50
Beef feedlot #	400 - 500	100 - 150	10 - 40
Abattoir waste water	300 - 3000	40 - 140	10 - 20

BOD after passing through a sedimentation basin and holding pond.

Australian domestic water consumption varies between 350 and 400 L/cap.d and roughly 40 to 50% of this is returned to the sewage treatment system. Public concern about effluent quality is usually inversely proportion to the degree of treatment.

Experience indicates that obtaining direct relationships between various land uses and water quality problems is not easy for a variety of reasons such as

* significant variation in soil properties between various land uses
* watercourses usually collect material from widely dispersed land areas
* land areas drained by a common waterway always have mixed uses
* transportation of material from land areas to watercourses varies with local rainfall patterns.

4.2 WATER QUALITY PROBLEMS

One of the most destructive and most prevalent forms of pollution is the deoxygenation of water bodies by chemical or biological action. Raw sewage and effluents from food processing plants contain organic matter which contribute to this phenomenon. So, too, do inorganic materials like sulphur compounds from mines. Deoxygenation may result in the disappearance of the normal flora and fauna of the water bodies and the unwelcome appearance of algal blooms and toxic conditions.

Eutrophication is the process whereby reservoirs, lakes, rivers and streams become over-enriched with nutrients. In recent years the natural rate of eutrification has been accelerating as a consequence of increases in the human, agricultural and industrial activities. As nutrients increase in surface waters, reservoirs, lakes and rivers may become eutrophic. The first signs of this are usually blooms of blue-green algae seen as a greenish haze in the water. A number of control measures are available

* removal of aquatic weeds
* draining the hypolimnion in storages during periods of flooding so the impact of the poor quality water is reduced downstream by dilution
* diversion of nutrient-rich waste waters
* tertiary treatment of point sewage sources

No ready solution exists for diffuse sources of pollution except long-term changes in agricultural practices. Several temporary controls for algal blooms (artificial mixing, harvesting of algae, chemical use and flushing) have been used to reduce the nuisance effects in enriched water bodies. Eutrophication of surface waters will continue and is likely to increase as the human population, water use and agricultural activities rise. Compromises must therefore be made over the methods by which eutrophication is mitigated.

Soil erosion is the chief contributor of suspended solids in rivers, steams and reservoirs. The clouding of the water and the inability of organisms that depend on vision while hunting to find prey or avoid predators upsets the ecological balance. It also causes a reduction in the light needed by aquatic plants for photosynthesis.

Water can become toxic when it receives effluent from steel mills, paint factories and storage battery manufacturing plants. It has been claimed that some pesticides cause infertility. Further, common chlorine-based agricultural pesticides show build-up in the fatty tissues of higher animals and can also persist in the environment for years.

4.2.1 Agricultural Land Use

The potential impact of runoff from agricultural and other open space land uses on water quality is very high. Water pollution occurs by

- runoff to surface waters
- the infiltration of dissolved impurities to groundwater
- wind transport of particles to surface waters.

Catchment imperviousness has a great impact on runoff. For agricultural land uses, catchment imperviousness may vary between 5 and 40% depending on soil type, vegetation time of year and soil moisture condition.

Crop type strongly influences runoff. Row crops such as corn and soybeans allow the greatest runoff particularly where rows follows the direction of slope rather than the contours. Approximately 50% of the sediment reaching water bodies originates on cropland.

Runoff from agricultural land always contains nutrient concentrations much greater than that required for algal growth so, unless these flows are substantially diluted, streams and lakes receiving them are threatened with eutrophication. Typical values of the nitrogen and phosphorus concentrations in different sources are given in Table 4.2.

Table 4.2 Values of Nitrogen and Phosphorus from Different Sources

Source	Nitrogen mg/L	Phosphorus mg/L
Agricultural Land	1 - 70	0.05 - 1.1
Non-Agricultural Land	0.1 - 0.5	0.04 - 0.2
Farm Animal Waste	1000 - 3000	15 - 400
Urban Runoff	1 - 10	0.1 - 1.5
Rainfall	0.1 - 2.0	0.01 - 0.03

4.2.1.1 Pesticides

The use of pesticides in agricultural management has increased dramatically during the last two decades. The pesticide characteristics of most concern from a water quality management aspect are:

* toxicity to target and other organisms
* solubility in water
* residual effect in environment
* potential for biomagnification.

The most troublesome pesticides are those with a high level of toxicity, which dissolve effectively in water, are not degraded rapidly, and can accumulate in plant and animal tissue, thereby allowing biomagnification. As a group, chlorinated hydrocarbons (aldrin, chlordane, DDT, dieldrin, endrin, toxaphene etc.) match these characteristics.

The organo-phosphate pesticides are more easily degraded and are not susceptible to biomagnification and are only slightly more soluble than chlorinated hydrocarbons. Runoff is the most common mode of water resource contamination by pesticides. It moves either in solution or attached to soil particles.

4.2.2 Mining Areas

Mining may produce massive water quality problems for two basic reasons

* surface and subsurface patterns of natural drainage are often completely disrupted.
* greater exposure of water-soluble materials to water and oxygen than had existed prior to mining operation.

The most serious water quality impact of mining is generated by the oxidation of pyritic materials (iron disulfide) in the presence of water to form sulfuric acid, as well as iron and other salts. This acid drainage can arise from both surface and deep mines, from the mining of coal and from many metal mining operations.

4.2.2.1 Sediments

The two biggest sources are soils disturbed by surface mining and tailings dumps.

4.2.2 Groundwater Pollution

The sinking of deep shafts or opening of deep faces may cause serious disruptions of aquifers and groundwater flows. Such disruptions may allow polluted surface water, leachate from mine tailings or spoil banks or poorer quality waters from other aquifers enter better quality groundwaters.

4.3 DRYLAND SALINITY

Dryland salinity, which is also referred to as saline seepage, occurs on lands which are out-flow zones for saline water tables. It is caused by the clearing of native forests for agricultural and pastoral production and is not connected with irrigation.

Plants continuously remove water from the soil by transpiration. Trees have deeper, more extensive root systems to extract water form the ground than do grasses or crops such as wheat or oats. When the trees are removed and replaced by grasses or crops, less water is used by the plants so the water table rises.

As the water table rises, salts which occur naturally in the soil and rock are dissolved and brought closer to the surface. Where the water table intercepts the ground surface, usually on footslopes and in drainage depressions, saline seepages develop. Salts become concentrated by evaporation, causing the death of the existing vegetation and formation of bare areas, which usually erode, aggravated by the trampling of stock licking the salt.

Dryland salinity in the New England seems to be less a function of tree clearing and the offending soil chemical seems to be alkaline.

4.3.1 Findings

Saline seepages occur mainly in the south-east of NSW in the Canberra-Yass-Boorowa-Crookwell district. Other significant areas are the Hunter Valley from Cessnock to Muswellbrook, the Macquarie Valley with the largest outbreaks in the Mudgee-Gulgong district and the Braidwood-Bungonia area. Increasing incidences are reported on cropping lands in the Young, Cootamundra and Inverell districts.

4.3.2 Treatments

Recommended treatments include

- fencing off salt outbreaks
- reducing stocking rates or totally excluding stock
- using salt-tolerant grassed, herbs, shrubs and trees on the saline areas
- surface mulching, using old meadow hay or straw
- surface tillage or deep ripping of the site to assist plant germination
- subsurface drainage
- installing interceptor banks to divert water away from the site
- strategic soil conservation works to isolate affected sites from run-off and to reduce the soil erosion hazard
- changes in the management of the subcatchment to incorporate high water using pastures (e.g. perennial species) and regeneration of timber on groundwater intake zones.

4.4 SUMMARY

- Rural land uses are generating diffuse sources of serious pollution threats to water quality.

- Urbanised areas, are responsible for many downstream water quality problems.

- Many land use generated sources of water pollution can be controlled through appropriate catchment management practices.

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ASSIGNMENT NO 3 (CONTAINS PART A & PART B).

To be submitted by Friday 30 October 1992.

PART A

1) A sewage treatment plant effluent of poor quality discharges into a sluggish stream already mildly polluted above the point of discharge and providing a fivefold dilution of the effluent. What biological, chemical and physical changes would you expect to take place downstream of the effluent outfall?

2) What is a trickling filter? How does it work? State its types.

3) Explain the basic operations involved in the activated sludge process with the help of a flow diagram.

4) Discuss the treatment of sewage by waste stabilisation ponds.

5) An inland rural community of 1500 people located in northern New South Wales must construct a new wastewater treatment facility. Discuss factors to be considered in choosing between the processes listed below
    a) waste stabilisation ponds
    b) conventional treatment plant with trickling filters
    c) extended aeration activated sludge
    d) wetland treatment system.

PART B

The population of a country town is 30 000. The present water treatment plant has reached the end of its economic life and is to be replaced a new one that will serve the population for 30 years; that is, to the census year 2021 when the population is expected to reach 56 000. The water supply scheme is to be designed on the following criteria

Per capita demand with house connections = 300 L/d
Anticipated industrial demand in 2025 = 25 kL/d
Anticipated agricultural demand in 2025 = 20 kL/d
Fire demand = 5% of the total

A river is to be used as a possible source of water. It has a water with turbidity 5 to 35 NTU with values exceeding 1000 NTU about once a year. The iron concentration varies from 0.5 to 2.9 mg/L but no associated manganese has been found. Bacteriological examination revealed an average faecal coliform concentration of 125/100 mL.

A further chemical analysis of the river water gave the following results

Carbon dioxide	26 mg/L as CO_2
Calcium	150 mg/L as $CaCO_3$
Magnesium	65 mg/L as $CaCO_3$
Sodium	6.7 mg/L as Na^+
Alkalinity (HCO_3^-)	185 mg/L as $CaCO_3$
Sulphate	29 mg/L as SO_4^{--}
Chloride	10 mg/L as Cl^-

1) Discuss the suitability of this river as a source of water supply.

2) Draw a line diagram of a workable treatment scheme.

3) Determine the approximate sizes of the different units.

4) Determine the total quantities of chemicals needed for the treatment process in the year 2021.

The wastewater from this town will be treated by a conventional sewage treatment plant and the effluent will flow into the same river downstream of the water intake. The effluent standard to be maintained at a maximum BOD_5 of 20 mg/L. The minimum rate of flow in the river is 5 m^3/s with a BOD_5 of 4 mg/L.

5) Determine the minimum dissolved oxygen level and its distance downstream in the river using the oxygen sag equation and the estimated dry weather river velocity of 35 km/d.

$K_1 = 0.1\ d^{-1}$ at 20°C $K_2 = 0.3\ d^{-1}$ at 20°C

Temperature °C	0	10	20	30
DO mg/L	14.6	11.3	9.1	7.6

You are allowed to make reasonable assumptions where necessary.