LECTURE NOTES

Degree Program
For Environmental Health Science Students

Water Supply II

Ethiopia Public Health
Training Initiative

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PREFACE

The principal risk associated with community water supply is from waterborne diseases related to fecal, toxic chemical and mineral substance contamination as a result of natural, human and animal activities. When people consume water from a contaminated source, they will be exposed to infectious and other related diseases, risking possible death and disability. Therefore, it is important to make the water safe for human consumption through the utilization of different methods of protection and treatment.

For this reason, a lecture note is developed for environmental health students on how to treat water at household, small scale and large scale levels, to make the water safe for human consumption. The lecture note also includes information on water quality control for the assessment of hygienic quality of the drinking water using physical, chemical and bacteriological analysis and the principle of water pumps to lift and distribute water from shallow and deep wells for individual and community utilization.

As the trainings at higher institutions have been upgraded to a degree level, this lecture note is developed as an upgrade version of the earlier one though some changes on the chapters, contents and sequences. A chapter, “Water Supply in Disaster Management” is also incorporated in this upgraded lecture note. In this lecture note, too, each chapter has its own learning objectives, review questions, and note for the teachers (wherever deemed relevant). Both Metric and English system of measurements were used. However, the conversion factors are given on the annex.

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ABBREVIATIONS AND ACRONYMS

BOD	Biochemical Oxygen Demand
cm^3	Cubic Centimeter
COD	Chemical Oxygen Demand
CFU	Colony Forming Unit
d	Day
^0C	Degree Celsius
DO	Dissolved Oxygen
EU	European Union
FC	Fecal Coliform
FS	Fecal Streptococci
ft	Feet
gm/l	Gram per Liter
HPC	Heterotrophic Plate Count
HP	Horsepower
Kg	Kilogram
MAC	Maximum Allowable Concentration
MF	Membrane Filter
m	Meter
m/h	Meter per Hour
m^3	Cubic Meter
m^3/d	Cubic Meters per Day
$m^3/c/d$	Cubic Meters per Capita per Day
µ	Micron
mg/l	Milligram per Liter

ml	Milliliter
MPN	Most Probable Number
NTU	Nephlometric Turbidity Unit
ppm	Parts Per Million
PCA	Plate Count Agar
%	Percentage
ppt	Precipitate
psi	pounds per square inch
SOC	Synthetic Organic Chemicals
SS	Suspended Solid
TC	Total Coliform
^{O}H	Unit of Color
US	United States
VOC	Volatile Organic Chemicals
GAC	Granular Activated Carbon
WASH	Water, Sanitation, and Hygiene Education
w	Weight
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

Learning Objectives

At the end of this chapter, the student (the reader) will be able to:-

- Understand water as an important and precious resource for life.
- Describe the toll of diseases related to water.
- Discuss the different views on water supply.
- Appreciate the problem of water in terms of quality and quantity.
- Identify the roles of different stakeholders, like Governmental and International agencies, NGOs, professionals and the public in accessing adequate and safe water supply.

1.1 Existing Problems of Water Supply

Water is humanity's second most precious resource after the air we breathe. It covers over 70% of the earth's surface but only less than 1% is available as fresh water, the distribution of which painfully reflects the failure of the modern world to build a fair society. Over 1.1 billion people lack access to safe water and 2.6 billion live without proper sanitation. Water-related diseases, such as cholera, diarrhoeal diseases, dracunculiasis (Guinea worm), filariasis, malaria, onchocerciasis (river blindness), schistosomiasis (bilharzia), trypanosomiasis (sleeping sickness), and typhoid, still represent the single largest cause of human morbidity and mortality, of whom most are children.

A primary requisite for good health is an adequate supply of water that is of satisfactory sanitary quality. It is also important that the water be attractive and palatable to induce its use otherwise consumers may decide to use water of doubtful quality from a nearby unprotected stream, well, river or spring.

Three trends exemplify the water problems now facing humankind. First, there is a strong move toward the “commodification” of water—treating it as an economic good rather than a gift of nature. In principle, there is nothing wrong with properly valuing of water’s role as a commodity. A second trend is the growing interest in returning some water to nature. This reflects rising concern about the loss of water’s fundamental environmental functions, as in the case of wetlands and other biologically diverse ecosystems that are rich in unique flora and fauna and on which many poor people depend. This trend stands as a potentially strong counterweight to the move to treat water as an economic good. The third trend has to do with the widening gap in water use between rich and poor- both within and between countries.

The problem of water is more a case of distribution and quality than that of quantity. All regions have some problems related to either groundwater or surface water resources. The development and efficient management of water resources is of particular concern in the Middle East and parts of Africa, particularly the Sudano-Sahelian belt and the Horn of Africa. Hence, the development and efficient management of water resources is a priority concern in the Middle East, Africa, Asia, and the Pacific. Water supply in the rapidly urbanizing regions of Latin America, Asia, and Africa is also an issue, particularly with regard to serving the burgeoning squatter settlements and other low-income urban communities. Since more than 1.5 billion people depend on groundwater for their drinking, water protection of groundwater supplies is also an issue of concern.

In regarding with the initiatives, a sound water policy for the 21st century is generally recognized as requiring long-term planning, active public participation, and a new vision of sustainable water use, including explicit goals to help resolve water conflicts and to meet basic human and environmental needs. It may also involve the decentralization of water resource management responsibilities from national to sub-national authorities, an increasing role for the private sector in environmental stewardship and policy development, and a move towards integrated water policies and management practices.

A progress monitoring report jointly released by the United Nations Children's Fund (UNICEF) and the World Health Organization (WHO) in August 2004 suggested that, although the drinking water target may be achieved in terms of absolute numbers, poorer countries are being left behind. For example, despite advancing from 49% coverage in Sub-Saharan Africa in 1990 to 58% in 2002, this rate is far too slow to meet the target by 2015.

Clean water is almost always indicated as the first priority by low-income communities when asked which services they would like to receive. There are two indicators for an adequate water supply -quality and quantity. Quality standards for drinking water are often specified by relevant national agencies, but, when national standards are not available, the World Health Organization's (WHO) International Standards for Drinking Water Quality have normally been adopted. These standards set minimum levels of physical, chemical and bacteriological quality for domestic consumption. Recently, the international standards have been superseded by a set of Guidelines for Drinking Water Quality, which WHO has produced and whose main emphasis is on the microbiological quality of drinking water supplies.

In order to guarantee adequate water quality at the consumer's end of the supply system, a series of quality-protection devices and/or treatment processes have to be incorporated. They range from simple spring or well protection to sophisticated physical and chemical treatment systems. In addition, large water-supply systems require investment in civil engineering works to protect water quality, mainly from bacteriological contamination. These works cover the transporting, storage and distribution stages. It is obvious that low-income communities cannot afford expensive systems, in terms of both capital and operating costs, and cannot operate and maintain sophisticated systems themselves.

Sometimes, it will be necessary to use a water source, which cannot be upgraded, to a satisfactory level of quality at an affordable cost. This trade-off between quality and cost will not normally apply to bacteriological quality but might be considered a reasonable approach with regard to the aesthetic characteristics of water. Health protection is a prime consideration in the provision of adequate water supplies, and actions in this respect will normally focus on the control of water-related diseases. However, it must be accepted that it will not always be possible to ensure an absolutely safe supply, particularly in the case of small rural systems.

Although different strategies for the provision of drinking water and sanitation were exerted by different public and NGO institution, the output for the last decades were not encouraging to a level that could impact the health of Ethiopian population. The Federal Ministry of Health, Ministry of Education and UNICEF are, among others, the leading pioneers that are involved in the development of Water, Sanitation, and Hygiene education (WASH). Like other east African countries, in Ethiopia the status of water supply is similarly reflected. This basic issue has been give priority attention by integrated working among, the ministries of Health, Education and Water resource.

With the memorandum of understanding with the ministries and as matter of facts the Ministry of Health is responsible for the health of the society at large. The quality of water is the concern and priority choice of every individual, and also the task of Ministry of Water Resources as this is part of the water treatment plant, however, reassuring of the quality of water for consumption is the responsibility of Ministry of Health.

The adequate knowledge and skills of water in relation to health is most significant in promotion of health. For the proper application of the measures one has to be trained in the area, hence environmental health professionals are meant for the prevention and control of health related problems, availability of proper guidelines and materials, which are considered to be mandatory.

Review Questions

1. Which health problems are related to water?
2. Justify why the problem of quality and distribution of water mostly matters more than quantity?
3. Discuss the roles of the ministries of Health and Water Resources on community water supply.

CHAPTER TWO

WATER QUANTITY AND QUALITY ASSESSMENT

Learning Objectives

At the end of this chapter students will be able to:-

1. Define physical, chemical and bacteriological analysis of water.
2. Describe the different methods of physical, chemical and bacteriological analysis of water.
3. List laboratory apparatus used in drinking water quality analysis.
4. Identify points to be considered in sanitary surveying of water sources.
5. Explain the drinking water quality standard.
6. Determine the quantity requirements of water supply for different purposes.
7. Identify the factors that should be considered to design quantity requirements for drinking water systems.

2.1 Introduction

2.1.1 Need Assessment

The knowledge of the quantity of water required is important to decide on the source for intake, amount to be processed daily, weekly, or above; or hourly per minute or lower time period, and the costs of construction, operation and maintenance. The multi purpose of water necessitates different approaches to stimulate the amounts for the different uses of water encountered in a given time period. Hence, *water consumption* must be distinguished from *water usage*. In the former case, some or greater amount of water is lost to the environmental (body atmosphere, or other environmental constituents) and is no longer available for some kind of reuse. In the case of the water usage the polluted water after its usage can be treated and subsequently reused. For example, washing water is water use while water used for drinking or irrigation is water consumption; because it is lost (partly) by perspiration or evapotranspiration, respectively. Major categories of water requirements can be domestic, industrial, agricultural and recreational which in turn have various other requirements. For instance, under domestic requirements drinking, washing, cleansing, gardening fire extinguishing etc can be subcategories, while the 2.5 (recommended) liter per day by an adult person for drinking alone, 2.100-4.200 liters for bread preparation, or 15200 liters for preparing a kiloliter of beer are examples for water consumption.

Quantity of water required also depends on the habits/ cultures of people who use the water. The amount of water required is not only calculated for the current purpose, especially when treatment plants are designed for the source of intake is determined by population growth, increasing urbanization features, industries, agro-industrial complexes etc, must be reconsidered for the future periods, say 10 years, 20 years or more. The size of water storage facilities (reservoirs) is also very much dependent on the quantity of water required both currently and in due time.

2.1.2 Water Quality Assessment

Natural water is rarely of satisfactory quality for human consumption. Chemically pure water is the one, which contains two parts of hydrogen and one part of oxygen.

The primary objective of water treatment and purification is to collect water from best available source and subject it to processing which will ensure water of good physical quality, free from unpleasant taste and/or odor, and containing nothing which might be detrimental to health.

Depending largely upon the sources from which they are derived, the various waters so obtained may differ greatly in purity and suitability for the purposes for which they are required.

Pollution and water quality degradation interfere with vital and legitimate water uses at scales from local to global levels. Therefore, water quality criteria are necessary to ensure that the appropriate quality of resources is available for an intended purpose.

Water quality and standards vary and may originate in a number of possible ways; there are international standards set by WHO and EU, regional standards set by local authorities, with ultimate objective of protecting the user from ill health.

Therefore, assessment of water quality is an important procedure in modern society.

Earliest and simplest methods were purely subjective- does the water look clean, smell right, etc? But the fact that water is such a good solvent and can contain all kinds of dissolved substances lead to requirements for more precise assessment methods of water quality.

The modern approaches to the description of water quality utilize three stages:

1. Quantitative measurements, such as physicochemical parameters in water.
2. Biochemical tests including BOD estimation, toxicity test, etc.
3. Semi-quantitative and qualitative descriptions involving biological indicators and species inventories.

2.1.3 Water Quality Requirement

The importance of water quality, at times determines the availability of “water proper” water that can be used for the intended purpose. This is better explained by the saying “water every where and not a drop to drink”.

To cite some examples of the presence of generally known as water, but not water proper:

Consumption

Water contaminated with sufficient dose of bacteria that cause typhoid fever detected (confirmedly) regardless of its being cold and clear, cannot serve its purpose of quenching human thirst. This is because the ingestion by human beings of a few typhoid organisms can cause a high prevalence of (epidemic of) typhoid. It can even be fatal in the case of cholera agents.

Industrial

A difference of, say, 4^0C in a cooling water system can be worth a million dollars a year in a very large steam, electric generation facility, etc.

Agricultural

Large stores of ground water/surface water may be found just beneath the surface in water hungry (thirsty) areas, but its salinity may be too great to use for irrigation of most crops.

However, in some places (communities, towns, and even big cities) it is difficult to be too selective, as available sources are limited. Thus a compromise is made with necessary protective measures incorporated such measures include selective a main intake, preliminary treatments, etc.

The selection of raw water sources is also influenced by the general categories of water use, such as, industry, agriculture, recreation, etc.

2.1.4 Affordability and technology options

Affordability of water treatment is paradoxically associated with two basic issues:

- The first issue is that safe and adequate water supply is an internationally accepted (UN/ WHO) health requirement of every individual human being
- The second is that "more than half of the world's population (most of them in the developing countries) lacks safe and adequate water, thus is exposed to preventable water borne disease that account for more than 40% of the communicable disease prevalent in these countries.

As to the quantity (adequacy) issue, the tiny 0.7% available fresh water worldwide of unevenly distributed is estimated to supply the current world population 256 liters per capita per day. So according to uses scarcity of water supply can be said is due to its uneven distribution geographically. However, the availability of water fit for all life (especially humans) is being endangered at an alarming rate by human irresponsible activities. These activities of crime against life on earth have already supposed the current generation and become the legality of the coming ones. Human interference through industrialization, agricultural complexes, urbanization, and nuclear reactions, nowadays is not only blamed of exploiting the water bodies but also of interrupting the natural hydrologic cycle, deforestation, eutrophication, global warming, greenhouse gas effect and ozone depletion are a few examples of the outcomes of human abuses on our planet.

Therefore, the affordability of getting safe and adequate water supplies on one hand is a global problem and on the other it is the problem of the poor countries like Ethiopia. The former is due to the burden of the problem over and above the capacity of a country, groups of countries or geographical regions and the latter due to the low socio-economic development levels (poverty).

Attempts to solve the global level problem include the Montreal, Kyoto, Rio de Janeiro, and Durban conferences resolutions, which yet did not get acceptance by all countries especially by the greatest polluters such the United States. Attempts to solve the problems due to the socio economic development levels include the “water and sanitation decade” of the WHO, UN “Health for All by the year 2000 (Primary Health Care)” etc. These also, though one cannot absolute due to a few changes, especially in the sphere of awareness-raising and some urban water supply treatment, did not reach at their stipulated goals. To this end the gap between the rich and poor nations in getting pure and adequate water supply is still wide apart.

Technological options available for making water safe and adequate are similarity different between the two categories of the world. This problem is more aggravated in the developing nations, as the problem of affordability is complicated with lack of knowledge and skills.

New technologies such as ozone disinfection (chlorine → carcinogenic and not effect against shielded micro organism bacteria, protozoa, fungi**,** viruses reverse osmosis), ionization treatment are utilized in rich nations, while the routine unit processes (sedimentation, filtration, and disinfections) are being applied only in a few towns and cities in the remaining parts of the world. Even then shortage of chemicals for disinfections as well as apparatus and reagents for quality control coupled with lack of trained human power and many items put the safety of the water supplies under question. The incidence of water borne disease (sometimes on an epidemic level, e.g. typhoid fever, shigellosis, dysenteries, etc) implicated to the so-called conventionally treated water supplies is not a rare phenomenon.

The cost of a conventional water treatment can be categorized under three (main titles):

1. ***Construction/ installation cost:*** this includes the cost of raw water if paid for:
   - The cost of technology (technological materials)
   - The cost of land
   - The cost of labor
   - The cost of construction materials; amount of sand, gravel and stones

2. ***Operational cost***: that is incurred to run the plant or the entire water treatment and distribution works, cost of chemical reagents, power, labor etc.

3. ***Maintenance cost*** :(repairing, cleaning, spare parts, labor etc.)

In general, in normal (routine) conventional water treatment system at the beginning the cost of construction, the cost of operation is greater than the cost of maintenance. This depends on the types of technology used. Thus, there are cases where construction (installation) cost is less than operation cost and even maintenance cost (after a certain time service greater or almost all parts may be replaced).

Technological as well as operational costs also depend upon the types of training and the expected standard of the water to be treated. This in turn indicate the inputs and outputs of each unit operation process (quality standard of water after sedimentation, filtration, disinfection etc.) while the gold standard for certifying the safety of treated drinking water supplies its being free from pathogens and a known dose of other substances that cause disease or ill health conditions of the consumer other quality issues are often established on threshold levels (maximum and minimum). Some minerals or chemical compounds that need to be removed from or added to the treated water supplies are dealt with in a process known as supplementary water treatment, which will be discussed in another chapter.

2.2 Water Quality Analysis

Impurities present in water can be determined by different water quality analysis techniques. The analysis can be done both for raw and treated water.

2.2.1 Purpose of Water Quality Analysis

- To classify the water with respect to general level of mineral constituents
- To determine the degree of clarity and ascertain the nature of matter in suspension
- To determine the chemical and bacteriological pollution of water

- To determine the presence/absence of an excess level of any particular constituent affecting potable quality and general use.
- To determine the level of organic impurities.
- To set the outlines of purification process and specify stages in it.
- To ascertain whether purification of water has reached the required standards or not.

In general, assessing the quality of water is used to classify, prescribe treatment, control treatment and purification processes and maintains public supplies of an appropriate standard of organic quality, clarity and palatability, etc.

Water quality parameters can be divided into three broad classes:

1. Physical parameter
2. Chemical parameter
3. Microbiological parameter

2.2.1.1 Aesthetic and Physical Quality Parameters of Water

Aesthetic and physical quality parameters that show wide variation in magnitude consists of: Color, turbidity, odor, taste, temperature and solids.

Colour: imparted to water by dissolved constituents that absorb white light and emit light at specific wavelengths. Color of water is also influenced by its turbidity. Humic and fulvic acids impart color to natural waters.

Watercolor caused by dissolved or colloidal substances that remain in the filtrate after filtration through a 0.45 mm filter is called "True color". "Apparent color" is the term applied to colored compounds in solution together with colored suspended matter. Color is measured in units of milligram/liter of platinum; with the EU drinking water upper limit is 20 mg/l, with a guideline value of 1 mg/l.

Turbidity: Imparted by the colloidal matter present in water, this can be clay and loam, or microscopic organisms. It is a measure of the resistance of water to the passage of light through it and is estimated against standard suspensions based on standardization photometric means. Turbidity is expressed in terms of ppm by weight. The permissible turbidity of domestic water may be between five to ten ppm.

Common methods of measuring turbidity of water are:

1. By turbidity rod
2. By Jackson's turbidimeter
3. By Baylis turbidimeter
4. By Nephlometers

Odor and Taste: are of prime importance in assessing the palatability of water. Their occurrence may be due to the presence of mineral salts, industrial wastes, domestic sewage, decomposing organic matter, certain types of microscopic organisms or chemical compounds, etc. However, taste and odor are the most difficult physical characteristics to measure because of personal factors, related to taste and odor, atmospheric conditions of impurity, temperature and humidity.

The odor threshold is determined by diluting a sample with odor-free water until the last perceptible odor is detected and the result is expressed as a dilution ratio in threshold odor number (TON). The test is conducted at 20^0C and the TON should not be more than three for public water supply.

Temperature: measurements are sometimes important to identify the magnitude of density, viscosity, vapor pressure, and surface tension of water. Also saturation values of DO, BOD, and biological activities are dependent on temperature of water. The temperature of water to be supplied should be between10-20^0C. The temperature higher than 25^0C is considered objectionable. It can be measured with ordinary thermometers graduated in 0.1^0C, range 0-50^0C.

Solids: the amount, size and type of solids depend on the specific water. High solid contents indicate either contamination or presence of excessive mineral matters and the amount of total solids should preferably be less than 500 ppm.

Classification of solids in water:

- Total solids, TS
- Suspended solids, SS
- Total dissolved solids, TDS=TS-SS

- Total volatile solids, TVS
- Volatile suspended solids, VSS

2.2.1.2 Chemical Quality Parameters of Water

The assessment of chemical water quality parameter may be either:

- Specific, for instance analysis for ions, Ca^{++}, HCO_3^-, heavy metals like Pb, Cr, etc; or
- General, for instance tests such as alkalinity, hardness, etc.

The aim of chemical analysis of water is to determine the quality and quantity of different types of chemicals that may be present in a water supply system, which are generally reported in concentrations of mg/l or ppm.

Gross chemical Parameters of Water

The gross chemical parameters of water that are in wide use relating to water quality are: pH, alkalinity and acidity, hardness, and conductivity.

pH: a measure of a degree of acidity or alkalinity of water. Though the concentration of the two free or uncombined components $[H^+]$ and $[OH^-]$ of water is extremely small, it is governed by the Law of Mass Action,

i.e. $\frac{[H^+][OH^-]}{[H_2O]} = \text{Constant}$

Since dissociation of water is only very slight, the concentration of undissociated molecules (the denominator) may be taken as 100% or unity. Hence, we have:

$[H^+][OH^-]$ = Ionization Constant.

When concentration of the equation is expressed in terms of ions per liter, the constant is 10^{-14} at 21^0C.

i.e. $[H^+][OH^-] = 10^{-14}$

for absolutely pure water, $[H^+] = [OH^-]$ at 21^0C, its value is 10^{-7} each.

Thus, (10^{-7} gm H-ion) x (10^{-7} gm OH-ion) = 10^{-14}

Because of very low value of H-ion concentration, this figure is inconvenient to be used, and instead a term pH value has been introduced.

$$pH = -\log_{10}[H^+] = \log_{10}\frac{1}{[H^+]}$$

Acidic water causes corrosion while alkaline water causes incrustation. For potable waters, the pH value should be between 6 to 9, and preferably between 7 and 8.5.

Measurement of pH value is important since it provides means of classifying and of correlating behaviors such as corrosive activity or other inter-related factors controlling biological function in a body of water. It is also helpful in controlling softening and coagulation processes in water treatment. There are colorimetric and electrometric methods of determining pH value of water.

Alkalinity and Acidity: alkalinity is the capacity of water to accept H^+ ion, is a measure of its acid neutralizing capacity and acidity is a measure of the base neutralizing capacity.

OH^-, CO_3^-, HCO_3^- and CO_2 contribute to alkalinity in relative amounts.

Stumm and Morgan (1981) define alkalinity as:

$[\text{Alkalinity}]=[OH^-]+ 2[CO_3^{-2}]+[HCO_3^-] -[H^+]$

Alkalinity is measured volumetrically by titration with N/50 H_2SO_4 and is expressed in mg as $CaCO_3$/L. The amount of acid required to react with OH^-, CO_3^{-2} and HCO_3^{-2} is called the total alkalinity.

Hardness: is due to presence of certain salts, such as CO_3^{-2}, HCO_3^-, Cl^- and sulphates of Calcium and magnesium dissolved in it.

Total Hardness= Temporary hardness (Carbonate hardness) + permanent hardness.

Temporary hardness (Carbonate hardness) is due to the presence of CO_3^{-2} and HCO_3^- of Ca^{+2} and Mg^{+2} ions. It is easily removed by either boiling the water and by adding lime to the water (H_2O). The permanent hardness is due to the presence of sulphates, chlorides and nitrates of calcium and magnesium, and cannot be removed by boiling and requires special method of water softening. Hardness is expressed in ppm or in terms of degree of hardness, 1-extremely soft water and 17 too hard to use.

There are different methods of determining total hardness of water like, Clark's method, Hehner's method and Versenate method.

Analysis of total hardness is usually expressed in terms $CaCO_3$ equivalent (mg/l of $CaCO_3$). Hard water wastes soap, forms scale in boilers, pipe lines and may act as a laxative under extreme cases.

Conductivity: a measure of the ability of an aqueous solution to carry an electric current. The greater the concentration of dissolved salts, the higher the ionic mobility; and the higher the magnitude of conductivity. Chemically pure water does not conduct electricity. Seawater with high salts has a conductivity of about 40,000 µs/cm.

A positive measure of conductivity is indicative of the concentration of dissolved inorganic salts.

Although conductivity has no health significance, the EU drinking water directive places an upper limit of 1500 µs/cm.

Some Specific Chemical Quality Parameters of Water

Chlorides: The test primarily carried out to determine the content of NaCl in water. The dominant ion in rainwater is chloride, as rainwater is largely derived from seawater. Chlorides are estimated by titration with standard silver nitrate solution using potassium chromate as indicator.

Metals and Other Chemical Substances

Iron and Manganese: Iron in water causes hardness, bad taste, discoloration of clothes and plumbing fixtures and incrustation in water mains. Manganese imparts a brownish or purplish color to H_2O and laundered goods when oxidized and stains plumbing fixtures. It also impairs tastes to coffee and tea.

Estimation of iron is a colorimetric procedure and also estimation of manganese is by matching the pink color produced on oxidation to permanganate.

Lead and Arsenic: Lead is a known cumulative poison. Under normal conditions, the concentration of lead should be less than 0.05 mg/l. The presence of lead can be detected by drops of H_2SO_4 in a glass of water, which will give white precipitate. Zinc-galvanized iron pipe, copper pipe with lead-based solder joints, and brass pipe, faucets, and fittings may contribute lead. The lead should not exceed 5 μg/l in the distribution system.

Lead, as well as cadmium, zinc, and copper, are dissolved by carbonated beverages, which are highly charged with carbon dioxide. Limestone, galena, water, and, food are natural sources of lead. Other sources are motor vehicle exhaust, certain industrial wastes, mines and smelters, lead paints, glazes, car battery salvage operations, soil, dust, tobacco, cosmetics, and agricultural sprays. Fallout from airborne pollutants also contributes significant concentrations of lead to water supply reservoirs and drainage basins. About one-fifth of the lead ingested in water is absorbed. The US Environmental Protection

Authority (EPA) estimates that in young children about 20 percent of lead exposure comes from drinking water; dust contributes at least 30 percent, air 5 to 20 percent, and food 30 to 45 percent.

Conventional water treatment, including coagulation, will partially remove natural or man-made lead in raw water. Measures to prevent or minimize lead dissolution include maintenance of pH $\geq$ 8.0 and use of zinc orthophosphate or polyphosphates.

Chronic arsenic poisoning is difficult to diagnose, and can be quite disabling prior to detection. Arsenic can be removed from water in ion exchange equipment using activated alumina or bone charcoal.

Fluorides and Iodides: In small concentration, both may be useful to human being. Excess concentrations of fluoride (>3 ppm) can cause dental fluorosis or mottled enamel in children. Flourides can be estimated colorimetrically by developing a color with Zirconium alizarin reagent. Iodide can be determined in water supplies by utilizing its utility to catalize the reduction of ceric ions by arsenious acid, the effect being proportional to the amount of iodide present.

Mercury: Episodes associated with the consumption of methyl mercury-contaminated fish, bread, pork, and seed have called attention to the possible contamination of drinking water. Mercury is found in nature in the elemental and organic forms. Concentrations in unpolluted waters are normally less than 1.0

μg/l. The organic methyl mercury and other alkyl mercury compounds are highly toxic, affecting the central nervous system and kidneys. It is taken up by the aquatic food chain. The maximum permissible contaminant level in drinking water is 0.002 mg/l as total mercury. The WHO guideline is 0.001 mg/l.

Pesticides: Pesticides include insecticides, herbicides, fungicides, rodenticides, and regulations of plant growth, defoliants, or descants. Sources of pesticides in drinking water are industrial wastes, spills and dumping of pesticides; and runoff from fields, inhibited areas, farms, or orchards treated with pesticides. Surface and ground water may be contaminated. Conventional water treatment does not adequately remove pesticides. Powdered or granular activated carbon treatment may also be necessary.

Barium and Boron: Barium can have serious to toxic effects on the heart, blood vessels and nerves. It occurs naturally in some mineral springs as the carbonate salt. Ingestion of large amounts of boron can affect central nervous system (CNS).

Cadmium and Hexavalent Chromium: Cadmium is highly toxic. It can become a water contaminant through careless discharge of electroplating plant washes or from galvanizing operations in which cadmium is a contaminant.

Chromium, when inhaled can be a cause of cancer in human, though the effects of ingestion are not known. The likely sources of hexavalent chromium in water could be pollution by wastes from chromium plating shops, tanneries, etc.

Phenols: water receives phenols from trade wastes; wash in from road banks, gas liqueurs, etc. Trace phenol concentrations can impart an objectionable taste to water following marginal chlorination.

Nitrogen and Its Compounds: Nitrogen can be present in water in the following forms:

I. Ammoniacal Nitrogen (free and saline ammonia)
II. Albuminoid Nitrogen
III. Nitrite
IV. Nitrate

1/Ammoniacal-nitrogen: The occurrence of free ammonia indicates the direct inclusion of organic matter.

2/Albuminoid Nitrogen: Normally derived from the animal and plant life normal to the aquatic environment. Its determination gives an appropriate indication of the quality of proteinaceous nitrogen present in water. Its presence gives an indication of organic pollution in a water supply.

3/Nitrite: Occurs in water as an intermediate in an oxidation or reduction process in raw surface water supplies the trace amounts of nitrite indicates presence of pollution.

4/Nitrate: Nitrate is the final stage in the oxidation of nitrogen compounds. When the nitrate is in excessive amounts, it contributes to the illness known as infant methemoglobinaemia (Blue Baby syndrome).

Phosphorus: Phosphates are present in surface waters as a result of weathering and leaching of phosphorus-bearing rocks, from soil erosion, from municipal sewage, industrial wastewater effluent, agricultural runoff and atmospheric precipitation.

The **commonly occurring compounds of phosphorus** in water are:

Orthophosphates:

Na_3Po_4 - Trisodium phosphate
Na_2HPo_4 - Disodium hydrogen phosphate
Na_2H_2Po4 - Sodium dihydrogen phosphate
$(NH_4)_2HPo_4$ - Diamonium hydrogen phosphate

Polyphosphates:

$Na_3\ (Po_3)$ - Sodium hexmetaphosphate
$Na_3P_3\ )O_3$ - Sodium tripolyphosphate
$Na_2H_2Po_4$ - Sodium dihydrogen phosphate
$Na_4P_2O_9$ - Sodium pyrophosphate

Dissolved Oxygen Gases:

DO: Surface waters get O_2 dissolved either from atmosphere or due to activities of algae & tiny plant life in water. Its content in surface water is dependent upon the amount &

character of the unstable organic matter in the water. The amount of oxygen that water can hold depends upon temperature.

BOD: is a measure of oxygen required to oxidize the organic matter in a sample through the action of micro-organisms contained in the sample. Unpolluted waters should have 5ppm of BOD found from an incubation period of five days at a temperature of 20^0 C.

CO_2: gets dissolved in water from the atmosphere from decomposing organic matter at the earth's surface or from underground sources. The CO_2 content of water may contribute significantly to some corrosive situations. The amount of CO_2 can be reduced either by aeration or by addition of alkaline.

H_2S: mostly found in ground water and may be produced either by reduction of sulphate by inorganic process or by decomposition of organic matter through biological agencies and sulphate reducing bacteria.

2.2.1.3 Biological Quality Parameters of Water

Contaminated water may contain a host of micro- organisms, due to which water borne diseases may be spread if water is not properly treated before it is supplied to the public. The various microorganisms found in water may be broadly classified under three categories:

1/ Aquatic plants
2/ Aquatic animals
3/ Aquatic molds, bacteria & virus

1/ Aquatic plants:

- Waterweeds (Spermophyta)
- Mosses & liverworts (Broyphyta)
- Ferns & horsetails (Pteridophyta)
- Algae (Thallophyta)

2/ Aquatic animals:

- Fish & amphibians (vertebrate)
- Mussels, snails, slugs, limplets, cocklets (Mollusca)
- Crustacea, insects, spiders, mites (arthropods)
- Aquatic earth worms, threadworms, rotifera (worms)
- Hydra, polyzoa etc (metazoa)
- Entameoba hystolytica etc. (protozoa)

a/ Coli-aerogenes group (Coliform group)

The number of coliform organisms in human faeces is estimated to be between $10^{11}$and 10^{13}/capita daily.

The coliform group includes the entire aerobic and facultative anaerobic, non-spore-forming, gram-negative rod shaped bacteria that ferment lactose (milk sugar) with the production of gas at 35^0C within 48hrs.

The coliform group is composed of two important species, Escherichia coli (E. coli) and Aerobacteria aerogenes. They are of advantage as indicators of water contamination. A negative test for gas-formers indicates that the water is safe.

b/ Clostridium welchi: Found in cultivated soils, sewage and polluted water. The intestines are its habitat where it causes no harm but assists digestion.

c/ Faecal Streptococci: Found in human intestine, not as numerous as E. coli in all normal cases. Hence the test for faecal streptococci offers no advantage over the E. coli test except in cases of doubt.

Microbiological Examination of Water: It includes both bacteriological and biological examination. Bacteriological examination of sample of water is aimed at determining its fitness for use for human consumption/intended purpose. Biological examination of water is aimed at determining the presence of the microscopic organisms, other than bacteria, such as algae, fungi etc. many of which affect the quality of water.

Purposes of bacteriological examination: To detect and assess the degree of excremental pollution in the sources of supply.

- To assess the amount of treatment required to render a source of supply safe for consumption.
- To ascertain the efficiency of the purification treatment at various stages.
- To locate the causes of any sudden deterioration in quality.
- To establish the bacteria purity of final water as it leaves the treatment plant/purification work/s.

Review Questions

1. What is the environmental significance of turbid water?
2. What is the implication of high/low conductivity?
3. What are the tablets used in testing P^H and residual chlorine?
4. Discuss briefly the similarities and differences between general and chemical analysis.
5. Coliform organisms are the preferred indicators compared with pathogenic micro-organisms – Do you agree? Justify your reason of agreement.
6. Which methods of water quality test for microbiological analysis are feasible during fieldwork?
7. Write the common ingredient of culture media.
8. Write and discuss types and forms of culture media.
9. What factors are to be considered in sampling water for bacteriological examinations?

Note to the teachers

It is difficult for the students to understand easily this chapter in the classroom teaching learning process. So, in your environmental health laboratory, arrange for the students to have a practical session on analysis of drinking water quality using different methods.

CHAPTER THREE
WATER TREATMENT

Learning Objectives

At the end of this chapter students will be able to:

1. Define water treatment.
2. Explain the main objective of water treatment.
3. Mention methods of treating household water supplies
4. Describe the principal health risk associated with household water storage
5. Design and construct different household water filtration method
6. Mention chemicals and their dosage used in water treatment at household level.
7. Identify the criteria required in classifying raw water for treatment.
8. Write and discuss steps of conventional large-scale water treatment.

3.1 Introduction

Water availability from various sources contains various types of impurities. The raw water available from various sources cannot be used unless it is made safe for human consumption. The objective of water treatment is to eliminate all such impurities, which cause troubles and make water unsafe. Impurities should be reduced to such an extent that water becomes suitable for intended purposes. Therefore, the nature of treatment to be given to raw water depends upon the initial quality of raw water and the desired degree of purity to be attained after treatment.

3.2 Water Treatment on Small Scale

In most rural areas and small communities in developing countries, adequate water treatment procedures are almost non-existent, mainly for economic reasons. Generally, water for human use is collected from various unprotected water sources, and is consumed without treatment.

Naturally, water-borne diseases are prevalent among communities that consume such untreated contaminated water, and such practices must be discouraged. Water must be adequately treated before consumption, even in rural areas.

Therefore, small-scale treatment of water in emergency situations, temporary settlement areas, at household level and in areas where the municipality is not well organized is very important to reduce the problem of waterborne disease through the utilization of different methods of water treatment

Treatment of household water supplies may be effected by the following methods, used singly or in combination, depending on the reliability of each method.

3.2.1 Boiling

Boiling is one of the most reliable methods of disinfecting water at household level. Provided that water is brought to the boiling point, and is kept boiling for 15 to 20 minutes, all forms of microorganisms, including the most resistant spores or cysts, will be destroyed.

Furthermore, boiling is effective for all kinds of raw water, unless the water contains toxic chemicals which boiling cannot destroy. Yet although boiling is one of the most practicable methods of treating water, it may not be used if a community has not developed the habit of drinking boiled water. Boiled water has at least one disadvantage, and that is its flat taste, due to the loss of dissolved gases (carbon dioxide and oxygen) and minerals during the process of boiling. This can be remedied, however, by keeping the boiled water for a few hours in partially filled containers. The flat taste may not be a hindrance if a continuous effort is made to develop the habit of drinking boiled safe water.

Great care must be taken to avoid recontamination of the boiled water either during storage or consumption. It must be stored in a clean, firmly covered container, preferably the same container in which it was boiled.

Health caregivers should take into consideration the importance of health education to change the habit of people towards safe water supply through boiling of water to reduce the problems of waterborne disease.

3.2.2 Filtration

Filtration for household water supply is generally carried out by simple filtration systems, such as:

A) Homemade Sand Filters

These can be set up in individual homes, in containers such as steel barrels, drums, etc., that are locally available. An example is shown in Figure 3.1.

The components of the filter media and the basic principles of operation of a homemade sand filter are the same as those of a slow sand filter. The minimum depth of filter sand should not be less than 60 cm.

properly constructed and carefully maintained homemade sand filter can remove most of the substances that cause turbidity, taste and odor, the cysts and ova of parasites, and other relatively larger organisms.

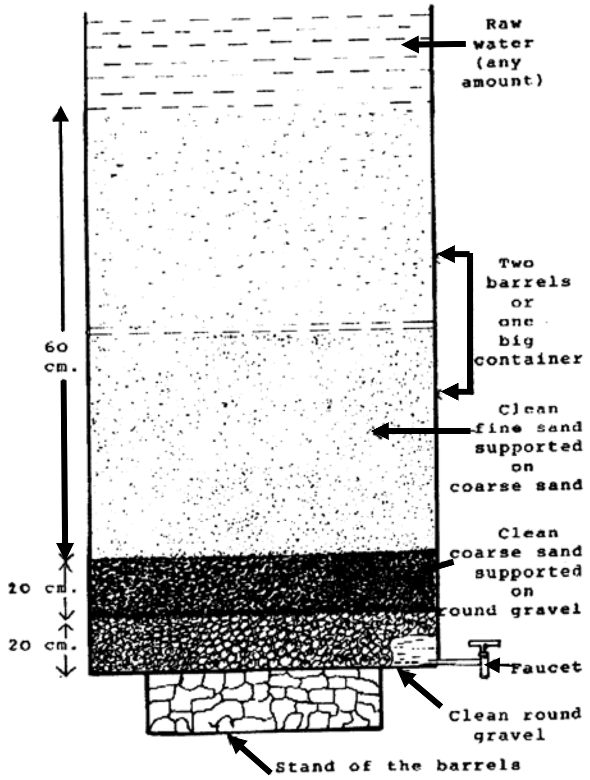


Figure 3.1 Homemade sand filter

(Adapted from Gabre- Emanual Teka. Water Supply-Ethiopia: An Introduction to Environmental Health Practice, 1997.)

Some of the limitations of a homemade sand filter are:

1. It cannot be relied upon to remove all forms of pathogenic organisms, particularly the viruses and some of the very small-sized bacteria.
2. It frequently gets clogged, particularly if the raw water to be filtered is turbid.

Maintenance of a homemade sand filter

1. There must be a continuous flow of raw water over the filter bed.
2. The rate of filtration should normally be controlled not to be more than 1.5 liters per minute. This rate will be achieved after the filter has been in operation for a few days.
3. The top-most layer of the sand must be scraped off, cleaned and replaced at fixed periods.

B) Home Candle Filters

These are commercially made for filtering individual water supplies. There are various types and sizes, known by different trade names.

The core of the filter is a porous cylinder (shaped like a wax candle, hence the name), made from high-quality unglazed porcelain (See Figure 3.2). The efficiency of filtration depends upon the pore size of the candle. Different manufacturers produce candle filters of varying pore sizes, but generally the pore size varies from a maximum radius of about 50 microns to a minimum radius of 0.3 micron. (A micron is one-millionth of a meter.)

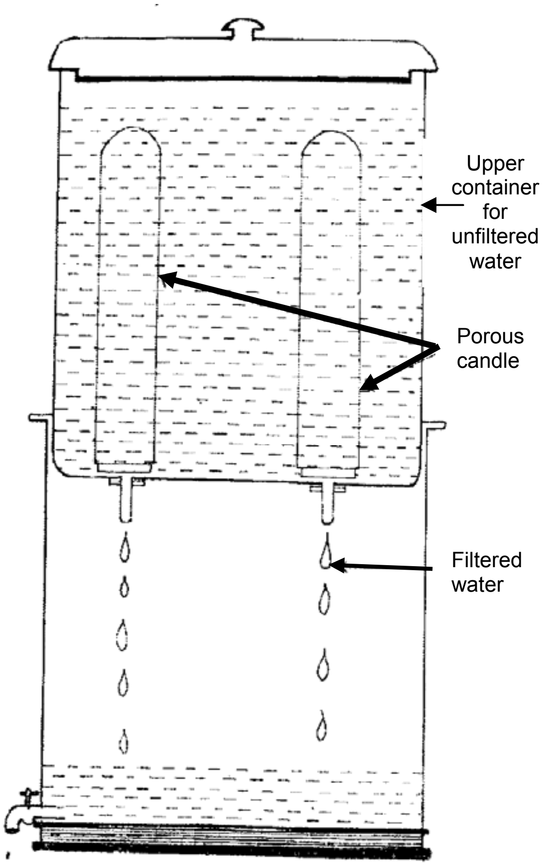


Figure- 3.2- Candle Filter

(Adapted from Gabre-Emanual Teka. Water Supply,Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Some of the limitations of candle filters are:-

1. The average size of a bacterium is about 1.5 microns. Thus, candle filters with a pore radius of more than 1.5 microns may not remove all the pathogenic organisms that may be present in the water. Viruses, for example, cannot be removed by a candle filter.
2. The rate of filtration of a candle filter is normally very low, although the rate can be increased by having a three-candle or four-candle filter
3. Candle filters are relatively too expensive for wide use by the general public.

Maintenance during operation

1. The raw water to be filtered must be reasonably clear, in order to reduce clogging of the candle pores.
2. The candle needs dismantling once a week, for washing and sterilizing in boiling water.

C) Stone Filters

Stone filters are similar to candle filters but are carved from porous local stone (see Fig. 3.3.). They are generally difficult to clean and heavy to lift, but have the advantage of being relatively inexpensive if they can be produced locally. If these filters were commonly used in a practical area, it would be worthwhile to test the water from a representative sample to determine the efficiency of removal of fecal contamination. This method of filtration could be possible in Ethiopia using the local “Beha” stone. But it needs research to introduce this method of filtration for individual and community use.

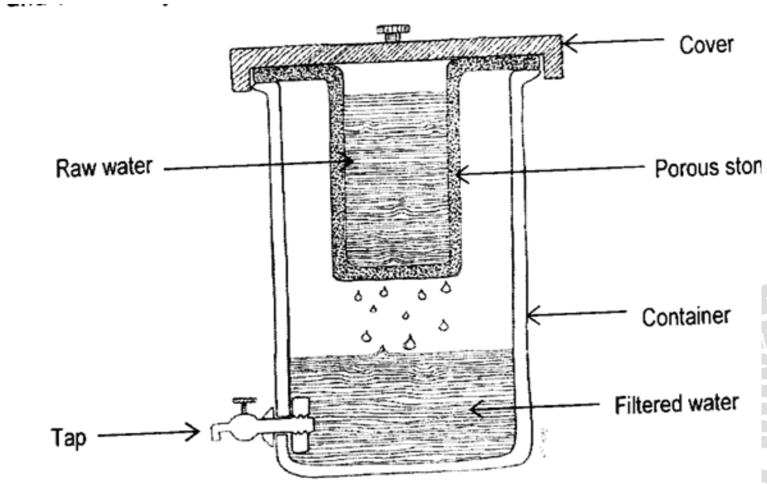


Figure –3.3- Stone filter

(Adapted from WHO’s Guidelines for Drinking Water Quality: Surveillance and Control of Community Supplies, 2nd edition, volume3, 1997.)

D) Cloth Filtration to Prevent Guinea Worm Disease

Guinea-worm disease (dracunculiasis) is transmitted via contaminated drinking water (e.g. from stagnate ponds, cisterns, or step wells). The disease occurs in a number of countries in Africa and Asia and causes severe suffering and disability among the world's most deprived people. Infected individuals do not develop immunity. There is no known animal reservoir, and people can disseminate the parasite one year after infection and during 1-3 weeks after emergence of the worm. For these reasons, control of transmission, including treatment of drinking water, is simple, and global eradication of this disease is feasible.

Dramatic reductions in the prevalence of dracunculiasis have been achieved through improvement of water supplies and by promoting proper hygiene in areas where the disease is endemic. In such areas, guinea worm (Dracunculus medinensis) can be effectively eliminated by filtering all drinking water through fine cloth (see Fig. 3.4). Filtration of drinking water is thus a primary strategy for the control of guinea-worm disease.

Filters should be of mesh size less than 130 µm; this should remove all infected intermediate hosts. Monofilament synthetic cloth (nylon) is most suitable because it clogs less rapidly and is easily cleaned; it has a mesh size of 100-130 µm. Cotton cloth can be used but tends to clog rapidly. Boiling is also effective as a means of controlling the disease.

Figure 3.4. Cloth filtration

(Adapted from WHO - Guidelines for Drinking Water Quality: Surveillance and Control of Community Supplies, 2nd edition, volume3, 1997.)

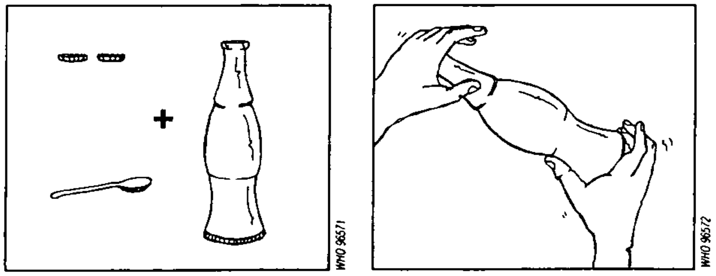
3.2.3 Chemical Disinfection

A) Chlorine or its compounds

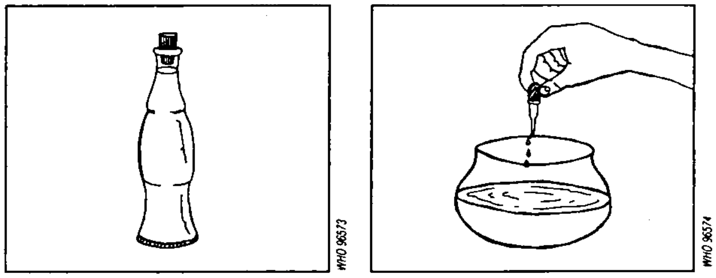
Chlorine or its compounds can be applied to disinfect water on a small scale, as described in the next chapter. Methods such as siphon-bottle feeders can be used easily for household water disinfection.

When dealing in terms of liters, 3 drops of 1% chlorine stock solution applied to every liter of water can give satisfactory disinfection; the dose can be doubled if the water is turbid.

The tablet forms of chlorine, such as Halazone, may be effectively used under field conditions when camping and during travel (dose: 1 tablet per liter of clear water.)



1. **Fill two tops or one level teaspoon with chlorine powder (HTH), put into a small drink bottle (about 300 ml) and add clean water to the top.**
2. **Cork the bottle and mix well for 2 minutes, Leave to stand for 1 hour.**



3. **Now you have the same chlorine as household bleach. Put it in a dark place away from children.**
4. **Add 3 drops of the chlorine solution for every liter of water. Leave for 1 hour, then taste. You should just be able to taste the chlorine, If you cannot taste it, add 1 drop per liter until you can. The water will only be safe to drink for 24 hours.**

Figure-3.5.- Method of preparing chlorine solution using local material

(Adapted from WHO's Guidelines for Drinking-Water Quality: Surveillance and Control of Community Supplies, 2nd edition, volume-3, 1997.)

B) Iodine and its compounds

Iodine and its compounds have also been effectively used for individual water disinfection. In fact, iodine is believed to be a better disinfectant than chlorine. Tablets of iodine, like those of chlorine, are available under various trade names (Globaline, Potable Aqua, etc.). Tincture of iodine (2%) applied at the rate of 2 drops per liter gives satisfactory results. Iodine, however, is relatively expensive for ordinary use, and in addition imparts to the water the familiar medicinal iodine smell.

C) Silver

Colloidal silver was used by the Romans to protect the quality of water in storage jars since, at concentrations of about 0.05 mg/l, silver is toxic to most micro-organisms. It is of value for small portable filter units for field use where silver-impregnated gravel filter candles remove turbidity and provide disinfection. The cost becomes excessive for other than very small supplies.

3.2.4 Household Water Storage

When household storage is well practiced in the community, turbidity will be reduced, bacteria and eggs of parasites will be sedimented, and schistosomiasis will be prevented because the chances of cercaria survival after 24 hours of water storage will be reduced.

The principal health risk associated with household water storage is the ease of recontamination during transport and storage; particularly if the members of a family or community do not all follow good hygiene practices. **Good hygienic measures include the following:**

- Careful storage of household water and regular cleaning of all household water storage facilities:
- Construction, proper use, and maintenance of latrines;
- Regular hand-washing, especially after defecation and before eating or preparing food;
- Careful storage and preparation of food.

Water that is clean from the supply or has been treated in the household needs to be protected from recontamination.

The most important elements of water storage can be summarized as follows:-

- Use a clean water source or treat the water, either at home or in a storage tank.
- Store water in an earthenware or plastic container with a lid.
- Store the water container at a height that puts it beyond the reach of children and animals.
- Fit a tap to the container for drawing clean water in order to prevent contamination by dirty cups, ladles, or hands.

Storage Tanks

Where a piped water supply to the household operates intermittently, a storage tank is commonly used to ensure that there is sufficient water for the family needs throughout the day. The tank should be covered to prevent contamination of the water and to restrict access by children and animals. It may be located inside or outside the house, but a secure cover should be fitted to an outdoor tank.

If the water running into the tank is clean (i.e. comes from a protected source or a treatment plant), the tank should be inspected, cleaned, and disinfected at least once a year. Where the water supplied is not clean, the tank will require more frequent cleaning, the frequency depending on the water quality. Water of poor quality should be treated by the most appropriate means.

The pipes running from a household storage tank to the taps must not be made of lead, which is toxic; pipes made of galvanized iron, copper, or plastic (such as potable grade PVC) should be used instead. Galvanized iron pipes should not be used where the water supplied is highly acidic or alkaline because they will corrode.

A non-lead solder should be used, where possible, to join metal pipes and a nontoxic solvent cement for plastic pipes. The system should be thoroughly flushed before use to remove and traces of solvent or metal solder from the pipes.

When a household storage tank and pipes for drinking water are installed, they should ideally be filled with water containing 50 mg/liter of chlorine and left to stand overnight so that the system is disinfected before use.

3.3 Design Principles and Unit Processes of Conventional (Large Scale) Water Treatment

3.3.1 Water Treatment Design Principles and Contents

Designing water treatment (large scale) entails the following water quantity upon which to base the design of a water system should be determined in the preliminary planning stages. Details of what current water quantity requires and future demands are discussed under need assessment. Social, economic, and land use factors, all of which can be expected to change with time, are also discussed.

- Population projection is of the basic consideration. Adjustments should be made for hospital and other institution populations, industries, fire protection, military reservations, transitions, and tourists.
- Health departments and other agencies that have design guides and standard texts give additional information

- In any case the characteristics of the community must be carefully studied and appropriate provisions made

Design period

The period of use for which a structure is designed, is usually determined by the future difficulties to acquire land or replace a structure or pipeline, the cost of money and the rate of growth of the community or faculty served.

In general, large dams and transmission mains are designed to function for 50 or more years; whereas filter plants, pumping stations and distribution systems for 25 years, and water lines less than 12 inches (30.5 cm) in diameter for the full future life.

- When temporary or short-term use is anticipated, a lesser design period would be in order. Suggestions indicate that the dividing line is in the vicinity of 3% per annum watershed run off and reservoir design

In addition to future water demand, rainfall data, unit hydrographs, maximum flow, minimum flows, mass diagrams, characteristics of the water shed, evaporation losses, percolation and transpiration losses should be considered for design purposes and storage determinations when these are applicable.

- Estimation of watershed run off; the maximum rate of run-off is:

$$Q = AIR$$

where,

Q is the runoff, ft^3/sec

A is the area of the water shed in acres (hectares)

R is the rate of rain fall on the water shed in inches (cm)/ hr and

I is the imperviousness ratio, that is, the ratio of water that runs off the water shed to the amount precipitated on it. I will vary from 0.01 to 0.20 for wooded areas; from 0.05 to 0.25 for farms, parks, lawns, and meadows depending on the surface slope and character of the subsoil; from 0.25 to 0.50 for residential semirural areas; from 0.05 to 0.70 for suburban areas; and from 0.70 to 0.95 for urban areas having paved streets, drives, and walks. R is the rate found for each specific area, e.g. 360/t + 30 for maximum storm for eastern USA.

- Another formula for estimation of the average annual runoff is by Vermuel'e formula:

$$F=R- (11 + 0.29R) (0.035)T- 0.65)$$

Where,

F is the annual run off in inches (cm),

R is the annual rainfall in inches (cm), and

T is the mean annual temperature in degree Fahrenheit (^0C)

* For small water systems, it is suggested that design be based on the year of minimum rainfall, or on about 60% of the average.

In any reservoir storage study it is important to take into consideration the probable losses due to seepages, outflows, evaporation from water surfaces during the year, and loss in storage capacity due to sediment accumulation if the sediment cannot be released during high inflow. This becomes very significant in small systems when the water surfaces exceed 6 to 10 percent of the drainage area. The annual evaporation from water surfaces is about 60% of the annual rain fall (in north Atlantic countries).

As water loss of the water shed due to land evaporation, plant usage, and transpiration is significant, it must be taken into consideration when determining rainfall minus losses.

3.3.2 Intakes and Screens

Conditions/factors to be taken into consideration in the design of intakes include:

- High- and- low water stages;
- Navigation or allied hazards;
- Floods and storms;
- Floating ice and debris;
- Water velocities, surface and subsurface currents, channel flows, and stratification;
- Location of sanitary, industrial, and storm sewer outlets; and
- Prevailing wind direction.

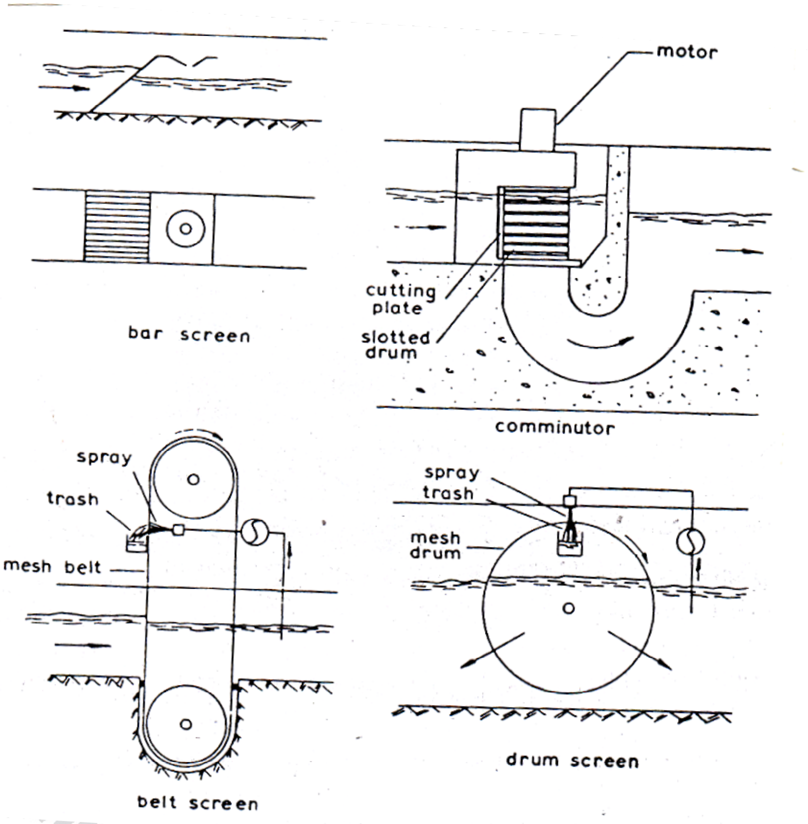


Figure 3.6 The preliminary treatment units

(Tebbutt. Principles of Water Quality Control. 3rd edition, University of Birmingham, Pergamon Press, 1983.)

Small communities cannot afford elaborate intake structures. The inlet fittings should have a coarse strainer or screen with about one inch mesh. For a river intake the inlet is perpendicular to the flow. A submerged intake crib, or one with several branches and upright tee fitting anchored in rock cribes, 4 to 10 ft (1.2 to 3 m) above the bottom, is relatively inexpensive. The total area of the inlets should be at least twice the area of the intake pipe and should provide an inlet velocity less than 0.5 fps (15 cm/s). Low-entrance velocities reduce ice troubles and less likely to draw in fish or debris. Duplicate stationary screens in the flow channel, with 1/8- to 3/8- inch (3.2-9.5 mm). Corrosion-resistant mesh are the types of screens recommended, as fine screens will become clogged. The screen is attached to the end of the intake conduit and mounted on a foundation to keep it off the bottom, and, if desired, crushed rock or gravel can be dumped over the screen. Attachment to the foundation should be made in such a way that removal for inspection is possible. As to the inlet capacity of the screen in relation to the diameter and the size of the screen, a 10 ft (~3m) section of a 24- in (61 cm) diameter screen with ¼- in (6.4 mm) openings is said to handle 12 mgd at an influent velocity of less than 0.5 fps (See figure 3.6).

In large installations, intakes with multiple-level streams to make possible depth selection of the best water when the water quality varies with season of the year and weather conditions.

Pumping (Station)

The distribution of water usually involves the construction of a pumping station, unless one is fortunate enough to have a satisfactory source of water at an elevation to provide a sufficient flow and water pressure at the point of use by gravity. Water may be pumped from the source or for transmission or both. Electrically operated pumps should have gasoline or diesel standby units having at least 50 percent of the routine capacity if standby units provide power failure.

The size of pump selected is based on whether hydropneumatic storage (*steel pressure tank for a small system*), ground level or elevated storage is to be used; the available storage provided; the yield of the water source; the water usage; and the demand. Actual meter readings are recommended with consideration being given to future plans, periods of low or no usage; and maximum and peak water demands. Metering can reduce water use by 25 percent or more. If the water system is to also provide fire protection, then elevated storage is practically essential, unless ground-level storage with adequate pumps is available.

- The capacity of the pump required for domestic water system with elevated storage is determined by the daily water consumption and volume of the storage tank.
- Site of location of the storage tank is governed by the hydraulic gradient necessary to meet the highest water demand.
- The pump should be of such capacity as to deliver the average daily water demand to the storage tank in 6 to 12hr. In very small installations the pump chosen may

have a capacity to pump in 2 hrs all the water used in one day.

Distribution storage Requirements

Water storage requirements should take into consideration of peak daily water use, and the maximum day demand plus the required fire flow, the capacity of the normal and standby pumping equipment, the availability and capacity of auxiliary power, the probable duration of power failure, and the promptness with which repairs can be made. Additional considerations are land use, topography, pressure needs, distribution system capacity, special demands, and the increased cost of electric power and pumps to meet peak demands.

- Water storage is necessary:

1. To help most peak demands, fire requirements and industrial needs;
2. To maintain relatively uniform water pressures;
3. To eliminate the necessity for continuous pumping;
4. To make possible pumping when the electric rate is low;
5 To use the most economical pipe sizes, and
6 Surges in water pressure due to water hammer are also dissipated

Other things being equal, a large-diameter shallow tank is preferable to a deep tank of the same capacity, because it is less expensive to construct and water pressure fluctuations on the distribution system is less.

The cost of storage compared to the increased fire protection and possibly lowered fire insurance rate, the greater reliability of water supply, and the decreased probability of negative pressures in the distribution system will be additional factors in making a decision.

In general, it is recommended that water storage equal *not less than one-half of the total daily consumption,* with at least one-half the storage in elevated tanks.

A preferred minimum storage capacity (let, a) would be a 2-day average use plus fire flow or the maximum day usage (let, b) plus fire requirement (let, c) less the daily capacity of the water plant (let, d) and system for the fire flow period (let, e) (i.e. a= [b + c] - [d + e]). Another basis is to provide sufficient water storage capacity to supply the maximum daily rate for a 4-hr period without depleting storage by more than one-half. Additionally, the minimum amount of storage that usually should be reserved for fire protection and other emergencies is one-third of system storage.

- The amount of water required during peak hours of the day may be equal 15 to 25 percent the total maximum daily consumption. This does not include fire requirements. Thus, some experts recommended 25 to 50% of the total average daily water consumption.

- It is a good practice to locate elevated tanks near the area of the greatest demand for water and on the side of town opposite from where the main enters.
- All distribution reservoirs should be covered; provided with an over flow that will not undermine the footing, foundation, or adjacent structures. And provided with a drain, water-level gauge, access manhole with overlapping cover, ladder, and screened air vent.
- Tanks located partly below ground must be at a higher level than any sewers or sewerage disposal systems and not closer than 50 ft (15m).

3.3.3 Peak Demand Estimates

The maximum hourly or peak demand flow upon which to base the design of a water distribution system should be determined for each situation. Characteristics difference is the premises, therefore the design flow to determine the distribution system capacity should reflect:

- The pattern of living or operation,
- Probable water usage, and
- Demand of that particular type of establishment or community.

All the same time, considerations should be given to the location of existing and future institutions, industrial areas, suburban or fringe areas, high-ways, shopping centers, schools, subdivision and direction of growth. In this connection, reference to city, town, or regional comprehensive or master plan, where available, are of great help.

> Note that larger cities generally have higher per capita water consumption than smaller cities, but smaller cities/ communities have higher percentage peak demand flow than larger communities

The maximum hourly domestic water consumption for cities above 50,000 population will vary from about 200 to 700 percent of the average day annual hourly water consumption; the maximum hourly water demand in smaller cities will probably vary from 300 to 1000 percent of the average day annual hourly water consumption.

- The daily variation is reported to be 150 to 250 percent and the monthly variation 120 to 150 percent of the average annual daily demand in small cities. Based on some studies (in England and USA), it can be said that the smaller and newer the community, the greater will be the probable variation in water consumption from the average.

3.3.4 Distribution System Design Standards

The distribution system design should follow usual good waterworks practice and provide for fire protection. Mains should be designed on the basis of velocities of 4 to 6 fps (1.2-1.8m/s) with maximum of 10 to 20 fps (3-6 m/s), the rate of water consumption (maximum daily demand), and fire demand, plus a residual pressure of not less than 35 pounds per square inch (psi) nor more than 100 psi, using the Hazen and Williams coefficient C=100, with a normal working pressure of about 60 psi.

- *Mains* tied together at least every 100 ft (30m); line less 6 in (15.24 cm) diameter should generally not be considered
- In new construction 8-in. (15.24 cm) pipe should be used. In urban areas 12-in. or larger mains should be used for principal streets and for all long linesthat are not connected to other mains at intervals close enough for proper mutual support.
- The design should aim to provide a pressure of not less than 35 psi in the distribution system during peak flow periods, though 20 psi may be acceptable.
- A minimum pressure of 60 to 80 psi is desired in business districts, although 50 psi may be adequate in small villages with one- and two-story buildings.
- *Valves* are spaced not more than 500 ft (150m) apart in commercial districts and 800 ft (240m) in other districts, and at street intersecting.
- *Hydrants* should be provided at each street intersection and spacing may range generally from 350 to 600 ft (8.89-15.24m), depending on the area served for fire

protection and as recommended by the state Insurance Services Office.

- Connection to the street main should be not less than 6 in. (15.24cm) in diameter.
- Main breaks occur longitudinally and transversely.
- Water lines are laid below frost, separated from sewers a minimum horizontal distance of 10 ft (3m) and a vertical distance of 18 in. (45.72cm) above thetop of the sewer lines.
- Mains buried 5 ft (1.5m) are normally protected against freezing and external loads.
- The selection of pipe sizes is determined by the required flow of water that will not produce excessive friction loss.
- Transmission mains for small water systems more than 3 to 4 mi long should not be less than 10 to 12 in. (25-30 cm) diameter.
- Design velocity is kept under staffs and head loss under 3 ft/100 ft (3m/100m). Velocities may be 11/2 to 51/2 fps (1.67-7.73 mps) for domestic use only.
- The friction loss in a pipe connected at both ends is about one-quarter the friction loss in the same pipe with a dead end & the friction loss in a pipe from which water being drawn uniformly along its length is about one- third the total head loss.

- In any case, only pipe and fittings that have a permanent- type lining or inner protective surface should be used.

Small Distribution System

In communities where no fire protection is provided, small diameter pipe may be used. In such cases:

2-in. line → not more than 300 ft (90m) long
3-in. " → not more than 600 ft (180m) long
4-in. line → not more than 1200 ft (360m) long
6-in. line → not more than 2400 ft (728m) long

If lines are connected at both ends 2- or 3-in. (5-7.5cm) lines should be no longer than 600 ft (18om); and 4-in. (10.2cm) lines, are not more than 200 ft (60.6m).

Fire Protection

- A water system must be capable of delivering at least 250 gpm at 20 psi at a fire location for at least 2 hr with consumption at the maximum daily rate.
- There should be sufficient hydrants within 1000 ft (300m) of a building to supply its needed fire flow.

N.B. The following assurance should be strictly observed concerning water for fire protection:

- Being alert to assure that fire protection programs do not include pumping from polluted or unapproved sources into a public or private water system main through hydrants or blow off valves nor should bypasses be constructed around filter plants or provision made for “emergency” raw water connection to supply water in case of fire.

- In extreme emergencies, the health department might permit a temporary connection under certain conditions, but in any case the water purveyor (supplier) must immediately notify every consumer not to drink the water or use for food or drink preparation unless first boiled or disinfected.

Cross –Connection Control (CCC)

A *cross- connection* is any physical connection between a otable water system and non potable water supply; any waste pipe, soil pipe, sewer, drain; or any direct or indirect connection between a plumbing fixture or device whereby polluted water or ontaminated fluids including gases or substances might enter and flow back into the potable water system. The backflow may occur by ackpressure *or* backsiphonage. In the *backpressure* situations, the pressure in the nonpotable water exceeds that in the potable water system. In *backsiphonage*, the pressure in the potable water system becomes less than that in the nonpotable water system due to a vacuum or reduced pressure developing in the potable water system.

- A discussion of water system design would not be complete without reference to cross-connection control and backflow prevention. The goal is to have no connection between a water of drinking water quality (potable) and usage of questionable (nonpotable) water system, or between a potable system and any plumbing fixture or device, where by nonpotable water might flow into the potable water system.

Negative or reduced pressure in a water distribution or plumbing system may occur:

- When a system is shut off or drained for repairs,
- When heavy demands are made on certain portions of the system causing water to be drawn from the higher parts of the system, or
- When the pumping rate of pumps installed on the system (or of fire pumps or fire pumpers at hydrants) exceeds the capacity of the supply line to the pump.

The more common acceptable methods or devices to prevent backflow are *air gap separation*, *backpressure units*, and *vacuum breakers*.

Nonpressure-type vacuum breaker is always installed on the atmospheric side of a valve and is only intermittently under pressure, i.e. when flusho-meter valve is activated. The pressure-type vacuum breaker is installed on a pressurized system and functions when a vacuum occurs.

To prevent backflow into the distribution system:

- An elevated or ground- level tank providing an air gap,
- The reduced pressure zone backflow preventer, and
- The double check valve assembly, are generally used on public water system connections; the vacuum breaker is usually used on plumbing fixtures and equipment.

An approved backflow preventer or air break should be required on the water service line to every building or structure using or handling any hazardous substance that might enter the potable water system. In addition, building plumbing codes should prohibit cross-connections within buildings and premises and require approved-type backflow preventers on all pumping, fixtures, and devices which might cause or permit backflow.

- It is the responsibility of the designing engineer and architect, the building plumbing inspector, the waterworks official, and the health department to prevent and prohibit possibilities of pollution of public and private water systems.
- There are two major aspects to a cross-connection control. One is protection of water distribution system to prevent its pollution. The other is protection of the internal plumbing system used for drinking and culinary purposes to prevent its pollution.
- The water purveyor (supplier) has responsibility to provide its customers with water meeting drinking water standards, which requires control over unauthorized use

of hydrants, blowoffs, and main connections or extensions.

A comprehensive cross-connection control programme includes:

1. An implementation ordinance that provides the legal basis for the development and complete operation of the programme.
2. The adoption of a list of devices that are acceptable for specific type of cross-connection control.
3. The training and certification of qualified personnel to test and ensure devices are maintained.
4. The establishment of a suitable set of records controlling all devices.
5. Periodic seminars wherein supervisory, administrative, political, and operating personnel, as well as architects, consulting engineers, and building officials, are briefed and brought up-to-date on the reason for the programme as well as on new equipment in the field.

Note that:

- Enforcement is best accomplished at the local level,
- In addition to the 5 steps above, a control program implementation requires that a priority system be established. grouping structures and facilities served as “hazardous”, “Aesthetically objectionable”, and “Not hazardous” can make inspection manageable

and permit concentration of effort on the more serious conditions

- Estimating the cost of installing backflow prevention devices (some highly costly) is helpful in understanding what is involved and in obtaining corrections.

3.3.5 Hydropneumatic Systems

Hydropneumatic or pressure-tank water systems are suitable for small communities, housing developments, private homes and estates, camps, restaurants, hotels, resorts, country clubs, factories, and institutions, and as booster installations. Only about 10 to 20 percent of the volume of a pressure tank is actually available. The tanks are usually made of 3/16 in. or thicker steel and are available in capacities up to 10,000 or 20,000 gal (38,878-75,756 L).

- The required size of a pressure tank is determined by peak demand, the capacity of the pump, and source, the operating pressure range, and air volume control (available).
- The capacity of well and pump should be at least 10 times the average daily water requirement rate.
- A simple and direct method for determining the volume of the pressure storage tank and size of the pump to provide is derived from Boyle’s Law and is based on the formula:

$$Q = \frac{Qm}{(1 - P_1/P_2)}$$

where,

Q = volume of pressure- tank in gal

Qm =15 minutes storage at the maximum hourly demand rate

P_1= the minimum absolute operating pressure (gauge pressure plus 14.7Ib/in^2), and

P_2 = the maximum absolute pressure

The pump capacity given on the curve is equal to 125% of the maximum hourly
Demand rate.

The maximum Hourly demand is based on:

- **Average daily rate =** $\frac{\text{Average water use per day}}{\text{1440 min/day, in gpm; based on annual water use}}$
- **Average maximum monthly rate =** 1.5 x average daily rate
- **Maximum hourly demand rate**
  = 6 x average maximum monthly rate or 9 x average daily rate
- **Instantaneous rate (Pump capacity)**
  = 1.25 x maximum hourly demand rate, or 11.25 x average daily rate
- The **water available for distribution** is equal to the difference between the dynamic head (friction plus static head) and tank pressure.

Pumps

The pump types commonly used to raise and distribute water are referred to as:

1. Positive displacement, including reciprocating, diaphragm and rotary;
2. Centrifugal, including turbine, submersible, and ejector jet;
3. Air lift; and
4. Hydraulic ram.

Pumps are classified as: low lift, high lift, deep well, booster, and standby. Other types for rural and developing areas include: the chain and bucket pump and hand pump.

3.3.6 Water Processing

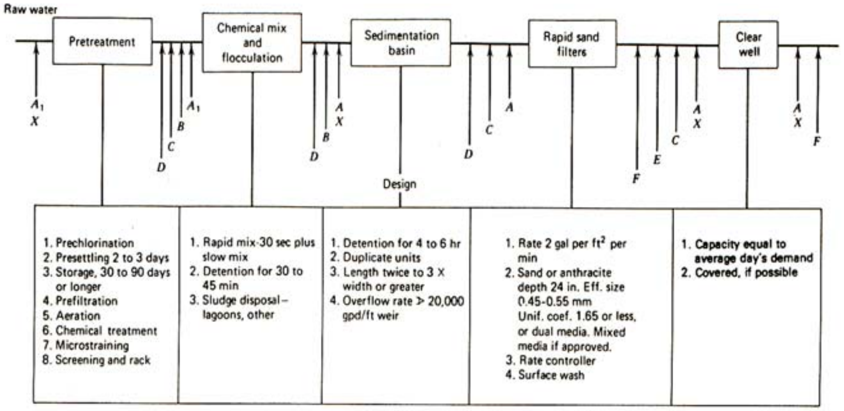
In all cases, the water supply must meet the standards of drinking water of the regulatory body or the international (WHO) recommendations, in the absence of local standards. To this end, conventional water treatment systems generally include the following units, especially for surface water sources (See figure 3.7)

1. Intake
2. Pumping station
3. Pre-chlorination and aeration
4. Plain sedimentation
5. Coagulation and flocculation
6. Sedimentation/clarification

7. Filtration
8. Disinfection
9. Distribution (Transmission/Distribution)

*As already intake & pumping (station) were discussed under design principles and contents, the remaining units and their processes are discussed separately as follows;

*Pre chlorination and aeration are discussed in combination with plain sedimentation



Possible chemical combinations:

A Chlorine. A_1 Eliminate if THMs formed.

B Coagulant; aluminum sulfate (pH 5.5 to 8.0), 10 to 50 mg/l; ferric sulfate (pH 5.0 to 11.0), 10 to 50 mg/l; ferrous sulfate (pH 8.5 to 11.0), 5 to 25 mg/l; ferric chloride (pH 5.0 to 11.0); sodium aluminate, 5 to 20 mg/l; activated silica, organic chemicals (polyelectrolytes).

C Alkalinity adjustment; lime, soda ash, or polyphosphate.

D Activated carbon, potassium permanganate.

E Dechlorination; sulfur dioxide, sodium sulfite, sodium bisulfite, activated carbon.

F Fluoridation treatment.

X Chlorine dioxide, ozone, chlorine-ammonia.

Note that the chlorinator should be selected to post-chlorinate at 3 mg/l. Provide for a dose of 3 mg/l plus chlorine demand for groundwater. Additional treatment processes may include softening (ion exchange, lime-soda, excess lime and recarbonation), iron and manganese removal (ion exchange, chemical oxidation and filtration, ozone oxidation, sequestering), organics removal (activated carbon, superchlorination, ozone oxidation), and demineralization (distillation, electrodialysis, reverse osmosis, chemical oxidation and filtration, freezing).

Figure 3.7 Conventional water treatment system flow diagram.

(Adapted from J.A Salvato. Environmental engineering and sanittion. 4th ed. John Wiley & Sons, Inc. 1992 .)

Table 3.1 Classification of Water by Concentration of Coliform Bacteria and Treatment Required to Render the Water of Safe Sanitary Quality (J.A Salvato,1982)

Group No	Maximum permissible average MPN Total coliform Bacteria per month**	Treatment required
1.	Not more than 10% of all 10ml or 60% of 10 ml portions positive; not more than 1.0 coliform bacteria/100 ml	None for protected under ground water, but at the minimum, chlorination for surface water
2.	Not more than 50/100 ml	Simple chlorination or equivalent
3.	Not more than 5000/100ml and this MPN exceeded in not more than 20% samples	Rapid sand filtration (including coagulation) or its equivalent plus continuous chlorination
4.	MPN greater than 5000/100m in more than 20% of samples and not exceeding 20,000/100ml in more than 5% of the samples	Auxiliary treatment such as 30 to 90 days storage, pre-settling, pre-chlorination, or equivalent plus complete filtration and chlorination
5.	MPN exceeds group No 4	Prolonged storage or equivalent to bring within groups 1 to 4

* Physical, inorganic and organic chemicals; and radioactive concentrations in raw water and ease of removal by the proposed treatment method must also be considered

** Fecal coliform not to exceed 20% of the total coliform organisms

* If sterile water is needed, water should be placed in a pressure-cooker at 250^{0}F (121^{0}C) for 15 min.

* Boil water for 20 min where protozoa and helminthic disease causing agent are endemic

3.3.7 Plain Sedimentation

Plain sedimentation is the *quiescent settling* or storage of water, such as would take place in a reservoir, lake or basin, without the aid of chemicals, preferably for a month or longer.

The Ideal Sedimentation Basin

The behavior of a sedimentation tank operating on a continuous flow basis with a discrete suspension of particles can be examined by reference to an ideal sedimentation basin (See figure 3.8), which assumes:

1. Quiescent conditions in the settling zone
2. Uniform flow across the settling zone
3. Uniform solids concentration as flow enters the settling zone
4. Solids entering the sludge zone are not resuspended.

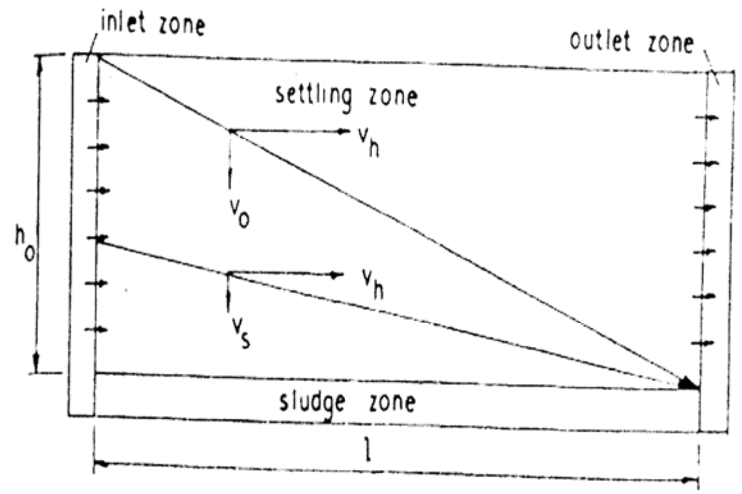


Figure 3.8 The ideal sedimentation basin

(Adapted from Tebbutt. Principles of Water Quality Control. 3rd edition, Pergamon Press, 1983.)

Advantages:

This natural treatment results in the settling out of:

1. Suspended solids, reduction of hardness, ammonia, lead, cadmium and other heavy metals; some synthetic organic chemicals and fecal coliform.
2. It also removes colour (due to the action of sunlight), and
3. Death of bacteria principally because of the unfavorable temperature, lack of suitable food, and sterilizing effect of sunlight

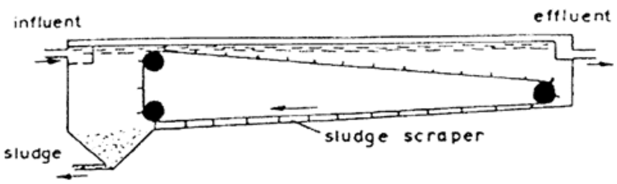
4. Certain microscopic organisms, such as protozoa consume bacteria thereby aiding in purification of the water
5. It is relatively inexpensive.

Experiments conducted by Sir Alexander Houston showed that polluted water stored for periods of 5 weeks at 32^0F(0^0C), 4 weeks at 41^0F(5^0C) effected the elimination of practically all bacteria (J. A. Salvato, 1992).

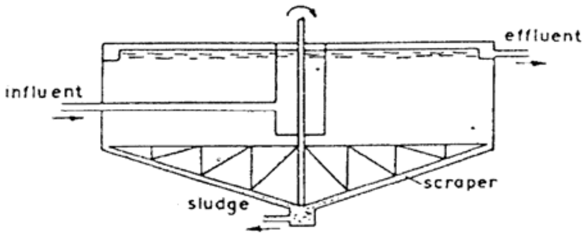
Disadvantages:

1. The growth of microscopic organisms that cause unpleasant tastes and odors is encouraged
2. Pollution by surface wash fertilizers, pesticides, recreational uses, birds, sewage and industrial wastes may occur unless steps are taken to prevent or reduce these possibilities
3. Although subsidence permits bacteria to die off, it also permits bacteria to accumulate and grow in reservoir bottom mud under favorable conditions
4. In addition, iron and manganese may go into solution, carbon dioxide may increase, and hydrogen sulfide may be produced

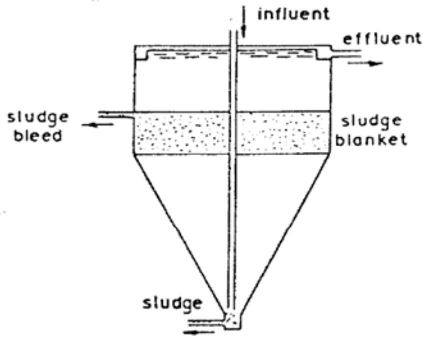
Presettling reservoirs are sometimes used to eliminate heavy turbidity or pollution and thus prepare the water for treatment by coagulation, settling and filtration. This process is known as *preliminary sedimentation*. When heavily polluted water is to be conditioned, provisions can be made for preliminary coagulation, aeration or pre-chlorination at the point of entrance of the water into the basins. However, considerations must be given to the possible formation of trihalomethanes and their prevention.



horizontal flow



radial flow



vertical flow

Figure 3.9. Types of sedimentation tank

(Adapted from Tebbutt. Principles of Water Quality Control. 3rd edition, Pergamon Press, 1983.)

Trihalomethanes are halogenated chloro-organic compounds (chlorination by product) in water, which are formed by the reaction of free chlorine with certain organic compounds in water. The major cause of trihalomethane formation in drinking water that is chlorinated is probably *humic* and *fulvic substances* (natural organic matter in soil peat and runoff) and simple low molecular weight compounds including algae referred to as *precursors*.

Ordinarily, at least two basins are provided for the sedimentation to permit one to be cleaned while the other is in use. A capacity sufficient to give a retention period of at least 2 or 3 days is desirable.

3.3.8 Clarification, Coagulation, Flocculation, and Settling

Micro straining- is a process designed to reduce the suspended solids including plankton in water; the filtering media consist of very finely level fabrics of stainless steel on revolving drum. Application to water supplies are primarily the clarification of relatively clean surface waters low in true colour and colloidal turbidity in which micro straining and disinfection constitute the pretreatment and the clarification.

These basins should be at least two in number to permit cleaning and repairs without interrupting completely the water treatment even though mechanical cleaning equipment is installed.

Adding a coagulant such as alum (aluminum sulfate) to water permits particles to come together, and results in the formation of a flocculent mass, or floc, which entangles and agglomerates microorganisms, suspended particles, and colloidal matter, removing and attracting these materials in settling out. Removal of 90 to 99 percent of the bacteria and viruses, and more than 90 percent of the protozoa and phosphate can be expected.

1. For the control of coagulation, jar tests are made in the laboratory to determine the approximate dosage (normally between 10 and 50 mg/L) of chemicals used that appear to produce the best results. Then, with this as a guide, the chemical dosing equipment, dry feed or solution feed, is adjusted to add the desired quantity of chemical proportional to the flow of water treated to give the best results. Standby chemical feed units and alarm devices are necessary to assure continuous treatment (See figure 3.10).

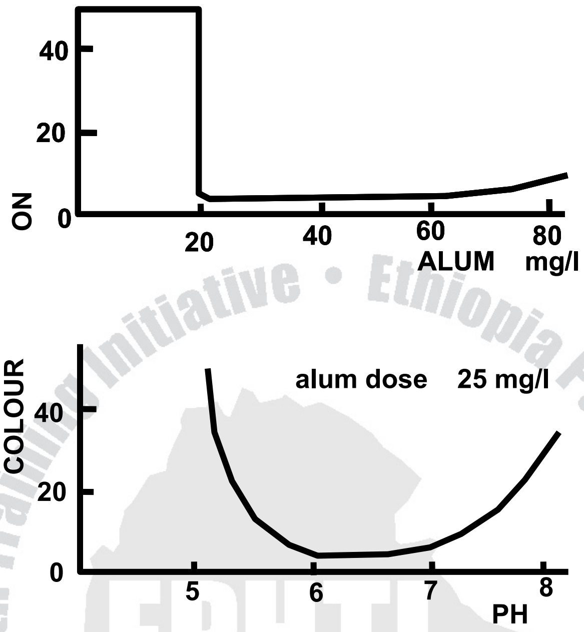


Figure 3.10 Jar- test results
(Adapted from Tebbutt. Principles of water quality control. 3rd edition, Pergamon press, 1983.)

2. *Zeta-potential* is also used to control coagulation. It involves the determination of the speed at which particles move through an electric field caused by a direct current passing through the raw water. Best flocculation takes place when the charge approaches zero, giving best precipitation when a coagulant such as aluminum sulfate, assisted by a polyelectrolyte (polymer), is added. Polymers may contain hazardous impurities. Quality control specifications should be met.

Advantages of the use of *alum, a polymer, and activated clay*:

a. May assist coagulation and clarification of certain waters
b. Faster setting and more filterable flock which is less effected by temperature change or excessive flows
c. Less plugging of filters, longer filter runs more consistent effluent turbidity, less back wash water, less sludge volume, and easier dewatering of sludge is claimed for polymer, clay- alum treatment

3. Another device for the coagulation and settling consists of a unit in which the water, to which a coagulant has been added, is introduced near the bottom, mixes with re-circulated sludge, and flows upward through a blanket of settled floc. The clarified water flows off at the top (see figure 3.11). Sludge is drawn off at the bottom.

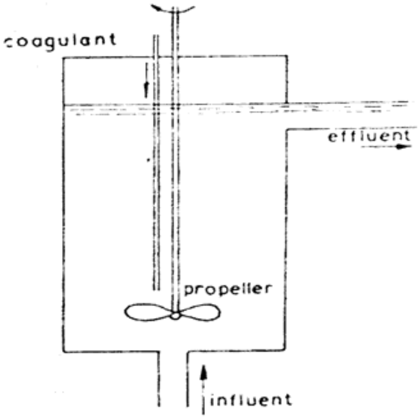


Figure 3.11 Rapid mixer

(Adapted from Tebbutt. Principles of Water Quality Control. 3rd edition, Pergamon Press, 1983.)

These basins are referred to as *up flow suspended-solids contact clarifier*. The detention period used in treating surface water is 4 hours, but may be as little as 11/2 to 2 hours depending on the quality of the raw water. The normal up flow rate is 1440 gpd/ sq feet of clarifier surface area and the overflow rate is 14,400 gpd per feet of weir (wall) length.

Advantage- A major advantage claimed, where applicable is reduction of the detention period and hence savings in space.

Disadvantages- include possible loss of sludge blankets with changing water temperature and variable water quality

4. Tube settlers are shallow tubes, usually inclined at an angle of approximately 60 degrees from horizontal. The tube cross section may be square, trapezoidal, triangular or circular. Effective operation requires laminar flow, adequate retention, non-scouring velocities, and floc particle settling with allowance for sludge accumulation and desludging at maximum flow rates. Pilot plant studies are advisable prior to actual design and construction.
5. *Lamella separators* are similar to the tube settlers except that inclined plates are used instead of tubes

Results expected

- Temperature- should preferably be < 60^0f
- Turbidity- A monthly average of 5 turbidity units may be permitted if it can be demonstrated that the turbidity does not interfere with disinfection maintenance of chlorine residual through out the distribution system. For the turbidity determination the standard measure is NTU. It uses nephelometer, which means the amount of light scattered, usually at 90^0 from the light direction by suspended particles in the water test sample greater
- Odour should be absent or very faint, not greater than 3 threshold odour number. Water for food processing, beverage, and pharmaceutical manufacture should be

essentially free from taste and odour. Colour should be <15 colour units

Ground and surface waters from mountainous areas are generally in the temperature range of $50-60^0$F

- Design and construction of water system should provide for burying or covering of transmission mains to keep drinking water cool and to also prevent freezing in cold climates or leaks due to vehicular traffic.

3.3.9 Filtration

The primary purpose of this unit is to remove suspended materials although microbiological organisms and color are also reduced. Filters are of the slow sand, rapid sand or other granular media (including the multimedia), and pressure (or vacuum) type each of which has application under various conditions. The slow sand filter is recommended for use at small communities and rural places, where adaptable. A rapid sand filter, because of the rather complicated control required to obtain satisfactory results, this requiring competent supervision and operation. It is recommended for urban with large population and skilled human-power. The pressure filter including the diatomaceous earth type is commonly used for the filtration of industrial water supplies and swimming poor water. It is not recommended for the treatment of drinking water unless under the conditions of the proposed use and except where considered suitable.

3.3.9.1 Slow Sand Filter (SSF) - A gravity based sand filter

A slow sand filter consists of a water tight basin, usually covered, built of concrete. The basin holds a special sand 30 to 48 in. (~75 to 120cm) deep, which is supported on a 12- to 18-in. (~30-45cm) layer of graded gravel placed over an under drain system that may consist of open-joint, porous, or perforated pipe or conducts. The sand should have an effective size of 0.25 to 0.35 mm and a uniformity coefficient not greater than 2.5 (See figure 3.12).

Operation of the filter is controlled so that the filtration will take place at a rate of 1 to 4 million gallons per acre per day with 2.5 million gal as an average rate. This would correspond to a filter rate of 23 to 92 gal/ft^2 of land area per day or an average rate of 57 gal. A rate of 10 million gal may be used if permitted by the approving authority.

Note that:

- 1 million gallons per day (mgd)= 1.547 cubic feet per second
- 1 cubic feet per second (cfs)= 0.646 million gallons per day
- 1 acre =43.560 ft^2,
- 1 pound per square inch (psi)= 2.31 ft vertical head of water
- 1 inch (in)= 2.54 centimeters (cm)

Water pressure – **h=P/w** where, P = pounds per ft^2

W = pounds per ft^3 ➔ 62.4 for water

h = head of water (ft)= $\underline{\ Px144}$=2.3 P,62.4 where, P is in psi **$h= V^2/2g$**

where, g=32.2ft/sec/sec,and

V=velocity, in fps

A *loss-of-head gauge* should be provided on the filter to show the resistance the sand bed offers the flow of water through it and when the filter needs cleaning. The loss-of-head through a clean filter is about 3" (~7.5cm) and this should be added to the maximum head required. The rate of filtration is controlled by a proper orifice and filter area, so as not to exceed the recommended rate that would endanger the quality of the treated water.

Expected maximum water flow (gal per day) = **rate** (gal/ft^2/day) x **filter area** (ft^2)

- A minimum of 2 to 3 ft (~60-90cm) of water over the sand is advised
- Design filter for twice the desired flow to assure air adequate delivery of water as the frictional resistance in the filter to the flow builds up.
- When no loss of head through sand and gravel or pipe is assumed, flow is based on:

$$\mathbf{Q = C_{\Delta}\, VA}, \text{ where, } V = \sqrt{2gh}$$

C_{Δ}= 0.6 with free discharge

Given the diameter of orifice in inches and maximum head (water), the maximum flow (gpd) can be found (from a table with diameters) to 1 and head from 1’ to 61/2’. Thus the filter area can be calculated using the formula:

$$\mathbf{A}\ (ft^2) \mathbf{=} \frac{\underline{\textbf{Max flow}}\ \text{(gpd)}}{\textbf{Flow rate,}\ \text{in gal/ } ft^2\text{/ day}}$$

Example. To find the size of the filter (let, A) that can yield 500 gpd at 50 gal /ft^2/ day will be:

$$A = \frac{500\ \text{gpd}}{50\ \text{gal}/(ft^2)(\text{day})} = 10ft^2$$

- From a practical stand point, the water that is to be filtered by the slow sand filter should have colour< 30 units, coliform concentration < 1000/100 ml and suspended matter with a turbidity of < 50 units, other wise the filter will clog quickly. Cleaning of the filter is done by draining the water out of the sand bed and scrapping 1 to 2 in (~2.5-5cm) of sand with adhering particles off the top of the bed. A scrapper or flat shovel is practical for removing the top layer of clogged sand. The sand is then washed and replaced when the depth of the sand is reduced to about 24 in (~60cm). The sand surface can also be washed (in place by a special washer traveling over the sand bed). Slow sand filters should be constructed in pairs. These filters are easily controlled and produce consistently satisfactory water, when followed by disinfection.

The level of the orifice or filter outlet must be above the top of the sand to prevent the developing of a negative head.

The filtered water storage should have at least two days’ storage capacity. The orifice is recommended to be 21/2 “diameter pipe. At least 6 in. of water over the sand will minimize possible disturbance of the sand when water from the influent line falls into the filter. Two glasses or clear plastic tubes are used to control or determine the frictional resistance to the flow of water through the filter, hence the need for cleaning the filter.

The tubes are calibrated before installation. They are assembled at equal elevation above the sand surface- one in the filter and the other in the filter storage compartments. The difference in water level between the two glass tubes represents the frictional resistance to the flow of water through the filter. When this difference approaches the maximum head and the flow is inadequate, the filter needs cleaning (See figure 3.13).

Inlet is just below frost while outlet is about 0.4” from floor of the filter storage. A well-operated plant will remove 98 to 99.5% of the bacteria in the raw water (after a film has formed on surface of the sand, which will require slow filtration for several days to 2 weeks. Chlorination of the filtered water is necessary to destroy those bacteria that grow or enter the storage basin and water system.

This type of plant will also remove about 25 to 40% of the colour in the untreated water. Chlorination of the sand filter itself is desirable.

Either continuously or periodically to destroy bacteria that grows within the sand bed, supporting gravel, or under drain system. Continuous pre-chlorination at a dosage to provide 0.3 to 0.5 mg/L in the water on top of the filter will not harm the filter film and will increase the life of the filter run.

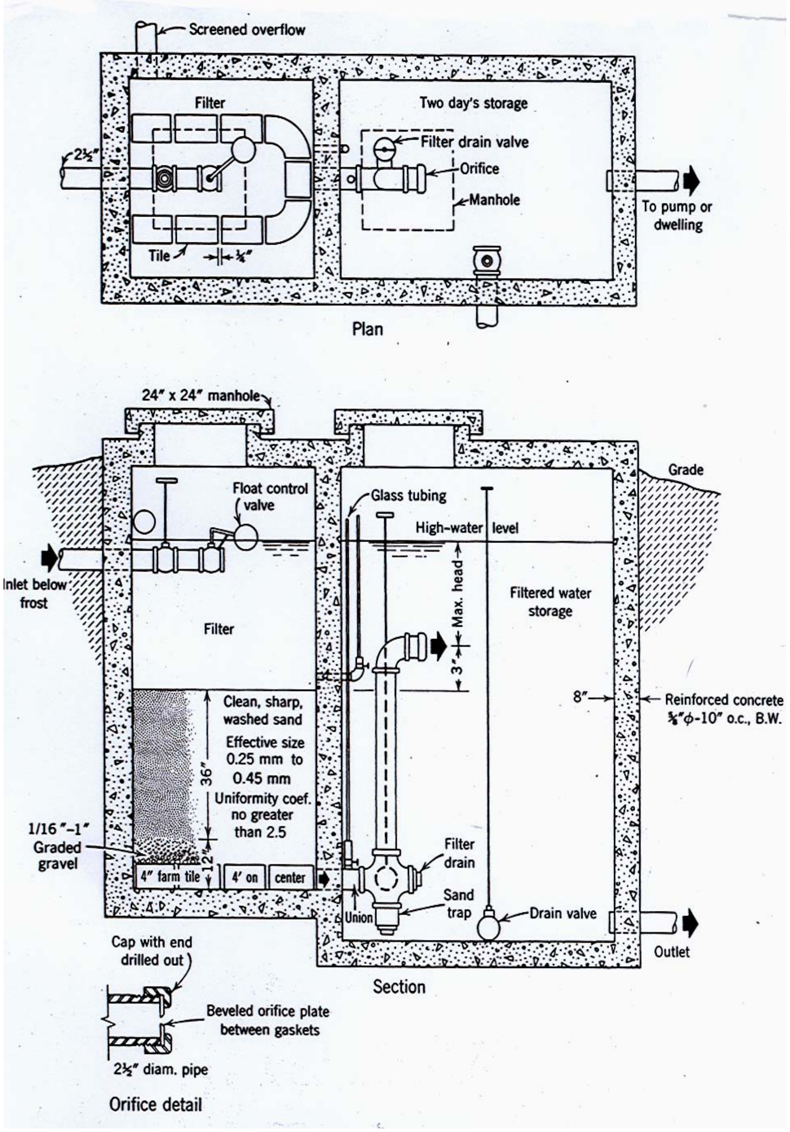


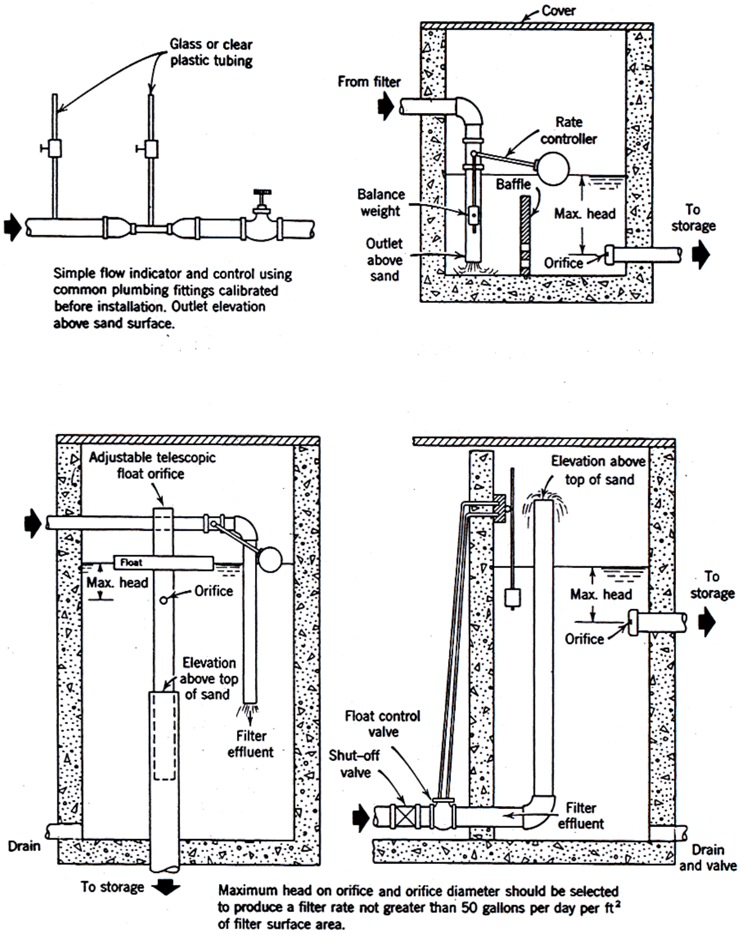
Figure 3.12 Slow sand filter for a small water supply.

(Source: J.A Salvato. Environmental engineering and sanittion. 4th ed. John Wiley & Sons, Inc. 1992 (pp. 351))

Filtering Mechanism in a Slow Sand Filter (SSF)

After the filter plant is installed according to the recommended design and construction, the water to be filtered is made to run through the layer of sand and grad gravel. Microorganisms (bacteria) in the raw water are trapped by the top layer of sand particles and start growing and multiplying. Gradually, they form a stick film layer, which traps the impurities including microorganisms from the water being filtered. As the spread of the film over the top surface of the sand increases, the quality of the filtered water increases, but the flow rate decreases. The future increase of the film layer both in thickness and surface area coverage causes further quality purification, but with further decrease in flow rate, which in its turn decreases the head of water coming out of the filtering media. Finally, a minimum rate of flow and water head is observed, which indicates the need for cleaning the filter media. This is done removing the few top layers of the sand as explained earlier.

When the formation of the gelatinous film on the top layer cannot take place on its own or when it is not sufficiently increasing as expected due to the less number of bacteria in the raw water, a section of such a film produced in other media or seeds of such organisms are used in order to enhance the mechanism of filtration. Strict precautions necessary as to the detection and removal of the possible microorganisms that may pass on to the filtered water and the proper disposal of the scrapped film/waste water from washing the sand scrapped with the film in order to replace it back.



Simple flow indicator and control using common plumbing fittings calibrated before installation. Outlet elevation above sand surface.

Maximum head on orifice and orifice diameter should be selected to produce a filter rate not greater than 50 gallons per day per ft^2 of filter surface area.

Figure 3.13 Typical devices for the control of the rate of flow or filtration.

(Source: J.A Salvato. Environmental engineering and sanittion. 4th ed. John Wiley & Sons, Inc. 1992 (pp. 353))

Slow sand filter is one of the oldest methods of purifying drinking water supplies. It is still effective especially for smaller communities. Regardless it is designed and constructed according to the recommended standard, and the unit process is regularly supervised and controlled. The type of raw water, type and effectiveness of the pretreatment given; the type, size, design and installation of the sand filter; regular and proper cleaning of the filter media; and the proper regulation of the quality of the filtered water are the critical areas to focus upon, for achieving the expected outcome and its consistency.

The other advantages of SSF are its running (operation) cost is low. Further more once properly designed and constructed, its operation doesn't necessarily need skilled human-power. The main disadvantage lies in its installation cost due to cost of large area of land it requires.

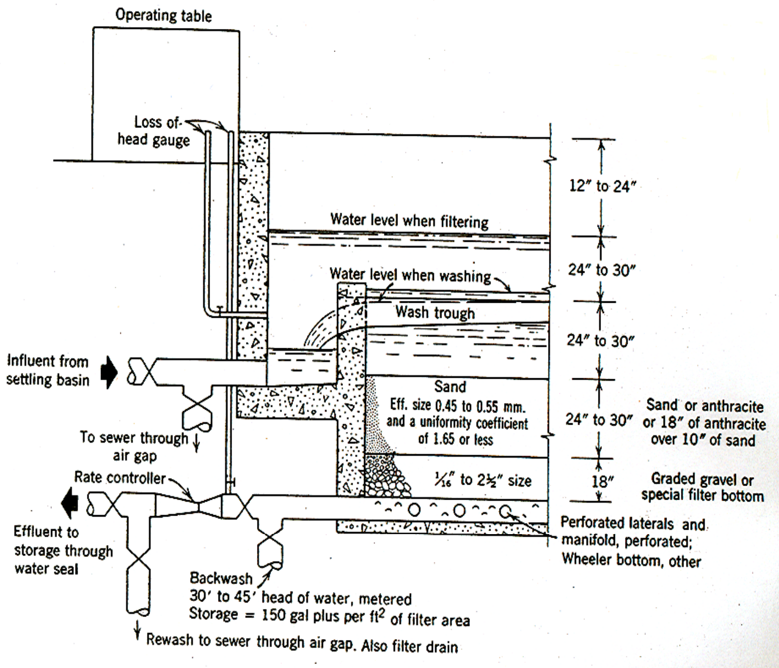
3.3.9.2 Rapid sand filter (RSF) or granular media filter (GMF)

A rapid sand gravity filter, also referred to as a granular media and mechanical filter, is shown in figure 3.14below.

Two important accessories to a rapid sand filter are the loss-of-head gauge and the rate controller:

- ❖ The lose-of-head gauge shows the frictional resistance to the flow of water through the sand, laterals, and artifices. When this reaches about 7 ft. with sand and 5 ft (~1.5m) with a dual media, it indicates that the filter needs to be backwashed.

- The rate controller is constructed to automatically maintain a uniform predetermined rate of filtration through the filter usually about $3 gpm/ft^2$, until the filter needs cleaning.



The minimum total depth is $8\frac{1}{2}$ ft, 12 ft preferred.

$$\text{Rate of filtration} = \frac{7.48}{\text{minutes for water in filter to fall 1 ft'}};$$

fill filter with water, shut off influent, open drain

Backwash time = 10 to 15 min minimum, until water entering trough is clear

Normal wash-water usage = 2 to 2.5% or less of water filtered

Sand expansion = 40 to 50% = 33.6 to 36 in. for 24-in. sand bed

= 25 to 35% for dual media, anthracite and sand

$$\text{Rate of backwash} = \frac{7.48}{\text{minutes for water in filter to rise 1 ft'}};$$

lower water level to sand, slowly open backwash valve,

20 to 25 gpm/ft^2 minimum (32 to 40 in. rise/min)

Orifice area = 0.25 to 0.30% of filter area

Lateral area = 2 × orifice area

Manifold area = 1.5 to 2 × total area of laterals

Figure 3.14Essential parts of a rapid sand filter

(Source: J.A Salvato. Environmental engineering and sanittion. 4th ed. John Wiley & Sons, Inc. 1992 (pp. 354))

Disturbance of filtrate or excessive head loss may cause break through of suspended particles and filter flock. Filter design and operation should reduce the possible magnitude of filter fluctuations. A filter rate of 3 to 4 gal or higher may be permitted with skilled operation, if pre-treatment can assure water on filter has a turbidity of less than about 10 and preferably 3 units and a coliform concentration of less than 2:2. Sand for the higher rate would have an effective size of 0.5 to 0.7 mm and a uniformity coefficient of 1.5 to 2.0.

In a combination of anthracite over sand bed, use is made of the known specific gravity of crushed anthracite of about 1.5 and the specific gravity of sand of 2.5 to 2.65. The relative weight of sand in water is three times that of anthracite. Fair and Geyer have shown that anthracite grains can be twice as large as sand grains and that after backwashing the sand will settle in place before the anthracite in two separate layers. Combination of sand –anthracite filters require careful operating attention and usually use of filter conditioner to prevent floc passing through while at the same time obtaining a more uniform distribution of suspended solids throughout the media depth. Longer filter runs such as 2 and 3 times the conventional filter, at rates of 4 to 6gpm/ft^2 and up to 8 or 10gpm/ft^2 and less wash water are reported.

Treatment of the row water by coagulation, flocculation, and settling to remove as much as possible of the pollution is usually a necessary and important preliminary step in the rapid sand filtration of water. Water, after the preceding settling process in passing to the filter carries with it some flocculated suspended solids, colour, and bacteria. These form a matt on top of the sand that aids greatly in the straining and removal of other suspended matter, colour, and bacteria, but this also causes rapid clogging of the sand. Special arrangement is, therefore, made in the design for washing the filter by forcing water backward up through the filter at a rate that will provide a sand expansion of 40 to 50% based on the water temperature and sand effective size. The following examples best illustrate the association among the four factors: *effective sand size, % sand expansion, wash-water rate rise and temperature.*

- With a 0.4mm effective size sand, a 40% sand expansion requires a wash-water rate rise of 21 in/min with 32g water; and
- A rise of 33 ½ in" with water at 70^0F, sand effective size and percent expansion of sand being constant.
- The dirty water is carried off to the waste by troughs built in above the sand bed 5 to 6 ft (~1.5-1.8m) apart. A system of scrape or a 1½" to 2" pressure line at 45 to 75 psc (pounds/square inch) with hose connection should be provided to clean the surface of the sand to assist in loosening and removing the material on the sand. Effective washing of the sand is essential.

Advantages

- When properly operated, a filtration plants, including coagulation, and settling of the bacteria, can remove a great deal of the odour, and colour, and practically all the suspended solids. However, safety for drinking water is guaranteed only after disinfection.
    - Larger amount of water filtration at ≈ 4320gpd very little time.
    - Less land requirement for construction
    - Less manual work, as the plant is mostly operated (mechanically).

Disadvantages

- Needs skilled human power. Construction of a rapid sand filter should not be attempted unless it is designed and supervised by a competent sanitary engineer.
- Not effective/can not be used for all raw waters, unless preceded by coagulation, flocculation and settling, and the water brought within the permissible limits.
- The MPN of coliform organisms in the raw water cannot exceed 5000/100ml.
- Removal of protozoa (Giardia cyst) and viruses cannot be assured unless the granular media filtration (RSF) is assisted by adequate coagulation, flocculation and settling a head of it and disinfection after.

3.3.9.3 Direct Filtration

It is a recent type of filtration using waters with low suspended matter and turbidity, colour, coliform organisms, and plankton, and free of paper fibers. It has been attractive because of the lower cost in producing a good quality water, if substantiated by prior pilot plant studies reflecting seasonal variations in raw water quality. In direct filtration, the sedimentation basin is omitted. The unit processes prior to filtration (dual or mixed media) may consist of only rapid mix, rapid mix and flocculation, or rapid mix and contact basin (1-hr detention) without sludge collector. A flocculation and contact basin is recommended for better water quality control. A polymer is usually used in addition to a coagulant.

Direct filtration can be a good possibility if:

1. The raw water turbidity and colour are each less than 25 units.
2. The colour is low and the maximum turbidity does not exceed 200 NTU; or
3. The turbidity is low and the maximum colour does not exceed 100 units.

The presence of paper fiber or of diatom in excess of 1000 areal standard units/milliliter (asu/ml) requires that settling (or Microscreening) be included in the treatment process chain. Diatom levels in excess of 200 asu/ml may require the use of special coarse coal on top of the bed in order to extend filter runs. Coliform MPNs should also be low.

While good operation control is essential, decreased chemical dosage and hence sludge production, but increased filter wash water, will usually result in reduced net cost.
Disadvantage's they can only work under the above criteria.

3.3.9.4 Pressure Sand Filter

It is similar in principle to the rapid sand gravity filter except that it is completely enclosed in a vertical or horizontal cylindrical steel tank through which water under pressure is filtered. The normal filtration rate is 2gpm/ft^2 of sand; but higher rates are also used. Pressure filters are most frequently used in swimming pool and industrial plant installations, and for precipitated iron and manganese removal (See figure 3.15).

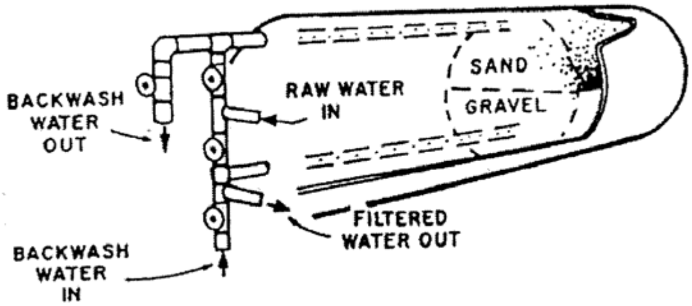


Figure 3.15 Pressure Filter cutaway

(Adapted from Pfaffin J.R. and E.N. Ziegler. Encyclopedia of Environmental Science and Engineering. 2nd edition, volume 3, Q- Z Gordon and Breach Science Publishers, 1983.)

Advantage – it is possible to use only one pump to take water from the source or out of the pool (and force it through the filter and directly into the plant water system or back into the pool).

Disadvantages:

1. Difficulty in introducing chemicals under pressure,
2. Inadequate coagulation facilities,
3. Lack of adequate settling,
4. The appearance of the water being filtered and the condition of the sand cannot be seen;
5. The effectiveness of backwashing can not be observed,
6. The safe rate of filtration may be exceeded; and
7. It is difficult to look inside the filter for the purpose of determining loss of sand or anthracite need for cleaning, replacing of the filter media, and inspection of the wash water pipes, influent, and effluent arrangements.

Because of these disadvantages and weaknesses, a pressure filter is not considered dependable for the treatment of contaminated water to be used for drinking purposes. Nevertheless, it may have limited application for small, slightly contaminated water supplies and for turbidity remova.l In which such cases, the water should be coagulated and flocculated in an open basin before being pumped through a pressure filter. This will require double plumping.

3.3.9.5 Diatomaceous Earth Filter

There are two types of diatomaceous earth filters: *the pressure type*, which consists of a closed steel cylinder inside of which are suspended septa, the filter elements; *the vacuum type*, where the septa are in an open tank under water that is re-circulated with a vacuum inside the septa. Normal rates of filtration are 1 to 1½ gpm/ft^2 of element surface (See figure 3.16).

In preparing the filter for use, a slurry or filter aid (precoat) of diatomaceous earth is introduced with the water to be treated at a rate of about 1½ oz/ft^2 of filter septum area, which results in about 1/16 in. depth of media being placed evenly on the septa, and the water is recirculated for at least 3 min before discharge. Then additional filter and (body coat) is added with the water to maintain the permeability of the filter media. The rate of feed is roughly 2 to 3mg/L per unit of turbidity in the water. Filter aids are available in different particle sizes. If forms a coating or mat around the outside of each filter element and is more efficient than sand, because of smaller media pore size, in removing from the water suspended matter and organisms such as cysts of amoeba and giardia, cercariae of schistosomes, flukes of fasciola, and worms of ascaris and trichuris.

The diatomite filter has also found greatest practical application in swimming pools, iron removal of ground waters, and industrial and military installations. It has a special advantage in the removal of oil from condensate water, since the diatomaceous earth is wasted. *The filter should not be used to treat a public water supply unless pilot plant study results on the water to be treated meet the requirements related to health in the regulatory issues.*

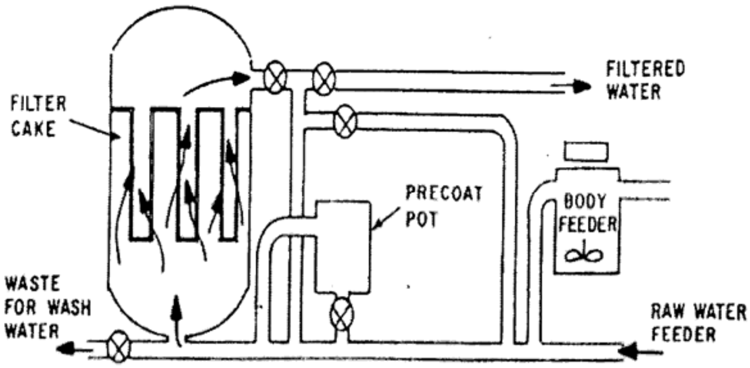


Figure-3.16 Diatomaceous earth filter

(Adapted from Pfaffin J.R. and E.N. Ziegler. Encyclopedia of Environmental Science and Engineering. 2nd edition, volume 3, Q- Z Gordon and Breach Science Publishers, 1983.)

Disadvantages/Weaknesses

A) A major weakness is that failure to add diatomaceous earth to build up the filtering mat, either through ignorance or negligence, will make the filter entirely ineffective and give a false sense of security.

B) Clogging of the septa, requires replacement or removal and chemical cleaning.

C) The head loss through the filter should not exceed 3o lb/in.^{2}, during filtration, thereby requiring a pump and motor with a wide range in the head characteristics.

D) Cannot be used where pump operation is intermittent, for the filter cake will slough off unless sufficient continuous recirculation is provided by a separate pump.

Backwashing – filter backwashing is done by reversing the flow of the filtered water back through the septa, thereby forcing all the diatomite to fall to the bottom of the filter shell, from which point it is flushed to waste. Only about 0.5% of the water filtered is used for backwash when the filter run length equals the theoretical or design length.

The filter should not be used to treat raw water with greater than 2400 MPN/100 ml, 30 turbidity units, or 3000 areal standard microscopic units per 100ml. It does not remove taste and odour producing substances. In any case, chlorination is considered a necessary adjunct to filtration. The diatomite filter must be carefully operated by trained personnel in order to obtain dependable results.

3.3.10 Water-Treatment Plant Wastewater and Sludge

Water-treatment plant sludge from plain sedimentation and coagulation-flocculation settling basins and backwash wastewater from filters are required to be adequately treated, prior to discharge to a surface water course. The wastes are characteristic of substances in the raw water and chemicals added in water treatment. They contain suspended and settleable solids (including organic and inorganic chemicals) as well as trace metals, coagulants (usually aluminium hydroxide) and polymers, clay, lime, powdered activated carbon, etc. The aluminum would interfere with fish survival and growth.

The common waste treatment and disposal processes include:

- Sand sludge drying beds -- where suitable,
- Lagooning – where land is available,
- Natural or artificial freezing and thawing,
- Chemical conditioning of sludge using inorganic chemicals and polymers to facilitate dewatering, and
- Mechanical dewatering by centrifugation, vacuum filtration, and pressure filtration.

Sludge dewatering increases sludge solids to about 15 to 20 percent. The use of a filter press involves a sludge thickener, polymer, sludge decant, lime, retention basin, addition of a precoat, and mechanical dewatering by pressure filtration. The filter cake solids concentration is increased to 40% (from the sludge 10%); it can be disposed of to a landfill when permitted.

The use of a polymer with alum for coagulation could cut the amount of alum used to less than one-fifth, the cost of coagulant chemicals by one-third, and the sludge produced by over fifty percent. Lime softening results in large amounts of sludge, increasing with water hardness. Recovering and recycling of lime may be economical at large plants. Sludge may be disposed of by lagooning, discharge to a wastewater treatment plant, or mechanical dewatering and land filling, depending on feasibility and regulations.

3.3.11 Disinfection

Disinfection is killing infectious agents outside the body by chemical or physical means. It is any chemical or physical process to destroy or remove undesirables present on the person, animal, plant, or in the environment.

Disinfection, as a unit process in conventional water treatment system, is the step (unit) at which chemicals or physical substances (disinfectants) are applied to the water under treatment in order, mainly to destroy disease-causing organisms in the water during the application as well as those, which may enter the water system thereafter, so as to make the water safe/ free of pathogens up to the stages of human consumption or other intended uses of the disinfected water.

The most common chemicals used for the disinfection of drinking water are chlorine (gas and hypochlorite or chlorine compounds), chlorine ammonia, chlorine dioxide and ozone. Other disinfectants that may be used under certain circumstances include ultraviolet radiation, bromine, iodine, silver and chlorinate lime.

Chlorination is the most common method of destroying disease-producing organisms that might normally be found in water used for drinking. This emanates from the following characteristics of chlorine and its compounds used as water disinfectants:

- The disinfectants readily kill the pathogens
- The disinfectants readily combine with the undesirable substances to inactivate or remove them.
- They are easy to utilize (comparatively) and are readily available (utilize implies prepare, apply and detect).
- After fulfilling the purpose in the first place, they also remain as a “reserve army” in the system to avoid the undesirables should they come later into the system.
- They are relatively of low cost which permits they widely use.

Some of the **disfavored properties of chlorine** are:

- Its volatility (especially gas chlorine)
- Its being poison, especially when used in excess amount
- Its ineffectiveness, especially when micro-organisms are shielded by turbidity or others
- Hypochlorite is corrosive and may produce severe burns, unless stored in the original containers in a cool, well-ventilated, dry place
- Its toxicity to fish and other aquatic life
- Its being suspected of being a carcinogen.

Table 3.2 Availability, forms of chlorine, and its compounds

Chlorine and its Compounds	**% chlorine**	**Form of existence (availability)**
1. Gas/ liquid chlorine	100	gas/ liquid in a closed cylinder
2. Hightest Hypo (per chlorine) Chlorite (potassium)	10	Powder
3. Chlorinated lime	25	Powder
4. Sodium hypo chlorite	14	Powder
5. Bleaching soda	5	Liquid ('Barakina')
6. Halazon	4	Tablet

(Source: J.A Salvato. Environmental engineering and sanittion. 4th ed. John Wiley & Sons, Inc. 1992 (pp. 354))

Chlorine and its compounds may be used in conventional water treatment system for the following purposes:

1. To kill algae, reduce some organic matter that cause odour, taste, and colour problems; the usage at this phase (in raw water for treatment) is known as pre-chlorination; the amount of chlorine to be added depends on the impurity. The addition can be continuous or intermittent.

2. To destroy the bacteria that may grow within the sand bed supportive gravel or under drain system. The addition can be periodical or continuous; the latter is usually true for slow sand filters. The chlorination is done at a dosage to provide 0.3 to 0.5 mg/L in the water on top of the filter. This chlorination is also termed as pre-chlorination.
3. To kill all pathogenic microorganisms as well as other undesirable substance in drinking water supplies at the treatment plant (after filtration) as well as in the distribution system up to the consumer. This type of chlorination is called post-chlorination or disinfections is done on a continuous basis, as will be explained later.
4. To kill or eliminate the coliform organisms and others entered into the distribution system as a result of a surface water supply or an inadequately filtered water supply coming into contact with treated water in the distribution system. These contaminants may include coliform organisms, organic matter, minerals and sediment, fungi, algae, macroscopic and microscopic organisms. They may pass through or settle in the mains or become attached and grow in the mains when chlorination is marginal or inadequate to destroy them suspended matter and iron deposits (favoring iron bacteria) will mater single with and harbor the growths.

Therefore, a positive program of continuous heavy chlorination at the rate of 5 to 10 mg/L coupled with routine flushing of the mains is maintained to obtain a free chlorine residual of at least 0.2 to

0.4 mg/L in active parts of the distribution system. Unless this residual chlorine is attained which indicates the removal of the organisms, bacteriological control of the water supply is lost. The rapidity with which a contaminated distribution system is cleared will depend on factors such as uninterruption of chlorination even momentarily; the chlorine residual maintained in the entire system, the growth in the mains and degree of pipe incrustation conscientiousness in flushing the distribution system; the social, economic and political deterrents; and mostly the competency of the responsible individual.

5. Similar chlorination process can be done at post chlorination stage in reservoirs (storage facilities) when found open to contamination.

3.3.11.1 The dosage of chlorine

The dosage of chlorine to treat a water supply system depends on:

a. Chlorine demand, and
b. The required residual chlorine to be available in the system at any time and in any place (in the system includes taps at individual premises and building fixtures)

a. Chlorine demand: is the amount of chlorine to be consumed in the water in reacting with the impurities in the water and in destroying the microorganisms and others during a specific time incrustation- formation of a hard outer covering. The required chlorine dosage should take into consideration.

- Pollution of the source of water (appearance as well as the quality of the water)
- The type of microorganisms likely to be present
- The PH of the water → the disinfecting capacity of chlorine HOCl decrease as the PH increases
- The temperature of the water, and
- The degree of treatment the water receives
- B. Residual chlorine- is the amount of chlorine available in the water system after the demand for chlorine is satisfied. The availability can be in the form of hypochlorous acid (HOCl) or hypochlorite (OCl^-) in which case it is known as free chlorine residual, or in the form of chlorine compounds (usually with nitrogenous compounds known as combined chlorine residual. Total residual chlorine in water is the sum of the free and combined residual chlorine present in the water at the time of measurement.
- In order to understand about the dose the demand and the residual chlorine in relation to water treatment it is better to go through the following briefing on the reaction of chlorine in water is very important.

3.3.11.2 Reaction of chlorine in water

In the presence of ammonia, organic matter and other chlorine consuming materials, the required chlorine dosage to produce a free residual will be high. The following 5 steps explain the reaction of chlorine in water after it is added to:

1. Destruction of chlorine by reducing compound; at this step, no disinfection takes place
2. Chloro-organic compounds are formed; only little disinfections is done here
3. Ammonia plus chlorine producing chloramines
4. Chloramines and Chloro-organic compounds destroyed
5. Free chlorine and the remaining Chloro-organic compounds are found in water

Due to these reactions (requiring high chlorine dosage) in it, the water is said to have a high chlorine demand. The **generic** idea efficiency of chlorine is primarily dependent on the present free chlorine that is in the form of hypochlorous acid (HOCl), which in turn is dependent on the pH and temperature of the water. (**See table 3.3**)

Free residual chlorination is the addition of sufficient chlorine to yield free chlorine residual in the water supply in an amount equal to more than 85 percent of the total chlorine present. When the ratio of chlorine to ammonia is 5:1 (by weight), the chlorine residual is all mono-chloramines; when the ratio reaches 10:1 dichloride (chlorine) is also formed; when the ratio reaches 15 or 20:1 nitrogen tri chloride is formed. Nitrogen tri chloride as low as

0.05 mg/L causes an offensive and acrid odour that can be removed by carbon, aeration, exposure to sunlight, or forced ventilation indoors. It is also highly explosive.

$$2NH_3 + Cl_2 \rightarrow 2NH_2 Cl + H_2O$$

$$2NH_2 Cl + Cl_2 \rightarrow NH Cl2 + H_2O$$

$$2NHCl_2 + Cl_2 \rightarrow 2NCl_3 + H_2O$$

The mono; and dichloramines have fairly some disinfecting power, though they act slowly and gradually, while nitrogen tri chloride has almost no disinfecting capacity. The former also elongate the residual effect water having a turbidity of less than 5 NT (ideally less than 0.1), a PH less than 8.0 and HOCl residual of 1 mg/L after 30 min contact provides an acceptable level of protection.

With free residual chlorination, water is bleached and iron, manganese, and organic matter are coagulated by chlorine and precipitated particularly when the water is stored in a reservoir or basin for at least 2hr. Most taste and odour producing compounds are destroyed the reduction of sulfates to taste and

Table 3.3 Chlorine residual for effective disinfection of filtered water

Approximate percent at 68 to 32^{0}F (10-0^{0}C)				Bactericidal treatment		Cysticidal treatment		
S.No	**pH**	**HCl**	**OCl**			**At 36 to 41 ^{0}F**	**60^{0}F**	**78^{0}F**
1.	5.0	-	-	-	-	-	2.3	-
2.	6.0	98 to 97	2 to 3	0.2	1.0	7.2	-	1.9 ^{d}
3.	7.0	83 to 75	17 to 25	0.2	1.5	10.0	3.1	2.5 ^{d}
4.	7.2	74 to 62	26 to 38	-	-	-	-	2.6 ^{d}
5.	7.3	68 to 57	32 to 43	-	-	-	-	2.8 ^{d}
6.	7.4	64 to 52	36 to 48	-	-	-	-	2.0 ^{d}
7.	7.5	58 to 47	42 to 53	-	-	14.0^d	4.7	3.2 ^{d}
8.	7.6	53 to 42	47 to 58	-	-	-	-	3.5 ^{d}
9.	7.7	46 to 37	53 to 64	-	-	16.0^d	6.0	3.8 ^{d}
10	7.8	40 to 32	60 to 68	-	-	-	-	4.2 ^{d}
11	8.0	32 to 23	68 to 97	0.4	1.8	22.0	9.9	5.0 ^{d}
12	9.0	5 to 3	95 to 97	0.8	Reduce	-	78	20.0 ^{d}

					pH of water to below			
13.	10.0	0	100	0.8	9.0	-	761	1706

(Source: J.A Salvato. Environmental engineering and sanittion. 4th ed. John Wiley & Sons, Inc. 1992)

Free available chlorine HOCl+ OCl. Combined available Chlorine = chlorine bound to nitrogenous matter as chloramines. Only free available chlorine or combined available chlorine is measured by percent testing methods, therefore, to determine acute free chlorine (HOCl), correct reading by percent shown above "chlorine residual", as the term is generally used, is the combined available chlorine and free available chlorine= total residual chlorine. When the chlorine to ammonia reaches 15 or 20:1 nitrogen tri chloride is formed, it is acid and highly explosive. Ventilate: Viricidal treatment requires free available chlorine of 0.53 mg/L at pH 8.5 in 32^0F demand free water. For water at a temperature of 77 to 82.4^0F and pH 7 to 9, free available chlorine of 0.3mg/l is adequate. At a pH 7 and temperature of 77^0F at least 9 mg/L combined available chlorine is needed with 30 min contact time. Turbidity should, be less than one Jackson unit. All the results are based on studies made under laboratory conditions using water free of suspended matter and chlorine demand. In practice, unless other wise indicated, at least 0.4 to 5 mg/L free residual chlorine for 30 min or 2mg/L combined residual chlorine for 3hr. should be maintained in a clear water before delivery to the consumer. The regulatory body (Health department) may require more dependent on source of raw water and sanitary survey.

- Expression: All residual chlorine results are reported as mg/L one mg/L hypochlorous acid (HOCl) gives 1.35 mg/L free available chlorine as OCl distributed as noted above the HOCl component is the markedly superior disinfectant, about 40 to 80 times more effective than the hypo chlorite ion (OCl)

3.3.11.3 Break point chlorine

It is the point at which chlorine added to the water satisfies the chlorine demand of the water and starts increasing in the water as free residual chlorine. After the break point, the amount of chlorine added to the water and the amount of fee residual chlorine are equal, unless now pollution is encountered. The chlorine in the treaded water there after acts as a stand by army in the distribution odour producing sulfides is prevented; and objectionable growths and organisms in the mains are controlled or eliminated provided a free chlorine residual is maintained in the water an indication of an accidental pollution of water in the mains is also obtained if the free residual chlorine is lost, provided chlorination is not interrupted (See figure 3.17).

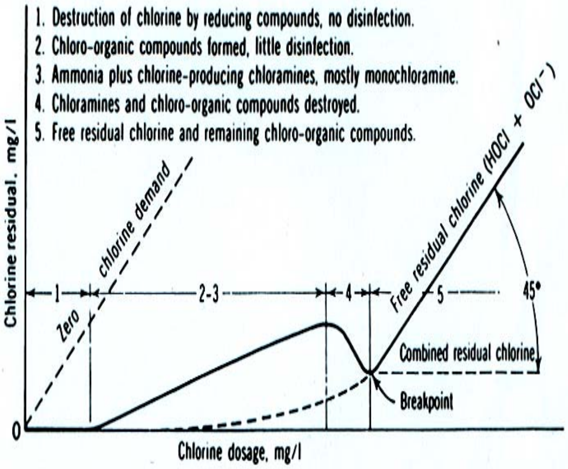


Figure 3.17 The reaction of chlorine in water.

(Source: J.A Salvato. Environmental engineering and sanittion. 4th ed. John Wiley & Sons, Inc. 1992 (pp. 351))

Laboratory studies (Kelly and Sanderson)

Indicated that depending on PH and temperature, residual chlorine values of greater than 4 ppm, with 5 min contact or per contact periods of at 4 hr with a residual chlorine value of 0.5 ppm are necessary to inactivated the virus of poliomyelitis at PH of 6.85 to 7.4 in 2 hr coagulation settling filtration and chlorination to 1.1 mg. L total and 0.4 mg/ L free chlorine was effective against infectious hepatitis virus. Removal of nematodes requires pre-chlorination to produce 0.4-to 0.5-mg/L residual after 5 hrs retention followed by settling. Fungicidal action is obtained at a PH of 7.4 and at a water temperature of 26^0C with 0.35 mg/l free chlorine after 4 hrs contacts and with 1.8-mg/L free chlorine after 35 min contact. In general water to be treated by chlorination should be relatively clear and clean with an average monthly MPN of coliform bacteria of $\leq$ 50/100 ml

3.3.11.4 Ways of feeding chlorine

(into water supplies and the underlying precautions)

Equipment tool for feeding chlorine is known as a chlorinator. In conventional water treatment system operation of the chlorinator should be automatic. Proportional to the flow of water and adjusted to the temperature and pH chlorine on line as well as a complete set of spare parts for the equipment so as to make possible immediate repair the chlorinator should provide for the positive injection of chlorine and be selected with.

Granular activated carbon due regard to pumping head and maximum and minimum flow of water to be treated. The point of chlorine application should be selected so as to provide adequate mixing and at least 15 min, preferably 30 min, chlorine contact with the water to be treated before it reaches the first consumer. Hypo-chlorinators are generally used to feed relatively small quantities of chlorine at 1 to 5 percent sodium or calcium hypochlorite solution. Positive feed machines are fairly reliable and simple to operate (See figure 3.18).

Chlorine to be feed into a water system for disinfections can be in powder liquid or gas or tablet form. While the gas form is usually used for treating large quantities of water mandatory mechanically, tablet chlorine is for small quantities of water, more often to disinfect individual water supplies applied manually. When using the powder form, make a paste with a little water then dissolve the paste in a recommended amount of water. Allow the solution to settle and then uses in clean liquid with out wasting time and hence should be made up fresh once a week. It is important to allow the treated water to stand for 3 min after the chlorine is added before it is used double the chlorine dosage if the water is turbid or coloured.

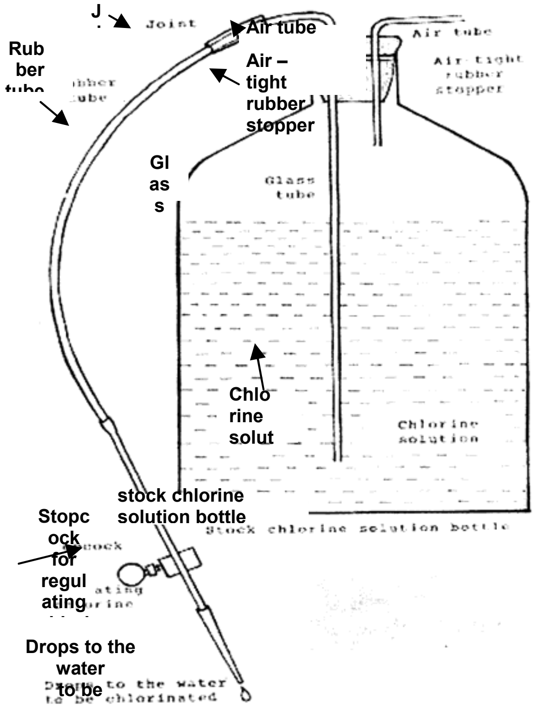


Figure 3.18 An Emergency Siphon Chlorination

(Adapted from Gabre- Emanual Teka. Water upply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Chlorine containing tablets (halazones) are suitable for use on camping, hunting, liking, and fishing trips. The tablets contain 46 grams of chlorine and they deteriorate, with age. As these are chloramines and chlorine are slow-acting disinfectants the treated water should be allowed to stand at least 60 min before being used.

Gas chlorinator

When a dry feed gas chlorinator or a solution feed gas chlorinator is used. The chlorinator and liquid chlorine cylinders should be located 1 gram= 64.8 mg calcium hypochlorite is in powder form, while sodium hypochlorite is in liquid. Separate gas-tight rooms that are mechanically ventilated to provide low air changes per minute with the exhaust openings at flow level opposite the air inlets. Exhaust ducts must be separate from any other ventilating system of ducts and extended to a height and location that will not endanger the public personnel or property and ensure adequate dilution. The door to the rooms should have a glass inspection panel and a chlorine gas mask or self- contained breathing apparatus approved by the regulatory body, should be available out side of the chlorinator and chlorine cylinder rooms. (The chlorine canister type of mask is suitable for low concentrations of chlorine in air while the self-contained breathing apparatus (pressure demand) is recommended for high concentrations of chlorine. The temperature around the chlorine cylinders should be between 50 to 85^0F and cooler than the temperature of the chlorinator room to prevent condensation of chlorine in the line conducting chlorination or in the chlorinator. Cylinders must be stored at a temperature below 140^0F. A flat form scale is needed for the weighing of chlorine cylinders of used to determine the pounds of chlorine used each day and to anticipate when a new cylinder will be needed.

> *N.B*: A chlorine contain along 100 lb of chlorine developing a leak that cannot be repaired can have the chlorine absorbed by 125 Ib of caustic soda in 40 gal of water; 300 Ib of soda ash in 100 gal of water, or 125 Ib of hydrated lime in 125 gal of water continuously agitated.

Cylinders should be connected to manifold so that chlorine may be drawn from several cylinders at a time and so that cylinders can be replaced without interruption of chlorine. In order to prevent clogging by chlorine ice, it is recommended not to draw more than 35 to 40 Ib of chlorine per day at a continuous rate from 100- or 150 Ib cylinders. Liquid chlorine comes in 100- and 150 Ib cylinders, in 1- ton containers and in 16 to 90 ton tank cars. There are also smaller cylinders. The major factors affecting withdrawal rate are ambient air temperature and size and type of cylinder.

The normal operating temperature is 70^0F. A relatively clear source of water of adequate volume and pressure is necessary to prevent clogging of injectors and strainers and to assure proper chlorination at all times. The water pressure to operate a gas chlorinator should be 15 psi and about three times the backpressure (water pressure at point of application plus friction loss in the chlorine solution hose, and difference in elevation between the point of application and chlorinator) against which chlorine is infected. About 40 to 50 gpd of water is needed per pound of chlorine to be added.

To assure that only properly treated water is distributed, it is important to have a component and trust worthy person in charge of the chlorination plant. He/she should keep daily records showing the amounts of water treated, the amount of chlorine used and its strength, the gross weight of chlorine cylinders if used the setting of the chlorinator the time residual chlorine tests made, the results of such tests, and any repairs or maintenance, power failures modifications or unusually occurrences the treatment plant or water system

Reading assignment to students: please read and take notes on the different types of chlorinators for small quantities and emergency water supply from J.A. Salvato (1982) p.p.368-372.

3.3.11.5Testing for Residual Chlorine

The recommended tests for measuring residual chlorine in water are the DPD (SNORT) methods. All tests should be made in accordance with accepted procedures. The leucocrystal violet method is also satisfactory. It determines free available chlorine with minimal interference from combined chlorine, iron, nitrates and nitrites. DPD is considered a more accurate field test.

However, studies showed that the best accuracy and precision was obtained by leucocrystal violet and the standardized neutral orthot (SNORT) procedures followed by DPD titrimetric amperometric filtration, DPD- colorimeteric, and methyl orange by for the best the orthotolidine arsenate (OTA) procedure.

In another study (Gutter, et al) it was reported that **syringaldaznie** the most specific for free available chlorine and DPD more accurate and precise over temperature and pH variations. The SNORT procedure showed false positive readings for free available chlorine in the presence of combined chlorine. Combined chlorine can also cause interference with DPD method if readings are not made with in one minute.

3.3.11.6 Preparation of chlorine stock solutions

Chlorine stock solutions are usually prepared as 1 percent (0.01) available chlorine and updated at least every week. The following steps are followed when calculating 1mg the stock solution from compounds containing a certain percentage of available chlorine.

1. Change the different units into one unit by using the proper changing factors
2. Find the amount of water to be treated at the rate intended to be treated
3. Find the amount of the disinfectant need to disinfect the calculated water at the specified rate 4/1 this being from the percentage of the available chlorine in the

compound find the 100% strength in the unit planned to be measured.

E.g. Find the amount of calcium hypo chlorite (powder in oz) that is needed to disinfect 1000 gal of water at 1 mg/L

Solution

1. 1gal =3.785L, =28359 mg
2. 1000 gal = 3785 L
3. at 1 mg/L 3785 L 3785x 1mg= 3785mg
4. 3785/28350 =0.133097 oz

If 0.1335097 oz is from 100% available chlorine, what amount is needed from 70%?

➔ 100/70 x 0.1.335097 oz

NB 1/100 = 10,000/1000000 ≈ 0.190728 oz

≈ 0.2oz

➔ Stock solutions ➔ 1/100 available chlorine

Class work

a. Calculate the above question from 5.2% available chlorine
b. From 25% available chlorine

3.3.11.7 Other disinfectants/Iodine, Ozone/

Sight drops of 2 percent tincture of iodine (8mg/dose may be used to disinfect 1 qt of clear water. The water to which the disinfectant is added to is allowed to stand at least 30 min before being used. Elemental iodine is good disinfectant over a pH range of 3 to 8 even in the presence of contamination combined amines are not formed to use up the iodine. A dosage of 5 to 10 mg/L, with the average of 7.5 mg/L for most waters, is effective against enteric bacteria, amoebic cysts, cercarial, leptospira, and viruses with 30 min. Iodine tablets which dissolve in less than 1min and stable for extended periods of time are available. They are known as iodine water purification tablets. Of these tablets globuline or tetraglycine hydrogen peroxide, is preferred. They contain 8.0 mg of active iodine per tablet. Furthermore; the treated water by these tablets is palatable. The main disadvantage of iodine is its high cost when compared to chlorine and its compounds.

Bromine can also be a water disinfectant although its use has been more of the time to disinfect swimming pool waters.

Ozone treatment and its Advantages

Ozone has been used for many years as disinfectant and as an agent to remove colour, taste and odour from drinking water. It is more effective in these latter purposes when compared to the other agents. It also oxidizes and permits removal or iron and manganese and aids in turbidity removal.

Ozone is a powerful oxidizing agent over a wide pH and temperature range, in contrast to chlorine. It is an excellent viricide, effective against amoeba cysts and destroys bacteria and phenols. The potential for the formation of chlorinated organics such as trihalomethanes (THMs) is reduced with prolongation; the removal of soluble organics in coagulation is also reported to be improved. Ozone is reported to be 3100 times faster than chlorine in disinfection.

Some of the **disadvantages** of ozone are:

- It is a toxic gas and very corrosive
- It provides no lasting residual in water for it disappears in 7 to 8 min and
- It is more expensive compared to chlorine and chlorine dioxide
- It cannot be stored as a compressed gas.

Adding chlorine to maintain chlorine residual in the distribution system can offset the disadvantage of no tasting. Careful consideration must be made to avoid the possibility of the formation of compounds with mammalian toxicity during ozonization of drinking water, though the probability is said to be small.

Ozone must be generated at the point of use even though ozone can be produced by electrolysis of perchloric acid and by ultraviolet lamps; the practical method of water treatment is by passage of dry clean air between two high- voltage electrodes. Pure oxygen can be added in a positive pressure injection system. The ozonized water is injected in a mixing and contact chamber with the water treated. The space above the chamber must be carefully vented after its concentration is reduced using an ozone destructive device to avoid human exposure, as ozone is very corrosive and toxic. As the vented ozone may contribute to air pollution, precautions must be taken in the storage, handling, piping, respiratory protection, and housing of ozone as chlorine.

Chlorine Dioxide Treatment

Chlorine dioxide is manufactured at the water plant where it is to be used. It is formed by pumping sodium chlorite solution and chlorine water (made by gas chlorine) ion to a glass cylinder. It is added to the water being treated from here, together with the chlorine water for a complete reaction with full production of chlorine dioxide, the pH of the solution with glass reaction cylinder must be less than 4.0 where hypochlorintors are used, it is produced by adding hypochlorine solution, a dilute solution of hydrochloric acid, and a solution of sodium chlorite in the glass reaction cylinder so as to maintain a pH of less than 4.0. The solution feeders are then needed. Cox, as indicated by Salvato, gives the theoretical ratio of chlorine to sodium chlorite as 1.0:2.57 with chlorine water or hypochlorite solution, and sodium chlorite to chlorine dioxide produced as 1.0:0.74. More chlorine is needed to drop the pH to less than 4.0.

Advantages- A chlorine dioxide dosage of 0.2 to 0.3 mg/L will destroy most phenolic taste producing compounds for which it was originally developed

3.4 Supplementary water treatment

3.4.1 Technologies for fluoride removal

Fluoride is a normal constituent of natural water samples. Its concentration, though, varies significantly depending on the water source

3.4.2 Sources of fluoride

Although both geological and man- made sources contribute to the occurrence of fluoride in water, the major contribution comes from geological resources.

Except in isolated cases, surface waters seldom have fluoride levels exceeding 0.3 mg/l. examples are streams flowing over granite rich in fluoride minerals and rivers that receive untreated fluoride-rich industrial wastewater.

There is several fluoride bearing minerals in the earth’s crust. They occur in sedimentary (limestone and sandstone) and igneous (granite) rocks. Weathering of these minerals, along with volcanic and fumarolic processes, leads to higher fluoride levels in ground water.

Dissolution of these barely soluble minerals depends on: the water composition and the time of contact between the source minerals and the water

3.4.3 Health impacts of excess fluoride in potable waters

Low dental caries incidence rates demonstrate that fluoride concentrations of up to 1.0mg/l in potable water are beneficial to the oral health of children and, to a lesser extent, adults. In several developed countries fluoridation of water supplies is practiced if the natural concentration is below the desired level.

Consumption of water having excess fluoride over a prolonged period leads to a chronic ailment known as fluorosis. Incidence of high- fluoride ground water has been reported from 23 nations around the globe. It has led to endemic fluorosis which has become a major geo-environmental health issue in many developing countries. According to a recent estimate, 62 million people are affected by various degree of fluorosis in India alone (Susheet, 2001)

Dental fluorosis, also called “mottled enamel”, occur when the fluoride level in drinking water is marginally above 1.0 mg/l. A relationship between fluoride concentration in potable water and mottled enamel was first established in 1931. Typical manifestations of dental fluorosis are loss of shining and development of horizontal yellow streaks on teeth. Since this is caused by high fluoride in or adjacent to developing enamel, dental fluorosis develops in children born and brought up in endemic areas of fluorosis. Once formed, the changes in the enamel are permanent. When the above manifestations are seen in an adult, they clearly indicate that the person has been exposed to high fluoride levels during her or his childhood.

Skeletal fluorosis affects both adults and children and is generally manifested after consumption of water with fluoride level exceeding 3mg/l. typical symptoms of skeletal fluorosis are pain in the joints and backbone. In severe cases this can result in crippling the patient.

Recent studies have shown that excess intake of fluoride can also have certain non-skeletal health impact such as gastro-intestinal problems, allergies, anemia and urinary tract problems. Nutritional deficiencies can enhance the undesirable effects of fluoride.

3.4.4 Guidelines and Standards

Taking health effects into consideration, the world Health organization has set a guideline value of 1.5mg/1 as the maximum permissible level of fluoride in drinking water
However, it is important to consider climactic conditions, volume of water intake, diet and other factors in setting national

standards for fluoride. As the fluoride intake determines health effects, standards are bound to be different for countries with temperature climates and for tropical countries, where significantly more water is consumed.

3.4.5 Fluorosis in Ethiopia

The highest fluoride levels worldwide have been reported from the East African rift system. The tests made so far were mapped and reported, by Kloos and Tekle-Haimanot, shows the same overall distribution pattern of very high fluoride concentrations in the rift valley and moderate to very low levels in the highlands and other parts of Ethiopia. Sixty-five percent of the 248 sources tested in the Rift Valley had fluorosis levels of 1.0 mg/l and higher, 23.4 % of them with concentrations between 5.0 and 9.9 mg/l and 26.6% above 10.0 mg/l. From the 219 sources in the highlands and other parts of the country that were mapped, only 20.5% of them had fluoride levels between 1.0 -4.9 mg/l and higher and concentrations in 19.2% of all the sources were below 0.5 mg/l.

It was also reported by Kloos and Tekle-Haimanot that all types of water sources in the Rift Valley except rivers had high fluoride levels. Lakes and hot springs had the highest fluoride concentrations, with all of the 6 hot springs and 9 of the 11 lakes tested exceeding 5.0 mg/l. The highest concentrations were recorded in Lake Shala (264 mg/l) and Lake Abayata (202 mg/l). All the 21 tested cold springs had fluoride concentrations below 5 mg/l, while about two-third of all deep- and shallow-wells exceeded 1.0 mg/l, with most of them falling in the 5.0-9.9 and above 10 mg/l categories. Concentrations on the9 river sites were below 4.9 mg/l but still higher, on average, than the highland and lowland in other parts of the country.

An extensive study of endemic fluorosis in Ethiopia, among 1,456 individuals in 14 communities, by Tekle-Haimanot and colleagues, reported that in central Rift Valley the prevalence rates of dental fluorosis between 69% and 98% (mean 84%), with a rate of 48.2% in the village with the highest fluoride levels (33.6 ppm).

A recent community-based study carried out in Wonji-Shoa by Zenebe and Colleagues reported an overall skeletal prevalence of 65.7%. (Y. Berhan, D. Haile Mariam, H. Kloos, 2005)

3.4.6 Fluoride control options

3.4.6.1 Search for alternative sources

If fluoride concentration in a community's water supply is significantly and consistently beyond the permissible level, it is essential to consider remedial measures to combat fluorosis. The first choice should be to search for water source with a lower fluoride level. Options are:

(a) Provision of a new and alternate source of water with acceptable fluoride levels

It may be possible to get a safe water source in the vicinity by drilling a new well and / or drawing the water from different depths, as leaching of fluoride in to ground water is a localized phenomenon.

(B) Transporting water from a distant source:

This may lead to lasting benefits, but initial cost will be high. Such an approach has been implemented in endemic fluorosis areas in few countries

(C) Blending high fluoride with low fluoride water

Mixing high and low fluoride waters so as to bring the concentration within permissible levels can be an appropriate long- term solution provided the low fluoride source is available within reasonable distance and is of acceptable quality with respect to other characteristics.

(D) Dual water sources:

If there are sources with low fluoride levels available to the same community, the source having low fluoride levels can be strictly limited to drinking and cooking. The water source with high fluoride can then be used for other purposes.

(E) Rainwater harvesting

There are two ways in which rainwater harvesting can be used as a solution for the fluoride problem. Individual household- roof rainwater harvesting and container storage can provide potable water for families. On harvested surface water run- off can be used to recharge high- fluoride ground water sources.

N.B. When non of the above options is feasible or if the only solution. Would take a long time for planning and implementation, defluoridation of drinking water have to be practiced.

3.4.6.2 Defluoridation of water

Two options are then available:

i. The central treatment of water at the source- this method adopted in developed countries, need skilled personnel and high cost
ii. The treatment of water at the point of use that is at the household level

Treatment at the point of use has several advantages over treatment at the community level. Costs are lower, as defluoridation can be restricted to the demand for cooking and drinking- usually less than 24% of the total water demand. Chemical treatment of the entire water demand would lead to production of large volumes of sludge, which requires a safe disposal.

Limitations of point of use treatment are that reliability of the treatment units has to be assured, and that all users should be motivated to use only the treated water for drinking and cooking when untreated water is also available in the house.

Defluoridation methods

Defluoridation methods can be broadly divided into three categories according to the main removal mechanism

- Chemical additive methods
- Contact precipitation
- Adsorption/ion exchanged methods

- Chemicals additive methods

These methods involve the addition of soluble chemicals to the water. Fluoride is removed either by precipitation, co-precipitation, or adsorption onto the formed precipitate. Chemicals include, lime used alone or with magnesium makes the water unsuitable for drinking because of the high pH after treatment. The use of alum and a small amount of lime has been extensively studied for defluoridation of drinking water. The method is popularly known as the Nalgonda technique (RENDWM, 1993), named after the town in India where it was first used at water works level. It involves adding lime (5% of alum), bleaching powder (optional) and alum ($Al_2(SO_4)_3.18H_2O$) in sequence to the water, followed by coagulation, sedimentation and filtration. A much larger dose of alum is required for fluoride removal (150 mg/mgF-), compared with the doses used in routine water treatment.

As hydrolysis of alum to aluminum hydroxide releases H^+ ions, lime is added to maintain the neutral pH in the treated water. Excess lime is used to hasten sludge settling. The dosage of alum and lime to be added to raw waters with different initial fluoride concentrations and alkalinity levels is given in **table** 5.1.

Table 3.4 Approximate volume of 10% alum solution (ml) to be added in 40 liters of test water to obtain the acceptable limit (1.0mg F/l) of fluoride at various alkalinity and fluoride levels. The lime to be added is 5% of the alum amount (mg/l)

Test	Test water alkalinity as mg $CaCO_3$/l							
Water fluorides (mg/L)	125	200	300	400	500	600	800	210
2	60	90	110	125	140	160	190	310
3	90	120	140	160	205	210	235	375
4		60	165	190	225	240	275	405
5			205	240	275	290	355	485
6			245	285	313	375	425	570
7					395	450	520	675
8							605	

(Source: J.A Salvato. Environmental engineering and sanittion. 4th ed. John Wiley & Sons, Inc. 1992 (pp. 354))

The Nalgonda technique has been successfully used at both individual and community levels in India and other developing countries like China and Tanzania. Domestic defluoridation units are designed for the treatment of 40 liters of water (Fig 3.4) whereas the fill- and – draw defluoridation plant (**Fig**. 5.2) can be used for small communities

Contact precipitation

Contact precipitation is a recently reported technique in which fluoride is removed from water through the addition of calcium and phosphate compounds. The presence of a saturated bone charcoal medium acts as a catalyst for the precipitation of fluoride either as CaF_2, and/ or fluorapatite (**Fig** 5.3). Tests at community level in Tanzania have shown promising results of high efficiency. Reliability, good water quality and low cost are reported advantages of this method (**Chilton**, etal.1999).

Adsorpiton/ion- exchange method

In the adsorption method, raw water is passed through a bed containing defluoridating material. The material retains fluoride either by physical, chemical or ion exchange mechanisms. The adsorbent gets saturated after a period of operation and requires regeneration.

A wide range of materials has been tried for fluoride uptake. Bauxite, Magnetite, Kaolinite, Serpentine, various types of clays and red mud are some of the naturally occurring materials studied. The general mechanism of fluoride uptake by these materials is the exchange of metal lattice hydroxyl or other anionic groups with fluoride. Fluoride uptake capacity can be increased by certain pre- treatments like acid washing, calcinations, etc. None of the above mentioned materials generally exhibits high fluoride uptake capacities.

Processed materials like activated alumna, activated carbon, bone char, defluoron-2 (sulphonated coal) and synthetic materials; like ion exchange resins have been extensively evaluated for defluoridation of drinking water. Among these materials, bone char, activated alumina and Calcined clays have been successfully used in the field. Application of these materials is described below.

Bone char as a defluoridating material:

Bone char consists of ground animal bones that have been charred to remove all organic matter. Major components of bone charcoal are calcium phosphate, calcium carbonate and activated carbon. The fluoride removal mechanism involves the replacement of carbonate of bone char by fluoride ion. The method of preparation of bone charcoal is crucial for its fluoride uptake capacity and the treated water quality. Poor quality bone char can impart bad taste and odour to water. Exhausted bone char is regenerated using caustic soda. Since acid dissolves bone char, extreme care has to taken for neutralizing caustic soda. Presence of arsenic in water interferes with fluoride removal. Bone char is considered as an appropriate defluoridating material in some developing countries. The ICOH (Inter- country Center for Oral Health) domestic defluoridator was developed in Thailand and uses crushed charcoal and bone char (**Fig**. 5.4). Its defluoridation efficiency depends on the fluoride concentration in raw water as well as the fluoride uptake capacity and the amount of bone char used in the filter.

Activated alumina as a defluoridating material:

Activated alumina or calcined alumina, is aluminum oxide, Al_2O_3. It is prepared by low temperature dehydration (300-600^{0}C) of aluminum hydroxides. Activated alumina has been used for defluoridation of drinking water since 1934, just after excess fluoride in water was identified as the cause of fluorosis.

The fluoride uptake capacity of activated alumina depends on the specific grade of activated alumina, the particle size and the water chemistry (pH, alkalinity and fluoride concentrations). In large community plants the pH of the raw water is brought down to 5.5 before defluoridation, as this pH has been found to be optimum and it eliminates bicarbonate interference. The mechanism of fluoride removal is most probably the ligand exchange reaction at the surface of activated alumina. Exhausted activated alumina has to be regenerated using caustic soda. To restore the fluoride removal is most probably the ligand exchange reaction at the surface of activated alumina. Exhausted activated alumina has to be regenerated using caustic soda. To restore the fluoride removal capacity, basic alumina is acidified by bringing it into contact with an excess of dilute acid.

Activated alumina has been the method of choice for defluoridation of drinking water in developed countries. Generally it is implemented on a large scale in point of source community plants. A few point of use defluoridation units have been developing countries. Domestic defluoridation units (**fig**.5.5) have been developed in India using indigenously manufactured activated alumina, which is commercially available in bulk quantities. Choosing the proper grade of activated alumina is important for its effective reuse in multiple defluoridation cycle. Around 500-1500 liters of safe water could be produced with 3 kg of activated alumina when the raw water fluoride is 11 and 4 mg/l respectively at natural water pH of 7.8-8.2. The frequency of regeneration is once in 1.5-3 months. The cost of activated alumina is around US$ 2 per kg and the total cost of the domestic filter depends upon material used for filter assembly. Regeneration of exhausted activated alumina cost around US$ 0.5 (Venkobachar et al., 1997).

Calcite Clay

Freshly fried brick pieces are used in Sri Lanka for the removal of fluoride in domestic defluoridation units (Fig. 5.6). The brick bed in the unit is layered on the top with charred coconut shells and pebbles. Water is passed through the unit in an upflow mode. The performance of domestic units has been evaluated in rural areas of Sir Lanka (Priyanta & Padamsiri 1997.) It is reported that efficiency depends on the quality of the freshly burnt bricks. The unit could be used for 25-40 days, when withdrawal of defluoridated water per day was around 8 liters and raw water fluoride concentration was 5 mg/l. As PVC pipes are costly, a defluoridator made out of cement and brick has also been recommended.

A part from the methods discussed above, specific synthetic ion exchangers and separation technologies such as rivers osmosis and electrodialysis have also been developed for fluoride removal from potable water

- To select a suitable defluoridation method for application in developing countries, some of the following criteria need to be considered:
    - Fluoride removal capacity
    - Simple design
    - Easy availability of required materials and chemicals
    - Acceptability of the method by users with respect to taste and cost

Both precipitation and adsorption methods have advantages and limitations. In the Nagonda technique easily available chemicals are used and the method is economically attractive. Limitations of the method are varying alum doses depending on fluoride levels in water, daily addition of chemicals and stirring for 10-15 min, which many users may find difficult.

In adsorption- based methods like activated alumina and bone char, daily operation is negligible. Activated alumina is costly. Hence exhausted alumina has to be regenerated using caustic soda and acid and repeatedly reused, at least for a few cycles. Improperly prepared bone char imparts taste and odour to the treated water. Since bone char from point of use units is not generally regenerated, a ready supply of properly prepared material needs to be available. Furthermore, bone char may not be culturally acceptable to certain communities as defluoridating material. Some of the merits and demerits of defluoridation methods are given in **table** 5.2.

3.4.7 Water desalination

Desalination or desalting is the conversion of seawater or brackish water to fresh water. To meet the ever-increasing demands for fresh water, especially in arid and semi-arid areas, much research has gone into finding efficient methods of removing salt from seawater and brackish water.

When health effects and cost issues are resolved in prior, the conversion of treated wastewater to potable water using modified desalination processes is also possible. Water containing more dissolved salts than seawater, e.g. Great Salt Lake, sea, etc is considered brine.

Under circumstances where adequate and satisfactory ground water, surface water, or rainwater is not available and higher quality water is required, but where seawater or brackish water is available, desalination may provide an answer to the water problem. Cost of construction and energy, however, could be major deciding factor.

Seawater has a total dissolved solids (TDS) concentration of about 36,000 mg/l. About 75% is sodium chloride, 11% magnesium chloride, 6% magnesium sulfate, 4% calcium sulfate, and the rest potassium sulfate, calcium carbonate, magnesium bromide, suspended solids and microorganism.

Desalting will remove to some degree dissolved salts and minerals such as chlorides, sulfates, sodium, hardness, nitrates, nitrites phosphates, fluorides, ammonia, and heavy metals. Very hard brackish (15,000 to 36,000 mg/l) water will require prior softening to make reverse osmosis or electro dialysis very effective.

Some known methods for desalting water are:

Membrane: Reverse osmosis, electro dialysis, transport depletion

Distillation: Multi-stage flash distillation, multi-effect multi-stage distillation, vertical tube distillation, vapor compression, solar Humidification.

Crystallization: vacuum-freezing vapor compression, electric freezing, secondary refrigerant freezing, Hydrate formation.

Chemical: Ion exchange

Distillation, particularly multistage, has been the process of choice for desalting seawater, with the vertical process gaining more acceptances. Electro dialysis and reverse osmosis appear to be more favorable for brackish water, also ion exchange for specific purposes.

Distillation

In distillation, seawater is heated to the boiling point and then into steam, usually under pressure, at a starting temperature of 250°F. The steam is collected and condensed in a chamber by coming into contact with tubes (condensed-heat-exchanges) containing cool seawater. The heated saline water is passed through a series of distillation chambers in which the pressure is incrementally reduced and the water boils (made to "flash"), again at reduced temperature, with the production of steam, which is collected as fresh water. The wastewater (brine) and distilled water are also used to preheat the incoming seawater the process referred to as multistage flash distillation (MSF). A major problem is the formation of scale (calcium carbonate, calcium sulfate and magnesium hydroxide) on the heat transfer surface of the pipe or vessel in which the seawater is permitted to boil. This occurs at a temperature of about 160°F, but scale can be greatly minimized by preheating the seawater to remove either the calcium or carbon dioxide. Distilled water is tasteless and low in pH if not aerated and adjusted before distribution.

Reverse Osmosis

In this process pressure (typically 600 to 800, but up to 1500 psi) is applied to the salt water on one side of a special flat or cylindrical supported membrane or hollow fiber. In the process fresh water is separated out from the salt water into a porous or hollow channel from which the fresh water is collected. The concentration of TDS in the salt water flowing through the unit must be kept below the point at which calcium sulfate precipitation takes place. Chlorinated methane and ethane, which are common solvents, are not removed by reverse osmosis; air stripping, however is effective. Some of the dissolved solids, 5 to 10% will pass through the membrane. An increase in TDS will result in a small increase of solids in the fresh water.

In reverse osmosis the salt water to be treated must be relatively clear and fell of excessive hardness, iron, manganese, and organic matter to prevent fouling of the system membranes. The pretreatment may consist of softening to remove hardness; coagulation and filtration to remove turbidity suspended matter, iron and manganese and filtration through activated carbon columns to remove dissolved organic chemicals. Acid is used if necessary to lower the pH and prevent calcium carbonate and magnesium hydroxide scale. Chlorine might also be used to control biological growth on the membranes.

Electro dialysis

Using this method the dissolved solids in the brackish water (less than 10,000 mg/l TDS) are removed by passage through a cell in which a direct electric current in imposed. Dissolved solids in the water contain positively charged cons (cations) and negatively charged ions (anions). The cations migrate to and pass through a special membrane, which allows passage of the positive ions. Another special membrane allows the negative ions to pass through exam the concentration of dissolved solids determines the amount of current needed. The partially desalted demineralized water is collected and the wastewater is discharged to waste.

The plant size is determined in part by the desired amount of salt removal. However, a change in the total dissolved solids in the brackish water will result in an equal change in the treated water. Similar to the reverse osmosis, pretreatment of the brackish water is necessary to prevent fouling of the membranes and to prevent scale formation. The cost of electricity limits use of electro dialysis.

Ion Exchange

1. In the deionization process, salt are removed from brackish water (2,000 to 3,000 mg/l TDS). Raw water passes through beds of special synthetic resins, which have the capacity to exchange ions held in the resins with those in the raw water.
2. In the two-step process, at the first bed (acidic resin) sodium ions and other cations in the water are exchanged for cations (cation exchange) in the resin bed. Hydrogen ions are released and, together with the chloride ions in the raw water, pass through to the second resin bed as a weak hydrochloric acid solution. In the second resin added bed, the chloride ion and other anions are taken up (anion exchange) from the water, are exchanged for hydroxide ions in the resin bed which are released, combine with the hydrogen ion to form water, and pass through with the treated water. The ion exchange beds may be in series or in the same shell.

When the resins lose their capacity and become saturated, the treatment of water is interrupted and the beds are regenerated, with acids or bases. The resins may become coated of fouled if the raw water contains excessive turbidity, microorganisms, sediment, colour, and organic matter including dissolved organics, hardness, iron, or manganese. In such cases pretreatment to remove the offending contaminant is necessary. Chlorine in water would attack the cation resin and must be removed prior to deionization.

3.4.8 Nitrate Removal

Nitrate in ground water originates from:

- Natural biological process in the soil, e.g. plants/ bacteria which are responsible for concentration up to 5-10 mg NO_3/l
- Oxidation of NH_4^+ in the aerobic zone in the soil
  - $2N_4+ +40_2 \; \underline{\text{bacteria }} \; 2NO_3^-+ 4H^++2H_2O$.This can result into concentration up to several hundred mg/l.
- Domestic solid and liquid waste fecal matter, urine
- Domestic waste water
- Waste of (intensive) animal farming (manure)

- Nitrate can be removed in the soil under anaerobic conditions e.g. if organic matter or FeS_2 is present:

- $5CH_2O_{(g)}+4NO_3- \; \underline{\text{bacteria}} \; 2N_2+4HCO_3-+CO_2+3H_2O$(3.g peat)
- 5FeS2(S)+14NO3-+4H+ 7N2+10SO4+5Fe2++$2H_2O$

This reaction can be continued by

- $5Fe^{2+} \; NO_3^- + 12H_2O \; 1/2N_2 +5Fe\;(OH)_{3(s)}+9H^+$

More over No $_2^-$ can be formed

- $CH_2O_{(S)} + 2NO_3^- \; 2NO_2^- + H_2O+CO_2$

Treatment processes for NO_3^-

- Reverse osmosis
- Ion exchange
- Biological Denitrification
- Distillation
- Electro dialysis

When pure water is separated from a salt solution by a semi-permeable membrane and the pressure on the salt solution exceeds the osmosis pressure, water is transported through the membrane and salts (cations and anions) are rejected, E.g. as NO_3^- is anions.

Nitrate can be removed from water membranes operated at a pressure between 14 and 70 bar. The rejection of the membranes is between 90-99.5%.

Effect of reverse osmosis, e.g,

Parameter	**Raw water**	**Product**
No_3-	50mg/l	7 mg/l
Cl-	23 “	3 “
SO_4-	18 “	3 ”
HCO_3-	2.9 mmol/l	0.1 mmol/l
Ca^{2+}	3.3 “	0.2 0.1 “
pH	7.2 “	0.3 4.6 “

Disadvantage of Reverse Osmosis

- costly
- discharge of brine

Ion exchange

Nitrate can be removed by anion exchange Anion exchanges consist of insoluble solid polymers, e.g. styrene, which act as carrier for quaternary ammonia groups. This group has a positive charge. The anion exchanger is in the form of spheres and is, e.g. in the chlorides form

$RN + Cl^-$ (R=Resin, e.g. styrene)

During the process NO_3- is exchanged with Cl^- and removed form the water.

$RN + Cl^- + NO_3^- ------ RN + NO_3^- + Cl^-$

When the anion exchanger is saturated with No_3^- regeneration with, e.g. 10%$NaCl^-$ solution is carried out

$RN + NO_3^- + Cl^- ---- RN^+Cl^- + NO_3^-$

Effect of ion exchange

Parameter	**Raw water**	**Product**
NO_3^-	50mg/l	2 mg/l
Cl^-	23 “	87mg/l
SO_4-	18 “	1 ”
HCO_3^-	2.9 mmol/l	2.6 mmol/l
pH	7.2	7.2

Disadvantages

- Costs
- Discharge regenerate

- Biological denitrification
  - Heterotrophic bacteria
  - Organic compounds for reduction nitrate to nitrogen eg. methanol, ethanol. Acetic acid
    - Methanol

      $5CH_3OH+6NO_3^- --- 5HCO_3^- + OH^- + 7H_2O+3N_2$
    - Ethanol

      $5C_2H_5OH + 12NO_3^- ---- 10HCO_3^- + 2OH^- + 9H_2O+6N_2$
    - Acetic acid

      $5CH_3COOH+8NO\text{-}_3 --- 8HCO_3^- + 2CO_2 + 6H_2O+4N_2$
  - Autotrophic bacteria
  - Inorganic compound for nitrate reduction eg Hydrogen, Sulfur

$5H_2(gas)+2H+2NO_3^- --- N_2 + 6H_2O$

$5S + 6NO_3^- + 2H_2O --- 5SO_4^- + 3N_2 + 4H^+$

Biological denitrification techniques: For denitrification with methanol, Ethanol and acetic acid

- Fluidized bed
- Floating bed
- Fixed bed. (R.S.F)- Techniques are applied

As very important factor in these techniques is the formation of significant amounts of biomass, this biomass has to be removed from the sand grains

- as in a fluidized bed the mass transfer to the active biomass is reduced
- In a fixed bed or floating bed channeling will occur which reduces the effectiveness

Disadvantages (Fluidized/floating/fixed techniques)

- removal of biomass not easy
- disposal of biomass
- Post treatment required(Removal of turbidity, biodegradable organic matter, bacterial)
    - For denitrification with hydrogen-Corrugated plate system is applied

Disadvantages

- H_2 explosive gas
- Complicated process

3.4.9 Removal of Ammonia (NH_4+)

- Originates from:
    - Domestic waste (water)
    - Fertilizer
    - Peat (groundwater)
    - Industrial waste water

* Presence of NH_4^+ & involves

1. Effectiveness of chlorine is affected due to the formation of NH_2Cl

2. After growth may occur in the net work, food for organisms

3. Toxic effects on fish (NH_3)

Methods into the removal of NH_4^+

1. Breakpoint chlorination
2. Bio-oxidation e.g.
   - S.S.F
   - R.S.F
   - Dry filtration
   - Lake or river
   - (waste water treatment)

3 Air stripping

1. Breakpoint Chlorination

When more chlorine is added than equivalent amount to oxidize ammonia completely into nitrogen (N_2), the following reaction takes place: The overall reaction which occurs, results from the three reactions together.

I. $2NH_4^+ + 2Cl_2 \rightarrow 2NH_2Cl + 4H^+ + 2Cl^-$

II. $2NH_2Cl + 2Cl_2 \rightarrow 2NHCl_2 + 2H^+ + 2Cl^-$

III. $2NHCl_2 \rightarrow N_2 + Cl_2 + 2H^+ + 2Cl^-$

IV. $2NH_4^+ + 3Cl_2 \rightarrow N_2 + 8H^+ + 6Cl^-$

This complete reaction is called *chlorine breakpoint reaction*, which means that NH_4^+ is oxidized by chlorine to N_2. In reality the formed Cl_2 during the third reaction is used for the second reaction. The required amount of chlorine per mg ammonium follows from the reaction equation and amounts

$$\boxed{6\text{mg } Cl_2\text{per mg } NH4^+}$$

When excess of chlorine is added a side reaction occurs

$$NHCl_2+Cl_2 \rightarrow NCl_3+ H^+ + Cl^-$$

The formed NCl_3 has a bitter taste, so this reaction is not desired. In practice chlorine breakpoint graph is applied to illustrate what is happening in this process. In this graph the total available chlorine concentration is given as function of the dosage of chlorine. <u>Total available chlorine</u> is the sum of free and combined available chlorine.

2. Bio-Oxidation

Oxidation of ammonium by bacteria follows the equations:

$$2NH^+_4\ 3O_2\ \underline{\text{Nitrosomonas}}\ 2NO_2^-+4H^++2H_2O$$

$$2NO_2^-+O_2\ \underline{\text{Nitrobacter}}\ 2NO_3\text{-}$$

____

____

$$2NH^+_4+4O_2\text{----}\ 2NO_3^-+4H^++2H_2O$$

$$\boxed{1\text{mg } NH_4^+=3.6\text{mg } O_2/1}$$

* Removal in a S.S.F. and a R.S.F.

The concentration that can be removed by S.S.F. and R.S.F. is limited by:

a. The available O_2 in water

Saturation concentration

Temp	O^0	5	10	15	20	25	30	35
O_2mg/l	14.6	12.8	11.3	10.1	9.22	8.4	7.6	7.17

b. The presence of biodegradable organic and inorganic matter, e.g. CH_4 BOD 5,Fe^{2+}; Mn^{2+}; NO_2^- which consume oxygen

* Removal in a dry filter up to 20 mg/l NH^+_4 can be removed due to the continuous aeration in the filter bed (filtration rate =2.5 m/h; H=1.5-2m)

3. Air Stripping

This method is very expensive as:

- High pH is required (10 to 11) as the ammonia ion NH_4^+ have to be transformed to the volatile NH_3 compound:

$$\underset{\text{(Non volatile)}}{NH_4^+ + OH^-} \text{----------}> \underset{\text{(Volatile)}}{NH_3} + H_2O$$

- And high air to water ratio due to low portion coefficient (NH_3 is very soluble in water)

Consequently

- high investment cost
- high energy consumption

- chemical costs e.g. $Ca(OH)_2$
- Clogging occurs due to precipitation of $CaCO_3$

3.4.10 Radionuclide Removal by Lime-Soda Ash Softening

The natural radionuclides of interest in water are within the decay series of Uranium (U-238), Actinium (U-235), and Thorium (Th-232). The U-238 decay series (i.e. Rn-222, Ra-226, and u) are of primarily health concern because of their relatively high exposure associated with drinking water.

The most significant exposures to radioactivity in drinking water occur in small public and private shallow ground water supplies. The removal from the large water supplies can be achieved by conventional treatment methods. Aeration is effective for removal of Rn-222 because of its high volatility and short half-life of 3.8 days. Traditional surface water treatment by coagulation and filtration is effective for removal of artificial radionuclides for the degree of contamination normally expected.

The best process for removal of radium and uranium from ground water is precipitation by lime-soda ash softening at pH greater than 10. The removal efficiency is generally 80%-90%. The recommended disposal of lime sludge containing the radionuclides is by spreading on land or by landfill.

3.4.11 Iron and Manganese Removal

Dissolved iron and manganese are often found in ground water from wells located in shale, sand stone, and alluvial deposits. Iron II (Fe^{2+}) and manganese II (Mn^{2+}) are chemically reduced to soluble forms that exist in a reducing environment (absence of dissolved oxygen and low pH) . These conditions exist in ground water and anaerobic reservoir water. When it is pumped from underground or an aerobic hypolimnion, carbon dioxide and hydrogen sulfide are released, raising the pH. In addition the water exposed to air, creating an oxidizing environment. The reduced iron and manganese start transforming to their stable oxidized, insoluble form of iron III (Fe^{3+}) and manganese IV (Mn^{4+}).

The rate of oxidation of iron and manganese depends on the type and concentration of oxidizing agent, pH, alkalinity, organic content and presence of catalysts.

Oxygen, chlorine and potassium permanganate are the most frequent oxidizing agents. The natural reaction by oxygen is enhanced in water treatment by using spray nozzles or waterfall-type aerators. Chlorine and potassium permanganate ($KMnO_4$) are the chemicals commonly used in iron and manganese removal plants.

Oxidation reactions using potassium permanganate are:

$$3Fe^{2+} + MnO^{-}_{4} \longrightarrow 3Fe^{3+} + MnO_2$$

$3Mn^{2+} + 2MnO_4^- \longrightarrow 5MnO_2$

The rate of oxidation of the ions depend on the pH and bicarbonate ion concentration. The pH for oxidation of iron should be 7.5 or higher; manganese oxidizes readily at pH 9.5 or higher. Organic substances like humic acid can create complexes with iron and manganese ions, holding them in the soluble state at higher pH levels. If a large concentration of organic matter is present, iron can be held in solution at pH levels of up to 9.5.

Copper ions and silica have a catalytic effect on the oxidation of iron and manganese. The presence of about 0.1 mg/l of copper increases the rate of iron oxidation 5-6 times. Silica increases oxidation rates of both metals. Manganese oxides are catalytic in the oxidation of manganese. Tray aerators frequently contain coke or stone contact beds through which the water percolates. These media develop and support a catalytic coating of manganese oxides.

Polyphosphates have been effective in sequestering iron and manganese in some well water supplies. When applied at the proper dosage, before oxidation of the iron and manganese occurs, polyphosphates tend to hold the metals in solution and suspension, preventing destabilization and thus, stopping agglomeration of the individual tiny particles of iron and manganese oxides. The concept is that the sequestered metals will pass through the distribution system with out creating discolored water. Nevertheless, oxidized particles often settle out and collect in water mains at times when the velocities of flow in the pipes are low and in storage reservoirs during quiescent periods. Then, when the velocities of flow increase and when water in storage is agitated, these particles are re-suspended in the water at much higher concentrations than in the raw water.

Removal of Iron

Iron may be present in three forms:-

- Dissolved - Fe^{2+}
- Colloidal -$Fe(OH)_3$ mainly
- Suspended - $Fe\ (OH)_3$ mainly

Removal of dissolved iron: Is based on the transformation of the soluble form of iron (Fe^{2+}) to the insoluble form of iron ($Fe(OH)_3$)

$$4Fe^{2+} + O_2 + 2H_2O <--> 4Fe^{3+}\ 4OH$$

$$4Fe^{3+} = 4OH + 8H_2O <--> 4\downarrow Fe\ (OH)_3 + 8H^+$$

$$4Fe^{2+} + O_2 + 10H_2O <--> \downarrow 4Fe\ (OH)_3 \quad + 8H^+$$

For this reaction oxygen is required

$$* \ 4\ Fe^{2+} + O_2 + 10H_2O <--> \downarrow 4\ Fe\ (OH)_3 \quad + 8H^+$$

$$4x56\ mg\ Fe^{2+} = 2x16\ mgO_2$$

$$1mg\ Fe^{2+} = 32/(4x56)mg\ O_2 = 0.14mgO_2$$

$$\boxed{1mg\ Fe^{2+} = 0.14\ mg\ O_2}$$

N.B. The pH is decreased due to the formation of H^+

* The rate of oxidation depends strongly on the pH. The lower the pH, the lower will be the rate of oxidation.

- The rate of oxidation of pH= 7 is limited

Example: O_2 = 8.9 mg/l; Tem. = 20^0C; HCO_3 = 570 mg/l; pH=7

Table 3.5 Removal of dissolved iron

Time(min.)	**Residual Fe $^{2+}$ (mg/l)**
1	9.5
2	7.8
3	6.2
4	4.8
6	3.0
9	1.9
10	1.0

What is happening in practice?

In practice iron is removed from ground water by aeration followed by rapid sand filtration.

Subsurface removal is a cheap alternative for the removal of iron by aeration and rapid sand filtration. At this method water is injected in the soil through a well. This water is free from iron and contains oxygen. After the injection of, e.g. 100 m^3, water is abstracted, which is free from iron that can be abstracted in much more than $1000m^3$ e.g. up to 10000 m^3.

The mechanism is as follows:

The oxygen in the injected water oxidizes the Fe^{2+} of the ground water in Fe^{3+} which forms a layer of Fe $(OH)_3$ on the surface of the soil material. During abstraction oxygen free and iron containing water passes this Fe $(OH)_3$ on which Fe^{2+} adsorbed. When the Fe $(OH)_3$ is saturated with Fe^{2+}, it is not any longer removed, consequently abstraction has to finished and oxygen containing water has to be injected, in order to oxidize the adsorbed Fe^{2+} to Fe $(OH)_3$ which is able to adsorb again Fe^{2+}.

In practice water can be produced free from iron, when two wells are applied and the abstracted is aerated. A part of this water is injected in the other well

The theoretical ratio between abstracted and infiltrated water can be estimated/ calculated

Example: raw water contains 2mg Fe^{2+}/l;

Oxygen concentration after aeration is approximately 10mg/l

Calculation:

2mg Fe^{2+}= 2x0.14 mg O_2 = 0.28mg O_2;

Consequently IL water with 10 mg O_2/L is able to oxidized the Fe^{2+} in 10/0.28~35 L water, the efficiency is not 100%

➔ 35Lx 50%=17.5L water

Removal of Manganese

Manganese is mainly present in water as Mn^{2+}. This is very well soluble. The removal of manganese is based on the formation of MnO_2 which is insoluble. This compound is formed when Mn^{2+} is oxidized e.g. by oxygen;

$$6Mn^{2+} + O_2 + 6H_2O \rightarrow 2Mn_3\,O_4 + \downarrow 12H+$$
$$2Mn_3O \downarrow + 2O_2 \rightarrow 6MnO_2 \downarrow$$

$$6Mn^{2+}\ 30_2 + 6H_2O \rightarrow 6MnO_2 \downarrow + 12H^+$$

$$\boxed{1mg\ Mn^{2+} = 0.29mgO_2}$$

The rate of oxidation in a solution is very low when the pH is below 8.6 In rapid sand filter the oxidation may take place when the pH is higher than 7.0.

- Mn_3O_4 acts as catalyst on which Mn^{2+} is oxidized to MN_3O_4 while the "Older" Mn_3O_4 is oxidized to MnO_2.
- The rate of oxidation of Mn^{2+} in much lower than for Fe^{2+} in a rapid sand filter
- This explains the necessity to back was Mn^{2+} removing filter, to avoid the removal of the catalyst Mn_3O_4
- Mn^{2+} can be oxidized as well by chemical oxidation agents e.g. Cl_2 and $KMnO_4$

  ➔ Disadvantage of this procedure:
- More complicated treatment

- Excess of $kMnO_4$ gives the water a violet colour

N.B. The removal of iron and manganese is in general combined in one rapid sand filter (with or with out dosage of Cl_2 or $KMnO_4$), it speeds up the oxidation rate. The process in which iron is removed after aeration in a RSF first and after that Mn^{2+} is removed in the next filter has advantages (when the Fe^{2+} con. is relatively high) as compared with the combined process:

E.g. The optimum back wash procedures can be realized for the Fe^{2+} and Mn^{2+} removing filters (which are different)

- The iron ($FeOH_3$) will not cover the catalyst Mn_3O_4 to make it inactive

- The disadvantage is that two filters in series is required. But this is compensated by the possibility the double the rate of filtration

3.4.12 Volatile Organic Chemical Removal

The two processes for removal of volatile organic chemicals (VOCs) are stripping by aeration and granular activated carbon (GAC) because of their volatility these chemicals are rarely found in surface waters. However, Volatile organic chemicals are stable in ground waters contaminated by leaching of chemicals from industrial discharges, improper chemical use and spillage. The maximum concentration levels for volatile organic chemicals are in the range of 2-10, 10,000 microgram per liter, with a most common value of 5 microgram per liter. Because of these extremely low allowable concentrations, air stripping in a countercurrent packed tower is the only aeration method satisfactory for drinking water treatment. In cold climates the process may not be feasible because of poor removal at low temperatures and the possibility of ice formation on the tower packing. The most costly processes of granular activated carbon adsorption may replace air stripping or be applied as a second stage following partial removal by aeration.

3.4.13 Synthetic Organic Chemical Removal

Synthetic organic chemicals (SOCs) include pesticides, (herbicides and insecticides), volatile organic chemicals, and trihalomethanes. Trace concentrations of pesticides are found in runoff from agricultural lands, occasionally in ground waters under agricultural lands, and in ground waters contaminated by seepage from improper disposal of industrial wastes and spillage of chemicals. Conventional water treatment provides limited removal of organic chemicals. If adsorbed on particles or associated with large hydrophobic molecules, they can be taken out by Coagulation -Sedimentation- Filtration. However, dissolved organic chemicals are rarely adsorbed to metal hydroxides and polymers, resulting in negligible removal. Adjustment of pH, changing coagulants or coagulants aids and application of powdered activated carbon are options to be considered for improved treatment. In surface water treatment, these process variables are generally successful for greater removal of natural organic precursors to reduce subsequent formation of trihalomethanes.

- **Activated carbon adsorption**

  Activated carbon can be made from a variety of carbonaceous raw materials. Processing is dehydration and carbonation by slow heating in the absence of air followed by chemical activation to produce a highly porous structure. Powdered activated carbon for water treatment, which has good characteristics for adsorption of taste and odor compounds, is commonly made from lignin or lignite. Granular activated carbon made from coal has the best physical properties of density, particle size, abrasion resistance and ash content. These characteristics are essential, since granular activated carbon is subject to filter back washing, conveyance as a slurry and heat reactivation.

  The activation process in manufacture creates a highly porous surface on the carbon particles with macro porous and micro porous down to molecular dimensions. Organic contaminants are adsorbed by attraction to and accumulation in pores of appropriate size; thus the pore structure is extremely important in determining adsorptive properties for particular compounds. In general granular activated carbon most readily adsorbs branch chained high molecular weight organic chemicals with low solubility. These include pesticides, volatile organic chemicals, and trihalomethanes.

  Powdered activated carbon is fine powder applied in a water slurry, which can be added at any location in the treatment process ahead of filtration. At the point of application, the mixing must be adequate to ensure dispersion and the contact time long enough for adsorption. The dosage for normal taste and odor control is usually up to 5mg/l with a contact time of 10-15 minutes. Although powdered activated carbon is an effective absorber of organic compounds that cause taste and odor, this success is not repeated by the adsorption of synthetic organic chemicals. Poor adsorption is attributed to the pore structure of the PAC, short contact time between the carbon particles and the dissolved organic chemicals, and interferes by adsorption of other organic compounds.

Efficiency in removal of SOCs requires a granular activated carbon filter to ensure close contact between the water and carbon for a sufficient time for adsorption to occur.

The activated carbon in powder form may be applied to water at various stages of its treatment as follows:

- It may be applied to raw water, ahead of treatment plant.
- It may be applied in the mixing basin, either alone or fixed with other chemicals such as alum, by mean of any of the types of dry chemical feed machines.
- It may be fed before, during or after coagulation, at more than one point. This is known as split treatment. Usually, a portion is fed in the mixing basin and the balance just ahead of filter.

  - It may be applied just ahead of filers. Its rate of application is high when filter is washed, and becomes lower and lower as filter gets clogged.

- **Granular activated carbon systems**

  Granular activated carbon (GAC) can be used in place of anthracite and sand media in conventional filters to increase removal of compounds that cause taste and odor in surface waters. The filter-absorber beds may be dual media granular activated carbon sand or single medium granular activated carbon grease, Snoeyink and Lee reviewed the performance of treatment plants with GAC filter absorbers. GAC filter absorbers do not perform well in removing compounds, such as trihalomethanes and volatile organic compounds, which are less strongly adsorbed.

  A fixed-bed contactor has GAC bed that remains stationary (fixed) during operation. Although the bed can be designed for down flow or up flow, down flow operation with provision for back washing is more common. The GAC is not reactivated until chemically breakthrough; then the entire bed is removed and replaced. In a surface water treatment plant, the conventional filter is retained for removal of turbidity, and the fixed bed contactor added as a second stage. Adsorptive capacity can be significantly reduced by organic contaminants in unfiltered water. Also, GAC suitable for filtration may not be optimum for adsorbing the contaminating organic chemicals.

Contact time is expressed as empty bed contact time, calculated by dividing the volume of the bed by the flow rate. In conventional filtration, the empty bed contact time is usually 3-9 minutes, while in a GAC contactor it is 15-30 minutes or greater. Pretreatment may be necessary to remove contaminants that can interfere with filtration through the GAC bed.

In general, activated carbon treatment has the following functions:

- It has been found effective in aiding coagulation, if adopted before filtration of water.
- It has valuable color removing properties.
- It is effective in preventing or retarding the decomposition of sludge in settling basins.
- It is useful in removing tastes and odors due to excess chlorine, hydrogen sulphide, phenols and other elements.
- It reduces the chlorine demand of treated water.
- It adsorbs organic matter in water.

3.4.14 Color, Odor and Taste Removal

The water to be supplied in the public water supply scheme should be free from color, odor and taste.

The objectionable tastes and odors may be due to the following:

- Organic and vegetable matters.

- Industrial waste and domestic sewage.
- Dissolved gases.
- Dissolved mineral matter.
- Microorganisms such as moulds, actinomycets; iron and sulphur bacteria; and algae.

Depending upon the cases, different methods can be adopted for the removal of taste and odor. Some of the methods described earlier, used for removal of color, odor and taste are:

- Coagulation followed by filtration
- Prechlorination
- Superchlorination followed by dechlorination: the excess of free chlorine breaks down the odor producing substances of oxidation. Dechlorination is usually done to remove some of the excess chlorine, after giving sufficient contact time.
- Chloramine treatment or lime is applicable in the removal of phenol tastes.
- Use of chlorine dioxide, has been found effective against both phenolic and algae tastes.
- Ozonization improves the appearance of water, remove traces of color, and removes odors if applied in sufficient quantity. However, it is always effective against 'earthy' and 'muddy' tastes and odors.
- Removal of iron and manganese

- Treatment by activated carbon or aeration: is especially applicable to the removal of tastes resulting from dissolved gases.
- Use of copper sulphate, is used to serve two purposes:
    - Removal of color, odor and taste from water.
    - Control of growth of algae, bacteria and aquatic weeds in the water reservoirs.
        - It is available in powder form or in crystal form. It may be applied either directly in the distribution pipes or in open reservoirs. In the powder form, the dose may vary from 0.3 to 0.6 ppm for its application to the reservoir.
- Use of potassium permanganate and bleaching clay are also helpful in removing tastes and odors. The tastes produced by microorganisms can be objectively controlled by the use of potassium permanganate. It can be used alone or in combination with chlorine. Potassium permanganate has also been found useful in removing tastes and odors caused by solvent naptha wastes, rosin, soap and fermenting cereal waste.

Review Questions

1. What makes boiled water less attractive than the unboiled water?
2. What are the health risks associated with household water storage?
3. What are the advantages and disadvantages of homemade sand filters?
4. Justify the reason why iodine is believed to be a better disinfectant than chlorine.
5. What is the advantage of raw water intake in water treatment?
6. What is the use of fine and coarse screens?
7. In water treatment plants, what is the most important use of clarifiers?
8. Explain the use of jar test.
9. Mention the most commonly used water coagulants.
10. Write the phenomena that occur in filtration.
11. In a water treatment plant, the Jar test results show that 5 mg/l of Alum at P^H 7 is required for coagulating. What is the consumption of Alum for 5,000 m^3 of water intended for coagulation?
12. Identify the disinfectant used in water treatment.
13. In a community water supply, 10 ppm of chlorine are added for disinfection. After 30 minutes, the residual chlorine was

found to be 0.3 ppm in laboratory test. What is the chlorine demand of the water?

14. The label of a chlorine powder container indicates that it contains 70% of available chlorine. How many grams of the powder must be added to $45m^3$ of water to give a dose of 2 ppm?
15. What are the conditions that lead to the formation of hardness?
16. Show the chemical reaction indicating how water becomes hard.

Note to the teacher

- In a developing country like Ethiopia, provision of adequate and safe water supply through large-scale water treatment is very difficult. The only choice to protect the community from waterborne disease is through the internalization of household water treatment methods that can be easily practiced.

- Using your own local materials, arrange a practical session in developing household filtration media and show students the efficiency of filtration of fecal coliform, using bacteriological analysis.

- After you have gone through this chapter, arrange a practical visit to a nearby conventional large scale water treatment plant and show the students the steps in treatment processes. Give them an assignment to write a report and present it.

- Arrange a practical session to an environmental health laboratory to show the students how to prepare stock solution and determine the residual chlorine concentration.

CHAPTER FOUR

SAMPLING TECHNIQUES AND PROCEDURES

Learning Objectives

At the end of this chapter students will be able to:

1. Define sampling and analysis of water
2. Describe the purpose of sampling and analysis
3. Mention steps involved in sampling water from different sources.
4. Make decisions on frequency of sampling.

4.1 Introduction

Quality control is mandatory for public water supply to ensure the health of the public. Taking samples from public water supplies (conventional and community level) is an essential part of the monitoring and evaluation activity. Though municipal conventional water treatment plants routinely take samples and analyzes it, the role of quality control activity is by large left to the environmental health professionals to make sure that the public is being provided with safe drinking water supply. Hence, the role of this chapter is to introduce students to the basic principles of sampling, the types, the frequency and procedures of water sampling, and to enable students understand the analysis of water and interpretation of the results.

4.2 Principles of Water Sampling and Analysis

Raw and finished water should be continuously monitored. A water treatment plant should have a well-equipped laboratory, certified operator, and qualified chemist. Disinfectant residual, turbidity, and pH should be monitored continuously where possible. In addition to routine testing equipment, equipment at large plants usually include a zeta meter for coagulant dosing measurements, a nephelometer for turbidity readings, a flame spectrophotometer for measuring inorganic chemicals, and a gas chromatograph with spectrophotometer instrument to measure organic chemicals in low concentrations (micrograms per liter or less). It should be understood that failure to report the presence of certain chemicals or microorganisms does not mean they are not present if the laboratory does not examine for them. All examinations should be made in accordance with the procedures given in *Standard Methods for the Examination of Water and Waste Water*, latest edition.

4.3 Types of Sampling and Sampling Techniques

Types of Samples

Water samples may be continuous (such as for turbidity or particle counting), grab (instantaneous), composite (an accumulation of grab samples of equal volume), flow-weighted composite (proportional to volume of flow). Most drinking water samples are grab, although this can be misleading when sampling for organic chemicals or heavy metals. Wastewater samples are composite or flow-weighted composite. When sampling, laboratory collection procedures should be followed.

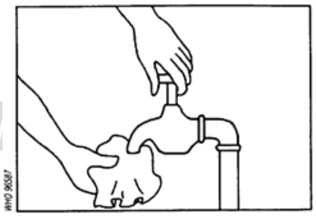
Sampling Techniques and Procedures

Hold the sterile bottle by the base in one hand. Use the other hand to remove the stopper and cover together the stopper and cover should be retained in the hand while the bottle is filled and then they should be replaced together. To prevent contamination, the person collecting the water must not touch, or allow any surface to touch , the screw thread of the bottle neck or the inside of the cap. If the bottles become contaminated, it must not be used.

Water can be divided into three basic types for the purpose of sampling:

- Water from a tap in a distribution system or from a fixed pump outlet, etc.
- Water from a water course (river, lake, etc.) or a tank
- Water from a dug well, etc.,.

Collecting a sample from a tap or pump outlet

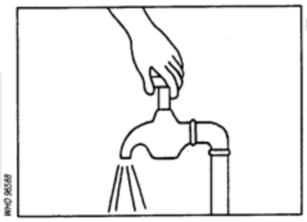


A) Clean the tap

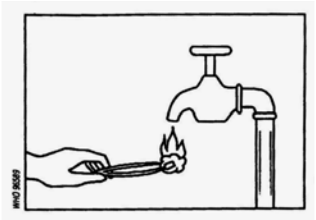
Remove from the tap any attachment that may cause splashing. Using a clean cloth, wipe the outlet to remove any dirt.

B) Open the tap

Turn on the tap at maximum flow and let the water run for 1-2 minutes.



Note: some investigators do not continue to stages C and D but take the sample at this stage. In this case, the tap should not be adjusted or turned off, but left to run at maximum flow. The results obtained in this way will provide information on the quality of the water as consumed. If the procedure is continued to stages C and D, however, the results represent the quality of the water excluding contamination by the tap.

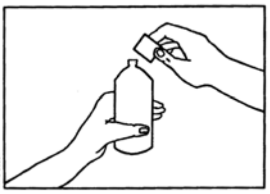


C) Sterilize the tap

Sterilize the tap for a minute with the flame from a gas burner, cigarette lighter, or an ignited alcohol-soaked cotton wool swab.

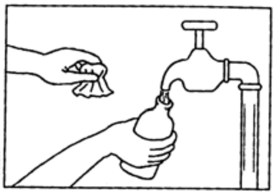
D) Open the tap before sampling

Carefully turn on the tap and allow the water to flow for 1-2 minutes at a medium flow rate. Do not adjust the flow after it has been set.



E) Open the sterilized bottle

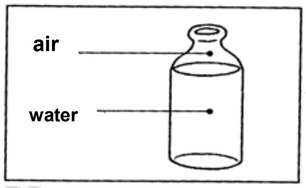
Take out a bottle and carefully unscrew the cap or pull out the stopper.

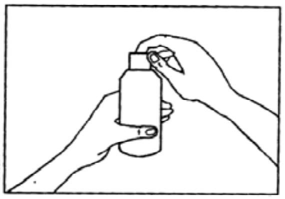


F) Fill the bottle

While holding the cap and protective cover face downwards (to prevent entry of dust, which may contaminate the sample), immediately hold the bottle under the water jet, and fill.

A small air space should be left to make shaking before analysis easier.





G) **Stopper or cap the bottle**

Place the stopper in the bottle or screw on the cap and fix the brown paper protective cover in place with the string.

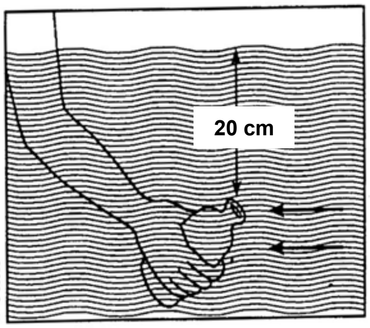
Note: Leaking taps may cause contamination of the sample from sources outside the water pipe and therefore leaks should be reported when sampling. A bacteriological sample should not be taken until the leak is repaired.

4.3.2.2 Collecting a sample from a river, stream, or other surface water:

Open the sterilized bottle as described in section 1.

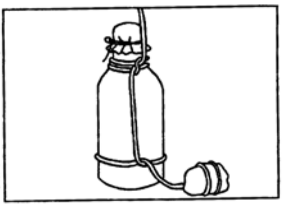
A) Fill the bottle

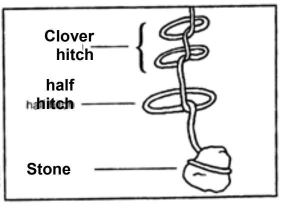
Holding the bottle by the lower part, submerge it to a depth of about 20 cm, with the mouth facing slightly upwards. If there is a current, the bottle mouth should face towards the current. The bottle should then be capped or stoppered as described previously.



4.3.2.2 Collecting a sample from dug wells and similar sources

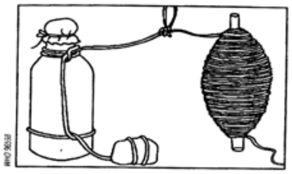
A) Prepare the bottle





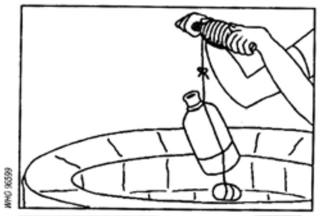
With a piece of string, attach a clean weight to the sampling bottle.

B) Attach the bottle to the string



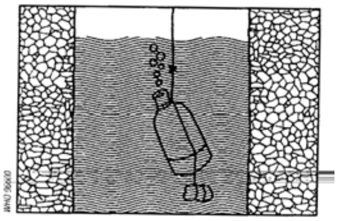
Take a 20-m length of clean string rolled around a stick and tie it to the bottle string. Open the bottle as described in section 1.

C) Lower the bottle



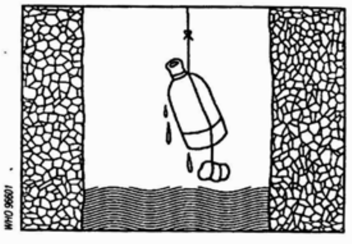
Lower the bottle, weighed down by the weight, into the well, unwinding the string slowly. Do not allow the bottle to touch the sides of the well.

D) Fill the bottle



Immerse the bottle completely in the water and lower it well below the surface without hitting the bottom or disturbing any sediment.

E) Raise the bottle



1. Once the bottle is judged to be full, rewind the string on the stick to bring up the bottle. If the bottle is

completely full, discard some water to provide an air space. Stopper or cap the bottle as described previously.

Transporting Water Samples to a Water Testing Laboratory

- Transporting after collection, samples should be placed in an insulated cold box for transport to a water testing laboratory
- Water samples should examined as soon as possible on arrival and always with in six hours of collection. When ever possible, process water samples in the field.

4.3 Frequency of Sampling

In large treatment plants, it should be a routine to sample water daily at each stage of treatment; untreated sources of water are used. In these situations, periodic sanitary surveys of raw water should be carried out to establish the level of epidemic water-borne disease to which the population is exposed. The survey should include an onsite inspection and evaluation of the water supply system, and a bacteriological analysis of the water.

From such survey, sources of pollution can often be identified and measures taken to prevent future contamination.

The frequency of sampling water in distribution pipes, unchlorinated water supplies before distribution and chlorinated water before distribution are as follows:

1. Water in distribution pipes

It is inevitable that water quality deteriorates in distribution, mainly as a result of corrosion in pipes allowing leaks and infiltration. The larger the population served, the longer the risk of contamination.

At least one sample per 5000 population per month should be examined and every effort should be made to establish a random routine sampling procedure.

2. Unchlorinated water supplies before distribution

The world Health organization has suggested that the maximum interval between successive samples for bacteriological analysis should be as follows:

Table 4.1 Frequency of sampling for unchlorinated water supplies

Population served	Maximum interval
Less than 20,000	1 month
20,000-50.000	2 weeks
50,000-100,000	4 days

3. **Chlorinated water supplies before distribution.**

Large supplies, serving populations of greater than 100,000 should be subjected to daily sampling for bacteriological analysis in conjunction with continuous chlorine residual recording.

For small rural community (< 10,000), where even sampling for bacteriological analysis at weekly intervals may be impractical, in such cases, it is important that the chlorine in water leaving treatment plants should be checked at least once daily.

4.4 Water Analysis

4.4.1 Bacteriological Testing of water

The bacteriological analysis of water can confirm whether a water supply has been faecally contaminated. To search directly in a water sample for the presence of specific enteric pathogens is impractical for routine control purposes. When no normal faecal bacteria are detected in water sample, it is probable that enteric pathogens (usually present in much smaller numbers) are also absent. It must be remembered, however, that some viruses and parasites survive longer and are more resistant to chlorination than some faecal bacteria used as indicators of pollution.

Faecal coliforms (Some times called thermo tolerant coliform organisms or E coli) are the most appropriate indicators of faecal pollution.

It is less useful to test for total coliforms because they are not directly related to the presence of faecal contamination and so not to the risk of disease. The most valuable test for the routine quality control of water supplies is the E. coli Count.

As perviously explained, the E. coli count is the most useful test for detecting faecal contamination of Water supplies in water quality analysis.

Two principal techniques are available for counting faecal coliforms:

1. Membrane filtration
2. Multiple tube / most probable number (MPN)

Membrane Filtration Technique

In this technique, a 100ml water sample or diluted sample is filtered through a membrane filter. The membrane, with the coliform organism on it is then cultured on a pad of sterile selective broth containing lactose and a gas indicator. After incubation, the number of coliform colonies can be counted. This gives presumptive number of E. coli in the 100 ml water sample.

Required

1. Sterile filtration unit for holding 47 mm diameter membrane filters with suction device.
2. Sterile grid membrane filters, 47 mm diameter with a pore size of 0.45 Nm.
3. Sterile 47 mm diameter cellulose pads (both culture medium is added just before use).
4. Sterile Petri dishes 50-60 m m diameter
5. Sterile membrane laury sulphate broth (lactose sodium laury sulphate broth).

When laury sulphate broth is unavailable, use macConkey membrane broth. E. Coli colonies appear yellow on both types of broth.

For use, place a sterile cellulose pad in a sterile Petri dish and add 2.5 ml of the sterile broth. The pad will swell slightly after adding the broth pour off any surplus broth before placing the membrane on the pad.

Method

1. Assemble the flirtation unit and suction device.
2. Using sterile blunt-ended forceps place a sterile membrane filter, gride-side uppermost, on the filter base and reassemble the unit.
3. Mix thoroughly the sample of water by inverting the bottle several times.

   Volume of water to filter

- Treated water samples and ground

water samples-------------------------------------- 100ml.

- Untreated water samples from
  surface water sources---------------------------- 10ml.
- Partially treated samples from protected
  borehole or well water -------------------- 50 ml or 10ml

4. Apply suction (Using hand, water or electric device) to draw the water sample through the filter membrane.
5. Using sterile blunt-ended forceps aseptically remove the membrane from the filtration unit and place it, grid side upper most, on the culture medium pad in the Petri dish, ensuring there are no air bubbles trapped under the membrane. Close the Petri dish. Label the top of the lid with the code number of the water sample and volume of water used.(See fig. 4.1)
6. Leave at least one hour (4hours for chlorinated samples) before incubating the samples at 44^0c for 12-16 hours. Place the Petri dishes (lids upper most) in the incubator, preferably in Petri dish holder.
7. Following incubation and using oblique lighting examine the membrane for yellow lactose fermenting colonies, 1-3 mm in diameter. Count the number of colonies. Ignore any pink colonies and very small colonies (less than 1 mm in diameter). When the number of colonies are too numerous to count, report such a confluent growth a ‘too numerous to count‘(indicative of gross contamination).
8. Calculate the presumptive E. Coli count / 100 ml as follows

- 100 ml water sample, multiply number of colonies by 1.
- 50 ml water sample, multiply number of colonies by 2
- 10 ml water sample, multiply number of colonies by 10.

Note: - Whenever possible use a standardized form to report the water analysis and interpretation of the E. Coli count.

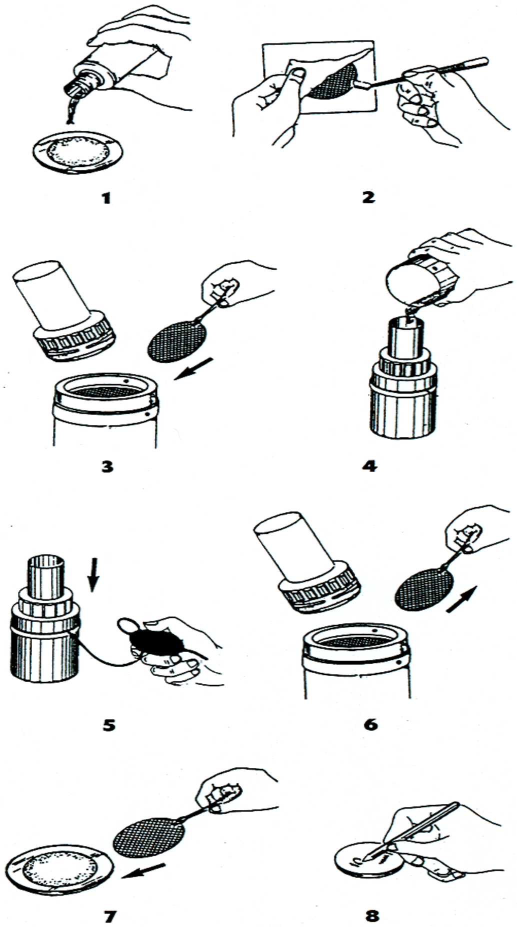


Figure 4.1 .Microbiological Testing of water by Membrane Filtration. 1 adding sterile broth to the cellulose pad in a petridish. **2** Aseptically removing the sterile membrane. **3** Placing the membrane on the filter base. **4** Pouring the water sample in the filter unit. **5** Drawing the water through the membrane by suction. **6** Removing the membrane. **7** Placing the membrane on the broth impregnated pad. **8** Labelling the petri dish before incubation.

Courtesy of Robens Centre for Public and Environmental Health. (Source: Monica Cheesbough. District Laboratory Practice in Tropical Countries. Part 2. Cambridge University Press. 2000)

4.5 Interpretation of Results

A distinction needs to be drawn between samples from chlorinated and unchlorinated water supplies.

Chlorinated samples:

- At least 90% of all samples taken over a 12-month period should have a zero E. coli count per 100me.
- The E. coli count should never exceed 5 per 100ml.

Unchlorinated samples:

Most untreated water supplies contain faecal bacterial but in case of protected ground water, e g. springs, protected wells and tube wells, it should be possible to achieve very low levels of contamination.

The following guidelines are, therefore, suggested:

Table 4.2 Guidelines for bacteriological quality of water.

Mean Count 44^0C. 100 ml E. Coli count	Category	Comments
0	A	**Excellent**
1-10	B	**Acceptable**: But make regular sanitary checks
10-50	C	**Unacceptable:** look for and correct for structural faults and [poor maintenance of pumps **plinth**. Then disinfect equipment and sources.
More than 50	D	**Grossly polluted:** look for alternative source, or carry out necessary repairs and disinfect well.

source: Monica Cheesbough. District Laboratory Practice in Tropical Countries. Part 2. Cambridge University Press. 2000

- Guidelines can only be applied when routine survey date are available e.g. 5-10 consecutive weekly samples.

NB. A single laboratory examination of any water whether raw or treated, and however favorable the result, does not justify the conclusion that all is well and that a water supply is suitable for drinking. Contamination is often intermittent and may not be revealed by the examination of a single sample. The value of water analysis is dependent upon it being performed frequently at regular intervals, using tests, which can be carried out, reliably in the field.

The interpretation of results is the same in both techniques of bacteriological analysis.

Review Questions

1. What is the objective of sampling?
2. What are the prerequisites taken into consideration in the handling of sample bottle for bacteriological analysis?
3. What is the importance of dechlorination of samples of water for microbiological analysis?

Note to the teacher

After you have gone through the different methods of sampling in the theoretical class, arrange a practical session for the students to show how to take samples from different sources of water.

CHAPTER FIVE

WATER SURVEILLANCE

Learning Objectives

At the end of this chapter, the students will be able to:

1. Define the terms sanitary survey, water surveillance, and sanitary inspection.
2. Explain the purpose of sanitary survey and water surveillance.
3. Describe the information required for sanitary survey of water supply.
4. Understand the functions of sanitary inspection report form.
5. Carry out and analyze the reports of sanitary inspection of water supply.

5.1 Introduction

Water sampling and analysis is usually done in conjunction with sanitary surveys. It is very crucial to accompany sanitary surveys with water quality analysis since it helps to interpret the result of the analysis. Sanitary survey results may indicate the need for examination of water, or the result of the water laboratory examination can be properly interpreted using the tool of sanitary survey. Nevertheless, the use of sanitary survey is not just limited to small-scale water supply schemes (well and spring water), it can also serve as an instrument to monitor and evaluate both large conventional water treatment plant and its distribution. Therefore, environmental health professionals should apply this vital tool in order to safeguard the health of the consumer. In this regard, this chapter aims to provide the students with the necessary knowledge about and equip them with important techniques of sanitary survey and surveillance.

5.2 Sanitary Survey

A **sanitary survey** of a water supply system is the complete, extremely careful and detailed investigation of the entire water supply system, from the source to the consumer, in order to detect the presence of actual or potential sources of contamination. The sanitary survey report of the water supply system is the single reliable and practical source of information for ascertaining the potability of the water supply.

5.2.1 Purpose of Sanitary Survey

A sanitary survey is necessary to determine the reliability of a water system to continuously supply safe and adequate water to the consumer. It is also necessary to properly interpret the results of water analyses and evaluate the effects of actual and potential sources of pollution on water quality. The value of the survey is dependent on the training and experience of the investigator. When available, the advice of the regulatory agency Sanitary engineer or Sanitary engineer or Sanitarian should be sought. Watershed protection includes enactment of watershed rules and regulations and regular periodic surveillance and inspections. It, in effect, becomes *epidemiological surveillance and is a study of environmental factors that may affect human health*. Watershed rules and regulations are legal means to control land use that might cause pollution of the water draining off and into the watershed of the water source.

5.2.2 Important Considerations in doing Sanitary Survey

If the source of water is a natural or man-made lake, attention would be directed to the following, for each contributes distinctive characteristics to the water:

- Drainage basin and location of sewage and other solid and liquid waste disposal or treatment systems; bathing areas; storm water drains; sewer outfalls; swamps; cultivated areas; feed lots; sources of erosion, sediment and pesticides; and wooded areas, in reference to the pump intake.

When water is obtained from a stream or creek, all land and habitation above the water supply intake should be investigated. This means inspection of the entire watershed drainage area so that actual and potential sources of pollution can be determined and properly evaluated and corrective measures instituted. All surface-water sources should be considered of doubtful sanitary quality unless given adequate treatment, depending on the type and degree of pollution received.

Sanitary surveys have usually emphasized protection of surface-water supplies and their drainage areas. Groundwater supplies such as wells, infiltration galleries, and springs have traditionally been protected by proper construction and location (at an arbitrary “safe” distance from potential sources of population and not directly downgrade). The rule-of-thumb distance of 75, 100, or 200 ft, coupled with well construction precautions, has usually served this purpose in most instances, such as for onsite residential wells, in the absence of hydrogeological and engineering investigation and design. However, greater attention should be given to potential distant sources of pollution, especially chemical sources.

The sanitary survey would include, in addition to the source as noted above, the potential for and effects of accidental chemical spills and domestic sewage or industrial waste discharges and landfill sites. Included in the survey would be inspection and investigation of the reservoir, intake, pumping station, treatment plant, and adequacy of each unit process; operation records; distribution system carrying capacity, head losses, and pressures; storage facilities; emergency source of water and plans to supply water in emergency; integrity of laboratory services; connections with other water supplies; and actual or possible cross-connections with plumbing fixtures, tanks, structures, or devices that might permit back-siphonage or backflow. Certification of operators, the integrity and competence of the person in charge of the plant, and adequacy of budgetary support are important factors. Consideration should also be given to land-use plans and the purchase of hydrogeologically sensitive areas and Zoning controls.

5.2.3 Sanitary survey of a water supply includes the following information:

A) Geological and topographical survey of the source: the type and nature of the rock formations of the locality, (including porosity, permeability, existence of limestone,), hydraulic gradient, depth to water table, etc.; the extent of the drainage or catchments basin of the source or other feeders of the source, the type of vegetation, and the factors that all these points may contribute to contamination.

B) Human habitation, livestock and animal population: the existence of actual or potential sources of contaminants as the result of human activities. For example, methods of excreta and refuse disposal, and animal waste disposal; the distance of such sources of contaminants, latrines, cesspools, sewage, etc., from the water source; industrial or other wastes, which are being drained or will be drained into the source.

C) Amount and duration of rainfall: the chances of infiltration or flooding of runoff during rainy seasons and dry seasons to the source; preventive measures against such infiltration by diversion ditches, if any or by other means.

D) Soundness of the protection technique: if the source is a well or a spring, the soundness of the casing platform and cover to exclude the infiltration of contaminants; the possibility of contamination through the method of drawing water (water pump, sanitary bucket and rope, etc.); the gradient and distance from potential sources of contaminants, with the chance or infiltration from nearby streams, ponds, septic tank effluents, seepage pits, cesspools, oxidation ponds, etc.

Note: Fluoresce in sodium solution is one of the chemicals commonly used for tracing underground infiltration of pollution.

E) Efficiency of treatment: the type of treatment used and the efficiency of each step: aeration, chemical coagulation, sedimentation, filtration (slow or rapid sand filter), chlorination; storage methods and condition of the reservoir; possibilities of contamination during pumping, transport (piping), storage and distribution, including public standpipes and house connections; frequency of supervision, type of personnel and their qualification for running the treatment processes; regularity of chlorination; presence of residual chlorine at all times and at all points in the system, availability of residual chlorine records (daily, weekly, etc.); frequency of disinfection, if any; and, if the source is ground-water, type and frequency of laboratory test performed.

5.2.4 Sanitary Inspections

A sanitary inspection is an on-site inspection and evaluation by qualified individuals of all conditions, devices and practices in the water supply system that pose an actual or potential danger to the health and well being of the consumer. Sanitary inspections provide a direct method of pinpointing possible problems and sources of contamination. They are also important in the prevention and control of potentially hazardous conditions, including epidemics of waterborne diseases.

Sanitary inspections are intended to provide a range of information and to locate potential problems. The data obtained may identify failures, anomalies, operator errors, and any deviations from normal that may affect the production and distribution of safe drinking water. When the inspections are properly carried out at appropriate regular intervals, and when the inspector has the knowledge necessary to detect and suggest technical solutions, the production of good quality water is ensured.

The frequency of routine sanitary inspections depends on a number of factors, such as geography, distribution of the population, access to the various localities, etc. as well as the overall development level, including facilities, number and expertise of technical staff, level of activity in programs, etc.

The two principal activities are sanitary inspection and water quality analysis. Sanitary inspection should take priority over analysis, but the two should be done together whenever possible. They are complementary activities; inspection identifies potential hazards, while analysis indicates whether contamination is occurring and if so, its intensity.

A sanitary inspection is indispensable for the adequate interpretation of laboratory results. No analytical, bacteriological or chemical survey, however carefully carried out, is a substitute for comprehensive knowledge of conditions at the water source and within the distribution system, the adequacy of water treatment, and the qualifications and performance of the operators. Samples represent conditions at a single point in time and even when there is frequent sampling and analysis, the results are reported after contamination has occurred, especially in systems without long-term storage. Microbiological contamination is often sporadic and may not be revealed by occasional sampling.

1. Sanitary Inspection Reports

The sanitary inspection report is that part of the survey based on the on-site inspection of the water sources (i.e. a field survey). It therefore provides a direct method of identifying all the hazards that are potential and actual causes of contamination of the supply. It is concerned with the physical structure of the supply, its operation, and external environmental factors. The hazards recorded during inspection are often tangible and observable and may be used together with analytical data to derive a risk assessment.

Sanitary inspections, thus, provide essential information about immediate and ongoing possible hazards associated with a community water supply, even in the absence of microbiological or chemical evidence of contamination.

A) Functions of Sanitary Inspection Report Forms

Inspections forms should provide a simple and rapid means of assessing and identifying hazards associated with water supply systems. The inspection form should include at least a checklist of the components of the water supply from source to distribution and incorporate all the potential points where hazards may be introduced. Any problems identified during the inspection should be highlighted so that a report may be provided directly to the community and copies forwarded to both supply agency and health authority.

The specific functions of the sanitary inspection report are to:

- Identify potential sources and points of contamination of the water supply;

- Quantify the hazard (hazard score) attributable to the sources and supply;
- Provide a clear, graphical means of explaining the hazards to the operator/user;
- Provide clear guidance as to the remedial action required to protect and improve the supply, and;
- Provide the raw data for use in systematic strategic planning for improvement.

B) Design of Sanitary Inspection Report Forms

The design, evaluation and refinement of sanitary inspection forms are among the most important aspects of developing a surveillance or quality-control program. Two approaches are possible: the use of pictures and brief checklists, or the use of detailed checklists with explanatory notes. Either may be used successfully. However, the use of pictorial inspection forms should be adapted to match local circumstances; they should be suitable for the inspectors to use, and the recipients of the information should be able to understand and act on them.

2. Carrying out Sanitary Inspections

Staff responsible for field sanitary inspection work should always try to notify the local community representatives in advance of the visit, especially where the presence of the latter is required in order to obtain access to certain points in the supply system and where the assistance of community members in conducting the inspection is needed.

Before visiting the community, the sanitarian should have prior knowledge of the type and number of supplies, sources and taps. This should be checked against local records and maps held by the local health post or health center. If no map is available, an attempt should be made to prepare at least a sketch map of the supply or sources.

The sanitarian should complete the sanitary inspection report onsite together with the community representatives. Opportunities to point out problems or defects in the field to community members, their representatives, or the system caretaker or operator should be taken whenever possible. It may also be appropriate to undertake simple repairs at the same time.

After completing the sanitary inspection, the sanitarian should circle each of the points of risk on the diagram. Before leaving the community, the sanitarian should discuss, agree and schedule any follow up actions and indicate the date of the next survey. The survey officer carrying out the sanitary survey should record whether or not sampling or analysis will be undertaken. Labor, and hence, time can sometimes be saved by carrying out the analysis in the field at the same time as the inspection.

Sanitary inspections should be undertaken on a regular basis. Regular or routine inspections are visits made with a defined frequency in accordance with a previously established plan. In addition, non-routine visits by the inspector will be necessary in atypical situations, such as the introduction of a new water source, and in cases of emergency. Emergency situations calling for the urgent presence of the inspector include:

a) Reports of epidemics
b) High turbidity caused by floods
c) Unresolved cases where bacteriological analysis repeatedly show the presence of excess levels of micro-organisms and where residual chlorine levels remain consistently low
d) The detection of any important changes that could impair drinking water quality.

Review Questions

1. Define what sanitary survey is and describe its purpose.
2. What factors are to be considered during sanitary inspection of water sources?
3. Which information is crucial when you do sanitary surveys?
4. What is the purpose of sanitary report?

Note to the teacher

At the end of this session, if possible, please arrange a water source visit and orient the students with the techniques of sanitary survey practically.

CHAPTER SIX

WATER DISTRIBUTION AND HYDRAULICS

Learning Objectives

At the end of this chapter students will be able to:

1. Define the meaning of water pumps.
2. Discuss the impact of atmospheric pressure on pumping.
3. Explain the principle of pumping water.
4. Identify the types of pumps used in drinking water supply.
5. Recognize cause of friction head.
6. Calculate power requirements of pumps.

6.1 Introduction

The water needs to be transported from the source to the treatment plant, if there is one, and onward to the area of distribution depending on the topography and local conditions that water may be conveyed through.

- Free- flow conduits
- Closed conduits
- A combination of both

The water conveyance will be either under gravity or by pumping

Free-flow conduits are generally laid at a uniform slope that closely follows the hydraulic grade line. Examples of such conduits are canals, aqueducts, tunnels or partially filled pipes. If a pipe or tunnel is completely full, the hydraulic gradient and not the slope of the conduit will govern the flow.

The hydraulic laws of <u>closed conduit flows</u>, also commonly called <u>pressurized flows</u> apply in this case. Pressurized pipelines can be laid downhill as needed, as long as they remain at sufficient distance below the hydraulic grade line, i.e. certain minimum pressure is maintained in the pipe.

Free-flow conduits have a limited application in water supply practice in view of the danger that the water will get contaminated. They are never appropriate for the conveyance of treated water but, may well be used fro transmission of raw water.

For community water supply purposes, pressurized pipelines are the most common means of water transmission. Whether for free flow or under pressure, water transmission conduits generally require a considerable capital investment. A careful consideration of all technical options and their costs and discussion with the community groups that will support and manage the system are therefore necessary when selecting the best solution in particular case.

Routes always need to be checked with community members as well to make use of local knowledge and ensure cultural acceptability (technically desirable routes may, for example, run through a burial site or be unacceptable for other local reasons).

o **Types of water conduits**

1. **Canals** – are laid in areas where the required slope of the conduit more or less coincides with the slope of the terrain.
2. **Aqueducts and tunnels** – are constructed in hilly areas. They should be of such a size that they are approximately three-quarters full at the design flow rate. Thy are constructed to shorten the overall length of a water transmission route.
3. **Free-flow pipelines** are used for transport of smaller quantities of water than tunnels. Compared with canals and aqueducts they offer better protection from pollution. Due to the free-flow conditions, simple materials may be used for construction Glazed clay or concrete pipes should be adequate. Similar hydraulic conductions occur as for other free-flow conduits.
4. **Pressurized pipelines** – The routing of pressurized pipelines is much less limited by the topography of the area to be traversed, than is the case of canals, aqueducts or free-flow pipelines. A pressure pipeline may run up-and downhill and there is considerable freedom for selection of the pipeline alignment.

- **Design parameters:**

1. Design flow

The water demand in a distribution area will fluctuate considerably during a day. Usually a service reservoir is provided to accumulate and even out the variation in water demand. The service reservoir is supplied from the transmission main, and is located at a suitable position to be able to supply the distribution system (Fig. 6.4). Again, its site needs to be chosen by the local people, based on technical advice and their own socio cultural criteria. The transmission main is normally designed for the carrying capacity needed to supply water demand on the maximum consumption day at a constant rate. All hourly variations in the water demand during the day of maximum consumption are then assumed to be evened-out by the service reservoir.

The number of hours the transmission main operates each day is another important factor. For a water supply with diesel engine or electric motor-driven pumps, the daily pumping often is limited to 16 hours or less. In such a case, the design flow rate for the transmission main as well as the volume of the service reservoir need to be adjusted accordingly.

2. Design pressure

Pressure as a design parameter is only relevant for pressurized pipelines. Consumer connections on transmission lines are rare, so the water pressure can be kept low provided that the hydraulic grade line is positioned above the pipe over its entire length and for all flow rates. A minimum of a few meters water column is also required to prevent intrusion of pollution through damaged parts of the pipe or faulty joints. In fact, nowhere should the operating pressure in the pipeline be less than 4-5 mwc (meters water column).

High pressures in transmission pipe occur as a result of long distances or specific topography. During supply by gravity the maximum pressure does not occur under operating conditions. It is the static pressure when the pipeline is shut. In order to limit the maximum pressure in a pipeline and thus the cost of the pipes, the route can be divided into sections separated by a break-pressure tank. The function of such a tank is to limit the static pressure by providing an open water surface at certain places along the pipeline. The flow from the upstream section can be throttled when necessary.

If water is to be transported to higher elevations, the maximum pressure will occur in the vicinity of pumping. High pressures in the transmission pipe can be avoided in this case by application of multistage pumping along the pipe route.

Critical pressures may also develop as a result of pressure surge or water hummer in the pipeline. The phenomenon is caused by the instant or too rapid closure of values, or by sudden pump starts or stops, e.g. due to electricity failure. A longitudinal water wave created in such a way causes over-and under-pressures well above the normal working pressure. This is potentially a very dangerous situation that may result in damage to the pipeline over long distances.

Proper prevention includes construction of surge tanks, air vessels or water towers as well as selection of suitable pipe materials that can withstand the highest pressures. Regarding values, specified minimum shut-off times should be strictly respected. This makes it important how communities choose, train and supervise value operators and that operators understand, and practice the proper regulation of the values.

3. Design velocity and hydraulic gradient

A velocity range is established for design purposes for two reasons. On the one hand, a certain minimum velocity will be required to prevent water stagnation causing sedimentation and bacteriological growth in the conduits. On the other hand, the maximum velocity will have to be respected in order to control head losses in the system as well as to reduce the effects of water hammer.

The velocity of flows in canals, aqueducts and tunnels usually ranges between 0.4 and 1.0m/s for unlined conduits, and up to 2m/s for lined conduits. Flows in pressurized transmission mains have the velocity range between 1 and 2 m/s.

In the case of pressurized pipes, design values may also be set for the hydraulic gradient. This is done primarily to limit the head losses, i.e. to minimize the energy consumption for pumping the water. Common values of the hydraulic gradients for transmission pipes are around 0.005, which means 5 mwc of head loss per km or the pipe length.

- **Hydraulic design**

Flow Q (m^3/s) through a cross-section A (m^2) is determined as = vA, where v (m/s) is the mean velocity of the cross-section.
Assumptions of 'steady' and 'uniform' flow apply in basic hydraulic calculations for the design of water transmission systems. The flow is steady if the mean velocity of one cross-section remains constant with a certain period of time. If the mean velocity between the two cross-sections is constant at a certain moment, the flow is uniform.

1. Hydraulic design in free-flow conduits

The sticker formula is widely used for conduits with free-flow conditions. The formula reads:

$$V = K_4 R^{2/3} S^{1/2}$$

Where;

V = mean water velocity in the cross-section (m/s)

K_4 = strickler coefficient ($m^{1/3}/s$)

R = hydraulic radium (m)

S = hydraulic gradient (m/km)

The strickler coefficient represents roughness of the conduit. For design purposes, table 6.1 provides indicative values of this coefficient for various of linings in clean, straight conduits. In practice, these values may differ from one channel section to another and are often subjected to seasonal variations.

Table 6.1 Indicative values of the strickler coefficient for various types of linings

Type of lining	Strickler coefficient K_4($m^{1/3}/s$)
Concrete, trowel finished	80
Masonry	
- Neat cement plaster	70
- Brickwork, good finish	65
- Brickwork, rough	60
Excavated	
- Earth	45
- Gravel	40
- Rock cut, smooth	30
- Rock cut, aged	25

In a wide range of literature, the strickler coefficient is listed as the *Manning coefficient*, n in $m^{1/3}$ s, where n = 1 ¼ consequently, the formula is called the manning formula:

$$V = 1/n(R^{2/3}S^{1/2})$$

The hydraulic radius, R = A/P, where A(m^2) is the cross-sections area and P(m), the wetted perimeter.

Finally, the hydraulic gradient, S, can be substituted by the slope of the conduit where the assumption of uniform flow conditions is valid.

examples, calculations

2. Hydraulic design in closed conduits

The Strickler and Manning formulas are also applicable for closed conduits by introducing the real hydraulic gradient of the flow and the wetted perimeter as the full perimeter of the conduit. Nevertheless, a problem may occur in the selection of the roughness factors for a wide range of pipe materials and flow conditions. More appropriate formulas for computing the head loss of water flowing through a pressurized pipeline are those of *Darcy-weilbach and Hazen-Williams*.

The Darcy-Weilbach formula states:

$$\begin{aligned}\Delta H &= [\lambda \text{ x } L/D \text{ x } Y^2/2g) \\ &= [(8\lambda\ L/\pi^2\ gD^5)Q^2) \\ &= [(\lambda L/12.ID^5)Q^2)\end{aligned}$$

Where:

ΔH = head loss (mwe)
L = pipe length (m)

D = pipe diameter (m)

λ = friction factor (-)

V = the mean velocity in the pipe (m/s)

g = gravity (9.81 m^3/s)

Q = flow rate (m^3/s)

Introduction the hydraulic gradient $S = \Delta H/L$, the formula can be rewritten as:

$V = \sqrt{(2gDS)} / \lambda$

The factor λ is the friction coefficient can be calculated by the *Colebrook-white formula*.

$1 / \sqrt{\lambda} = 2\log(2.51/Re\sqrt{\lambda}) + (k/3.7D)]$

Where:

Re = the Reynolds number (-)

K = absolute roughness of the inner pipe wall (mm)

D = pipe diameter (mm)

μ = kinematic viscosity (m^2/s)

Finally, the kinematic viscosity is dependent on the water temperature. For T in ^{0}C:

$\mu = (497 \times 106) / (T + 42.5)^{1.5}$

The Colebrook white formula is developed for a turbulent flow regime, i.e. **Revalues** about ± 4000. The common values in practice are much higher, typically in the order of 10^4 and 10^5. If by chance the flow is laminar ($Re < 2000$) the friction factor λ will be calculated as:

$\lambda = 64/Re$

Calculation by the Colebrook-white formula is not straightforward, as the λ-factor appears on both sides of the equation. The alternative formula of Barr can be used instead:

$$1/\sqrt{\lambda} = 2\log\ (5.1289/Re^{0.89}) + (k/3.7D)]$$

The common range of k-values is listed in table 6.2 for various pipe materials. For practical calculation these values can be increased depending on the number of years the pipe was in service and the influence of head losses caused by bends, joints, values, etc.

Table 6.2 Absolute roughness (Bhave, 1991)

Pipe material	K (mm)
Asbestos cement	0.015-0.03
Bitumen/Cement lined	0.03
Wrought iron	0.03-0.15
Galvanized/Coated cast iron	0.06-0.3
Uncoated cast iron	0.15-0.6
Ductile iron	0.03-0.06
Uncoated steel	0.015-0.06
Coated steel	0.03-0.15
Concrete	0.06-1.5
Plastic, PVC, PE	0.02-0.05
Glass fiber	0.06
Brass, cooper, lead	0.003

(source**:** Bhave, P.R, (1991) Analysis of flow in water distribution systems. Lancaster, PA, USA Technomic publishing.)

The Hazen-williams formula is simpler, although less accurate than the Dracy Weilbach equation. It states for SI-unit.

$$V = 0.355C_{kw}D^{0.63}S^{0.54}$$

This formula is applicable for a common range of flows and diameters. Its accuracy becomes reduced at lower values of C_{kw} (much below 100) and/or velocities that are dimensionally uniform and if other units are used than SI, it has to be readjusted. Nevertheless, due to its simplicity this formula is still widely used in the USA and in many, predominantly Anglophone, developing countries.

Table 6.3 The Hazen-williams factor (Bhave, 1991)

Pipe material	Ckw D=75 mm	Ckw D= 250mm	Ckw D = 300mm	Ckw D = 600mm	Ckw D=1200 mm
Uncoated cast iron	121	125	130	132	134
Coated cast iron	129	133	138	140	141
Uncoated steel	142	145	147	150	150
Coated steel	137	142	145	148	148
Wrought iron	137	143			
Galvanized iron	129	133			
Uncoated asbestos cement	142	145	147	150	
Coated asbestos cement	147	149	150	152	
Concrete, minimum values	69	79	84	90	95
Concrete, maximum values	129	133	138	140	141
Prestressed concrete	147	149	147	150	150
PVC, brass, copper, lead	142	145	150	152	153
Wavy PVC	147	149	147	150	153
Bitumen/cement lined			150	152	153

(source**:** Bhave, P.R, (1991) Analysis of flow in water distribution systems. Lancaster, PA, USA Technomic publishing.)

Application of the discussed head loss formulas is illustrated in the examples.

Example 1

Determine the capacity of the rectangular concrete canal if the water depth is 0.2 m. The width of the canal is 1.0 m and the slope of the bottom is S = 1 */00.

Solution

From table 6.2, Ks for concrete = 80 $m^{1/3}$/s Further.

R = A/P = b y(b +2y) = 1*0.2/1+2*0.2 =0.1429 m

V = $KsR^{2/3}S^{1/2}$ =80*$0.1429^{2/3}$ $0.001^{1/2}$ = 2.19m/x

Q = V by = 2.19 **1**0.2 = 0.437m^3/s = 437 1/s

Example 2

Find out the head loss in the concrete transmission pipe, L = 300m and D = 150 mm, following full. The flow rate is 80 m^3/hour and the water temperature is 10^0C. Compare the results of the Darcy-weisbach, Hazen-williams and strickler formulas.

Solution

For water temperature of 10^0C, the kinematics viscosity

The pipe kiscosity $\mu = (497 * 10*) / (T +42.5)^{1.5}$

$= (497 * 10^{-6}) / (10 + 42.5)^{1.5}$

$= 1.31 * 10^{-6}\ m^2/s$

The pipe velocity: $V = 4Q / D2\pi$

$= (4 * 80/3600)(0.15^2 * 3.14)$

$= 1.26$ m/s

And the Reynolds number: $Re = vD/\mu$

$= (1.26m/s *0.15m)/1.31 * 10^{-6}m^2/s$

$= 1.44 * 10^{5}$

From table 6.2 the k-value for concrete pipes ranges between 0.06 and 1.5 mm. For k = 0.8 mm, λ factor form the Barr equation.

$1/\sqrt{\lambda} = 2\log [(5.1289/Re^{0.89}) + (k/3.7D)]$

$1/\sqrt{\lambda} = 2\log [(5.1289)(1.44\ \mathbf{10^{5})^{0.89}}\ \mathbf{)+ (0.8/3.7}150)]$

$= 5.60887; \lambda = 0.032$

Finally, $\Delta H = [\lambda \times L/D \times V^{2}/2g]$

$= [0.032*(300/0.15)*1.26^{2}/(2*9.81)]$

$= 5.12$ mwc

According to table 6.2, the Hazen-williams factor for ordinary concrete pipe.

D = 150 mm ranges between 79 and 133, For C_{kw} assumed at 105

$V = 0.355C_{kw}D^{0.63}S^{0.54}$;

$S = [V/0.355C_{kw}D^{0.63}]^{1/0.54}$

$= [1.26 / (0.355 * 105 *0.15^{0.63})]^{1.852} =0.01722$

Consequently: $\Delta H = SL = 0.01722 * 300 = 5.17$ mwc

Finally, for $K_{s} = 85\ m^{1/3}/s$

$R = A/P = [(D^{2}\pi/4)/D\pi) = D/4 = 0.15/4 = 0.0375m$

$V = K_{s}R^{2/3}\,S^{1/2}$; $S = (V/(K_{s}R^{2/3}))^{2} = 0.01743$

$\Delta H = SL = 0.01743 * 300 = 5.23$ mwe

All three formulas show similar results in this case. This can differ more substantially for different choice in roughness parameters. E.g in case of $C_{kw} = 120$, the same calculation by the Hazen-williams formula would yield ΔH = 4.03 mwc while for K_4 = 80 $m^{1/3s}$, the sterickler formula gives ΔH = 5.90 mwc.

In practice, the accuracy of any head loss formula is of less concern than a proper choice of the roughness factor (K, C_{kw} or K_4) for a given surface. Errors in results originate far more frequently from insufficient knowledge about the condition of the conduit, than from wrong choice of formula.

Example 3

What will be the flow in a 100 mm-diameter pipe to transport water from a small dam to a tank at 600 m distance? The difference between the water surfaces in the two points is 3.60m. the absolute roughness of the pipe wall is k = 0.25 mm and the water temperature equals 10 *C.

Solution

The difference between the water levels indicates the available head loss. Hence, ΔH = 3.60 mwc and S = 3.60/600. From the previous example, $\mu = 1.31 * 10^{-6} m^2/s$ for the water temperature of 10^0C. the calculation has to be iterative due to the fact that the velocity (flow) is not known and it influences the Reynolds number, i.e. the flow regime. A common assumption is v = 1m/s. Further:

$Re = (1.0*0.1)(1.31*1.10^{-6}) = 7.65*10^4$

$1/\sqrt{\lambda} = 2\log [(5.1289) 7.65*10^4)^{0.89})+(0.25/(3.7*100)$

$= 6.0851; = \lambda = 0.027$

$V = \sqrt{\ } (2gDS/\lambda = \sqrt{[(2*9.81*0.1*0.006)/0.027]}$

$= 0.66 m/s$

The calculated velocity is different from the assumed one of 1 m/s. The procedure has to be repeated starting with this new value. For V = 0.66 m/s, Re = $5.06 *10^{-4}$ and λ = 0.0 28, which yields V = 0.01 m/s considered as acceptable and hence:

$Q = V * A = 0.65 *(0.12 \pi/4) = 0.0051 m^3/s = 5.1 1/s$

6.2 Water Distribution

6.2.1 Introduction

Water distribution systems convey water drawn from the water source of treatment facility, to the point where it is delivered to the users. Unlike the transmission system discussed in chapter 6, these systems deal with water a demand that varies considerably in the course of a day.

Water consumption is highest during the hours that water is used for personal hygiene and cleaning when food preparation and clothes washing are done. Water use is lowest during night.

This variation in flow can be dealt with by operating pumps in parallel and/or building balancing storage in the system. For small community water supplies the distribution system with water storage (e.g. a service reservoir) is the preferable option, given that supplies of electricity or diesel to power pumps will usually be unreliable. Although it can be kept simple, construction of such a system may represent a substantial capital investment and the design must be done properly.

Generally the distribution system of a small community water supply is designed to center for the domestic and other household water requirements. Stock watering and garden plot irrigation water may also be provided.

Service reservoirs accumulate and store water during the night so that it can be supplied during the daytime hours of high water demand.

It is necessary to maintain sufficient pressure in the distribution system to protect it against contamination by the ingress of polluted seepage water. For small community supplies a minimum pressure of 5-10 mwc (maters of water column) should be adequate in most instances.

6.2.2 Types of Distribution Systems

There are basically two main layouts of a distribution network:

- Branched configuration
- Looped (or “grid”) configuration

Branched networks: are predominantly used for small-capacity supplies delivering the water mostly through public standpipes and having few house connections, if any. Although adequate, having in mined simplicity and acceptable investment costs, branched networks have some disadvantages:

- Low reliability, which affects all users located downstream of any breakdown in the system.
- Danger of contamination caused by the possibility that a large part of network will be without water during irregular situations.
- Accumulation of sediments, due to stagnation of the water at the system ends ('dead' ends) occasionally resulting in taste and odour problems.
- Fluctuating water demand producing rather large pressure variations.

Branched systems are easy to design. The direction of the water flow and the flow rates can readily be determined for all pipes. This is different in looped distribution networks, where consumers can be supplied from more than one direction. Looped network greatly improve the hydraulics of the distribution system. This is of major importance in the event that one of the mains is out of operation for cleaning or repair.

A looped network: usually has a skeleton of secondary mains that can also be in a form of branch, one loop ('ring') or number of loops. From there, the water is conveyed towards the distribution pipes and further to the consumers. The secondary mains are connected to one or more loops or rings.

The network in large (urban) distribution system will be much more complex; essentially a combination of loops and branches with lots of interconnected pipes that requires many valves and special parts. To save on equipment costs, over-crossing pipes that are not interconnected may be used but at the cost of reduced reliability.

Points at which the water delivered to the users are called service connections. The number and types of service connections has considerable influence on the choice of a network layout.

The following types of service connections may be distinguished:

- House connection
- Yard connection
- Group connection
- Public standpipe

A house connection is a water service pipe connected with in-house plumbing to one or more taps, e.g. in the kitchen and bathroom. Usually 3/8 inch (9mm) ands ½ inch (12mm) taps are used.

The service pipe is connected to the distribution main in the street by means of a T-piece (on small-diameter pipes), a special insert piece (ferrule) or a saddle (on large size secondary pipes). A special insert piece is mostly used of cast iron and ductile iron pipes.

A yard connection is quite similar to a house connection, the only difference being that the tap is placed in the yard outside the house. No in-house piping and fixtures are provided**.**

Plastic (polyvinyl chloride or polyethylene), cast iron and galvanized steel pipes are used for both house connections and yard connections.

Group connections are outside tap that are shared by a clearly defined group of households, often neighbors. They share the tap and pay the bill together. Each family may pay the same (flat) share or contributions may be weighed according to the estimated volume of water each family consumes. Consumptions estimates may be based on indicators such as family size and composition and types of use by the different households. Sometimes the taps can be locked and a local committee holds the key and manages the use and financing.

Public standpipes can have one or more taps. Single-tap and double-tap standpipes are the most common types in rural areas. They are made or brickwork, masonry or concrete, or use wooden poise and similar materials. The design should be done in close consultation with the users (especially women) is order to arrive at an ergonomically optimal solution. Standpipes may have platforms at levels, making it easy for adults and children to use them with containers or different sizes. Cattle watering and/or washing and/or breathing facilities may be constructed nearby. The design and often also the construction is best done in consultation and with participation of the user households, i.e. both men and women. Public taps drawing from a small reservoir (cistern) represent an alternative method of water distribution.

Each standpipe should be situated at a suitable point within the community area in order to limit the distance the water users have to go to collect their water. The walking distance for the most distant user of a standpipe should, whenever possible, be limited to 200 m; in sparsely populated rural areas 500 m may be acceptable. The required discharge capacity of a standpipe normally is about 14-18 litters/minute at each outlet. A single-tap standpipe should preferable be used by not more than 40-70 people; a multiple-tap standpipe may provide a reasonable service for up to 250-300 persons; in no case should the number of users dependent on one standpipe exceed 500.

Public standpipes can operate at a low pressure. Distribution systems that serve only standpipes may therefore use low pressure piping, whereas the pipes for distribution systems with house connections generally have to be or a higher pressure call.

Water collected at a public standpipe will have to be carried home in a container (bucket, jerry can, vessel, pot, etc). This means that the water that was safe at the moment of drawing may no longer be so at the moment it is used in the house. Water consumption from standpipes generally is not higher than 20-30 liters per person per day. This consumption increases when other facilities (e.g. for washing/bathing) are added to reduce the amount of water women and children have to carry home. Water use for other purposes than drinking and cooking, is likely to be curtailed, will usually encourage a more generous water use for personal hygiene and cleaning purposes.

Wastage of water from standpipes can be a serious problem, especially when users fail to turn off the taps. Furthermore, poor drainage of spilled water may cause stagnant pools of dirty water with the associated health hazards. It is also not uncommon for the taps to be damaged by the users and pilferage sometimes occurs. These problems occur particularly when designs do not meet the user requirements, i.e. there has not been adequate consultation with the users (women and men) and/or there are no clear management arrangements. One way to cope with these problems is through payment for water consumed. When there is a fair and effective way of water demand management often those selling water are women, as they are chosen for their reliability and trustworthiness, their need to be present for work within their own neighborhood and their suitability as hygiene promoters with other women and children.

In spite of their shortcomings, group connections and public standpipes are really the only practical options for water distribution at minimum cost to a large number of people who cannot afford the much higher costs of house or yard connections. In fact, housing is frequently not suitable constructed to allow the installation of internal plumbing. It would often be impossible for a small community to obtain the substantial capital for a water distribution system with house connections. Also, the costs of adequate disposal of the considerable amounts of wastewater generated by a house connected water supply service would place an additional heavy financial burden on the community. Consequently, public standpipes have to be provided and the principal concern should be to lessen their inherent shortcomings as much possible.

To achieve sustainability of this type of service, the management at the public standpipe level needs special attention in terms of organization, O & M and cost recovery.

6.3 Hydraulics and Its Applications to Drinking Water Supplies

6.3.1 Introduction

Hydraulics- as the principles and applications of motion physics applied to drinking water systems is only considered here to provide an outline of the basic principles of flow through channels and pipes so far as they are important to the correct choice and selection of water-lifting system. So, students are advised to read far more details on the subject, in case they want a comprehensive knowledge about it.

In common with the prime moves and the water-lifting device; cost effectiveness is focused upon, rather than mere mechanical efficiency, because the aim of the course is to deal with passive items like pipes or distribution systems. Nevertheless, flow through channels is also considered due to the fact that channels are used to convey raw water from the source to a treatment plant or somewhere in between; and for comparison between channels and pipes as raw water conveyance so as to derive the most economical and efficient system.

The channels are usually cheap to build, but require regular maintenance, offer more resistance to flow, and depending on the soil conditions, are prone to lose water by both percolation and evaporation. The pipe is expensive, but usually needs little or no maintenance and involves little or no loss of water.

In general, since the power needed is the product of head and flow, any losses that cause water to fail to reach the treatment plan, hence the final user represent a reduction of effective flow (other constraints being normal) from the system. Such losses, therefore, add to the power demand and represent a further source of inefficiency. The losses occur through adding to the actual pumping head or through decreasing the effective flow rate due to losses of water (or both). Because purchase costs are obvious and running costs (and what causes them) are less clear there is a tendency to error the side of minimizing capital costs or refraining from investing in drinking water supply systems.

However, with the proper design of water conveyance systems, especially in terms of the prime mover and the water lifting devices, an entire water treatment system can be sub-divided into stages, each of which has a (variable) efficiency and a describe need for power. Mask components have an optimum efficiency. All components need to be chosen so as to be optimized close to the planned operating condition of the system if the most economical and efficient system is to be derived. The concept of cost effectiveness is an important one in this connection, since most drinking water treatment systems are a compromise or trade-off between the conflicting requirements of minimizing the total cost (capital and running costs) and supplying adequate and safe drinking water to the public. It is at this juncture that the knowledge of applied physics, such as hydraulics and the skill of applying them effectively, are most important.

6.3.2 Flow Through Channels and Pipes

Even though hydraulics includes the flow of gases and liquids, we only consider the flow of water, through channels and pipes related to conveying raw water to a treatment plant and to the distribution of the treated water to the public. The device to move (lift) the water and the prime mover (power) of the device are the basic components around which the discussion winds. The main aim is to provide the necessary slope or hydraulic gradient to cause the water to flow at a sufficient rate.

6.3.2.1 Channels

It is natural that when water is at rest, the water level will always be horizontal. However, if water flows down an open channel or canal, the water level will slope downwards in the direction of flow. This slope is called the “hydraulic gradient. The greater the frictional resistant to the flow the steeper it will be. Hydraulic gradient is usually measured as the ratio of the vertical drop per given length of channel, e.g. 1m.per 100m is expressed as 1/100 or 0.01. The rate of flow (Q) that will flow down a channel depends on the cross-sectional area of flow (A) and the mean velocity (v). The relationship between these factors is

$$Q = vA$$

E.g. If the cross –sectional area is $0.5m^2$ and the mean velocity is 1m/s, then the rate of flow will be: $1m/s \times 0.5m^2 = \underline{\underline{0.5m^3/s}}$. The mean velocity (v) of water in a channel can be determined with reasonable accuracy for typical irrigation channels by the Chezy Formula.

$$V = C\sqrt{rs}$$

Where C is the Chezy coefficient, which is dependent on the roughness of the surface of the channel (n); its hydraulic radius (r), which is the area of cro-section of submerged channel divided by its wetted submerged perimeter, and the hydraulic gradient (s) of the channel (measured in unit fall per unit length of channel). The Chezy coefficient is found from Manning’s Formula:

$$C = K \frac{r_{1/6}}{n}$$

In this formula K = 1 if metric units are used, or K = 1.486 if feet are used. R is the previously defined hydraulic radius and n is the Manning's co-efficient of roughness appropriate to the material used to construct the channel, e.g. sand, clay, rock. The materials used to construct the channel are in an established table that also indicates the recommended side slopes and maximum flow velocities for a selection of commonly used types of channels, ranging from earth ditches to concrete, metal or wooden flumes. Combining the above equations gives an expression for the quality of water that will flow down a channel under gravity as follows:

$$Q = AK \frac{r_{2/3}\ S_{1/2}}{N}$$

Where Q will be in m2/s, if A is in m^2, r is in m and K is 1.

To obtain a greater flow rate, either the channel needs to be large in cross-section (and hence expensive in terms of materials, construction cost and land use) or it needs to have a greater slope. Therefore it requires determining the best trade-off between capital cost or first cost (i.e. construction cost) and running cost in terms of the extra energy requirement if flow is obtained by increasing the hydraulic gradient rather than the cross-sectional area. The nature of the terrain also comes into consideration as channels normally need to flow the natural slope of the ground if extensive regarding or supporting structures are to be avoided. A proper design of the system of bends, functions, changes in section, slope of surface, etc is another consideration. A further point to be considered with channels is the likely loss of water between the point of entry to the channel and the point of discharge caused by seepage through the channel walls and also by evaporation from the open surface. Any such losses need to be made up by addition of extra water, which in turn requires pumping power (and energy) in proportion. One of the methods for calculating conveyance losses is

$$S = CLPR\ ½$$

Where S will be the conveyance loss in m3/s per length L if C is coefficient depending on nature of soil (e.g. C = 0.0015 for clay and 0.003 for sand)

L = length in Km
P = Wetted perimeter of cross-section
R = hydraulic mean depth (i.e. flow cross-sectional area divided
by width of surface

6.3.2.2 Pipes

A pipe can operate like a channel with a roof on it i.e., it can be unpressurized, often with water not filling it. The advantage of a pipe, however, is that it need not-follow the hydraulic gradient like a channel since water cannot over flow from it if it dips below the natural level. In other words, although pipes are more expensive than channels in relation to their carrying capacity, they generally and are therefore more cheaply and simply installed. They are of course essential to convey water to a higher level or across uneven terrain.

As with a channel, a pipe is also subject to a hydraulic gradient, which also necessarily becomes steeper if the flow is increased, that is, a higher load of a higher pressure is needed to overcome the increasing resistance to a higher flow. This is clearly seen in a pipeline with vertical tapping in it. When no flow takes place due to the outlet valve being closed, the water pressure along the pipe will be uniform and the levels in the vertical tappings will co-respond to the head of the supply reservoir. If the valve is opened so that the water starts to flow, then a hydraulic gradient will be introduced and the levels in the vertical tappings will relate to the hydraulic gradient, in becoming progressively lower further along the pipe. The same applies if a pump is used to push water along a pipe. Here the pump needs to overcome a resistance equal to the static head of the reservoir, which is the pipe friction head.

The pictures (figure 6.1) below illustrate the concept of a 'hydraulic gradient' in general and the two conditions explained above. In the two upper diagrams, the static head of the reservoir is equal to the pipe friction head, which is the resistance the pump needs to overcome.

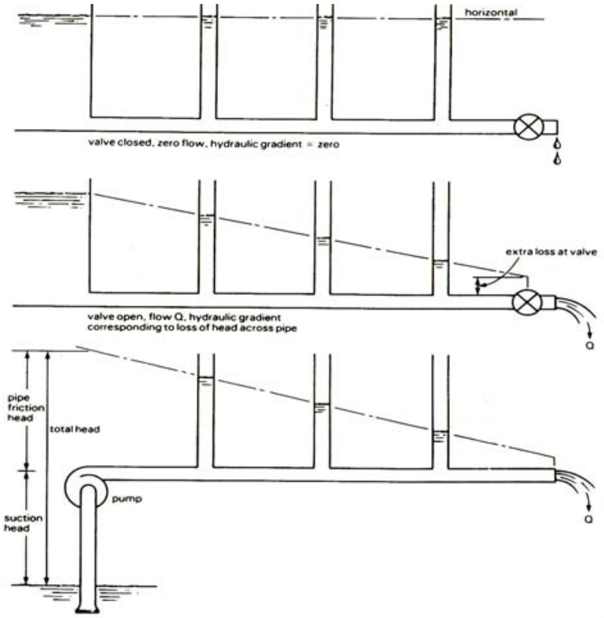


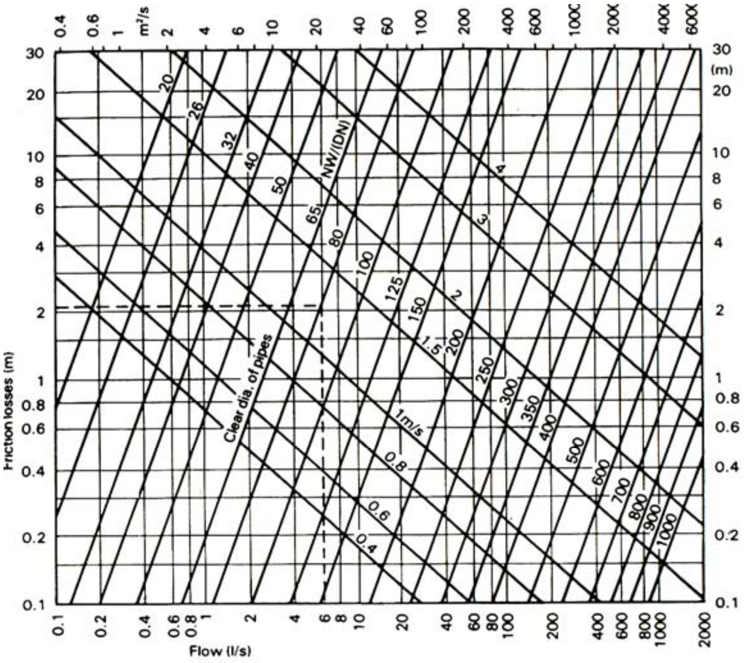
Figure 6.1 The concept of a 'hydraulic graient'

(Source: Peter Fraenkel. Water-pumping devices: A handbook for users and choosers. 2nd ed. Intermediate technology publications. 1997)

As indicated in the third lower figure in low lift applications, the pipe friction head can in some cases be as large or larger than the static head which is all the suction head (in the diagram, since the pump is mounted at the same level as the discharge). The power demand, and hence the energy costs will generally be directly related to the total head for a given flow rate, so that, in the example figure, friction losses in the pipe could be responsible for about half the energy costs.

The easiest way to estimate pipe friction is to use charts, which are commonly published both in the literature of pipe and pipe fitting manufacturers and in hydraulics textbooks (See figure 6.2 below).

As an alternative method, a nomogram (as seen in figure 6.3 below) for obtaining the head loss (as m/km in the figure) can be used. But the results may have to be modified depending on the type of pipe, by multiplying the result obtained from the chart by the roughness coefficient of the pipe relative to material for which the chart or monogram was derived.



Friction losses in metres per 100m for a new pipeline of cast iron

For other types of pipe multiply the friction loss as indicated by the table by the factors given below:

New rolled steel	–	0.8
New plastic	–	0.8
Old rusty cast iron	–	1.25
Pipes with encrustations	–	1.7

Figure 6.2 Determination of head friction losses in straight pipes.

(Source: Peter Fraenkel. Water-pumping devices: A handbook for users and choosers. 2nd ed. Intermediate technology publications. 1997)

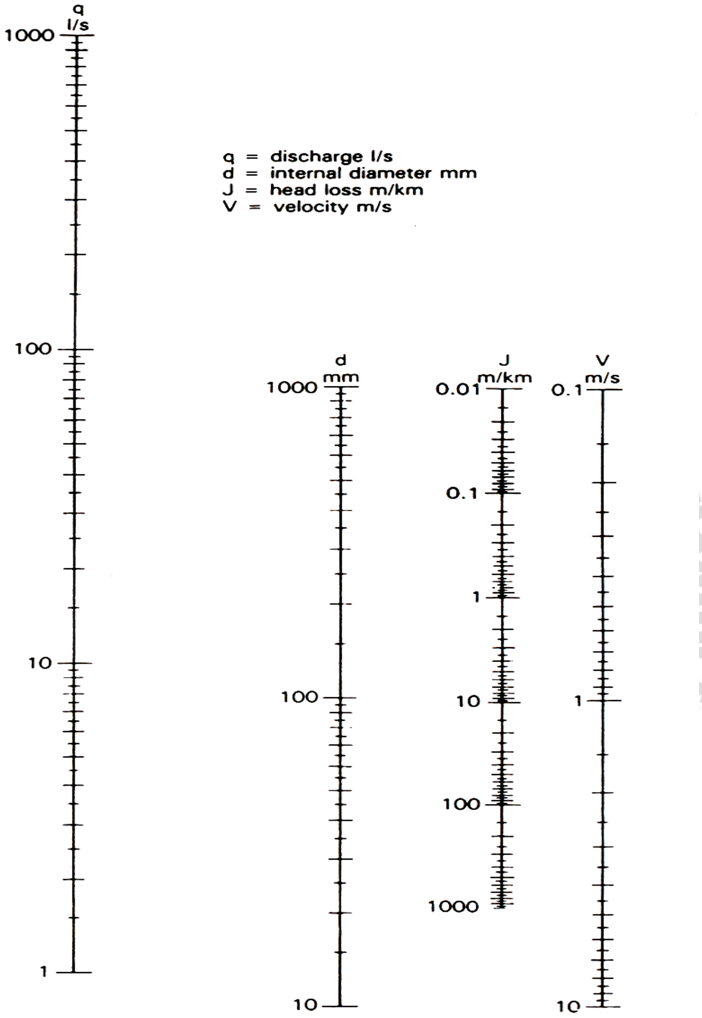


Figure 6.3 Head loss nomogram calculated for rigid PVC pipes using Blasius formula

(Source: Peter Fraenkel. Water-pumping devices: A handbook for users and choosers. 2nd ed. Intermediate Technology Publications. 1997)

In general, the relationship between head of water, m (ft) and water pressure in pounds per ft^2 is

$$H = P/W$$

Where W is 62.4 for water.

The head loss due to friction in a pipe line is approximately related to the mean velocity and hence the flow rate squared:

$$\text{Head loss, } h_f = KQ^2$$

Therefore, the total head felt by a pump will be approximately the sum of the static head (hs.) the friction head (hf) and (if the water emerges from the outlet with significant velocity) the velocity head (See also Table 6.4 below for more illustration):

$$\text{Total head, } H_t = hs + KQ^2 + V2/2g$$

- Where g = 32.2 ft/sec/sec, and velocity is in fps (feet per second)
- When pressure in pounds per square such,

$$\text{Head} = \frac{P \times 144}{62.4} = \underline{2.3\ p}$$

When water is flowing with gravity alone

$$h = \frac{v2}{2g} = \frac{V^2}{2 \times 32.2 \text{ ft/sec/sec}}$$

$$= \frac{V^2}{64.4 ft/sec/sec}$$

Since the velocity of flow is proportional to the flow rate (Q), total head can be

$$H_t = hs + K'Q^2$$

Where $K=K' + 1/(2gA^2)$ and A is a constant, and the pipeline efficiency which can be expressed in energy terms is:

$$\text{Pipeline efficiency, } \eta \text{ pipe} = \frac{[hs - K'Q^2]}{Hs}$$

The capacity of the pump required for domestic water system with elevated storage is determined by the daily water consumption and volume of the storage tank.

The head loss due to friction in a pipeline is approximately related to the mean velocity and hence the flow rate squared:

$$\text{Head loss } h_f = KQ^2$$

Therefore, the total head felt by a pump will be approximately the sum of the static head, the friction head and (it the water emerges from the out-let with significant velocity) the velocity head:

$$\text{Total head } H_t = h_s + KQ^2 + v2/2g$$

i.e. (total head) = (static head) + (friction head) + (velocity head). Since the velocity of flow is proportional to the flow rate (Q), the above equation can be re-written:

$$\text{Total head } h_t = h_s + K'Q^2$$

where K = k' + 1/2gA2) and A is a constant. Fig. 6.4 below illustrates the relationship between the total head and the flow rate for a pumped pipeline, and the pipeline efficiency, which can be expressed in energy terms as:

$$\text{Pipeline efficiency } \eta \text{ pipe} = (h_s - k'Q^2)/h_s).$$

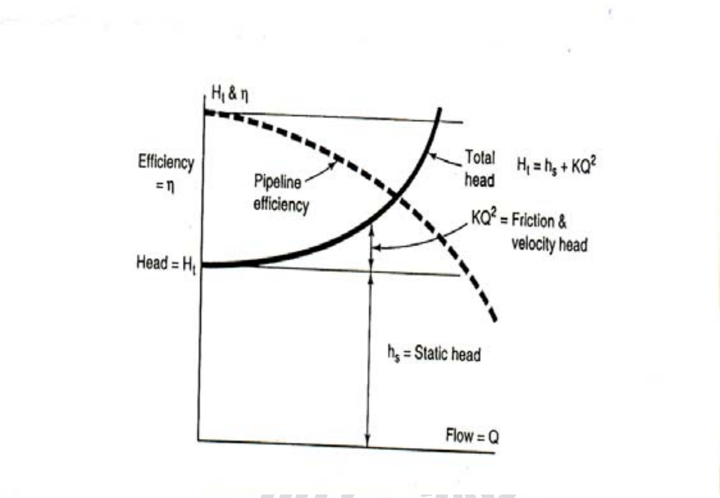
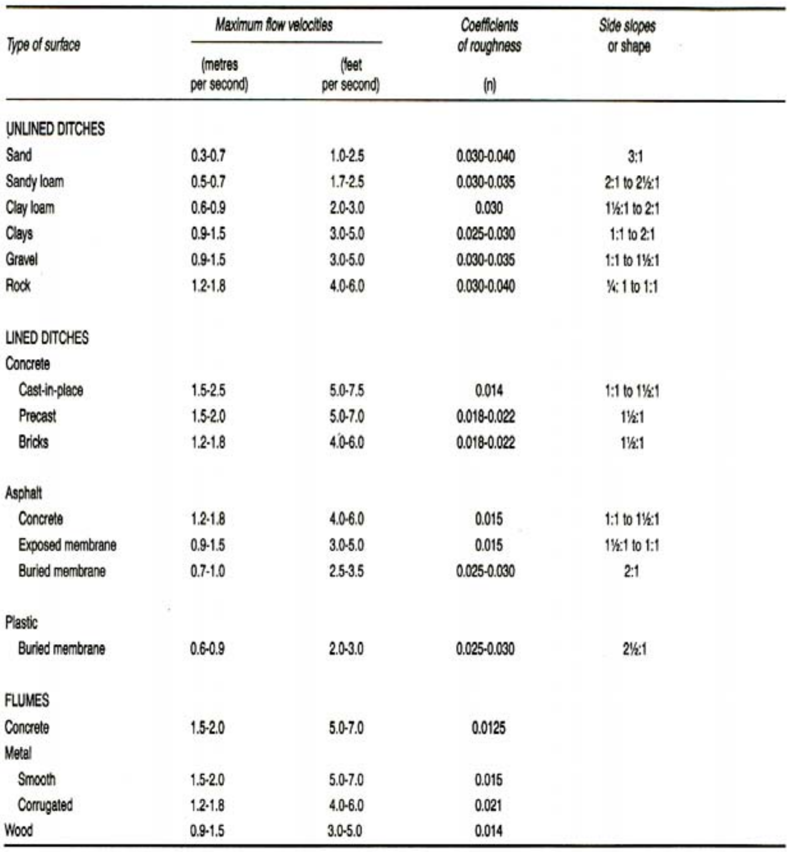


Figure 6.4 How total head and efficiency vary with flow.

(Source: Peter Fraenkel. Water-pumping devices: A handbook for users and choosers. 2nd ed. Intermediate technology publications. 1997)

Table 6.4 Suggested minimum flow velocities, coefficients or roughness and side slopes, for lined and unlined ditches and flumes



Type of surface	*Maximum flow velocities* (metres per second)	(feet per second)	*Coefficients of roughness* (n)	*Side slopes or shape*
UNLINED DITCHES				
Sand	0.3-0.7	1.0-2.5	0.030-0.040	3:1
Sandy loam	0.5-0.7	1.7-2.5	0.030-0.035	2:1 to 2½:1
Clay loam	0.6-0.9	2.0-3.0	0.030	1½:1 to 2:1
Clays	0.9-1.5	3.0-5.0	0.025-0.030	1:1 to 2:1
Gravel	0.9-1.5	3.0-5.0	0.030-0.035	1:1 to 1½:1
Rock	1.2-1.8	4.0-6.0	0.030-0.040	¼: 1 to 1:1
LINED DITCHES				
Concrete				
Cast-in-place	1.5-2.5	5.0-7.5	0.014	1:1 to 1½:1
Precast	1.5-2.0	5.0-7.0	0.018-0.022	1½:1
Bricks	1.2-1.8	4.0-6.0	0.018-0.022	1½:1
Asphalt				
Concrete	1.2-1.8	4.0-6.0	0.015	1:1 to 1½:1
Exposed membrane	0.9-1.5	3.0-5.0	0.015	1½:1 to 1:1
Buried membrane	0.7-1.0	2.5-3.5	0.025-0.030	2:1
Plastic				
Buried membrane	0.6-0.9	2.0-3.0	0.025-0.030	2½:1
FLUMES				
Concrete	1.5-2.0	5.0-7.0	0.0125	
Metal				
Smooth	1.5-2.0	5.0-7.0	0.015	
Corrugated	1.2-1.8	4.0-6.0	0.021	
Wood	0.9-1.5	3.0-5.0	0.014	

(Source: Peter Fraenkel. Water-pumping devices: A handbook for users and choosers. 2nd ed. Intermediate technology publications. 1997)

6.3.3 Suction Lift: The Atmospheric Limit

Certain types of pump are capable of sucking water from a source; i.e. the pump can be located above the water level and will literally pull water up by creating a vacuum in the suction pipe. Drawing water by suction depends on the difference between the atmospheric pressure on the free surface of the water and the reduced pressure in the suction pipe developed by the pump. The greater the difference in pressure, the higher the water will rise in the pipe. However, the maximum pressure difference that can be created is between sea level atmospheric pressure on the free surface and a pure vacuum, which theoretically will cause a difference of level of water or 10.4m (or 34ft). However, before a drop in pressure even approaching a pure vacuum can be produced, the water will start gassing due to release of air held in solution (like soda water gases when released from a pressurized container). If the pressure is reduced further, the water can boil at ambient temperature. As soon as this happens, the pump loses its prime and the discharge will cease (due to loss of prime) or at least be severely reduced. In addition, boiling and gassing within the pump (known as cavitation) can cause damage if allowing continuing for any length of time.

The suction lifts that can be achieved in practice are therefore much less than 10.4m. For example, centrifugal pumps, which are prone to cavitations due to the high speed of the water through the impeller, are generally limited to a suction lift of around 4.5m (15ft) even at sea level with a short suction pipe. Reciprocating pumps generally impose lower velocities on the water and can therefore pull a higher suction lift, but again, for practical applications, this should never normally exceed about 6.5m (21ft) even under cool sea level conditions with a short suction pipe.

At higher altitudes, or if the water is warmer than normal, the suction lift will be reduced further. For example, at an altitude of ~3000m (10,000ft) above sea level, due to reduced atmospheric pressure, the practical suction lift will be reduced by about 3m compared with sea level (and proportionately for intermediate altitudes, so that 1500m above sea level will reduce suction lift by about 1.5m). Higher water temperatures also cause a reduction in practical suction head; for example, if the water is at, say 30^0C (or 86^0F) the reduction in suction head compared with water at amore normal 20^0C will be about 7%.

Extending the length of the suction pipe also reduces the suction head that is permissible, because pipe friction adds to the suction required; this effect depends on the pipe diameter, but typically a suction pipe of say 80m length will only function satisfactorily on half the above suction head.

A suction rod tied to the handle running through the suction pipes and finally fitted the upper valve of the sucking cylinder

- The sucking cylinder fitted to both the suction pipe and the suction rod and immersed in the water as explained earlier.

The cylinder is open with a fine screen and a control valve similar to the upper one. The valves are gasketed air tight.

- The pumps operate based on the principle of air displacement. This is effected by the down and up stroke of the handle, which in its turn moves up and down the suction rod fitted to the cylinder. The two valves of the sucking cylinder function alternately. Accordingly one the upper valve opens, the lower valve closes. With down stroke of the handle and the up stroke a of the handle and the up stroke a vacuum is formed in the suction pipe and the suction cylinder. After such complete strokes, water displaces the air in the system and water gashes out (discharge) in other words, the down stroke pulls out the air, thus opening the upper valve and clothing the lower valve. The up stroke of the handle compresses first the air and then the water in the suction pipe. This makes the upper valve closed and the bottom valve open. Thus, when the bottom valve opens, water fills the cylinder and when the upper valve is opened, water enters the suction pipe as the bottom valve is closed this time. Finally such repeated strokes alternately effect the discharge of water at the surface through the discharge opening (discharge pipe). When any of the suction rod and suction cylinder fittings are dismantle the process of water procuring stops and it should be repaired to continue the process. Silt and mud may also block the suction cylinder

Repairing can be done taking out both the suction pipe and the suction cylinder with the suction rod. If only part or the whole suction cylinder is disconnected it is possible to repair the part by entering through the inspection hole, but the water then should be disinfected and bailed out before using the source for consumption.

6.3.4 Drawdown and Seasonal Variations of Water Level

Groundwater and river water levels vary, both seasonally and in some cases due to the rate of pumping. Such changes in head can significantly influence the power requirements, and hence the running costs. However, changes in head can also influence the efficiency with which the system works, and thereby can compound any extra running costs caused by a head increase. See more on *suction lift: The Atmospheric limit (Pumps).*

a) At sea level and with pumps

Certain types of pump are capable of sucking water from a source; ie. The pump can be located above the water level and will literally pull water up by creating a vacuum in the suction pipe. Drawing water by suction depends on the difference between the atmospheric pressure on the free surface of the water and the reduced pressure in the suction pipe developed in the plump. The greater the difference in pressure, the higher the water will rise in the pipe. However, the maximum pressure difference that can be created is between sea level atmospheric pressure on the free surface and a pure vacuum which theoretically will cause a difference of level of water of 10.4cm. Nevertheless, before a drop in pressure even approaching a pure vacuum can be produced, the water will start gassing due to the release of air held in solution (licensed water gases when released from a pressurized container). If the pressure is reduced further, the water can boil at ambient temperature. As soon as this happens the pump loses its prime and the discharge will cease (due to loss of prime) or at least be severely reduced. In addition, boiling and gassing within the pump (known as capitation) can cause damage if allowed to continue for any length of time.

- The suction lifts that can be achieved in practice are, therefore, much less than 10.4m.

For example, centrifugal pumps (See figure 6.5 below), which are prone to prime cavitations due to the high speed of the water through the impeller, are generally limited to a suction lift of around 4.5m(14ft) even at sea level with a short suction pipe reciprocating pumps generally impose lower velocities on the water and can, therefore, pull a higher suction lift, but again for practical applications this should never normally exceed about 6.5m(25ft) even under cool sea level conditions with a short suction pipe

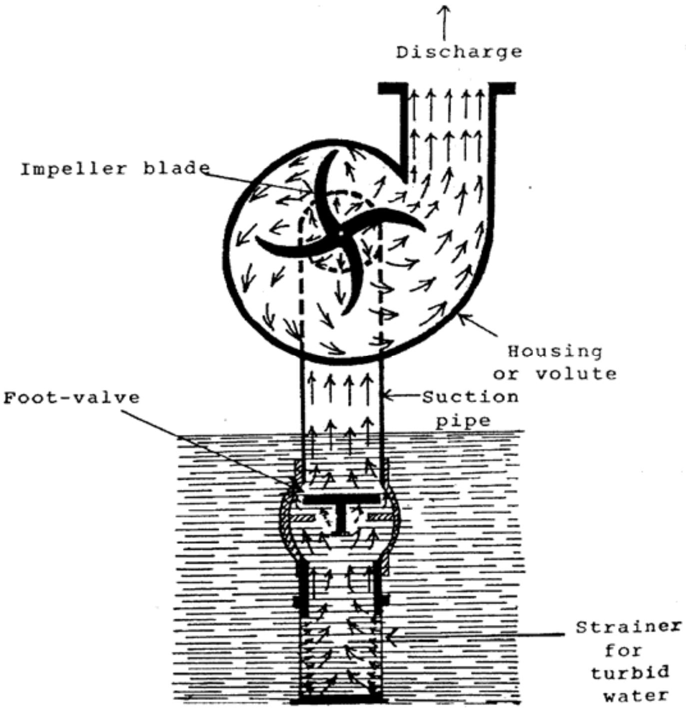


Figure 6.5 A centrifugal force pump

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

a. If a higher attitude or if the water is warmer than normal, the suction lift will be reduced further. For example, at an attitude of ~3000m (10,000 ft) above sea level due to reduced atmospheric pressure the practical suction lift will be reduced by 3m compared with sea level (and proportionally for intermediate attitudes so that 500 m above sea level will reduce suction lift by about 1.5m above sea level will reduce suction lift by about 1.5m)

b. Higher water temperatures also cause a reduction in practical suction head; for example if the water is at say 30^0C (Or 86^0F), the reduction in suction head compared with water at a more normal 20^0C will be about 7%.
c. Extending the length of the suction pipe also reduces the suction head that is permissible because pipe friction adds to the suction required; this effect depends on the pipe diameter, but typically a suction pipe of say, 80 meter long will be on function satisfactorily on half the above suction head.

6.3.4 Pumps and their Application in Conventionally Treated Water Supplies' Distribution System

Unless sufficient gravity force is available the distribution of water involves the use of pumps to provide a sufficient flow and water pressure at the point of use. Water may be pumped directly from the treatment plant to the final consumer or from the treatment plant to a reservoir (transmission) where it can be distributed by gravity or still by a pump known as booster pump. Pumps commonly used to raise and distribute water are referred to as positive displacement pumps. These include reciprocating, rotary, centrifugal, airlift, force, turbine, submersible ad ejector jets and hydraulic ram, pumps. Others such as chain and bucket and simple hand pumps are also available, but for small water supplies.

The type to be selected is mainly based on the power to move it and the cost.

The *size of pump* to be selected is based on:

- The amount of the water to be pumped,
- The water usage and demand
- The storage facility and the elevation to be used, and
- The actual periods of low or no usage and, maximum and peak water demands, and future plants

If the water system is also to provide fire protection, adequate pumps need to be available. The capacity of the pump to be chosen is determined by the water head, amount velocity and pressure preset to be achieved. This maximum hourly or peak demand flow is the basis for both the design of a water distribution system and determining the capacity of the pump to be used. However, the pump should be of such a capacity as to deliver the average daily water demand to a storage facility in 6 to 12 hours. (For small installations, the pump chosen may have a capacity to pump all water to be used in one day in 2 hours). The capacity of the pump required for domestic water system with elevated storage is determined by the daily water consumption and the volume of the storage facility.

A simple and direct method for determining the volume of the pressure storage facility and the size of the pump to provide is:

$$\mathbf{Q = \frac{\underline{Qm}}{(1-P_1/P_2)}}$$

Where Q = volume of pressure-facility in gallons,

Qm = 15 minutes storage at the maximum hourly demand rate(35 psi)

P_1 = the minimum absolute operating pressure (gauge pressure plus 14.7lb/in^2, and

P_2 = the maximum absolute pressure.

*The pump capacity determined by the given formula is equal to 125% of the maximum hourly demand rate. The capacity of a pump (of course the capacity of the water source) should be at least 26 to 10 times the average daily water requirement.

* The maximum hourly demand is based on:

1) The average daily rate = $\dfrac{\text{average water use per day}}{\text{1440 min/day}}$

   (in gallons per minute based on annual water use)
2) The average maximum monthly rate = 1.5 x average daily rate
3) Maximum hourly demand rate = 6 x average maximum monthly rate

   or

   = 9 x average daily rate
4) Instantaneous rate (pumping capacity) = 1.25 x maximum hourly rate

   or

   = 11.25 x average daily rate

* In general, the water available for distribution is equal to the difference between the dynamic head (friction head plus static head) and the tank pressure.

6.3.4.1 Pump Power and Drive

The power available will usually determine the type of motor or enquiry used. Accordingly:

- Electric power is given the first preference, with other sources used for standby or for, emergency equipment.
- Steam power should be considered if pumps are located near existing boilers (if any).
- Diesel oil engines are good, economical pumps driving units when electricity is not available or is not dependable. The constraints are their being constant low speed units.
- Gasoline engines are satisfactory, portable or stand by pump power units with low first cost but high operating (running) cost.
- Natural gas, methane and butane can also be used.

6.3.4.2 Manual Pumps: Their Parts and Operations

Pumps such as pitcher, lift and force pumps are sometimes referred to as hand pumps or manually operated pumps.

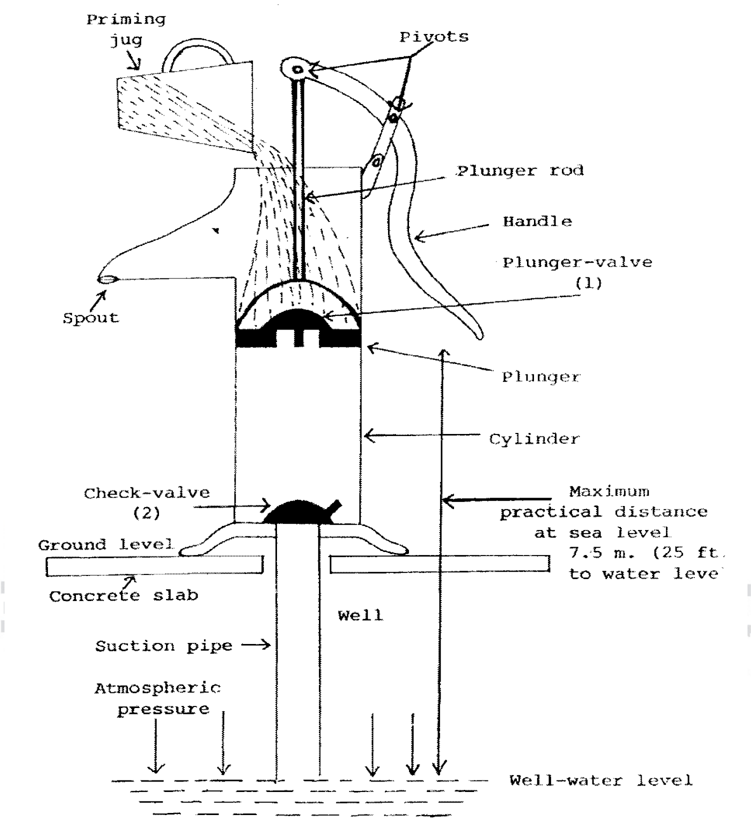


Figure 6.6 A typical pitcher pump being primed

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

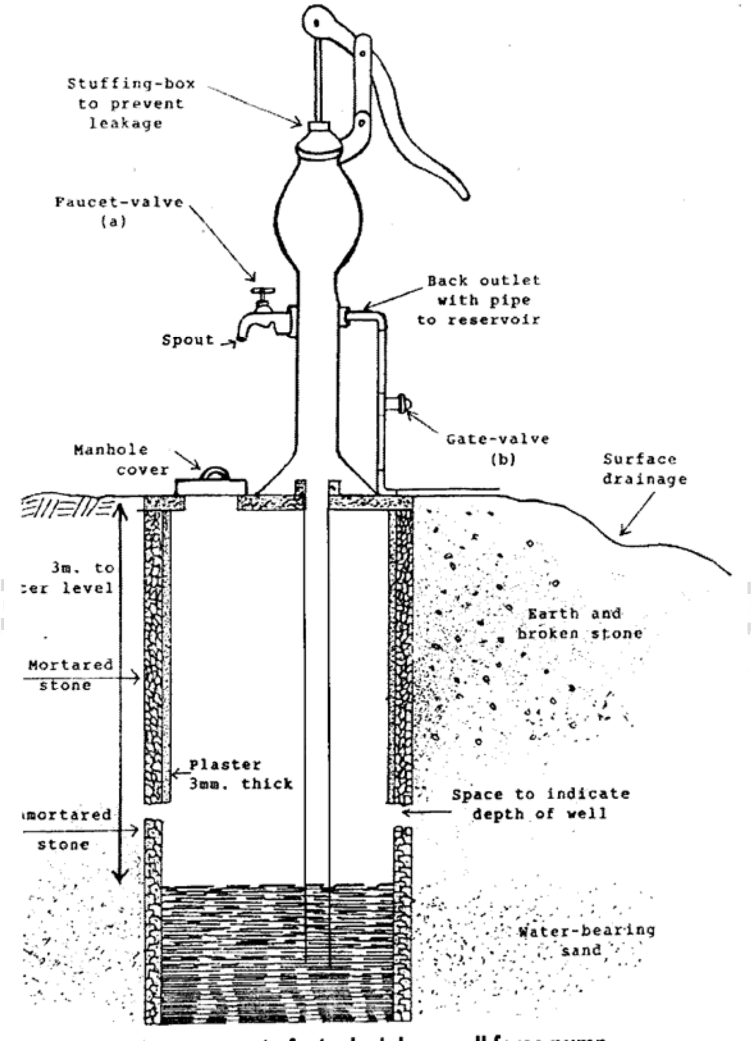


Figure 6.7 Arrangement of a typical deep well force pump

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

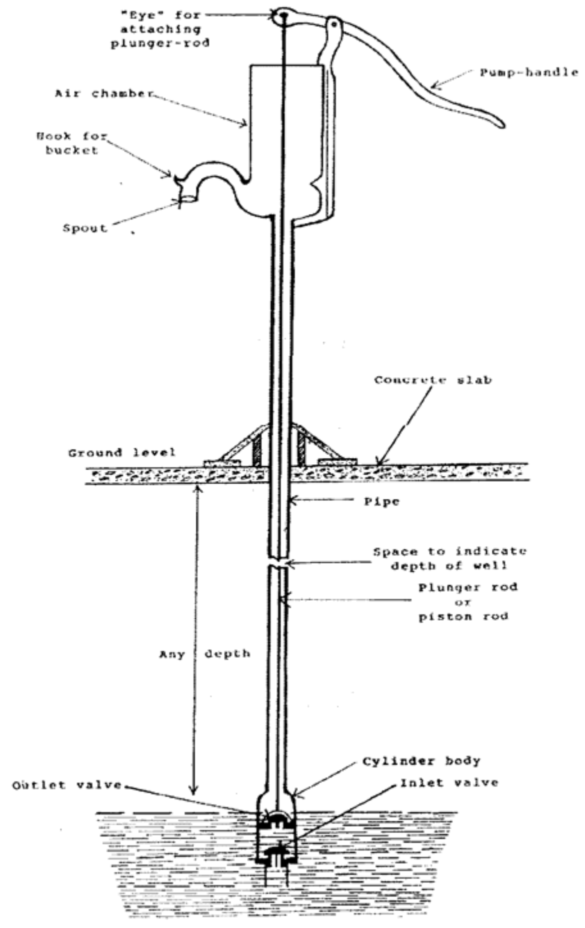


Figure 6.8 Arrangement of a typical deep-well lift pump

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

These pumps are mostly used to draw ground water especially well water for a household or group of households in rural areas. They can also be operated by wind wherever possible.

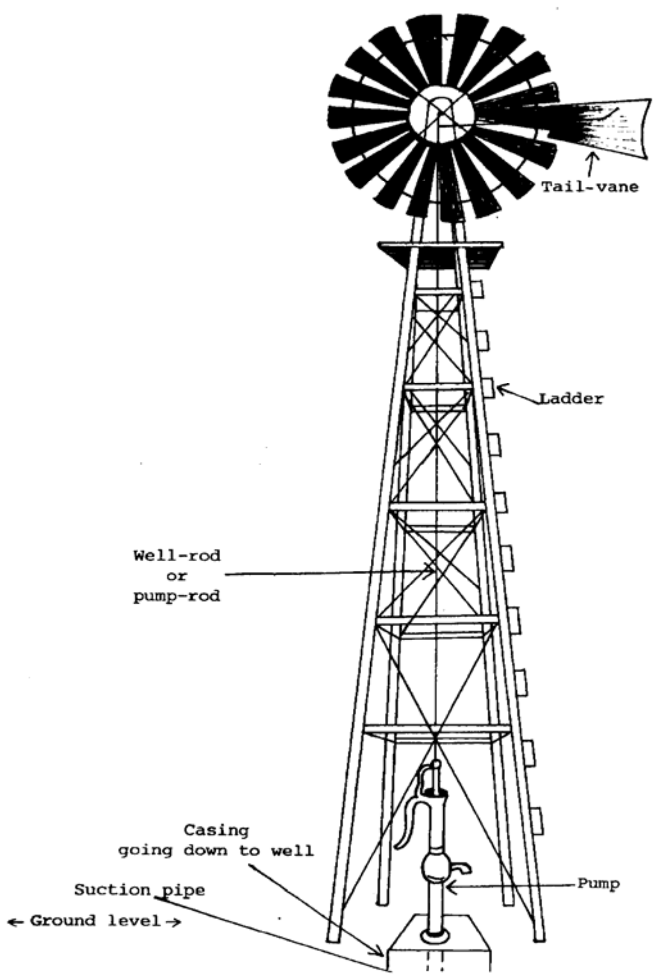


Figure 6.9 A typical arrangement of part of windmill tower and well

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Majority of these pumps are used to suck water from shallow or limited depth of hand dug wells and discharge at the very sites of the protected ground water sources. However, those like the force pumps may extend their discharges to a little further distance to the community or a convenient place for supplying the water. This is effective only where the force of gravity is available for conveying the water.

A *typical hand pump* consists of the following parts:

- The body of the pump with a handle and discharge opening/pipe must be installed on slab (concrete top floor) of the protected well/spring.
- A suction pipe fitted to the bottom of the pump and extending to the well water up to 15-35 cm above the bottom of the well water finally fitted to a sucking cylinder immersed in the water at least 5 cm above the bottom.

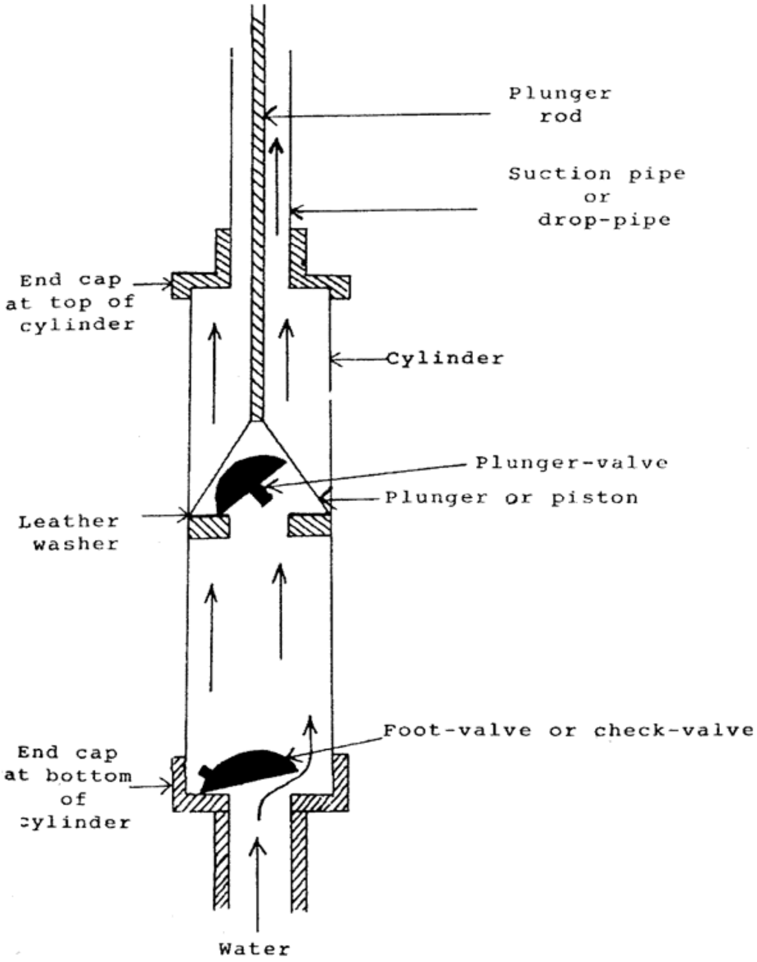


Figure 6.10 A typical single – action pump

(Adapted from Gabre-Emanual Teka. Water Supply- Ethiopia, An Introduction to Environmental Health Practice, 1997.)

Review Questions

1. What is hydraulics?
2. What are points to be considered in selection of a specific type of pump for community water supply?
3. What is the theoretical and practical suction height to which atmospheric pressure can lift water for a locality that is 2000 m above sea level?
4. Taking a typical example of hand pump in your locality, explain the principle of operation.
5. What is the difference between a positive displacement type of pump and a centrifugal force pump?
6. What needs to be considered before installation of windmill as a source of power supply in the groundwater supply?
7. In a rural village having 10,000 people, a bore hole well was dug at 200 m depth, with a yield of 4.5 liters per second, and having 81 m^3 water reservoir tank with 210 m total pumping head and 85% pump efficiency.

Find :

A) The time required to fill the reservoir using a motor pump.

B) The length of time required for the motor to operate daily in order to fill the reservoir, if 18 liters per day per person is used in this community.

C) Calculate the water and brake horsepower.

Note to the teacher

After you have gone through this chapter, arrange a practical session to show different parts of the pump and principles of operation in your environmental health workshop, together with a field visit to show the already installed pump giving service to the community.

CHAPTER SEVEN
WATER SUPPLY IN DISASTER MANAGEMENT

Learning Objectives

At the end of this chapter the students will be able to:

1. Understand the general principles of emergency water management.
2. Identify the water needs and requirements of displaced people in emergency.
3. Identify the possible sources of water, water related health risks, the quality assessment methods used, the type of treatment technique needed, and the protection of water source in disaster.

7.1 Introduction

Water and the environment play an essential role in the spread of many communicable diseases and epidemics. Potable water is the most important immediate relief commodity necessary for ensuring the survival of disaster-affecting populations, particularly when they have been displaced to regions where the supporting public health infrastructure has been destroyed. Diarrhoeal diseases, mostly caused by poor hygiene and a lack of safe water supply, are major causes of morbidity mortality among the refugee and displace populations. The most striking example is that reported among Rwandan refugees in Goma (Zaire) in 1994, where extremely high mortality rates were associative with explosive epidemics of Cholera and shigellosis; a household survey reported that more than 585 of deaths during the first weeks following the initial massive influx were associated with diarrhoeal diseases.

The goal of water, hygiene and sanitation programme is, therefore, to plan for and maintains the minimum risk threshold in regard to water and environment-related morbidity and mortality. Such a programme must be considered as an integral part of the preventive health activities in the same way as, for example, measles immunization, the technique used in the emergency phase; these techniques should be simple but effective.

In the emergency phase priority should be given to the following:

- The water supply to the population, focusing on providing sufficient quantities of water; the quality should be improved as quickly as possible, but improvements must not affect the quantity actually distributed.
- Increasing the public awareness of the basic rules of hygiene.

General Principles of Emergency Water Management

To reduce public health threats associated with the human consumption of contaminated water at disaster sites, emergency water programs must satisfy certain conditions. First they must provide adequate quantities of water for fluid replacement, personal hygiene, cooking, and sanitation. If potable water supplies are insufficient in quantity, it is likely that population will supplement their intake with water from unsafe sources. Second programs must provide water of sufficient quality to prevent the transmission of diseases. Potential sources of water for human consumption may need to be evaluated and treated to ensure potability. Last, because the quality and the quantity of public water are so closely related to the health status of a disaster-affected population, emergency water programs must be an integral part of the public health component of disaster response.

7.2 Water Supply Activities

Like any other population, refugees require immediate access to an adequate water supply in order too maintain life and health and this becomes even more vital in refugee camps where overcrowding increases the risk population and epidemics of water borne diseases. Attention must therefore be paid to water provision from the out set of any attempt to deal with a refugee emergency.

1. First step: Ensuring a sufficient quantity of water

It is essential that water supply is in sufficient quantities. Extreme water shortages can lead to dehydration and death. Lack of water also leads to poor hygiene and increases the incidences hygiene-related diseases such as faeco-orally transmitted diseases (diarrhoeal diseases), diseases transmitted by lice (e.g. typhus) and other milder diseases such as scabies and conjunctivitis. The first objective is therefore to supply a sufficient quantity of water; its quality is a later consideration. A large amount of proper quality water is preferable to a small amount of good quality drinking water.

Requirements

- During the first days of the emergency phase, a minimum amount of water is required for survival: **5 liters of water per person per day (source: WHO)**
- In the next stage of emergency phase, the amount of available water must rapidly be increased to a sufficient quantity: **15 to 20 liters per person per day.**
- Although water requirement standards have been set, the quantity of water consumed varies from one country or region to another, depending on the climate and the habits of the population. However, for health reasons it is recommended not to put any limit on water consumption.

Water availability

It is not enough to supply large amounts of water to a refuge site. To ensure adequate availability, it is essential to adhere as closely as possible. The water points should be set up so as to ensure accessibility in regard to both distance and waiting time, and the following provisions should be foreseen:

- **1 hand pump for 500 to 750 persons**
- **1 tap for 200-250 persons**
- **a maximum of 6 to 8 taps per distribution point unit**
- **Water point yields- the number of water point should be increased if the out-flow is sufficient (under 5 liters/ minute/ tap) in order to speed up the water distribution.**
- **Water containers- minimum overall capacity of 40 liters per family.**

2. Second steps: improving water quality

Water should not pose a health risk and should have an appearance and taste acceptable to the population. Ideally, the water supplied should meet WHO quality standards. However, in emergencies it is generally very difficult or even impossible to adhere to these standards. The main goal is to provide water, which is clean enough to restrict water-borne diseases, i.e. containing the fewest possible pathogenic germs. The presence or absence of pathogenic organisms is the only criteria or real importance to health.

Water for consumption should contain less than 10 faecal coliforms/100 ml.

Measures for Meeting the Requirements

The following principles must be respected in order to ensure good quality water:

- Water from deep protected wells, protected springs and deep drilling may be considered safe and used without treatment;
- Surface and near-surface water are considered to be contaminated, and this water must be treated
- Prior to treatment (usually chlorination), water should be checked for its turbidity and pre-treated if necessary
- Priority should be given to the selection and protection of water points

7.3 Water in Camps of Displaced People

The objective of this section is to suggest some concrete responses to water supply problems faced in camps of displaced people. However, most of the points considered concern water problems in general, and apply to any deprived situation.

A. Needs

Like any population, displaced people need access to good quality water in sufficient quantity. This need is that much greater in camps where the population concentration increases the risks of pollution and of epidemics of water-borne diseases.

Quantity

The notion of sufficient quantity is very subjective and depends strongly on the climate and on the habits of the population. Nevertheless, it may be assumed that ten liters per person per day is a minimum need (See table 7.3), while aiming to reach the following targets as soon as possible (UNHCR 1982):

- For domestic consumption: 15 - 20 liters per person per day (drinking, cooking, hygiene).
- For collective feeding centers: 20 - 30 liters per person per day.
- For hospitals: 40 - 60 liters per person per day.

In case of severe shortage, a daily ration of 4 to 5 liters may suffice very provisionally. Unless there is a shortage, it is better not to put any limit on consumption as the health status of the population is influenced by the quantity of water used.

It is not enough to supply 10 - 15 liters of water per person per day to a camp; people should actually be able to use this quantity. Therefore water should be reasonably accessible (in terms of distance and of waiting time at the water point), and the means to transport and store it should be available (if the supply is via taps, allow at least one tap per 200 - 250 people and arrange these taps in groups of 6 or 8 maximum). It is important to ensure that the population has enough containers (jerry-cans, buckets, etc.) for the collection and storage of water; otherwise a distribution will be necessary. If a sufficient quantity of water is not available near the site, moving the camp should be considered.

Quality

The water should be harmless to health and have an appearance and taste acceptable to the population. Ideally the water supplied should meet the water quality standards of the WHO. However, in practice it is often necessary to supply water which does not conform to these standards, simply because there is no alternative.

COMMENTS

- The quantity of water available has relatively more importance than its quality. It is preferable to have a lot of water of average quality than little water of very good quality. The lack of water to ensure a minimum of hygiene entails even more problems than does the consumption of relatively poor quality water.

- Water quality is important for drinking water but is of less importance for other uses (except where there is a risk of schistosomiasis). It is sometimes possible to supply water of two different qualities, but this generally entails more disadvantages than advantages.

B. Water Related Health Risks

Problems due to a Lack of Water:
In extreme cases of lack of water, life is simply not possible (dehydration and death). Less extreme shortages also have an impact on the health status of a population.

They provoke an increase in the incidence of numerous diseases due to a lack of hygiene. Good personal hygiene requires a sufficient quantity of water.

The diseases linked to a lack of water for personal hygiene, called "water-washed diseases", are:

Dermatological and Ophthalmic Diseases:
Dermatological and ophthalmic diseases directly due to a

lack of hygiene such as scabies, trachoma, conjunctivitis, etc.

Diseases Transmitted by Lice: Lack of personal hygiene and washing of clothes encourages the proliferation of lice which, in addition to the problems caused by their presence (itching and scratching, skin sores), are disease vectors. They transmit louse-borne typhus and recurrent fever.

Faeco-Orally Transmitted Diseases: A lack of hygiene, particularly of hands and food, allows the transmission of these diseases from infected individuals (sick people or carriers) to uninfected individuals.
These so-called "dirty hands diseases" or “filth-borne diseases” are: diarrheas and dysenteries (bacterial, protozoan, or viral), cholera, typhoid and paratyphoid fevers, hepatitis A, poliomyelitis and various helminthic diseases. Most of these diseases can be spread epidemically in concentrated populations.

Problems due to Poor Chemical Water Quality:
Water may contain numerous dissolved chemical substances which come either from pollution fertilizers insecticides, industrial waste, etc.), or from the composition of the rocks themselves (fluorine, arsenic, iron, etc.).

These substances may give the water such a bad taste that it is undrinkable (for example, if it contains too much salts or too much iron), but it may also, in the long term, cause severe health problems, for example:

- Methaemoglobinaemia in babies, due to high nitrate levels,
- Arsenic poisoning, etc.

The possible presence of toxic substances in water is something, which must be borne in mind, but in the situations considered here, the microbiological quality of the water is a much more important and preoccupying problem.

Problems due to Poor Biological Water Quality:

Water may contain numerous pathogenic organisms and thereby become a means of transmission for many diseases:

- Typhoid and paratyphoid fevers	(bacteria)
- Hepatitis A	(virus)
-Cholera	(bacteria)
- Poliomyelitis	(virus)
- Diarrhoeas (caused by Escherischia Coli, salmonellas and Yersinia Enterocolitica)	(bacteria)
- Viral gastroenteritis	(virus)
- Bacillary dysentery (caused by various species of shigellas)	(bacteria)
- Campylobacter dysentery	(bacteria)
-Amoebic dysentery	(protozoa)
-Giardia (lambliasis)	(protozoa)

-Balantidiasis	(protozoa)
- Helminthiasis caused by Ascaris and Trichuris	(helminths)

It should be noted that these so-called "water-borne" diseases form part of the group of "water-washed" diseases as well. They may also be transmitted by any of the faeco-oral routes: dirty hands, dirty food, dirty water, etc. Besides these diseases, water is also involved in the transmission of "water-based" diseases (in other words, those diseases of which the causative agent passes part of its life-cycle in an aquatic plant or animal):

- The different schistosomiases or bilharzias: diseases caused by helminths (worms) which are usually contracted by contact with infested water (washing clothes, bathing, etc.), but sometimes also via the oral route.

- Dracunculiasis (Guinea worm), transmitted only by drinking infested water.

Lastly, water may also transmit:

- Leptospirosis: a bacterial disease, which is contracted primarily by contact with water contaminated with the infected urine of various animals (principally the rat), but also by drinking such water. All the infectious diseases transmitted by water-with the exception of Guinea worm-are linked to the pollution of water by the excreta of humans or other animals (from the sick or from healthy carriers).

Problems due to Water-based Insect Vectors:

One last category of water-related diseases is those with an insect vector, which develops in or lives near to water, for example malaria, dengue and yellow fevers and onchocerciasis.

The solution to these problems lies among other things with the choice of site for a settlement and with environmental hygiene measures (drainage, elimination of stagnant water, covering reservoirs, etc.). They will not be considered in more detail here.

In terms of health

It is of primary importance that the population should be able to use a sufficient quantity of water to allow a minimum of hygiene, in addition to use for cooking. This means that the water should be available in sufficient quantity and easily accessible, and that people should have enough water containers.

In terms of water quality

The major danger is pollution of water by fæcal matter. Everything possible should be done to prevent such pollution. Nevertheless, it is preferable to have a lot of water of average quality than a little water of very good quality.

C. Water Supply

Different types of water

Potentially, three types of water may be available:

Surface Waters: Streams, Rivers, Lakes, Ponds, Reservoirs (Dams)

- It is generally heavily polluted particularly during the rainy season.
- Its quantity varies with the season.
- It generally needs complex treatment before use. Nevertheless, certain catchment methods allow a significant improvement of water quality: shallow wells dug close to river banks, river bed filters, infiltration galleries.

Ground Waters: Wells, Boreholes, Springs

- Deep groundwater (boreholes, deep wells, certain springs):
    - Generally clear and of good bacteriological quality (filtered by percolation through rocks).
    - Sometimes containing substances rendering it undrinkable because of its taste or because of toxicity.
    - Not generally subject to much seasonal variation in quality or quantity.

- Shallow groundwater (wells a few meters deep, certain springs, groundwater near water courses):

  - The higher the water table, the lower the bacteriological quality tends to be (water from less than 3 meters deep should be treated like surface water).
  - Subject to seasonal variation in quantity.

Rainwater

- In non-industrialized regions, rainwater is relatively pure and may be consumed without treatment as long as it is collected with certain precautions, i.e. on a clean surface (tin roof, tent, plastic sheeting) and the first flow of water is rejected.
- Although rainwater rarely provides a regular supply, it may sometimes be a useful temporary or complementary supply (it may be a good alternative to heavily polluted surface water during the rainy season).
- Rainwater may dissolve the metal in which it is stored. Do not use containers or pipes made of copper, zinc or lead: clay, cement or plastic containers are suitable.

In practice there is rarely a choice between these different sources of water, particularly in emergency situations.

When settlement begins, surface water (the most polluted or the most easily polluted) is often the only supply available. It is, therefore, imperative to concentrate on the problem of water as top priority. Sometimes, at first, supply by water tanker is the only solution. Other solutions should quickly be planned: drilling, digging wells, moving the camp, etc. (specialist advice will usually be needed). Sometimes a piped supply from an urban area may be possible.

Priorities

What are the priorities in terms of water supply, when dealing with a concentrated population?

Before anything else:

- Find out where and how the people go to collect water and where they defecate.

Then:

- Designate defecation areas far away from water points.
- Distribute water containers if necessary (very important).
- Take specific steps to protect water points.
- Determine the amount of water available.
- If necessary, set up a water rationing system.

Finally:

- If necessary, increase the output of the water points or look for additional sources of supply.
- Create a reserve water stock.
- Improve measures to protect water points.
- If possible, set up a system whereby water is pumped into reservoirs before being distributed.
- Check water quality if necessary.
- Possibly, install a treatment system.

Water Point Protection Measures

All the protection measures aim at preventing the introduction of fæcal germs into the water (either directly, or indirectly by run-off or dirty soil falling into the water, etc.).

- Protection of water courses

  Organize the use of the water course according to environmental health considerations. The point used for collecting water should be upstream of all other uses.

Note: surface water is always difficult to protect (there may be a village upstream). As soon as possible, use other sources (wells, springs, boreholes), or at least, pump the water so that people and animals do not have direct access to the water course.

- **Well protection**

Immediately (and this does not require any particular materials or skills):

- Employ a watchman to monitor access to the well.
- Surround the well with a fence against animals. If it is used to water animals, make a channel to take water to a trough situated outside the protective fence.
- Forbid the use of personal water containers: one rope with a single container should be provided for this use.

- Install a winch or similar system so that the bucket and rope are not laid on the ground and so that people do not lean over the well.
- Keep sources of pollution such as latrines at least 30 metres away from the well and downhill from it if there is a slope (caution: in certain hard and fissured rocks, 30 metres is not enough).

As soon as possible:

- Make the improvements needed to prevent infiltration of run-off (make the upper part watertight to at least 3 metres depth, install an apron, a concrete slab on the head wall, and drainage of the surroundings, etc.).
- Cover the well and install a hand pump or a self-priming motor pump (plan for maintenance and the supply of spare parts).

\- **Spring protection**

Immediately:

- Install a system which prevents water from standing at the spring (collect the running water with a split bamboo, for instance).
- Erect a protective barrier around the spring (10 metres above it).
- Dig a drainage channel 10 metres above the spring to avoid it being polluted by run-off.

As soon as possible:

- Build a spring box.

Certain measures for the protection of water points can, and should, be taken during the very first days. Others require particular materials, equipment and skills, and should only be envisaged at a later stage, though as quickly as possible. Do not wait to be able to solve the whole problem before starting work; every step taken is an improvement.

Note: Fæcal pollution of water may occur at any stage between its origin and its consumption. For example, for water from a well there may be:

- Pollution of the water table,
- Pollution of the water inside the well (from soil, run-off, etc.)
- Pollution during transport (from dirty containers, dirty fingers, etc.),
- Pollution during storage in the home (from insects, dust, people taking water with dirty recipients, etc.).

Consumption of clean water can only be achieved by action at all levels, with a global programme of water point protection, excreta control and health education which is a long-term programme).

Pollution at the source or during collective transport is nevertheless more dangerous than pollution in the home, because it affects the whole population at once and consequently encourages large-scale epidemics.

Containers for Transport and Storage

If the displaced people have not been able to bring enough containers with them they cannot use the water, which is provided for them.

Each family should have containers with a total capacity of 40 liters as a minimum. If the people do not have enough containers, it is vital to distribute them as a top priority.

Containers with small openings (like ‘jerrycans’) with a cap are the most suitable because they are used by pouring the water and not by dipping into it (which risks contaminating it each time).

Cooking oil is often distributed in such cans, and they can be re-used.

Traditional clay containers may be suitable as long as they are covered to prevent contamination by dust and insects.

D. Assessment of water quality

Is the water potable or not?

> The only criteria really of importance to health are the presence or the absence of pathogenic organisms and of toxic concentrations of certain chemicals.

Unfortunately these two criteria cannot be assessed by simple tests.

For example, there is no direct relation between the appearance of a sample of water and its potability. (A cloudy sample may be safe, whereas a clear sample may be both chemically and biologically dangerous.)

In non-industrialized areas the presence of pathogenic organisms is an infinitely more frequent problem than the presence of chemical substances at toxic concentrations.

In practice, which analysis should be done and when?

Turbidity (Cloudy Appearance)

The presence of suspended solids is always a problem (the water is unpleasant to drink, there is a sediment, etc.), even if it does not necessarily mean that the water is polluted. But it is particularly important to take the turbidity into account if the water needs treatment.

The measurement of turbidity may be done with special equipment (graduated plastic tubes), but generally simply looking through the water in a transparent container gives enough information.

Chemical Analysis

In emergency situations a blind eye is usually turned to the acceptability of the taste and smell of water.

However, a laboratory chemical analysis may be requested:

- if a long term water supply is being planned,
- if there are particular reasons to suspect chemical pollution.

Biological Analysis

In other words, how to tell if water contains pathogens?

- **Principle:**

The pathogenic organisms which may be present in water are too numerous and too various to be identified individually in practice (bacteria, protozoa, helminthes, etc.).

As their presence is always linked to fæcal pollution (except for Guinea worm), it is preferable to look for organisms which are "indicators" of this pollution.
The indicator organisms generally looked for are the fæcal coliforms, principally Escherichia coli (E. coli).

These germs are always present in large numbers in the faeces of man and other warm blooded animals.

The presence of fæcal coliforms in water indicates the possible presence of pathogenic organisms.

The absence of fæcal coliforms in water indicates the probable absence of pathogens, but is no proof of this (certain pathogens are more resistant than fæcal coliforms).

The count of fæcal coliforms (or E. Coli) per 100 ml gives an indication of the degree of fæcal pollution.

Note:

Other bacteria very similar to fæcal coliforms live more or less everywhere in the environment. They also belong to the coliform group.

Coliform group =

- Fæcal coliforms (principally E. Coli)
  (total coliforms)
- Other coliforms

In raw water (untreated), only the presence of E.coli is significant for health, because they are the only coliforms, which prove fæcal contamination.

Although in certain cases total coliforms are identified, only fæcal coliforms are used as indicators in the field.

- Method of bacteriological analysis

  The membrane filtration method is generally used. This consists of filtering the water through a membrane which retains bacteria.

The membrane is then incubated at 44ºC for 14 - 18 hours on a specific culture medium.

The count of those colonies which develop with a characteristic appearance gives the number of fæcal coliforms in the sample of water which was filtered.

Note:
When incubating at 37 C all the coliforms develop, so the count is of total coliforms.
There are kits available for field analysis (for example the Del Agua/Oxfam kit or the Milliflex kit from Millipore), composed of portable filtration and incubation systems.

However, these kits are expensive and require good training in their operation and in the reading and interpretation of results.

- How to express the results of analyses?

- Number of coliforms/100 ml if it concerns total coliforms.
- Number of fæcal coliforms/100 ml or sometimes number of E. Coli/100 ml (the two may be

interchanged, as in human faeces E. Coli represents more than 90% of fæcal coliforms).

When to do a bacteriological analysis?

A bacteriological analysis is rarely necessary. It is generally much more important and useful to do a sanitary inspection (the origin of the water, protection of the water point, its siting in relation to defecation areas, protection of the water during storage and transport, etc.). Such an inspection will often make it possible to see that the water is polluted or has strong chances of being polluted at some time or other.

Analysis only gives an indication of pollution at the precise moment of sampling, and not of the potential risk of pollution.

Moreover, a sanitary inspection may be done by anyone, whereas bacteriological analysis needs equipment and proper training in its use and in the interpretation of results.

A bacteriological analysis should only be considered when:

- Deciding whether or not to treat surface water (see the next section).

- Using properly protected groundwater which, despite everything, is suspected of being the cause of a high incidence of diarrhoeal disease, or of being the origin of an epidemic of diarrhoea, cholera or typhoid.

Caution: in no case is the detection of fæcal coliforms in water proof that the water is the origin of an epidemic. Detection of heavy pollution indicates that it may be the source of the epidemic, but is no proof of this. However, in this case, action must be taken anyway.

The analysis is done:

- Either by a competent local laboratory within 6 hours of sampling (after this time the samples are no longer representative of the water to be analysed).
- Or in the field by someone trained in the use of field testing kits.

As long as the water is chlorinated and the free residual chlorine level is satisfactory (see brief Chlorination), bacteriological analysis is neither necessary nor appropriate.

E. Simple water treatment technique

Storage and sedimentation

Storage is the simplest procedure to improve water quality (certain pathogens do not survive beyond several days), but it needs large reservoirs. Storage alone is not always a very effective procedure.

During storage there also occurs purification by sedimentation. Suspended material settles to the bottom of the reservoir with a proportion of the pathogens (mainly the largest: helminthes eggs and protozoan cysts).

Sedimentation of turbid water is essential before filtration and disinfection.

If natural sedimentation is too slow, flocculation may be necessary (a specialist's help is needed for this). In practice, if water in a bottle is still muddy after an hour, then the natural sedimentation will not be enough.

Filtration

Passing water through a permeable bed eliminates a proportion of the pathogens by retaining them mechanically on the surface or within the filter.

Ceramic candle filters and certain sand filters (known as rapid sand filters) work on this principle.

Slow Sand Filtration

Under certain conditions, in passing water through a bed of sand, particularly effective filtration is achieved by biological purification in addition to the mechanical action of the filter. For this to occur, the filtration must be relatively slow.

A deposit is formed at the surface and in the top few centimetres of sand, in which breeds a whole range of bacteria and microscopic plants, forming a skin (called the Schmutzdecke, biological membrane or bacterial film), which works both biologically and mechanically. It acts as a very fine filter which retains or kills most pathogenic organisms: it eliminates eggs, cysts, nearly all pathogenic bacteria and a proportion of viruses.

Slow sand filtration is the only procedure, which achieves such an improvement of water quality in a single operation.

A slow sand filter can operate for weeks or even months without maintenance (which consists of the removing of a thin layer of sand when the filtration rate becomes too low).

In practice:

At the collective scale, the construction of this type of filter needs the input of a specialist, and then the maintenance is relatively simple.

At a smaller scale, for example in a feeding centre, a small filter may be made with local materials.

Whatever the size of the filter, the operating principle remains the same.

Important

The bacterial layer is fragile and certain precautions should be taken to preserve it: never let it dry out, and never pass chlorinated water through it.

Disinfection with chlorine

Chlorine is a suitable disinfectant for water because it is very powerful without being toxic. It allows the destruction of all viral and bacterial pathogens in water.

Chlorine can also be used to disinfect surfaces in contact with water: the insides of wells, pumps, pipes, spring boxes, reservoirs, etc.,(when putting into service, after repairs or after accidental pollution).

For this purpose it is used at much higher concentrations than for the disinfection of drinking water because the pollution may be much greater (see technical briefs Chlorine-generating products and Chlorination).

In the situations considered here, gas chlorination is not recommended because it can be dangerous and is not practical on a small scale. Chlorine-generating products are preferred: calcium hypochlorite, chloride of lime, sodium hypochlorite solution (see technical brief Chlorine-generating products).
All these chemicals release chlorine when they are dissolved in water.

Chlorine reacts immediately with all the oxidizable substances, which may be present in the water (organic matter and certain mineral substances as well as pathogens and other organisms).

These substances consume chlorine. For the chlorination to be effective, sufficient chlorine must be added to meet this initial chlorine demand. This is confirmed by checking that an excess of unconsumed chlorine remains in the water (residual free chlorine: see technical brief Monitoring chlorination). (See table 7.2)

Effectiveness
At the doses normally used, chlorine destroys all pathogenic viruses and bacteria in water, but it is ineffective against:

- protozoan cysts and helminth eggs or larvae, - pathogens within suspended particles (as they are thus not in contact with the chlorine), so it is advisable to filter water prior to chlorination, to remove eggs, cysts, larvae and suspended particles.

Practical Use

Chlorination is a very suitable treatment method for emergency situations (e.g. typhoid or cholera epidemics), because it is very effective, but it is relatively tricky to set up and needs constant attention.

If water has to be treated, which method should be used?

The choice of treatment method will depend on the appearance of the water, the supposed degree of pollution, or that measured by bacteriological analysis, and the technical options. See the following table 7.1.

In an emergency, chlorination is often the best technique, but in the long term, slow sand filtration is generally the most appropriate solution. However, it is always better to use water, which does not need treatment.

Water quality

Potable water is defined as water that is free from microbiologic or toxicological contamination that would adversely affect human health. In general water quality is assessed by laboratory analysis of representative water samples. Water characteristics such as microbial content, turbidity, color, salinity, pH, and chemical contamination may require immediate testing. Under emergency conditions, water quality analysis may be limited to testing for the presence of coliform bacteria or determining whether treatment with water –purification agent such as chlorine is adequate.

Table 7.1 Microbial guidelines for water samples collected of disaster sites

Coliforms per 100 ml of water	Water quality
Reasonable quality	
Polluted	
100-1,000	Dangerous
>1,000	Very dangerous

Source: United Nations Children's Fund (UNICEF), assisting in emergencies: handbook for UNICEF field staff. New York: UNICEF, 1992. Situation

Regardless of the standards used to evaluate water quality or to purify water supplies at disaster sites, water thought to be responsible for disease outbreaks should be considered contaminated until it can be treated at a central location to ensure its portability.

Table 7.2 Bleach calculations for dug wells

Bleach calculation for dug wells		
Diameter of well in feet	**Amount of 5.25% launder Bleach per Foot of Well depth**	**Amount 70% chlorine Granulates per foot of well depth**
3	1.5 cups	1 ounce
4	3.0 cups	2 ounce
5	4.5 cups	3 ounce
6	6.0 cups	4 ounce
7	9.0 cups	6 ounce

8	12.0 cups	8 ounce
10	18.0 cups	12 ounce

One cup= 0.24 liter and One ounce= 30 milliliter

Source: Center for Disease Control and Prevention. Flood: A prevention guide to promote your personal health and safety. Atlanta Center for Disease Control and Prevention, 1993.

Table 7.3 Daily potable water needs per person

Liters	**Need to be addressed**
3-5	Minimum for survival
15-20	Individual (optimum)
20-30	Mass –feeding centers (per beneficiary)
35	Washing facilities (per beneficiary)
40-60	Health centers (per patient)

Source: United Nation Children's Fund (UNICEF): Assisting in emergencies: a resource book for UNICEF field staffs NEW York: UNICEF, 1992.

7.4 Conclusion

Populations affected by disaster often require emergency environmental health programs during the initial emergency response phase. Although this chapter has focused on the emergency management of water, other environmental health activities are also vital to the health of the population; such activities include vector control, solid-waste management, injury prevention, personal hygiene, and proper food preparation and distribution. Emergency environmental health program should begin with a rapid environmental survey to determine the need of the disaster affected population and the availability of local natural resources such as suitable land for emergency settlement. Health professional must ensure that all disaster victims have access to a source of potable water, a system of sanitation, and adequate shelter. To achieve the greatest benefit for a disaster-affected population, coordinative environmental health activities should be an integral part of the overall emergency public health response.

Review Questions

1. Discuss the general principles of emergency water management
2. List the types of water related health risks/ diseases. Give examples for each of them.
3. What are the minimum water quality and quantity requirements in disaster situations?
4. Describe the measures that should be taken in order to meet the requirements of disaster affected people.
5. Mention and describe the different simple water treatment techniques that can be used in emergency.
6. What protection measures of water points should be sought immediately after a disaster happened and as soon as possible?

GLOSSARY

Aeration - supply with air

Agar - an extract from algae, used to grow bacteria, etc.

Air washing - Cleaning by using aeration

Algae - a simple form of plant life

Alkali - a substance that combines with an acid to form a salt

Alkalinity - the state of being alkaline

Altitude - height

Asphyxiate - to stop life or consciousness because of lack of oxygen

Atmosphere - the mass of air surrounding the earth

Atmospheric pressure - pressure or thrust caused by the weight of air

BOD - the amount of oxygen needed to stabilize organic matter through the action of bacteria

Brake horsepower - power of a motor estimated from the force operated on the friction brake

Centrifugal - moving away from the center

Centrifugal force - the power that causes an object or substance on a curve or rotating surface to move outward from the axis or center

Chlorination - treatment with chlorine or with hypochlorite

Clogging - prevention of movement because of dirt or other substances.

Coagulant - a substance that makes other substances clog

Coefficient - a number that measures a quality or characteristic.

Colloid - a substance in such small particles that it does not easily settle in a liquid.

Contact time - the time needed for a reaction between two or more substance placed together.

Conventional water treatment system- the system of making water free from pathogens and other harmful substances, on a large scale for human consumption as well as the different uses of water for development and better well being of humans.

Dechlorination - removal of chlorine or a chlorine compound

Defluoridation - the removal of fluoride

Disinfection - destruction of agents of infection

Effective (grain) size - is a measure of the diameter of particles, when compared to a theoretical material having an equal transmission constant. It is the dimensions of that mesh which will permit 10 percent of its sample to pass and will retain 90 percent. This means that, the size of the grain in mm, such that 10% by wt are smaller.

Feces - discharged body waste, excrement

Fluoridation - addition of fluoride

Friction - resistance caused by the motion of, for example, water against another substance or a wheel against a brake

Gate valve - a valve with a control that can close or open a pipe

Head - the difference in height between two points in a body of liquid; the resulting pressure of the liquid at the lower point, expressed as the height

Horsepower - a unit of power

Impeller - the driving part of a machine

Loss of head - the decrease in head between two points, i.e. the difference in pressure between a higher and lower point; loss of energy

Nozzle - a tube forming the opening of a pipe, used to control the quantity or direction of a fluid

Orifice - an opening

P^H - potential of hydrogen

Piston - a sliding cylindrical piece of equipment that moves within a hollow cylinder

Plunger - a piece of equipment made to slide up and down in a cylinder piston

Potable water- safe water for human consumption

Prime mover - original or initial source of power

Pre-chlorination - addition of chlorine compounds to water before it is filtered

Precipitate - solid that can usually be separated from a liquid by filtration

Purveyor (n): a person or company that supplies or makes water available.

Raw water- water that did not undergo any of the processes that make water safe for human consumption and other uses

Safe water- water free of pathogens and other substances deleterious to human health

Sedimentation - the action of setting down or depositing matter in a liquid

Siphon - a method of continuously transferring a liquid to a lower point by air pressure forcing it up the shorter end of a bent tube

Specific Gravity - the ratio of one substance's density to another density

Spout - the part of the pipe through which fluid comes out

Suction Head - the part of the total that exists on the intake or suction part of a pump

Treated water- water made safe for human consumption and other uses by modern water treatment schemes

Ultra-Violet Ray – short wave radiation beyond the violet end of the visible spectrum. Used to treat some diseases and to kill microbes

Uniformity coefficient - is the ratio of the grain size that has 60 percent finer than itself to the size, which has 10 percent finer than itself (effective size). It is recommended not be greater than 2.5 for SSF. A s*ize of graded gravel* ranges from ¼"-1¼".

Valve - a movable piece of equipment designed to open, close or control the opening of a pipe or other piece of equipment

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No Fluoride:http:WWW. Nofluoride. Com
Inter country Center for Oral Health: http:/WWW.icoh. Org
UNICEF:http://WWW. Unicef.org

Annexes

Annex I. Water Quality Standards

WHO Recommendations for Drinking Water Quality

1 – Primary Standards – Microbiology Contaminants		
Bacteria	Limit (Count/100 m)	Remarks
Treated water fed into mains 1. E. coli 2. Coliforms	0 0	Turbidity <1 NTU; pH – value on cholrianation < 8.0; after 30 min contact time free chlorine 0.2 – 0.5 mg/L
Untreated water fed into mains 1. E. coli 2. Coliforms 3. Coliforms	0 0 3	In 98% samples tested per year in larger supply systems Occasionally but not in sequential samples
Mains water 1. E. coli 2. Coliforms 3. Coliforms	0 0 3	In 95% samples tested per year in larger supply systems Occasionally but not in sequential samples
Non-mains water supply 1. E. coli 2. Coliforms	0 10	Should not appear in sequential samples

2 – Primary Standards – Chemical Contaminants

Inorganic constituents	Limit (mg/L)	Organic Constituents	Limit (μg/L)
Turbidty (NTU)	5, (1 after disinfection)	Aldrin, dieldrin	0.03
		Benzene	10
Arsenic (As)	0.05	Benzo(a)pyrene	0.01
Cadmium (Cd)	0.005	Carbon tetrachloride	3
Chromium (Cr)	0.05	Chlordane	0.3
Cyanide (CN)	0.1	Chloroform	3
Fluoride (F)	1.5	DDT	1
Lead (Pb)	0.05	1,2 dichloroethene	10
Mercury (Hg)	0.001	1,1 dichloroethane	0.3
Nitrate (NO^{3-})	45	Trichloroethene	30
Selenium (Se)	0.01	Methaoxychlor	30
		Pentachlorophenol	10
		Tetra chloroethene	10
		2,4,6 - trichlorophenol	10

3 – Secondary Standards – Chemical Constituents

Inorganic constituents	Limit (mg/L)	Inorganic Constituents	Limit (μg/L)
Color (TCU)	15	Hydrogen sulfide	nil
Taste and odor	none	Sodium (Na)	200
pH	6.8-8.5	Iron (Fe)	0.3
Dissolved solids	1,000	Manganese (Mn)	0.1
Hardness as $CaCO_3$	500	Aluminum (Al)	0.2
Chloride	250	Copper (Cu)	1
Sulfate	400	Zinc (Zn)	5

Adapted from WHO, Guidelines for Drinking Water Quality, Vol. 1, Recommendations WHO, Geneva,

Annex II Unit conversions

Conversion From customary to metric units (in alphabetical order)

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
Acre	ac	4.047 x 10^{3}	m^{2}[a]
		0.404 7	ha (hectare)
acre-foot	ac-ft	1233	m^{3}[a]
atmosphere	atm	101.3	kPa[a] (pascal)
bar[b]	bar	100.0	kPa[a]
Cubic feet per gallon	cu ft/gal	7.482	m^{3}/m^{3}[a]
		7.482 x 10^{-3}	m^{3}/L
cubic feet per hour	cfh or cu ft/hr	7.867 x 10^{-6}	m^{3}/s[a]
		7.867 x 10^{-3}	L/S
cubic feet per hour per square foot	cfh/sq ft	8.467 x 10^{-5}	$m^{3}/m^{2} . S$[a]
		304.8	$L/m^{2}h$
cubic feet per million gallobs	cu ft/mil.gal	7.482	mL/M^{3}
cubic feet per minute	cfm or ft/min	4.719 x 10^{-4}	m^{3}/s[a]
		0.4719	L/s
cubic feet per minute per foot	cfm/ft	1.549	L/m . s
cubic feet per minute per thousand cubic feet	cfm/1000 cu ft	1.667 x 10^{-2}	$L/m^{3} . s$
cubic feet per minute per thousand gallons	cfm/1000 gal	0.124 7	$L/m^{3} .s$
cubic feet per pound	cu ft/lb	6.243 x 10^{-2}	m^{3}/kg[a]

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
cubic fees per second (or second-feet)	cfs	2.832×10^{-2} 28.32	m^3/s^a L/s
cubic feet per second per acre	cfs/ac	6.997×10^{-6} 69.97	$m^3/m^2 \cdot s^a$ L/ha . s
cubic feet per second per square mile	cfs/sq mile	1.093×10^{-8} 0.109 3	$m^3/m^2 \cdot s^a$ L/ha . s
cubic foot	cu ft	2.832×10^{-2} 28.32	m^{3a} L
cubic inch	cu in.	16.39×10^{-6} 16.39	m^{3a} mL
cubic yard	cu yd	0.764 6	m^{3a}
Curie[b]	Ci	3.700×10^{10}	s^{-1a}
cycles per second	cps	1.000	Hz (hertz)
degrees Fahrenheit	°F	0.555 6 (°F - 32)	°C
Rankine	°R	0.555 6	K (kelvin)
degrees Per second	degrees/sec	1.745×10^{-2}	rad/s^a
degrees per second squared	degrees/sec^2	1.745×10^{-2}	rad/s^{2a}

Multiply Customary Unit	Abbreviation	By	To Obtain Metric Unit
feet of head	ft	0.304 8	m^a
feet per hour	ft/hr	8.467 x 10^{-5}	m/s^a
feet per minute	ft/min or fpm	5.080	mm/s^a
feet per second	ft/sec or fps	0.304 8	m/s^a
feet per second squared	ft/sec^2	0.304 8	ma (meters per annum)
gallons per day	gpd	4.381 x 10^{-5}	L/s
gallons per day capita	gpd/cap	3.785	L/cap . d
gallons per day square foot	gpd/sq ft	4.715 x 10^{-7}	$m^3/m^2 .s^a$ or m/s^a
gallons per hour	gph	1.051	mL/s
mile	mile	1.609	km
		0.446 9	m/s^a
miles per hour	mph	0.446 9	m/s^a
million gallons	mil. gal	3.785 x 10^3	m^{3a}
		3.785	ML
million gallons per day	mgd	4.383 x 10^{-2}	m^3
mst probable number per hundred milliliters	MPN/100 mL	10.00	ML/ha . d MPN/L
Parts per million	ppm	1.0 (approx.)	mg/L
		1.000	mg/kg

quare foot	ft^2	2.0	9.290×10^{-2}	m^{2a}
yard	yd	3.0	0.914 4	m^a

(Adapted from Joseph A. Salvato. Environmental Engineering and Sanitation. 4th edition, A Wiley – Interscience Publication, 1992)