Appropriate Technology for Water Supply and Sanitation

(1st draft for review)

A.K.M. Nurul Islam
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September 1996

International Environmental Planning Center (INTEP)
Department of Urban Engineering
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Preface

After the establishment of International Environmental Planning Center (INTEP) at the Department of Urban Engineering, the University of Tokyo, a great public desire to have a text book on 'appropriate technology' for water supply and sanitation was recognised. This is because there is virtually no text book on the subject published in Japanese. Therefore, there is a strong need for this kind of book among Japanese students, professionals and researchers working on the international cooperation on water supply and sanitation. However, we decided to prepare the draft of such text book in English first so that experienced engineers in other countries can review it before we begin to prepare it in Japanese.

Along this line, we finally made the 1st draft of the book ready. Basically this version is only for review by respected professional in this field. We invite all types of comments on this book to improve its contents.

Most of this book is compiled from various existing reference materials including books, reports, papers, articles and documents as shown at the end of this book. Thanks to these informative materials, we could able to compile this draft.

Although this draft covers mailly technical parts, we think that different areas such as managerial aspects should also be covered. To expand the scope of this book in the future, we provided some hints for consideration. Readers can find those topics which we want to incorporate in future in the table of contents (between two thick lines). We also appreciate any comment on those.

We want to thank Kubota Corporation for their financial support to INTEP without which this trial could not have been done.

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September, 1996

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1.1 Introduction

Development is a relative term, depends on the evaluators. It is inherently more subjective than objective. However, for the sake of the world economics and international relations, various organizations have been trying to measure the *development* with the yardstick of their own, basically depending on the purpose and target of the concerning organization. As the current practice, some countries of the world are levelled as developed countries and the rest are bracketed in the term *developing countries.* However, the exact definitions of developing countries can vary according to the defining agency.

The most common standard used to describe the development state of a country is income level. One of the widely used way to describe a country's income is Gross National Product (GNP). The GNP is the total value of all goods and services produced by the economy over a period of time (usually one year). GNP per capita, that is, GNP divided by population, is a common yardstick to measure the development of a given country. However, it must be noted here that although the income level is most widely used tools for the assessment of development, this does not mean that income data are precise, scientific or objective measures of development. They are universally used because they are more easily measured and quantified than other types of development indicators, such as social well-being or health. Data for income levels are simply more readily available and despite its limitations, GNP per capita provides a useful broad measure of the material well-being of nations.

1.2 Classifications

World Bank classifies all the countries and regions of the world into three categories (The World Bank, 1995). *Low-income economics* are those with a GNP per capita of US $695 or less in 1993. *Middle-income economics* are those with a GNP per capita of more than $695 but less than $8,626 in 1993. A further division, at GNP per capita of $2,785 in 1993, is made between lower-middle-income and upper-middle-income economics. *High-income economics* are those with a GNP per capita of $8,626 or more in 1993. According to the same report, "*Low-income and middle-income economics are sometimes referred to as developing* *economics*."

The Development Assistance Committee (DAC) of the Organization for Economic Cooperation and Development (OECD) is currently following the same definition for the developing countries as of the World Bank (OECD, 1995). However, it is necessary to mention here that, within the low-income economics, another group is established by the Economic and Social Commission of the United Nations, which is called as Least Developed Countries (LDCs). To qualify for admission, countries must fall below thresholds established for income, economic diversification and social development (OECD, 1995). As of 1995, 47 states and territories are classified as LDCs.

The United Nations Development Program (UNDP) once followed their own criteria, however, to reduce the misunderstanding, starting from 1995 they decided to follow the guideline set by the World Bank (UNDP, 1995).

However, United Nations also considers literacy rate and the percent share of GDP by manufacturing industry (World Bank, 1995). Some of the rich countries are better off in monetary terms than many industrialized countries (like oil exporting UAE has a GNP per capita of US $21,430 compared to Canada's 19,970 and UK's 18,060) but classified as developing countries because of a very unequal distribution of income within their countries, as well as low levels of development in other areas, such as agriculture, industry, education and health services.

1.3 General features of developing countries

85.23% of the world's population, or around 4,689 million people out of the total world population of 5,501.5 million live in the developing countries (World Bank, 1995). Most of these countries located in Africa, Asia and Latin America. Despite its large area and population, only about one-fifth of the world's wealth is produced in developing world (Barke and O'Hare, 1991). With a few exception, most of the developing countries are located in the southern part of the earth, as such sometimes these countries are referred as '*South*' (Fig. 1.1).

The countries of the developing world share a number of common characteristics which distinguish them as a group from the developed world. For instance, ways of earning a living in poor agricultural developing countries like Bangladesh and Ethiopia have a number of shared features of poverty and hardship which can not be found in a developed country such as UK or Japan (Barke and O'Hare, 1991). The average person in the 'developed' world consumes ten times as much energy and one and-a-half times as much food and produces 16 times as much air pollution as the average person in the 'developing' world (Seager, 1990). The common characteristics of the developing countries include low productivity, low income, high income inequality between regions and social classes, low capital formation, low economic growth, low energy consumption, low levels of technology, large agricultural population and high dependence on agriculture (over two-thirds of the population of the developing countries is dependent upon agriculture as a means of subsistence, Reed, 1989), low share of industry in GDP (in the distribution of GDP, the share of agriculture and industry of Bangladesh are 34 and 17% respectively, whereas, those of Japan are 2 and 42%, World Bank, 1994), production and export of primary produce (like, minerals, food), low level of industrialization and tertiary types of industry (like, assembling, finishing), poor infrastructure, small market size and high technological dependence. They share some common social features also like poor human nutrition, low health levels, high infant mortality, poor life expectancy, high rate of population growth, low literacy and low technical skill. There are some unity even in cultural and political condition, like, low political stability, high share of military/authoritarian government, high ethnic/cultural variety, traditional behaviour and low status of women. A comparison between the developed world and developing world is given in the table 1.1. The LDCs have an extremely low level of exploitation of their natural resources. Agricultural output is usually stagnating relative to population increase and starvation and disease are very real issues for many of the inhabitants. Many of these countries are also constrained by one or more geographical or climatological handicaps.

Table 1 General comparison between developed and developing world.

	Unit	World	High income economics	Middle income economics	Low income economics
Population	million	5501.5	812.4	1596.3	3092.7
Area	million of sq.km.	133.69	32.15	62.45	39.09
GNP per capita	US$	4420	23090	2480	380
Avg. annual rate of inflation, 1980-1993	percent	19.6	4.3	90.1	14.1
Life expectancy at birth	years	66	77	68	62
Adult illiteracy	percent	33	a.	17	41
Adult female illiteracy *	percent	45	a.	---	52
Energy use (oil equivalent) per capita	kg	1421	5245	1563	353
Crude birth rate	per 1000 person	25	13	23	28
Total fertility rate	per women	3.2	1.7	3.0	3.6
Infant mortality rate	per 1000 live birth	48	7	39	64
Under 5 mortality rate	per 1000 live birth	75	9	57	103
Population per physician*	person	3850	420	low+middle income economies = 4810	
Female in secondary education	per 100 male	81	98	102	67
Urban population	percent of total	44	78	60	28
Access to safe water**	percent	---	95+	73	49
Access to safe sanitation**	percent	---	95+	54	33

Source : Compiled from World Bank, 1995 except *, which were compiled from World Bank, 1994 and **, which were compiled from WHO, 1995.
Note : --- denotes that data is not available, a. according to UNESCO, less than 5%

Low incomes are usually associated with meagre living conditions, including inadequate diet, poor health, poor housing, insufficient education and low sanitation condition as revealed in the table 1.1. Health levels in the developing countries are usually very low and closely related to hunger and malnutrition. While in the industrialized countries of the west, food energy intake may exceed requirements by about 20%, in the developing world many millions of people exist on diets whose daily calorific intake is below the accepted minimum of 2200, which is the lowest amount required for the average adult *at rest* (Barke and O'Hare, 1991). The average daily per capita calorie and protein intake is shown in fig. 1.2. A closer examination of those figures reveals that in addition to very low calorie intake, the protein intake of many countries are below 55 grams which is much less than the 70 grams per capita recommended for healthy development (Barke and O'Hare, 1991).

Another unique feature of the developing countries is the inter and intra country widening of income gap. It is a common feature that the income distribution is quite high for developing countries. Despite the continual efforts for development for the last four decade, very little impact has been made to alleviate the poverty of the very poorest groups in these poor countries. The benefits of the United Nations' two Development Decades (1960 – 70 and 1970 – 80) has effectively bypassed perhaps as much as one-third of the entire population. It has been the already better-off groups, such as the land owners, businessmen, professional and technical personnel, local influential leaders, which have benefitted from economic growth. For the substantial and increasing portion of the population in the very poorest groups, improvements in income and welfare have been negligible. In many cases, their situation has even been worsening.

The income gap between the middle income economics (MIE) and the low income economics (LIE) is also increasing. Table 1.2 shows that the income of the MIEs has grown at a greater pace than the LIEs over the 30 years. Since the MIEs already had much higher absolute incomes in 1950, these growth rates also indicates a widening gulf in income level between the two groups of countries.

Table 1.2 The widening development gap

	Per capita GNP (US$)			Actual growth in per capita GNP	Percentage growth in per capita GNP
	1950	1960	1986	1950–86	1950–86
MIEs	4130	5580	12960	8830	214
LIEs	315	371	610	295	94

Source : World Bank, 1989

It is an irony, however, that the net flow of money from rich to poor nations has been reversed. About a decade ago, around US$ 40 billion flowed from the northern hemisphere to the developing nations in the south. Today, taking into account loans, aid, repayments of interest and capital, the south is transferring at least US$ 20 billion a year to the north. If the effective transfer of resources implied in the reduced prices paid by the industrialized nations for the developing world's raw materials is taken into account, the annual flow from the poor to the rich could be as much as US$ 60 billion each year (UNICEF, 1989). Fig. 1.3 shows the details of such transfer. As an obvious impact, public spending on the environmental issue suffer.

1.4 Features related with the improvement of environmental sanitation

For the purpose of the analyzing, planning, managing or apprizing the development projects in environmental sector in the developing countries, some of the specific features of the developing world is worth to note.

From the poor correlation between the occurrence of resources and levels of development, it can be stated that, natural resources can not be a major driving force for economic growth. For evidence, China and India have large untapped resources but are not highly developed. On the other hand, Japan and Switzerland proved that high levels of development are possible even with the possession of meager natural resources. Availability, accessability and recoverability of resources should be taken into consideration, in the selection process of appropriate technology. Climate can be another serious consideration as some of the unique climate types are very special and can not be experienced in developed world. Most parts of the developing world are, however, in one of the four special climatic regions. These are moist tropical or equatorial, tropical monsoon, tropical wet and dry or savanna and arid climate. Fig. 1.4 shows these distribution. Vegetation and soil type can also play some role in environmental sanitation. Natural disasters like flood, drought and storm should be given much importance as catastrophic natural disasters are widespread in the developing world and they are particularly concentrated in heavily populated areas (fig. 1.5). In addition to the natural disasters, the developing world is now empowered by man made disasters. Population explosion forces agricultural expansion, resettlement, logging and fuelwood collection at an alarming rate which results in soil erosion, siltation of waterways, severe and prolonged floods, and extensive drought and desertification.

In preparing the development strategies in environmental field for the developing world, a keen interest should be paid into the local social and economic aspects. Poverty is one of the main symptoms of underdevelopment. However, it is said that poverty fosters more poverty and the most poorest has little opportunity of changing their fate. A vicious circle (fig. 1.6) of poverty prevents them from better life. Breaking this circle is one of the main aim of development. The similar type of vicious cycle can be constructed for health. Because of low income people can not have proper diet, which causes poor health and subsequent poor productivity and ultimately low income. Although malnutrition is a important aspects of the poor health condition in the developing world, probably the most important reason is the lack of decent sanitary facilities and supplies of safe drinking water. In insanitary conditions, feacally related diseases, other intestinal diseases, as well as typhoid, dysentryand cholera, spread easily. It has been estimated that about 80% of the disease problems of the LDCs can be related to poor water supply and sanitation (Barke and O'Hare, 1991). Lack of awareness is another principal aspect which reduces the willingness to use even there is availability of safe water and sanitation. This is a product of poor education, both formal and informal. However, the strange social practices also should not be overlooked. These includes strict caste system, capitalistic class structure, low status of women, religious and cultural practices and family structure. The last but not the least point in social aspect is political influence, which can play the most important role in the development process, as the ultimate decision is made by the political authority.

Figure 1.1 Major world divisions. First, Second and Third Worlds and the 'North'–'South' division (indicated by the broken line).

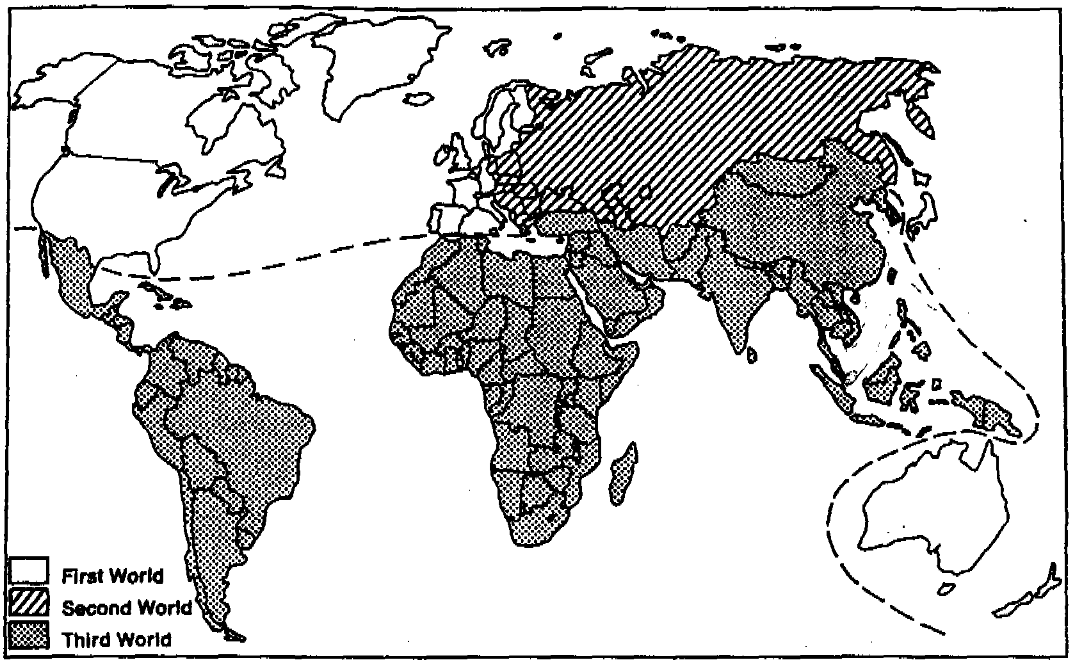


Fig 1.1 (The Third World)

(a)

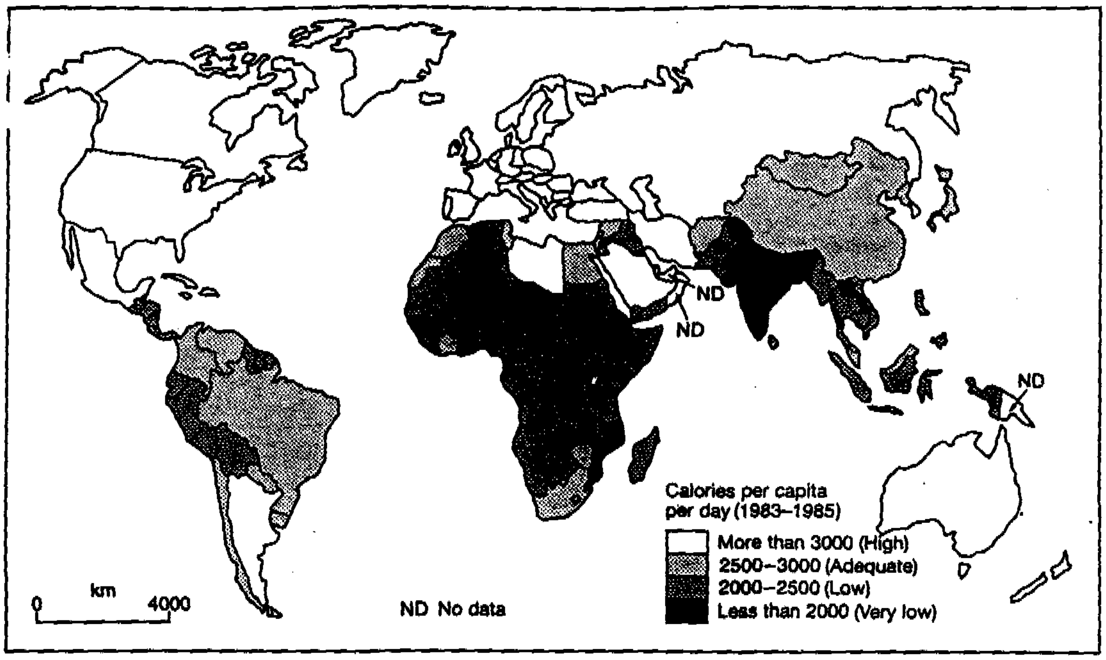


Figure 1.4 Calorie consumption per capita per day, 1983–5. (Source: *FAO Production Yearbook*, 1986)

Figure 1.5 Daily per capita protein intake (grams) 1983–5. (Source: *FAO Production Yearbook*, 1986)

(b)

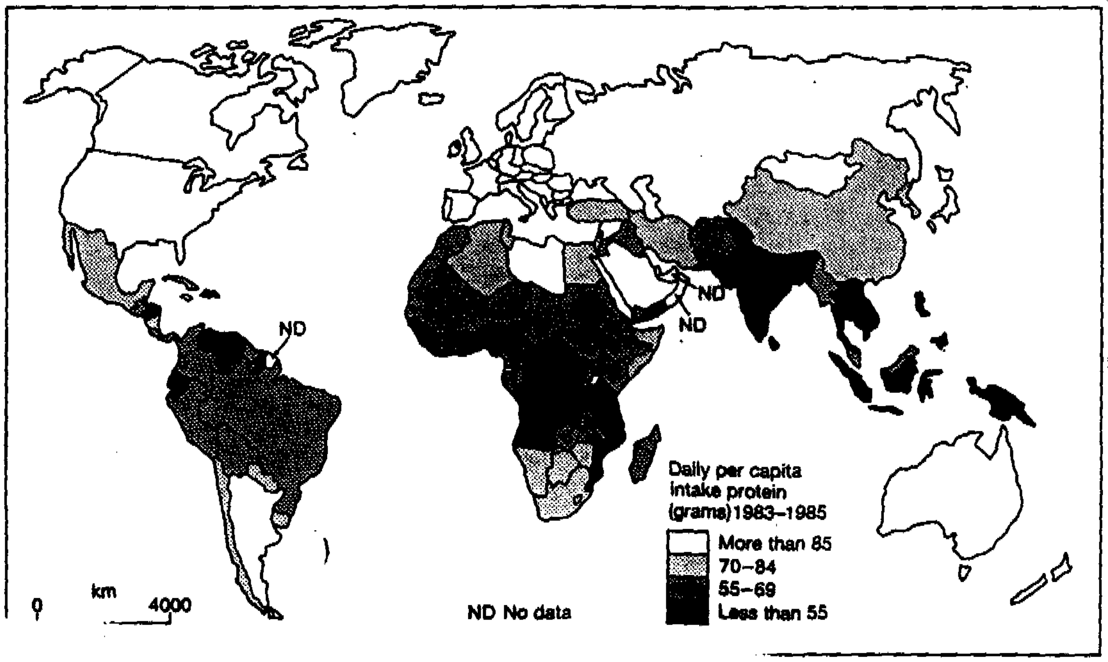


Fig 1.2 (The Third World)

FIGURE 2.1

Net flow of resources from South to North

US$ billions

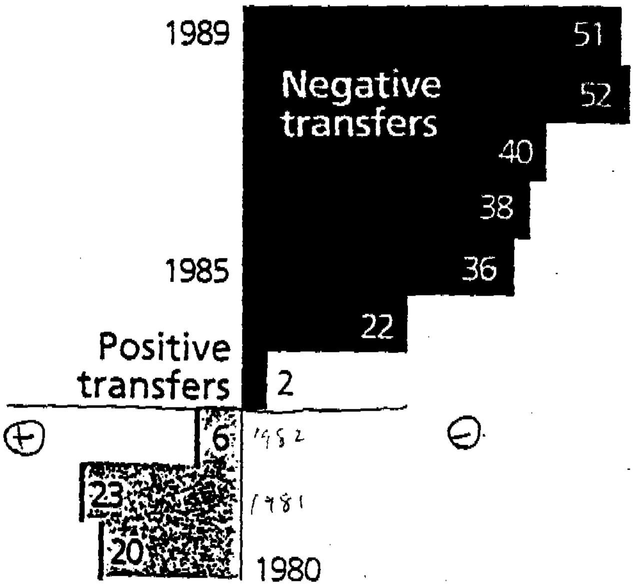


Fig 1.3 (UNDP, 91)

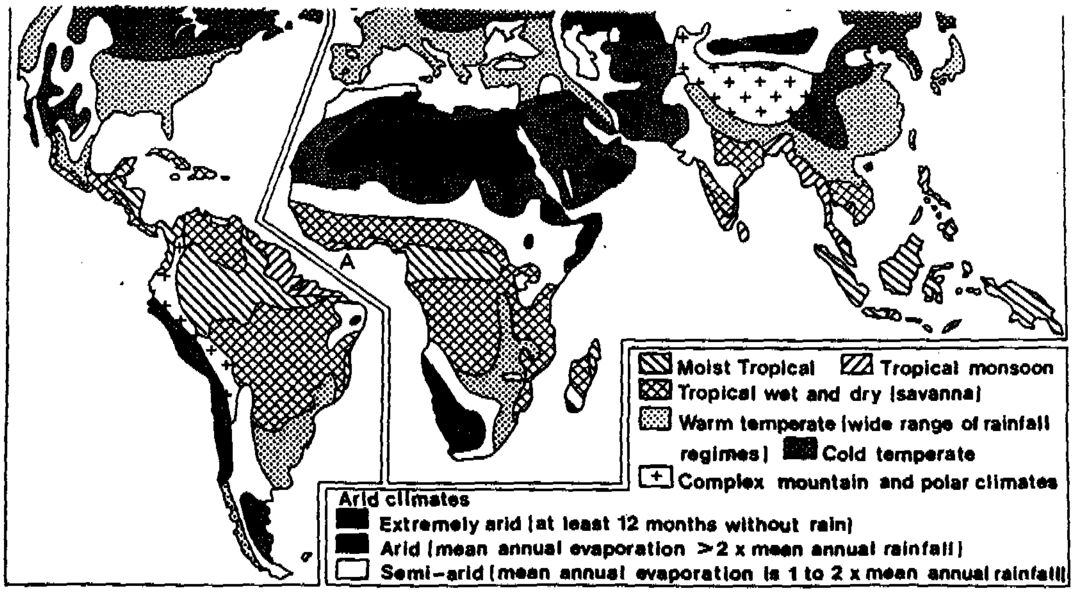


Figure 2.2 Distribution of climate in the Third World and adjoining areas. (Sources: Trewartha, 1954; Meigs, 1953). For transect A–B see Figure 2.4.

Fig 1.4 (The Third World)

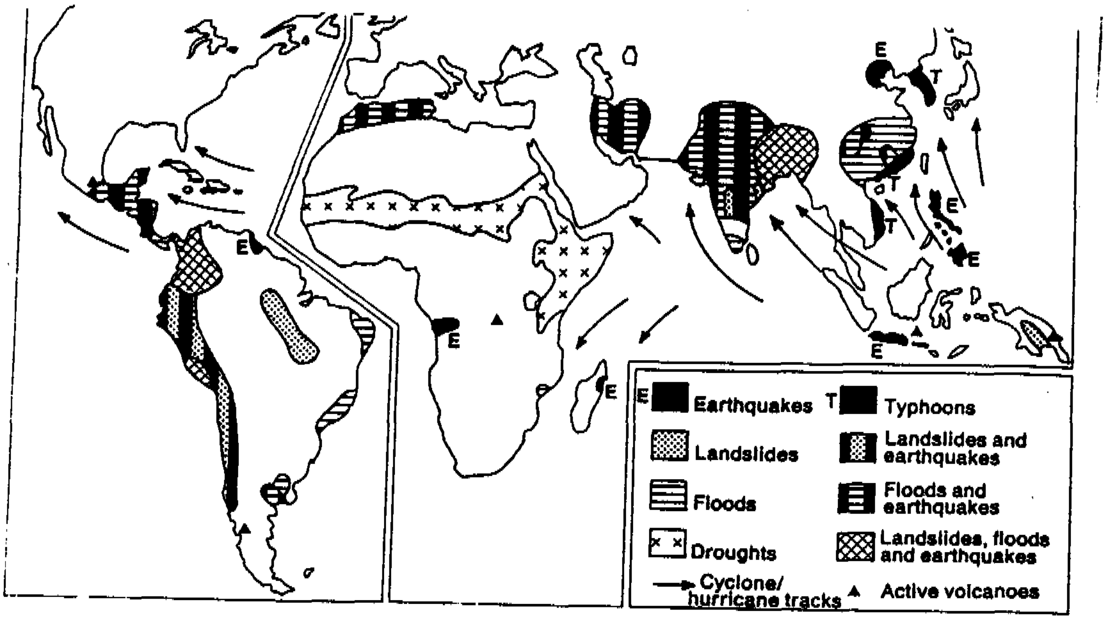


Figure 2.6 Natural hazards in the Third World which over the past 50 years have involved the loss of more than 100 lives in a single incident (volcanoes excluded). (Source: Doornkamp, 1982)

Fig 1. 5 (The Third World)

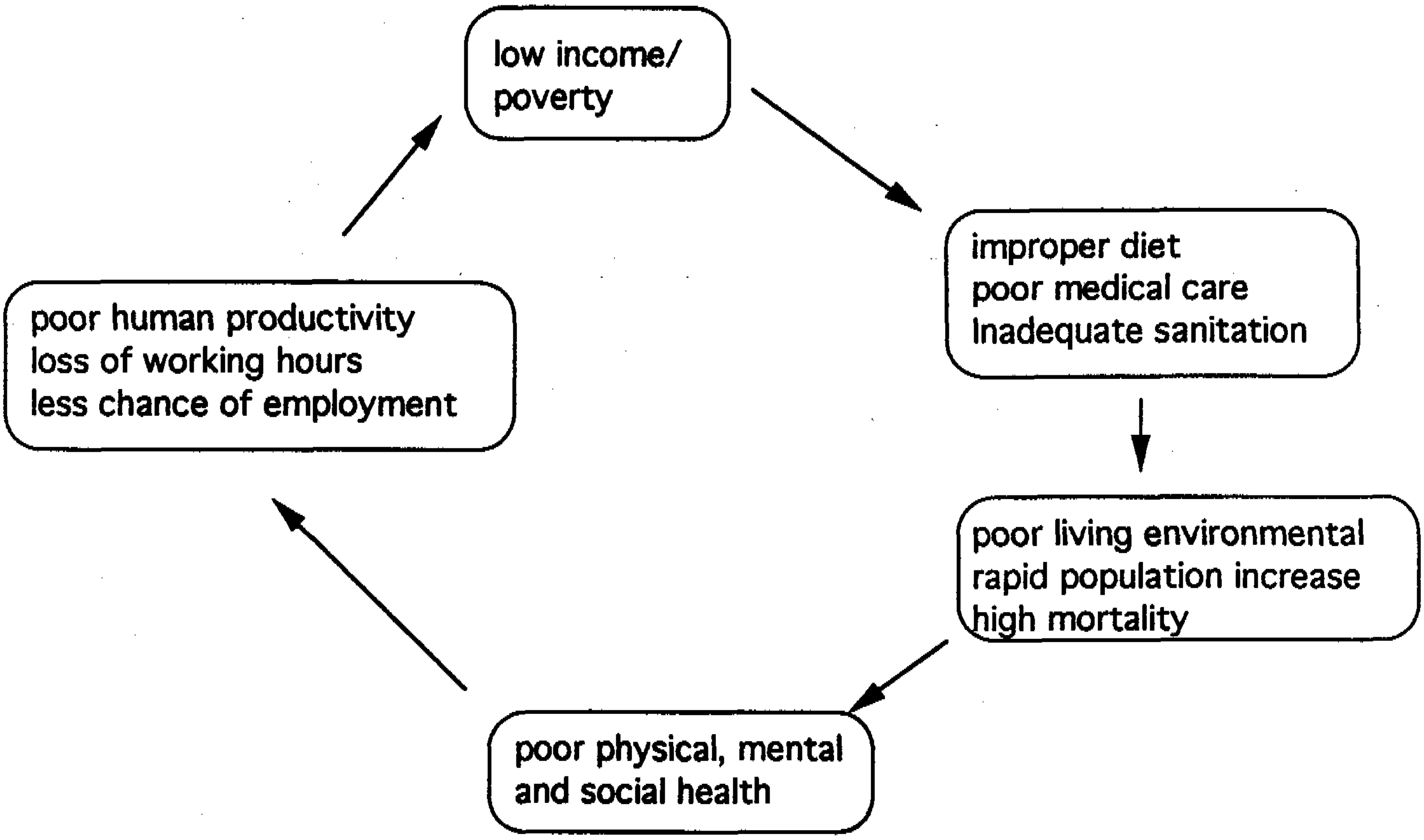


Fig. 1.6 The vicious circle of environmental health

Chapter 2 Present situation of public health in developing countries

2.1 Introduction

All over the world, in developed and developing countries alike, environmental degradation is undermining development and damaging human health. This ill-health saps the strength of the work-force, and so further obstructs development, increases social unrest, leads to greater environmental loss, and causes even more disease. If the environment is improved, both economics and people will become healthier.

A lack of sanitation may result in the spread of communicable diseases. In lesser developed countries, this is the most important component in determining the state of the public's health. Therefore, environmental control is very important in controlling the etiological (causative) agents of disease before they enter the human body.

Although improved environment indicates many aspects ranging from safe water supply and sanitation, acceptable level of air pollution to social and mental well-being, a great deal of public health is directly linked with water supply and sanitation. This is because water borne diseases are infectious and epidemic in nature, and closely related with personal hygiene. More people in the world suffer from the water borne diseases than any other type of infectious diseases and since this is a major concern in the developing countries, appropriate low cost technology is an essential to cope with this.

Sanitation aspects to control the causative agents of disease while they are in the environment, prior to attack human is, therefore, highly recommended. Controlling environmental conditions by environmental health practice provides *human's first line of defence against disease.* Before considering the methods of environmental health management, it is of great help to take a note the defence which are available to mankind, as shown in Table 2.1.

Table 2.1 Human practices and Role of environmental health

I. Human's first line of defence against disease *(Environmental management)*
a. Water quality management b. Proper human waste disposal c. Solid and hazardous waste management d. Rodent control e. Insect control f. Milk sanitation g. Food quality management h. Occupational health practice i. Interstate and international travel sanitation j. Air pollution control; k. Water pollution control l. Environmental safely and accident prevention m. Noise control n. Housing hygiene o. Radiation control p. Recreational sanitation q. Institutional environmental management r. Land use management s. Product safety and consumer protection t. Environmental Planning
II. Human's second line of defence against disease *(Public health)*
a. Proper nutrition b. Good personal health practice c. The body's reflexes d. Routine health check-up e. Application of health education f. Other
III. Human's third line of defence against disease *(Preventive medicine)*
a. Phagocytosis (a natural process) b. Immunity (active and passive)
IV. Human's forth line of defence against disease *(Curative medicine)*
a. Surgery b. Administering of medicine and radiation c. Diagnosing by means of various lab methods d. Corrective dentistry e. Corrective therapy (i.e., speech, hearing, respiratory)

Source : Morgan, 1993

2.2 Present situation of public health

For the last two centuries, improved water supply and sanitation played a decisive role in reducing sickness and death from infectious diseases in the industrialized countries in particular and in the world in general. Infant mortality has decreased and life expectancy increased in almost every nation. Yet a large gap exists between the developed and developing countries. A baby born in a developing country is ten times more likely to die before its first birthday than one born in an industrialized nation. A European or a North American can expect to live more than 20 years longer than an African or South Asian (WHO, 1984). People in developing countries mainly suffer from communicable diseases, largely caused by unsafe water sanitation, by contrast, people in industrialized countries die predominantly from degenerative diseases, mainly cardiovascular diseases and cancer, which are caused, to a great extent, by ill-planned development and over-consumption. The current improved situation in the public health sector in the industrialized societies are basically achieved with improved sanitation practices. It is therefore obvious that the morbidity and mortality that prevail in the developing countries today can also be reduced with the further improvement in water supply and sanitation sector.

Some 11.475 million children under the age of five die every year in developing nations as a result of tainted drinking water, poor sanitation, environmental pollution, common diseases and malnutrition, which is more than 4.11 million children under age five die each year in developing countries from the respiratory infections caused by air pollution. The total number of death by causes related to poor sanitation is 16.31 million or 41.5% of all death occurred in the developing countries. Compared to that the number of death by the same reason in the developed countries are 0.135 million, which is only 1.2% of the total death (WHO, 1995). However, many million of these deaths can be prevented at low cost, by breast-feeding, oral rehydration therapy, proper food preservation and immunization, and, in effect, by better management of environment (UNICEF & UNEP, 1990). Thus, this tremendous annual carnage is due more to the failure to achieve such management, rather than to the nature of the human environment itself.

Every year 3 million children under five die of diarrhoea in developing countries (WHO, 1995). Every small child in the third world suffers an average of three diarrhoeal attacks a year – and such repeated attacks, even if they do not cause death, lead to malnutrition which stunts physical and mental growth (Snyder and Mason, 1982). Across the globe there are an estimated 1.8 billion episodes of childhood diarrhoea annually, mostly in the developing countries (WHO, 1995). 200 million people annually suffer from the debilitating vector-borne disease, schistosomiasis (UNEP, 1986). Yet these water-borne diseases are preventable. Schistosomiasis and diarrhoeal diseases arise from the pollution of water by human wastes, as a result of poor sanitation. Most people in the developing countries do not have clean drinking water or proper sanitation facilities. If these were provided the diseases would be controlled. The problem is extremely serious in rural areas and urban fringes where the quality, availability and accessibility of water is poor, and storage facilities are inadequate. In the scene of sanitation, the picture is worse. A larger percentage of population – particularly the poorest ones – lacks any forms of sanitary excreta disposal. However, it is not to be undermine that when these facilities are available, they are often inadequately maintained or improperly used. Hence provisions for proper maintenance and required social education for the appropriate use are also important.

A basic comparison of public health between developed and developing economics are given in Table 2.2.

Table 2.2 State of public health in developing countries with comparison to developed countries

indices	developing countries	developed countries
Life expectancy, year**	64	77
Infant mortality rate, per 1000 live birth**	55	7
U-5 mortality rate, per 1000 live birth**	87	9
Maternal mortality rate, per 100,000 live birth	420	26
Annual population growth (1960–1990)*	2.3	0.8
(1990–2015)	1.7	0.5
Annual urban population growth (1960–1990)*	4.0	1.4
(1990–2010)	5.7	1.3
Population below poverty line (%)*	32	2
Total fertility rate (1990–1995)	3.8	1.9
Health expenditure per capita (US$)	36	1295
Deliveries attended by trained personnel (% of live birth)	55	99
Prenatal care (% of live birth)	59	98
Low birth weight (% of live birth)	19	7
Population per doctor #	420	4810

Source : Compiled from WHO, 1995 except with * marks which are compiled from UNDP, 1991, with ** marks which are compiled from World Bank, 1995 and with # marks which are compiled from World Bank, 1994.

Some other situation of public health in the developing countries are listed in Table 2.3.

Table 2.3 Situation of public health in developing countries

12.2 million young children and 10 million older children and young adults die each year – most from preventable cases. Out of this, only Diarrhoeal diseases claim the lives of some 3 million children.
Access to health service is 79%, means 0.985 million people lack basic health care*
Only 44% of rural population have access to basic health care
Access to safe water is 70%, still 1.41 billion people do not have safe water
Access to safe sanitation is 51%, over 2.29 billion people lack safe sanitation
One fifth of the population (800 million) still goes hungry every day*
174 million children under five suffer from serious malnutrition *
Over 1.3 billion lives in absolute poverty , more than one forth of humanity*
0.5 million women die each year from causes related to pregnancy and childbirth
Half of the pregnant women in the underdeveloped regions are anemic
Half of the world's population still lacks regular access to most needed essential drugs
A quarter of children U-5 in the developing world are in the risk of Vitamin A deficiency, out of these 2% are blinded or suffer serious sight impairment, preventive capsules cost 0.02 US$ each
About 130 million at primary level and more than 275 million children at the secondary level are out of school (enrollment 70%)*
Over 860 million adults still illiterate (Adult literacy 68.4%) *
40% of the women over 15 are illiterate*
There are 2.4 person per habitable room, three times the average in the North#
Three forth of the poor people in developing countries live in ecologically fragile zones#
14 million people become environmental refugees – driven from their homes by ecological degradation#

Source : Compiled from WHO, 1995 ,# from UNDP, 1991.* from UNDP, 1995

With the situation described in the preceding articles, it is beyond any doubt that the problem of the developing countries in the sector of water supply and environmental sanitation must have to be addressed.Due to the lack of fund the conventional technology can not be a just solution; we need some low cost alternatives. Again, technology transfer also needs some careful consideration. Same technology which proved successful in some location may not necessary be a successful approach in other location. Hence we need local sustainable technology. We can finally infer that the sound understanding of the appropriate technology and its application approach is a pre-requirement for integrated development.

Chapter 3 Managerial aspects of public health in developing countries

3.1 Introduction

People depend for their well-being on the health of the societies in which they live. This depends in turn on a decent level of sustained economic development, on a healthy environment and a proper use of its resources. The achievement of sustained development, the promotion of health, and the rational use of environmental resources are simply inseparable.

The maintenance and improvement of health should be at the center of concern about the environment and development. Yet health rarely receives high priority in environmental policies and development plans, rarely figures as an important item in environmental or developmental programs, despite the fact that the quality of environment and the nature of development are major determinants of health.

3. 2 Public health and environment

Public health damages by the environmental effects of both a lack of development and inappropriate development. In most cases for the developing countries, the two factors act together to varying degrees. For example, Schistosomiasis can spread through poorly planned water resources projects. Good design can prevent this happening. However, poverty and underdevelopment, including illiteracy, bring in other factors of tradition and ignorance, like barefoot farming, to play a role in spreading Schistosomiasis.

In developing countries more and more people are crowding into the unhealthy squatter settlements that are proliferating in almost every major city. These rapidly growing urban and sub-urban centers are a particular challenge for environmental health. Urbanization is usually associated with the development of a more productive economy, and it can bring major benefits to health and the environment; as the concentration of population and business lowers the unit cost of piped water, sanitation, and the collection and disposal of solid waste. However in the absence of proper planning and management or in the case of too fast growth, environmental health can suffer to a great extent. The provision of clean water and sanitation cannot keep pace, and diarrhoeal diseases are, in most cases, the largest single cause of death, particularly among the young children. Provision for standpipes and public toilets are seem to be an unattainable dream in most squatter settlements. However, these services do not necessarily provide proper hygiene as, unless clean and safe vessels are used, the water may become contaminated while it is being hauled and stored after collection. It is obvious that unplanned urban expansion and rapid slum prolification increase the spread of infectious diseases and degrade public health. As many slums are not officially recognized, they are not considered for even the most basic health and sanitation facilities, and thus they become centers of unhygienic condition. Such problems are particularly critical when large populations are resettled, like refugee settlement or slum relocation. Apart from the lack of adequate and safe water supply and insanitary disposal of excreta, the other reasons behind the spread of communicable diseases in the squatter area are inadequate disposal of solid waste, the absence or insufficient drainage of surface waters, inadequate personal and domestic hygiene, and poor housing and living condition.

Urban poor, who account for a substantial and increasing proportion of humanity, constitute the largest risk group from the point of view of health. However, among them children, women, elderly people and physically handicapped are the most vulnerable to the ill-health.

Natural disasters have also significance in the consideration of public health aspects. In the aftermath of a natural disaster, infectious diseases spreads due to disruption of water supply and sanitation services. Sometimes, post-disaster diseases have more victims than the disaster itself. It must be noted here that the degree of damage caused by a natural disaster is often aggravated by the human activities. Deforestation of watersheds, for example, leads to increases in the number and severity of floods in the plains. Poor buildings are more vulnerable in case of earthquakes.

Any consideration regarding on the relation of environment and health must take care of the population and their level of consumption. A very high consumption without planning will definitely cause degradation of public health, as seen in the developing countries. Income and asset distribution is also a major concern, as public health will suffer in case of lack of proper distribution.

3.3 Public health and development

Development is generally understood as the process of improving the quality of human life. It has three equally important aspects : raising people's living standards (can be measured by the increase of income and consumption and improvement of health), creating conditions conductive to self-esteem, and increasing people's freedom to choose (Todaro, 1977). Hence, it is evident that development of some society provides significant scope for health improvement and the public health is closely related with income and income distribution, development of infrastructure, improvement of services, living and working environment, and level of education. However, poor development planning can create or exacerbate the diseases of poverty as well as health problems of industrialization and development.

To integrate development and public health, steps should to taken to ensure development addressing people's need, where health is a major concern, and to ensure ecological sustainability so that natural resources are not depleted and natural systems are not damaged or degraded. Health and development are so closely connected that the state of health of a country is one of the most revealing indicator of its development. Still in many cases, especially in the developing countries, health is treated as the responsibilities of the health authorities alone, rather than as a shared responsibility of many agencies at all levels and of individual and community. This integration should be of a major concern of sound management of the interaction of health and development.

Expenditure on public health to keep good environment is highly expected. Provision of clean water and hygienic sanitation will bring better health of the workforce and which in turn provide increased productivity and less expenditure on treatment. Unfortunately, it is hard to measure the costs and benefits of such expenditure in conventional ways. It is very difficult to assess all the environmental effects and their impact on health. Similarly, it is also difficult to attach a monetary value either to the damage or to its mitigation. Due to these reasons, expenditure on the public health usually go through rigorous scrutiny. However, it is really important to understand that if the public health is improved, health, development and the environment will become interlocked in a positive, upward spiral instead of negative, downward one (fig. 3.1). If this is to happen, much greater priority to environmental and health issues have to be given.

For the better enforcement of public health and for the prevention and control of water-borne disease, a thorough and constant concertation among different authorities within national administrations is a primary requirement. This will enable a dialogue to be established and maintained between those responsible for health and the environment and those responsible for agriculture, water development, planning, public works, social services, education and information. Since sound planning is a prerequisite for sustainable development, the planning stage must take care to assess the existing situation, identify the problem, fix the targets, define the way and speed to attain the goal, establish the operation and maintenance procedure, and fix the method to use to experience as a feedback for future projects. Moreover, planning process should not be fragmented, it should cover all the aspects like urban development, land-use, economic aspect together with all the concerned sectors like industry, commerce, education, recreation, housing, transportation, social service, health service and cultural affairs.

Since there is a strong relation between the state of health and income level (Fig. 3.2), a balanced income distribution can upgrade both the state of public health and development. Health risks are increased by poverty, not only because basic minimum needs go unmet and exposures to hazards increase, but also poverty lead to environmental deterioration: in their struggle to survive, poor people inevitably exert pressure on the capacity of absorptive resources such as land, water and air (WCED, 1987 and WHO, 1991).

3.4 Cost reduction in public health

It was found in a macroeconomic policy study that the effect on health resulting from reductions in public expenditure are associated with greater morbidity and sometimes, higher infant mortality, acute shortages of pharmaceutical and medical supplies, and reduced health capital stock (WHO, 1990). It was also reported that in case of economic stagnation of a country, health sector becomes one of the most affected sector. In the Philippines, per capita GDP fell by about 3% annually over the period 1979–84. Per capita public expenditure on health, housing, and other basic social services in 1984 came to only about one-third of the 1979 level (UNICEF, 1988). Hence effective cost reduction is of great importance as the extra money saved by this can used for better health programs without affecting the national budget.

For the improvement of public health sector with the limited resources, appropriate opportunities have to be find out for considerable savings. In the USA, as estimated 25% of health expenditure is waste (UNDP, 1991). It is therefore possible to make large savings by choosing lower-cost treatment, selecting more appropriate drugs and purchasing them more efficiently.

Usually the cost of drug constitutes a major portion of the health services and some estimates of wastage run as high as 50% (UNDP, 1991). By giving emphasis on the basic drugs could make considerable savings. In 1985, the estimated cost per capita for medicine consumption was US$ 5.40, yet basic drugs costs around US$ 1.00 and an even more basic list could be provided for US$ 0.25 (UNDP, 1991). This money saved could be use for the people still have little or no regular access to essential drugs and whose number is ranging between 1.5

and 2.5 billion.

It must have to understood that some of the cheaper treatments are just as effective as their high cost alternatives. Diarrhoeal diseases are one of the leading causes of death in developing countries. The conventional treatment is intravenous rehydration therapy. But oral rehydration is just as effective as intravenous and this can cut cost by about 90% (UNDP, 1991).

Drug purchasing policies can also be made cost effective by introducing generic rather than brand name drugs. Improved storage and distribution can also increase efficiency. The wastage in immunization campaigns has been estimated at 33%. If this can be reduced to 20%, the cost of vaccines and syringes per child will become US$ 1.15 from $1.40 (UNDP, 1991).

For the reduction of cost, another approach is to recruit personnel with fewer formal qualifications but greater field experience. Village level health workers and tradition birth attendants can provide a good service level. Finally, improved organization and management is an essential for higher cost reduction.

In the implementation stage of water supply and sanitation programs, effective cost reduction can be achieved by the use of more low-cost technology, better designs, improving existing resources rather than establishing new ones, encouraging private sector participation, involving community, and standardising equipment and spare parts (Nigam, 1993).

3.5 Cost and cost reduction in water supply and sanitation projects

The cost of constructing water supplies varies widely, depending largely on the availability of water resources. For instance, a water supply with house connections for urban water systems in monsoon South-east Asia, can cost as little as US$ 60 per head, whereas in the arid Eastern Mediterranean area, it is likely to cost five times as much. A typical figure for a developing country would be US$ 120 per person served (Cairncross, 1990). A cheaper alternative is public standposts. These cost roughly half as much to build as house connection. The difference is not primarily due to savings in the cost of distribution pipes, as the distribution system normally accounts for only one-third of the total cost of a water supply; rather, it is due to the fact that those who use standposts consume much less water than households with private connections, so that there is less demand on the abstraction, treatment, pumping, and storage capacity of the system.Households with yard connection use roughly half as much as those with house connections, so that the cost for them is nearer to the lower figure. The typical cost of water supply system is shown in the table 3.1.

Table 3.1 Typical per capita costs of urban water supply

Level of service	Typical construction cost (US$)	Equivalent annual amount* (US$) = a	Typical water consumption (liters per person per day)	Annual operating cost** (US$) = b	Total annual cost (US$) = a+b
Pubic standpost	60	9	20	3	12
Yard connection	80	12	60	8	20
House connection	120	18	150	19	37

* Converted on the basis of amortization over 10 years at 10% interest.
** Calculated on the basis of US$ 0.35 per cubic meter
Source : (Cairncross, 1990).

Improved sanitation can be achieved at far less per capita cost than conventional sewerage systems and is at the same time more effective and hygienic than the pit latrines or bucket latrines, that remain the most widely used sanitation system, and obviously is much improved than over hanged latrine or open defecation, which also prevail in the developing countries. The World Bank has identified a wide range of household and community systems that could greatly improve sanitation while taking due account of local physical conditions, social preferences, and economic resources (Kalbermatten, 1980). Several have a total annual cost per household of between one-tenth and one-twentieth of that of conventional sewerage systems. Most need far lower volumes of water for efficient operation. Some need no water at all. Table 3.2 outlines different sanitation options and their costs.

Table 3.2 Typical range of capital costs of sanitation systems per household

Type of system	Cost (US$)
Twin-pit pour-flush latrine	75–150
Ventilated improved pit latrine	68–175
Shallow sewerage	100–325
Small-bore sewerage	150–500
Conventional septic tank	200–600
Conventional sewerage	600–1200

Note : Capital cost alone are not a sufficient basis for determining the cost of a system, since some systems are more expensive than others to operate and maintain. The total discounted capital, operation, and maintenance costs for each household must be calculated to determine the charge that must be levied for the service and establish whether households can afford to pay for the service. If the monthly cost of providing sanitation exceeds 5% of the family income, it may be deemed unaffordable. Most low-cost sanitation alternatives come within this limit even for the poorest of communities, especially urban communities.

Source : Sinnatamby, 1990.

Although it is shown, that the annual operating cost is only US$ 3 to provide safe water through public standposts, the poor are badly served. In average, urban water supply coverage is more than double than rural water supply coverage. In some countries, the disparities are much greater. In Ethiopia, people in urban areas have 14 times greater access to sanitary facilities than those in the countryside (UNDP, 1991). Around US$ 10 billion is spent each year in the developing countries, and estimated 80% of this goes to services for the better off (UNDP, 1991). It is ironic that in many countries the wealthy receive a good service very cheaply while the poor get inadequate service at a higher price.

Cost reduction is, therefore, a prime objective to provide sanitation service to more people with a reduced unit cost. New and appropriate technologies combined with proper management can make a great contribution. For instance, gravity-fed water supplies can decrease costs and cover a wide area in hilly areas. Water can be treated with slow sand filtration, which purify moderately polluted surface water more cheaply. Wells can be fitted with lower diameter pipe and improved pumps. In a project in India, water is pumped from a deep well for capital costs of less than US$ 1.00 per user per year — with operating and maintenance costs of about US$ 0.10 per user (UNDP, 1991).

3.6 Importance of proper management in water supply and sanitation

The fact that fresh water is limited both in quality and quantity in most places strongly suggests the need for comprehensive water management. Good water management should be based on recognition of the importance of safe and sufficient supplies for health and on the fact that fresh water is a scarce and finite resources and has a cost that, whenever possible, its user should bear. Sound financial practices can play an important role in a proper water management. Water should be priced in such a way that it ensures efficient use of water. Users of large amounts of water (including large industrial and agricultural concerns) are often charged well below the cost and are encouraged to overuse water, while the population who use the water for a minimum requirements have to pay a high charge, and even worse, a high proportion of the population lack access to piped water. It would be a good practice if it can be ensured that revenue from water sales will be sufficient to maintain the water supply system. Other important considerations are minimizing water loss and protecting the system from contamination. Many water supply systems lose 60% of the water from leaks in the pipes. If it can be reduced to 12% (the typical figure for systems in the USA or UK), the water available to use will become double, without any large investments in water production (Cairncross, 1990).

Provision of adequate sanitation in developing countries is an important aspect in the overall socio-economic development as it will provide improved health and nutrition status particularly among children, reduced risk of disease transmission in the community, and greater privacy, convenience and status. Yet, the scale and quality of sanitation program falls far short of need. To achieve wide sanitation coverage, appropriate management is a prerequisite. Successful selection of a basic sanitary technology requires careful consideration of consumer preferences and local conditions. There should be a balance between level of amenities and cost. While the choice of a low-cost technology may appear rational, demand and utilization may be higher for a facility which is more attractive and requires less maintenance. Sanitation programs often suffer due to weak public institutions. Sometimes, programs implemented by NGOs or the private sector – separately or in collaboration with government – are more likely to meet their objectives than programs implemented by government alone. For the sustainability of a sanitation project, high involvement of the consumer may prove advantageous. However, community participation should not be restricted only to the construction phase, but community should be given a level of responsibility for operation and maintenance. To prevent failure of a sanitation project, behavioral consideration if the user must also have been considered. This should include consideration of user's latrine utilization and general hygiene practice. This should also include the way to increase demand and to change hygiene practice. Instead of setting a new institution for the project implementation, it is better to use the existing institution so that it complements to the capacity building.

1 Influencing factors in a stable environment

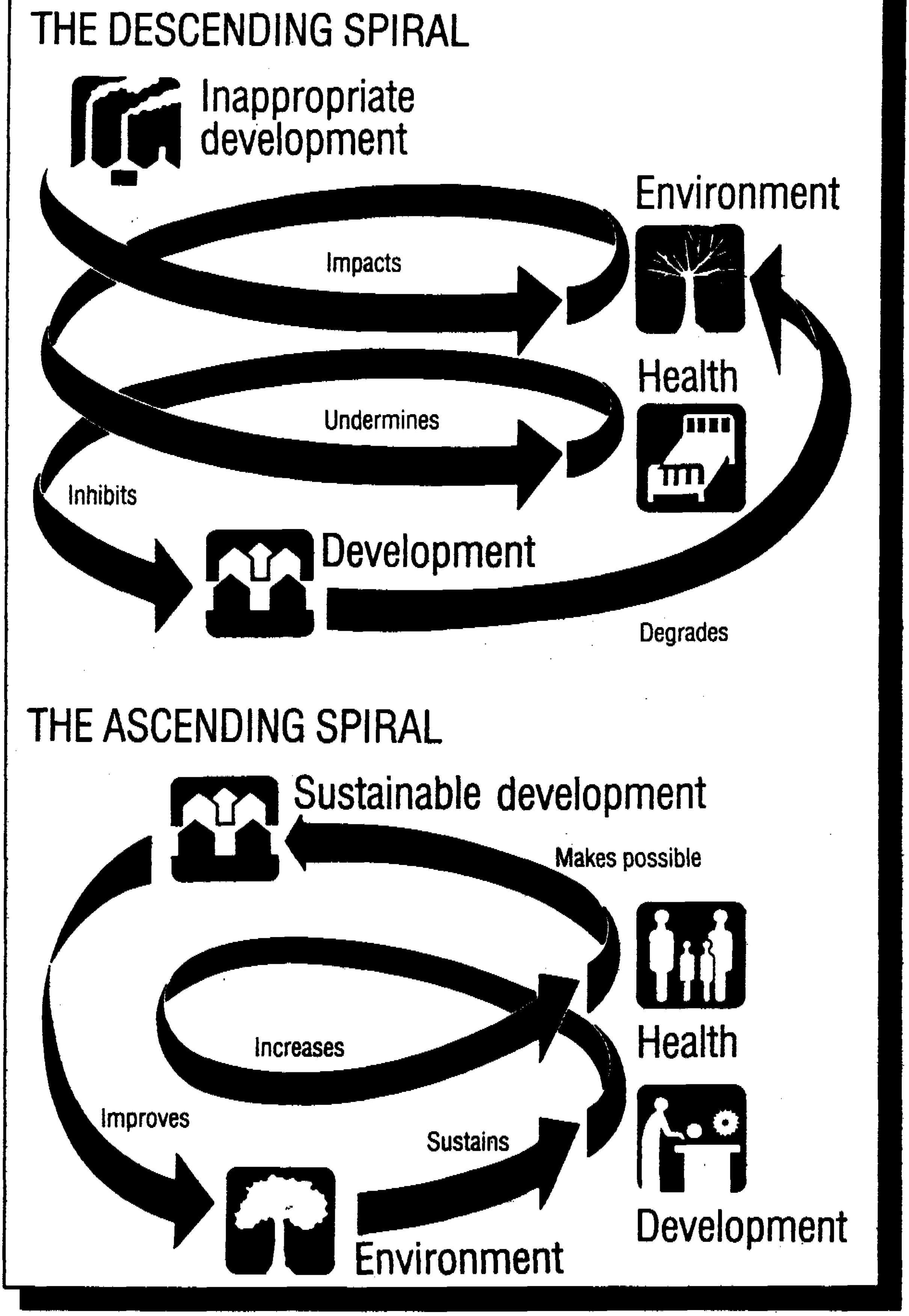
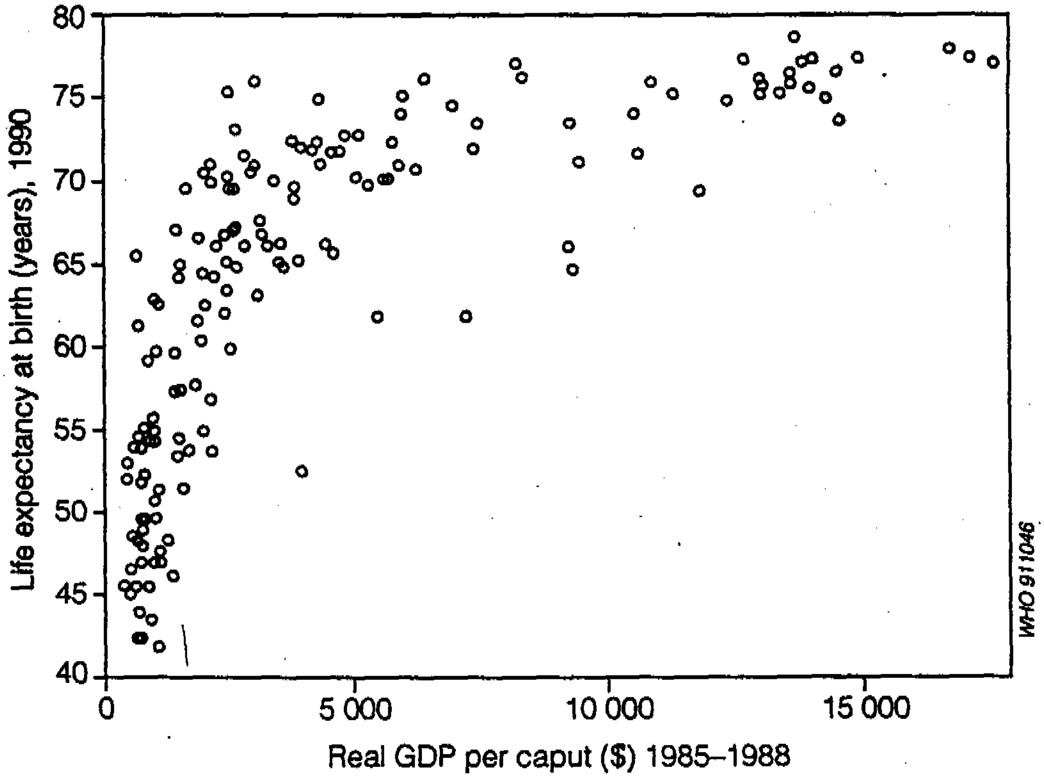


Fig 3.1 (UNEP, 86)

Box 3. Countries' per caput GDP for latest available year plotted against life expectancy



Sources: The figures for real GDP per caput for 1985–88 come from the United Nations International Comparison Project which has developed these on an internationally comparable scale using purchasing power parities instead of exchange rates as conversion factors, and expressed in international dollars. These figures and the figures for life expectancy at birth (1990) were drawn from UNDP, *Human development report 1991*, Oxford, Oxford University Press, 1991.

Fig 3.2 (WHO, 92)

Chapter 4 Public health aspects of environmental sanitation

4.1 Introduction

The tools for measuring public health status are still insufficient and even, those we have can often not be employed because of lack of resources. There are also different schools in selecting the yardsticks that should be used to measure public health.

One approach is to look at mortality. One report (WHO, 1995) suggests, that globally the biggest group of killers are infectious diseases and parasites, taking 16.4 million lives a year. These are followed by heart disease, which kills 9.7 million.

Another way to measure health is in terms of disease incidence – the number of new diseases each year. Looked at this way, the biggest global problem is diarrhoea in children under age 5, with 1.8 billion episodes a year (WHO, 1995). According to available data, sexually transmitted diseases come next, with 297 million new cases per year. In third place are acute lower respiratory infections among children under age 5, such as pneumonia, with 248 million cases.

With the above discussions, it is understood that the biggest threat to the public health is the poor environmental sanitation. This is further supported by the fig. 4.1 and 4.2. It can be inferred from that figure, that the reason why the infectious and parasitic diseases are lower in the industrial countries is the general improved prevailing conditions of environmental sanitation.

Globally about 51 million people of all ages died in 1993. Some 39 million deaths took place in the developing world and about 12 million in the developed. Poor countries had three times more deaths than rich ones (WHO, 1995). Of the estimated 51 million deaths (fig. 4.1) :

- communicable diseases account for about 20 million, or 40% of global deaths, and 99% of these occur in the developing world.
- noncommunicable diseases account for 19 million, or 36% of the total, with both the developing and the developed world sharing the burden more or less equally.

The difference between infectious and noncommunicable diseases is very marked. One in 2 deaths in the developing world is due to communicable diseases, but in the developed world 3 out of every 4 deaths are due to noncommunicable diseases.

The provision of safe water and the management of wastewater have had a central role in reducing the incidence of many water related communicable diseases. Although much progress is achieved in the past century in the field of controlling water related communicable diseases, especially in industrialized countries and in the rich group of the developing countries, the diseases associated with contaminated water remain among the most serious public health problems for much of the world's population.

There are three crucial concerns in the relationship between water and health. The first is the shortage of water availability, the second is the maintenance of water quality and the third is direct link health and water (WHO, 1992). Rapidly increasing population with increasing per capita water demand will create a strong pressure on water availability. Assurance of the safety of available water is a prime concern especially in the face of growing demand. The insufficient and poor-quality water, in combination with inadequate wastewater disposal, leads to breakout of various diseases.

4.2 Scarcity of water

Over the last 300 years, the rate of increase in the volume of water withdrawn from freshwater sources for human use is much higher than the rate of increase of the population.The volume of water withdrawal has increased more than 35 times, whereas human population has only increased sevenfold (L'Lvovich & White, 1990). The water demand in most of the developed countries are now stabilizing whereas it is growing in the developed countries. This trend is likely to continue as more people are coming into water coverage and as the per capita consumption is also rising. Most industrialized countries have annual freshwater withdrawals of over 500 m^3 per person, while a few have over 1000 m^3 and the USA has over 2000 m^3. Some developing countries also have high per capita withdrawal but most of the developing countries have withdrawals of between 20 and 50 m^3 per person per year (World Resources Institute, 1990). Most freshwater withdrawal is for agriculture, followed by industrial sector. Domestic and municipal needs accounts for around 7% of total withdrawal (World Resources Institute, 1988).

Table 4.1 Water distribution

Oceans (71% of earth's surface area	approximately 97%
Fresh water	approximately 3%
Glaciers and ice	approximately 2%
Available liquid fresh water	less than 1%

Source : Morgan, 1993

Despite the fact that the volume of fresh water available worldwide is only a small fraction of the total global water (97% of which is saline, as shown in table 4.1), it still greatly exceeds present and projected future needs. However, its geographical distribution is very uneven. Fig. 4.3 shows the potential availability of water as a function of latitude, the maximum availability is around latitude 50°S, where the land area is small and the population sparse. Latitudes 40° N to 70° N contain the most water rich area and which includes countries like Canada, Norway, Russia, and USA. Another water rich area is between equator and latitude 30° S, and which houses Brazil, ecuador, and Indonesia. Most of the countries in latitudes 10° N to 40° N lack water like, China, Egypt, Haiti, India, and Saudi Arabia (WHO, 1992). In most of the countries where potential water supply is scarce, the situation become more difficult by the seasonal distribution of rainfall – long dry seasons followed by heavy floods. This is an irony that most of the flood waters that pass through India and Bangladesh during the monsoon are not available for use and water scarcity is a problem in those countries in the dry season. Further, even in the monsoon, sometimes the rain is very intense but separated by uneven time gap between two rain fall. That is the reason that most of the irrigation practiced in Bangladesh is supplemental irrigation in monsoon season rather than capital irrigation in dry season. Finally, it have to be mentioned that the classification of countries on the sole basis of precipitation per unit area can be misleading, since many countries possesses rich river run-off like Egypt draws 50 times more water than rainfall (World Resources Institute, 1988).

Better water management with increased efficiency can provide better service to more person with the same amount of water. Many cities in the developing countries draw a considerable amount of water from ground water aquifers, sometimes it is as high as 97.5% of the total water supply as in the case of Dhaka (Islam, 1992). Sometimes this type of excessive ground water withdrawal exceeds the natural rate of recharge and which leads to severe land subsidence and in costal cities, saline water intrusion into the aquifers.

Water losses in the water distribution systems are sometimes considerably high, mainly in the developing countries. Based on a research paper (Hueb, J.A., 1986), it is reported that (WHO, 1992) the unaccounted-for water ranged from 39% to as high as 67% in 15 of the largest Latin

American cities in 1986, while it is only 13% in Geneva in 1989. In Sao Paulo, Brazil, an intensive program to reduce losses in water distribution systems reduced the unaccounted-for water from 36% in 1977 to 27% in 1982; the savings permitted an increase of about 46% in the number of house connection without the increase in water production (SABESP/CNEC, 1986).

4.3 Water Quality

Water quality maintenance can become very difficult in case of insufficient water availability. Basically, the four most important sources of water pollution are sewage, industrial effluents, urban run-off, and agricultural run-off. In certain countries, mines and oil production systems are also a major water pollution source (WHO, 1992).

In the developed world, non-point sources are of major concern, as point sources such as industrial effluents and the outflow of sewers and storm drains are usually treated before disposal. However, the situation in the developing world is much more complicated. In addition to pollution carried by urban and agricultural run-off, two very important factors exert high level of pollution. The first factor is the insufficient and unhygienic sanitation and solid waste management and the second factor is the failure to enforce pollution controls concerning with industrial effluent.

Agriculture is a major contributor of water pollution due to use of fertilizers and pesticides. Ten percent of the rivers monitored under the Global Environment Monitoring System (GEMS) have nitrate concentrations higher than WHO guideline for drinking water (World Resources Institute, 1988). Table 4.2 shows the impact of nitrates on health. In South America, many lakes and man made reservoirs are reaching hyper eutrophic levels owing to the discharge of nutrients, mainly nitrogen and phosphorus, from run-off and untreated domestic wastewater (SABESP/CNEC, 1986).

Table 4.2 Impact of Nitrates on health

High levels of nitrates in drinking water can lead to serious, even fatal, consequences in infants below six months of age. After nitrates enter into a baby's body, it reduces to nitrites, absorbed into the blood, and finally combine with haemoglobin, by which the oxygen transport capacity of the blood is severely hampered. This is called blue baby syndrome, which may lead to death.

Although the adults are not harmed by exposure of nitrates in the drinking water, they are susceptible to other type of nitrate hazard. Nitrites formed from the reduction of nitrates can combine with other substances to produce nitrosamines and other powerful carcinogenic compounds. It has therefore been suspected that long term exposure to these compounds may increase the risk of various forms of cancer especially gastric cancer.

Sources : *Nitrates, nitrites and N-nitroso compounds*, WHO, 1978
Unwelcome harvest: agriculture and pollution, Conway & Pretty, Earthscan, 1991
Adopted from : WHO, 1992.

The agriculture run-off can increases the concentration of pesticides in rivers, lakes and groundwater aquifers. Uncontrolled practices make this situation more alarming in developing countries. For instance, in countries like Colombia, Malaysia, and Tanzania, the levels of dieldrin in drinking water are much higher than the WHO guideline. In Colombia the levels of DDT are also higher than the WHO guideline value for drinking value (WHO, 1992).

The contamination of rivers, lakes and seashores by liquid wastes arising from poor sanitation systems can have various types of environmental impacts. Fisheries can be damaged and the livelihood of peoples who rely on fishing may be threatened. This type of phenomenon are reported from India, Malaysia, Dakar, and China (WHO, 1992). Some other examples of water pollution is shown in Table 4.3.

Table 4.3 Example of water pollution in developing countries

INDIA
Of India's 3119 cities, only 209 have partial sewerage treatment facilities and 8 have full facilities. On the river Ganges alone, 114 cities each with 50,000 or more population dump untreated sewage into the river. The Hooghly estuary receives untreated industrial wastes from more than 150 major industries in calcutta, in addition to 361 raw sewage outfalls. The Yamuna river receives 200 million liters of untreated sewage each day.

SHANGHAI (CHINA)
Some 3400 million liter of industrial and domestic waste go into the Suzhou Creek and the Huangpu river. It is virtually the open sewer for the city, as a result, the Huangpu has essentially been dead since 1980. The normally high water table also means that a variety of toxins find their way into groundwater and contaminate wells, which also contribute to the city water supply.

ALEXANDRIA (EGYPT)
Industries in Alexandria account for around 40% of all Egypt's industrial output and most discharge untreated liquid wastes into the sea or into lake Maryut. As a result, in the past decade, fish production in lake Maryut declined by some 80%.

Adopted from : WHO, 1992, based on
India: Center for science and environment, *The state of India's environment 1982: a citizen's report*, Delhi, 1982; Shanghai: Sivaramakrishnan & Green, *Metropolitan Management–the Asian experience*, Oxford university press, 1986; Alexandria: Hamza, *An appraisal of environmental consequences of urban development in Alexandria*, "Environment and Urbanization", 1 (1), 1989.

The sight, smell, taste, and even the feel of water is affected by chemicals contained within it. The chemistry of water can lead to disease either if there is an absence of a necessary constituent or, more commonly, if there is an excess of a harmful chemical. These diseases are clearly not infectious and are prevented simply by adding the chemical which is deficient or removing the chemical which is harmful. For communities which take water from a piped and treated source, it is quite easily possible that the chemicals may be added or removed at the treatment plant. However, these can be serious problem for the communities that use untreated supplies, such as most villages in developing countries. If they lack a necessary chemical it would be extremely difficult to add it to the water and, since the water is untreated, it is impossible to remove a harmful chemical pollutant. This is potentially serious if it causes the rejection of a ground water source of good microbiological quality with unpleasant taste or appearance, in favour of a surface water source of poor microbiological quality.

Water chemistry and disease may be considered under three headings : the absence of necessary chemicals, the excess of harmful organics, and the excess of harmful inorganics (Cairncross & Feachem, 1993).

The absence of essential substances in water is not generally a problem because there are alternative sources of these substances in food. Iodine deficiency in water, for instance, has to occur in association with iodine deficiency in the diet before widespread goitre is likely to result. This can be controlled by the introduction of iodized salt and injections of iodized oil. A deficiency of fluoride in water and diet can cause poor growth of bones and teeth in the young.

Some organic compounds, or groups of compounds, are known to be either toxic or carcinogenic, or to produce odors or tastes, sometimes after reacting with chlorine used for disinfection. Most of the toxic substances are pesticides. Others include PAH (polynuclear aromatic hydrocarbons) and THM (tri halo methane).

Harmful inorganics are of greater potential risk out of the three possible types. A number of metallic ions are known to cause metabolic disturbances in human by upsetting the production and function of certain enzymes, or to cause a variety of other toxic effects. Antimony, arsenic, barium, beryllium, boron, cadmium, cobalt, lead, mercury, molybdenum, selenium, tin, uranium, and vanadium are all known to cause some disorder in human body and all these can be uptaken by water. A more significant problem in developing countries is the effect of salts in ground water. Chlorides and sulphates make the water unpalatable, and so leading people to use surface water which is more likely to be bacteriologically polluted. High intake of sodium chloride has a link with high blood pressure. Although a deficiency of fluoride is implicated in tooth decay, high concentrations of that have been associated with mottling of tooth enamel and very high concentration can ultimately lead to stiffness and pain of the joints, and skeletal deformities. Nitrate concentration is potentially hazardous to health. This was described in table 4.2.

4.4 Communicable diseases associated with water

For a improved community health, especially in the developing world, control of infectious diseases is a vital. Although most of these have now been brought under control or even eliminated in the industrialized countries, they are still the principal cause of ill-health among the world's poor.

An infectious disease is one which can be transmitted from one person to another or, sometimes, to or from an animal. All infectious diseases are caused by living organisms, such as bacteria, viruses, or parasitic worms, and a disease is transmitted by the passing of these organisms from one person's body to another.

During the transmission process, the organisms may be exposed to the environment, and their safe passage to the body of a new victim is then vulnerable to changes in the environment. Environmental health engineering therefore seeks to modify the human environment in such a way to prevent or reduce the transmission of infectious diseases.

Most of the diseases associated with water are communicable in nature and basically they are caused by various micro organism like bacteria, viruses, protozoa and helminths. Most water related disease causing microorganisms, called pathogens, come from animal or human excreta, basically faeces, and occasionally urine. The most common route of pathogen attack is fecal-oral contact established by ingestion with food or water and by conveying to the mouth with contaminated fingers or utensils. Once ingested, most of them multiply in the alimentary tract and may cause disease in the host. These will then excreted from the body mainly with the faeces. Without proper sanitation, they find their way into other water bodies, and without safe water supply, from there they can again infect other people. Many of the pathogens can even survive for a long period outside the hostbody. Thus, they can survive in human sewage and occasionally in the soil and be transmitted to water and foodstuffs. Sometimes they even transmitted by vector. These diseases start their journey from an infected individual to a new victim when the causative agent is passed in the excreta. Therefore the collection, transport, treatment, and disposal of excreta are of the utmost importance in the protection of the health of any community.

Bradley suggested that diseases associated with water can be classified in four categories based on the role of water in disease transmission (White, 1972).

Water-borne diseases: This happens when water drunk or used for the preparation of food is contaminated by human or animal faeces or urine containing pathogenic micro organisms. However, sometimes direct fecal -oral cycle, food contamination or contact of abraded skin with infected water also take place. Potentially water-borne diseases include the classical infections, notably cholera and typhoid, but also include a wide range of other diseases, such as infectious hepatitis, diarrhoeas, and dysenteries.

It is very important to note here that, even a disease is labelled as a 'water-borne', that does not necessarily describes its usual or even its only means of transmission. Although the epidemics of water-borne diseases are largely caused by inadequate sanitation, all water-borne diseases can also be transmitted by any route which permits fecal material to pass into the mouth, for instance via contaminated food.

Water-washed diseases : People can be infected from diseases due to use of infected water for domestic purposes other than drinking and due to unhygienic handling of safe water. Scarcity and inaccessibility of water make washing and personal cleanliness difficult and infrequent. All water borne diseases can also be water washed diseases, however, this category also includes some vector borne diseases. A water washed disease may be defined as one whose transmission will be reduced following an increase in the volume of water used for hygienic purposes.

Water washed diseases are of three main types. Firstly, there are infections of the intestinal tract, such as diarrhoeal diseases, which include cholera, bacillary dysentery, and other diseases previously mentioned under water borne diseases. These first sub group are all fecal-oral in their transmission route and are therefore potentially either water borne or water washed. A number of investigations have shown that (Cairncross & Feachem, 1993) diarrhoeal diseases, especially bacillary dysentery (shigellosis), decreased with the availability of water used but did not decrease significantly with improvements in the microbiological quality of the water.The conclusion is that these diarrhoeal diseases, although potentially water borne, were in fact primarily water washed in the communities studied, and were mainly transmitted by fecal-oral routes which did not involve water as a vehicle.

The second type of water washed infection is that of the skin or eyes. Bacterial skin sepsis, scabies, and fungal infections of the skin are extremely prevalent in many hot climates, while eye infections such as trachoma are also common and may lead to blindness. These infections are related to poor hygiene and it is to be anticipated that (Cairncross & Feachem, 1993), they will be reduced by increasing the volume of water used for personal hygiene. However, they are quite distinct from the intestinal water washed infections because they are not fecal-oral and cannot be water borne. They therefore relate primarily to water quantity and are not significantly related to water quality.

The third type of water washed infection is also not fecal-oral and therefore can never be water borne. These are infections carried by lice which may be reduced by improving personal hygiene and therefore reducing the probability of infestation of the body and clothes with these arthropods. Louse-borne epidemic typhus is mainly transmitted by body lice, which can not persist on people who regularly launder their clothes. (Note that these are not the same as head lice.) Louse borne relapsing fever may also respond to changes in hygiene linked to increased use of water for washing.

Water-based diseases : Water provides the habitat for intermediate host (water snail or other aquatic creature), in which some parasites pass part of their life cycle. Later the infective larval forms of these parasites released in the fresh water and find their way to humans by boring through skin, being ingested through water plants or fish, eaten raw or inadequately cooked, and ofcourse, being swallowed. All these diseases are due to parasitic worms (helminths) which depend on aquatic intermediate hosts to compete their life cycles. The degree of sickness depends upon the number of adult worms which are infecting the patient and so the importance of the disease must be measured in terms of the intensity of infection as well as the number of people infected. An important example is schistosomiasis in which water, polluted by excreta, contains aquatic snails in which the schistosome worms develop until they are shed into the water as infective cercariae and re-infect human through skin. The life cycle of schistosome worms is shown in the fig. 4.4.

Another water based disease is Guinea worm, which is found in most of West Africa, and has a unique transmission route (fig. 4.5). The mature female worm, about 0.5 m long, lies under the skin, usually on the leg, and creates a painful blister. When this blister is immersed in water or water is splashed onto it, as is often done to soothe the pain, the worm releases thousands of microscopic larvae. It the larvae are washed into a pond or shallow well, they are eaten by cyclopoids, which then become infected, and they develop inside these new hosts. Cyclopoids are tiny crustaceans that are found in many small bodies of water. They are only 0.8 mm long, and so are easily consumed inadvertently in water from an infected pond or well. Infected cyclopoids tend to sink to the bottom, so the risk is greatest when only a shallow depth of water remains. The cyclopoids are not dangerous to drink, but any *Dracunculus* worms they contain will develop further in the human host and any fertilized female worm will make its way to the legs and form a new blister a year later, ready to start a new cycle. Although a water based disease, Guinnea worm is the only infection which is exclusively transmitted in drinking water.

The other diseases in this category are acquired by eating insufficiently cooked fish, crabs, crayfish or aquatic vegetation. They are clearly unrelated to water supply, but they may be affected by excreta disposal.

Water-related vector borne diseases : Water may provide a habitat for water related insect vectors like mosquitos and flies. Although some of the vectors prefer relatively clean water, most of them prefer highly polluted water like flooded pit-latrine or muddy swamps. Malaria, yellow fever, dengue, and onchocerciasis (river blindness), for example, are transmitted by insects which breed in water while West African sleeping sickness is transmitted by the riverine tsetse fly which bites near water.

Table 4.4 lists some of the water related diseases and estimates their impact. The water related diseases are mainly concentrated in the developing countries, and within developing world, among the poorer population group. Nearly half of the population in developing countries suffer from health problems associated with water. Among them, water-borne diseases are the largest cause for infant mortality in developing countries (3 million deaths per year; WHO,1995) and second only to tuberculosis for adult mortality. It is important to note here that only a few fatal cases of waterborne diseases are now recorded in developed countries. The only reason behind this is the provision of safe water, proper sanitation and adequate personal hygiene. Hence the situation of the developing countries can be improved with proper water supply and sanitation.

Table 4.4 Examples of water-related diseases with their impact on health

Diseases	Impact
Water-borne and water-washed	
Diarrhoeal Diseases, under age 5	3 million death, 1.821 billion incidence
Cholera (official report only)	6,800 death, 380,000 incidence
Enteric fevers (paratyphoid, typhoid)	No figures available
Poliomyelitis	5,500 death, 110,000 incidence
Ascariasis (round worm)	60,000 death
Water-washed	
Skin and eye infections	
Trachoma	No figures available
Leishmaniasis	0.197 million death, 7.2 million incidence
Other	
Typhus fever (rickettsiosis)	No figures available
Water-based	
Penetrating skin	
Schistosomiasis	0.2 million death
Ingested	
Dracunculiasis (guinea worm)	2 million incidence
Water-related vector	
African trypanosoiasis (sleeping sickness)	55,000 death
Malaria	2 million death
Lymphatic filariasis	43 million disabled
Onchocerciasis (river blindness)	35,000 death
Dengue fever	23,000 death, 560,000 incidence
Yellow fever	30,000 death, 200,000 incidence

Source : WHO, 1995

The environmental strategies for disease control which are appropriate to water related diseases are shown in table 4.5.

Table 4.5 The preventive strategies for water related diseases

Transmission route	Preventive strategies
Water borne	Improve quality of drinking water Prevent casual use of unprotected sources
Water washed	Increase water quantity used Improve accessibility and reliability of domestic water supply Improve domestic and personal hygiene
Water based	Reduce contact with infected water Control snail populations Reduce contamination of surface waters
Water-related vector	Improve surface water management Destroy breeding sites of insects Reduce need to visit breeding sites Use mosquito nettings

Source : Cairncross & Feachem, 1993

A classification of the water related diseases from the environmental health aspect is given in table 4.6.

Table 4.6 Environmental classification of water related infections

Category	Infection
Fecal-oral (water borne or water washed)	Diarrhoeas and dysenteries Amoebic dysentery, Cholera, E.Coli diarrhoeas, Rotavirus diarrhoeas, Salmonellosis, Bacillary dysentery Enteric fevers Typhoid, paratyphoid Poliomyelitis Hepatitis
Water washed	Infectious eye and skin diseases Other Louse-borne typhus, relapsing fever
Water based	Penetrating skin Schistosomiasis Ingested Guinea worm (Dracunculus), Liver fluke (Clonorchis), Fish tapeworm (Diphyllobothriasis), Intestinal fluke (Fasciolopsis), Lung fluke (Paragonimus)
Water related insect borne	Biting near water Sleeping sickness Breeding in water Filariasis, Malaria, River blindness, Yellow fever, Dengue

Source : Cairncross & Feachem, 1993, and Feachem, et al., 1983

4.5 Water and sanitation

Sanitation, as defined in the "Glossary : Water and Wastewater Control Engineering" (Glossary, 1981), is *a general program of environmental health designed to provide a safe source and safe distribution of potable water and proper collection of wastewater.* However, with the ever increasing concern on environment, the scope of sanitation is also multiplying. It now envelops water supply, excreta disposal, grey water treatment, drainage, solid waste management, chemical safety, food safety, vector and rodent control, indoor air pollution, radiation control, etc. However, relation of water with the sanitation is almost inseparable.

Estimates of the numbers of people lacking access to safe and sufficient water supplies and adequate sanitation can testify about the numbers of people at risk from water related diseases. Safe and sufficient water supplies and adequate sanitation would reduce infant mortality by more than 50% and prevent a quarter of all diarrhoeal incidence (Esrey, 1990; WASH technical report). Similarly it will reduce the morbidity caused by the water related diseases, in the range of 40 to 100% (WHO, 1986). Increasing the supply of water would greatly reduce the incidence of water-washed diseases. Improved sanitation would disrupt the cycle of many water related diseases.

As mentioned in Chapter 2, about 1500 million people lack access to safe water supplies and 2450 million people lack adequate sanitation. It was also stated that the situation in the rural area is more grave than the situation in urban areas in the developing countries. However, these figures for the number of population inadequately served with water and sanitation are likely to understate the problem.

Many urban centers in the developing world have no sewerage system at all, and most human excreta and household wastes finally end up untreated, in rivers, canals and other waterbodies. For the cities which have some sewage disposal system, this system usually serve a small proportion because of high system cost. Alternative appropriate technologies with low cost per beneficiaries, are essential to address this problem.

Another problem is the lack of attention given to the quantity of water available to the users. For instance, the availability of a water tap or tubewell within 100 meters of a household is often considered adequate by many organization, but it is not necessarily adequate for the water needed for washing, cooking, and personal hygiene.

Moreover, official figures for the numbers of people adequately served often overstate the number actually served. For instance, they may assume that all those with water taps in their settlements are adequately served, but there are often so few communal water taps that people have to wait for a long time in queues and this tends to reduce water consumption to below what is needed for good health. Piped water systems in many tropical cities also function only intermittently for a few hours a day, which makes it especially difficult for households relying on communal taps. The water in piped systems is often of doubtful quality because of contamination of old and leaky distribution pipes by groundwater and sewage. Many urban dwellers often draw water from piped distribution systems through illegal connection and these are often a major source of leak and pressure reduction. Leaky distribution mains presents an additional hazard when the water pressure is low, and pollution from contaminated groundwater or wastewater from leaking drains and sewers may enter through damaged joints or pipe fissures when the pressure drops (Cairncross, 1990).

Many households and settlements judged by official statistics as adequately served by public systems may resort to other water sources because of the problems mentioned above. Improvements in the quality of the water supply and in its availability are usually possible at relatively low cost, especially if optimal use is made of local resources and knowledge. In many instances cost recovery is possible. In cities where poorer households pay private water vendors relatively high unit prices for water, a proper piped water system can often replace the vendors and provide these households with a more economical and convenient supply at the same price as they previously paid to vendors (Adrianzen & Graham, 1974; and World Bank, 1991).

4.6 Infectious diseases and sanitation

A basic objective of proper sanitation is to keep the public health away from infectious diseases. For the environmental engineers, it is convenient to classify the relevant infectious diseases into categories which relate to the various aspects of the environment which can be altered by engineering. The infections are classified into four broad groups namely water related infections, excreta related infections, refuse related infections, and housing related infections. The water related infections are described in details in earlier article. Here the other type of infections will be looked upon briefly.

Excreta related infections

All the diseases in the fecal-oral category mentioned in the table 4.6, as well as most of the water based diseases and several others not related to water, are caused by pathogens transmitted in human excreta, normally in the faeces. Those of the excreta related diseases which are also water related can of course be controlled, at least partially, by improvements in water supply and hygiene. But these and other excreta related infections may also be affected by improvements in excreta disposal, ranging from the construction or improvement of toilets to the choice of methods for transport, treatment, and final disposal or re-use of excreta. To understand the effects of excreta disposal on these diseases, a further classification is required (Table 4.7).

Table 4.7 Excreta related infections : Classifications, transmission and control

Category	Infection	Transmission route	Control measures
1. Fecal oral, non-bacterial	Poliomyelitis Hepatitis A Rotavirus diarrhoea Amoebic dysentery	Person to person contact Domestic contamination	Domestic water supply Improved housing provision of toilet Health education
2. Fecal oral, Bacterial	Diarrhoeas and dysenteries Cholera, E. Coli diarrhoeas, Salmonellosis, Bacillary dysentery Enteric fevers Typhoid, paratyphoid	Person to person contact Domestic contamination Water contamination	Domestic water supply Improved housing provision of toilet Health education Excreta treatment
3. Soil-transmitted helminths	Round worm Whip worm Hook worm	Soil contamination Yard contamination	provision of toilet Health education Excreta treatment
4. Helminths, animal intermediate host	Tape worm	Soil contamination Yard contamination Fodder contamination	provision of toilet Health education Excreta treatment Proper cooking
5. Water based helminths	Schistosomiasis Liver fluke Fish tapeworm Intestinal fluke Lung fluke	Water contamination	provision of toilet Health education Excreta treatment Proper cooking Control of host animal
6.Excreta-related vector borne	Filariasis Category 1 & 2	Insects breed in fecally contaminated site	elimination of breeding site Use of net

Adopted with modification from : Cairncross & Feachem, 1993

The life cycle of round worm and whip worm is shown in fig. 4. 6. The influence of time and temperature on selected pathogens in excreta is shown in fig. 4.7. It is clear from the figure that the life expectancy of most of the pathogens are more than one month at temperature more than 35^{0}C. Hookworm is a kind of similar type of disease and the life cycle is shown in fig. 4.8.

For most of the excreta related diseases, an improvement in excreta disposal is only one of the several measures required for their control. Personal hygiene practice as another essential aspect.It is essential that people of all ages use the improved toilets and keep them clean. The disposal of children's excreta is at least as important as that of adults. Studies in the past have often failed to detect beneficial effects from improved sanitation because, although latrines were built they were not kept clean and were not used by children, or by adults when working in fields (Cairncross & Feachem, 1993).

Refuse related infections

Poor refuse disposal will encourage fly-breeding and may thus promote the transmission of fecal-oral infections. It can also promote diseases associated with rats, such as plague, salmonellosis, endemic typhus and rat bite fever. Some species of mosquitoes breed on the uncollected refuse or on wastewater near garbage and may transmit filariasis, dengue and yellow fever.

Housing related infections

The interaction between housing and human health can be mentioned as the table 4.8.

Table 4.8 Housing and human health

Aspect	Mechanism	Infections
Location	Housing close to high vector concentration	Vector borne diseases like malaria and sleeping sickness
Design	Promotes or hinders domestic hygiene	All fecal oral and all water washed infections
Internal pattern	Ventilation, air temperature, humidity	All respiratory infections like measles, mumps, meningitis, diphtheria, pneumonic plague
Precaution against vectors	Promotes or discourages rats, insects, etc.	Vector borne diseases
Construction material	Earth floors harbour eggs or larvae of intestinal worms and are conductive to many parasitic insects	Vector borne diseases Helminths

Prepared with information from Cairncross & Feachem, 1993

4.7 Vector and vector control

Certain diseases are transmitted by some particular arthropod and other types of animal, and these animals are known as vectors. The most significant arthropod vectors are mosquitoes, flies, cockroaches, bugs, ticks and lice. Vectors may be mechanical or biological. A mechanical vectors simply transports pathogens on or in its body from one place to another. An example is the transportation of fecal pathogens by flies or cockroaches. A biological vector is actually infected by the pathogen, which develops or multiplies (or both) inside the body of the vector.

Rodents like rats and mice are mammals and also carry and spread diseases. Schistosomiasis is carried by an aquatic snail.

Mosquito borne diseases

Mosquitoes help spreading diseases to millions of people. The major diseases that can be spread by mosquitoes are malaria, dengue, yellow fever, filariasis and encephalitis. A good sanitation system and solid waste management can prevent the spread of diseases by controlling mosquitoes. There are many species and each mosquito species has marked preferences for particular target animals. Each species has a particular ecology, and control measures must be specific to the target mosquito. Mosquitoes lay their eggs in water, but different species have differing, and often very specific requirements for a suitable site.

One of the control measures is destroying of breeding sites either by drainage or by covering suitable pools with oil. Sometimes 'species sanitation' is practiced which involves the identification of the principal vector species in one locality and its breeding habits, and the implementation of control measures aimed to the specific species. Thus shade loving breeders were controlled by clearing vegetation and sun loving species were discouraged by planting. The last control method is the use of chemical insecticides or larvicides.

Fly borne diseases

House fly poses one of the greatest public health hazard. They can spread typhoid fever, dysentery, diarrhea, sleeping sickness, onchocerciasis and many more. It is necessary to have safe sanitation and proper solid waste management to prevent the direct contact between the germ of the diseases and flies. The fly has a hairy body and sticky padded feet. A single fly may carry as many as 6,500,000 microorganisms (Salvato, 1992). They can also carry bacteria in the digestive system.

Some of the diseases carried by flies are as mechanical vector and some are as biological vectors. Sleeping sickness (trypanosomiasis) and river blindness (onchocerciasis) are carried by biological way. Sleeping sickness is caused by tsetse flies, found in Africa. Some of these flies are riverine and forest dwelling species. As it breeds and lives around bushes along the bank of streams, and bites people visiting the stream to collect water, the disease is thus potentially controlled if the need to visit breeding site is reduced by providing adequate water supplies in the village. This type of tsetse can also be controlled by clearing vegetation from the banks of streams. The other type breeds in open woodland and feeds mainly on game animals.

As tsetse flies do not travel far from their breeding places, one general control measure is to separate the human settlement from the woodland. Finally baited traps can also be used to control tsetse flies. River blindness is transmitted by the blackfly, which usually lays its eggs in fast flowing and well-aerated streams. Large scale control is possible only by the application of larvicides to the streams and rivers of a whole basin or area.

Flies of many species can carry fecal material in or on their bodies and thus transport pathogens contained in animal or human faeces. They provide another route for the transmission of fecal-oral infections.Flies frequently lay their eggs in excreta, and transmission is most probable when a fly visits human food having recently visited excreta. Housefly control by DDT spraying has been successful in the past but many flies are now resistant. Sanitary methods are still the best and require the removal of all breeding sites such as exposed refuse, excreta, and poorly designed latrines. A degree of good housekeeping is also necessary like cleanliness and elimination of food.

Cockroaches

Cockroaches can found in most parts of the world and harbour in the cracks and crevices provided in and around human habitats. They also can spread diarrhea, dysentery, typhoid and cholera among many others. Since they can live on by eating various things and they can adjust with harsh condition, it is very difficult to get rid of them. However, the control strategies includes proper refuge storage, litter control, deprive of harbourage, proper food storage, and use of insecticides and traps.

Rodents

Rodents are an important part of vector and in addition to spreading diseases, they also destroy property, consume human food and frighten people. In some areas, rats destroy as much as one-third of entire harvest. They cause an estimated damage of $ 900 million in the USA alone (Salvato, 1992), with higher losses in the developing countries. Some of the major rodent-borne diseases are murine typhus, bubonic plague, leptospirosis, rat bite fever, salmonellosis, rickettsialpox, trichinosis and lymphocytic. There can be four ways to control rodents (1) eliminating sources of food, (2) eliminating breeding and nesting places, (3) rodent-proof construction of buildings, and (4) killing program.

A very common source of rodent food is garbage. To deprive the rodents from getting the garbage as food, garbage must be stored, collected and disposed in a sanitary manner. Another source is the human food. One must be very careful to make the food unavailable to rodents. Eliminating the breeding and nesting places of the rodents is a very effective way to control them. An open dump of solid waste provides a good living shelter for rodents. Proper storage and disposal of garbage including bulk items are essential. Most modern houses are rat-proof. However, an appropriate method have to be implemented in the houses in the developing countries which essentially lack these facilities. Sometimes, if all other way prove not sufficient, killing program is necessary. Some of the methods are natural like use of cat or trap, some other are chemical like use of rodenticides.

Snail

Schistosomiasis is being spread by four species of aquatic snail (trematode worms). The individual snail species prefer different habitats. One species prefer still or very slowly moving water, other can live in gently flowing water, yet another species are amphibious. Most of these have a capacity to survive dry periods, usually burrowing into mud. The way of infection is described earlier and the life cycle is shown in fig. 4.4.

Control measures may be grouped in the following way :

1) Treatment by drugs of infected persons to reduce the number of viable eggs being released into the environment
2) Reduction in the snail population by chemical molluscicides
3) Engineering and sanitation means like hygienic excreta disposal to prevent the release of eggs in the environment; and improved water supplies to reduce the need for contact with polluted water.

Fig 4.1 (WHO, 95)

Fig. 4. Global distribution of deaths by main causes, 1993

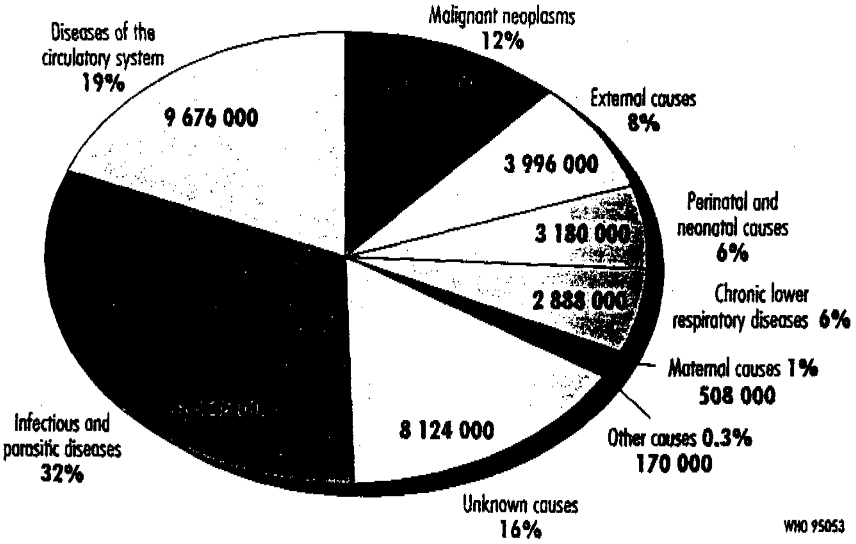
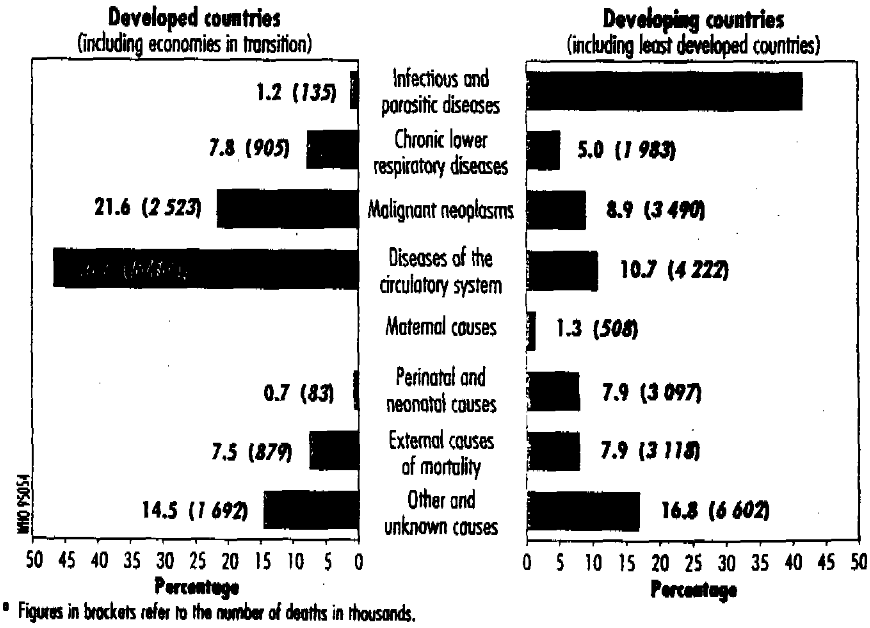


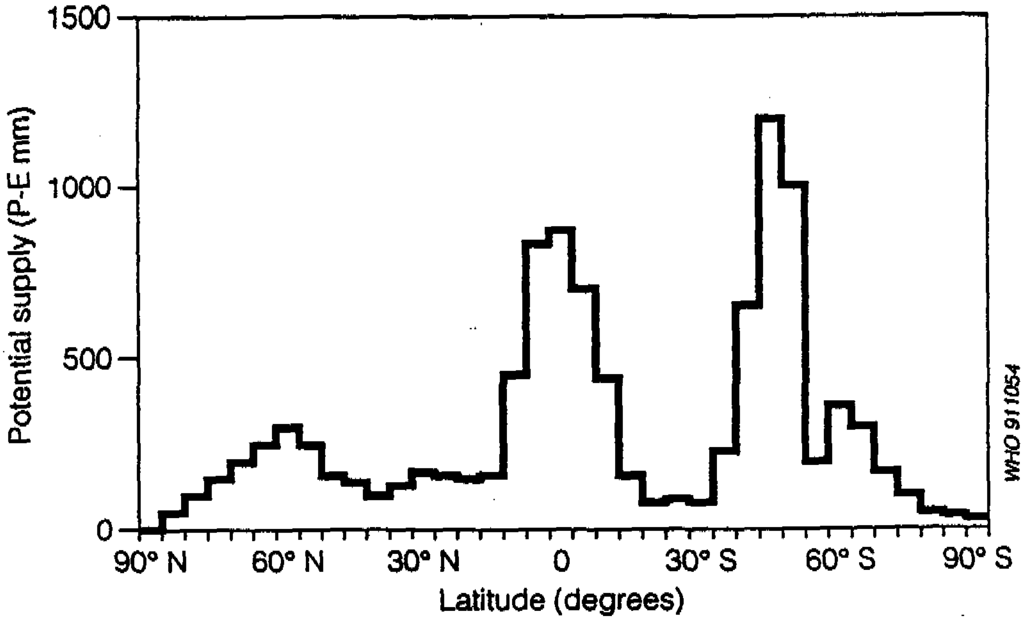
Fig. 5. Causes of death, 1993[a]



[a] Figures in brackets refer to the number of deaths in thousands.

Fig 4.2 (WHO, 95)

Box 30. Potential water supply (precipitation – evaporation) over the land surface of the globe



Source: Piper, B.S. *Water resources for irrigation.* Paper presented at the World Water '86 Conference, 14–16 July 1986. Institution of Civil Engineers.

Fig 4.3 (WHO, 92)

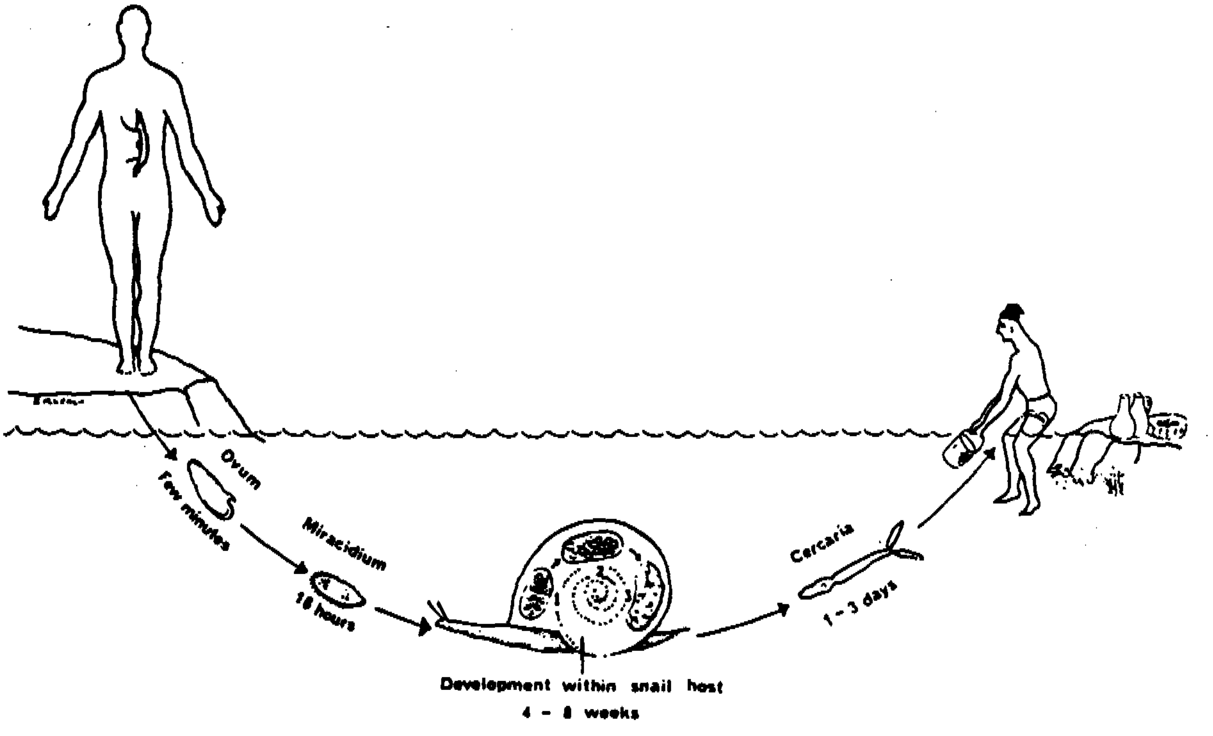


Figure 17.3 The life cycle of the schistosome worms which infect man
Source: From Jeffrey and Leach (1975). Reproduced by permission of Churchill Livingstone

Fig 4.4 (C & F, 93)

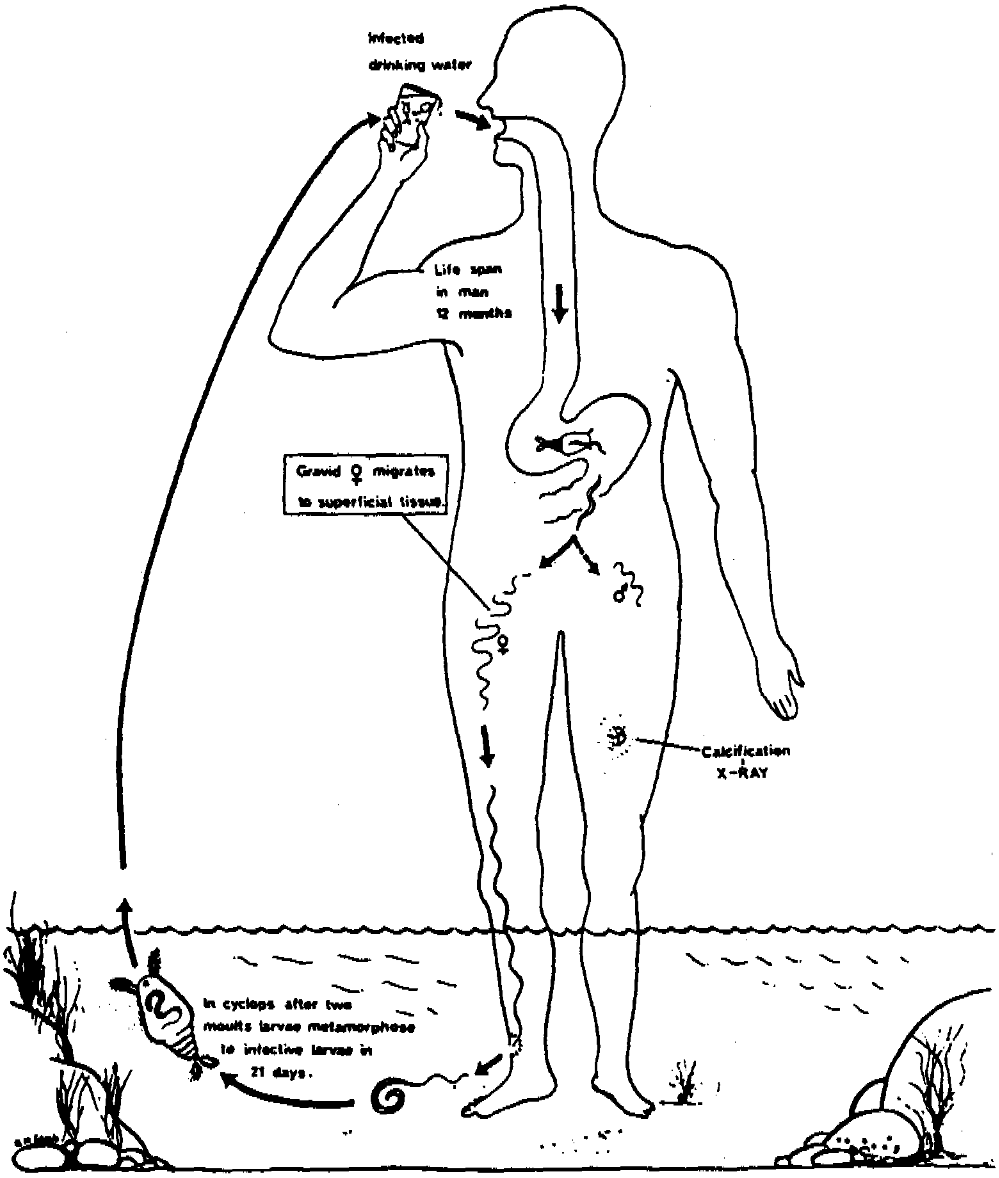


Figure D3 The life cycle of *Dracunculus medinensis* (the Guinea worm)
(*Source*: From Jeffrey and Leach (1975). Reproduced by permission of Churchill Livingstone)

Fig 4.5 (C & F, 93)

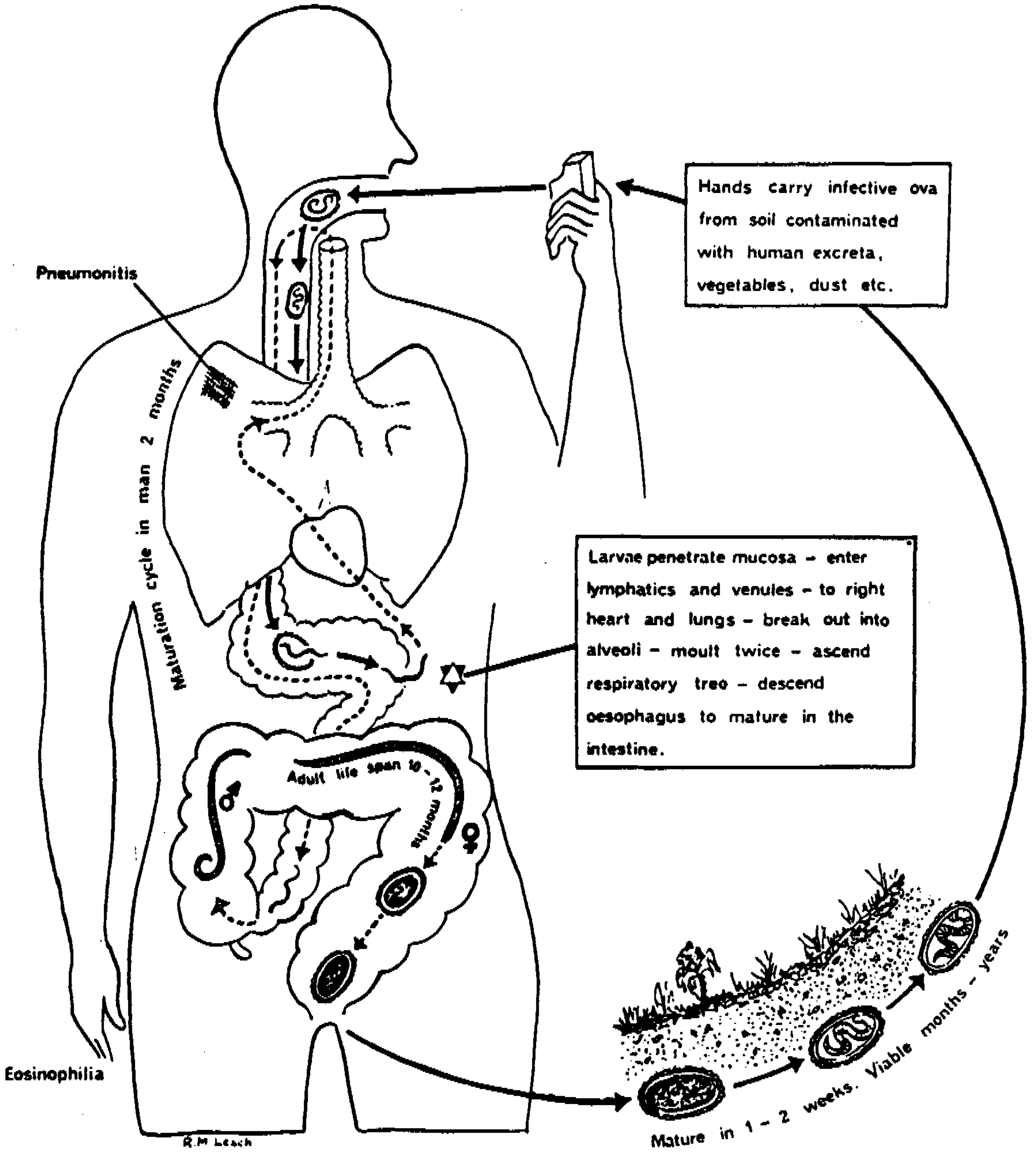


Figure D1 The life cycle of *Ascaris lumbricoides* (the round worm). *Trichuris trichiura* (whipworm) has a similar life cycle
(*Source*: From Jeffrey and Leach (1975). Reproduced by permission of Churchill Livingstone)

Fig. 4.6 (C & F, 93)

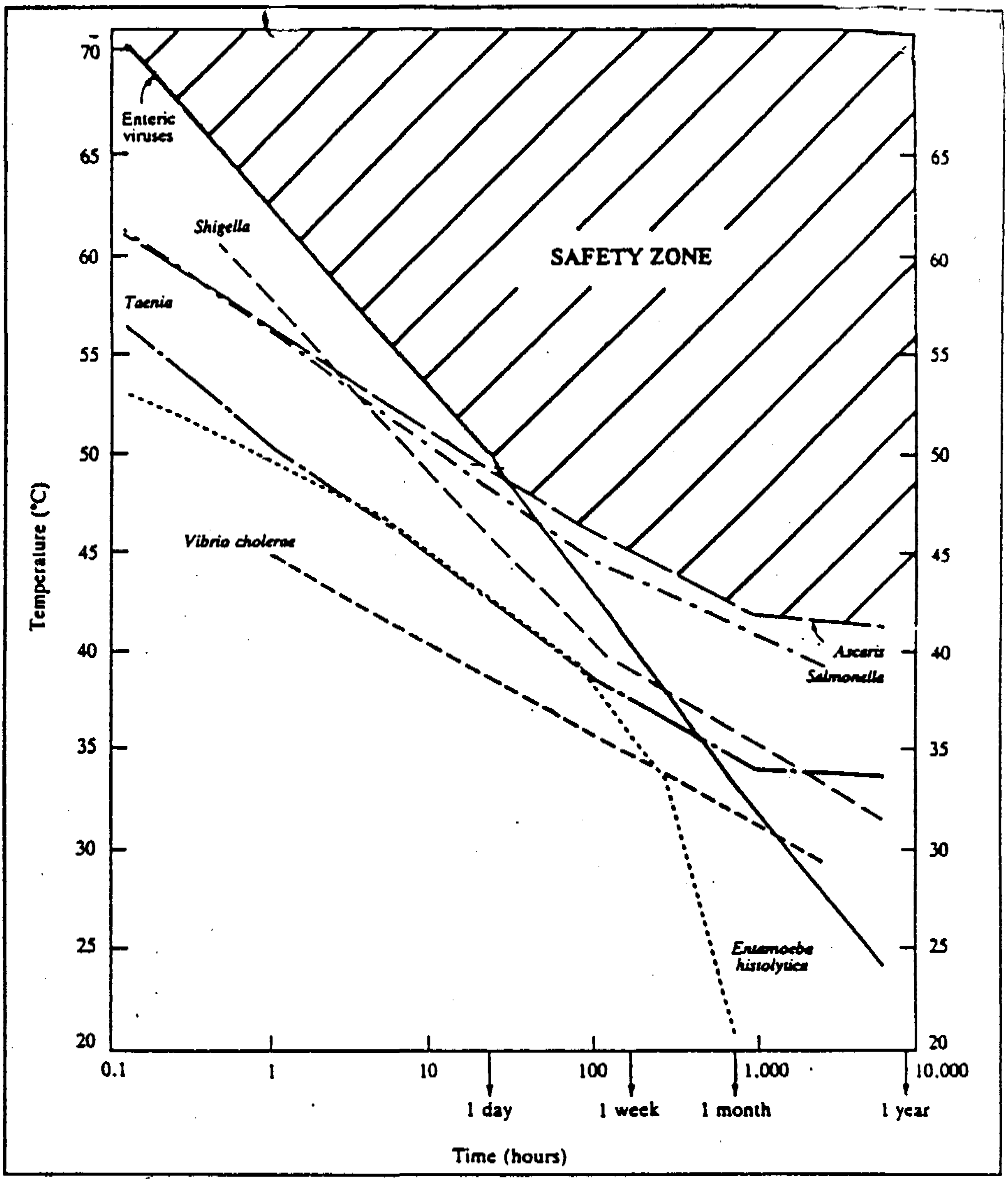


Figure 7.10 Influence of time and temperature on selected pathogens in night soil and sludge (*Source:* Feachem et al. 1983)

Fig 4.7 (C & F, 93)

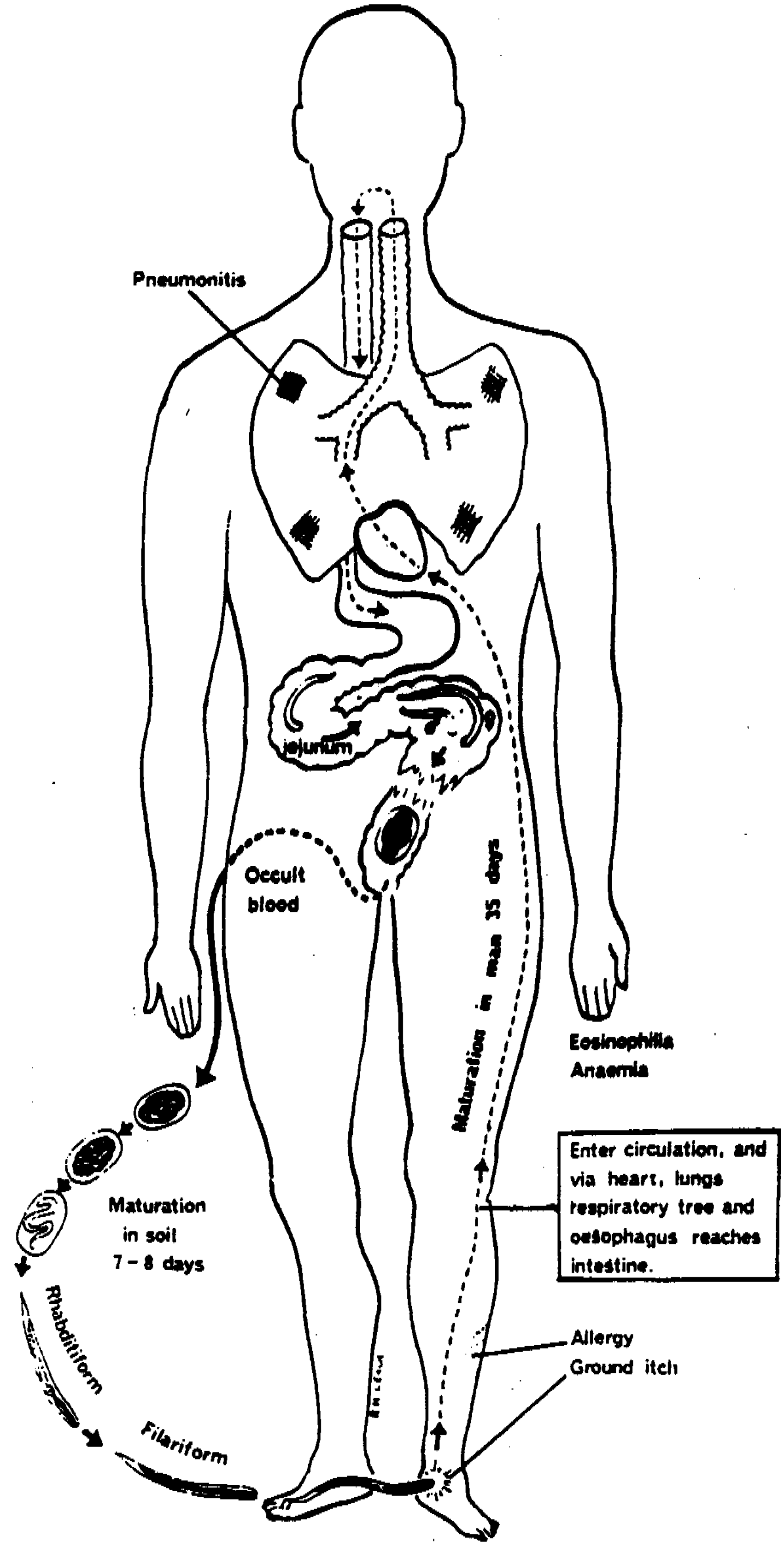


Figure D2 The life cycle of the hookworms (*Source*: From Jeffrey and Leach (1975). Reproduced by permission of Churchill Livingstone)

Fig 4.8 (C &F, 93)

Chapter 5 Aspects of appropriate technology

5.1 Introduction

The principal purpose of improving water supply and waste disposal is to help overcome the ill effect of debilitating and killing diseases that hinders developing countries to improve their well-being and productivity. Various studies and estimates indicate that in these countries disease typically takes up a large portion of the average person's potentially productive time and, in addition, affects risk-taking and initiative adversely, disrupts the education and nurture of children, stunts physical development, and causes vast suffering and hardship. Life expectancy in the developing countries is considerably less compared to the highly developed countries, mainly because of high rates of infant and early childhood mortality. In many areas diseases related to deficiencies in water supply and waste disposal are contributory causes of most infant deaths and account for a very large population of adult sickness.

Control of diseases related to water and sanitation requires ample quantities of safe water, good hygiene, and sanitary disposal of excreta. Safe drinking water alone is likely to have only a modest effect on disease, except in arid areas. Sanitary disposal of human wastes is generally necessary if contamination of water and food is to be eliminated and people are to be able to avoid direct contact with disease-producing organisms. Especially in tropical areas, where conditions for multiplication of these organisms are ideal, good personal and household hygiene are critical to control of diseases; education in health and hygiene that is tailored to local beliefs and conditions can contribute to the improvement of hygiene. Thus, a combined approach is required that includes ample water supplies,hygienic disposal of excreta, and education as to water-use practices and household hygiene wherever people have been unaccustomed to good water supply and sanitation. And from this approach, the concept of appropriate technology evolved.

Due to limited resources, many times it happen in the developing countries, that the desirable sanitation technology can not be implemented. Instead of waiting for the required fund available, it is more prudent to adopt some intermediate measures. In this way, better service is possible to provide to the consumer even with the limitation of fund. These technologies can be designed in such a way so that it can be upgraded to the higher technology in some future date.

The general feature of such step-wise improvement is that the health risks should be minimized first and environmental pollution should be taken cared of next. This is another criteria for the appropriate technologies.

5.2 Definition

It is very difficult to find out a definition of appropriate technology, which is accepted all over the world. The other related terms are low-cost technology, intermediate technology, environmentally sound & appropriate technology and socially appropriate technology. The definition of appropriate technology is different according to different agencies. Some of these are listed below.

Definition by ILO (Saito, 1980)

- It has big capacity to expand employment.
- It firmly associates with local industry and meets a demand from the market.
- It needs small investment corresponding to the local income level.
- It can use local resources.
- It has higher productivity compared to that of traditional local technology.
- Its maintenance is easy.
- It is socially acceptable.

Definition by AID (Saito, 1980)

- It maximize national income and products.
- It maximize the opportunity to get commodities.
- It maximize the rate of economic growth.
- It minimize the unemployment rate.
- It redistribute the wealth or income.
- It makes a contribution to the local development.
- It improves the balance

Definition by World Bank (World Bank, 1986)

An appropriate or alternative technology must :

- be effective : do whatever task it is designed to accomplish,
- be convenient : so people will be encouraged to use it,
- be acceptable to users : it should not conflict with people's beliefs and customs,
- use local materials and skills : a major way to lower costs and get people involved,
- be easily maintained : to avoid long breakdowns and allow local people to fix

equipment,

- be adaptable : so it can be improved or modified to suit changing conditions,
- be affordable : so people will be encouraged to install the technology.

WHO definition (WHO, 1987)

To be appropriate, a technology should :

- be as inexpensive as possible without jeopardizing the effectiveness of the improvements sought,
- be easy to operate and maintain at the village, community, or municipal level, and not demand a high level of technical skill or require a massive deployment of professional engineers,
- rely on locally produced materials rather than on externally provided equipment and spare parts, where there is practicable,
- make effective use of local labour, especially in areas where there is a surplus of labour,
- facilitate and encourage the local manufacture of equipment and parts under the leadership of entrepreneurs,
- facilitate the participation of village communities in its operation, and maintenance, and
- be compatible with local values and preferences.

Another WHO definition (WHO, 1990)

The appropriate technology element for water supply and sanitation is characterised by :

- socio-cultural appropriateness,
- affordability,
- ease of maintenance with the skills available in the agency or community,
- maximum use of locally available materials or spare parts,
- easily understood attributes,
- technical efficiency.

5.3 Necessity of appropriate technology

As indicated in art. 5.1, the appropriate technology is essential for the sustainable development of the developing countries. Many aid projects can not meet their target due to lack of adoptability of appropriate technology. This is also necessary to ameliorate various constraints. This is illustrated in table 5.1.

Table 5.1 Development constraints and their measures with appropriate technology

Constraints	Measures with appropriate technology
Environmental aspects	
Topography	Appropriate design criteria
Arid area	Alternative methods for WS & S
Frequent flood	Appropriate rain water elimination
Lack of space/land	Space saving design, advanced technology ex. Double floor sedimentation tank, Treatment in space ships
Low environmental capacity	Special treatment methods ex. tertiary treatment
Public health aspects	
Animals, vectors and rodents ex. animals scavenge solid wastes polluting drinking water	Use of appropriate design, control method
Endemic diseases	Special attention such as education, simple disinfection of drinking water
Safety of drinking water	Natural coagulants, various disinfection of drinking water, filtration or other treatment methods
Engineering aspects	
Lack of construction materials sand, stones, cement, metal plates	Locally available materials
Lack of tools ex. tools for bore hole latrines	Alternative technology
Lack of energy	Renewable energy sources
Difficulty in O&M ex. lack of skilled labourer	Simple technology ex. roughing filter + slow sand filtration run by the community
Low water table	Design criteria
Brackish water table	Sustainable use (avoid water mining) Alternative sources
Insufficiency in water resource	Special technology ex. rainwater harvesting, wastewater reuse
Houses on stilts	Special sanitation techniques
Too dense population ex. difficulty in constructing pipes	Appropriate design ex. shallow sewer

Managerial aspects	
Institutional aspects ex. weak WS & S sector	Intersectral coordination
Lack of funds	Low-cost technology Community participation for construction, operation, and maintenance
Lack of understanding of culture	Anthropological approach
Lack of human resources	Education
Low sustainability	Institutional and financial study
Low willingness to pay (especially in rural area)	Construction by subsidy or aid, O&M by beneficiaries
Squatting area (illegal settlements) difficulty in getting public sector assistance	Public toilet on the fringe

The poor, particularly the women and the children, suffer most from present deficiencies. They lack information on the effects of unsanitary conditions, and their access to safe water and waste disposal services is restricted. The pressure of population growth, moreover, is threatening even present unsatisfactory levels of health and hygiene. The productive potential of poor households, and particularly of the women in these households, is often reduced by the time and energy spent in obtaining water. In many rural areas, drawers of water, most of whom women, commonly have to walk one to five miles to the nearest sources of acceptable water, while in towns that have public standpipes to serve the poor quarters, women often have to wait in lengthy queues, sometimes for hours, to fill their buckets and pans. Only appropriate technology can provide the proper solution for these problems with a fraction of resources that required for the traditional solutions, more efficiently than their classical counterpart.

The rural area is overwhelmingly neglected sector. This situation has developed over the years not only because of distinct urban bias on the part of the planners but also as a result of prevalent political and institutional pressures. Furthermore, because of the low population concentration in villages, capital investments appear uneconomical. To revert this situation, appropriate technology is the only solution.

Again, the urban fringe area consisting of urban poor in squatter settlements, slums and shanty towns has been largely overlooked. In some ways they are even worse off than their rural counterparts. For example (World Bank, 1986), the official social survey of 1974 for the Tondo Foreshore, the largest slum and squatter settlement of metropolitan Manila in the Philippines, indicating that 63 percent of the residents bought water from vendors at a per capita cost which could be as much as three times higher than their more affluent counterparts, who receive more water of a better quality in the convenience of their homes.

Moreover, improving water quality via standpipes does not automatically improve personal hygiene practices which have developed over centuries. In very incidence where potable rural water supply schemes have been developed have provisions also been made for bathing and laundry facilities. People thus continue to use contaminated sources for such purposes, and these continue to remain sources of infection. This aspect need to be taken cared of before a marked decrease in water related diseases can be expected. Thus, the importance of educating the public about good hygienic practices can not be overemphasized. At present such services in rural areas are mostly non-existent, even for those households which are looking for information. All these aspects must include in the appropriate technology.

5.4 Selection of appropriate technology

Selection of an appropriate technology for a certain development project for a certain area is literally a very difficult job. It must come from the extensive experience and research. However, a list of principal actions which must complement standard practice to accelerate progress in providing water and sanitation services includes :

- Particularly careful attention must be given to the proper balance among water supply, waste disposal, and hygiene education.
- Results in research in appropriate technology must be disseminated to all to help them consider and analyze the alternatives of meeting the demands of the few at high standards or meeting the basic needs of the many at simple standards.
- Institution-building efforts should be strongly oriented toward the development of institutions and institutional hierarchies that can reach large numbers of communities and beneficiaries effectively.
- Increased attention should be given to the training of staff in developing countries for improvement of water supply and sanitation – not only technical and commercial personnel, but also promotion, health and extension works.

The process of selecting the appropriate technology begins with an examination of all of the alternatives available for improving sanitation. There will usually be some technologies that can be readily excluded for technical or social reasons. For example, septic tanks requiring large drainfields would be technically inappropriate for a site with a high population density. Similarly, a composting latrine would be socially inappropriate for people who have strong cultural objections to the sight or handling of excreta. Once these exclusions have been made, cost estimates are prepared for the remaining technologies.These estimates should reflect real resource cost, this may involve making adjustments in market prices to counteract economic distortions or to reflect development goals such as employment creation. Since the benefits of various sanitation technologies can not be quantified, the health specialist must identify those environmental factors in the community that act as disease vehicles and recommend improvements that can help prevent disease transmission. The final step in identifying the most appropriate sanitation technology rest with the intended beneficiaries. Those alternatives that have survived technical, social, economic, and health tests are presented to the community with their attached price tags, and the users themselves decide what they are willing to pay for.

The first step in community health is an accessible and safe water supply. Clean water helps to break the transmission routes of disease. The second step is a sanitary method of excreta disposal. Good sanitation facilities help control disease causing organisms. Hygiene education is the third step in community health and is just as important as the provision of clean water and sanitation. To select an appropriate technology, one have to consider all these three components. In addition, the technologies must be less expensive, requiring less time in planning and construct, requiring less water use, include education programs, make best use community participation and include O&M training.

In the selection process, various point should be considered. Some examples can be considered. For cost reduction, rainwater catchment tanks are made of bamboo-reinforced concrete in Thailand. Gravity water systems are convenient and the costs are low since most of the planning and construction can be done by community workers. The simple VIP (Ventilated Improved Pit) latrine is very effective to minimise flies and odors.

In the selection process, the institutional and financial issues are also very important. The important points are given in Fig. 5.1. The relation between the resource mobilization and the sustainability is shown in Fig. 5.2.

5.5 Examples of appropriate technology

Village level operation and maintenance (VLOM) type handpumps (UNDP, 1984)

VLOM pumps are those which (1) are suitable for maintenance and repair by trained village handpump repairs, including the below-ground components which can be pulled out of a well for maintenance by such repairers, and (2) can be manufactured in developing countries. They should be generally simple in design and fabrication as well as durable and robust. Parts which require periodic replacement have to be cheap and easily accessible. This type of project is now implemented in Ivory Coast, Malawi, Kenya, Bangladesh, Thailand and China.

Pump selection

Pump selection criteria would be quite different for the following two scenarios which represent two typical conditions. Scenario one applies to pumps suitable for the wells in the Sahelian region of West Africa, where the water table is deep. Most drilling is done in hard rock in remote and dispersed locations, with 500 or more users per well. This means that the cost of the well is high, that the pump will be heavily used, and the implied value of the pumped water is high. It calls for a very durable pump, possibly with a standby unit in case of major breakdown. A stock of frequently used spares should be kept with the pump to avoid the expense and delay of bringing in spare parts from a long distance. The local caretaker must be well trained and well equipped because the cost of calling in a central maintenance team is very high. Scenario two applies to densely populated areas with shallow water tables, where access to traditionally polluted sources are relatively easy. Each handpump serves a smaller number of people (50 to 200), and the total population to be served by a scheme is large. Cost savings for wells and pumps therefore critically affect the extent of service. Bangladesh and Thailand are examples of countries where such conditions prevail.

Changing customs

What seems like a 'low cost' latrine to the planner may prove to be a high cost latrine to local families if it takes a long time to clean, is difficult uncomfortable or embracing to use, or if it involves radical changes in customs or organization of family habits. A badly planned, badly constructed, badly maintained latrine can create far more serious problems than existed before it was built. Some low cost latrines are incapable of being cleaned properly. Their floors are of rough porous cement – ideal for harbouring roundworm or hookworm eggs. In some places, these diseases are more common in city people with latrines than in country-dwellers with no sanitation at all.

Invisible technology

The most impressive examples of this are probably to be found in China. Sanitation equipment in the countryside is still very crude, shallow pit latrines, bucket latrines and chamber pots emptied manually into buckets. All this would seem to be very unhealthy. Yet China has made achievements in reducing the incidence of excreta related diseases. They have achieved this by employing large numbers of people in sanitation teams to empty and clean latrines and to supervise the hygienic composting of wastes. In other words, better hygiene was achieved by strengthening the organization and discipline of sanitation rather than replacing the relatively primitive hardware. People may not have very good hardware, but they often have excellent software. Without respecting and taking advantage of the software, the hardware – however 'appropriate' in design – will always seem inappropriate to the people.

Case study 1 PATNA, INDIA (Charnock, 1984)

Patna has the reputation of being the dirtiest state capital in India. More than 25,000 poor people who previously defecated in streets and parks started to use a string of public toilets and baths set up by a NGO called Sulabh International. Although the technology used (pour flush twin pit water sealed latrine) was nothing new, its appropriate approach made it successful. The facilities had been built on land donated by the municipalities. The maintenance cost is covered by collecting a nominal fee, however, women and children were allowed to use for free. The local governments subsidize half of the cost, and convert the remaining sum into a loan payable in easy instalments. Its low cost and ow water consumption makes the Sulabh latrine a preferred alternative to sewage system or septic tank.

Case study 2 KISHI, SAVANNAH ZONE, AFRICA (Adeniyi et al, 1983)

Traditionally, people of this town used to defecate in the bush and the children used to defecate on the village refuge heaps. To improve the state of human waste disposal, public latrines were constructed. Units consisting of ten holes (five of men and five for women) were put at strategic points in the town such as market, town hall, etc. However, the project was not successful as the latrines were put in places that were too publicly visible, which was against the local custom. The small children did abandon the refuse heaps, but because they feared the deep holes, stopped short of the latrines, thereby littering the surroundings with feces and making the latrines even less acceptable to the public. A native health inspector finally realised the problem and suggested to place the latrines on the edge of town. This would offer the users the much desired privacy that was missing from the earlier ones.

CASE STUDY 3 Urban WS&S, Banjar Ketap (WHO, 1990b)

This city is a rapidly growing region of a South-East Asian country. A cop with the situation of rapid population increase a flexible mixed service level system were decided upon. A separate sewerage system with oxidation pond treatment is the mainstay of the sanitation provisions, with some allowance for construction of septic tanks in low-density areas. A looped network piped water supply will offer a mixture of service level, including house, yard and neighbourhood connections, and some public taps. The noteworthy point is the role of the users, who will help decide on the most appropriate levels of service and of payment of resources necessary to sustain them, which is an example of partnership approach. It shows that appropriate technology is important for even a major investment project.

CASE STUDY 4 Miluni : Peri urban water supply (WHO, 1990b)

It is a medium sized town in Southern Africa, which is growing fast but outside the planning restrictions. Because the new peri urban settlements are largely unplanned, house connections, as already provided in the official section of the town, would be difficult to introduce. Moreover, the peri-urban communities would not be able to afford the costs of such a level of service. An alternative acceptable to all is agreed upon : each cluster of dwellings will be served with a shared standpost or "neighbourhood tap". Because the water supplied is pumped and treated, the new user groups will have to cover the corresponding costs, with support by some small cross-subsidy from the house connection water rates in the town. A system is developed whereby each neighbourhood tap is metered, but where the cost of the water supplied is shared between different individual users in ratios determined by the user group itself, through its users' committee, comprising both women and men representatives.

CASE STUDY 5 Paichuri : Rural water supply (WHO, 1990b)

Paichuri is a small and remote village in the Indian sub-continent. The community meet their water needs from unprotected traditional wells, which frequently collapse. A discussion was held between the authority and the community for the betterment of the situation, and leads to agreement to jointly develop new community water supply facilities. Because of the limited financial resources of the community, the lowest level of service capable of providing safe water is jointly selected : protected wells with buckets and windlasses. To make the project a success, maximum community inputs were a necessity. Contributions of skill, labour and local materials (as well as some cash) are agreed upon with the community. External inputs to the operational phase are minimized by using simplified technology and training local community members in repair and maintenance work.

CASE STUDY 6 Septic tank sanitation : A rehabilitation project (WHO, 1990b)

Santa Martha is a provincial inland town in Latin America. Rapid expansion during the oil boom has led to a series of infrastructure improvements, including sewerage in some sections of the town. Where ground levels or scattered housing made sewerage impossible, systems based on individual septic tanks were often constructed by the municipality. The responsibility of maintenance was ill-defined. Cover slabs had become broken, the tanks were overloaded and were never desludged. Accumulated solids flow into the soakaway pits, causing them to block. This had led to a deteriorating public health situation. At that time, community opinion was strongly in support of action. The municipality initiated discussions with the neighbourhoods concerned. People were willing to pay towards an improvement in the situation, providing there is a clear division of responsibilities in the future. Following detailed agreements, a rehabilitation program was started in conjunction with some new construction. Householders are trained in the proper operation and maintenance of their septic tank systems. A small company was set up jointly by the municipality and a local organization. This will offer at cost support services (such as repairs and regular desludging of septic tanks).

CASE STUDY 7 Household sanitation : An upgrading project (WHO, 1990b)

Kusunga is a small fertile village in East Africa. Existing sanitation facilities are basic. About 70% of all households have a simple pit latrine with earth floor. To improve the situation, a program was developed for the upgrading os existing latrines, which were deep and odorous, to ventilated improved pit (VIP) standard. A maximized self-help program was planned. The individual householders carry out most of the construction activities, contribute local materials and pay in full for the additional materials needed. The agency provided all necessary outside materials at cost, but does not attempt to recover the costs of training the community in construction and maintenence skills, monitoring, or the costs of its hygiene education activities, which it will fund from an externally-funded institutional development project.

WATER SUPPLY AND SANITATION
INSTITUTIONAL AND FINANCIAL ISSUES*

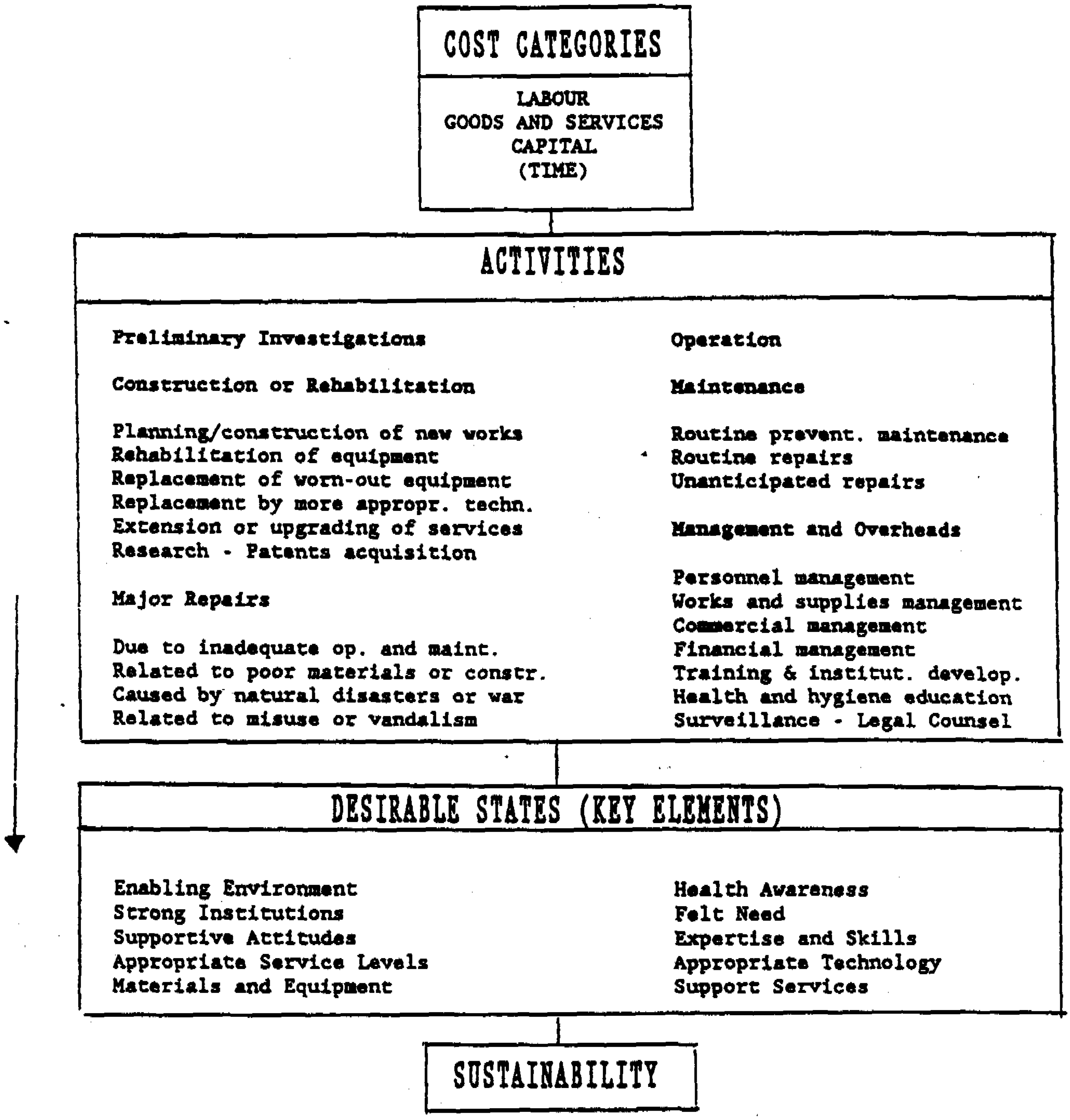
Sector Management Issues
Inter-ministerial coordination in planning
Institutional and human resources development
Agencies' autonomy (including over tariffs)
Agencies' regulations and monitoring
Activities that can be privatized
Activities that can be devolved on to communities
Funding for operation and expansion

Agency Management Issues
Financial planning and management information
Project preparation and appraisal
    .reduction of non-revenue water
    .efficient use of resources
    .preventive maintenance
Billing and collection
Other revenue sources
Consumers' willingness to pay (surveys)
Women's involvement in projects
Effective and efficient ways to serve the poor

Tariff Issues
Balance feasibility, efficiency, equity and expansion objectives against free services
Cover operating costs, and generally investment costs (charges to reflect value to the economy)
For the poor, willingness to pay may be high because the alternatives are unattractive
Stepped and differentiated tariffs
Metering
Cross-subsidization

* S. Ettinger and H. Garn
Senior Economists, World Bank.

Fig 5.1 (WHO, 90 b)



COST CATEGORIES

LABOUR
GOODS AND SERVICES
CAPITAL
(TIME)

ACTIVITIES

Preliminary Investigations

Construction or Rehabilitation

- Planning/construction of new works
- Rehabilitation of equipment
- Replacement of worn-out equipment
- Replacement by more appropr. techn.
- Extension or upgrading of services
- Research - Patents acquisition

Major Repairs

- Due to inadequate op. and maint.
- Related to poor materials or constr.
- Caused by natural disasters or war
- Related to misuse or vandalism

Operation

Maintenance

- Routine prevent. maintenance
- Routine repairs
- Unanticipated repairs

Management and Overheads

- Personnel management
- Works and supplies management
- Commercial management
- Financial management
- Training & institut. develop.
- Health and hygiene education
- Surveillance - Legal Counsel

DESIRABLE STATES (KEY ELEMENTS)

- Enabling Environment
- Strong Institutions
- Supportive Attitudes
- Appropriate Service Levels
- Materials and Equipment
- Health Awareness
- Felt Need
- Expertise and Skills
- Appropriate Technology
- Support Services

SUSTAINABILITY

Fig 5.2 (WHO, 90 b)

Chapter 6 Water Supply

6.1 Introduction

Water is essential for life and all human communities must have some kind of water sources. It may be dirty, it may be inadequate in volume and it may be several hours' walk away but, nevertheless, some water must have to be available. However, if we apply any reasonable criteria of adequacy – in terms of quantity, quality, and availability of water – then most people in developing countries do not have an adequate water supply. Compared with the urban population, more people in rural area lack the water supply. Even in the urban areas, some of the populations served by the stand posts. Many of these services are intermittent. Rapid population growth, particularly in urban areas, means that capacity must be increased simply to prevent the percentage served from falling.

6.2 Water quantity requirement

Depending on climate and work load, the human body needs about 3 — 10 liters of water per day for normal functioning (IRC, 1983). But to keep hygienic condition, more water is required. Part of this water is derived from food. The use of water for food preparation and cooking is relatively constant. The amount of water used for other purposes varies widely, and is greatly influenced by the type and availability of the water supply. Factors influencing the use of water are cultural habits, pattern and standard of living, whether the water is charged for, and the cost and quality of the water. It may be noted here, during emergencies, a minimum of 2 liters of water per person should be provided daily for drinking (IRC, 1983).

The use of water for domestic purposes may be subdivided in various categories :

- drinking
- food preparation and cocking
- vegetable garden watering
- stock watering, and
- other uses including waste disposal.

Individual house connections provide a higher level of service than a tap placed in the house yard (yard connection) which in its turn is generally preferred over a communal water point such as a village well or a standpipe. In the selection of the type of water supply, finance is usually an important factor, and the choice also depends on the location and size of the community, the geographical conditions, and the available water source.

In table 6.1, typical domestic water usage data are listed for different types of water supply systems. Usually water from the community water supply is also used for other than domestic purposes, and in such cases additional amounts of water should be provided for these categories. Table 6.2 gives indicative data.

It is very difficult to estimate accurately the future water demand of a community and the design engineer must exercise considerable judgement in his analysis.

6.3 Sustainability

The construction of new water supplies does not necessarily solve the problem, without the capability to operate and maintain the water supplies which have been built. Many countries have found that construction is relatively easy compared to the task of large waterworks running continuously, or of servicing hundreds of rural supplies scattered over the countryside. Besides, it is usually easier to obtain development finance for the construction of new supplies than funding for the recurrent expenditure of a maintenance program. Frequently, not enough money is available to cover operating costs and to carry out running repairs, let alone to carry out necessary preventive maintenance. Operation and maintenance require a long term commitment of money, staff, and institutions and can be a major drain on the resources of a developing country. Even where the money is available, there is frequently a shortage of technicians, and a lack of viable institutions able to carry out the job.

Water supplies for the larger cities often use sophisticated equipment for which spare parts – and skilled workers to install them – are not easily available. They require chemicals such as chlorine for their operation, which may become difficult or impossible to import. Poor pipe-laying, frequent illegal connections, and soil erosion in the dusty streets of these cities may cause frequent damage to distribution mains, and the public taps are rapidly worn out or broken by heavy use, or even stolen for re-sale. Water rates are extremely difficult to collect from more than a fraction of subscribes, and what can be collected is usually inadequate to cover the full costs of operation and maintenance.

Urban supplies may provide water of doubtful quality, and for only a few hours of the day, but only occasionally do they break down completely. In rural areas, however, problems of operation and maintenance have resulted in very high breakdown rates. In a typical developing country, a large portion of the rural community water supplies may be out of action, with no adequate organization able to repair and operate them. Some countries rely upon community involvement to maintain supplies, but even this good method has often failed due to inappropriate approach. Broken-down supplies represent an enormous waste of investment and, in many countries, the most economical way of bringing good water to more people is to repair the broken supplies rather than build more new ones. Operation and maintenance is the most deficient area in most water supply programs. It is very difficult and requires more efforts, not less, than construction if success is to be achieved.

6.4 Appropriate Technology

There is an utmost importance for the use of appropriate technology in the design of water supplies in the developing countries. Appropriate technology is the technology which fits the circumstances and thus appropriate. Technology must be appropriate in terms of cost in order that it can be afforded, it must be appropriate in performance so that it does the job required, and it must be appropriately simple so that it can be operated and maintained. Unfortunately, there are many cases of inappropriate technology and most of these arises from the unquestioning export of technologies from the developed world to the developing countries. Engineering should not involve the rigid application of certain standard designs. Good engineering involves the sensitive application of basic principles to a particular problem so that a solution is derived which is genuinely appropriate to the local context.

Rural areas are, generally, poorly served by comparison with urban areas, but major deficiencies occur in the case of the many underprivileged urban dwellers living in slums and squatter settlements. These poorer sections of the populations cannot possibly be supplied with costly systems. Thus the justification to adopt low cost appropriate technology is apparent.

For designing a water supply project, in addition to the cost, benefits must have to be considered. Engineers are usually accustomed to designing with cost in mind, but as far as water supplies are concerned it is not so common to evaluate benefits or to define exactly what objectives it is hoped to reach. This is largely because in the developed countries a high level of water services has come to regarded as essential, and to be embodied in codes of practice and legislation. There the available resources are generally adequate to provide this level of service, so that it has not been necessary to consider carefully whether the major objective is concerned with health, or convenience, or something else. However, for the majority of the world's population in the poor villages and urban slums of the developing countries, there is no possibility with the available resources of having the same high level of water provision enjoyed by the rich people, and so decisions about the level of service and the type of technology are not pre-ordained but are important aspects of the design. The types of water supply improvement with the most benefits, at a given limited cost, should be determined so that the anticipated cost-effectiveness of alternatives can be compared.

Benefits can be claimed by the three fields : production, health, and the saving of the time and energy in the water-collection process. Even, in some cases, production of relatively small amounts of good quality water for the domestic purpose is an achievement. Water quality is clearly important from health point of view. However, it seems that most endemic cases of fecal-oral disease are not water-borne but water-washed (Cairncross & Feachem, 1993). Insofar as they are water-borne, improvements in water quality will reduce their incidence. A more general benefit results from increased availability and accessability of water if it leads to an increase in the volume of water used for hygiene, as this affects all water-washed diseases. Observation of people's behaviour in various rural settings (White, 1972, and Feachem, 1978) suggests that when water is available within about 1 km or within half-an hour's return journey of the home, water use does not significantly increase when the distance or time is reduced, until it is less than 100 m. When the point is reached where a tap can be provided within each house or yard, water use may increase dramatically from 10–30 l to 30–100 l/person/day (Fig. 6.1). Quantity related health benefits are therefore most likely where traditional water sources are particularly far away, where queuing at the existing water sources is particularly time-consuming, or where water can be supplied to each household. The most immediate and easily measured benefits are the time and energy savings and their money value. These aspects are the most appreciated by the population. However, the magnitude of the time savings depends on conditions prevailing before installing the new water supply. In rural areas, a large amount of time may require to collect water due to the distance of the sources. In some urban areas, the time spent collecting water is due not so much to distance as to the long queues which form at water points. It is not usually practicable to predict how the time saved will be spent, but it represents a significant improvement in people's standard of living, and can be regarded as a benefit in itself. Reductions in the cost of water to the poor are also an important point. It has been estimated that 20–30% of the urban population of the developing world, mainly the poorest, buy water from vendors. Typically, these households spend one fifth of their income in this way (Cairncross and Kinnear, 1991). In fact, the amount they pay to informal water vendors in many cities is greater than the total revenue of the formal water agency – although it is often the agency's water which is being re-sold (Cairncross, S. & Feachem, 1993). The fact that poor housewives are prepared to pay for water delivered to their door, rather than collect it themselves, shows that they put a money value on their time. For appraisal of the benefits of a water project, a reasonable valuation of this time is the local unskilled wage rate (Churchill, 1987). Since this is not far from the value the poor themselves place on their time (Whittington, 1989), it can also be used to estimate their willingness to pay for the service.

6.5 Appropriate Management

Cost recovery, introduction of private sector, self-help, project evaluation and hygiene education are some of the aspects of appropriate management.

Cost recovery is essential for sustainability. Many poor people in the developing countries already pay substantial amounts to water vendors, so that a payment for a cheaper, more reliable water supply may represent a saving to them, not an extra charge. Payment of the full cost of water supply by the consumers brings several advantages Cairncross, S. & Feachem, 1993) :

- the rate of water supply construction is not limited by the budgets of governments and aid agencies,
- water supplies are more likely to meet people's real needs if they are built only when people are willing to pay for them,
- scare government funds are less likely to be used in providing luxury supplies for the urban middle class,
- local bodies can become the principal investors in local water supplies and keep a better eye on how effectively their money is spent than a distant government department.

Privatization of water supplies has many pros and cons.

- Privatization does not necessarily guarantee greater coverage or better cost recovery. Companies avoid serving poor communities if it is unprofitable, or they may exploit consumers or extract subsidies from governments.
- All-or-nothing in privatization may not lead to better service. Certain functions, such as design and construction, can be contracted out; others could be, such as financing, operation, and revenue collection can be kept in public hands.
- It is not only private companies which could take over some of government's work in the sector, local bodies such as residents' associations and cooperatives can also play a role.

Many governments feel that the task of building, and more particularly maintaining, thousands of scattered rural water supplies places an intolerable burden on their scarce resources. They have therefore turned to community involvement and self-help programs as a way of passing a share of the commitment to the beneficiaries of the supplies. This policy has been supported by the belief that community involvement stimulates a new sense of responsibility and dynamism in the community and leads to more rapid progress in rural development. There is a great deal of debate about the pros and cons of community involvement, and they need to be based on a very carefully worked-out policy.

Unacceptably high breakdown rates in many development scheme led to greater consciousness of the need for evaluation. International donor agencies have been especially active in supporting a number of evaluations of water supply programs, often in the form of epidemiological studies which seek to measure a health benefit. However, it is extremely difficult to draw a concrete conclusion from such kind of study, by a process known to statisticians as 'confounding'. More can be found elsewhere (Blum and Feachem, 1992). A more useful approach is set out in the World Health Organization's Minimum Evaluation Procedure (MEP) for water and sanitation projects (WHO, 1983). This approach is like a causal chain :

construction —→ functioning —→ use —→ benefits

A water supply cannot bestow benefits if it is not used. Nor can it be used it is not functioning. So the MEP approach is to look first at whether the water supplies are functioning, and whether they are being fully and correctly used. This can be done much more quickly and cheaply than epidemiological study, and will produce much more useful information for the program planners. If an increase in domestic water use is detected, there is a good chance that considerable health benefits will result, as most of the increase is likely to be used for hygiene purposes. If water use being observed, it may also be possible to collect information about the other major benefit — time saving. A comprehensive guide to evaluation of rural water supply programs is given by Cairncross et al (1980).

Studies of the health impact of water supply and sanitation improvements have generally found that changes in behaviour have played a central role. It is now widely believed that water supply and sanitation programs should be accompanied by hygiene education, to ensure that the greatest possible health benefits are achieved. A few points are note worthy.

- Participatory methods, involving discussions, are more effective than those in which an audience listens or watches passively.
- People are more ready to accept what they hear from neighbours and friends than from outsiders.

- Messages should build on existing positive beliefs and practices, rather than try to deny or suppress negative ones.

Program rather than projects (IRC, 1983) : The term project is used here to describe all the preparations for the construction of a single scheme (water supply system). A program is here understood to be an integrated group of continuing activities directed at the implementation of a water supply schemes. When planning water supply systems for rural communities, the approach should be that of a program rather than a project. For example, the number of different types of pumps used in a program should be kept to a minimum in order to reduce supply and maintenance problems. In the project approach, a pump would be selected to fit a technical specification, and the maintenance system would then be adapted to the pump's characteristics and service requirements.

Financial considerations : In urban areas, inhabitants have usually accepted the principle, or at least are familiar with the requirement that they must pay for the water. In small rural communities, the principle of paying for water is usually not widely accepted. People feel the water, like air, is a natural gift. Thus, developing financial schemes will require special consideration for rural water supply projects.

Training : It would be appropriate to recruit and train potentially good employees for both administrative and operational functions. Training should stress the practical aspects of the subjects covered.

Community involvement : Acceptance of a water supply system by a community is by no means assured. The users may not be satisfied by the supply provided, if it does not meet their expectations. If the installations are not accepted and supported by the community, they are likely to suffer from misuse, or even vandalism. Conversely, with proper consultation and guidance, people can be motivated to help in the planning, construction, operation and maintenance of water supply systems for their communities.

6.6 Rural water supply

Many rural water supplies in developing countries can be found as out of order. Very often the reason why a rural water supply project has been failed is linked with the managemental problems mentioned earlier, but there are usually technical reasons why it failed in the first place. These technical reasons may at first sight appear to be problems of poor workmanship, poor material and poor coordination. But such problems are almost inevitable in most developing countries. Good engineering requires designs which can be made to work, with the labor and materials currently available. For instance, the design engineer cannot usually rely on high standards of pipe-laying to regular slopes. The slopes on pipelines should be large enough to allow for air locks due to uneven gradient, and for errors in the original survey. This means that pipe sizes of a gravity-fed pipeline can be chosen from a table like Table 6.3 by a technician who would find a Hazen-Williams pipe flow chart or equation confusing.

If it is important for water supply technology to be chosen so that it can be made to work under the existing construction conditions, it is even more important that it should continue to work under the prevailing maintenance conditions. Water treatment plant, for example, generally requires a level of attention and skill in operation quite unattainable in a small community. Thus, it is always preferable to find a source of good-quality water and protect it from pollution, rather than to take water from a doubtful source and treat it. Pumps, too, of any kind, frequently break down in rural areas. Motorized pumps, especially, should only be installed where adequate arrangements have been made to pay for their running costs.

It is best to try to build a 'fail-safe' character into rural water supplies so that one small fault is not likely to put the whole system out of action. For example, a ring main is preferable to a 'dendritic' distribution system (Fig. 6.2), so that if a pipe is broken the whole community is not necessarily deprived of water. Again, a series of hand pumps on tube wells may have the advantage over a piped supply from a distant water source, because if one pump breaks down the villagers can continue to use the others until it is repaired.

As a general rule the cheaper and simpler the technology, the less maintenance it requires, the more reliable it is in practice, and the easier to repair under village conditions. The major exception is in the choice of hand pumps, where the more robust and reliable pumps are often more expensive and more difficult to repair; here the choice depends not only on technical considerations but also on factors such as whether maintenance is to be carried out by a village caretaker, a local mechanic, or a mobile team. Village Level Operation and Maintenance, known as VLOM, is generally preferable.

Institutional requirements will tend to be different in the rural scene than the urban localities. They need to be more community orientated. The lower the income level of the target beneficiary groups the more difficulties any project will encounter on its passage from concept to satisfactory continuous operation. For this reason, and despite their apparent technical simplicity, rural water supply or sanitation projects can be the most difficult for the engineer to bring to a successful conclusion.

The engineer , in dealing with projects for rural areas anywhere, obviously will depend on his technical expertise. However, he should look for assistance to other disciplines such as demography, sociology, and behaviourial science. He will certainly need the help of hydrologists, hydrogeologists, meteorologists, health workers, bacteriologists, and would do well to listen to agronomists and other workers in rural development.

The perceived needs of the rural communities may be different from those seen as priorities in the urban sanitation. Needs will vary as development proceeds. Water quality is not of first priority as more effective public health improvements derive from an adequate quantity for washing, even if it is poor quality. When available, quantities increase and distribution becomes more advanced, perhaps from standpipes to house connections; the expectations of quality will rise even though the need is the same and the provision of potable quality may be more difficult. Needs will vary according to the influence of all the physical, economic, social, and technical aspect specific to the location involved, and these will also affect the provision for those needs incorporated in a project.

It sometimes questioned whether studies are necessary before designing rural water supply and sanitation projects, as, certainly, much time and money can be and has been wasted on large scale feasibility studies and master plans. However, certain technical aspects of water and sanitation have to be checked specifically for each project, and each project must be related to its locality, both physically and socially. Studies should be as brief as possible and the written report concise. They should be constructed from a standard pattern, so that nothing is overlooked. Studies should not only precede design and implementation, but every project should also have an evaluation study after it has been operating for some time.

6.6.1 Sources of water

The first step in designing a water supply system is to select a suitable source or a combination of sources of water. The source must be capable of supplying enough water for the community. If not, another source or perhaps several sources will be required. The potential water sources include ground water, rain water, surface water, and sea water. The water on earth, including the above mentioned sources are in a state of continuous recycling movement and this is called the hydrological cycle (Fig. 6.3). Table 6.4 provides an overview of the average precipitation and evaporation rates for the various continents.

All rainwater contains constituents that are taken up or washed out from atmosphere. After recharging the ground surface, rainwater forms surface runoff or groundwater flow. It will pick up considerable amounts of mineral compounds and of organic matter. Table 6.5 shows the range of sources, together with the contaminants that may be present in each.

Because of the unreliability of treatment plant under most rural conditions, the best sources of water are those which do not need treatment. Rainwater collected from a metal or cement roof is relatively pure, and is of course available close to the users. However, many rural houses are roofed with other materials, such as thatch, and rainfall patterns may require large and expensive storage tanks to guarantee a supply all year round.

Surface water may be readily available and easy to abstract, but is typically very polluted. In some sparsely populated upland areas, streams may be of a quality good enough for domestic use, but in most regions streams, lakes, and ponds are subject to substantial fecal pollution.

Underground water can be found below the surface. The location of a suitable groundwater source may vary from a few feet to thousands of feet below. A porous stratum that stores water underground and yields the water is called an aquifer. Where it can be extracted with reasonable ease, ground water is normally preferable to surface water because it is purified by the filtering action of the soil through which it flows. Nevertheless, ground water in some areas may contain iron, manganese, salt, fluoride, or other substances which make its use undesirable or unpleasant, and the use of a surface source — a river, stream or lake — may be unavoidable. Even in these cases, a well beside the surface source usually gives fresh water and is to be preferred. Where it is not possible to locate a reliable year-round source of water within the village, a more distant source may be supplemented by a 'wet-season well' which, although it may not be in use in the dry season, at least supplies water during the rains, which is usually the period of greatest disease incidence.

Water source selection : The process of choosing the most suitable source of water for development into a rural public water supply largely depends on the local conditions. Possible sources of drinking water are listed in Table 6.6 with an indication of their suitability for supplying communities of various sizes. The sources are listed in order of probable purity, the sources of better quality water appearing first. The final selection of the source is made on the basis of an evaluation of the local situation, taking into account such factors as hydrological conditions, the quantity of water available, human activities and the implications of long term planning. Fig. 6.4 is a flow chart of source selection.

6.6.2 Rainwater catchment systems

Rainwater harvesting is the collection and storage of rain water on a natural or man made catchment surface. Catchments include rooftops, compounds, and hill slopes. Storage takes place in tanks, lined pits, behind small dams or in the sandy bed of a seasonal river. The system is suitable where rainfall is plenty and where neither piped water supply nor groundwater is available due to reasons like high salinity of groundwater, low water table, or scattered settlements.

This is an appropriate water supply technology. A typical system is illustrated in Figure 6.5. The advantages of this system are :

- the quality of rainwater is high,
- the system is independent, and therefore suitable for scattered settlements,
- local materials and craftsmanship can be used in construction,
- no running energy cost,
- ease of maintenance by the user,
- convenience and accessibility of water, time is saved in collecting water.

Some limitations of this system are :

- capital cost is high,
- the water available is limited by rainfall and roof area,
- mineral-free has a flat taste,
- mineral-free water may cause nutrition deficiencies.

The initial consideration of the feasibility of this system concerns water availability. The yield or supply of the system depends on how much rain falls during the year and the variability of the rainfall. So reliable rainfall data are required when determining the supply from the system. Cost of this system must be evaluated and compared with the costs of alternative water supply improvements. Once it has been tentatively established that it is technically and economically feasible to construct this system, the next step involves social and community assessment. This stage is critical for the success of the scheme. The details of the planning, designing and constructing of this system can be found in World Bank publication (1986).

Improved systems may have a first-flush device or detachable downpipe, excluding the first few liters of runoff during a rainstorm, which is generally most contaminated with dust, leaves, insects and bird droppings. An arrangement for diverting the first rainwater running from the roof is shown in the Fig. 6.6. Another arrangement is an under-ground storage tank receiving rainwater that overflows from a vessel placed above the ground (Fig. 6.7). In addition, the roof should be cleaned regularly to safeguard the quality of the collected rainwater.

Sometimes ground catchments are also used for collecting rainwater runoff. In that case, part of the rainfall will serve to wet the ground, is stored in depressions, or is lost through evaporation or infiltration into the ground. A considerable reduction of such water losses can be obtained by laying tiles, concrete, asphalt or plastic sheeting to form a smooth impervious surface on the ground. The portion of rainfall that can be harvested ranges from 30% for pervious, flat ground catchments, to over 90% for sloping strip catchments covered with impervious materials. Fig. 6.8 shows a typical ground catchment.

Storage facilities can be above-ground or below-ground. Whichever type of storage is selected, adequate enclosure should be provided to prevent any contamination from humans or animals, leaves, dust or other pollutants entering this storage container. A tight cover should ensure dark storage conditions so as to prevent algal growth and the breeding of mosquito larvae. There is a wide choice of materials for the construction of water storage containers, for example, wood, cement, clay and so on. Below ground facilities have the general advantages of being cool, less evaporation loss, and saving in space (Fig. 6.9). More examples of rainwater storage are shown in Fig. 6.10 to Fig. 6.12.

The storage tank may provide a breeding place for mosquitos, potentially aggravating health problems. To remove this problem, government of Thailand advised netting of tanks (IRC, 1992). If required, simple disinfection could be done before consumption of harvested water. During storage, the quality of the rainwater collected from the roof or ground catchment may deteriorate through the breakdown of organic material in the water, or through growth of bacteria and other micro organisms. Measures to protect the quality of the stored water include the exclusion of light from the stored water, cool storage conditions, and regular cleaning. Simple disinfection devices such as the pot chlorinator (see next article) may be useful in rainwater storage containers. Filtration of the collected water is also a desirable option (Fig. 6.13).

The boiling of water drawn from the storage tank before it is used for drinking or food preparation, would be desirable but it is not often practicable. In some places, a little bag containing a coagulant is suspended in the storage tank to flocculate the suspended solids in the water.

6.6.3 Ground water extraction by wells

Handpumps installed in wells, where groundwater of appropriate quality is readily available, provide one of the simplest and least costly means of supplying drinking water to rural and urban fringe areas. They also allow for maintenance by their users, reducing dependence on centralized maintenance systems. For community water supply systems, groundwater always should be the preferred source from the contamination point of view.

The advantages of this system are :

- Wells are a low-cost alternative of providing clean water. Foe example, the initial coat of a conventional water supply system (borehole with motor-driven pump or treated surface water conveyed by pipeline) is about 75 to 100 US$ per person. However, a hand pump based well system amounts to only 10 to 25 US$ per person (World Bank, 1986).
- Well based low cost option can offer the possibility of wide coverage.
- It requires simple maintenance compared to conventional system.
- As wells are point source supply, they are ideal for serving dispersed populations.
- The system can be constructed and maintained by the users.
- As ground water is generally pathogen-free, treatment is seldom required if the well is protected from surface pollution.
- As the income and aspirations at the community increase, wells can be upgraded with pumps to connect to a water distribution network.

The success of a well project depends to a large extent on good borehole design. The design of an efficient borehole depends on a thorough understanding of water occurrence and movement through rocks (the science of hydrogeology). The location of water bearing aquifer (water bearing ground formations, which hold most of their water in large pores), type of aquifer (confined or unconfined, Fig. 6.14 and 6.15), porosity of the water bearing formation (which is an index of how much water can be stored), storage coefficient (volume of water released from storage per unit surface area per unit change in pressure head), recharge, permeability (a measure of the aquifer to transmit water) and specific capacity (the yield divided by the drawdown) are some of the points to be considered while designing a well. Details can be found in any standard textbook on groundwater hydrology.

There are many different ways of constructing wells, each requiring different levels of investment and each appropriate to different hydro-geological, social and institutional environments. In general, wells can be divided into two broad categories; dug wells and drilled wells.

Dug wells are usually constructed in areas where the aquifer is shallow (groundwater is close to the surface). Depths of dug wells range from 5 to 20 meters. Particular sources of pollution (such as latrines, leaching pits, animal pens) must also be avoided. The minimum desirable diameter for a dug well is 0.8 meters. This makes it possible for at least one person to enter the excavation and dig (in the case of the hand dug well and which is usual). To prevent the walls of the dug well from caving in after excavation is complete, the well may need to be lined. Once lining is complete, the well will require protection from polluted water and foreign matter entering into it from the top part of the well. Dug wells have a unique advantage that they can be used in very low yielding aquifers because they are able to store water. Another advantage is that to lift the water even a bucket and rope is sufficient.

There are different drilling methods (Fig. 6.16) and equipment available for drilling boreholes. The diversity of equipment means there is no simple way to determine what drilling method is best suited for rural groundwater supply boreholes. A great deal depends on particular requirements.

- The driven tube well, in which a specially perforated or slotted tube known as a 'well point' is driven into the ground. It is expensive and normally lasts only 5 years. This is appropriate where water table is shallow, soil is soft and speed of construction is required.
- The bored tube well, which can be sunk by hand with an auger, a simple tool twisted by hand to drive it into the ground. Hand operated drilling equipment may be appropriate for boreholes up to 15 m deep and 200 mm diameter which a re drilled into unconsolidated (soft) formations.
- The jetted tube well is one in which a pipe is sunk into soft ground while the soil is loosen and removed by water pumped down (or up) the pipe. One modified version of this type is called 'palm and sludger', which is popular in Bangladesh.
- Cable-tool drilling rigs may be most appropriate for boreholes up to 50 m deep and 200 mm diameter which are drilled into unconsolidated and semiconsolidated formations.
- Small air flush rotary rigs may be most appropriate for boreholes up to 50 m deep and 200 mm diameter which are drilled into consolidated (hard) formations.
- A large multipurpose rotary rig could be justified for all holes, if cost, manpower, and back-up support are not constraints and speed is all important.

The construction of the various types of well is described in several technical manuals (FAO, 1977; Watt and Wood, 1977; Brush, 1979; Blankwaardt, 1984; IDRC, 1981) and so is not discussed here.

In situations where a thin water-bearing aquifer situated at a considerable depth, tunnels in consolidated ground and radial collector wells in unconsolidated ground may be considered (Fig. 6.17).

Pollution of open wells :

Tube wells are normally protected from pollution by a concrete slab, used as a base for the pump. Open dug wells are more liable to pollution. Some pollution type is described below, where only the first two normally affect tube wells.

- 1. Polluted ground water : This can result from location of the well too close to pit latrines, soakaways, or refuse dumps, whose influence may extend to about 10 m in a typical soil (Cairncross, S. & Feachem, 1993).
- 2. Water seepage from the surface : This may enter through the top few meters of the well lining if it is not sufficiently watertight near the surface.
- 3. The vessels used for drawing water : This can cause some pollution of the well. A improvement can be achieved by having a bucket permanently hanging in the well, probably from a windlass.
- 4. Rubbish thrown down the well : This can be completely prevented by having a permanent cover over the wall and install a pump.
- 5. Surface water : This may be washed straight down the well, if there is no headwall.
- 6. Split water : If there is no headwall, or if people stand on the headwall to draw water, water which has splashed against their feet can fall back into the well.

The most important which can be made to an existing is the construction of the well head consisting of a headwall and drainage apron to take split water to a soakaway. This single measure can completely prevent Guinea worm transmission at a well, and considerably reduce other health risks. The headwall can be fitted with rollers, a pulley, or a windlass to help people to pull up the bucket. A new type of arrangement can be found in Fig. 6.18. Better protection from pollution can be gained by covering the well with a concrete slab and fitting a hand pump (Fig. 6.19). A 'pot chlorination' type disinfection process can be also incorporated (Fig. 6.20). However, this will increase the cost of the well.

A well itself requires maintenance too. Dust, rubbish, and dead animals can accumulate remarkably quickly in the bottom of an open well. Apart from polluting the water, this accumulation in the well may reduce its depth or block it up. Ideally, any open well should be cleaned once a year in the dry season when the water level is low, and then heavily disinfected before being put back into service.

6.6.4 Protected springs

Springs, where they exist and have a reliable flow, can make ideal sources of water for a community water supply. No pumping is required to extract water from them, and all that is usually necessary to obtain water of good quality is to collect it and protect it from pollution. This is done by building a box of brick, masonry, or concrete around the spring so that water flows directly out of the box into a pipe without being exposed to pollution from outside (Fig. 6.21). One or more small springs may be connected to a single 'slit trap' (Fig. 6.22), where the slit is allowed to accumulate and is periodically cleaned out. Care is required to prevent surface water from running into the spring box and polluting the water in it.

Springs are found mainly in mountainous or hilly terrain. A spring may be defined as a place where a natural outflow of groundwater occurs. Spring water is usually fed from a sand or gravel water-bearing ground formation (aquifer), or a water flow through fissured rock. Where solid or clay layers block the underground flow of water, it is forced upward and come to the surface. The water may emerge either in the open as a spring, or invisibly as an outflow into a river, stream, lake, or the sea (Fig. 6.23). Where the water emerges in the form of a spring, the water can easily be tapped.

Gravity overflow springs in granular ground formations can be tapped with drains consisting of pipes, with open joints, placed in a gravel pack. To protect the spring, it is necessary to dig into the hillside so that a sufficient depth of the aquifer is tapped even when the groundwater table is low (Fig. 6.24). The water collected by a drain discharges into a storage chamber, which is sometimes referred to as the 'spring box' (Fig. 6.25). In fractured rock aquifers, pipes packed in gravel may be used, or the water may be collected by tunnels, lined (Fig. 6.26) or unlined, depending on the nature of the ground formation. Where fissures convey local high-rate outflows of water, a small spring tapping structure will be adequate (Fig. 6.27).

Although artesian depression springs are quite similar to gravity depression springs in outside look, their yield is greater and less fluctuating, as the water is forced out under pressure. To tap water from an artesian depression spring, the seepage area should be surrounded by a wall extending a little above the maximum level to which the water rises under static conditions. For sanitary protection the storage chamber should be covered (Fig. 6.28). Fissure springs belong to the same category as artesian depression springs but the water rises from a single opening so that the catchment works can be small (Fig. 6.29). For a large lateral spring, a retaining wall should be constructed over its full width with the abutments extending into the overlying impervious layers and the base of the wall constructed into the bedrock; in this way leakage of water and any risks of erosion and collapse are avoided (Fig. 6.30).

6.6.5 Surface water

River : Except few cases of mountain streams, river water is almost always polluted, and treatment will be necessary to render it fit for drinking and domestic purposes. The quality of river water will usually not differ much across the width and depth of the river bed. The intake, therefore, may be sited at any suitable point where the river water can be withdrawn in sufficient quantity. The design of a river water intake should be such that both clogging and scouring will be avoided. The stability of the intake structure should be secured, even under flood conditions.

Where the river transports no boulders or rolling stones that would damage the intake, an unprotected intake may be adequate (Fig. 6.31). In cases where protection of the intake is necessary, intake structures of the type shown in Fig. 6.32 may be suitable. The bottom of the intake structure should be at least 1 m above the river bed to prevent any boulders or rolling stones from entering. A baffle may be needed to keep out debris and floating matter such as tree trunks and branches. To reduce the drawing in of silt and suspended matter, the velocity of flow through the intake should be low, preferably less than 0.1 m/sec. Frequently, pumping is needed for the intake of water from river sources (Fig. 6.33). Another arrangement worth considering uses a sump constructed in the river bank. The river water is collected with infiltration drains laid under the river bed; under gravity it flows into the sump (Fig. 6.34).

Lake : The quality of lake water is influenced by self-purification through aeration, biochemical processes, and settling of suspended solids. The water can be very clear, of low organic content and with high oxygen saturation. Usually, human and animal pollution only present a health hazard near the lake shores. At some distance from the shore, the lake water is generally free from pathogenic bacteria and viruses. However, algae may be present, particularly in the upper water layers of lakes.

In deep lakes, provision should be made to withdraw the water at some depth below the surface (Fig. 6.35). In shallow lakes, the intake should be sufficiently high above the lake bottom to avoid the entrance of silt (Fig. 6.36). For small community water supplies the quantity of water needed being small, often very simple intake structures can be used. With a per capita water use of 30 liters/day and the peak intake 4 times the average water demand, 1000 people would require an intake capacity of only 1.4 liters/sec. A 150 mm intake pipe would be sufficient to keep the entrance velocity of flow below 0.1 m/sec. If an entrance velocity of flow of 0.5 m/sec is allowed, a pipe as small as 60 mm would be adequate (IRC, 1983). For small capacity intakes, simple arrangements using flexible plastic pipe can be used (Fig. 6.37). Another intake construction using a floating barrel to support the intake pipe, is shown in Fig. 6.38. The water is pumped from the well sump.

6.6.6 Groundwater recharge

Groundwater usually has the great advantage over surface water from rivers and lakes in that it is free from pathogenic organisms and bacteria causing water- related diseases. However, groundwater is not always available and the amounts that can be withdrawn are usually limited. In the long run, the withdrawal of groundwater cannot exceed the amount of natural recharge. Therefore, when this recharge is small, the safe yield of the aquifer is also small. Under suitable conditions it is possible to supplement the natural recharge of an aquifer and so add to its safe yield capacity. This is called artificial recharge. It involves measures to feed water from rivers or lakes into the aquifer, either directly or by spreading the water over the infiltration area allowing it to percolate downward to the aquifer. Artificial recharge can have great potential for improving small community water supplies in many parts of the world. Apart from adding to the yield of an aquifer, artificial recharge also provides purification of the infiltrated water. When water from a river or lake flows through a ground formation (Fig. 6.39), filtration will take place with a substantial removal of the suspended and colloidal impurities, bacteria and other organisms. The aquifer acts as a slow sand filter.

Provided that the water is recovered at a sufficient distance from the point of recharge, preferably more than 50 m, the water will flow underground for a considerable time, normally two months or more. As a result of the bio-chemical processes, adsorption and filtration, the water will become clear and safe for domestic use. In many instances it can be used without any further treatment. If artificial recharge is combined with underground storage of the water, water taken from a river in the wet season can be stored in the aquifer and recovered during the dry period when the river flow is small or absent (Fig. 6.40). It will often be much easier and more economical to provide such underground storage of water rather than surface reservoirs.

Additional advantages are the great reduction of evaporation losses of water and the prevention of algal growth.

The principal methods of artificial recharge of aquifers are bank infiltration and spreading of the water over permeable ground surfaces.

Bank infiltration : For bank infiltration (induced recharge), galleries or lines of wells are placed parallel to the shoreline of a river or lake, at a sufficient distance (Fig. 6.41). In the original situation the outflow of groundwater feeds the flow of the river. When amounts of groundwater are withdrawn, the flow of groundwater into the river will fall. Water from the river, then, will be induced to enter the aquifer. Considerable amounts of water may thus be recovered.

The means for recovery of the recharged water may also be set in the river bed itself. Fig. 6.42 shows a line of jetted well points interconnected by a central suction line. Another option is a horizontal collector drain placed under the river bed (Fig. 6.43).

Water spreading : The bank infiltration described in the previous section can only be used where a suitable aquifer is adjacent to the source of surface water. Sometimes, both a suitable aquifer and a water source are present but some distance apart. Artificial recharge then can be practised but the water from the river, lake or other source has first to be transported to those sites where ground formations suitable for infiltration and underground flow are available.This certainly represents a complication of the recharge scheme but important additional advantages are attained, like (1) the intake of water can be stopped when the river water is polluted or otherwise of poor quality, and (2) a saving in cost may be achieved when the recharge scheme is situated near the water distribution area. An artificial recharge by water spreading scheme is shown in the Fig. 6.44. It may include pre-treatment of the water before recharge in an infiltration basin, and further treatment after recovery. For the artificial recharge of shallow aquifers, particularly aquifers with fine grain composition, the spreading basins should be constructed as ditches, with galleries for groundwater recovery constructed parallel to them (Fig. 6.45).

6.6.7 Water raising devices

Methods of lifting water are numerous and varied. The simplest mechanisms are often the cheapest, and can more easily be made and repaired with local materials. However, there can be exception to this comment. Which of these many methods is most appropriate will depend on the local conditions, the funds available, and the probability of regular maintenance in the future.

The flow chart in Fig. 6.46 can be used to check the feasibility of energy sources for water pumping at a specific location. The entry point to the selection chart is the available water source. The various sources of energy should be considered in the order in which they are generally rated as technically feasible and economically attractive. Through this step by step process, the most promising type of pumping system is identified. If several energy sources appear to be feasible, a comparison of the costs per unit of water output should be made.

Based on the mechanical principles involved, pumps classification with basic information is given in the Table 6.7. An indication of the pump type to be selected for a particular application can be obtained from Fig. 6.47.

Hand power :

Hand power is suitable for a supply where water is drawn straight from the source, such as a well. If water is to pumped to a storage tank some other type of power will have to be used, such as wind, diesel, or electricity, unless an institutional framework (school, hospital, commune, etc.) exists to organize the work of pumping by pump.

The simple method of raising water is a bucket of some kind on the end of a rope. It is best to use rollers (Fig. 6.18), a windlass (Fig. 6.18) or a shaduf (Fig. 6.48) so that people do not have to lean over the well headwall to raise the bucket.

Hand pump : However, these devices are not suitable for tube wells, or for very deep dug-wells, and for these a hand pump is required. A hand pump also enables the water to be protected from pollution until it enters the user's bucket, but it cannot usually be made in the village, and it also requires regular maintenance (Fig. 6.49). However, using human power for pumping water has certain features like

— The power requirements can be met from within the users' group,

— The capital cost is generally low,

— The discharge capacity of one or more manual pumping devices is usually adequate to meet the domestic water requirements of a small community.

Hand pumps are of two kinds. Shallow-well pumps (Fig. 6.50) are cheaper and easier to maintain because the pumping mechanism is above the ground level, but they can work when the water level is less than 8 m deep. In deep-well pumps, the pumping mechanism is immersed in the water at the bottom of the well (Fig. 6.51). The 'open cylinder' type of deep-well pump has a large riser pipe, so that the piston can be pulled up for maintenance, like the 'Tara' pump widely used in Bangladesh. This makes maintenance by villagers much easier.

The most commonly used pumps are of the reciprocating type, such as the piston pump, direct action pump and suction pump (Fig. 6.52), where a piston is moved up and down in a cylinder with the aid of a pump rod. Several non-reciprocating pumps also exist, some of which are very popular in a certain region. Example is a rotary pump with helical stator and rotor (progressive cavity type) (Fig. 6.52). Advantages and disadvantages of such pumps depend upon local circumstances.

When designing a hundpump, a fundamental consideration must be the pumping head. The UNDP/World Bank Handpumps Project refers to low-lift pumps as those suitable for pumping heads of no more than about 15 meters. Suction pumps are a subset of low-lift pumps, and are able to lift water from a maximum of about seven meters. High-lift pumps are referred to as suitable for pumping heads of up to 45 meters. In considering the pumping heads for which a suitable, it is the water level rather than the well depth which is the main parameter. Furthermore, it is important to consider drawdown of the water table in low-yielding wells during prolonged pumping. It may be noted here that, in principal, handpumps can operate with heads of as much as 90 meters. Since these are very specific, the description of such high head pump is out of the scope of this book.

Low-lift Pump : For pumping heads of up to 15 meters, reciprocating pumps is the most suitable. At present most pumps which are used at this depth range are either suction pumps, capable of pumping only from heads less than about seven meters or direct action pumps which can operate at greater heads. Many existing suction pumps approach VLOM insofar as they are easily maintained (with all the parts which are subject to wear being above ground – except in some cases the foot valve, if one is installed at the base of the rising main), have simple designs that can be made in most countries, are cheap, and are fairly robust (except for the pivots on the lever).

But suction pumps have serious disadvantages. First, the need to prime the pump when the foot valve or suction check valve below the cylinder leaks (which frequently happens) is an unacceptable practice which introduces contamination into the well. Second, the depth limitation of about seven meters seriously constrains the application of suction pumps, which is exacerbated by the fact that water tables are falling in many areas because of extensive groundwater extractions for irrigation or because of drought.

Direct action pump can lift water from aquifers which is more than seven meters deep. Although these types of pumps have no lever, because of improved design and light weight materials, a person would have to work about as hard to pump a given amount of water from the same depth with either a lever pump or a direct action pump. Examples of direct action pumps which are now being field tested are TARA (Bangladesh), Ethiopia BP50, Malawi Mark V, PEK (Canada), Blair (Zimbabwe), and Rower irrigation pump (Bangladesh).

High-lift pump : Most of the pumps of this type is lever pump. The purpose of the lever for reciprocating pumps is to provide a mechanical advantage as well as to counterbalance the weight of the rod, piston, and water column to be lifted.

Pump choice : In order to achieve widespread, sustained coverage of the rural and urban fringe populations, pump designs must be based on the VLOM principle. Significant improvements in pump design have been made in this direction over the last few years, but no VLOM pump has reached the stage where it has become a production model with proven successful performance in field trials of adequate duration.

Each country using handpumps will, at some time, have to decide which pump types to use. This choice will rarely be a single pump type. Nonetheless, standardization on a small set of pump types must be achieved in order to facilitate the distribution of spare parts, exercise stringent quality control of manufacturing, and train installers and village repairers.

The country-wide pump choice will depend on a variety of factors determined by local conditions, such as the range of water table depths, availability of alternative water sources, in-country manufacturing capability, self-help potential in villages, and user acceptability of pump types.

Natural source of power :

In developing countries, sources of energy commonly used for community water supplies are human muscle, diesel fuel, and electricity. Hand pumps may be suitable for very small communities, however, for a larger community, handpump may not be a suitable choice. On the other hand, the high costs, difficulties of ensuring regular fuel supplies and meeting the operation and maintenance requirements, make the use of diesel or electrical pumps less attractive. Thus, interest in renewable sources of energy, such as solar energy, wind energy, hydropower and biomass fuels has increased. Pumping systems based on these energy sources have become technically reliable and economically attractive, particularly for small water supply systems with a capacity of up to about 250 m^3/d. The capital cost of renewable energy pumping devices is relatively high, but they can be cost-effective because of their low running costs.

Wind power can be used for raising water, with the advantage that wind is free. However, a windmill is necessary to harness wind power, and windmills are rather expensive. A large and expensive storage tank is also necessary to ensure a reasonably reliable supply over windless period. Alternatively, a wind pump may be installed which is designed to be operated as a hand pump when there is no wind. Hydraulic ram pump is another kind of pump which uses natural energy. A hydraulic ram uses the energy of flow of a large volume of water, to pump a small portion of that volume. It therefore requires a much larger flow of water of suitable quality than would be necessary for the community's need alone. Solar pumps are suitable for arid areas, they can pump as much as 10 l/s, but they involve sophisticated technology. Several have been installed, with mixed results, in rural areas of West Africa and in Somalia.

An overview of energy sources used for water pumping and devices for energy conversion is resented in Table 6.8.

In selecting the most appropriate renewable energy source for small water pumping systems, environmental, social, technical and economical factors are to be considered. The necessary data required for the systematic assessment of relevant factors in selection of energy sources are given in the Table 6.9.The minimum requirements for environmental feasibility of pumping devices are given in the Table 6.10.Most renewable energy pumping systems require a well-established back-up support for maintenance, Table 6.11 shows the maintenance frequency and technical skill required. A general indication of back-up service requirements is given in Table 6.12. Cost analysis is a useful tool to support selection of the renewable energy source to be used for water pumping systems. Since both the capital and the recurrent costs must be assessed, it is necessary to use discounting techniques because the various types of pumping systems under consideration have different time profiles of costs. For example, foe solar pumps, the capital cost is relatively high and may represent more than 70–75% of total lifetime costs, while for diesel pumps, the capital cost is relatively small and may be no more than 25–30% of total lifetime costs (Fig. 6.53). An indication of the distribution of capital and recurrent costs for various pumping systems is given in Table 6.13. The general level of costs of the various types of pumping systems has been calculated from global cost data, and on this basis, the economic feasibility ranges for the various energy sources have been estimated (Fig. 6.54). It must be emphasized that these ranges are indicative only, and that local cost data may give quite a different result. Thus the economic feasibility of a particular pumping system can only be determined reliably fro local cost data. A flow diagram to select the most appropriate system based on the local condition is given in references (IRC, 1986). If several types of pumping systems appear to be economically feasible, comparison of unit output costs is important in the final selection process.

Solar energy : In photovoltaic pumping systems, solar radiation energy is converted into electricity by solar cells. This generated electricity then in turn, runs the electric pump. The modularity of photovoltaic pumping systems has a distinct advantage. If more power is required, the solar array can be easily expanded by adding more modules. By contrast, a larger diesel engine would have to be installed for greater output if this was the power source. Hence, photovoltaic pumps have considerable potential for remote areas where solar conditions are favorable. The power conversion and component of a photovoltaic pumping system is shown in the Fig. 6.55.

To assess whether a location is suitable for solar pumps, a record of daily irradiation over at least one, preferably two years, is required. The design of a solar pump system cannot be based on average daily irradiation, because insufficient water would then be pumped in months of below-average solar irradiation. Therefore, the month of the lowest irradiation is usually selected as the basis for sizing solar pump installations, and allowance must be made for cloudy periods in which irradiation may be much lower than the average.

Wind energy: A wind powered pumping system consists of a rotor, a pump, and a power transmission mechanism connecting the rotor to the pump. The most common type of wind pump has a multi-bladed rotor mounted on a horizontal axis which transmits the power to the pump through a rod (Fig. 6.56). The potential for using wind power to pump water in small scale systems is greatly affected by the local wind speeds and the wind regime. For example, at a wind speed of 5 m/s, a power output double that at a wind speed of 4 m/s can be generated. Although the capital costs of wind pumps are higher than for diesel pumps or electric pumps of the same output capacity, lower running costs and longer service life can make wind pumps economically attractive in areas of sufficient wind and suitable wind regime.

Hydraulic ram pumps : A wide range of water pumping devices have been developed which use the energy of flowing water. The three main types of hydro-powered pumps for small community water supply are :

- hydraulic ram pump
- turbine pump
- river-current pump.

Hydraulic ram pumps use the kinetic energy of water running through a drive pipe to lift a small proportion of that water to a higher level than the supply source. Turbine pumps have a submerged runner coupled to a pump. They can work satisfactorily under a head as low as 0.5 m, for example, at a weir in a river. River current pumps are mounted on a floating platform. They have a partly submersed rotor which rotates by the force of the river current. Some details of hydraulic ram pump is given below.

These pumps operate on the principle of creating a pressure surge, or water hammer, in the drive pipe by the sudden stoppage of water flowing through it (Fig. 6.57). The pump works by using the energy of a large amount of water falling a small height to lift a small amount of that water to a much greater height. The supply of water from the source must be steady and continuous to operate the hydraulic ram pump. Hilly or mountainous areas with a good supply of flowing water are suitable locations. These pumps can be operated by a flow of as little as 4 l/min., provided there is sufficient fall. Alternatively, if the water flow is fairly great, a fall of 0.8 m is adequate to operate a ram pump.

The inclined pipe feeding the water from the source to the ram pipe is called the drive pipe. The essential moving part of the pump is the impulse valve, which, when opened, allows the flow in the drive pipe to gain speed and power. Sudden closure of the valve causes the flow to stop, and thus creates the pressure surge in the drive pipe which is converted into power for water pumping. When correctly installed, these pumps are very reliable and can lift water against considerable pumping heads. They can work satisfactorily for many years and need only limited maintenance. The operation of the pump is illustrated in the Fig. 6.58.

The design parameters for hydraulic ram pump installations are shown in the Fig. 6.59. The water flow (Q) from the source and the supply head (H), determine the combination of delivery flow (q) and delivery head (h) that the ram pump can produce. This is indicated in the Table 6.14.

Table 6.14 Water delivery (q) as a proportion of supply flow (Q) for hydraulic ram pumps operating under various combinations of supply head (H) and delivery head (h)

h/H	2	3	4	5	6	7	8	9	10
q/Q	0.40	0.26	0.18	0.13	0.11	0.085	0.07	0.06	0.05
Efficiency (approx.)	0.8	0.78	0.72	0.65	0.66	0.595	0.56	0.54	0.5

Source : Based on IRC, 1986

Motor pumps :

Pumps may also be driven by diesel or electric motors. Electric motors need less maintenance and are usually more reliable than diesel engines, so that they are preferable where electricity is available. Unfortunately, electricity supplies themselves are not always reliable in rural areas. The energy conversion efficiency, that is "wire-to-water", of an electric motor pump is about 30–40% (IRC, 1986). On the other hand, small diesel engines have an efficiency of about 10–15%. Because of additional power losses in power transmission and in the pump, the conversion efficiency is normally 5–10%, but actual efficiency under field conditions depends heavily on the level of maintenance of the engine, as diesel engines require extensive maintenance.

6.6.8 Water storage

When designing storage tanks for village water supplies, it is often better to use reinforced concrete or corrugated steel sheet, as these are easier to make reliably watertight. However, a few small leaks in a tank above ground may not be a serious concern in village circumstances. Perfectly adequate tanks may be built of local building materials such as brick or masonry, especially galvanized wire is laid between courses to give the walls horizontal reinforcement. Watt (1978) describes simple methods for building water tanks by plastering cement mortar on to reinforcement of chicken mesh and steel wire (ferrocement).

Small earth dams, too, do not need to be of sophisticated design, being made with clay core walls and rip-rap, although certain basic safety requirements are of course necessary. A good account of small dam construction is given by Wagner and Lanoix (1959).

Care should be taken to prevent tanks and reservoirs from becoming breeding places for malaria mosquitos.The creation of any permanent water surfaces accessible to mosquitoes may promote their breeding in the dry season, unless special precautions are taken. Storage tanks should therefore be covered, ventilation pipes screened with mosquito-proof mesh, and steps taken to avoid the creation of breeding sites downstream from the overflow.

6.6.9 Water treatment

There will be situations where treatment of the water is necessary to render it fit for drinking and domestic use. Unfortunately, there is no such thing as a simple and reliable water treatment process suitable for small community water supplies. The provision of any form of treatment in a water supply system will require a capital outlay that may be relatively substantial. More important, it will greatly expand the problems of maintaining the water supply system, and the risks of failure. Therefore it is preferable to choose a source of naturally pure water, and then to collect that water and protect it from pollution so that treatment is unnecessary. Treatment of village water supplies should only be considered if it can be afforded and reliably operated in the future. Simple arrangements can be effective, provided they are well-designed. The water treatment process diagram in Fig. 6.60 is illustrative.

The purpose of water treatment is to convert the water taken from a source, the 'raw water', into a drinking water suitable for domestic use. Most important is the removal of pathogenic organisms and toxic substances such as heavy metals causing health hazards. Other substances may also need to be removed or at least considerably reduced. These include : suspended matter causing turbidity, iron and manganese compounds imparting a bitter taste or staining laundry, and excessive carbon dioxide corroding concrete and metal parts. Often a treatment result can be obtained in different ways (Table 6.15). Artificial recharge (discussed earlier) may also be regarded as a water treatment process.

In the process of the selection of treatment plant for small rural community, the following parameters are most important.

— turbidity,

— fecal coliform count,

— presence of guinea worm or schistosomiasis.

The guidelines are given in the following tables. (Table 6.16, 6.17 and 6.18)

Storage :

The simplest method of treating water is to store it in a covered tank. This will permit some slit to settle out, and allow time for some pathogens to die off. If water is stored for at least forty-eight hours, for instance, any schistosome cercariae in it will become non-infective before they leave the tank. Storage, however, may promote algal growth in the water. Evaporation loss is another drawback. This can be minimized by covering the tank which would also prevent dust, insects, and air borne pollution from contaminating the stored water.

Sedimentation :

Sedimentation is the settling and removal of suspended particles that takes place when water stands still in, or flows through a basin. These particles will ultimately be deposited on the bottom of the tank forming a sludge layer. Sedimentation takes place in any basin, however, settling tanks specially designed for sedimentation are more effective. The most common design provides for the water flowing horizontally through the tank.

For larger communities it may be useful to build a small sedimentation tank (Fig. 6.61), although it will not usually be possible to arrange for coagulant chemicals to be added to the water to assist the sedimentation. Sedimentation does not only remove many of the harmful organisms from polluted water, but it also helps to clarify water for treatment by filtration or chlorination. The details of other two different types of sedimentation tanks are shown in Fig. 6.62.

Coagulation and flocculation :

Coagulation and flocculation is the water treatment process by which finely divided suspended and colloidal matter in the water, is made to agglomerate and form flocs. This enables their removal by sedimentation or filtration. The substances that frequently are to be removed by coagulation and flocculation, are those that cause turbidity and color.

Generally, water treatment processes involving the use of chemicals are not so suitable for small community water supplies. They should be avoided whenever possible. Chemical coagulation and flocculation should only be used when the needed treatment result cannot be achieved with another treatment process using no chemicals.

Alum (aluminium sulphate) is by far the most widely used coagulant but iron salts (like ferric chloride) can also be used. In Indonesia and some other countries, grind seed of Moringa tree is used as a natural coagulant.

Filtration :

Filtration is not suitable for village conditions. If filtration is unavoidable, it should be by slow sand filters.

Filtration is the process whereby water is purified by passing it through a porous material (or 'medium'). In slow sand filtration a bed of fine sand is used through which the water slowly percolates downward (Fig. 6.63). The suspended matter present in the raw water is largely retained in the upper 0.5 – 2 cm of the filter bed (IRC, 1983). This allows the filter to be cleaned by scraping away the top layer of sand. The interval between two successive cleanings can be fairly long, usually several months. The filtration rate is usually low, 0.1 – 0.3 m/h = 2 – 7 m/d (IRC, 1983), which is, however, 4 – 5 m/d according to Japanese standard (JWWA, 1990).

The main purpose of slow sand filtration is the removal of pathogenic micro organisms from the raw water. It is capable of reducing the total bacteria content by a factor of 1000 to 10000, and the E. Coli content by a factor 100 to 1000 (IRC, 1983). A well operated slow sand filter can also remove protozoa and helminths.

Rapid filtration : For rapid filtration (Fig. 6.64), much coarser sand is used with an effective grain size in the range of 0.4 – 1.2 mm, and the filtration rate is much higher, generally between 120 and 360 m/d (IRC, 1983). According to Japanese standard, this rate is 120 – 150 m/d (JWWA, 1990).

In groundwater treatment, rapid filtration is used for the removal of iron and manganese. In the treatment of river water with high turbidity, it may be used as a pre-treatment to reduce the load on the following slow sand filters. It may be applied for treating water that has been clarified by coagulation, flocculation and sedimentation.

Roughing filtration : Sometimes a more limited treatment than rapid filtration using a sand bed, can be adequate for treating the raw water. This can be obtained by using gravel or plant fibres as filter material. This coarse (roughing) filter will have large pores that are not liable to clog rapidly. A high rate of filtration, up to 20 m/h, may be used (IRC, 1983). Another possibility is the use of horizontal filters as shown in Fig. 6.65. In that case, a large area will be required, but the advantage is that clogging of the filter will take place very slowly, so that cleaning will be needed only after a period of years. Coconut fibers can also be used as a filter medium.

Disinfection :

The single most important requirement of drinking water is that it should be free from any micro-organisms that could transmit disease to the consumer. Processes such as sedimentation and filtration can reduce to varying degrees the bacterial content of water. However, these processes cannot assure that the water they produce is bacteriologically safe. Final disinfection will frequently be needed. In cases where no other methods of treatment are available, disinfection may be resorted to as a single treatment against bacterial contamination of drinking water.

The following factors influence the disinfection of water (IRC, 1983) :

1) The nature and number of the organisms to be destroyed.

2) The type and concentration of the disinfectant used.

3) The temperature of the water to be disinfected; the higher the temperature the more rapid is the disinfection.

4) The time of contact; the disinfection effect becomes more complete when the disinfectant remains longer in contact with the water.

5) The nature of water to be disinfected; if the water contains particulate matter, especially of a colloidal and organic nature, the disinfection process generally is hampered.

6) The pH of the water.

7) Mixing; good mixing ensures proper dispersal of the disinfectant throughout the water , and so promotes the disinfection process.

A good chemical disinfectant should possess the following important characteristics (IRC, 1983) :

- Quick and effective in killing pathogenic microorganisms present in the water,
- Readily soluble in water,
- Capable of providing a residual,
- Not imparting taste, color or odor to water,
- Not toxic to human and animal life (in low concentration),
- Easy to handle, transport, apply and control,

Readily available at moderate cost.

The chemicals that have been successfully used for disinfection are : chlorine, iodine, ozone, potassium permanganate and hydrogen peroxide. Among them chlorine and chlorine compounds are found to be most suitable for rural communities of developing countries. Among the chlorine compounds, they widely used ones are liquid and gaseous Chlorine, Chlorinated lime (Bleaching Powder), Hypochlorites, Sodium Hypochlorite, etc. However, probably the appropriate chemical for small scale plants in developing countries is the Bleaching Powder.

Pot chlorination : A recommended method of chlorination in village wells involves a pot containing a mixture of coarse sand and bleaching powder, which is hung underwater in a well (Fig. 6.20). Two type of pot chlorinator is shown in Fig. 6.66.

The double pot is suitable for a well serving up to twenty people, and needs to be refilled with 1 kg of bleach and 2 kg of sand every three weeks. The single pot will serve up to sixty people if it contains 50% more bleach and sand, but it requires replenishing every two weeks. The trouble with these pots is that they tend to make the water taste unpleasant for the first few days after refilling. There is no point at all in using a water disinfection process if it drives people to use water of worse quality, or if it is not reliably operated. Nevertheless, chlorination of a rural water source may be a worthwhile temporary measure during an epidemic which is suspected to be water-borne.

When water from the source is pumped to an elevated service reservoir and supplied by gravity to the distribution system, a bleaching powder solution may be dosed as in fig. 6.67.

Aeration :

In a few areas, heavy concentrations of dissolved iron and manganese in the ground water can give it an unpleasant taste, and give a brownish color to food and clothes. These chemicals can be a serious nuisance, and may even prevent people from using the water. If so, they can often removed by aeration, for instance when the water falls into a storage tank from the inlet. Aeration causes the iron and manganese to become insoluble so that they form a fine dark sediment which is more easily removed.

Aeration is the treatment process whereby water is brought into intimate contact with air for the purpose of (a) increasing the oxygen content, (b) reducing the carbon dioxide content, (c) removing hydrogen sulphide, methane and various organic compounds responsible for taste and odor, and (d) reducing iron and manganese content. The intimate contact between water and air, as needed for aeration, can be obtained in a number of ways. For drinking water treatment, it is mostly achieved by dispersing the water through the air in thin sheets or fine droplets (waterfall aerators), or by mixing the water with dispersed air (bubble aerators).

Fig. 6.68 shows a simple unit for the aeration of water, which will also remove the iron and manganese sediment produced. It is made of four cylinders, the top three of which each have a mesh or sieve in the base, and ventilation slots in the side. Water is sprayed over the stones at the top and is collected in the bottom cylinder, to be withdrawn through a tap at the bottom. The water is exposed to the air as it trickles down through the stones, and the sediment is deposited on the sand lower down. The sand requires replacement roughly once a month.

Another type of aerator is 'multiple-platform aerator', where sheets of falling water are formed for full exposure of the water to the air (Fig. 6.69).

Others :

Other chemicals in water, particularly salt, fluorides, and nitrates, are less easily removed under village conditions. The simplest fluoride-removal process, for example, requires the regular addition of alum to the water, however, alum is not always available. Thus, when harmful chemicals are dissolved in the water, it is usually preferable to look for alternative sources of water.

6.6.10 Water transmission and distribution

The water needs to be transported from the source to the treatment plant, if these is one, and onward to the area of distribution. Depending on the topography and local conditions, the water may be conveyed through free-flow conduits, pressure conduits or a combination of both (Fig. 6.70). The transmission of water will be either under gravity or by pumping. For community water supply purposes, pipelines are most common means of water transmission but canals, aqueducts and tunnels are also used. Water transmission systems generally require a considerable capital investment, thus, a careful consideration of all technical options and their costs is, therefore, necessary when selecting the best solution in a particular case.

Many of the potential health benefits from rural water supplies come from an increased use of water. There is therefore good reason for designing water points so as to encourage the maximum possible water use, particularly for hygiene. There are two ways for doing this: by constructing individual wells near the users or by constructing a pipe network that transports water from the source to the users. This section is concerned with the networks. The water distribution system serves to convey the water drawn from the water source and treated when necessary, to the point where it is delivered to the users.

A community's water demand varies considerably in the course of a day. Water consumption is highest during the hours that water is used personal hygiene and cleaning, and when food preparation and washing of clothes are done. During the night the water use will be lowest.

Service reservoirs serve to 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 a sufficient pressure in the distribution system in order to protect it against contamination by the ingress of polluted seepage water. For small community supplies, a minimum pressure of 6 m head (IRC, 1983) of water should be adequate in most instances. Intermittent water supply is, therefore, poses serious health threat.

The number and type of the points (service connections) at which the water is delivered to the users, have considerable influence on the design of a water distribution system. The following types of service connections may be distinguished : House connection, Yard connection, and public standpipe.

A house connection is a water service pipe connected with in-house plumbing to one or more taps, like in the kitchen and bathrooms (Fig. 6.71). 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 (Fig. 6.72). Public standpipes (Fig. 6.73) are 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. They are used for reasons of costs and technical feasibility. The walking distance for the farthest user of a standpipe should be around 200 m, with maximum 500 m (IRC, 1983). A single tap standpipe should preferably used by not more than 40 - 70 people (IRC, 1983). In spite of their shortcomings, public standpipes are really the only practical option for water distribution at minimum cost to a large number of people who cannot afford the much higher costs of house or yard connections.

Ideally, water should be provided inside or near each house (a yard connection), as this usually leads to an increase by several times in the volume of water used, even if only a single tap is installed. When individual connections can not be afforded, the alternative is to provide public water points, known as standpipes, from which the public may collect their water. In addition, showers, clothes-washing facilities, and possibly toilets may be constructed beside the water points and connected to the piped water supply. In designing a water point, provision should be made for the disposal of split water and waste water used for washing at the water point. Areas on which water will be split should be paved, preferably with the concrete, and the waste water taken to a soakaway, such as a pit filled with stones and covered over with a layer of soil. One serious problem is damage to water points through heavy use, or sometimes through vandalism. The most common component to break is the tap, and this should be as durable as possible. In any case, arrangements should be made for the regular inspection and maintenance.

Most community networks are either branched or looped (Fig. 6.2, and Fig. 6.74) or combinations of these.

Branched networks typically used in areas where there are relatively few connections. This type of system is easy to design, minimize total pipe length and cost. The main disadvantage is unreliability; if a pipe breaks, then all downstream users will be without water.

Looped networks are used in places where most houses are served with individual connections. This system provides good reliability in the event of a break. However, determination of flows in pipes requires lengthy calculations which, except for single loops cannot be done by hand, but instead require a computer.

There are four basic steps of design, namely layout selection, flow calculation, pressure calculation and pipe diameter selection.

Out of these, perhaps layout is the most important. This is because pipe length is the principal determinant of network cost. Design flow, on the other hand (which affects pipe diameter) usually has less effect on cost. If the length is double, the cost will also be double. However, if design flow doubles, cost will increase only about 50% (World Bank, 1986). Although layout is such an important step in design, it usually gets less attention than selection of diameters. One of the reasons for this is that there are almost no objective guidelines or standards for deciding layout; there is no formula that can be used to calculate how the network should be laid out. On the other hand, there are formulas for calculating pipe diameters.

Some considerations about layout are :

- attempts are made to keep total length as short as possible.
- pipes are laid where construction access are easy, usually in streets.
- the layout should be made in such a way that it can be easily upgraded in the future to provide individual connections without having to do major reconstruction.
- long lengths of pipe at the edges of networks to serve just a few houses should be avoided.

The majority of networks are fed from an elevated storage tank into which water is pumped from the source of supply. The power requirements of the pump depend primarily on two factors: the flow of water and the head against which the pump operates. It follows that the higher the elevated tank, the higher will be the pumping costs. On the other hand, the higher the tank, the more head is available for overcoming friction, which makes it possible to use smaller diameter pipe in the network. Hence, there is said to be a trade off between the inlet pressure to the network and the diameter of pipes; that is, between pumping and piping cost. One task of design is to determine the optimal balance between pressure and diameter so as to minimize total cost.

Selection of service level is also very important. Public standposts provide the lowest level of service; water is least accessible to users, they must always carry it, and sometimes for long distances. Associated with standposts are low per capita flows and low network pressures. The next higher level of service, which provides increased accessibility, are yard taps, and beyond that are multiple in-house taps. According to a study (World Bank, 1986), networks designed for multiple house taps can be six times and that for yard tap can be two times more expensive than those designed for public standpipes. Each different level of service provides greater accessibility and convenience. However, once the water is piped onto the premises of a house, health benefits may increase only slightly. Thus it is upto the designer to fix the service level considering the affordability.

Another consideration is revenue collection. Probably the strongest argument against standposts is that it is difficult to collect revenue from the users. With individual connections, on the other hand, it is relatively easy.

Finally, a general principle to follow is that the level of service for any new system should be higher than the present level of service.If users are presently collecting water from natural sources such as rivers and springs, they will probably be quite satisfied with public standpipes, and it is unlikely that they would demand individual house connections. However, if users have private wells which have become polluted thereby necessitating a new water system, it is unlikely that they would be satisfied with standposts; rather, they will continue to use their wells even though polluted because of unwillingness to give up their convenience.

Gravity-flow water supply :

Some times adequate amounts of safe water is available only at considerable distances from people's houses. In that case, much time is required to carry water to the home. This is a hard work and only small amounts of water are carried. Water can be transported from its source to villages by pipelines. If the water flows through the pipeline using only gravity, the network of pipes is called a gravity-flow water system.

The components of a gravity-flow water system are :

- 1. An elevated source of water, like spring, clean river or stream. Where disinfection is necessary, simple methods should be used. In all cases the source should be protected from contamination.
- 2. A sedimentation tank, if necessary.
- 3. The main distribution pipeline. This can follow land contours and may even go up and over small hills.
- 4. District reservoirs that may be required to store water overnight for peak use during the day time.
- 5. Networks of smaller pipes.
- 6. Standpipes.

Advantages :

- 1. No energy is required.
- 2. As there are very few moving parts, maintenance is simple and is required only infrequently.
- 3. Water is delivered close to user's home.
- 4. The system can be build by the villagers themselves.

Disadvantages :

- 1. Water quality depends on the source water quality. Sometimes, additional treatment facilities may have to be built at additional cost.
- 2. Available sources of water may not provide adequate amounts of water throughout the year.
- 3. Water rights cause problems in some areas as villages near the source may object to having "their" water piped to villages below them. Pipelines may be damaged in local disputes.

6.7 Urban water supply

Most of the technology suitable for urban water supply in developing countries is similar to that used in the developed countries, and can be found in conventional textbooks on water supply. However, by no means all of the systems used in developed countries are appropriate for conditions in the developing countries. For example, some pumping and treatment plants could not cope with the very silty water of many tropical rivers. More importantly, some equipment is too difficult to operate, to maintain, and to repair due to difficulties of importing spare parts, shortage of trained staff, and a lack of correct operational and maintenance procedures. In general, therefore, the technology appropriate for urban water supply in developing countries must be chosen in such a way as to make it easily understandable by its operators, and easy to operate and repair without too much technical knowledge or need for imported materials (Cairncross and Feachem, 1993).

6.7.1 Treatment

Treatment is usually necessary for town water supplies. Sufficient water for a whole town is not always available from the ground, and so polluted surface sources often have to be used. The larger scale of a town water supply makes the quality of the water more important than for a small rural water supply. A single source of pollution in an urban supply could cause a water-borne epidemic in the whole town, so that the consequences of poor water quality are more serious.

Sedimentation and coagulation :

Because of the high silt loads of most tropical rivers, sedimentation is usually necessary as a first stage of water treatment. This involves passing the water slowly through a large tank to allow time for solid matter to settle out. It does not significantly improve the microbiological quality of the water, but makes subsequent processes more efficient.

Sedimentation is usually assisted by adding chemicals called coagulants, often alum (aluminium sulphate), to the water. This causes the small solid particles to come together in larger clusters known as 'flocs', which can settle faster through the water. The correct dose of a coagulant depends on the water being treated. The equipments for adding the chemicals should have as few moving parts as possible, and preferably not require electricity. Some turbulence is required to mix the chemicals thoroughly with the water. This can be achieved by passing the water over a weir, through a constriction, or around baffles, and no motor-driven equipment is necessary (Cairncross and Feachem, 1993).

Sedimentation can be accomplished in 'horizontal-flow' tanks in which the water moves from one end to the other, or in 'upward-flow' tanks, usually circular, in which the water enters at the bottom and is taken off at the surface (Fig. 6.75). They are often more efficient than horizontal-flow tanks and typically have retention times in the range 1 – 3 hours as opposed to 4 – 6 hours for horizontal-flow designs. They therefore have smaller volumes, though they may not cost less.

Horizontal-flow tanks are considerably easier to build because they need not be as deep as upward-flow tanks and they have fewer internal walls. They are also easier to operate. Horizontal-flow tanks perform better with heavily silted waters than the upward-flow type, which become increasingly difficult to operate once the suspended solids exceed 1000 mg/l (Cairncross and Feachem, 1993), as occurs in some tropical rivers. In addition, the viscosity of water is lower in warm climates, so that flocs can settle more rapidly, and large horizontal-flow tanks can be an appropriate and economical solution.

A third type combining some advantages of the other two is the spiral-flow tank, developed for treating the heavily silted water of the Nile (Fig. 6.76). Further details are given by Twort et. al (1985).

Alum assisted sedimentation can also be used for the removal of fluoride. This is known as the Nalgonda process (Cairncross and Feachem, 1993), and requires a much higher alum dose than is usual for conventional water treatment. The exact dose required depends on the hardness of the water and the amount of fluoride to be removed, but is typically 600 mg/l of hydrated alum (Cairncross and Feachem, 1993), or about twenty times the typical dose for ordinary sedimentation. However, this method is expensive and the use of an activated alumina bed, although more complicated, would be cheaper. Both methods of fluoride removal are complicated to perform and there is no simple check that the process is being reliably operated. Surface water, although requiring treatment to remove silt and pathogens, is therefore frequently preferable to ground water containing dangerous amounts of fluoride.

The chemicals required to assist sedimentation are often applied in powder form by a 'dry feeder'. But the powder tends to 'cake' and clog the machine in humid, tropical conditions so that a solution feeder is preferable.

Filtration :

The most commonly used method of filtration is the rapid sand filter, in which water passes downwards through a sand bed about 0.45 – 1.0 m thick, at a rate of over 5 m/h. The water is driven through the bed either by gravity or by pressure. The bed requires cleaning at frequent intervals, usually at least once a day. This involves 'backwashing' by forcing water, or air followed by water, upwards through the bed for a period of time. Various modifications and simplifications in the control of the filtration rate and of backwashing have been developed (Cleasby, 1972), and are especially appropriate in developing countries.

However, because of their construction cost, their complexity, and their need for regular backwashing, rapid sand filters are inappropriate for many applications in developing countries. In those occasions, slow sand filters are more suitable. They are simple to build and operate, and also improve microbiological water quality substantially, a result the other types of filter cannot reliably achieve.

Slow sand filters are so called because the water moves down through them at a rate of only 0.2 m/h. This means that the filter beds for a large town can take up a considerable area of land, but land prices in developing countries tend to be low, so that this is not usually a severe constraint.

Fig. 6.77 shows a simple design for a slow sand filter. It consists of a large tank, in which water stands about 1 m deep over a bed of carefully graded sand. The raw water filters down through the sand to a set of underdrains, which can be made with ordinary bricks laid without mortar beneath gravel, and is collected in an outlet chamber before passing down the vertical outlet pipe. The top of the outlet pipe is fixed above the level of the sand surface to avoid negative pressures in the sand bed, and thus prevent air being entrapped.

The sand bed is 600 to 900 mm deep (Cairncross and Feachem, 1993), but most of the filtration takes place in the top layer. At the very top of the sand bed, a dense slimy layer of retained fine material develops, with an active flora and fauna. This biologically active zone is responsible for most of the water-quality improvement provided by a slow sand filter. In particular, this layer retains or kills the great majority of viruses, bacteria, protozoal cysts, and helminth eggs and thus makes the slow sand filter a far more efficient pathogen-removing process than the rapid sand filter.

Over a period of time, the development of biological film increases the resistance of the filter bed to the flow of water, and it is necessary to clean it every few weeks. This is done by removing 20 mm of sand from top of the bed (Cairncross and Feachem, 1993). If cleaning is required more than once a week, it means either that the sand is too fine, the flow too fast, or the water too dirty. The water may be improved before filtering by sedimentation, or by prefiltration using coarse media, such as coconut fibre or burnt rice husks.

Disinfection :

Slow sand filters improve the microbiological quality of water considerably, but if water completely free of pathogens is required, it is necessary to apply a chemical disinfectant. In practice, all urban water supplies require disinfection. Chlorine is the disinfectant most readily available and suitable for use in most circumstances.

Chlorine demand : Chlorine is an oxidizing agent. If it is added to impure water, it will immediately oxidize the impurities and no longer be available for disinfection. It is therefore essential that the chlorine dose should be greater than required to satisfy the immediate 'chlorine demand' of the water. This chlorine demand will vary, depending on the quality of the water. Roughly speaking, 1 mg/l of chlorine is required to satisfy 2 mg/l of BOD (Cairncross and Feachem, 1993). If an adequate dose is used to satisfy the chlorine demand, a 'residual' of chlorine remains which provides protection against contamination occurring during subsequent distribution of water.

Chlorine residuals are of two kinds, free and combined. After the chlorine demand is satisfied, the hypochlorous acid and chlorite ions are free residuals. If ammonia is present in the water, the chlorine combines with it to form chloramines, known as combined residuals. A graph of the total residual, both free and combined, against the dose of chlorine added to a water may show a characteristic curve like that in Fig. 6.78.

The chlorine dose must be sufficient to produce the desired free residual, after satisfying the chlorine demand. A minimum free residual of 0.3 mg/l is recommended, with a contact period of 30 minutes. Free chlorine is less effective as a disinfectant at high pH and low temperatures. A longer contact time is required in such conditions.

The chlorine demand can be estimated by adding various large doses to the water and measuring the free residuals they produce :

$$(\text{demand}) = (\text{dose}) - (\text{residual})$$

Than, the demand and the desired residual are added to determine the necessary dose. Even quite clean water is likely to have a chlorine demand of about 2 mg/l.

Control of the dose : The aim of free-residual chlorination is to ensure a free residual in the water until it is supplied to the public. To check that the chlorine dose is sufficient, the residual should therefore be measured in samples taken from various points throughout the distribution system. A suitable arrangement is to check the residual in the water leaving the treatment works once every shift – two or three times a day – and to check samples from the distribution system once a week.

Samples from the distribution system should not be taken from dead-end pipes. It is convenient to take them from institutions such as schools, fire stations and hospitals. The tap should run for several minutes before filling the sample bottle, to ensure the water is form the mains, and not the internal pipeworks. The absence of a free residual in only one part of the system suggests that pollution is entering the mains nearby, and should be dealt with by repairing the mains rather than increasing the dose. The tests should be conducted at the sampling point, immediately after collecting the sample, so that the residual does not have time to change before testing.

Sources of chlorine : There are many types of chlorine to chose for application in a urban treatment plant.

(1) Gas : In large scale water treatment plants, chlorine is obtained as liquefied gas cylinders. Chlorine gas is poisonous. For small supplies, the complex equipment needed to apply chlorine gas and the precautions needed to handle it safely may be impractical.

(2) High test hypochlorite (HTH) : This can be obtained as a solution or in powder form. It contains up to 70% available chlorine.

(3) Solutions : Proprietary disinfectants and bleaches may be used as chlorine sources. The disinfectants (like Milton, Zonite) typically contain about 1% of available chlorine by weight. They may be used directly, without dilution, as 1% stock solution. The bleaches (like Chlorous, Chlorox) usually contain 3-5% of available chlorine and must be diluted to make up a 1% stock solution. Chlorine solutions are unstable in warm climates. They should be kept in brown or green bottles, well-stoppered, and stored in dark, cool places.

(4) Powder : Bleaching powder or chlorinated lime (calcium hypochlorite) may also be used. It contains about 30% of available chlorine when fresh but the strength rapidly diminishes when the container is opened. Even when unopened, long periods of storage can lead to reduced strength. It is best to open the container and use the entire contents immediately to make up a 1% stock solution. The inert lime will settle in a few hours leaving the active chlorine in the clear solution which can then be poured off and kept as described above.

(5) Tablets : Various kinds of chlorination tablet are on the market. They are expensive and are suitable mainly for the short-term protection of small quantities of water. Tablets of calcium hypochlorite containing 60 — 70% available chlorine are made for use in tablet chlorinators.

The application of chlorine :

Chlorine needs at least half an hour in contact with water to disinfect it. It is therefore applied before the water enters a storage tank, so that it can take effect during storage. It helps if the chlorine is applied just upstream of a weir, a water meter, a sharp bend, or some other point where turbulence of water will help to mix the chlorine. The chlorinated water should not be exposed to sunlight after dosing, as that would remove the protective residual.

Chlorine would kill off the organisms in a slow sand filter, so that it should never be added before slow sand filtration. Besides, the chlorine demand of raw water, and its tendency to vary over time, is reduced by purification, so it is preferable to apply chlorination after other treatment processes, although chlorine is sometimes also added before hand to control algae in the treatment works.

Chlorine gas is not applied direct to water, but used to form a strong solution in a small quantity of water which is then injected into the main stream. This ensures that the chlorine is fully dissolved. It is done by a chlorinating apparatus designed to keep the dosing rate constant and independent of the pressure in the cylinder, which varies widely with temperature.

Some chlorinators are activated by the flow through the dosed pipe, using a small by-pass from a constriction as the injector pipe. More sophisticated control devices use an automatic measurement of the downstream residual to control the input of chlorine or sulphur dioxide, but they are an unnecessary complication in a small treatment works.

For small town supplies, especially in remote areas, chlorine is usually applied in the form of hypochlorite solution. Solution feeders, such as that in Fig. 6.79, can supply a chlorine solution at a rate proportional to the flow in the main and can be operated electrically, or preferably, by the energy of the water flow provided that a minimum head is available.

Chlorine can also be applied in a solution by various drip-feed devices which can be set to add chlorine solution at an approximately constant rate (Fig. 6.80). Some other types of drip-feed devices are described by Assar (1971) and Pickford (1977). However, it is less easy to make them stop automatically when there is no flow in the dosed water pipe, and they are not normally used for dosing water at high pressure. Those using single orifices or jets to regulate the flow are unreliable when used over extended periods, as the jets become encrusted with chloride deposit.

Several devices are available to add chlorine to water by the erosion of tablets of calcium hypochlorite (Fig. 6.81). This system is convenient and easy to operate but the tablets are more costly than hypochlorite powder and it is sometimes difficult to guarantee the supply of tablets.

6.7.2 Distribution

In many cities of the developing countries, the water distribution system is one of the biggest headaches of the municipal water supply system. Sometimes as much as 60% of the water entering the system may be unaccounted for, and for much of the day the water pressure may be inadequate to reach areas at all, let alone meet their potential fire-fighting needs. The problems of distribution systems are as follows.

1. Unauthorized connections : Numerous unauthorized connections made to the water mains by private individuals is an enormous problem in many cities of developing countries.This may result from high water charges, from delays or corruption in the allocation of water connections, or from a refusal to provide connections to squatters. The resulting erosion of the water authority's revenue makes it hard to lower the charges, the leakage from badly installed unauthorized connections diverts the authority's resources (so making it difficult to shorten the delays), and attempts to police these illegal connections frequently result in increased corruption. There is no simple solution to the problem, but it is probably more constructive for the water authority to reduce its connection charges, to provide more public standpipes or to offer technical assistance to householders wishing to make their own connections.

2. Damage of public water points : In many cases, the public water points are frequently damaged. Water is wasted by leaking taps, and money is wasted in repeatedly repairing them. The provision of more public water points does not necessarily increase community water use, but reduces the number of households using each. A water point serving a small group of families is more likely to be looked after and less likely to be broken by overuse or vandalism. It may even be possible to levy a water rate from them jointly. Proper institutional arrangements are necessary to ensure that it is in the interests of an identifiable individual to look after a water point. He or she may be an elected citizen, a municipal employee, or a concessionaire who pays for the right to sell water from a water point, in return for an obligation to maintain it.

3. Over loaded system : The capacity of the system is often far exceeded by the water demand of the community. The rapid, but variable, growth in the urban population of most developing countries is one cause for this. Again, an improvement in the water supply can itself cause a significant increase in water demand. Some people begin to use a community water supply when the level of provision improves, having transferred from some alternative source such as a private well. Others use many times more water. While households served by standpipes use only 15 — 30 l/person/day, households with yard connections typically use two to four times

as much, and those with house connections use still more. Further, households with lawn watering can use 30 times as much. However, there is substantial room for uncertainty in these figures, which could be reduced by empirical observation and measurement of existing water use, particularly at times of peak demand. When designing a distribution system, accurate population predictions are often impossible to make, but which may be less important than estimation of domestic water use per capita and its future rate of increase.

4. Leakage : High rates of leakage further overburden the distribution system. Typically, 30% of the water treated and pumped into the water supply system of a developing country town, and sometimes as much as 60%, is lost in this way. It may result from incompetent pipe-laying, from exposure of mains by soil erosion, from construction of houses over mains due to poor physical planning, or from sheer age of the system. Leaky distribution mains are of particular concern with intermittent supplies and where there are low pressures, as pollution from drains and sewers may enter through the leaks when the pressure drops. Even if the overall pressure is positive, hydrodynamic effects at bends and constrictions can cause localized negative pressures sufficient to suck in pollution. Distribution mains should therefore be laid at shallower depth than any adjacent foul sewers. Repair of leaking mains is made more difficult by the lack of accurate records showing pipe routes. Leakage detection methods are described in standard texts and beyond the scope of this book.

Since the rate of leakage ie roughly proportional to the pressure in the mains, a possible stopgap measure is to reduce the pressure where possible, although minimum pressure for fire-fighting must be maintained at peak times. The ultimate solution to the problem of an old and inadequate system is to replace it with one built to last. If it is completely replaced, the old distribution system may be kept for garden-watering, fire-fighting, etc.

The problem of low pressure is aggravate where there are no regulations to prevent direct pumping from water mains by consumers. This further reduces the pressure in the distribution system, and can even cause negative pressures. Pumping, to the tops of high buildings for instance, should only be permitted from storage tanks fed by gravity from the mains.

In many towns and cities, the overburdening of the system leads to its providing only an intermittent supply of water, which can have serious health consequences. The drop in pressure in a leaky distribution system when the supply is shut off can allow pollution of the supply, for instance from leaking sewers and from open drains. Another effect of intermittent supplies is that people collect water in larger quantities and store it for longer periods. Individuals going to public taps make fewer journeys and collect more at each journey, while those with house connections fill basins and baths with water to be used during periods when the supply is off. These practices may promote contamination of the water before it is used and therefore increase water-borne disease transmission. They may also provide new breeding sites for the mosquitos. Higher residual chlorine levels should be maintained in intermittent water supplies.

Economics of urban water supply system :

Urban water supplies are, as economists say, a 'lumpy' investment. This means that an extension to a town's water supply cannot normally be made gradually, but usually requires a lump sump expenditure. Even a small increase in the size of a pipeline (diameter) requires a whole new pipeline, for instance, and the capacity of a dam reservoir cannot usually be increased without a new dam. It is therefore economically worthwhile to plan urban water supplies to last for more than one or two decades, particularly in view of the low rates of interest on loans available for water development and the long service lifetime of modern piping.

This is particularly important where distribution systems are concerned, as their cost depends primarily on the length of the pipe installed and only secondarily on its diameter. Since the health benefits of water supply are greater when water is provided in the home, diameters should if possible be chosen to pass the flows which will result from future improvements in the level of service, at least to the yard connection level. When deciding on the characteristics of a distribution system, the following working rules may be helpful for estimating the relative costs of the various options (Cairncross and Feachem, 1993).

In a typical urban water supply, the cost of the distribution system accounts for about one third of the total construction cost. A sizeable increase in flow through a pipe is permitted by a relatively small increase in its diameter. So the cost of a distribution network depends roughly on the square root of the volume of water use per capita for which it is designed. Twice as much water may be supplied through a distribution system costing only 50% more.

For a given rate of water use per capita, the length of piping in a system varies approximately with the square root of the number of taps or connections it serves. Since the additional piping required to supply more taps tends to be smaller, the total cost only increases with the forth root. This means that, if a system with only one tap for each 500 people costs US $15 per person, it could be extended to give one tap for every 30 people (six families) at an additional cost of only $15 per person. This does not include the cost of the standpipes themselves.

A progressive system of connection charges may be used in the same way as a progressive tariff system to make the richer consumers cross-subsidize the poor ones, and to cover the cost of extensions to the network.

Service reservoir and water towers :

Frequently and whenever ground conditions permit, service reservoirs should be provided to command the supply to a single pressure zone of limited extent. If the area of the zone is excessive, large sized pipes will have to be used to convey peak flows to more distant points. Costs can be minimized by so locating service reservoirs that the peaking of flows in the main is reduced. At the same time, however, where the capacity of a new system will be absorbed only slowly over a long period (say 8-15 years) some saving can be achieved by delaying construction of some of the service reservoirs until the demand on the system reaches the capacity of the pipework.

Service reservoirs have also a second but equally important function; that of providing a reserve of water in the event of failure of the incoming supply. Considering both peak lopping and reserve, experience indicates that storage equivalent to the supply needed for 10-12 hr is probably the minimum to be expected, and that the provision of storage equivalent to 24 hr is common practice (IWES, 1983).

6.7.3 Water demand management

The important influence of per capita water demand on total community water use has already been mentioned. However, it have to be considered that water demand is not an independent, uncontrollable factor. On the contrary, the level of service to be provided, and hence of water consumption, must be chosen in accordance with the means available to provide it. Increase in capacity can be avoided, delayed, or reduced by measures to manage water demand and produce economics in water use. Such measures would bring similar benefits to waste water disposal, because less water used means less wastewater to be disposed of.

The demand on a water supply may be reduced without a fall in the standard of service by the following methods :

1. Leakage reduction
2. Tariff policy
3. Water saving taps and fittings
4. Consumer education and information

1. Leakage reduction

Leakage has been discussed before. The others are discussed in turn.

2. Tariff policy

Simply introducing water meters to houses with private connections can lead to substantial reductions in water demand. For examples, domestic consumers in towns in the Netherlands whose water is metered use 30% less water than in those with unmetered delivery (Cairncross and Feachem, 1993).

Water meters also permit the introduction of a *'progressive'* tariff policy. This means that the largest consumers, much of whose water goes for luxury uses such as lawn-watering and car-washing, would pay more per unit volume than the cost of supplying it. Besides helping to reduce the wasteful use of water, the surplus revenue can cross-subsidize the users of free water from standpipes as well as other poor, small consumers who use the water for their basic needs. A nominal charge may be levied for a minimal amount (say 10 cu. meter/month) of water, while water tariffs would increase progressively, for larger volumes.

Progressive water tariffs are not a new idea, more than 20 developing countries have already put them into practice (Cairncross and Feachem, 1993). In the capital city of an East African country, it is reported that (Warford & Julius, 1979), the majority of the population use relatively small quantities of water which could be subsidized by the massive consumption of the rich few.

The problem with meters is that they are expensive to install and replace. In most developing countries, they have to be imported. One African country found that the cost of replacement water meters was taking up half the yearly allowance of foreign exchange for the whole urban water sector (Cairncross and Feachem, 1993). Intermittent supplies cause special problems; when the pressure comes on, the rush of air through a meter can cause it to give a false high reading. This may lead the meters to vandalized by an angry, overcharged consumer. Moreover the meters may be damaged by the impact when the water first reaches it. In Lahore, Pakistan, a World Bank study found that the average meter lasted only 5 years, and that metering would have to reduce water consumption by 80% for the meters to be worth the cost — assuming that those meters which worked were regularly read (Cairncross and Feachem, 1993). One option to overcome this problem is to selective metering. Households with only a single tap do not usually use large amounts, and could pay a nominal monthly rate, dispensing with the needs for meters. An alternative form of tariff, which can also be progressive and avoids metering, though it will not constrain water demand, is one based on house values.

3. Water saving taps and fittings

Devices are now available which can be installed in line on private connections or on individual taps and which restrict flow to a fixed amount irrespective of the pressure in the mains. These are simple to manufacture, cheap and easy to install.

Special shower nozzles and spray taps for sinks are increasingly used, and can give the same washing efficiency with less than a quarter of the flow of water from conventional fittings. A range of waste-saving taps and other control devices is described by IRC (1979) and UNCHS (1989).

The enormous volumes of 10 – 20 liters which are used to flush conventional cistern-flush toilets are unnecessary for efficient operation. In the developed countries, they account for one-third to one-half of domestic water use, but can be reduced to about 3-6 l/flush, as the more efficient cisterns and flushing pans in Scandinavia (Cairncross and Feachem, 1993). The introduction of such fittings can be assured by building regulations and bye-laws, and by government house building policy.

4. Consumer education and information

Publicity campaigns to reduce water wastage and unnecessary consumption have been successful in a number of developed countries, and it is likely that, if socio-cultural preferences are taken into account, similar campaigns would prove equally effective in developing countries.Information on water supply systems could advantageously be coupled with health education aimed at schools, factories, and clinics, focusing on the relationship between health, water, and excreta and sullage disposal.

6.7.4 Groundwater supply

Ground water is a major water source for many urban water supplies in the developing countries. The quality of the ground water is dependent upon many factors, such as depth of the well, existing geological formations, distance from sources of pollution, and demand for groundwater in the vicinity.

The degree of treatment required for the ground water varies greatly depending almost exclusively upon the quality of the water. In some areas, the water only needs chlorination before use. In other areas, where water is of poor chemical, physical, and biological quality, the water must undergo complete treatment like that for surface supplies discussed in the previous section. For example if the water contains hydrogen sulphide, aeration and chlorination are the basic treatments.

Table 3.1.
Typical domestic water usage

Type of Water Supply	Typical Water Consumption (litres/capita/day)	Range (litres/capita/day)
Communal water point (e.g. village well, public standpost)		
- at considerable distance (> 1000 m)	7	5 - 10
- at medium distance (500 - 1000 m)	12	10 - 15
Village well		
walking distance < 250 m	20	15 - 25
Communal standpipe		
walking distance < 250 m	30	20 - 50
Yard connection		
(tap placed in house-yard)	40	20 - 80
House connection		
- single tap	50	30 - 60
- multiple tap	150	70 - 250

Table 6.1 (IRC, 83)

Table 3.2.
Various water requirements

Category	Typical Water Use
- Schools	
. Day Schools	15 - 30 l/day per pupil
. Boarding Schools	90 - 140 l/day per pupil
- Hospitals	
(with laundry facilities)	220 - 300 l/day per bed
- Hostels	80 - 120 l/day per resident
- Restaurants	65 - 90 l/day per seat
- Mosques	25 - 40 l/day per visitor
- Cinema Houses	10 - 15 l/day per seat
- Offices	25 - 40 l/day per person
- Railway and Bus Stations	15 - 20 l/day per user
- Livestock	
. Cattle	25 - 35 l/day per head
. Horses and Mules	20 - 25 l/day per head
. Sheep	15 - 25 l/day per head
. Pigs	10 - 15 l/day per head
- Poultry	
. Chicken	15 - 25 l/day per 100

Table 6.2 (IRC, 83)

Table 5.1 Diameters for gravity pipelines (mm)

Flow (l/s)	Steel		Polythene		Bamboo		PVC	
	Flat	Steep	Flat	Steep	Flat	Steep	Flat	Steep
0.10	19	19	12	12	25	19	19	12
0.15	25	19	19	12	32	25	19	19
0.20	25	19	19	12	32	25	25	19
0.30	32	25	25	19	32	25	25	19
0.40	32	25	25	19	37	32	25	25
0.60	37	32	32	25	50	32	32	25
0.80	50	32	32	25	50	37	37	32
1.00	50	37	37	32	62	50	37	32
1.50	62	50	50	32	76	50	50	37
2.00	62	50	50	37	76	62	50	37
3.00	62	50	62	50	76	62	62	50

'Flat' is < 1:15
'Steep' is > 1:15

Table 6.3 (C & F, 93)

Table 4.1.
Precipitation and evaporation rates by continent

Continent	Precipitation mm/year	Evaporation mm/year	Run-off mm/year
Africa	670	510	160
Asia	610	390	220
Europe	600	360	240
North America	670	400	270
South America	1350	860	490
Australia and New Zealand	470	410	60
Mean values derived after weighting according to area	725	482	243

Table 6.4 (IRC, 83)

Table 2. Water sources and potential contaminants

Source	Contaminant
Deep groundwater (boreholes)	*Fe, Mn* Colour, H_2S, NO_3, NH_3, CO_2 (pH)
Shallow groundwater	*Fe, microorganisms* NO_3, NH_3
Infiltration water	*Fe, colour, organic matter, taste*
Spring waters	*Fe,* CO_2 *(pH)*
Rainwater (cisterns)	*Microorganisms, constituents of atmospheric pollution, pH*
Surface waters (streams, rivers, lakes and reservoirs)	*Suspended solids, microorganisms, colour, algae, taste, odours, organic matter* NO_3, NH_3

Note: The most important contaminants relevant to each source type are italicized. They are considered important when they are directly associated with, hinder, or are caused by, the control of microbiological quality.

Table 6.5 (WHO, 82)

Table 4. Applicability of sources to rural or dispersed communities

Type of source	Applicable to isolated houses or farms and small communities (yield <2 l/s)	Applicable to larger communities (yield >2 l/s)
Groundwater		
Spring water	yes	yes
Galleries	no	yes
Deep groundwater (boreholes)	yes	yes
Shallow groundwater (wells)	yes	yes
Infiltration galleries	no	yes
Surface water		
Streams and rivers	yes[a]	yes
Lakes	yes[a]	yes
Reservoirs	yes[a]	yes
Direct catchment		
Rainwater (cisterns)	yes[b]	no

[a] It is necessary to take into account that these types of source need the kind of treatment that may not be easily available for the smallest supplies.

[b] Due to the limitations set by seasonal variation in quantity and quality, and by the storage required, the use of rainwater is not advised unless no other source is practicable.

Table 6.6 (WHO, 82)

Table 10.1.
Information on types of pumps

Type of Pump	Usual depth range	Characteristics and Applicability
1. RECIPROCATING (plunger)		low speed of operation; hand, wind or motor powered; efficiency low (range 25 - 60%)
a. Suction (shallow well)	up to 7 m.	capacity range: 10-50 l/min; suitable to pump against variable heads; valves and cup seals require maintenance attention.
b. Lift (deep well)		
2. ROTARY (positive displacement)		low speed of operation; hand, animal, wind powered;
a. Chain and bucket pump	up to 10 m.	capacity range: 5-30 l/min. discharge constant under variable heads.
b. Helical rotor	25 - 150 m. usually submerged	using gearing; hand, wind or motor powered good efficiency; best suited to low capacity - high lift pumping.
3. AXIAL - FLOW	5 - 10 m.	high capacity - low lift pumping; can pump water containing sand or silt.
4. CENTRIFUGAL		high speed of operation - smooth, even discharge; efficiency (range 50-85%) depends on operating speed and pumping head.
a. Single-stage	20 - 35 m.	requires skilled maintenance; not suitable for hand operation; powered by engine or electric motor.
b. Multi-stage shaft-driven	25 - 50 m.	as for single stage. Motor accessible, above ground; alignment and lubrication of shaft critical; capacity range 25 - 10,000 l/min.
c. Multi-stage submersible	30 - 120 m.	as for multi-stage shaft-driven; smoother operation; maintenance difficult; repair to motor or pump requires pulling unit from well; wide range of capacities and heads; subject to rapid wear when sandy water is pumped.
5. AIR LIFT	15 - 50 m.	high capacity at low lift; very low efficiency especially at greater lifts; no moving parts in the well; well casing straightness not critical.

Table 6.7 (IRC, 83)

human energy	HANDLE MECHANISM
animal energy	TRANSMISSION RACK
fossil fuel	COMBUSTION ENGINE
electricity (grid)	ELECTRIC MOTOR
hydropower	HYDRAULIC RAM PUMP
	TURBINE OR RIVER - CURRENT ROTOR
wind energy	LOW SPEED MULTI-BLADE WIND ROTOR
	HIGH SPEED ELECTRICITY GENERATING WIND ROTOR + ELECTRIC MOTOR
solar energy	PHOTOVOLTAIC ARRAY + ELECTRIC MOTOR
	DIGESTER + COMBUSTION ENGINE
biomass energy	GASIFIER + COMBUSTION ENGINE
	ALCOHOL FERMENTER + COMBUSTION ENGINE

Figure 1.1: Overview of energy sources and conversion devices for water pumping systems

Table 6.8 (IRC, 86)

Factors	Selection criteria	Information required
Environmental feasibility	Availability of energy sources	– data on energy sources – hydrology – climate – topography
Technical feasibility	Existing level of technological infrastructure	– design – manufacture – installation – operation – maintenance
Social feasibility	Social acceptability of energy source and pumping device	– social structure – organization – potential for productive water use – willingness and – capacity to pay
Economic feasibility	Cost-effectiveness of energy device	– cost data – time profile of costs – economies of scale – local manufacture

Figure 2.1: Systematic assessment of relevant factors in selection of energy sources for water pumping

Table 6.9 (IRC, 86)

Table 2.1: Indication of minimum requirements for environmental feasibility of renewable energy sources

Renewable energy source	Minimum requirements for environmental feasibility
Micro-hydropower	
hydraulic ram pumps	average monthly flow rate of at least 3-5 1/s in combination with a hydraulic head of at least 1 m
river-current pumps	minimum current speed of 1 m/s
Wind energy	
wind pumps	average annual wind speed greater than 3.5 m/s average wind speed in least windy month more than 2.5 m/s
Solar energy	
photovoltaic pumps	average annual solar irradiation at least 15 $MJ/m^2/d$ (4.0 $kWh/m^2/d$) solar irradiation in least sunny month more than 12.5 $MJ/m^2/d$ (3.5 $kWh/m^2/d$) clearness factor (lack of clouds) at least 60%
Biomass energy	
biogas production	humid climate, annual average temperature higher than 15°C
gasification	50-100 kg of dry wood or crop waste of 10-20 ha per day
alcohol production	200-400 ha of land for energy crop production

Table 6.10 (IRC, 86)

Table 2.2: Frequency of maintenance attention and level of technical skills required for various types of pumping devices

Energy source	Type of pumping device	Frequency of maintenance attention[1]	Technical skills[2]
Renewable			
micro-hydropower	hydraulic ram	low	low
	turbine pump	low	medium
	river-current pump	low	low
wind energy	commercially manufactured	low	medium
	intermediate technology	medium	medium
	village level product	high	low
solar energy	solar photovoltaic	low	high
biomass energy	biogas digester	high	medium
	gasification unit	high	high
	alcohol fermenter	high	high
Conventional			
human energy	hand pump	medium	low
diesel fuel	diesel engine	medium	medium
electricity	electric motor	low	medium

[1] Low, once a month; medium, once a week; high, daily

[2] Low, locally trained villagers; medium, trained operators (local mechanics, carpenters, blacksmiths); high, qualified technicians

Table 6.11 (IRC, 86)

Table 2.3: Indication of back-up service requirements for various types of pumping systems

Energy source	Type of pumping device	Frequency of back-up support required[1]	Level of back-up service required[2]
Renewable			
micro-hydropower	hydraulic ram	low	low
	turbine pump	low	medium
	river-current pump	low	medium
wind energy	commercially manufactured	low	high
	intermediate technology	medium	medium
	village level product	low	low
solar energy	photovoltaic	low	high
biomass energy	biogas digester	medium	medium
	gasification unit	medium	high
	alcohol fermenter	high	high
Conventional			
human energy	hand pump	low	medium
diesel fuel	diesel engine	medium	high
electricity	electric motor	medium	high

[1] Low, once a year; medium, once every 3-4 months; high, once a month

[2] Low, local mechanic; medium, specially trained mechanic; high, qualified technician

Table 6.12 (IRC, 86)

Table 2.4: Level of capital and recurrent costs of various types of pumping systems

Energy source	Type of pumping device	Capital cost	Recurrent costs
Renewable			
micro-hydropower	hydraulic ram	low	low
	turbine pump	low	low
	river-current pump	low	low
wind energy	commercially manufactured	high	low
	intermediate technology	medium	medium
	village level product	low	medium
solar energy	photovoltaic pumping system	high	low
biomass energy	biogas digester engine	medium	medium
	gasification unit engine	medium	medium
	alcohol fermenter engine	medium	medium
Conventional			
Human energy	hand pump	medium	low
diesel fuel	diesel engine	medium	high
electricity	electric motor	medium	low

Table 6.13 (IRC, 86)

Note: Table 6.14 is within the text.

Table 2.3: Guideline for the selection of a water treatment system for surface water in rural areas

Average raw water quality	Treatment required
Turbidity: 0-5 NTU Faecal coliform MPN*: 0 Guinea worm or schistosomiasis not endemic	– No treatment
Turbidity: 0-5 NTU Faecal coliform MPN*: 0 Guinea worm or schistosomiasis endemic	– Slow sand filtration
Turbidity: 0-20 NTU Faecal coliform MPN*: 1-500	– Slow sand filtration; – Chlorination, if possible
Turbidity: 20-30 NTU (30 NTU for a few days) Faecal coliform MPN*: 1-500	– Pre-treatment advantageous; – Slow sand filtration; – Chlorination, if possible
Turbidity: 20-30 NTU (30 NTU for several weeks) Faecal coliform MPN*: 1-500	– Pre-treatment advisable; – Slow sand filtration; – Chlorination, if possible
Turbidity: 30-150 NTU Faecal coliform MPN*: 500-5000	– Pre-treatment; – Slow sand filtration; – Chlorination, if possible
Turbidity: 30-150 NTU Faecal coliform MPN*: > 5000	– Pre-treatment; – Slow sand filtration; – Chlorination
Turbidity: > 150 NTU	– Detailed investigation and possible pilot plant study required

* Faecal coliform counts per 100 ml

Table 6.15 (IRC, 87)

Table 11.1.
Effectiveness of water treatment processes in removing various impurities

+++ etc. = increasing positive effect
o = no effect
- = negative effect

TREATMENT PROCESS WATER QUALITY PARAMETER	Aeration	Chemical Coagulation and Floc.	Sedimentation	Rapid Filtration	Slow sand Filtration	Chlorination
Dissolved Oxygen Content	+	o	o	-	--	+
Carbon Dioxide Removal	-	o	o	+	++	+
Turbidity* Reduction	o	+++	+	+++	++++	o
Colour Reduction	o	++	+	+	++	++
Taste and Odour Removal	++	+	+	++	++	+
Bacteria Removal	o	+	++	++	++++	++++
Iron and Manganese Removal	++	+	+	++++	++++	o
Organic Matter Removal	+	+	++	+++	++++	+++

* Turbidity of water is caused by the presence of suspended matter scattering and absorbing light rays, and thus giving the water a non-transparant, milky appearance.

Table 6.16 (IRC, 83)

Table 11.2.
Treatment of groundwater

WATER QUALITY	Aeration for		Plain Sedimentation	(Rapid) Filtration	Safety- or Post- Chlorination
	increasing O_2	reducing CO_2			
Aerobic, fairly hard, not corrosive					O
Aerobic, soft and corrosive		X			O
Anaerobic, fairly hard, not corrosive no iron and manganese	X				O
Anaerobic, fairly hard, not corrosive with iron and manganese	X		O	X	O
Anaerobic, soft, corrosive no iron and manganese	X	X			O
Anaerobic, soft corrosive with iron and manganese	X	X	O	X	O

(X = necessary, O = optional)

Table 6.17 (IRC, 83)

Table 11.3
Treatment of surface water

treatment process / water quality	Pre-chlorination	Chem.coag. and floc.	Sedimentation	Rapid Filtration	Slow Sand Filtration	Safety- or Post-chlorination
clear and unpolluted						0
slightly polluted, low turbidity				0	X	0
slightly polluted, medium turbidity			0	X	X	0
slightly polluted, high turbidity		X	X	X	X	0
slightly polluted, many algae	X	X	X	X		X
heavily polluted, little turbidity	X			X	X	0
heavily polluted, much turbidity	X	X	X	X		X

(X = necessary, 0 = optional)

Table 6.18 (IRC, 83)

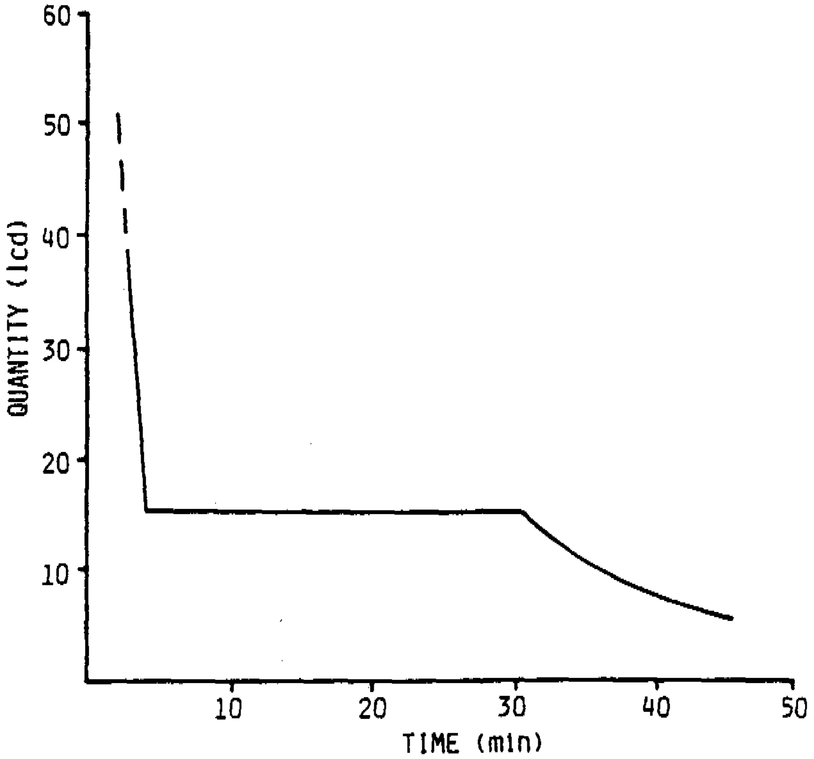
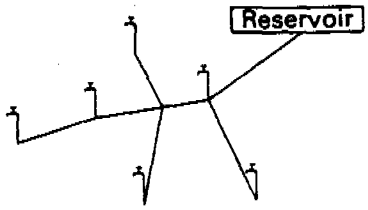
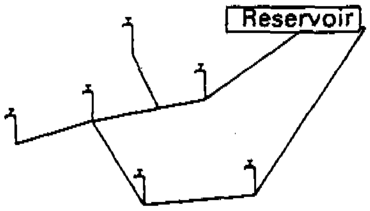


Figure 4.4 This graph relating domestic water consumption in litres *per capita* per day (l.c.d.) to the time required for water collection shows a plateau for times less than 30 min. The height of the plateau (i.e. average water usage by those in its range) depends on local circumstances. The plateau has been noted in studies in East, West and Southern Africa, Nicaragua and India

Fig 6.1 (C & F, 93)



(a) Dendritic system



(b) Ring main

Figure 5.1 Alternative village water supply distribution systems

Fig 6.2 (C & F, 93)

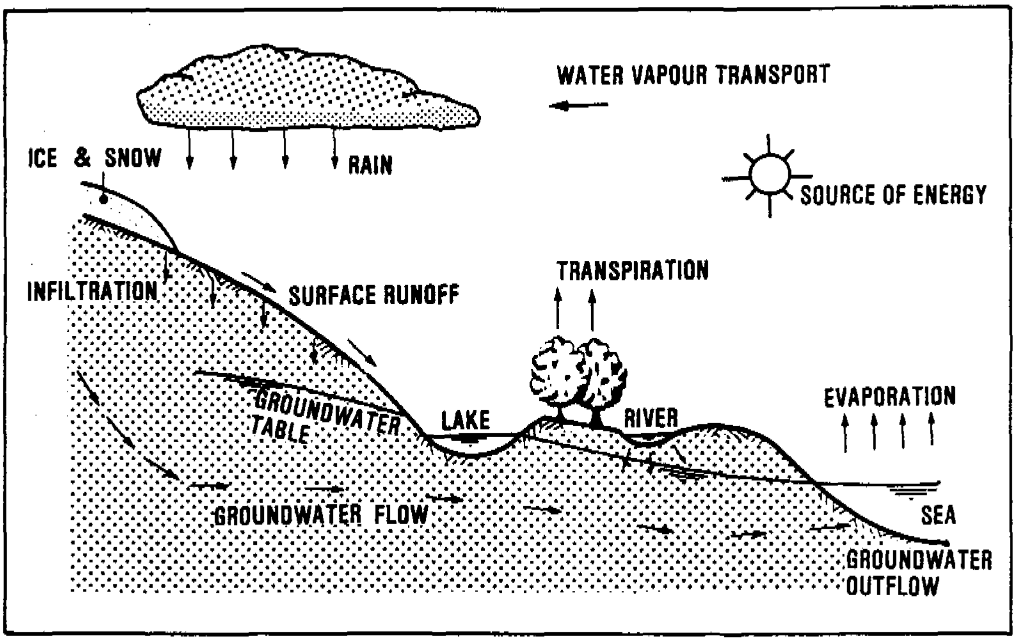


Figure 4.1.
Hydrological cycle

Fig 6.3 (IRC, 83)

Fig. 1. Source selection

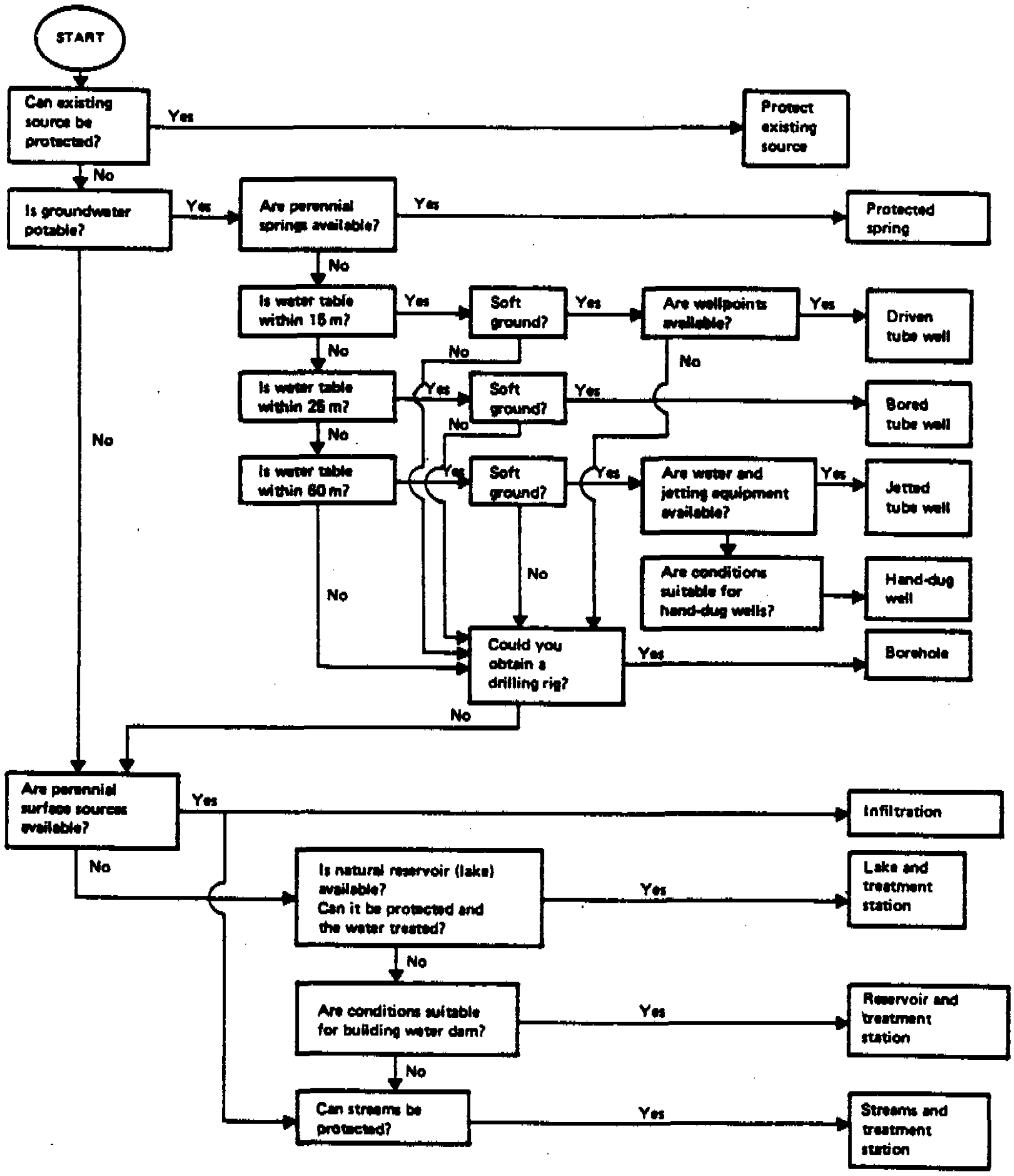


Fig 6.4 (WHO, 82)

Figure 1: Typical rainwater roof catchment system.

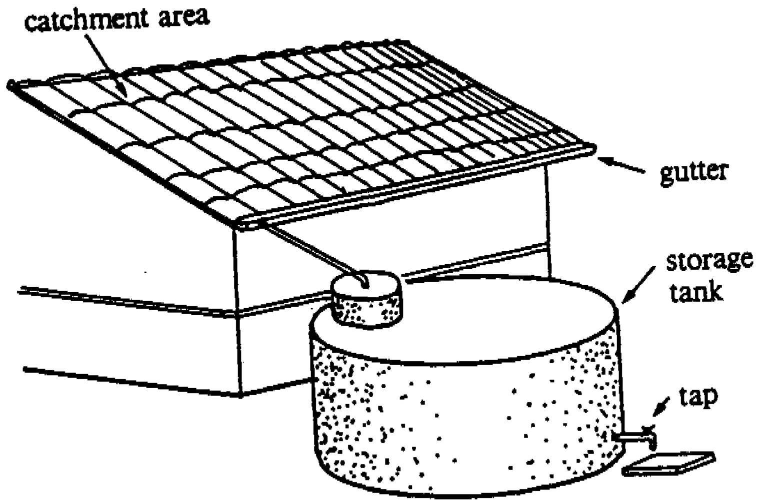


Fig 6.5 (WB 86)

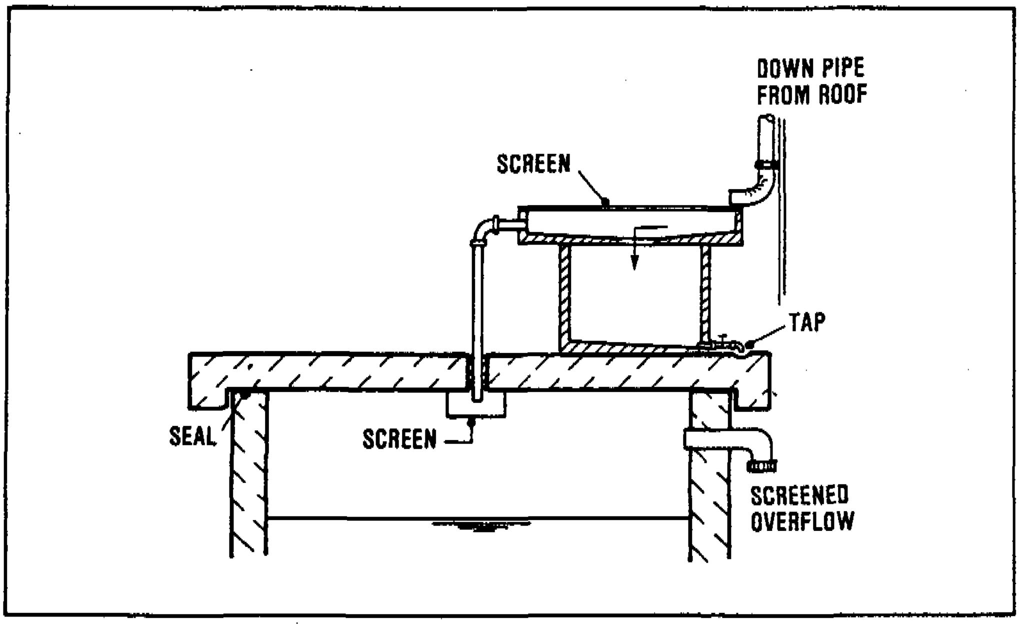


Figure 5.2.
Arrangement for diverting the 'first foul flush'

Fig 6.6 (IRC, 83)

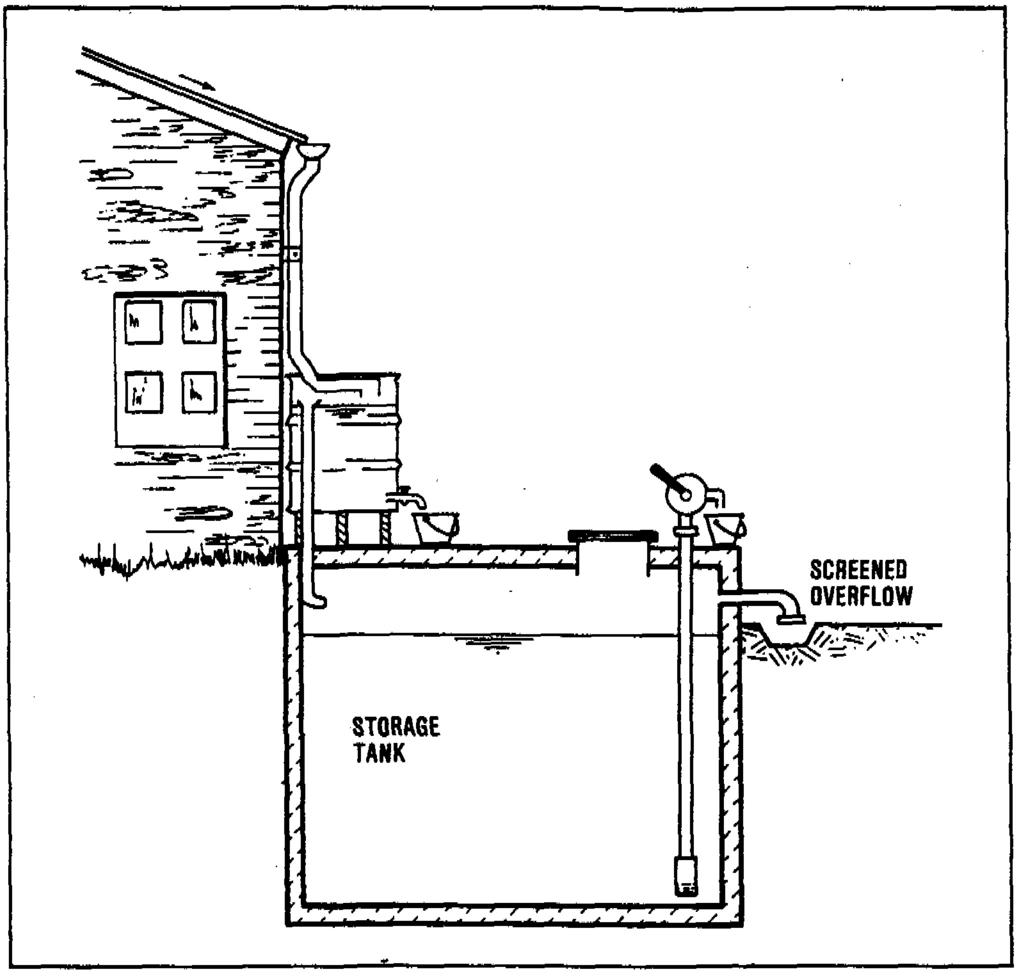


Figure 5.3.
Roof catchment and storage of rainwater (withdrawal by handpump)

Fig 6.7 (IRC, 83)

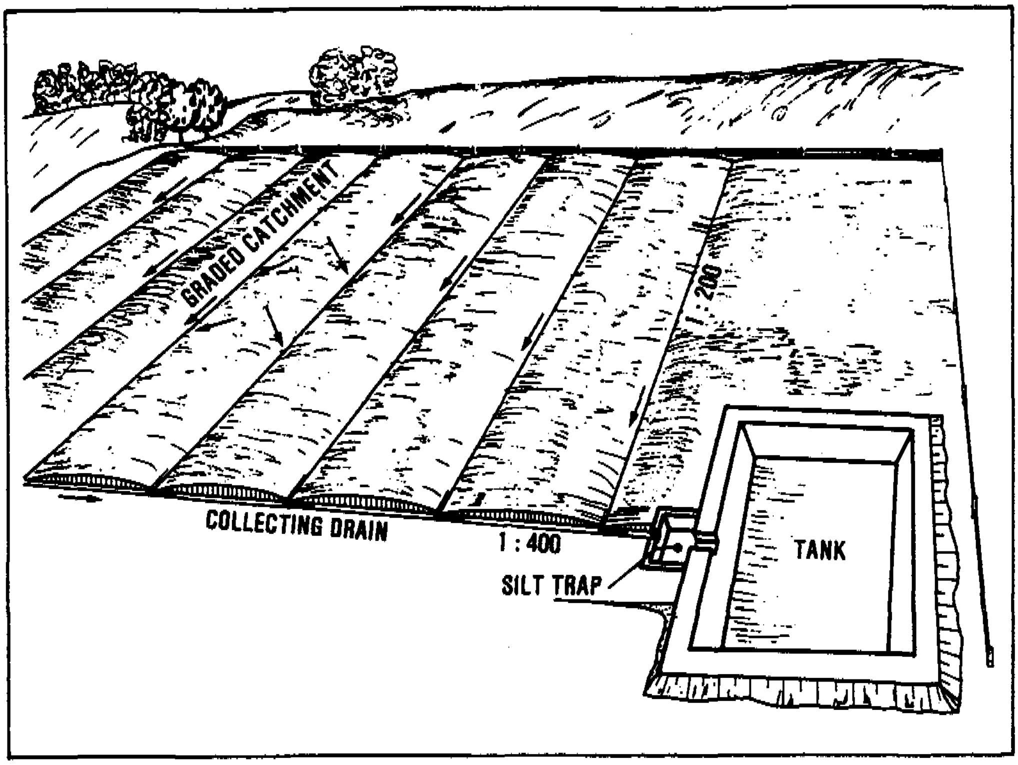


Figure 5.4.
Ground catchment

Fig 6.8 (IRC, 83)

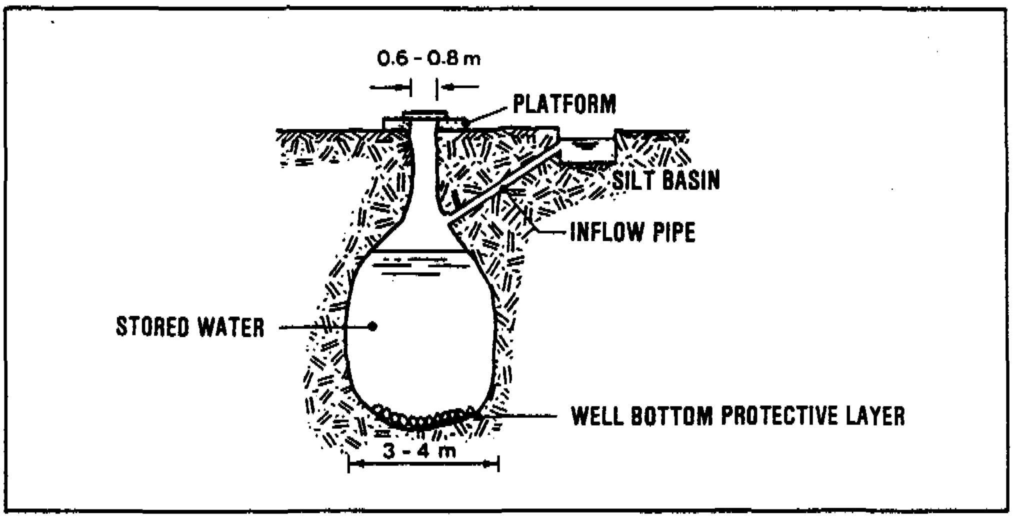


Figure 5.5.
Underground rainwater storage well
(as used in China)

Fig 6.9 (IRC, 83)

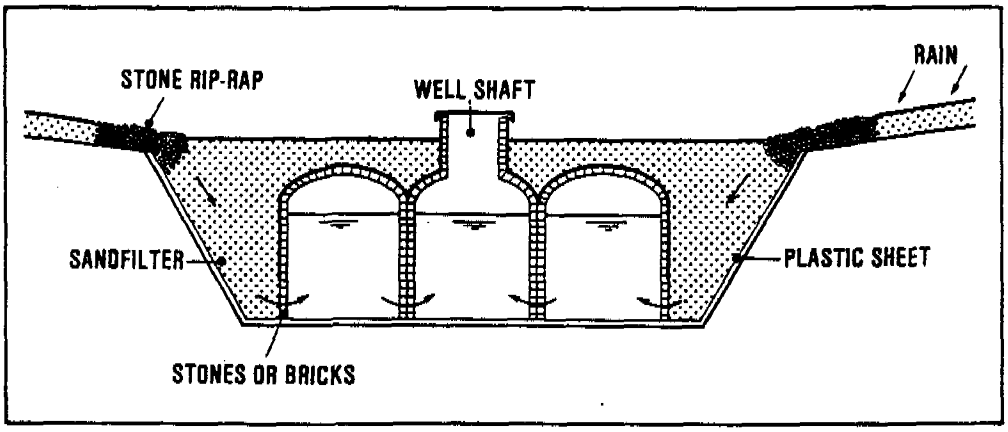


Figure 5.6.
Cistern built of polythene tubes

Fig 6.10 (IRC, 83)

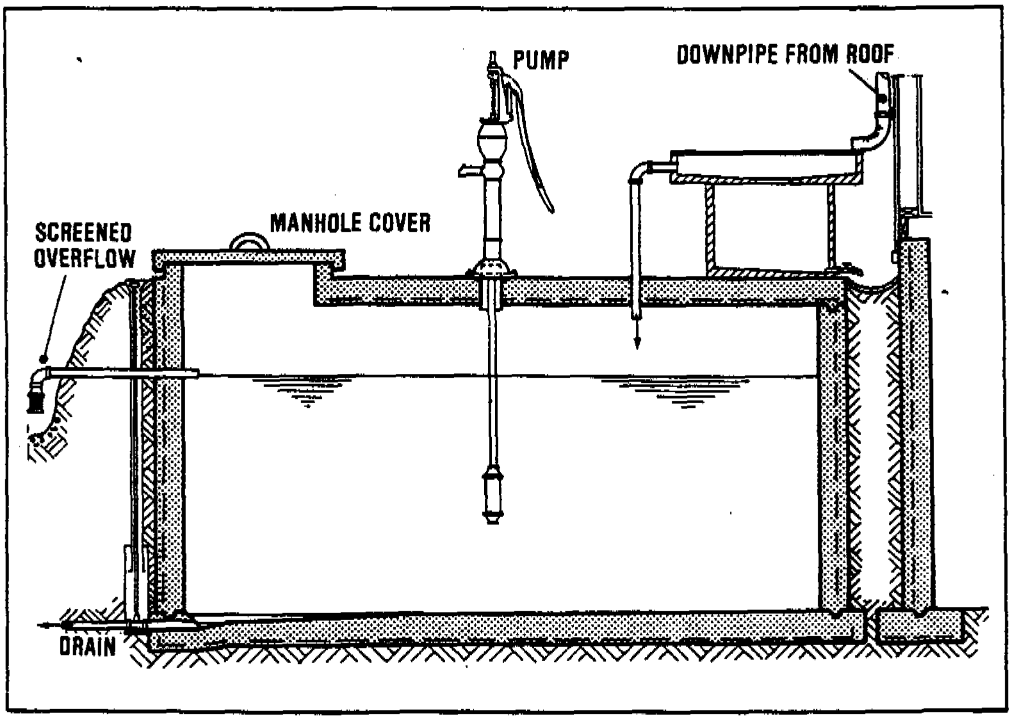


Figure 5.7.
Rainwater storage arrangement

Fig 6.11 (IRC, 83)

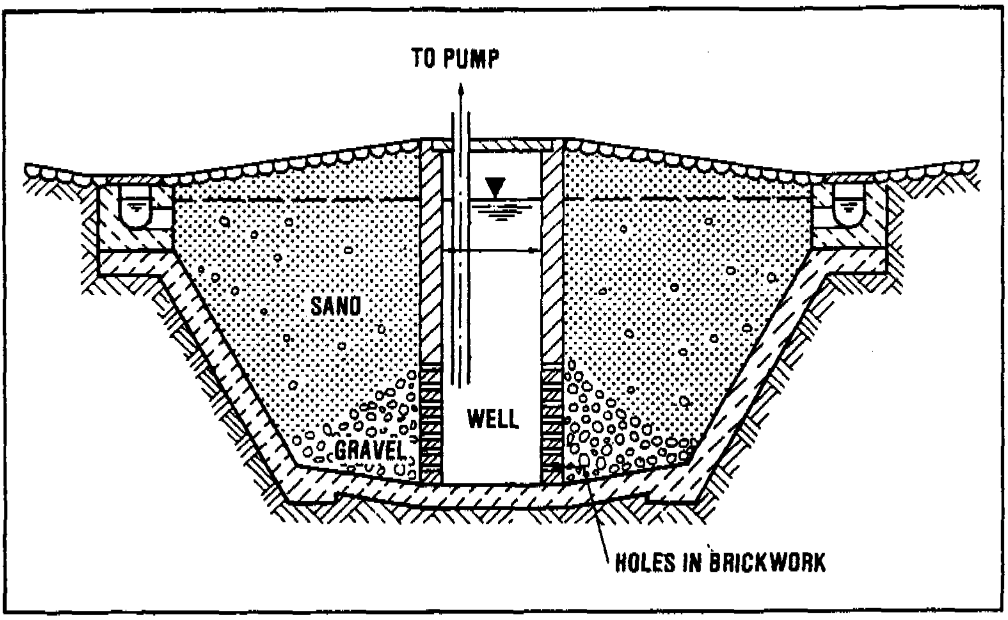


Figure 5.8.
Venetian Cistern

Fig 6.12 (IRC, 83)

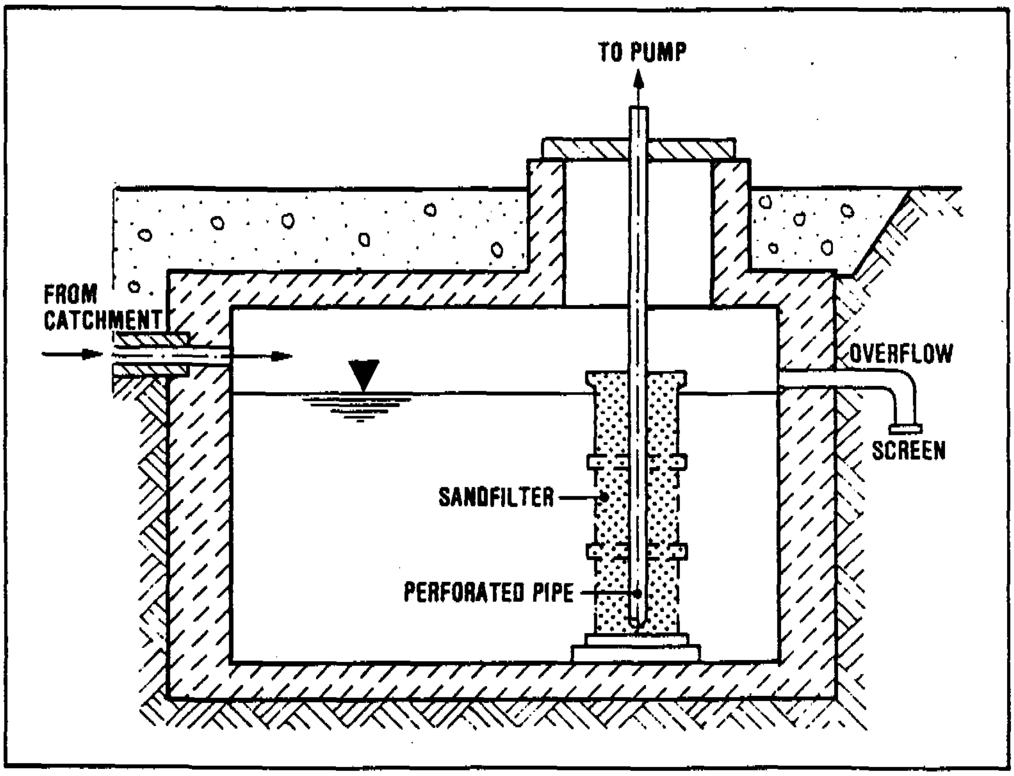


Figure 5.9.
Withdrawal of filtered rainwater from storage

Fig 6.13 (IRC, 83)

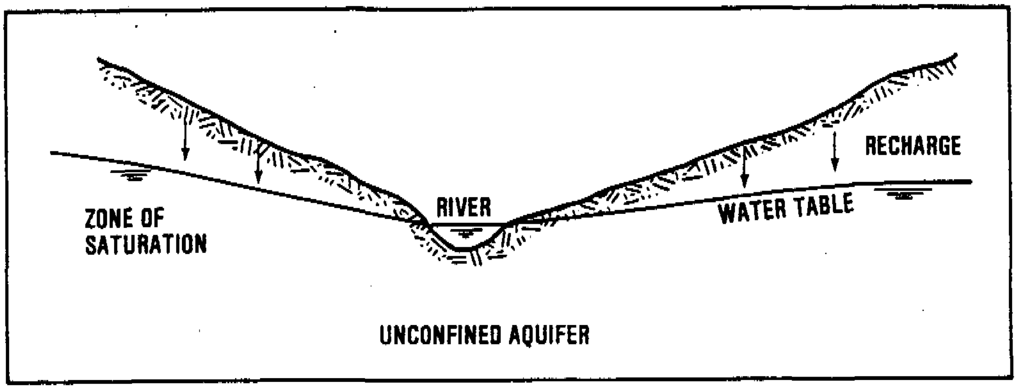


Figure 7.4a
Infiltration of water into an unconfined aquifer during the wet season

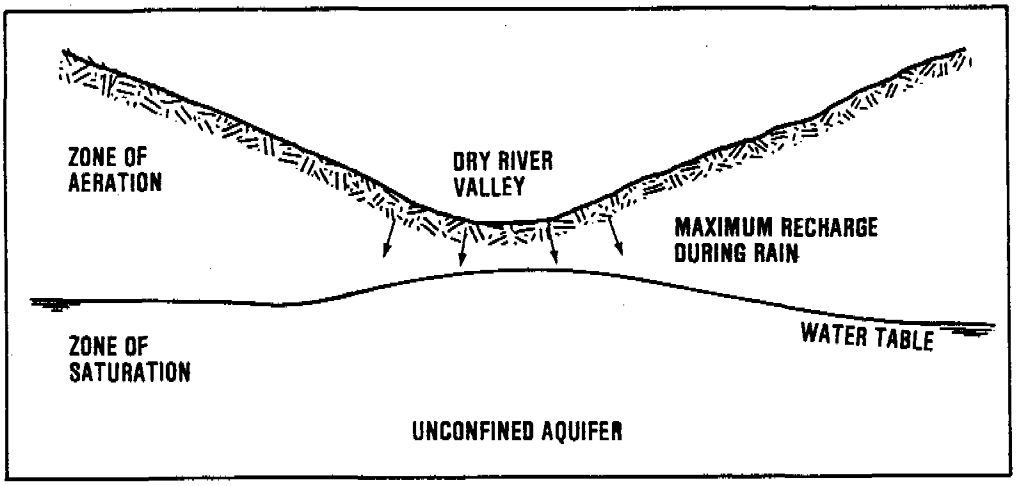


Figure 7.4b
Infiltration of water into an unconfined aquifer during the dry season

Fig 6.14 (IRC, 83)

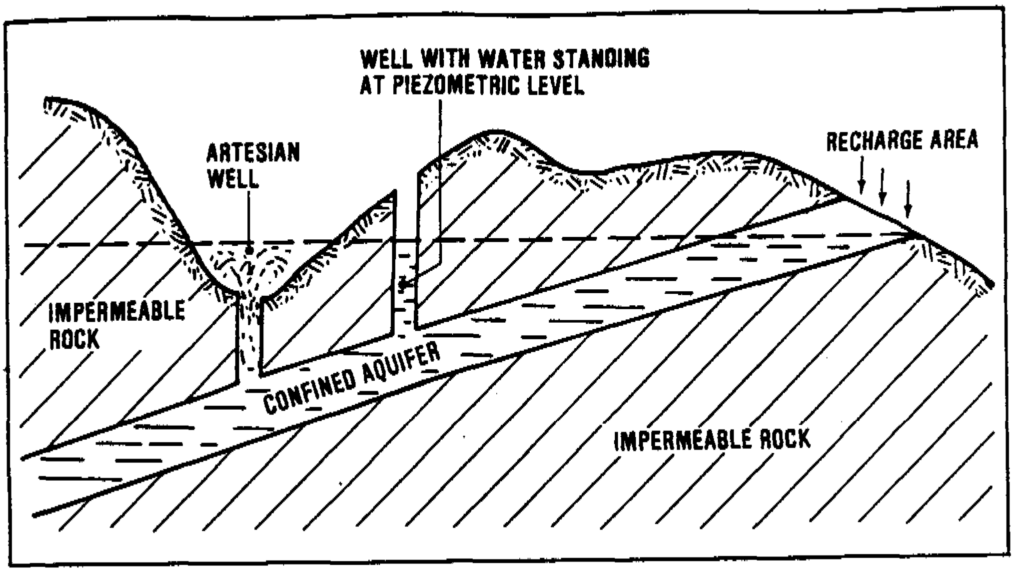


Figure 7.5.
Confined aquifer fed from a recharge area

Fig 6.15 (IRC, 83)

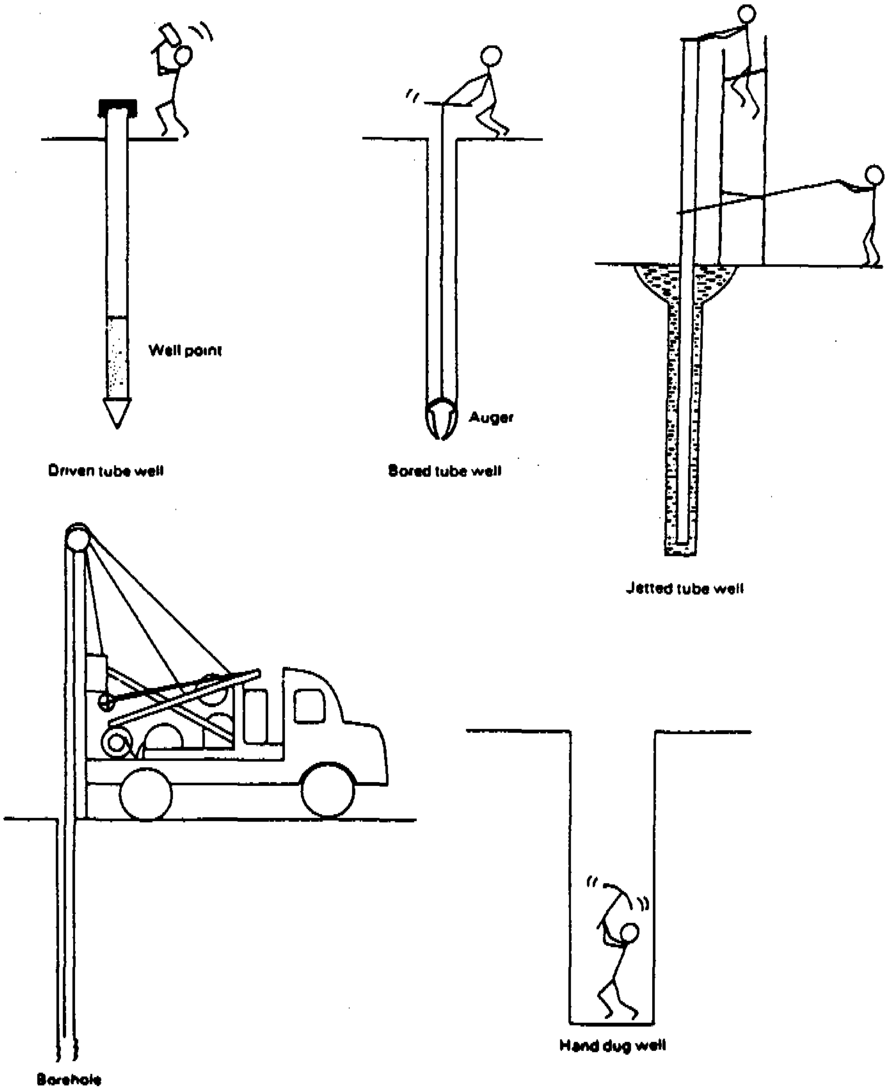


Figure 5.4 Schematic illustration of five basic methods of ground water extraction

Fig 6.16 (C & F, 93)

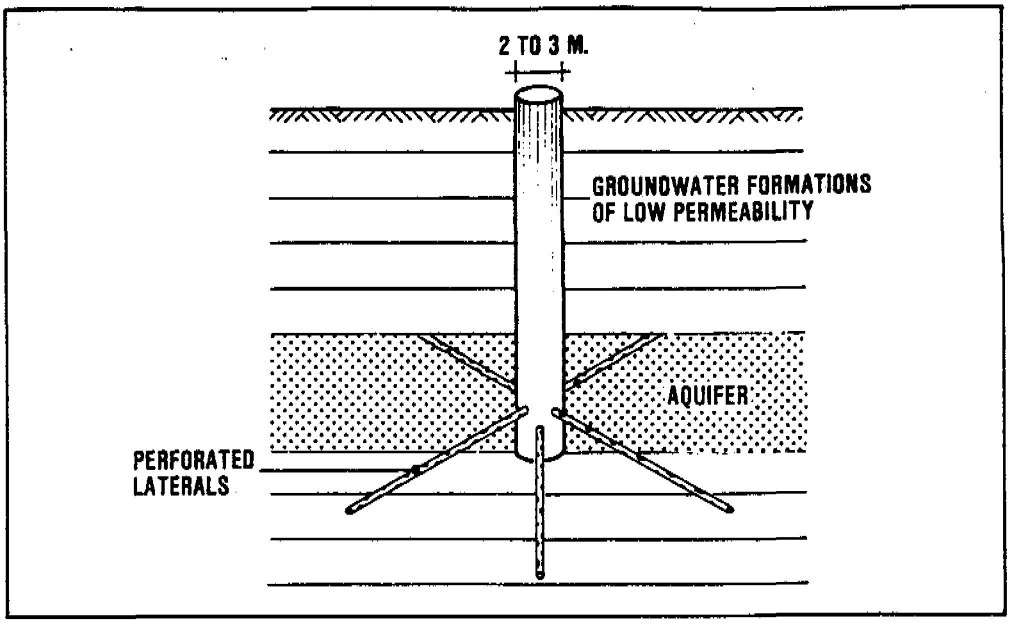


Figure 7.14.
*Radial collector well**

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* Also called "Ranney Well"

Fig 6.17 (IRC, 83)

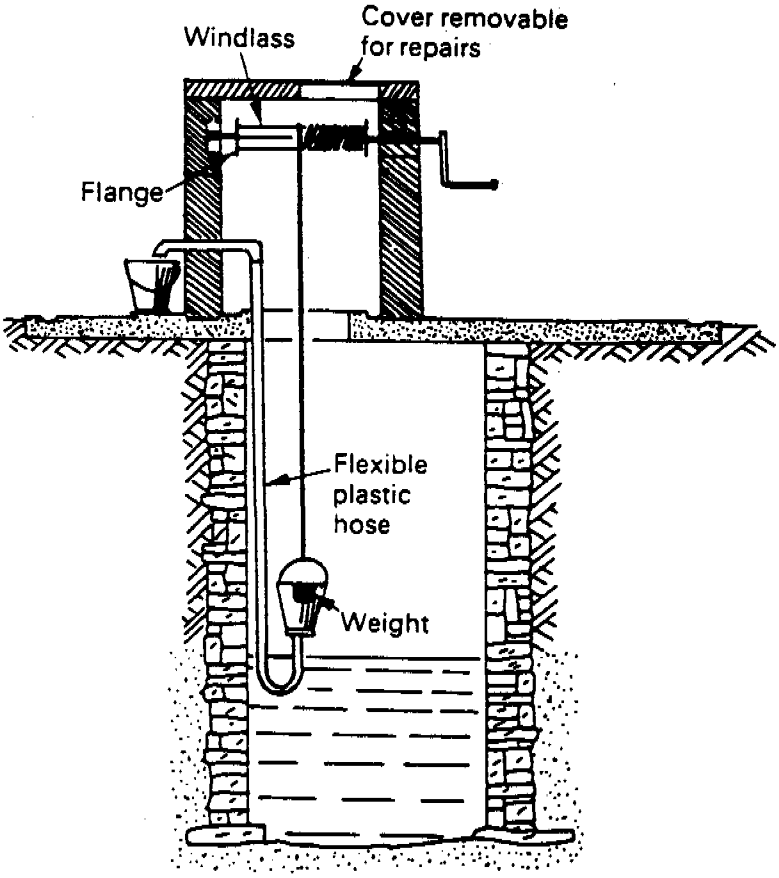


Figure 5.8 One method of protecting a well from pollution. Methods of this kind have not yet been adequately tested in the field

Fig 6.18 (C & F, 93)

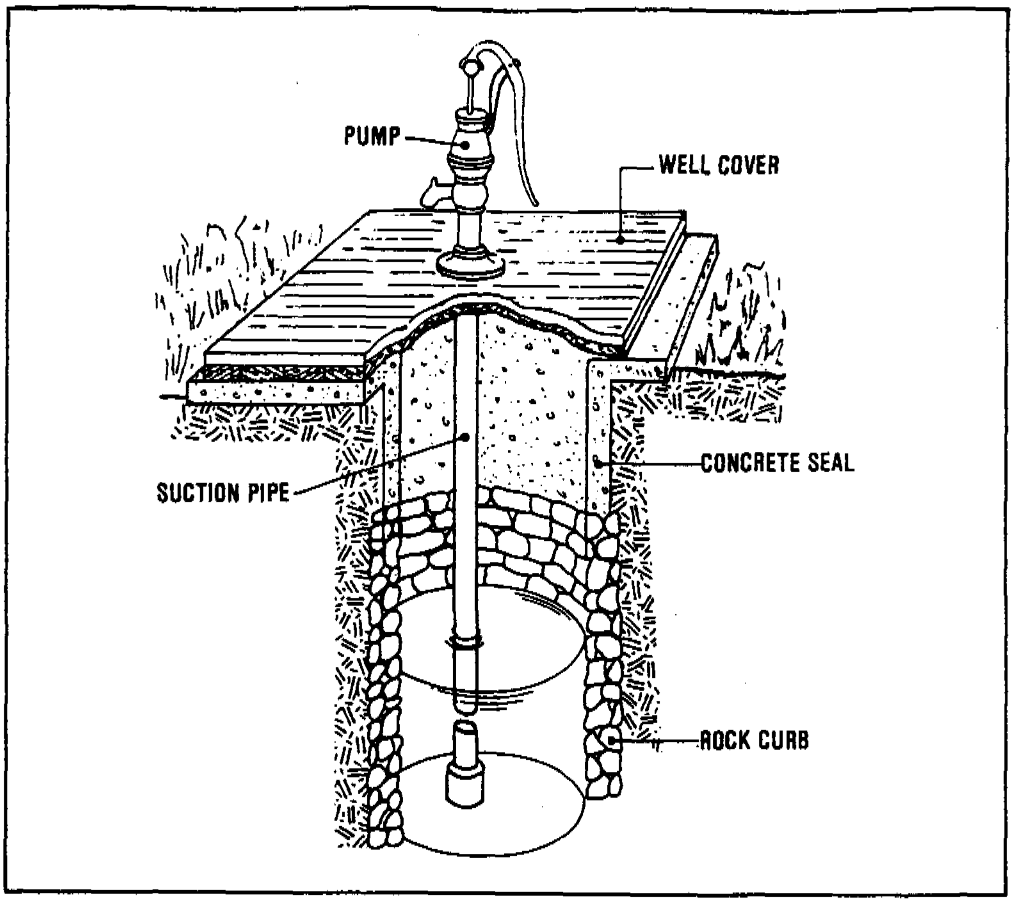


Figure 7.11.
Dug well

Fig 6.19 (IRC, 83)

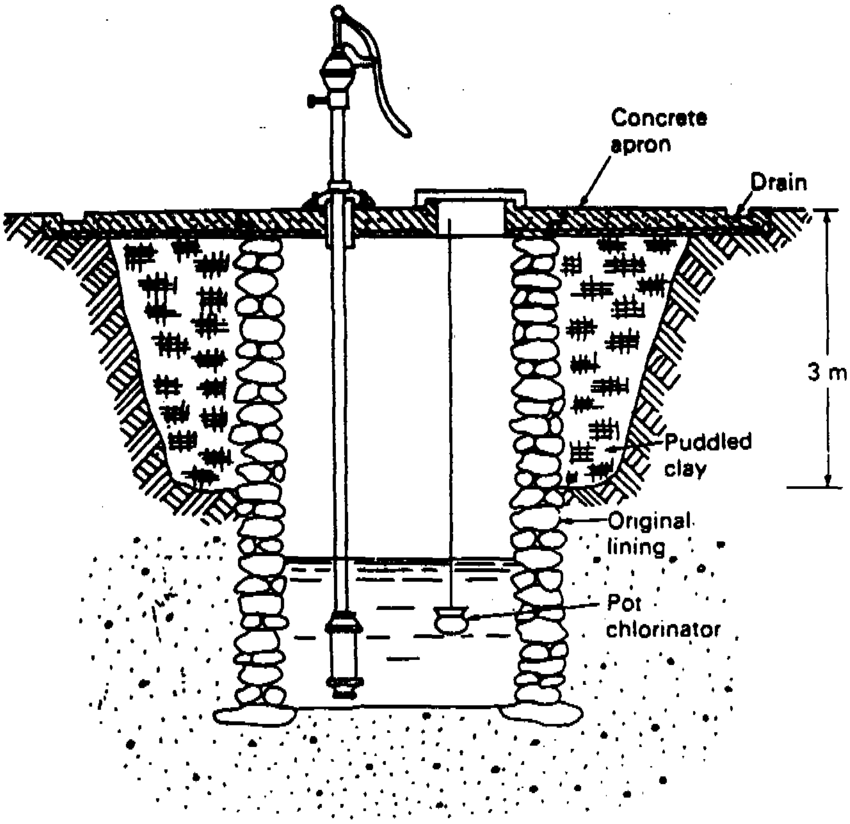


Figure 5.10 Improving an existing well by adding a hand pump, a cover slab, an apron and drain, and a puddled clay barrier against seepage of surface water
Source: After Wagner and Lanoix (1959)

Fig 6. 20 (C & F, 93)

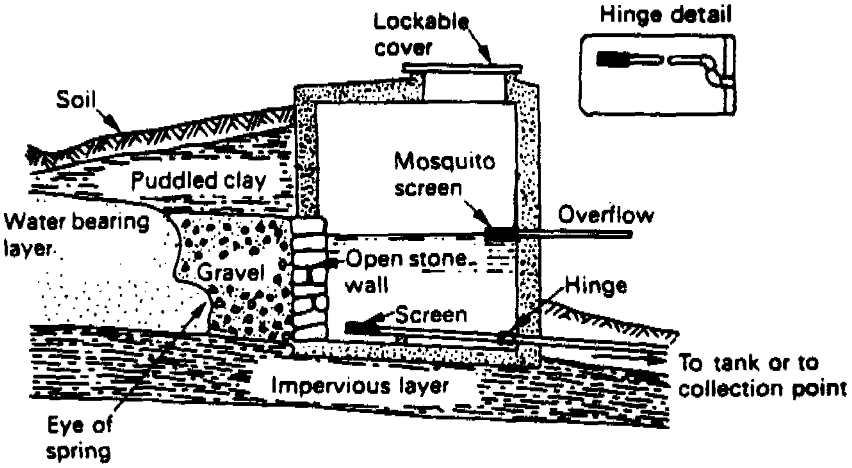


Figure 5.2 A spring box. The inset detail shows a hinge made with two flexible pipe bends, enabling the screen to be lifted above the water for cleaning

Fig 6.21 (C & F, 93)

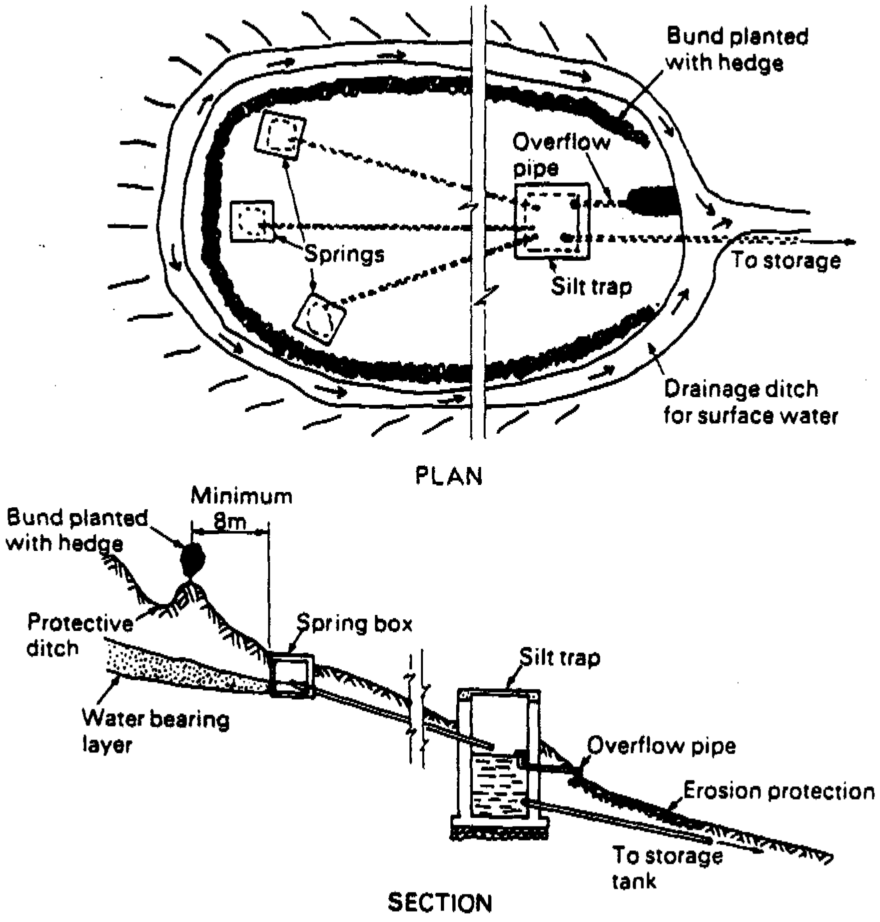


Figure 5.3 Three protected springs connected to a silt trap

Fig 6.22 (C&F, 93)

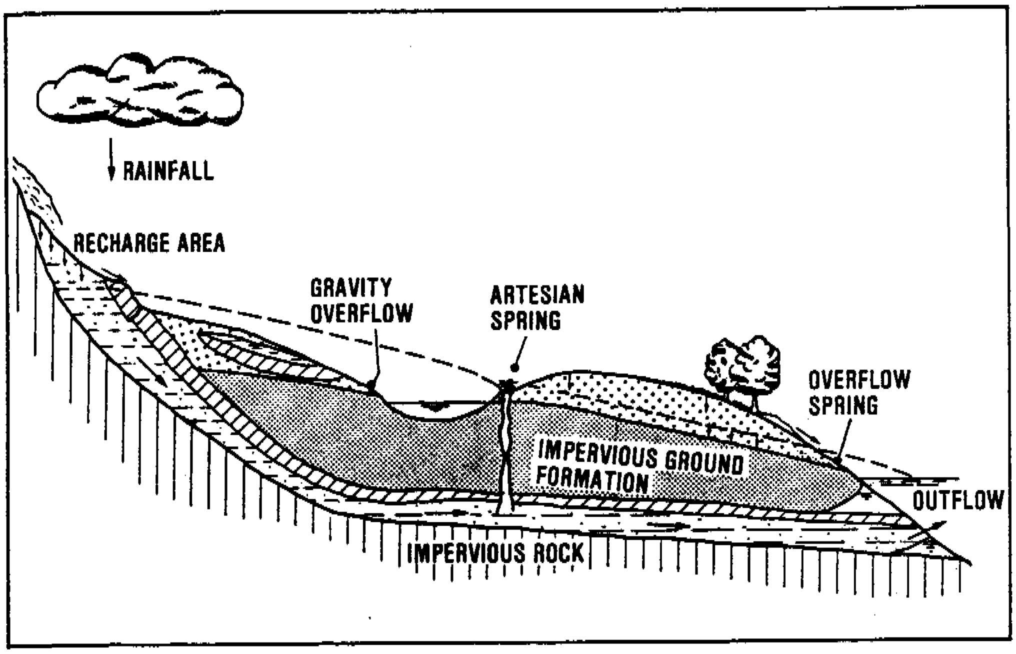


Figure 6.1.
Occurrence of springs

Fig 6.23 (IRC, 83)

Fig 6.24 (IRC, 83)

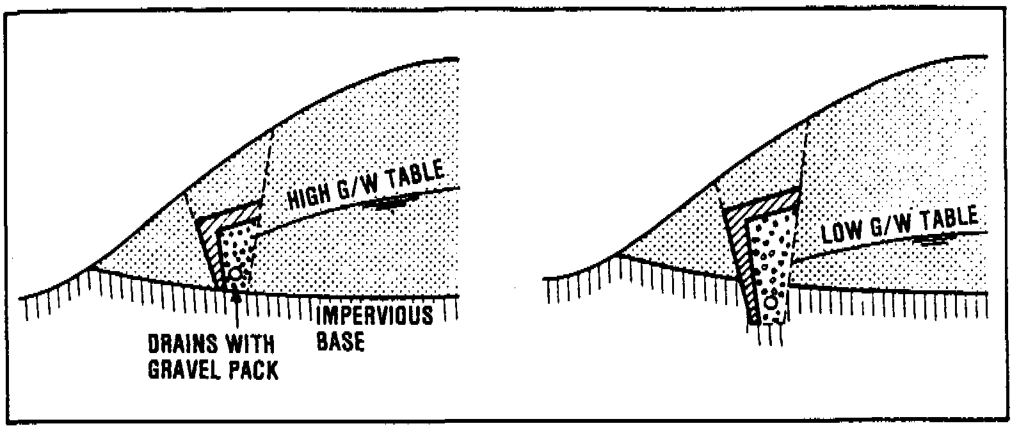


Figure 6.7.
Tapping of a gravity spring

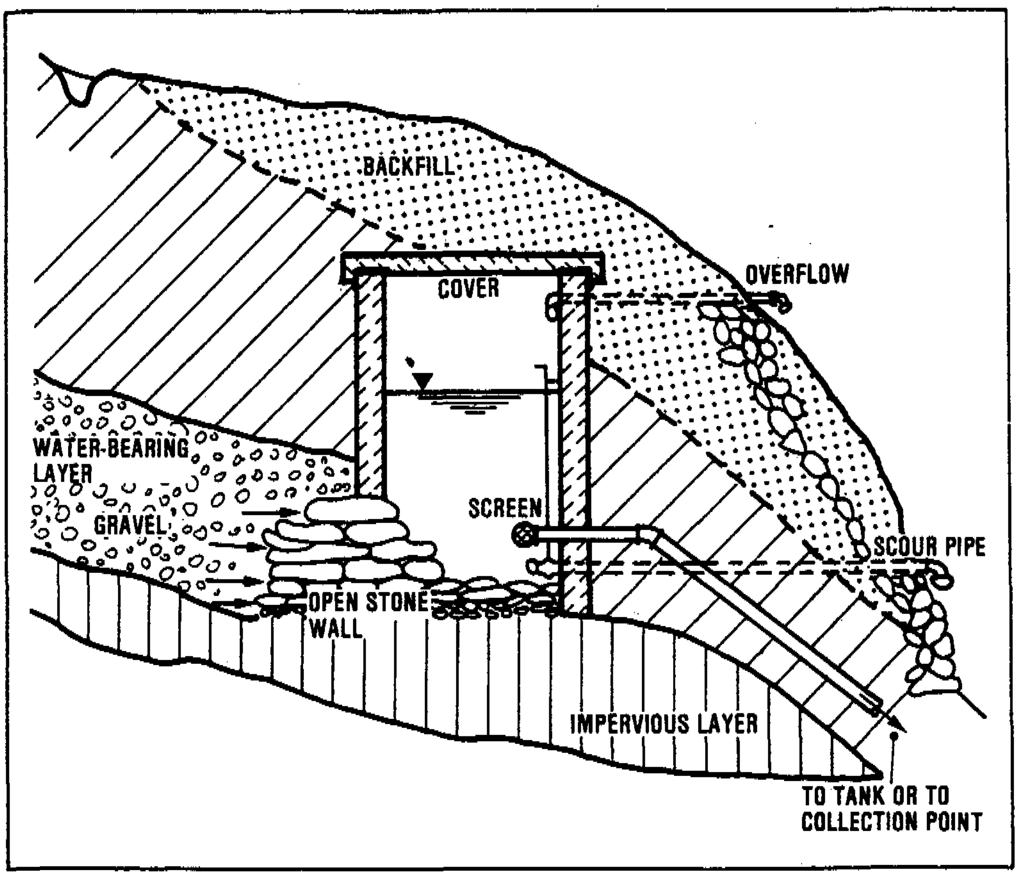


Figure 6.8.
Spring water storage chamber ('spring box')

Fig 6.25 (IRC, 83)

Fig 6.26 (IRC, 83)

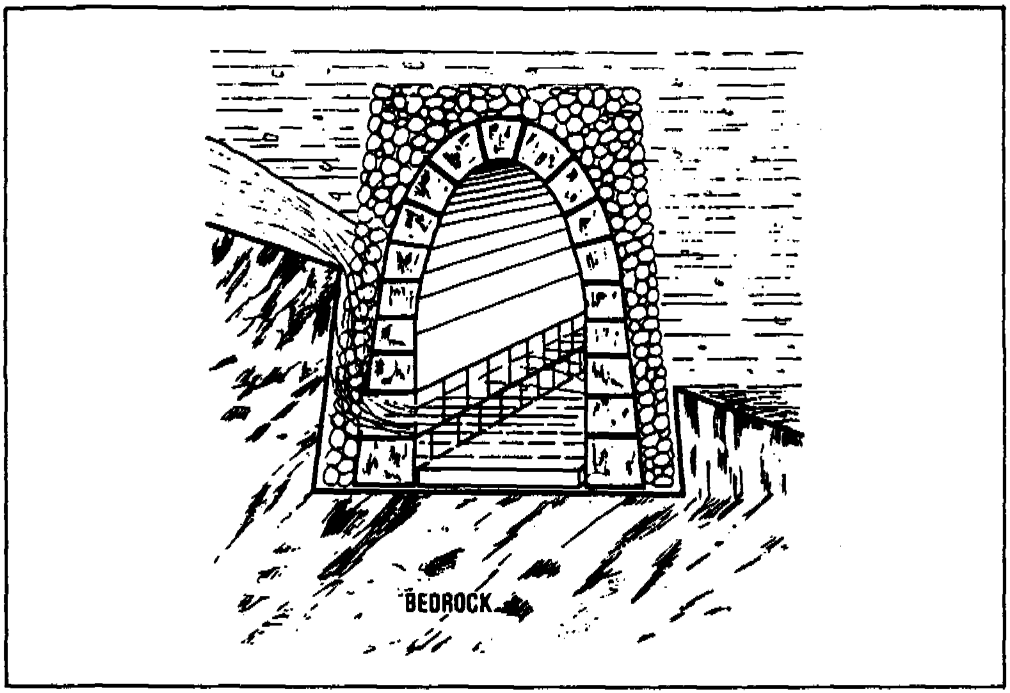


Figure 6.9.
Tunnel for tapping gravity overflow spring

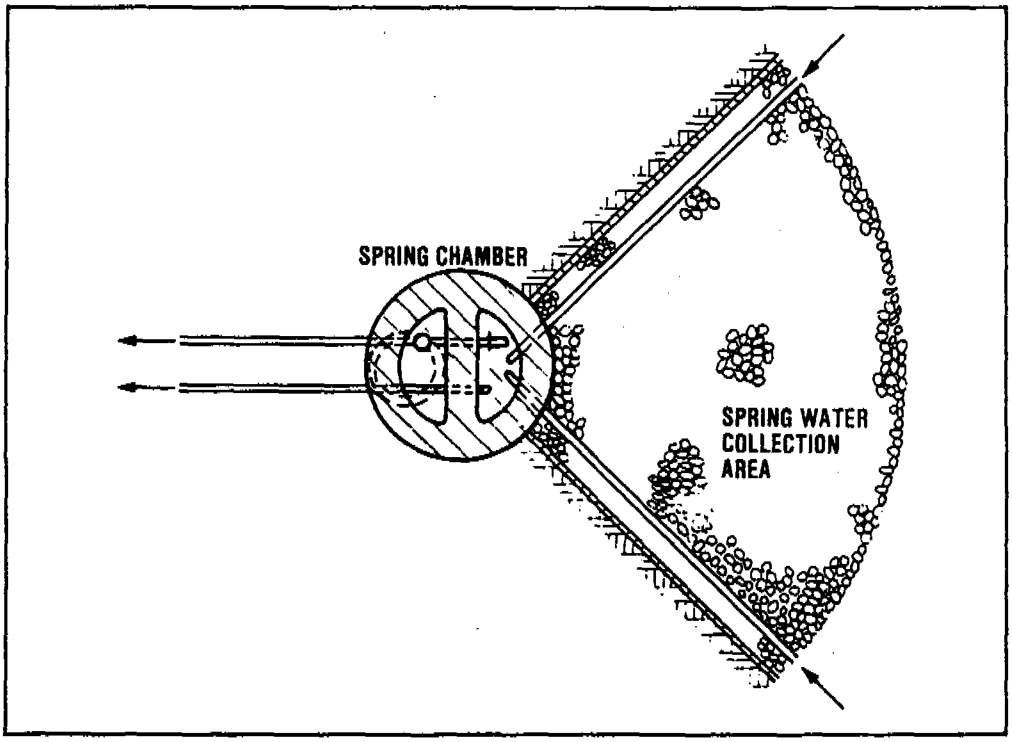


Figure 6.10.
Tapping spring water from a fractured rock aquifer

Fig 6.27 (IRC, 83)

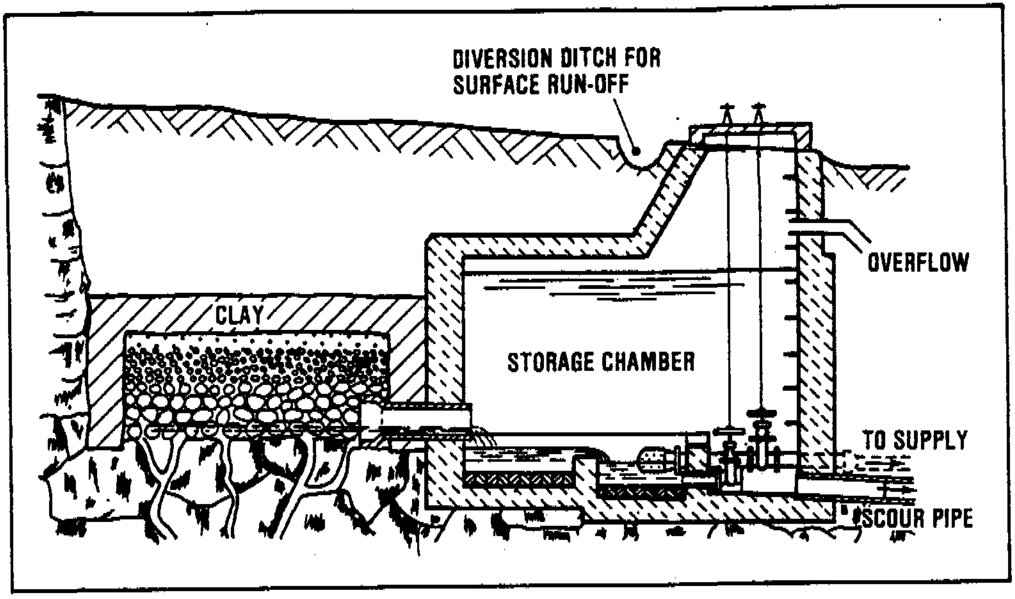


Figure 6.11.
Artesian depression spring

Fig 6.28 (IRC, 83)

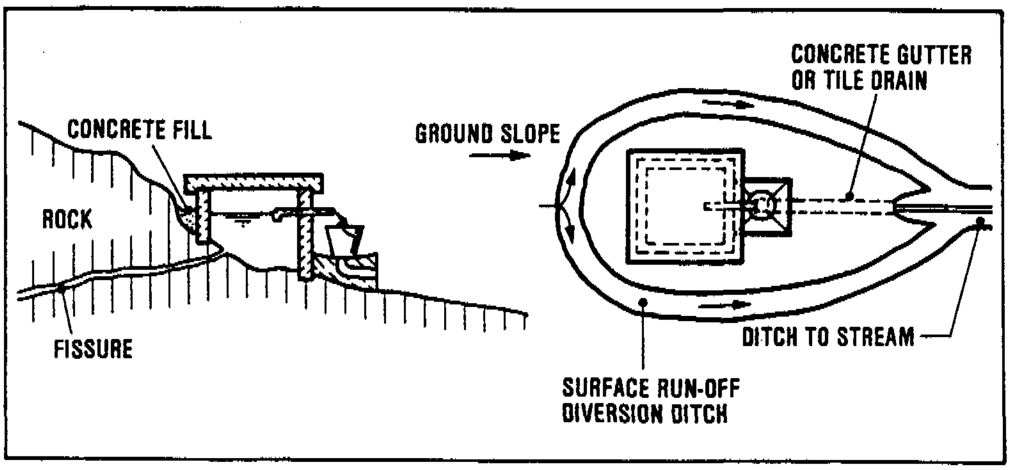


Figure 6.12.
Fissure spring of small capacity

Fig 6.29 (IRC, 83)

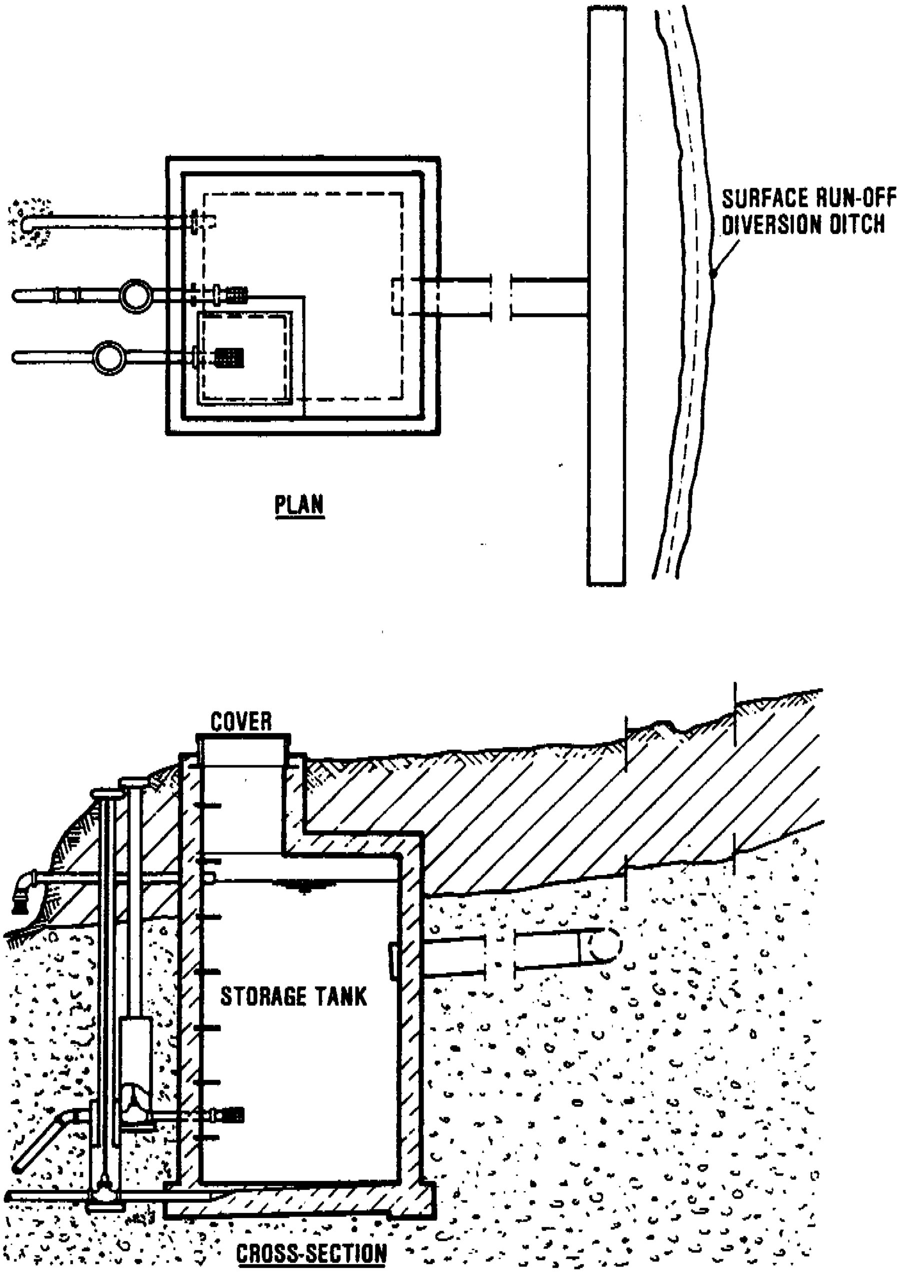


Figure 6.14.
Artesian contact spring of large lateral width

Fig 6.30 (IRC, 83)

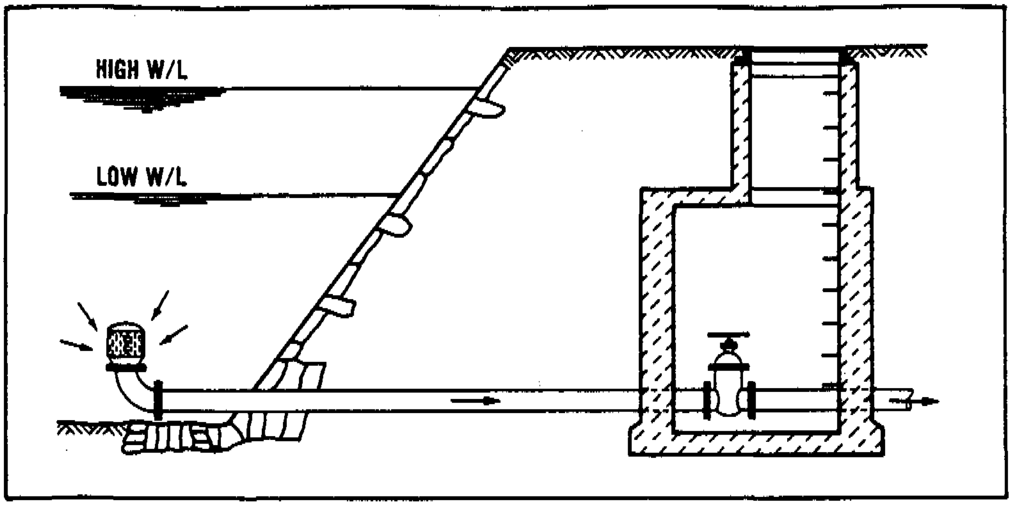


Figure 8.1.
Unprotected river intake

Fig 6.31 (IRC, 83)

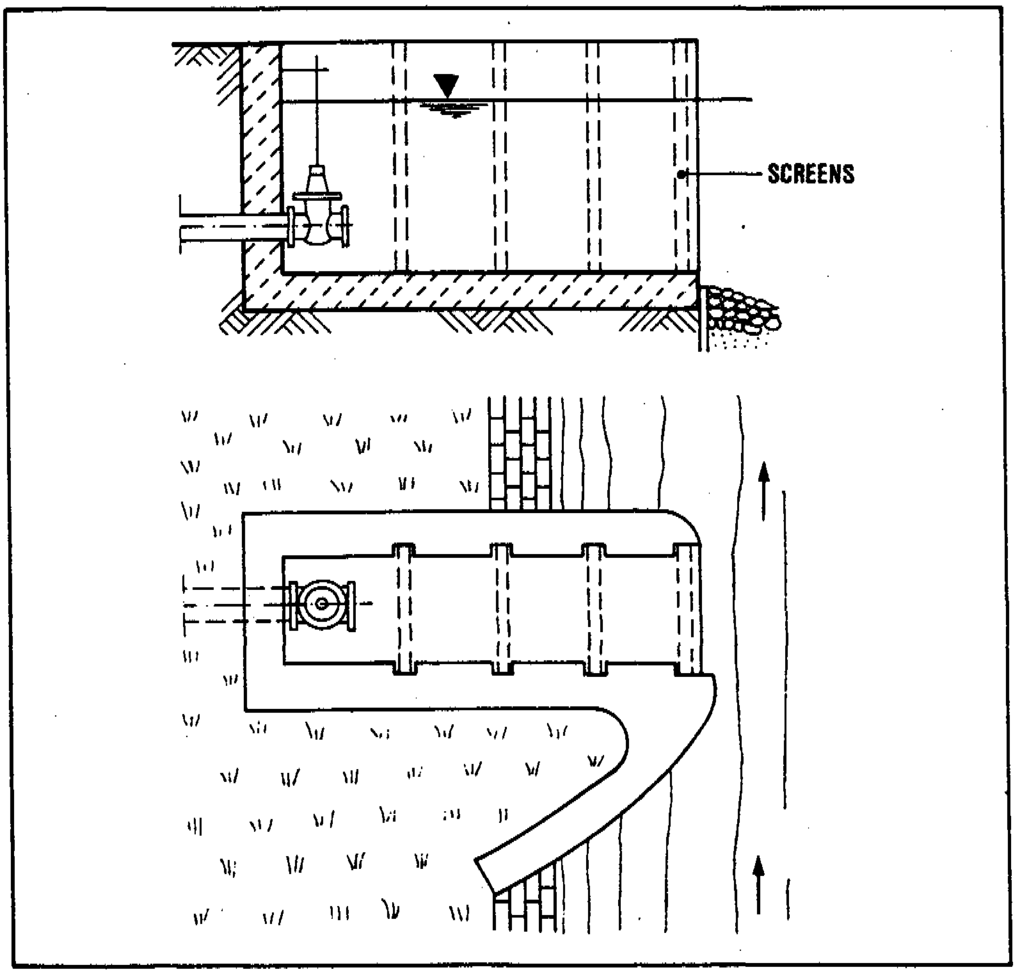


Figure 8.2.
River intake structure

Fig 6.32 (IRC, 83)

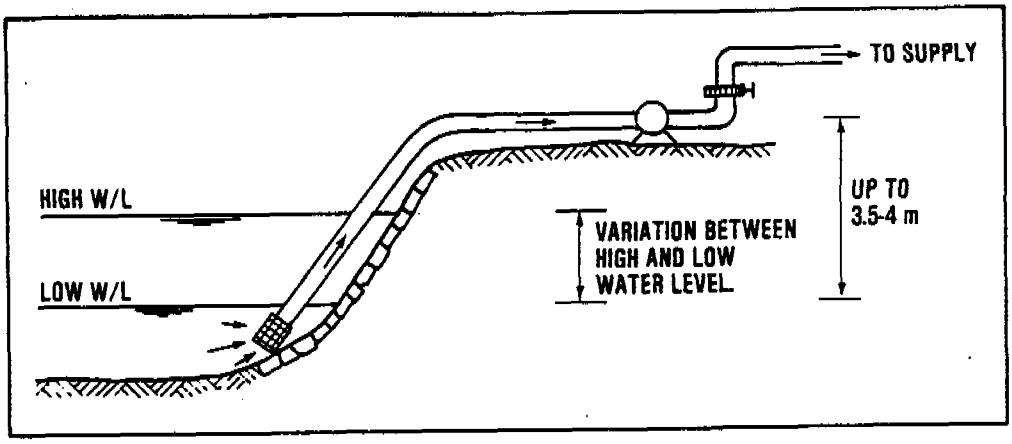


Figure 8.3.
Pumped river water intake

Fig 6.33 (IRC, 83)

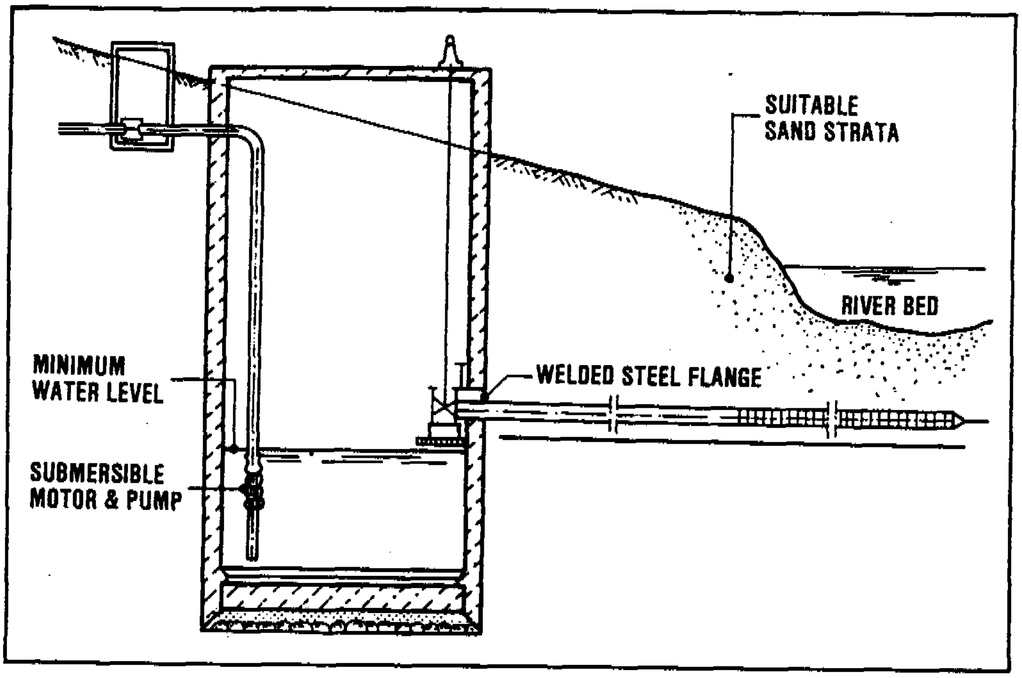


Figure 8.4.
Bank river intake using infiltration drains

Fig 6.34 (IRC, 83)

Fig 6.35 (IRC, 83)

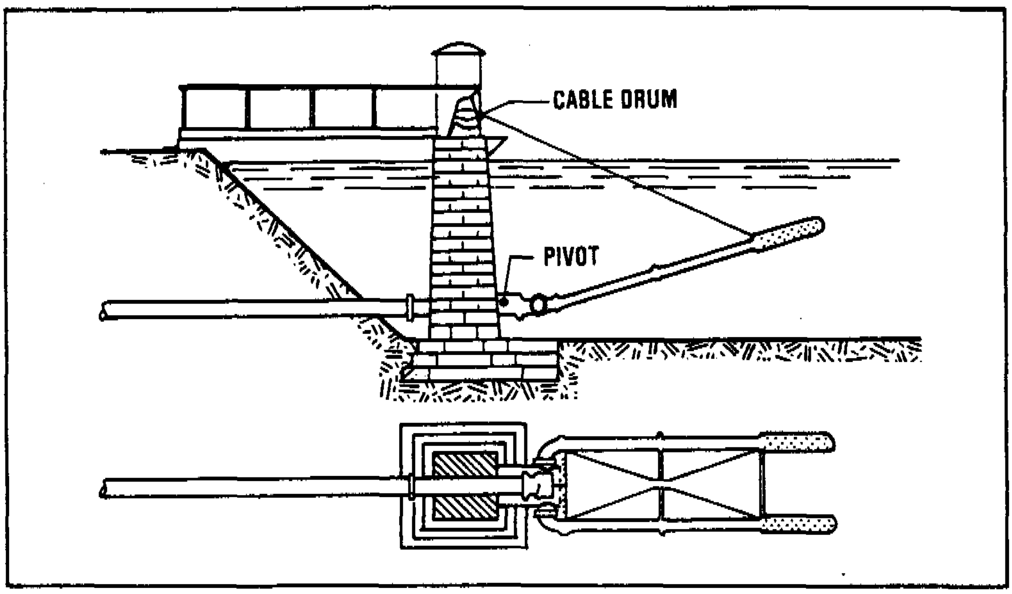


Figure 8.6.
Variable depth lake water intake.

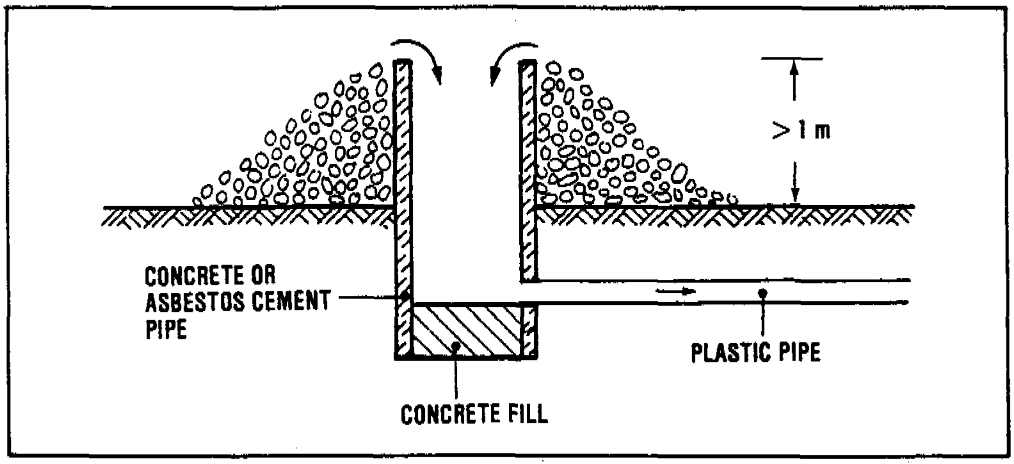


Figure 8.7.
Intake structure at bottom of shallow lake.

Fig 6.36 (IRC, 83)

Fig 6.37 (IRC, 83)

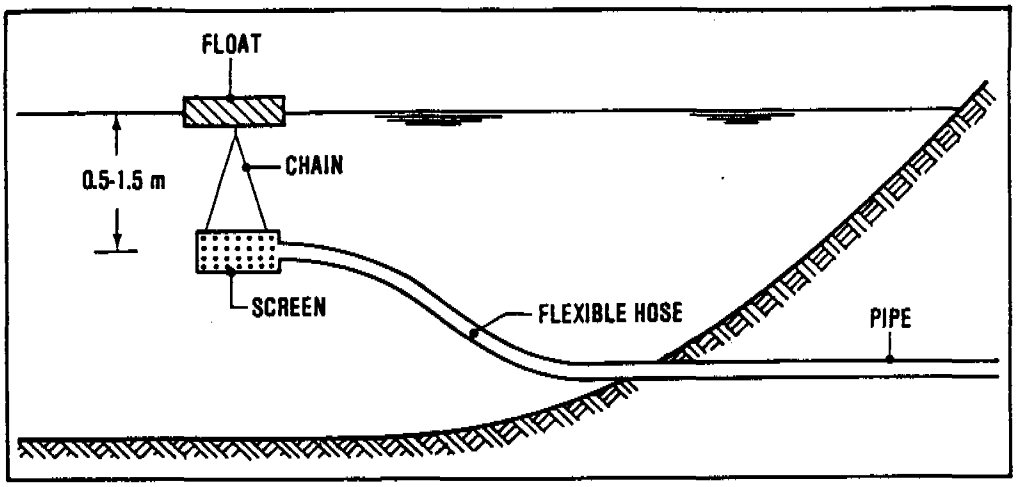


Figure 8.8.
Simple water intake structure

Another intake construction using a floating barrel to support the intake pipe, is shown in Fig. 8.9 The water is pumped from the well sump.

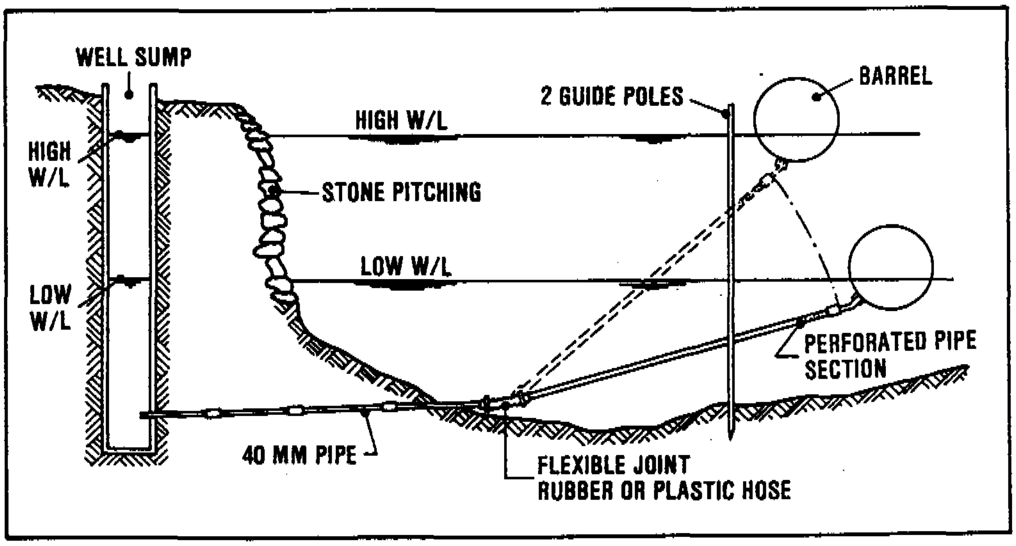


Figure 8.9.
Float intake

Fig 6.38 (IRC, 83)

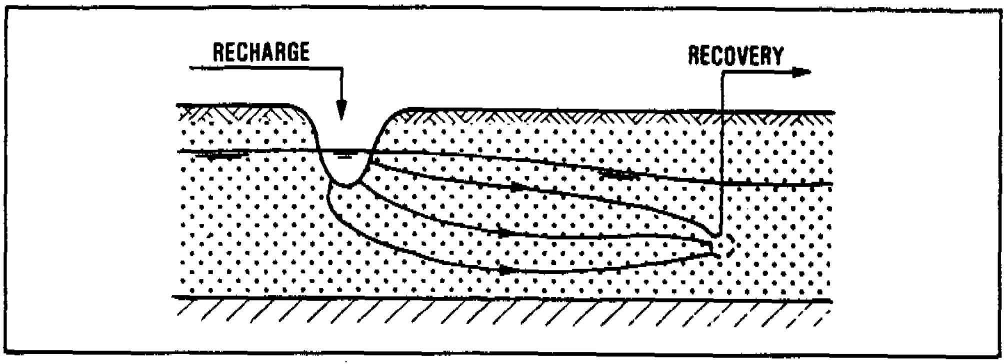


Figure 9.1.
Artificial recharge of aquifer

Fig 6.39 (IRC, 83)

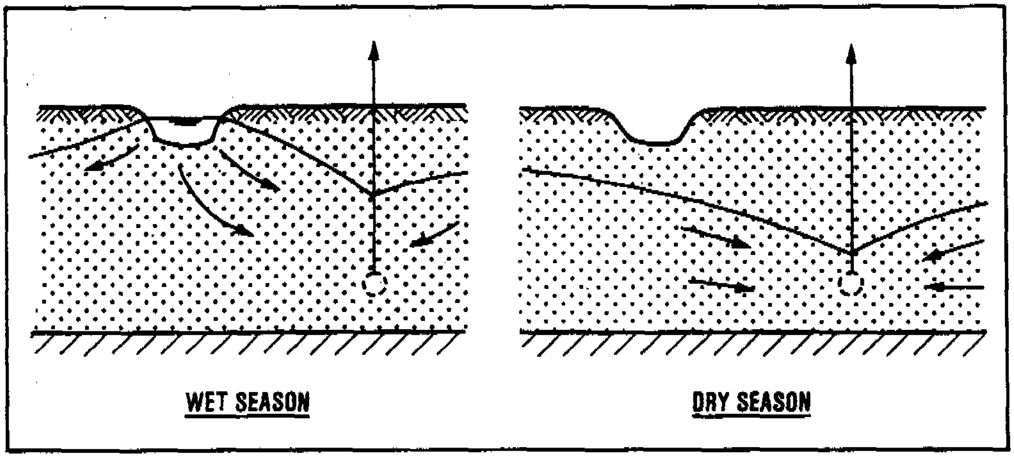


Figure 9.2.
Artificial recharge with underground storage of water

Fig 6.40 (IRC, 83)

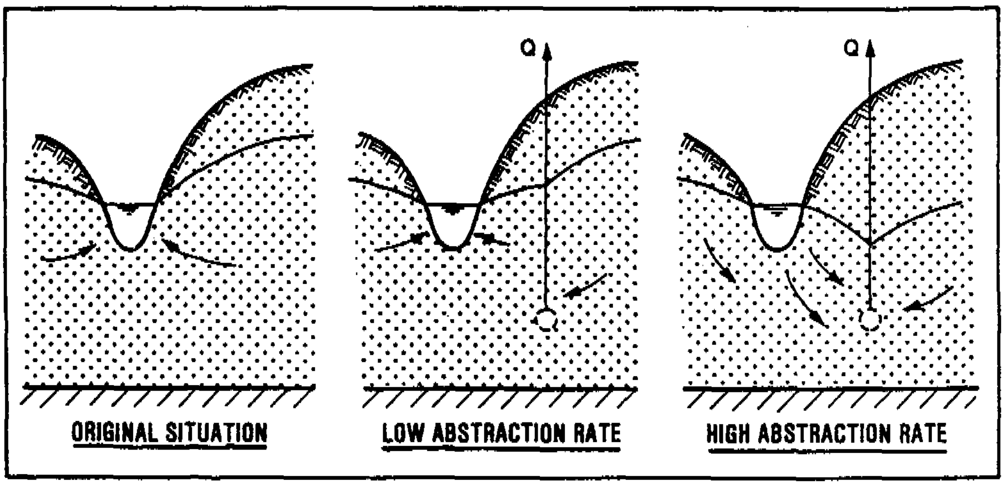


Figure 9.3.
Bank infiltration

Fig 6.41 (IRC, 83)

Fig 6.42 (IRC, 83)

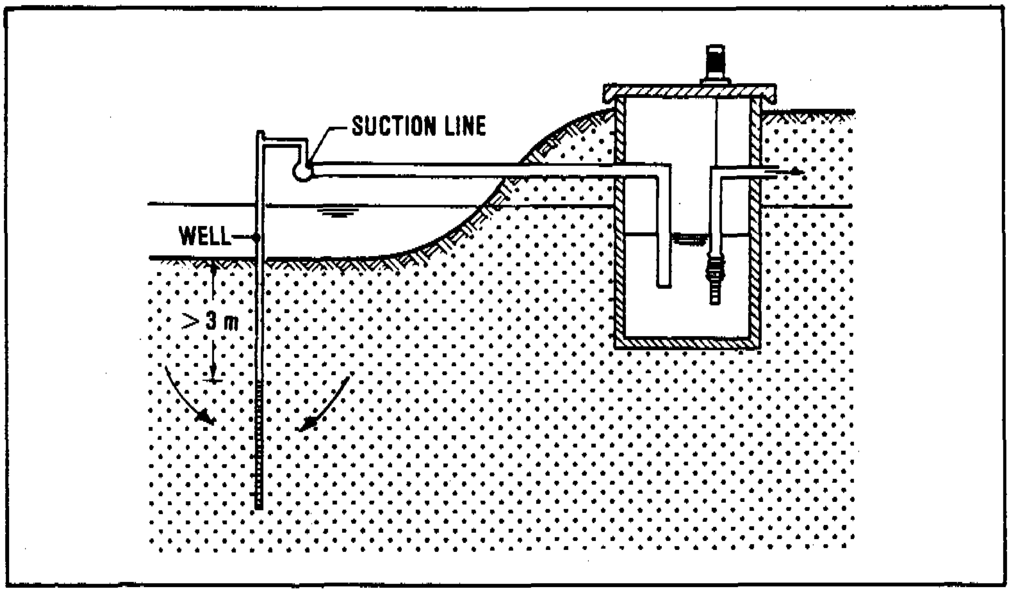


Figure 9.6.
Line of wellpoints placed in riverbed

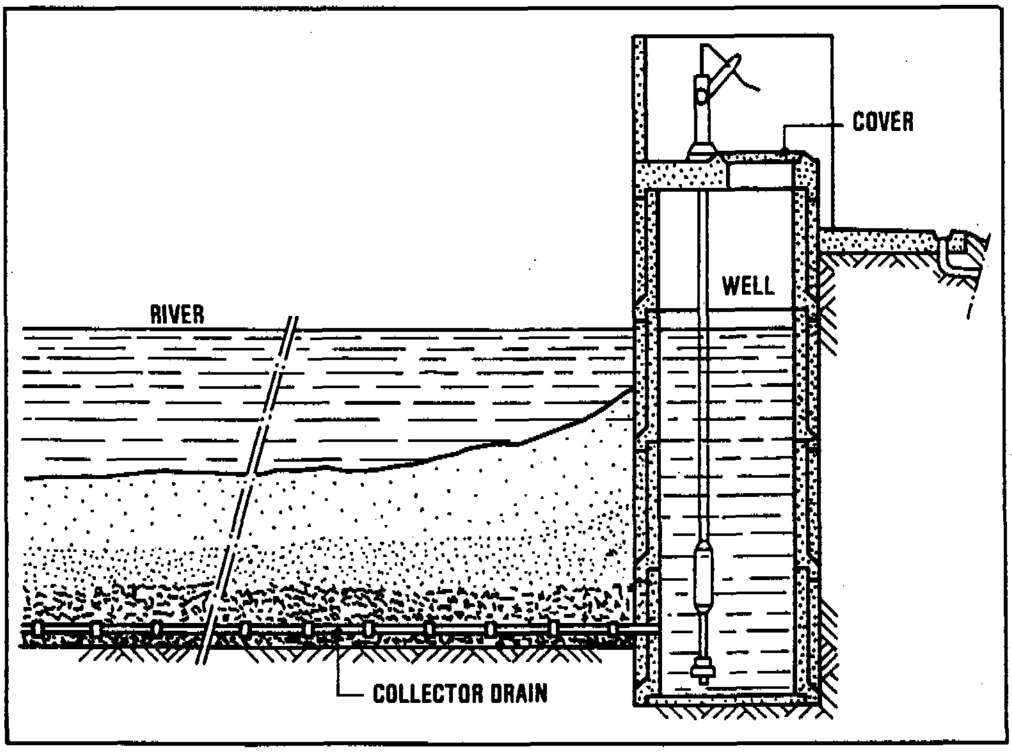


Figure 9.7.
Horizontal collector drain under river bed

Fig 6.43 (IRC, 83)

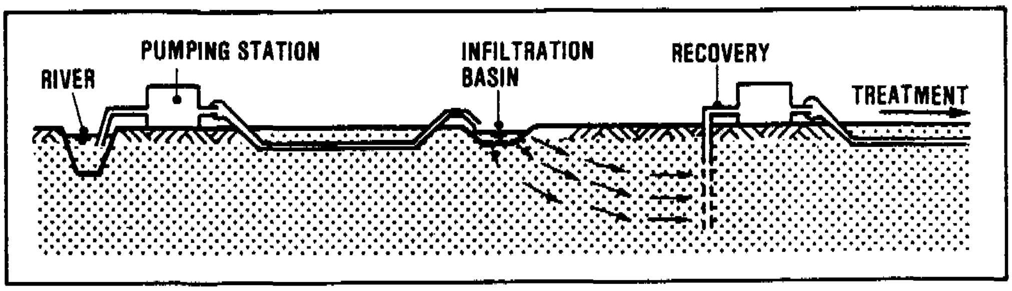


Figure 9.10.
Scheme for artificial recharge and recovery

Fig 6.44 (IRC, 83)

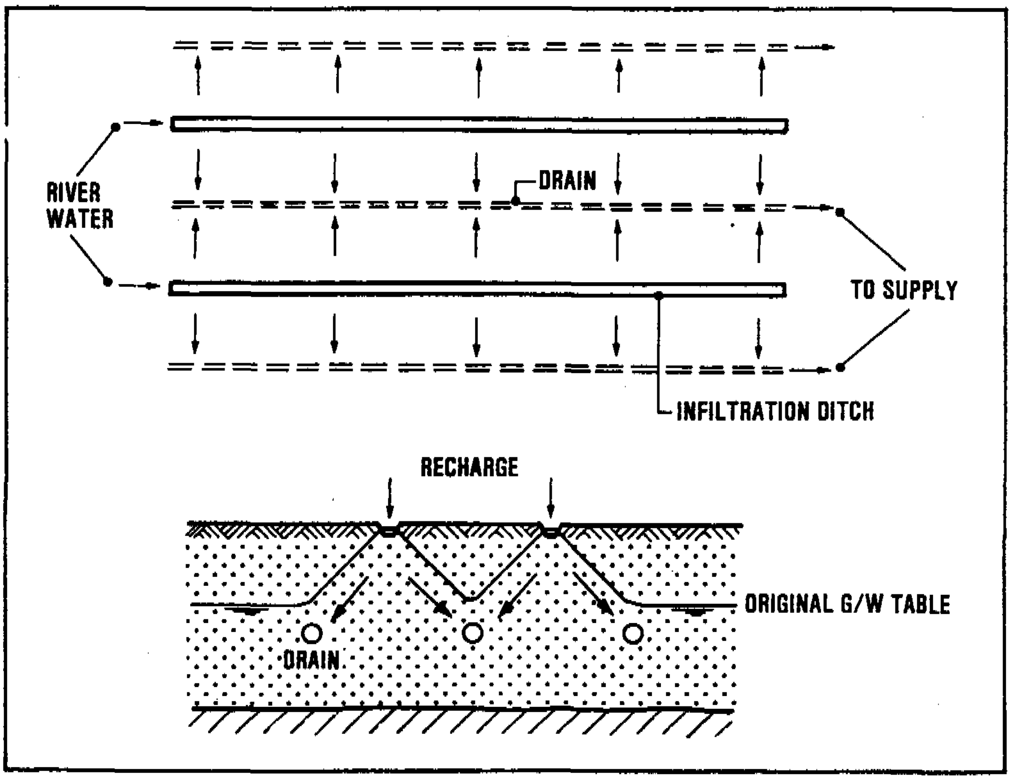


Figure 9.11.
Water recharge in shallow aquifer using infiltration ditches and drains

Fig 6.45 (IRC, 83)

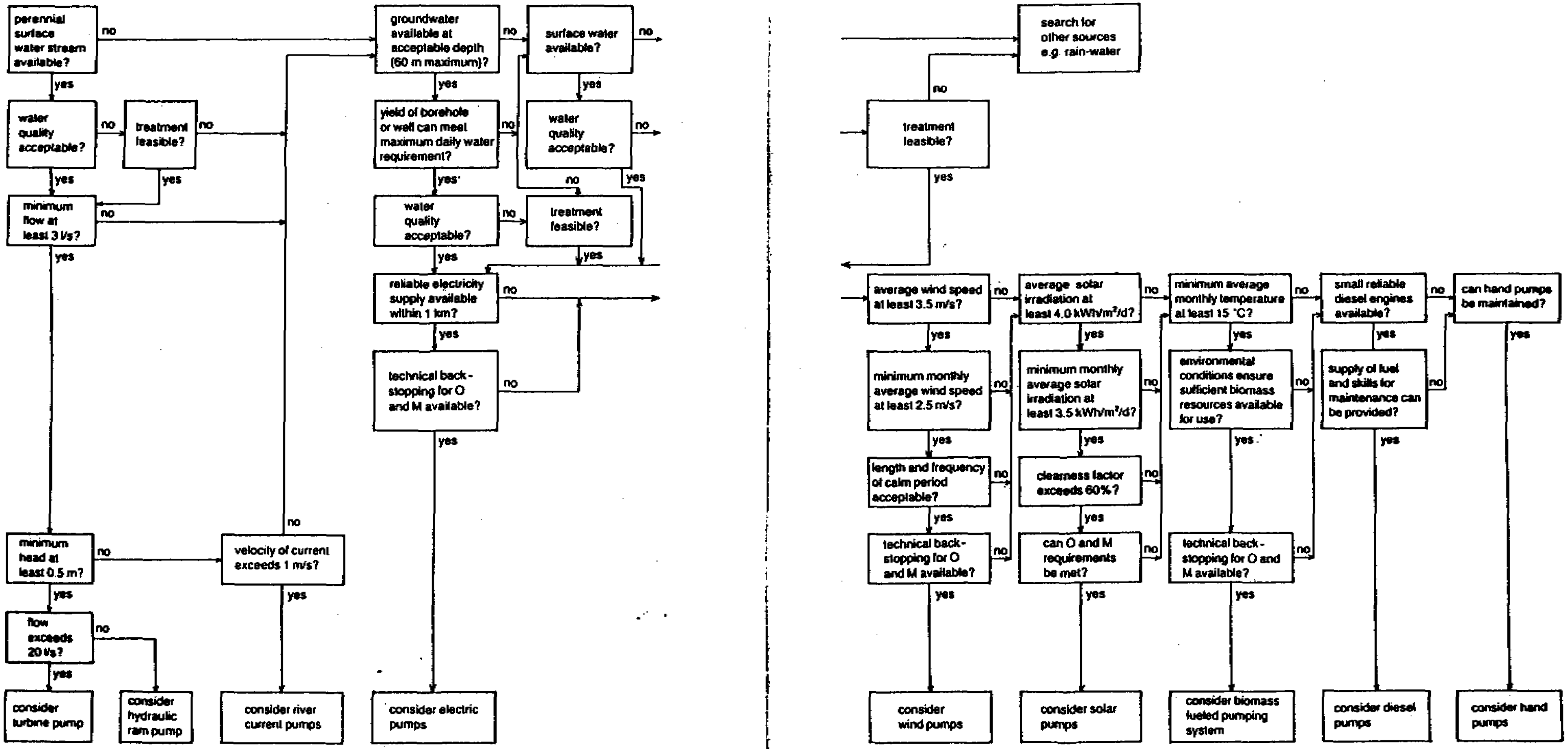


Figure 2.4: Selection chart for determination of energy source(s) and pumping system(s) to be considered for a particular location

Fig 6.46 (IRC, 86)

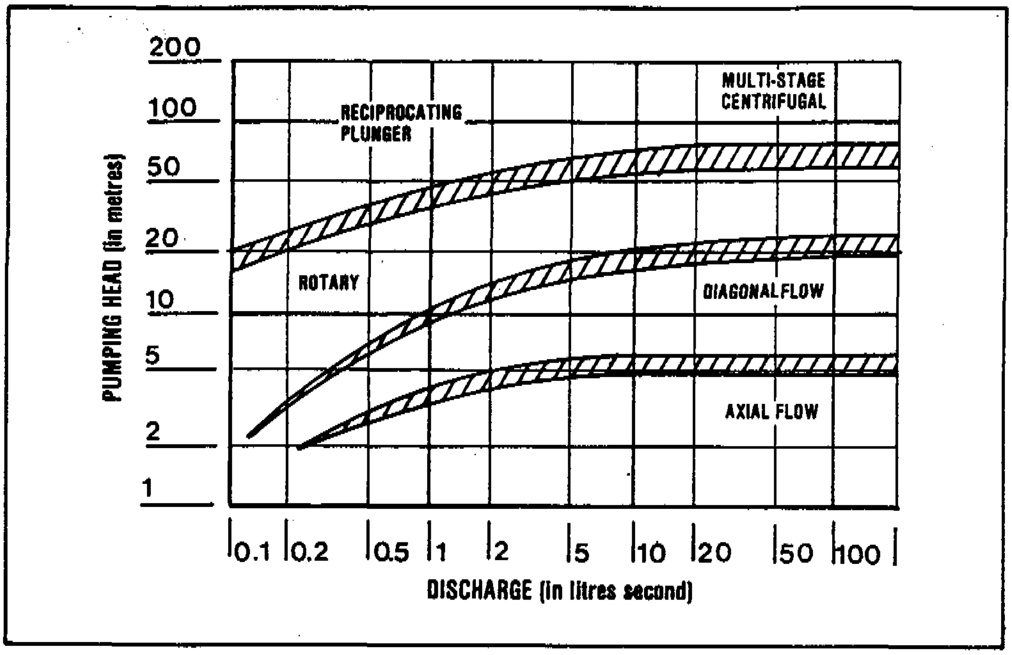


Figure 10.3.
Pump type selection chart

Fig 6.47 (IRC, 83)

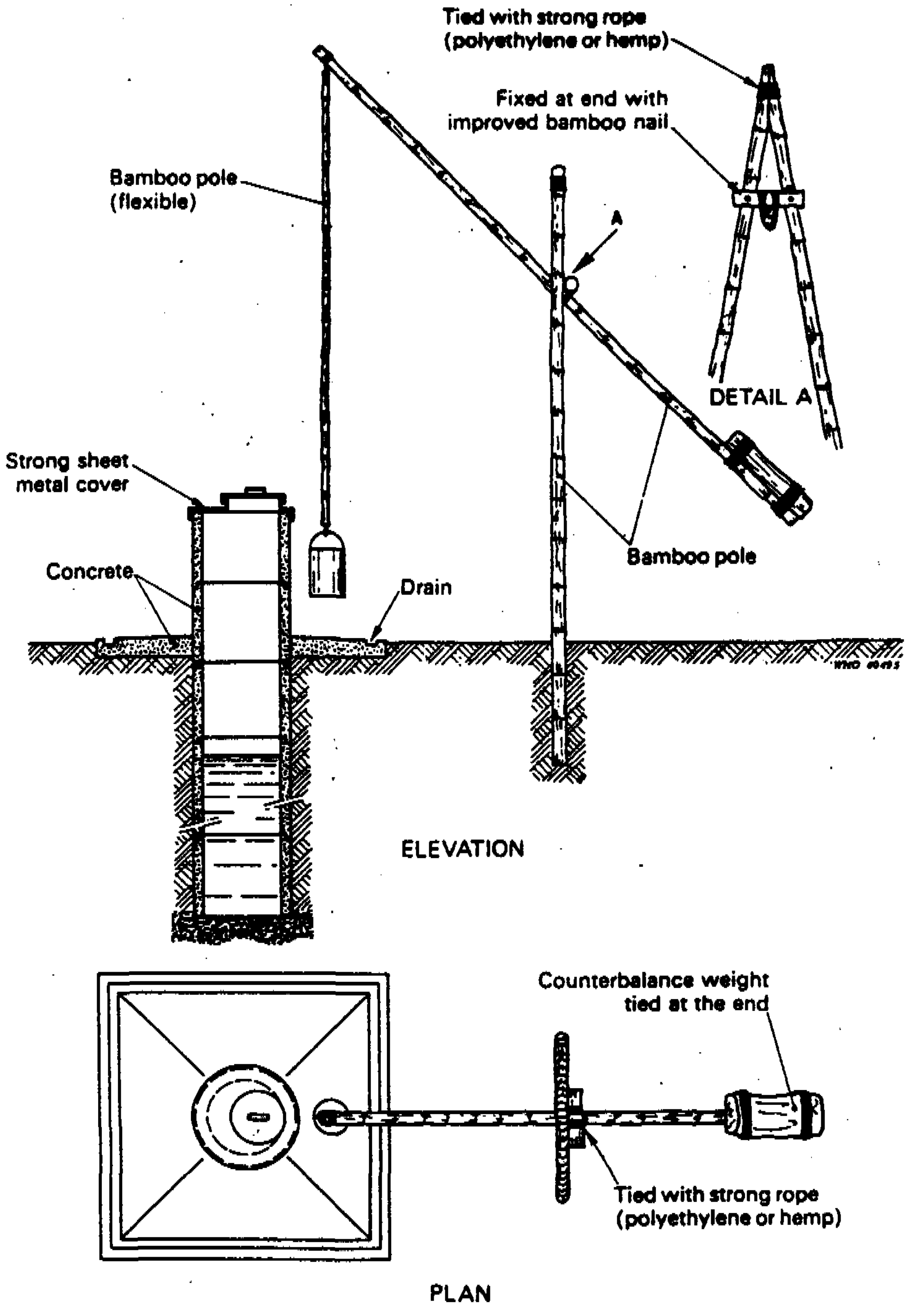


Figure 5.11 A shaduf used over a hand-dug well
Source: From Rajagopalan and Shiffman (1974)

Fig 6.48 (C & F, 93)

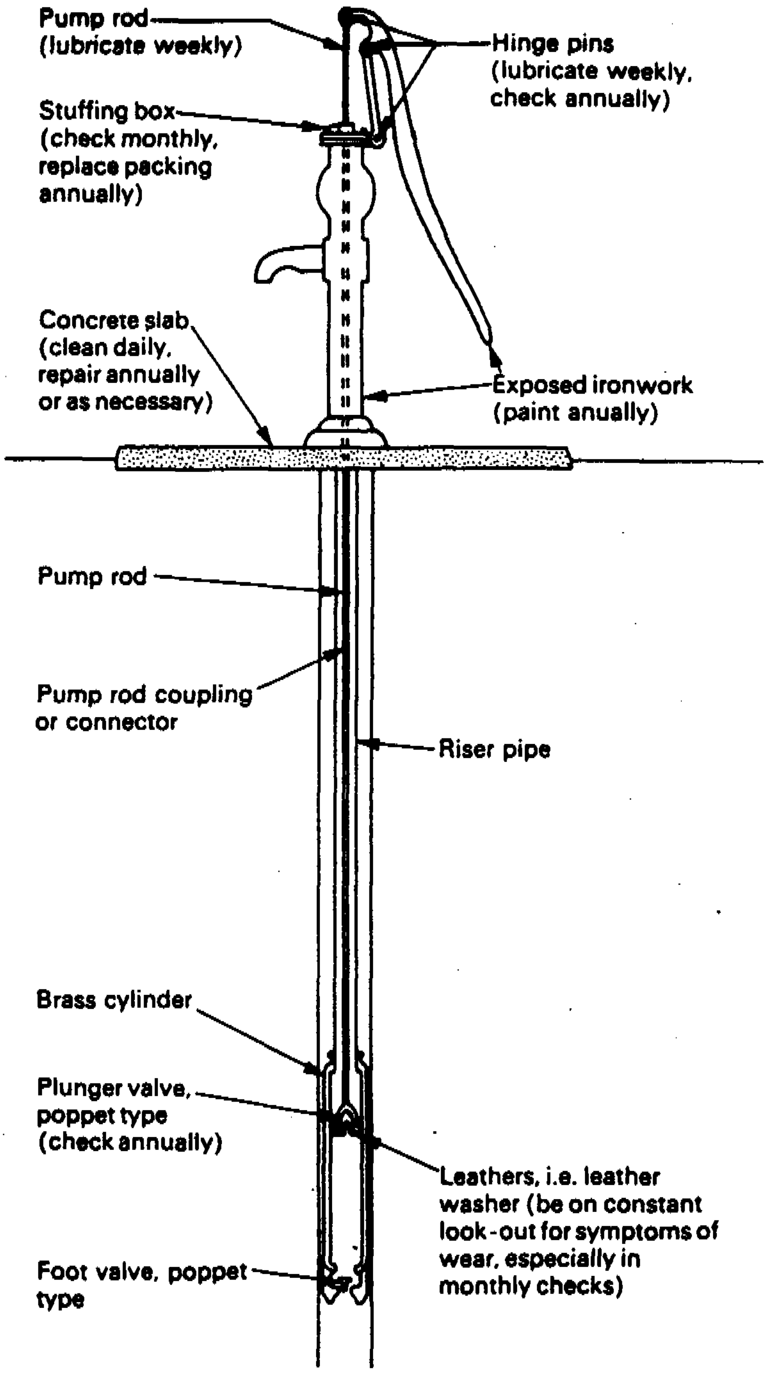


Figure 5.12
Maintenance points on a simple hand pump
Source: From Pacey (1977)

Fig 6.49 (c 8F, 93)

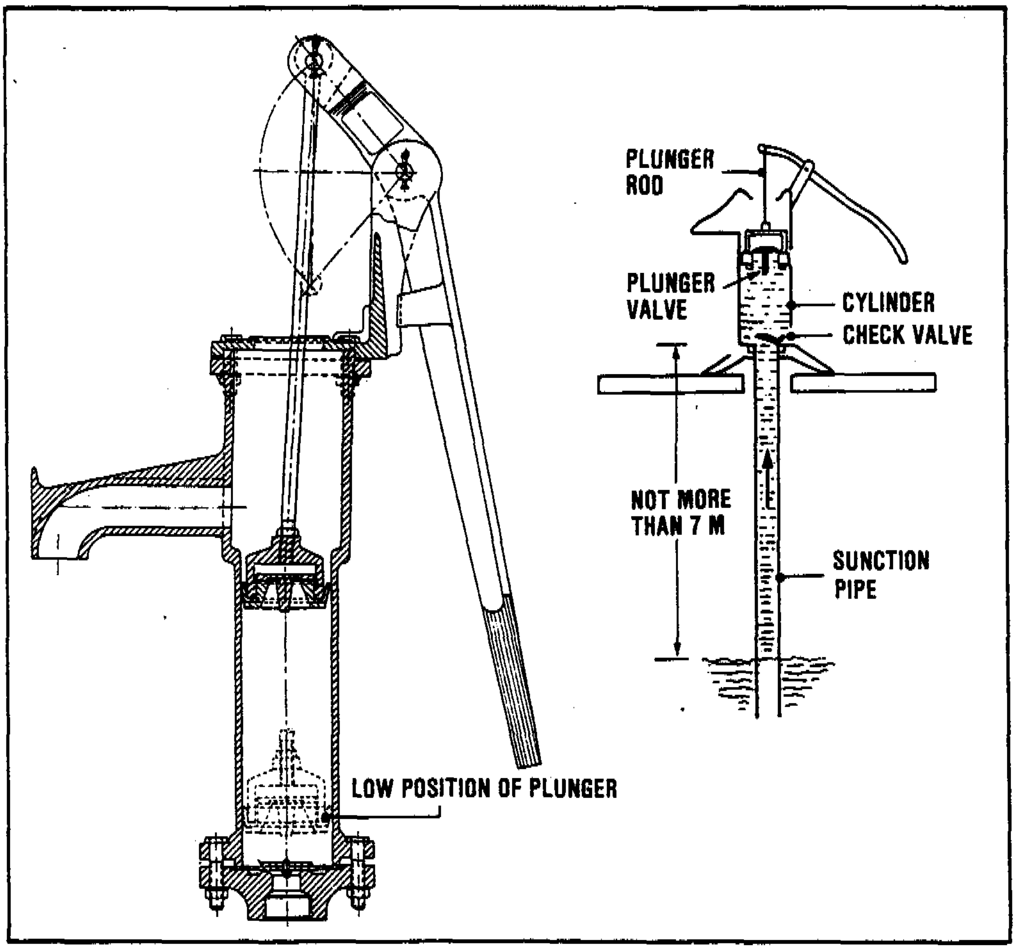


Figure 10.4.
Suction pump (shallow well)

Fig 6. 50 (IRC, 83)

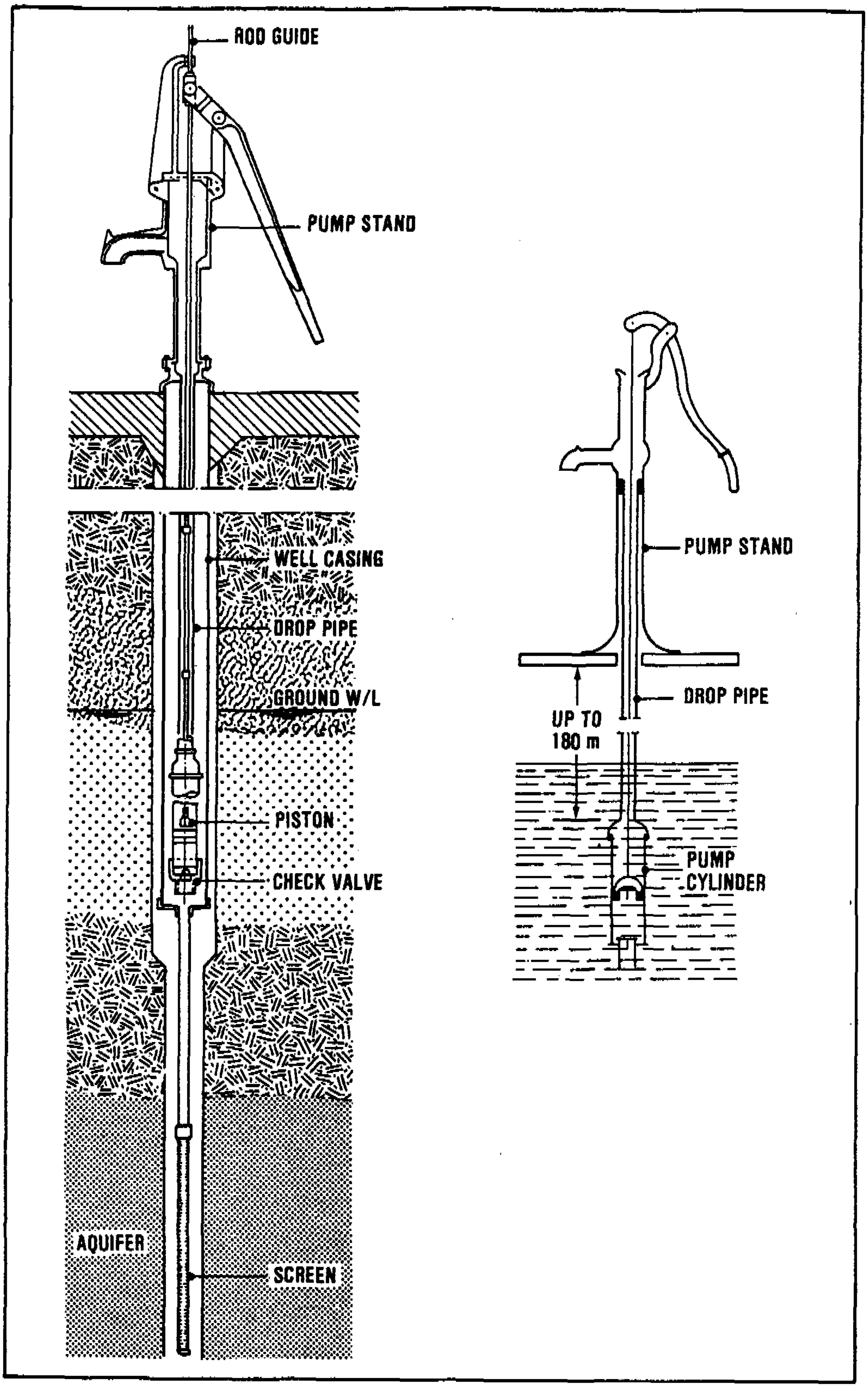


Figure 10.5.
Lift pump (deep well)

Fig 6·51 (IRC, 83)

Figure 1: Pump Types

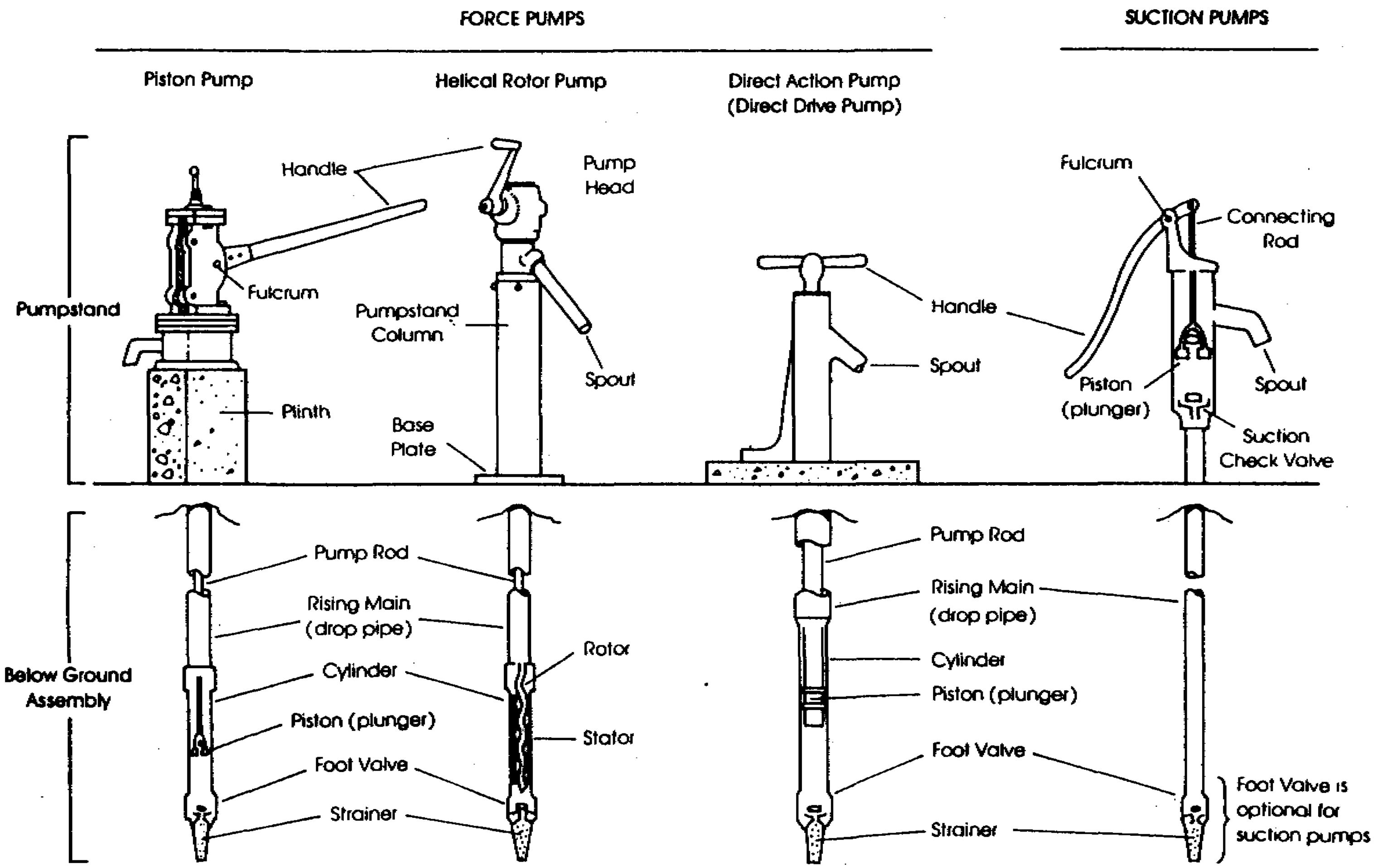


Fig 6.52 (WB, 86)

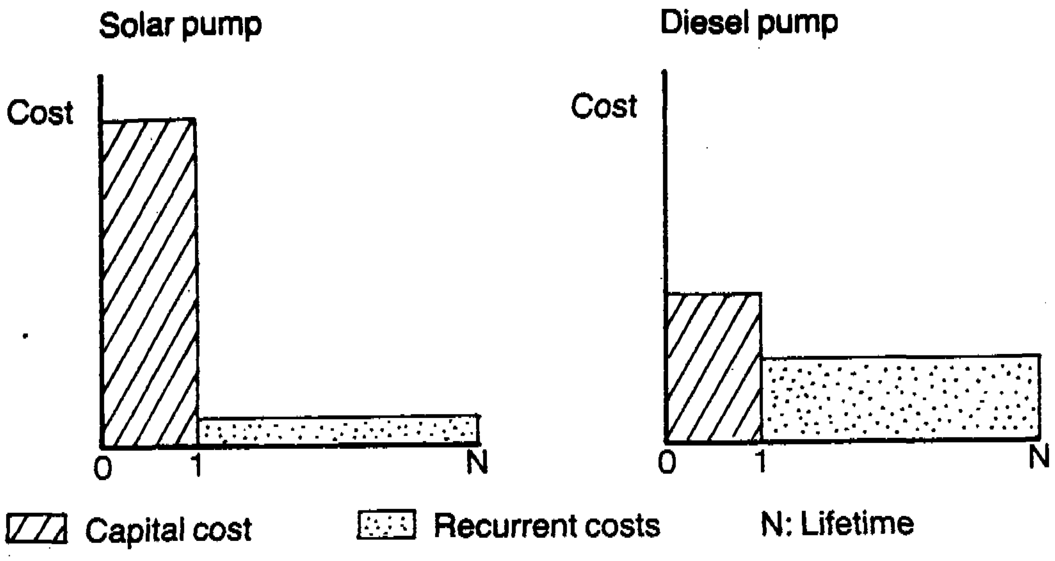


Figure 2.2: Comparison of time profile of costs for solar pump and diesel pump

Fig 6.53 (IRC, 86)

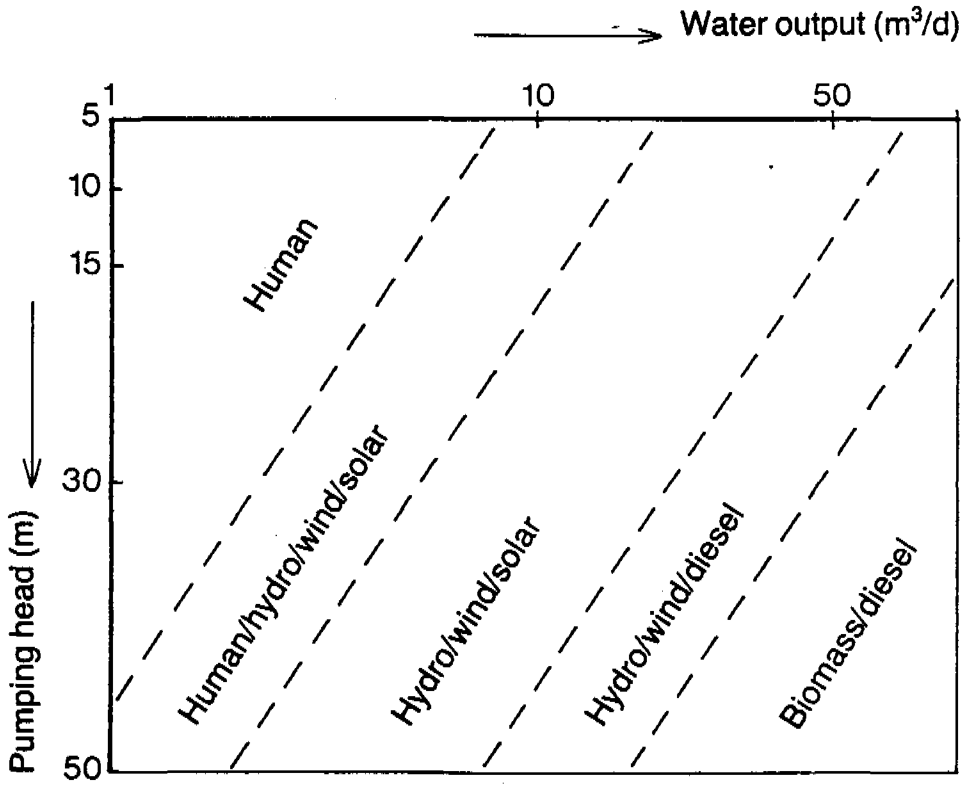


Figure 2.3: Estimated range of economic feasibility of energy sources for a particular water pumping duty

Fig 6.54 (IRC, 86)

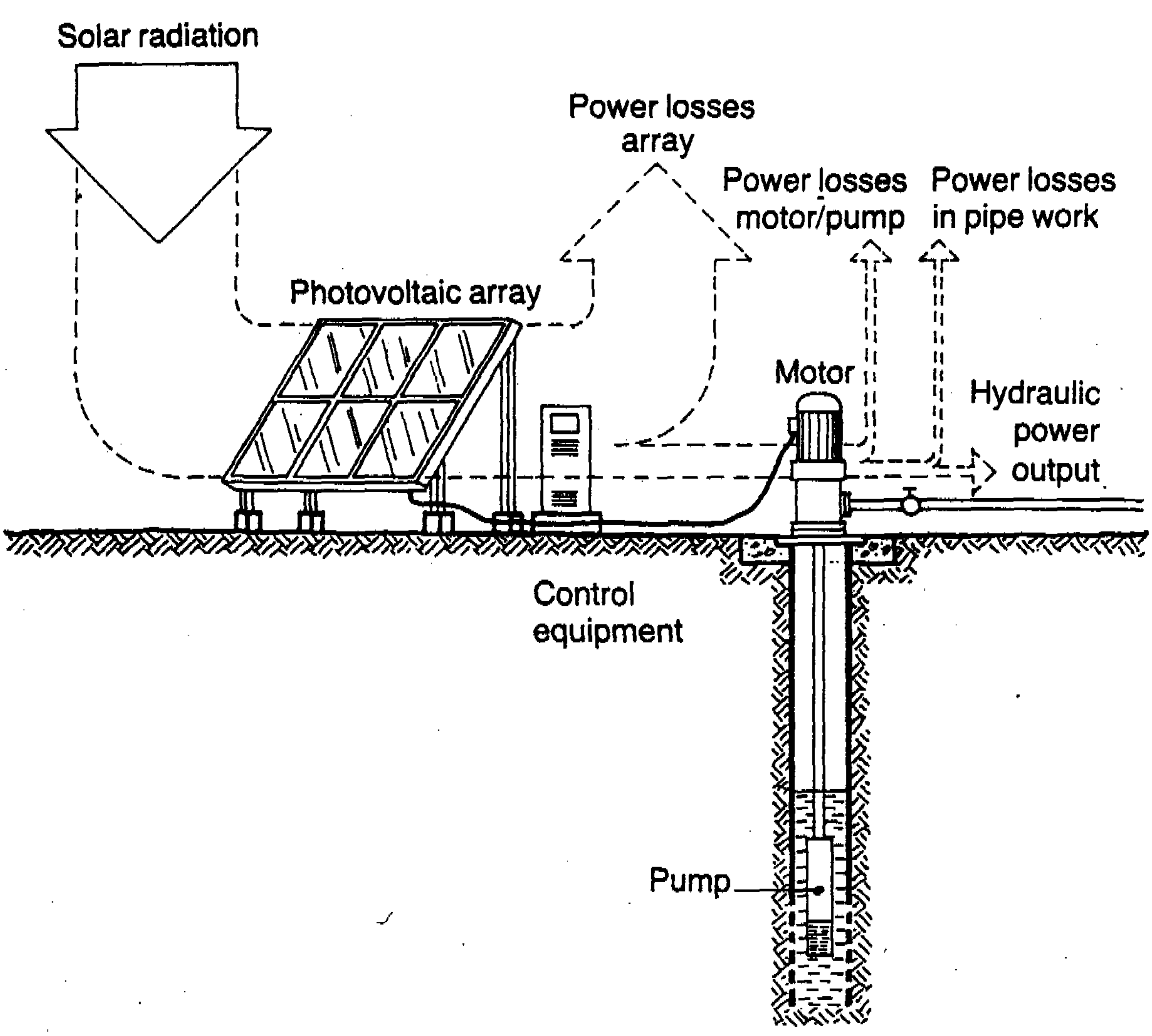


Figure 5.5: Power conversion in a solar photovoltaic pumping system

Fig 6.55 (IRC, 86)

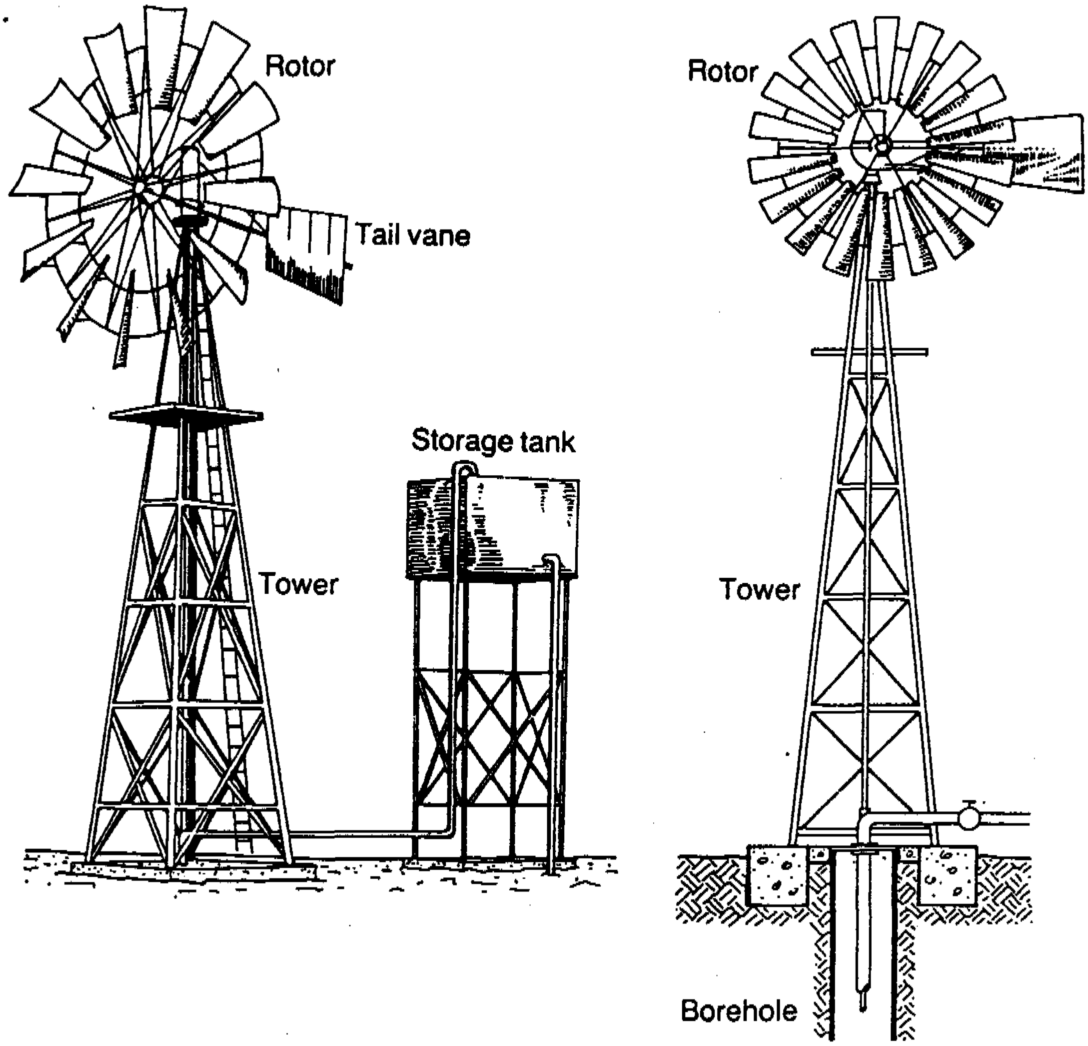


Figure 6.2: Main features of mechanically coupled wind pump

Fig 6. 52 (IRC, 86)

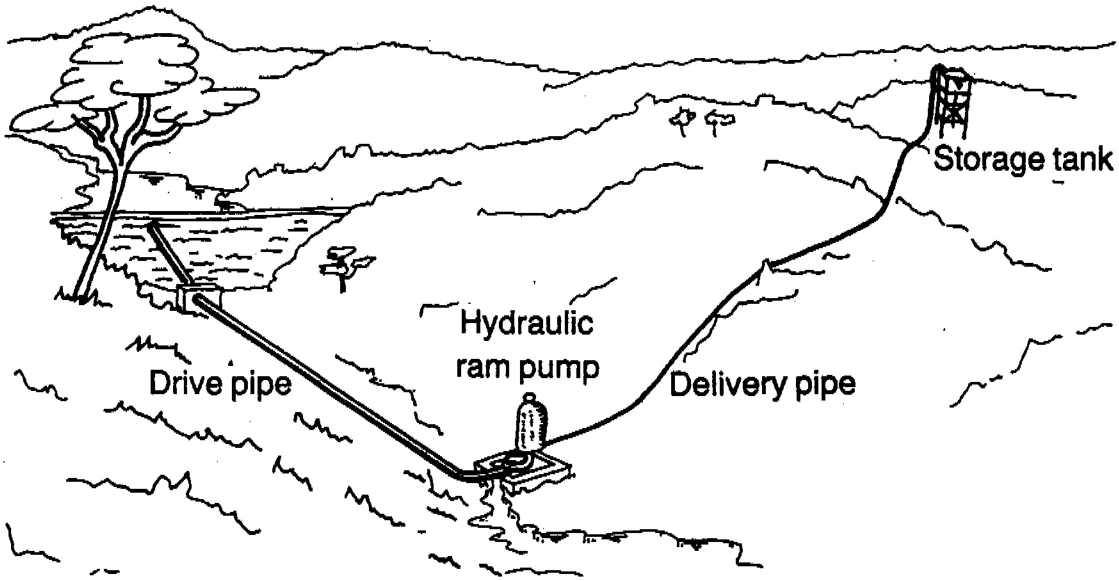


Figure 7.1: Hydraulic ram pump installation

Fig 6. 57 (IRC, 86)

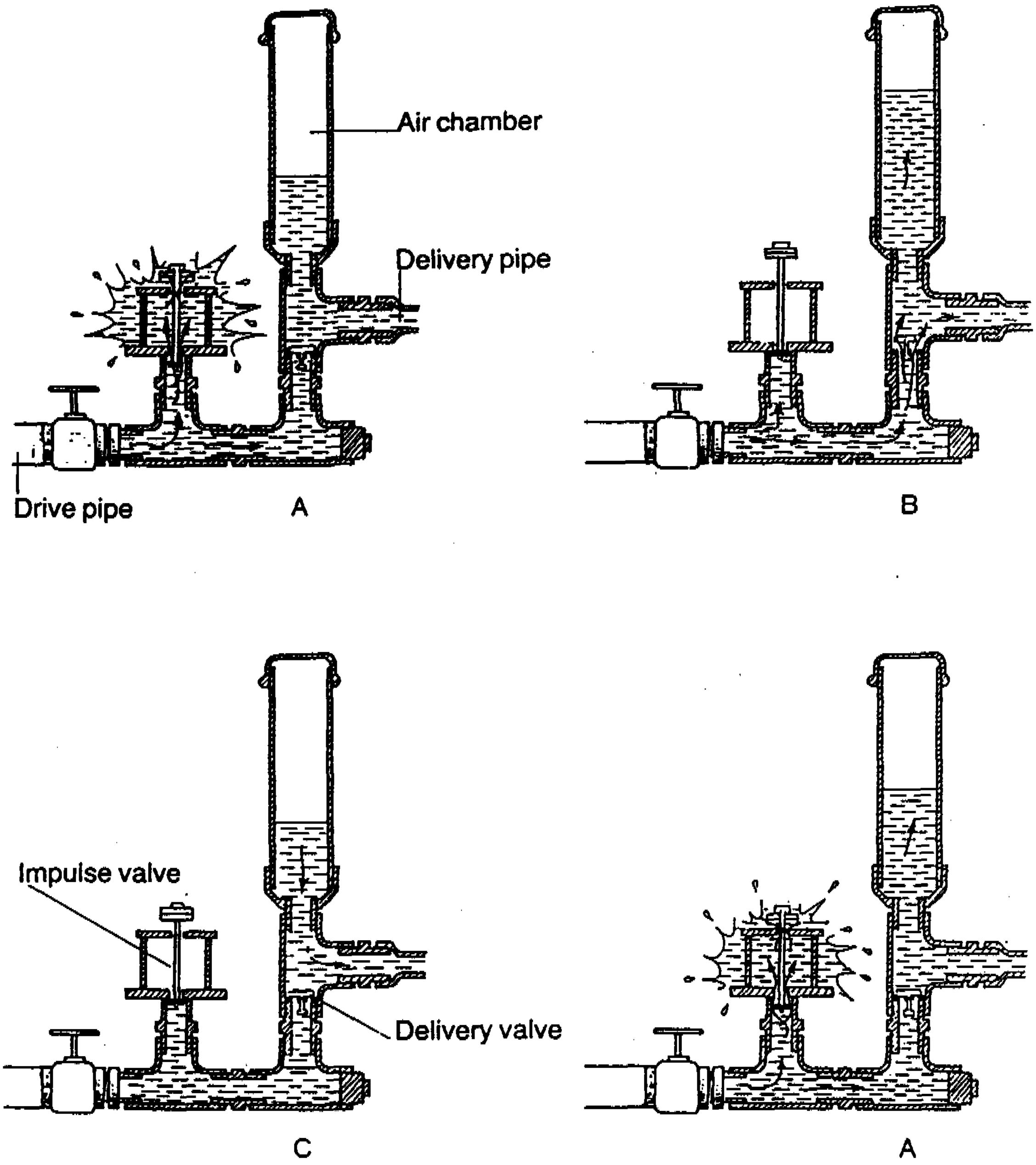


Figure 7.5: Operation of hydraulic ram pump

Fig 6. 58 (IRC, 86)

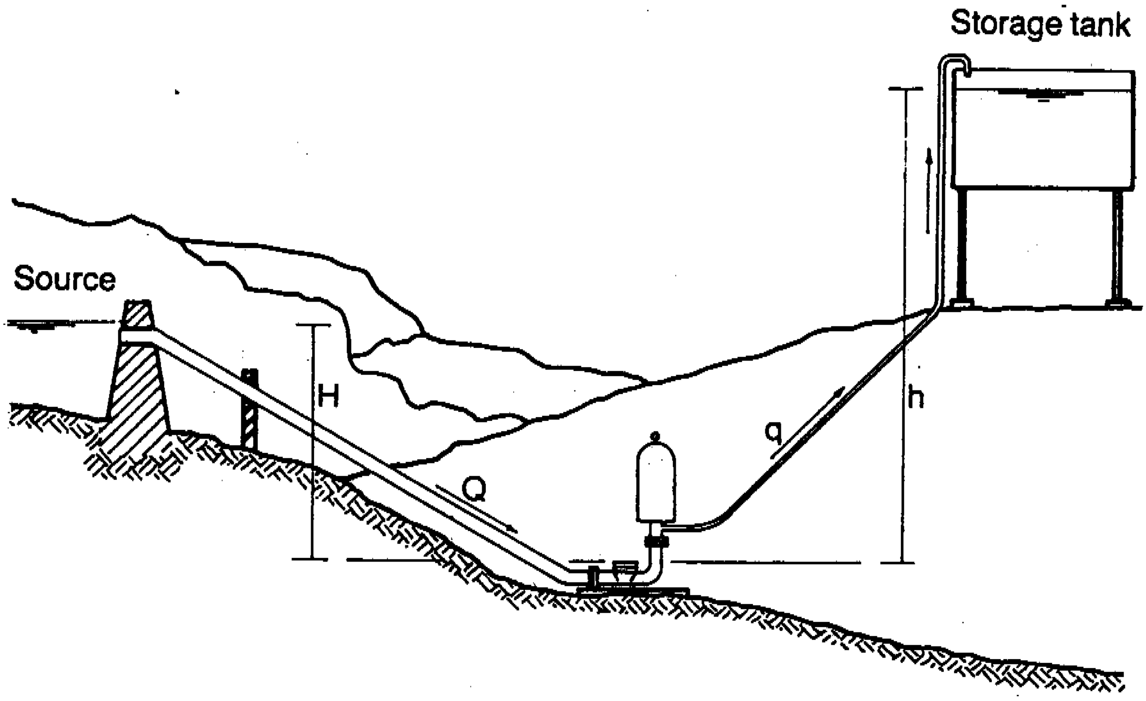


Figure 7.6: Design parameters of hydraulic ram pump installation

Fig 6. 59 (IRC, 86)

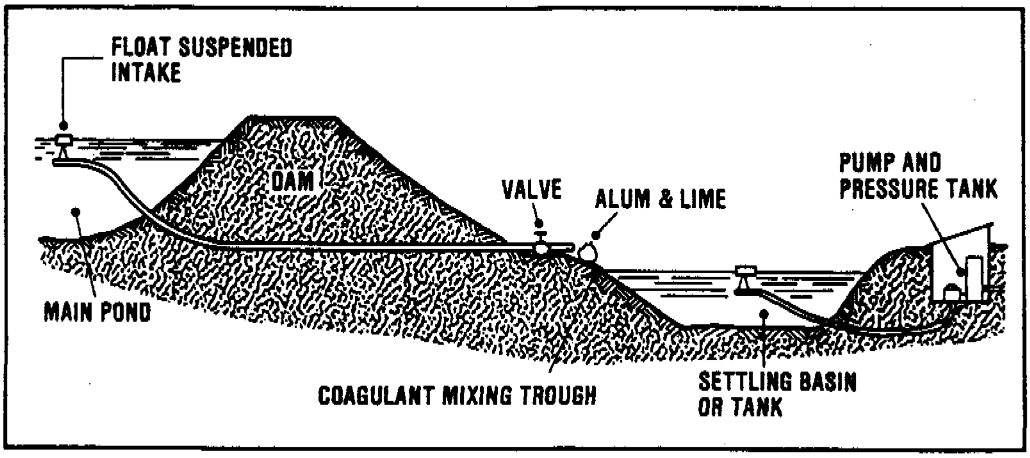


Figure 11.1.
Simple arrangements for water intake, coagulant mixing and settling

Fig 6. 60 (IRC, 83)

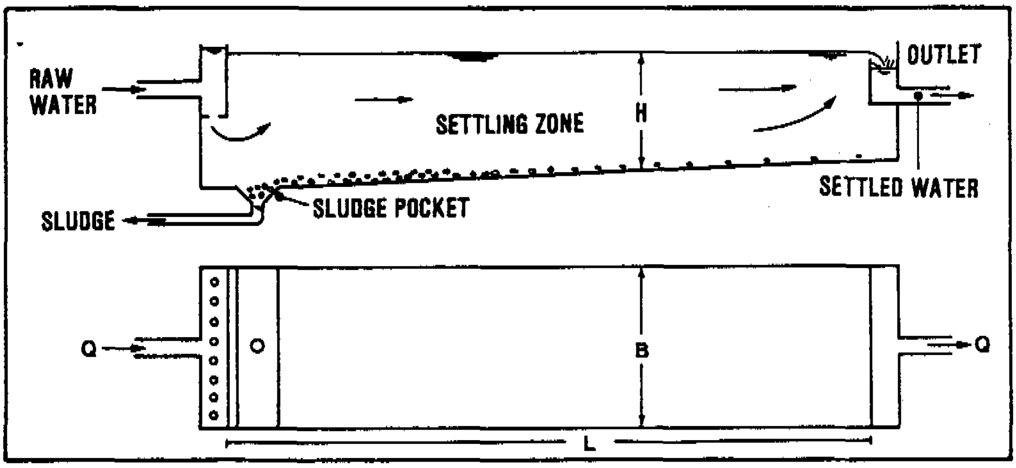


Figure 14.1.
Rectangular horizontal flow settling tank

Fig 6.61 (IRC, 83)

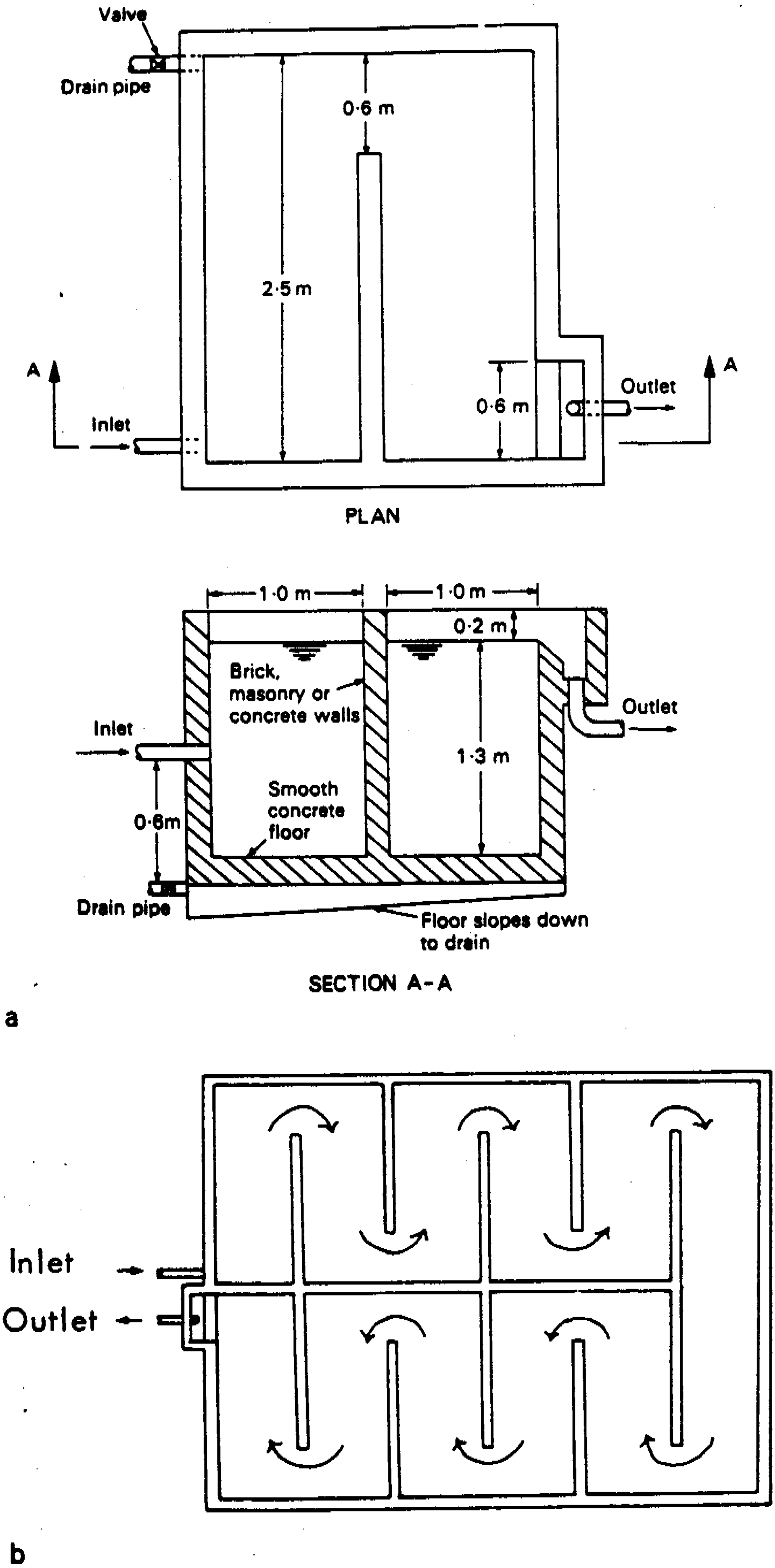


Figure 5.17 (a) A simple sedimentation tank for flows of up to 2000 l/h. (b) A method of combining six small sedimentation tanks to take a flow six times the capacity of each

Fig 6.62 (C & F, 93)

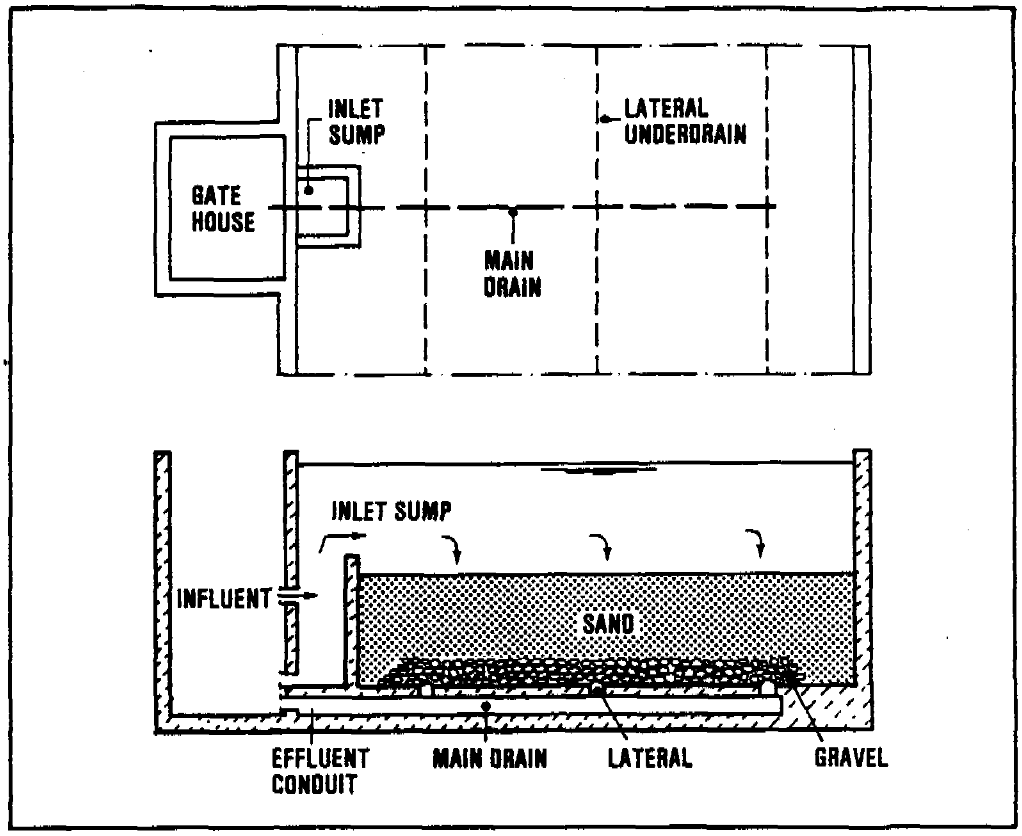


Figure 15.1.
Slow sand filter

Fig 6.63 (IRC, 83)

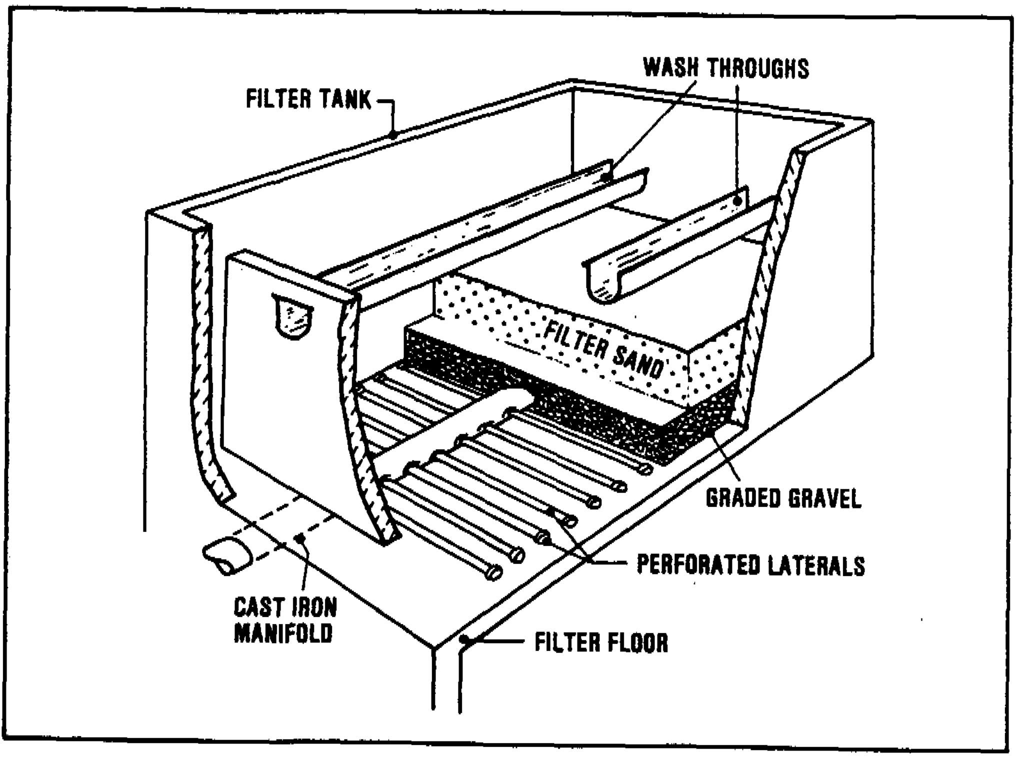


Figure 16.1.
Rapid filter (open,gravity-type)

Fig 6.64 (IRC, 83)

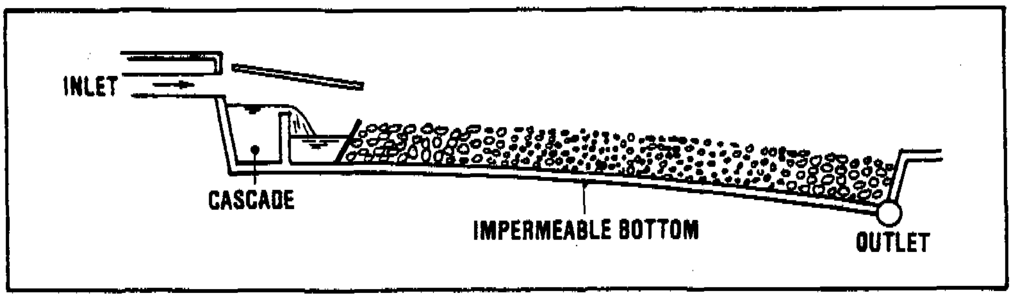
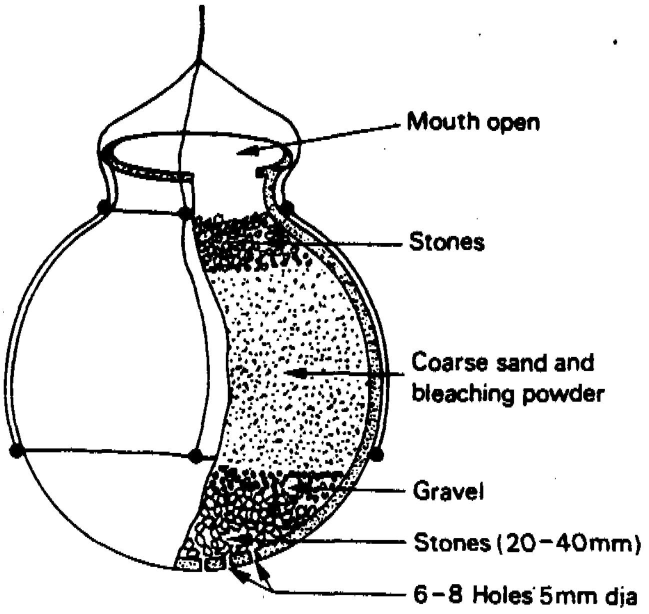
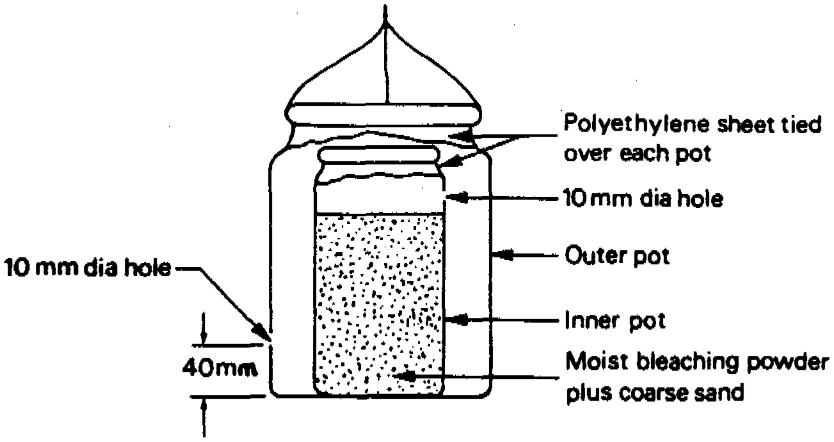


Figure 16.25.
Horizontal gravel filter

Fig 6.65 (IRC, 83)



(a) Single pot system



(b) Double pot system

Figure 5.18 Pot chlorinators for disinfecting wells. Two alternative designs

Fig 6.66 (C & F, 93)

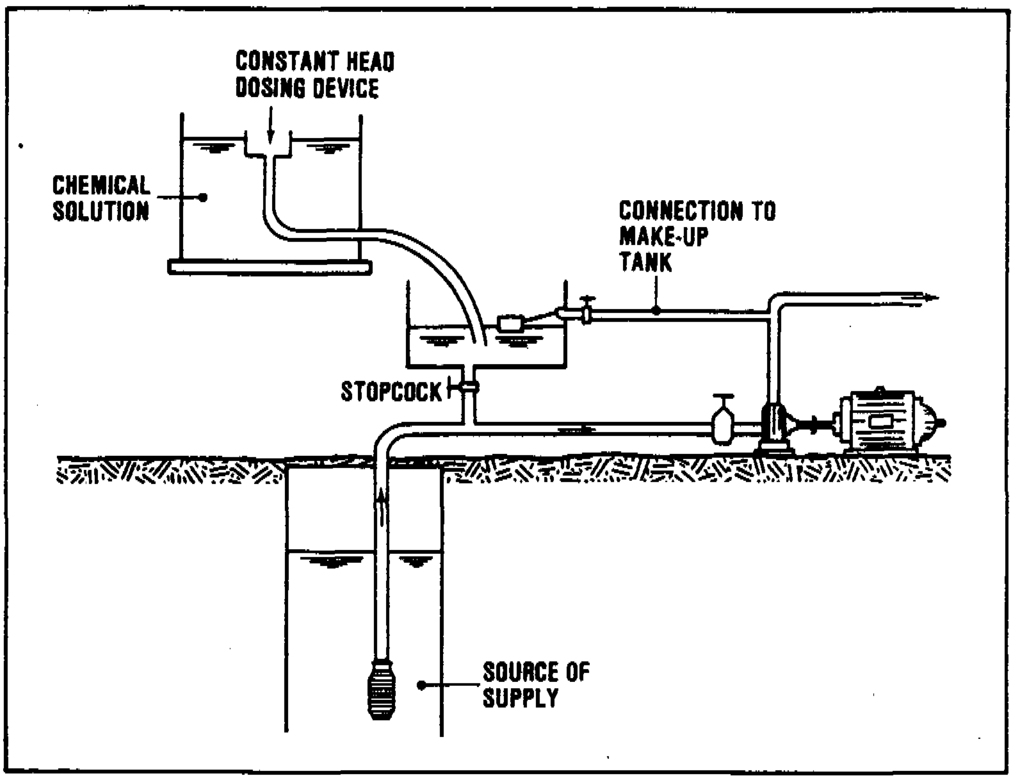


Figure 17.6.
Chlorination arrangement for pumped supplies

Fig 6.67 (IRC, 83)

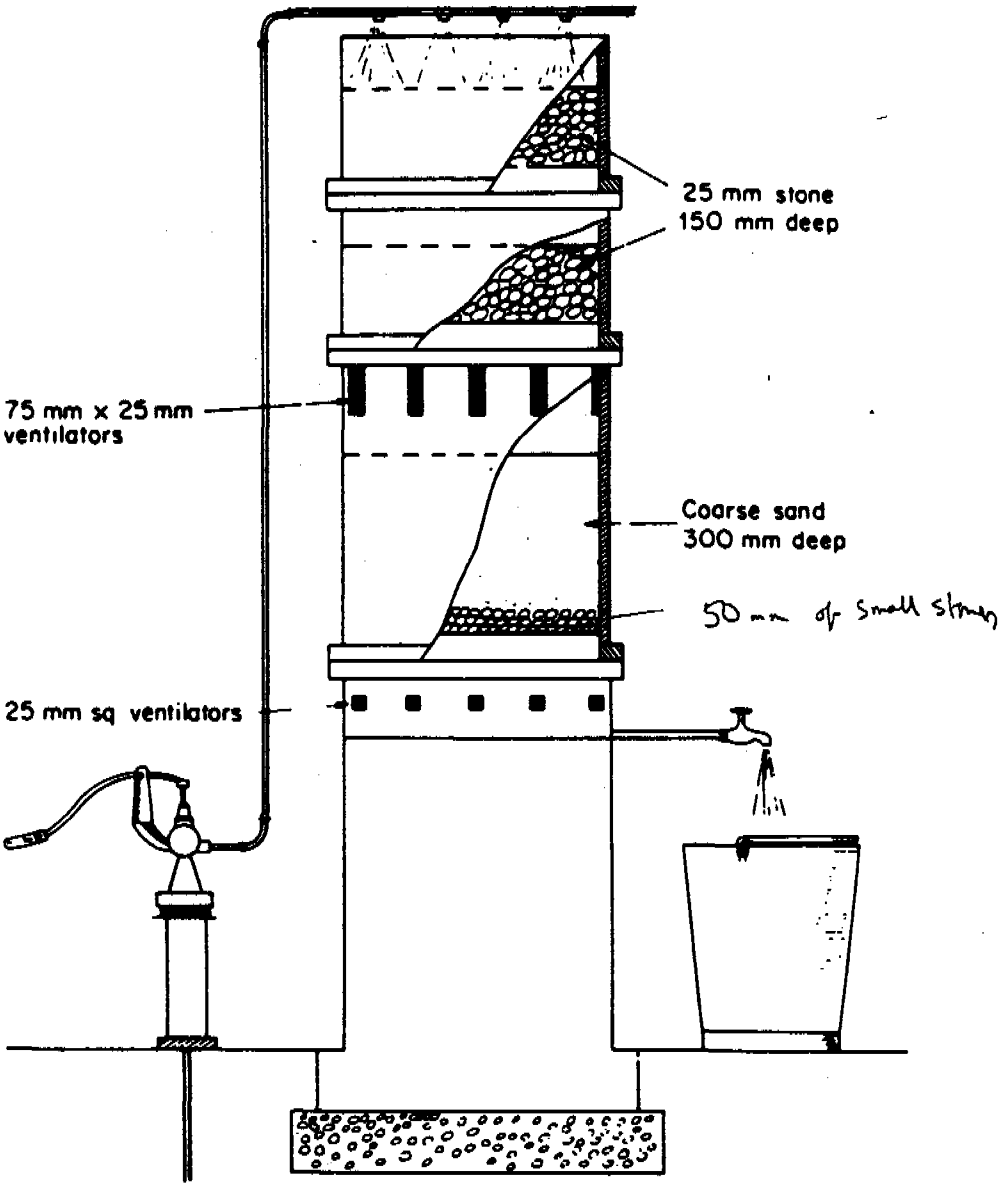


Figure 5.20 A hand-operated unit for iron and manganese removal
Source: From Pickford (1977)

Fig 6.68 (C8K, 93)

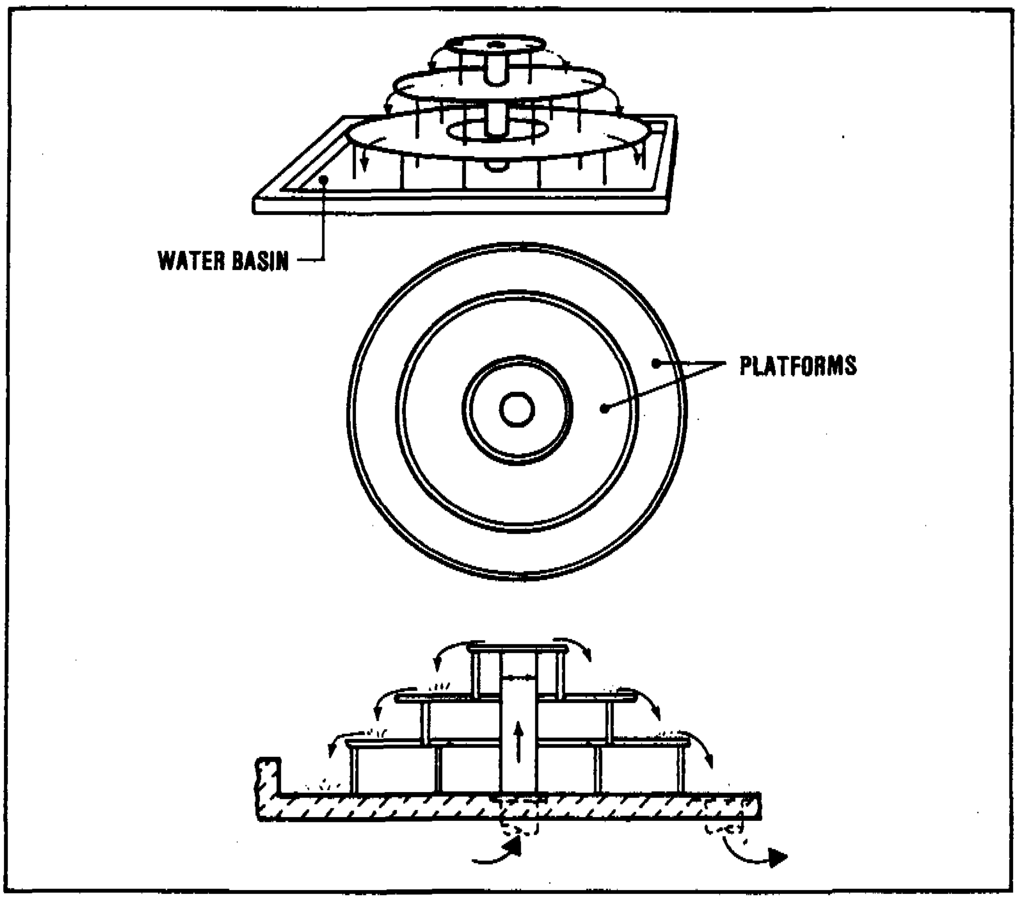


Figure 12.5.
Multiple-platform aerator

Fig 6.69 (IRC, 83)

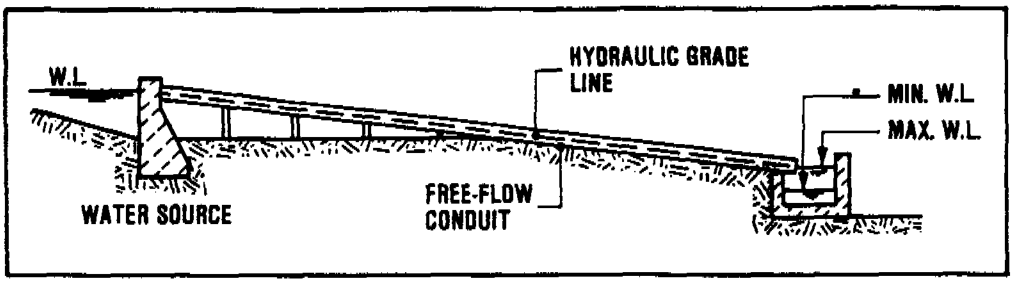


Figure 18.1.
Free-flow conduit

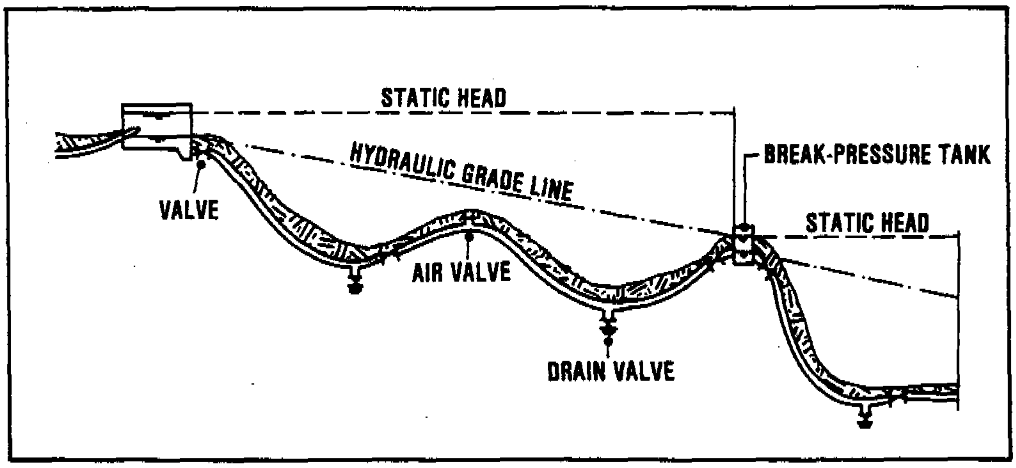


Figure 18.2.
Pressure pipeline

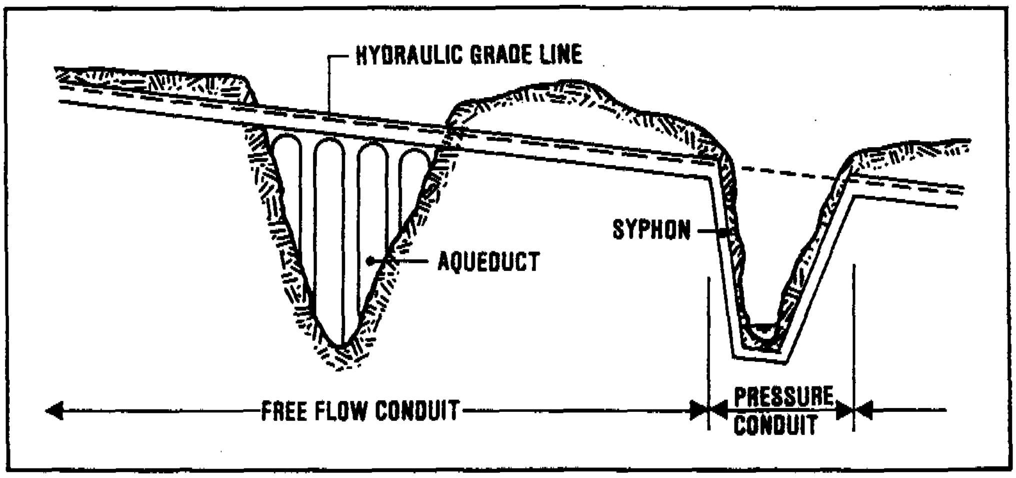


Figure 18.3.
Combined free-flow/pressure conduit

Fig 6.70 (IRC, 83)

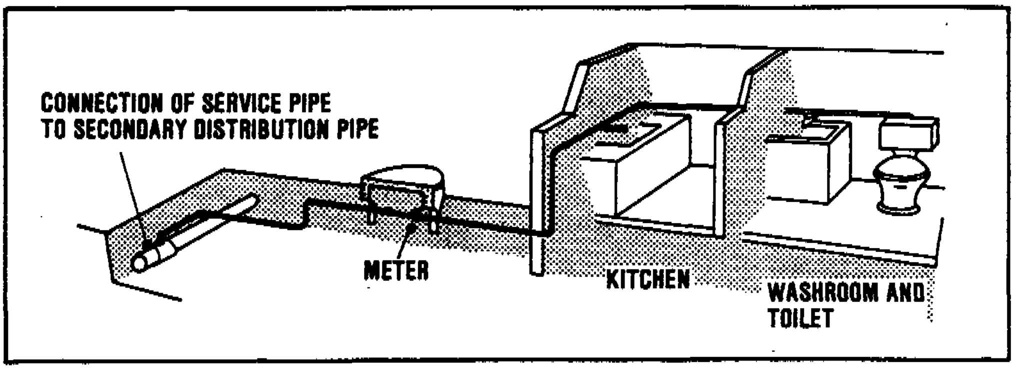


Figure 19.4.
House connection

Fig 6.71 (IRC, 83)

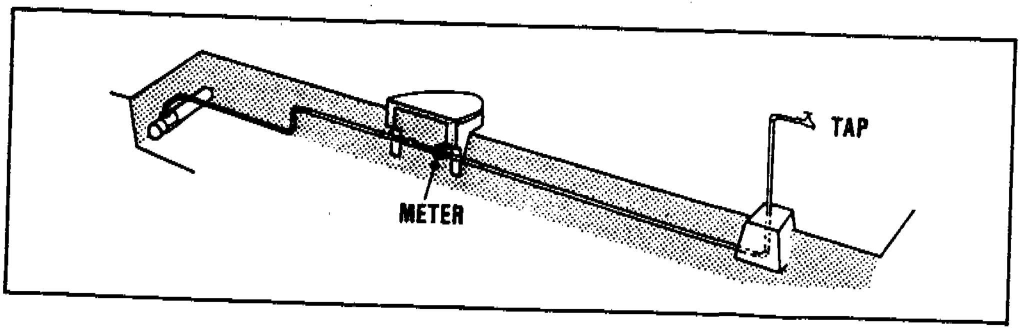


Figure 19.5.
Yard-connection

Fig 6. 7 2 (IRC, 83)

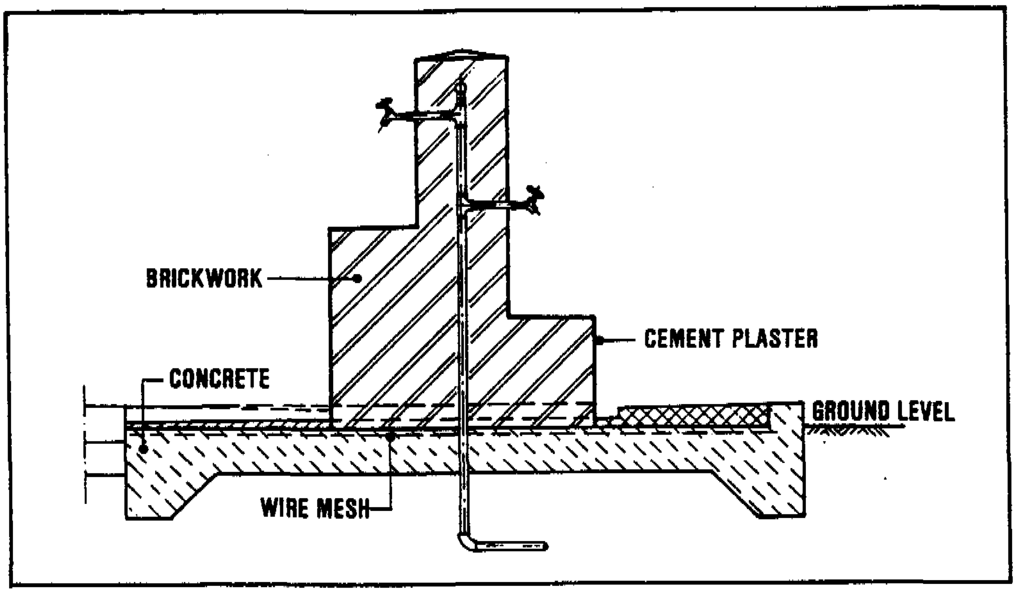


Figure 19.7.
Cross-section of multiple-tap standpipe

Fig 6.73 (IRC, 83)

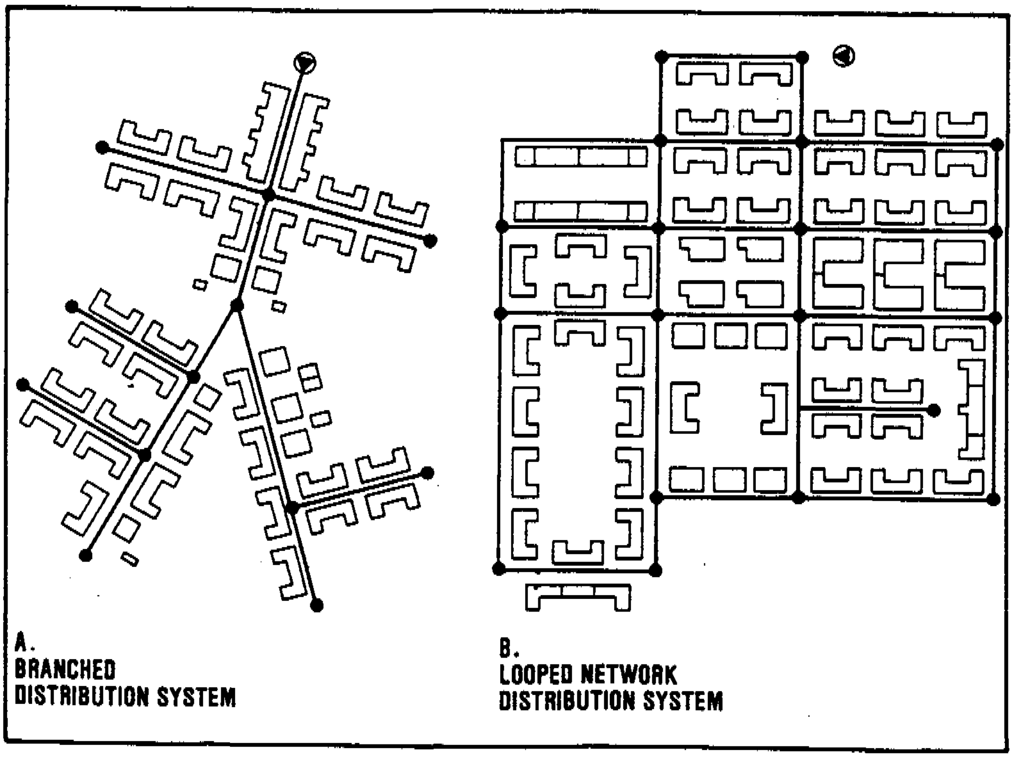


Figure 19.1.
Types of distribution systems

Fig 6.74 (IRC, 83)

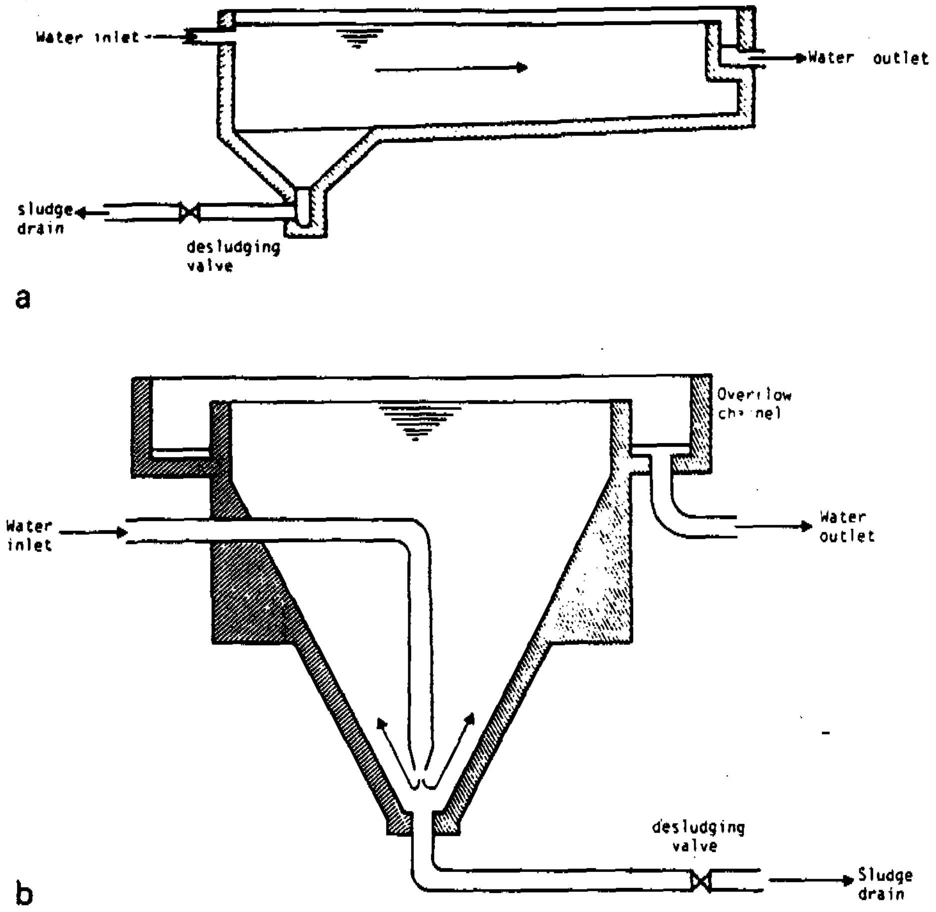


Figure 6.1 Two common types of setting tank. Many other designs exist, most of them modifications of these two basic forms (see also Figure 5.17). (a) A horizontal-flow settling tank. (b) An upward-flow clarifier

Fig 6.75 (C 8F, 93)

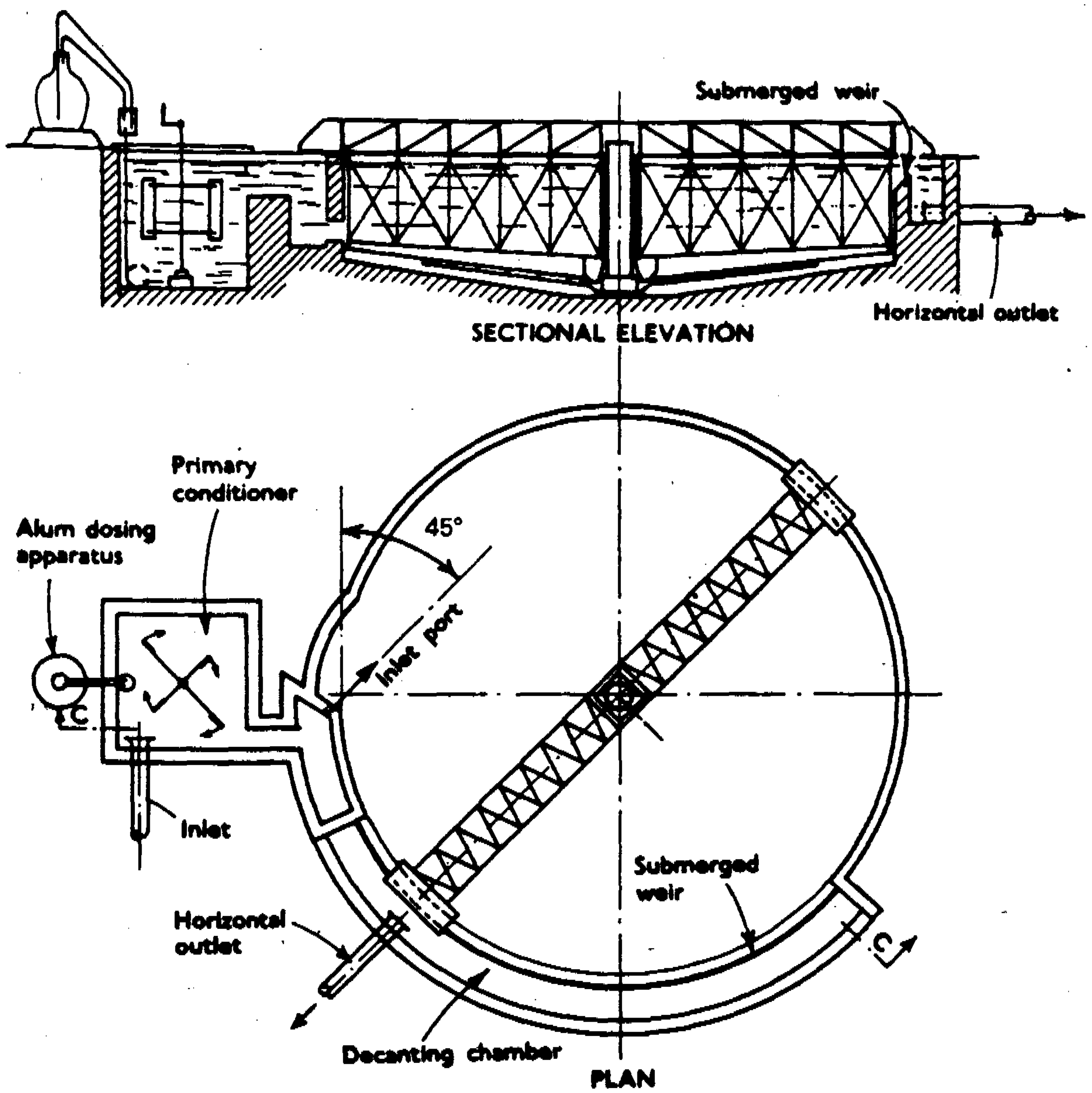


Figure 6.2 A spiral-flow settlement tank as designed by Walton and Key
Source: From Twort *et al.* (1985) Reproduced by permission of The Institution of Civil Engineers

Fig 6.76 (c 8F, 93)

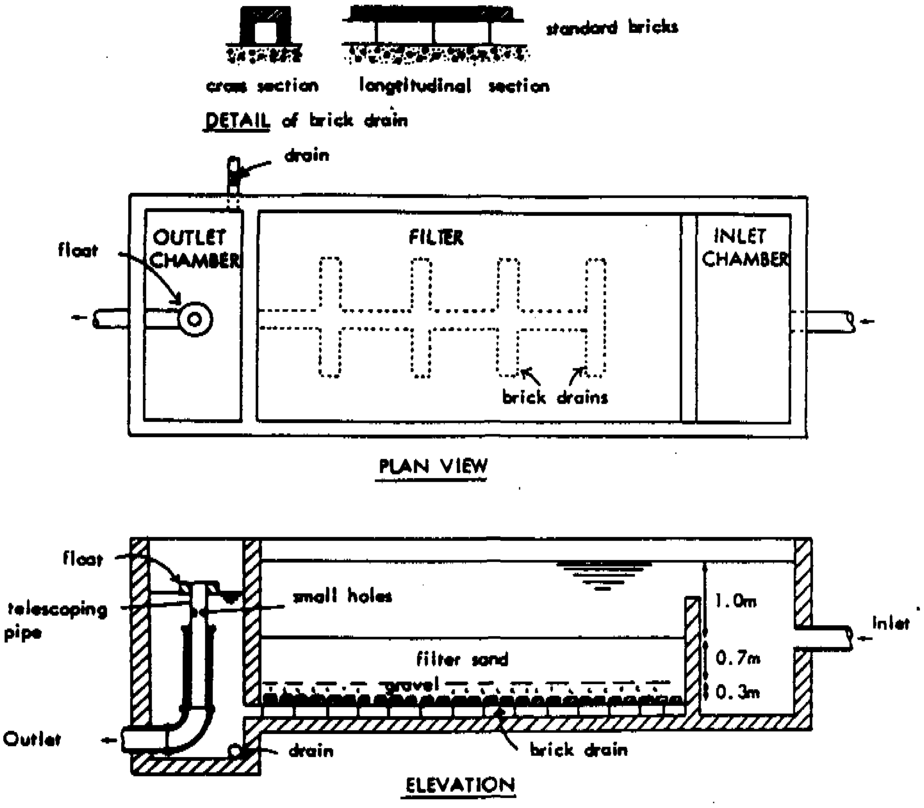


Figure 6.3 A slow sand filter

Fig 6.77 (C & F, 93)

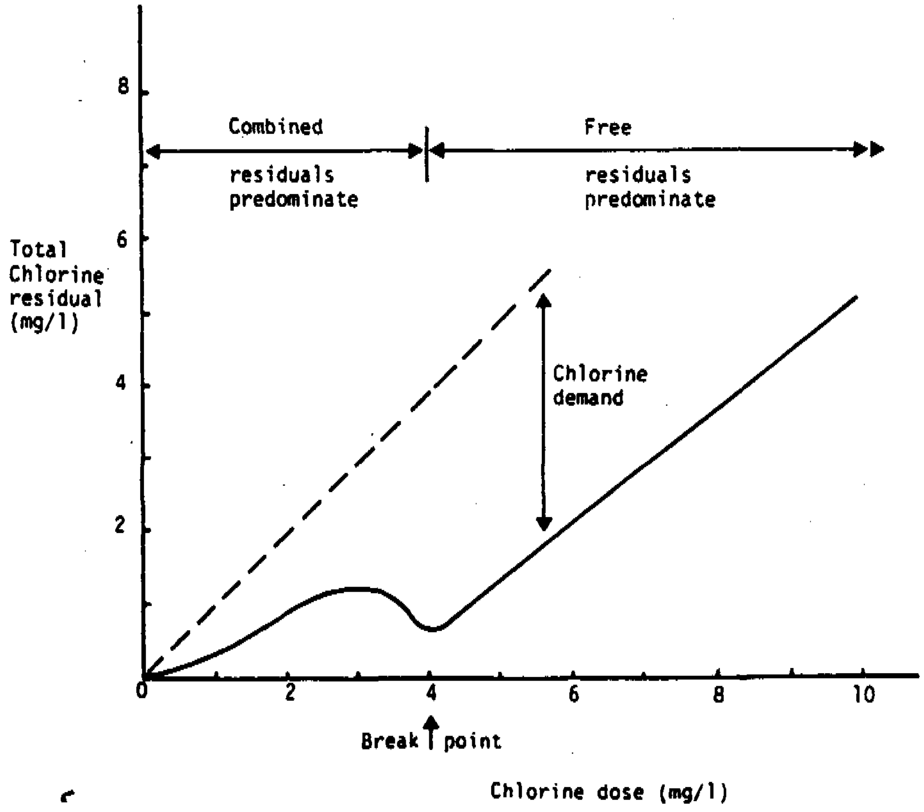


Figure 6.4 Chlorine-residual curve for a water with 0.6 mg/l ammonia
Source: After Tebutt (1992)

Fig 6.78 (C & F, 93)

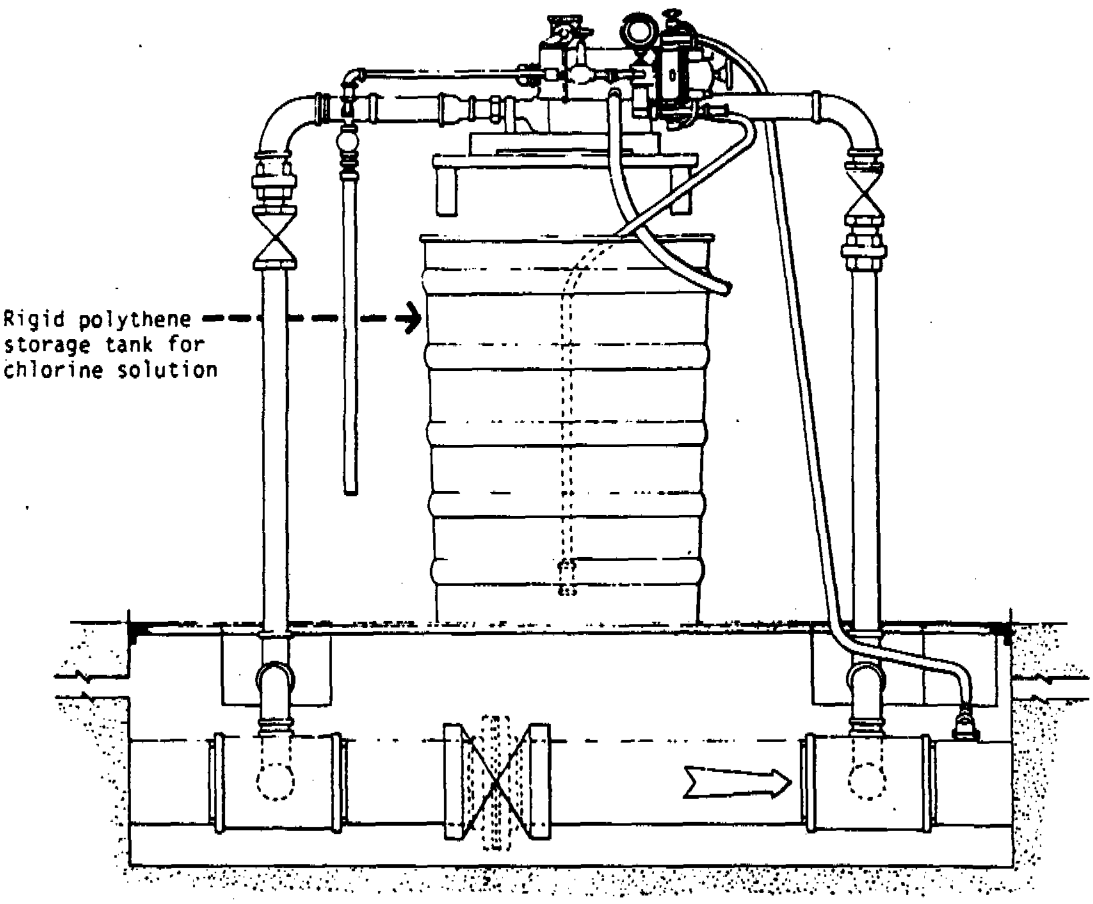


Figure 6.5 A chlorine-solution feeder. The solution is fed into the main at a rate proportional to the flow (measured by the meter on the by-pass pipe). No electricity is required and power is provided by the water itself. This model can operate with a head in the main between 7 and 90 m (Drawing: Wallace and Tiernan Ltd)

Fig 6.79 (C & F, 93)

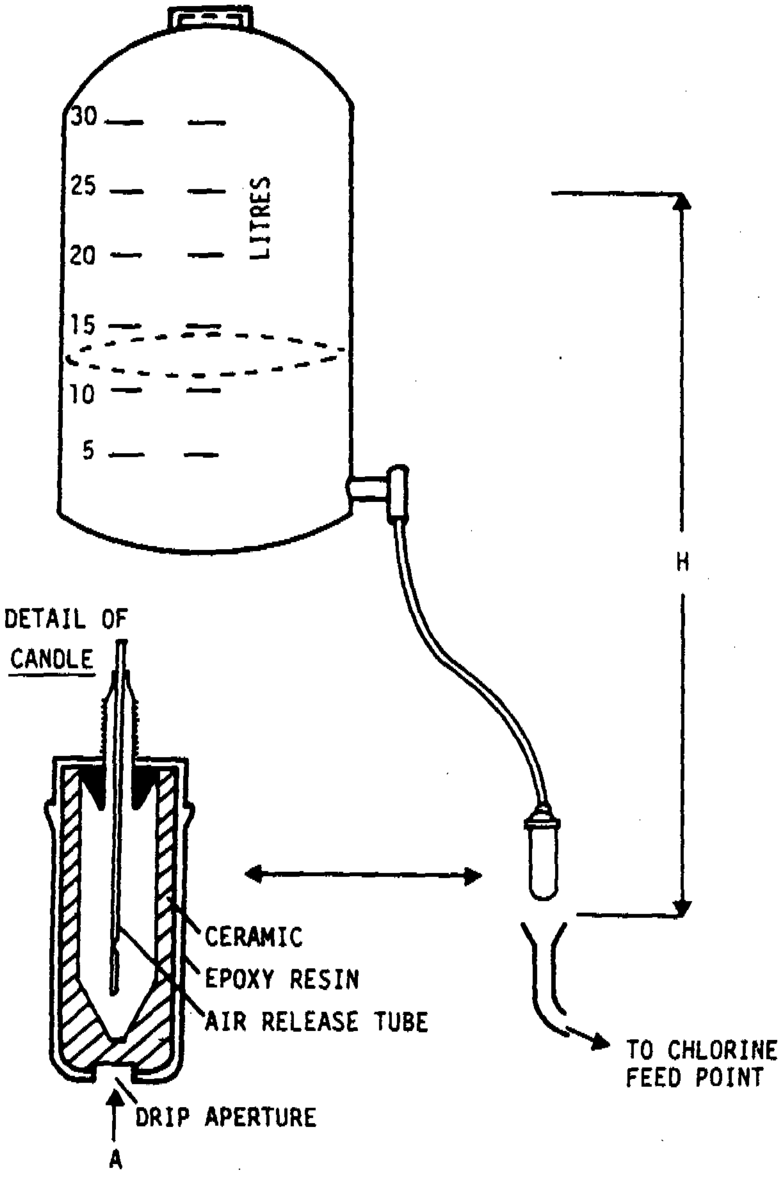


Figure 6.6 A simple drip-feed chlorinator using a ceramic filter candle. It is painted on the outside with resin and a small depression made in the tip with a 3 mm drill to penetrate the resin. The drip rate reaches a steady value within a week, and can then be adjusted by altering H or enlarging the hole at A
Source: After Barker (1967)

Fig 6.80 (C 85 93)

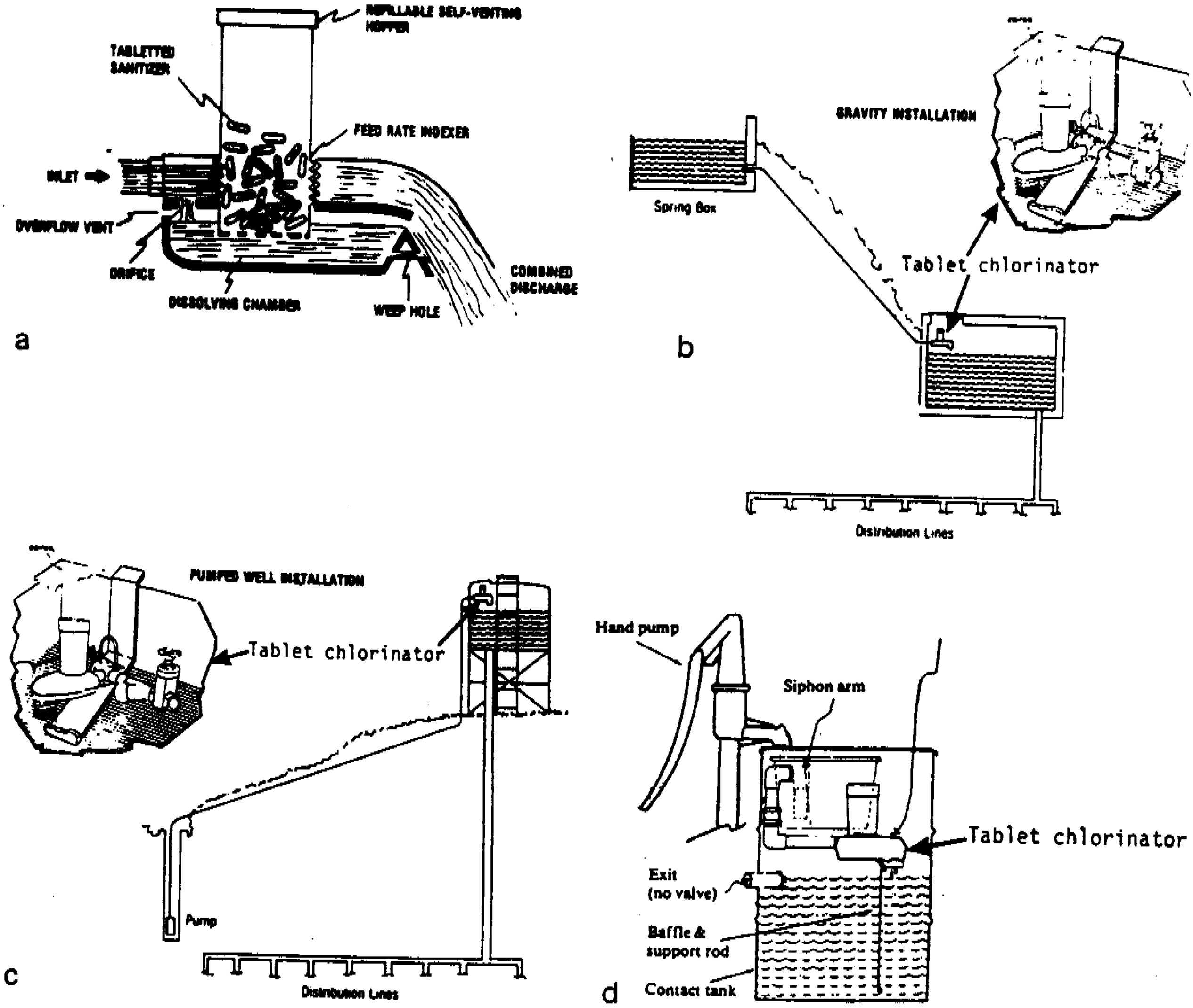


Figure 6.7 Tablet chlorinators made by World Water Resources Inc. The chlorinators use tablets of calcium hypochlorite which are eroded by the water flow as shown in drawing a. They may be installed on the storage tank of a gravity supply (drawing b) or a pumped supply (drawing c). Tablet chlorinators may also be adapted for use with a hand pump (drawing d) (Drawings: World Water Resources Inc)

Fig 6.81 (C 8F, 93)

Chapter 7 Sanitation

7.1 Introduction

As mentioned earlier the term 'sanitation' covers a wide aspects. However, discussion in this chapter will mainly be concentrated on wastewater disposal. Basically this includes human waste and sullage.

Water is a limited natural resource that is too often taken for granted in human culture. Unlike many consumer goods, water contaminated by human waste cannot be simply 'thrown away', as that are capable of the spread of the disease. Water containing human waste, termed sewage or wastewater, generally contains more than 99.9% pure water (Morgan, 1993). The remaining less than 0.1% consists of the waste we should remove from the water.

Excreta disposal is an important part of environmental sanitation. Its provision is among the first basic steps which should be taken towards assuring a safe environment in rural areas and small communities. In large areas of the world, and indeed in parts of every country, proper excreta disposal is among the most pressing public health problems.

7.2 Importance of sanitation

The inadequate and insanitary disposal of excreta leads to the contamination of the ground and of sources of water supplies. It often affords an opportunity for certain species of flies to lay their eggs, to breed, to feed on the exposed material, and to carry infection. It also attracts domestic animals and rodents and other vermin which spread the faeces, and it sometimes creates intolerable nuisances.

Poor excreta disposal is often associated with the lack of adequate water supplies and of other sanitation facilities and with low economic status of the population. These conditions, all of which affect health, make it difficult to assess the role played by each component in the transmission of disease. However, it is well known that (WHO, 1958), there is a relationship between the disposal of excreta and the state of health of the population. The relationship is both direct and indirect in character.

The direct effect can be shown by the reduced incidence of certain diseases when proper disposal of excreta is practised. This group of diseases includes cholera, typhoid and paratyphoid fevers, the dysenteries and diarrhoeas, hookworm and ascariasis,and other similar intestinal and parasitic diseases. These diseases usually lay a heavy hand on infants of the developing countries.

The indirect relationships of excreta disposal to health are many, but they are generally associated with other components of environmental sanitation. Some of these are as follows.

1. The improvement of hygienic conditions promotes a state of well being in the population which is conductive to its social development.
2. There is considerable evidence that the reduction of excremental and water-borne diseases which results from improvements in environmental sanitation is accompanied by a marked decrease in morbidity from other diseases the cause of which is not directly related to either excreta or contaminated water supplies.
3. An increase in life expectancy caused by the improvement of sanitation leads to various economic benefits.
4. Increase in possible work hour occurs due to absent of various sickness.

7.3 Context of rural and urban sanitation

There are some points of difference to note in rural and urban sanitation.

7.3.1 Rural sanitation

The unique point of the rural sanitation is the social and psychological implications of the program.

Community participation : Experience available from all parts of the world leads to the conclusion that a program of rural sanitation cannot be successful without the participation of the local community. Mere technical improvement of the facilities without public education in hygiene and sanitation, based on local customs, traditions, and beliefs, has again and again proved unsuccessful.

One measure of the success of a rural sanitation program is its power to sustain itself and grow. In order to achieve this success, it is necessary to find ways of gaining popular support and of overcoming popular objection. In both, health education of the public can play a major role. More important still is the desirability of bringing the people into the program as partners.

The health education stage is the most difficult in a sanitation program. Once it is successfully done, the program will move at by its own. For example, in rural parts of Bangladesh where community health program have been going on for some time, sanitary latrines are constructed almost exclusively by the families, with some guidance from Department of Public Health Engineering. The people have to buy rings and slab for the sanitary latrine, still in many places the demand is higher than the supply.

Continuous support : The sanitation work cannot be considered completed after the construction of the sanitary latrine, in fact, it has just begun. The public health inspectors must remain continuously in touch with the family to stimulate and educate its members into using and maintaining this facility. This continued education process can make the family to accept the latrine as a part of their life, willing to maintain it, and even involve in teaching the neighbours.

Motivation : Health workers have to visit the community to motivate the potential users. People who come to a health center seeking treatment of intestinal disorder can be provided with the suggestions as to how to avoid those diseases and wit the information on relation between the sanitation and those diseases.Visual media based teaching can also prove rewarding, which includes photographs, slides, posters, film show and so on.

7.3.2 Urban sanitation

A major problem in environmental health in developing countries is that of excreta disposal system in high-density, low-income communities. This type of slums consists of a significant portion of population in the developing countries cities. It have to noted that water-borne system may not be an appropriate choice in those areas.

Cost : The water-borne system is the most expensive of all sanitation system and has a very high capital construction cost. Experience has shown that most slum dwellers are unable or unwilling to cover the real capital and running costs of water-borne sewerage and that city authorities are reluctant to subsidize urban sanitation for the poor.

Water use : Water-borne systems use large volumes of drinking water merely to transport wastes along pipes — water which has to be expensively treated before being released back into the ambient environment. It is not justified in many developing countries, where water is scarce and expensive and where distribution systems are very limited and frequently overloaded. Moreover, sewers can become blocked where the water supply is intermittent.

Construction : Water-borne sewerage is a complex technology requiring careful and skilled construction if it is to operate smoothly. The skills necessary to design and install such a system may be in very short supply in a developing country, thus forcing the employment of expatriate companies, with consequent loss of foreign exchange.

Sewer laying : As far as possible, sewers must be laid in straight lines. To dig trenches in straight lines through squatter may require the demolition of a substantial number of houses, which is often be politically and socially unacceptable.

Pumping : Sewers must be laid to a constant falling gradient. If the cover area is flat, this means that numerous pumping stations are required if the pipes are not to be laid excessively and thus expensively deep below ground. These add to the cost and the maintenance problems of the system, especially where the electricity supply is unreliable.

Blockage : Conventional water-borne systems are prone to blockage if large objects are fed into them, or if inadequate water is available for flushing. Communities unused to water-borne sewerage will often try to use the system to remove a variety of household wastes, some of which block the sewers. Materials used traditionally in certain areas for anal cleansing, such as stones or clothes, may also obstruct sewers.

There is no single most hygienic and appropriate alternative to conventional water-borne sewerage for the urban poor. Various systems are required to suit the diverse environments into which they are to be introduced.

7.4 Low cost appropriate sanitation

A major reason why sanitation has not been provided at the same rate as water supply in developing countries is because designers feel comfort to think in terms of conventional water-borne sewerage, which is not usually affordable. As water supplies improve, the need for proper wastewater disposal becomes more critical and the planning both services at the same time is more prudent. It is easy to combine them into a single program if water supply and excreta disposal both imply pipes laid beneath the street. However, in the context of low income communities in developing countries this become highly complicated. In such a setting, water supply may mean a tubewell in a village square and a sanitation, on the other hand an on-site disposal system.

The choice of sanitation system will be limited by the availability of water, and yet will also have an effect on water use. Simpler forms of sanitation capable of operating with a low level of water supply service and not requiring expensive household plumbing will be less costly than conventional sewerage and yet can provide the same health benefits. Nevertheless, both water-borne sewerage and on-site sanitation systems can be integrated by providing the appropriate form of technology for different areas.

The World Bank research program on "Appropriate Technology for Water Supply and Sanitation" has done much to promote the acceptance of low-cost sanitation systems as a means of providing satisfactory hygienic sanitation. many useful publications have been produced in the course of the program, identifying technical options and stressing the importance of social and economic criteria in the selection of sanitation systems. Volume 1 in the World Bank Report Series (Kalbermatten, Julius & Gunnerson, 1980) presented the financial requirements for a range of sanitation technologies (Table 7.1), illustrating the economic advantages of some of the simpler systems and the heavy financial burden which would be placed on low-income households by the provision of septic tanks and sewerage if no subsidy was available. International lending agencies, such as World Bank, now have the policy that the cost of minimal sanitation can not be more than 5 to 10 percent of the household income of the lower income consumer (IWES, 1983).

Low-cost appropriate sanitation technology thus, has to be marketed for better implementation and some of the ways are as follows (Cairncross and Feachem, 1993).

1. In general, health improvement does not motivate many people to buy latrines, because the connection between latrine usage and health is not clearly perceived. The desire for privacy, convenience or social status is usually more effective in generating demand.
2. The cost is not a function of the design criteria, rather, the design criteria should depend on the price which purchasers are willing to pay.
3. A modification to an existing practice or type of latrine is likely to be much easier to implement than a completely new package of technology.
4. The acceptability of the product or the sanitation technology must be checked at every stage in its development by consulting likely purchasers or users.
5. The marketing operation requires constant monitoring of the consumer's response through a cader of staff in direct contact with the consumers in the field.
6. The rate of installation depends on consumer demand. Demand may take several years to build up, as many people will wait until their neighbours have installed a latrine and found it to

perform satisfactorily, before they buy one for themselves.
7. There must be someone to provide 'after-sales-service' if the technology is not to become discredited.

7.5 Factors influencing sanitation systems

There are several factors which influence the choice and design of a system applicable to a particular community. Some are biological in character, others are of an engineering nature, and still others, which are of no less importance, involve careful consideration of human behaviour.

Decomposition of Excreta :

Excreta, wherever deposited, immediately start to decompose, and are ultimately converted to an inodorous, inoffensive, and stable product. In the design of excreta disposal facilities it is important for the health worker to know and understand how this process takes place and how it affects the material itself and the harmful organisms such material may contain.

The main actions of decomposition are to break down the complex organic compounds, such as proteins and urea, into simpler and more stable forms; to reduce the volume and mass (sometimes as much as 80%, WHO, 1958) of the decomposing material by the production of such gases as methane, carbon dioxide, ammonia, and nitrogen, which are dissipated into the atmosphere, and ny the production of soluble materials which, under some circumstances, leach away into the underlying soil; and to destroy pathogenic organisms which in some instances are unable to survive the processes of decomposition or attack by the rich biological life of the decomposing mass.

Bacteria play the major role in decomposition; and bacteria action may be either aerobic, like in certain composting operations, or anaerobic like in septic tanks. The strong smell noted during the decomposition is due to ammonia and hydrogen sulphide, which escapes before it has been converted into a more stable form. Decomposition may proceed very rapidly, the period varying a few days in the case of carefully controlled mechanical composting to several months, perhaps up to nearly a year, under average conditions in a pit latrine (WHO, 1958).

Conditions prevailing in decomposing faeces are generally unfavourable to the survival of pathogenic micro organisms because of temperature, moisture conditions, and predatory bacteria and protozoa. The bacterial pathogens probably do not survive more than two months in undisturbed latrine. The ova of hookworm can remain for much longer period depending on moisture and temperature and may live upto six months. Ascaris ova may live upto three months in pit-privy material (WHO, 1958). The final products of decomposition contain valuable soil nutrients and may profitably be used as fertilizers.

Quantities of human faeces :

The public health engineer have to know the amount of the raw material which must be processed. It is recognized that the quantities of human excreta produced may be influenced by local conditions, not only physiological, but also cultural and religious. An example may be the use of ablution water or other personal cleansing materials. A review of published data shows that in Asia the amount of faeces is about 200-400 gm per person per day (wet weight), as compared to 100-150 gm per day for European and American countries (WHO, 1958). It is reported also that (Macdonald, 1952), in the tropics faeces will range from 280 gm to 530 gm per person per day, and urine, depending upon temperature and humidity, from 600 gm to 1130 gm. However, it has been suggested for design purposes that for total excreta the figure of 1 kg (wet weight) per person per day should be used (WHO, 1958).

Soil and ground water pollution :

The study of methods of pollution of the soil and water by excreta also provides useful information concerning the design of disposal facilities, especially their location with respect to sources of drinking-water supplies. After excreta are deposited on the ground or in pits, the bacteria, unable to move much by themselves, may be transported horizontally and downward into the ground by leaching liquids, urine or by rain water. The distance of travel of bacteria in this way varies with several factors, the most important of which is the porosity of the soil (Fig. 7.1, 7.2, & 7.3). Baars (1957) found that, unless accompanied by a considerable amount of water, bacterial contamination did not travel more than 7.5 m through fine sand.

Depending upon conditions of humidity and temperature, pathogenic bacteria and ova of parasitic worms will survive varying lengths of time in the ground. Pathogenic bacteria do not usually find an the soil a suitable environment for their multiplication, and will die within a few days. On the other hand, hookworm eggs will survive as many as five months in wet, sandy soil, and three months in sewage (WHO, 1958).

Location of latrines :

Regarding the location of latrines with respect to sources of water supply, the following points should be taken into consideration.

1. There can be no arbitrary rule governing the distance that is necessary for safety between a pit and water source. Many factors, such as slope and level of ground water and soil-permeability, affect the removal of micro-organism in ground water. However, the typical distance between a pit and a ground water source is in between 7.5 m to 15 m.

2. In homogeneous soils the chance of ground water pollution is virtually nil if the bottom of a pit is more than 1.5 m above the ground water table.

3. A careful investigation should be made before building pit latrines in areas containing fissured rocks and limestone formations, since pollution may be carried through the cavities to the ground water.

7.6 Classification of sanitation systems

Different sanitation technologies can be classified in various ways. One of the major classification is based on the water use. Under that aspect, sanitation systems are divided into two categories, dry system (like compost toilet) and wet system (like pour flush latrines). However, more widely accepted classification is based on the location of excreta treatment. Under this aspect, sanitation systems are divided into two categories, on-site system, where the excreta is treated at the site of the latrine, like pit latrine, septic tank, etc., and off-site system, where the excreta is treated at some location other than the site of the latrine, like volt latrine, conventional sewer system, etc.

7.7 Pit latrines

This is a type of latrine which traditionally used in rural areas in many developing countries. Simply speaking, it means a hole in the ground into which people defecate by some way or other. Basically this is not a recommended method, however, it is much better than open defecation. With little intervention, these type of latrines can be altered to be a hygienic one.

7.7.1 Simple pit latrines

The simplest and cheapest improvement to a pit latrine is to provide it with a prefabricated floor, in the form of a squatting slab or with a seat (Fig. 7.4). This has the following advantages (Cairncross and Feachem, 1993) :

- the latrine will be structurally safer and it will feel safer,
- it will be easier to clean,
- using the footrests, it will be easier for users to position themselves over the drop hole, so as not to foul it,
- a hole with the dimensions shown is too small for a child to fall into it, and is therefore safer and less frightening,
- the cement floor will prevent hookworm transmission,
- it also permits a small measure of fly control, through the use of a tight-fitting lid.

The need for steel reinforcement can be reduced or even avoided by making the slab slightly domed or conical in shape (Fig. 7.5). Alternatively, a latrine with a strong floor made with local materials such as wood and earth can be improved by placing a small slab, 60 cm square, over the center. Since this 'finishing slab' is not a structural bridge over the pit, it needs no reinforcement and can be only 40 mm thick.

The pit can be greatly strengthened against collapse by building a lining or a ring beam around the upper part. Materials may include rot-resistant timber, brick, concrete, stone or stabilized soil blocks. In loose soils, circular pits are more stable than rectangular ones. A ring beam can be pre-casted, as in case of 'ring-slab latrine' of Bangladesh, or can be cast with concrete in situ. In situ construction can possibly be done in an excavated trench before digging the pit. A lining is particularly important in loose soils or where the pit will be full of water, however, it can not prevent the seepage of fluids into the ground.

The pit should be as large as possible, however, it should not be more than 1.5 m wide because constructing a cover to span more than this is expensive (World Bank, 1986). The volume required for the pit is given by the product of sludge accumulation rate, number of people, and design filling time. The pit volume should be at least 0.06 cu.m per person per year of anticipated life, not including the top 0.5 m. A further 50% should be added where the bulky materials such as clothes or stones are used for anal cleaning. When the excreta in the pit will be under water, the volume may be reduced to 0.04 cu. m per person per year (Cairncross and Feachem, 1993).

One of the very important aspects of the pit is its useful life. The longer a pit will serve a family without being moved or rebuilt, the more certain is the health protection which it can give and, therefore, the more value it has to the family and community. It is important, by increasing the capacity and efficiency of pits, to extend their useful life and thereby to reduce the annual cost per person of the installation. The life of a privy depends on the care with which it is built, the materials used in its construction, and the time required for the pit to fill. The critical factor, usually, is the time required for the pit to fill; this in turn, depends on the method of anal cleansing and on the volume of the pit and the conditions within it. By the word 'conditions' are meant the efficiency of bacterial decomposition and the degree of abuse to which the pit is subjected (i.e., the stones, sticks, mud balls, garbage, coconut husks, etc. thrown into it).

Where ground conditions allow and where there is no danger of contaminating water sources, the need for a structural cover may be avoided by drilling a hand-augured borehole instead of digging a pit. Although the borehole latrine has a smaller volume and therefore fills up faster than a pit, it is quicker to install in large numbers and requires only a small and relatively portable slab.

In some countries, a seat is more acceptable than a squatting slab in spite of its higher cost. It also has the advantage that it is less likely to be fouled by excreta which miss the hole. Moreover, when a toilet with a squatting slab is cleaned, grit and other debris on the floor will be swept down the hole, tending to fill up the pit prematurely.

Flies often lay their eggs in faeces, and poorly built latrines can lead to an increase in population of flies carrying fecal pathogens. Pouring insecticides into the pit to kill flies is not recommended. Although it will kill flies in the short term, it may permit a still greater resurgence later, by killing the flies' competitors and predators. Sometimes they can get resistance to insecticides. There is also a danger of the insecticides polluting nearby water sources.

7.7.2 Ventilated improved pit (VIP) latrines

Traditional pit latrines have two main disadvantages : they usually smell badly and they attract flies and other disease-carrying insects that breed in the pits. In addition, they are often poorly built and dangerous to use.

A much better type of latrine called the ventilated improved pit (VIP) latrine has been developed, which has none of these problems. VIP latrines have two very important features which distinguish them from traditional types of pit latrines, which are,

1. they are designed to be safe for the user and are built to last for a long time (at least 2 years),
2. they have a superstructure that is slightly offset from the pit and a tall, vertical vent pipe with a fly screen that is fitted outside of the latrine superstructure.

The vent pipe should be painted black and located on the sunny side of the latrine superstructure. The air inside the vent pipe will thus heat up and create an uplift with a corresponding downdraft through the squatting plate. Due to action of wind passing over the top of the vent pipe, and due to the rising of hot air heated by sun, the air inside the vent rises and escapes to the atmosphere, so creating a downdraught of air through the squatting plate or seat. This circulation of air effectively removes the odors emitting from the fecal material in the pit.

The vent pipe also has an important role to play in fly control. Female flies, searching for an egg-laying site, are attracted by the odors from the vent pipe but are prevented from flying down the pipe by the fly screen at its top. Nonetheless, some flies may enter via the drop hole and lay their eggs. When new adult flies emerge they instinctively fly towards the light; if the latrine is suitably dark inside the only light they can see is that at the top of the vent pipe. As the vent pipe is provided with a fly screen at its top, the new flies will not able to escape and they will eventually fall down and die in the pit.

The components, operation principal, basic scheme of internal action, and construction design is shown in fig. 7.6, 7.7, 7.8 and 7.9.

There are three main types of VIP latrines :

1. Single pit latrine : Designed for at least two years. They are generally suitable in rural areas where land price and labour are cheap and it is possible to relocate an existing one.

2. Twin (or double) pit latrine : To eliminate the need to construct very deep pits, to preclude the necessity of constructing another latrine once the pit is full, and to facilitate the emptying of the pit where space for a replacement latrine does not exist, a double-pit latrine should be used. They are with permanent structure and they use two pits alternatively (Fig. 7.10). These latrines are more appropriate in urban areas, where people can afford to pay for a permanent structure, and where land price prohibits relocating latrine every few years. In long run, it is often more convenient and possibly less expensive. In this version, one pit is used for a given period (at least one year) until it is full, when the second pit is put into use; when that is full, the first is emptied and used again. Thus the excreta are never handled until they are at least twelve months old, when only a few Ascaris eggs at most will still be alive. The humus-like material remaining in the old pit can be used as fertilizer. In any event, the arrangements for removing and disposing of the pit contents must be planned before VIP latrines are built on a

wide scale.

3. Multiple pit latrines : These are latrines with more than one cubicle. These are suitable for communal institutions such as schools.

Advantages and disadvantages of the VIP latrines

The main advantages of well maintained VIP latrines are :

- low annual cost,
- easy construction and maintenance,
- all types of anal cleansing materials may be used,
- minimal water requirements,
- low level of municipal involvement,
- minimal risks to health.

The disadvantages which may limit the use of VIP latrines are :

- lack of space for relocating the pit in dense urban areas,
- potential for groundwater pollution,
- difficulty of construction in rock or boulder-laden subsoil,
- difficulty of construction in places of high water table,
- does not dispose of large quantities of sullage water.

Possible measures against these disadvantages :

- Twin pit latrines are best solution for the space problem in the urban areas.
- As a general rule, pit latrines should not be build within 10 m of a well or other drinking water source and should not be located uphill from it.
- There is no easy answer to the construction difficulties in rocky ground. However difficult, it would be wiser to construct pits as larger as possible.
- A built-up latrine (Fig. 7.11) is appropriate for areas of high water table. The pit must be lined to prevent collapse in the wet season. The raised part of the plinth should be plastered on the inside and soil from the pit placed against the outside, to prevent leakage of fluids above ground and erosion by storm water.

Construction principles

Superstructure : The most important function of the superstructure is to provide privacy. The superstructure should also protect the users from poor weather conditions. The superstructure must keep the interior shaded, otherwise fly control in the pit will be ineffective. However, adequate ventilation must be provided, otherwise the draught through the squatting hole and up the vent will be restricted. It is always better to follow local house building methods and architectural styles.

Vent pipe : Both the vent pipe and the fly screen must be from corrosion-resistant materials. Materials commonly used for the vent are asbestos cement, PVC, bricks and concrete blocks. Large diameter bamboos with the nodes removed have also been successfully used. To provide sufficient air flow and admit light to the pit, the recommended diameter is from 15 cm to 25 cm (World Bank, 1986). As the main force causing the air flow up the vent is the wind blowing across its top, and sometimes sunlight; to work efficiently, the latrine should not be built on places that are sheltered from the wind and sunlight by trees or buildings.

(7.8 Pour-flush latrines

A further improvement to the pit latrine can be obtained with a water seal, which is a U-pipe filled with water, below the seat or squatting pan (Fig. 7.12), and which completely prevents the passage of flies and odors. By careful design of the pan, with a water seal only 15 – 25 mm deep, the two main disadvantages of conventional cistern-flush toilets can be overcame, (1) they are very expensive, and (2) the water demand is very high. Moreover, a pour-flush toilet can be flushed by hand. Because of the water seal, this toilet is as hygienic to use as a conventional cistern flush toilet although they are much cheaper than conventional ones.

The smaller quantities of water used in pour-flushed toilets are not sufficient to operate a conventional system of sewerage, but are enough to carry the excreta to a soakage pit up to 8 m away (Fig. 7.13), which will be easier to empty than a pit directly beneath the seal. The components of a pour-flush toilet is shown in Fig. 7.14. Pour-flush toilets are very common in the Indian subcontinent and the Far East.

There are two general types of pour-flush toilets :

1. Single pit pour-flush toilets : where the water-seal trap is built into the underside of a concrete slab that is placed, in most cases, directly over a pit,
2. Double pit pour-flush toilets : where the excreta are transported from the toilet compartment to a nearby leach pit by flushing water which is poured by hand into the toilet bowl. Double-pit pour-flush toilets are frequently built with two pit, and one of which is in use at any one time. This makes the pour-flush toilet a permanent facility which can be used without interruptions for pit emptying or relocation (Fig. 7.15).)

Advantages and disadvantages of pour-flush latrines

The advantages of pour-flush toilets include the following :

- They are inexpensive compared to conventional latrines. It is said that (World Bank, 1986), average annual costs (including annualization of capital costs) is US$ 400 per year for conventional sewerage systems and US$ 28 per year for pour-flush toilets.
- They offer long term, appropriate, and hygienic solution for excreta disposal.
- They use low volumes of water for flushing, (1–3 l/flush as opposed to 10–20 l/flush for most cistern-flush toilets).
- They can be upgraded to connect to a sewer system or septic tank system.
- They eliminate odors, insect and fly breeding.
- It is entirely safe for children.
- They involve easy construction and easy maintenance.
- Only low level of municipal involvement is required.
- They can be located, if desired, inside the house, and not necessarily only on the ground floor, but they can even be installed on the upper floors of low-rise buildings.
- There is potential for resource recovery.
- They abolish the need for the scavenging system where labours have had to carry and transport excreta.

The disadvantages of pour-flush toilets are :

- They require separate sullage disposal facilities.
- Water (at least 4 liters per person per day) must be available throughout the year.
- They clog easily where bulky anal cleansing materials are used.
- In areas with high groundwater, shallow soil overlying hard rock or impermeable soil, construction is more difficult and expensive.
- Like any other on-site sanitation systems there is a risk that pour-flush toilets will pollute water sources.

Design principles

Pit volume : The volume of the pit may be calculated from the equation (Kalbermatten, et al, 1980) :

$$V = 1.33\ CPN$$

where,

V = Volume of the pit,

C = Sludge accumulation rate, which is 0.04 m^3/person/year for PF toilet,

P = Number of person using the latrine, and
N = Number of years the pit is to be used before emptying.)

Service compatibility : Since flushing is done manually, they do not require a multiple-tap in-house level of water supply; they are thus best used in conjunction with a yard-tap level of water supply, although they can be used in conjunction with public standpipes if the standpipe density is such that the users can and will carry enough water home for their operation.

Number of pits : As in the case of VIP latrines, probably the better long-term solution is for pour-flush toilets to have two pits which are used altematively. However, this depends on the ease with which the pits can be desludged, whether desludging is to be done manually or mechanically and whether in high-density areas there is sufficient room for twin pits. If desludging is to be done by hand, then to protect the health of the person carrying out this operation and to avoid the need for sludge treatment, twin pits each with a life of at least 1 year are preferable.

Pour-flush pan : The pans can be made from concrete or ferrocement, but these are not entirely satisfactory because of the difficulty in creating a smooth finish and attractive appearance with these materials. Pans made from glass fiber, injection-molded plastic and glazed ceramics can be more popular because they are easier to keep clean and need less water to flush them.

Trap : The water seal trap which are made separate from the pan is the best as it can be fixed with the outlet pointing in any direction relative to the pan. It is recommended that the water seal should be at least 20 mm and the diameter should be 70 mm (World Bank, 1986). The inside should be as smooth as possible. The trap can be of concrete but smoother finishes can be coated with plastic or glass fiber or ceramic material.

Pipe : The pits can be some distance away from the toilet but the layout of the connecting pipe is very important because it can easily get blocked if not properly designed. The connecting pipes should slope by at least 1 in 30, and have a minimum diameter of 75 mm (World Bank, 1986). Wherever possible, bends should be avoided, but they will be less likely to cause blockages if they are of a large radius or if, for instance, two 45^0 bends are used in place of a 90^0 one. The pipes that are most easily available and resistant to corrosion are made from asbestos cement or PVC. In installations with double-pits, a small chamber is constructed at the point where the pipe divides.

Maintenance : Very little maintenance is necessary to keep the pour-flush toilet in good order.

However, the toilet bowl and the floor should be regularly washed. No sullage water should be disposed of in the toilet because the pit may flood. No solid waste should be put down the toilet because this is likely to block the pipes. In the case of double pit latrines, the full pit should be kept sealed for two years if possible. It should be emptied before the pit that is in use fills completely. This gives the surrounding soil more chance to recover its infiltrative capacity before it is returned to use.

Sludge disposal : In the double-pit system, the alternating use of pits allows sludge disposal of the pit not in use. After two years, the pathogens in the sludge of the unused pit will be dead, and the sludge can be removed by a shovel. The pit material is useful as a soil conditioner. The single pit system must be emptied when the pit has used up the effective volume. However, fresh excreta are dangerous to health and should be handled with great care. If possible, contents should be removed by a pump truck. Further treatment of pit contents can be done using waste stabilization ponds, or composting.

7.9 Other low cost sanitation technology

This section presents other low cost sanitation systems that are common in many parts of the world.These systems can be classified into four distinct groups.

7.9.1. On-site water dependent systems

Pour flush toilet is a low cost water dependent system, which is described elaborately in sec 7.8. Septic tank is also a water dependent on site system but relatively expensive. Another type of on site water dependent system is briefly described in the following.

Aquaprivy

Aquaprivies are essentially small septic tanks located directly below a squatting plate which has a drop-pipe extending below the liquid level in the tank to form a water seal. Figure 7.16 shows a conventional aquaprivy. To prevent odor, fly and mosquito nuisance in the toilet, this water seal has to be maintained by adding sufficient water per toilet visit to the tank via the drop-pipe to replace any losses. The excreta are deposited directly into the tank where they are decomposed anaerobically in the same manner as a septic tank. The digested sludge, which is reduced to about a quarter of the volume of the excreta deposited (WHO, 1958), accumulates in the tank and must be removed at intervals. The tank volume is usually calculated (World Bank, 1986) on the basis of 1.5 liters of excreta per day plus an additional 4.5 liters per day per person for maintenance of the water seal. Thus, the aquaprivy effluent flow is about 6 liters per person per day. The soakaway should be designed on this basis, although it is common practice to include a factor of safety so that the design flow would be about 8 liters per day per person. The sidewall area of the soakaway should be calculated assuming an infiltration rate of 10 m^2/day. As with septic tanks, there is an accumulation of sludge (0.03 — 0.04 m^3/person/year), which should be removed when the tank is 2/3 full. As a result, the desludging process is normally carried out every 2 – 3 years. The liquid depth in the tank is normally 1 to 1.5 meters in household units.

The self-topping aquaprivy incorporates a washing sink with the aquaprivy (Figure 7.17). Sullage from the sink produced by hand washing and clothes washing provides the necessary volume of water to maintain the privy's water-seal. The sink does not have to be connected to a water supply, but water must be available nearby to encourage use of the sink.

The main advantages of the aquaprivy are :

- no danger of clogging by bulky anal cleansing materials,
- possible location inside the house,
- low odor and insect problems,
- minimal risks to health,
- low annual costs,
- potential for upgrading,
- sullage disposal potential.

The main disadvantages of the aquaprivy are :

- the water seal is often broken. Therefore, user education in operation and maintenance of the aquaprivy is necessary. Water seal is easily maintained in self-topping aquaprivy.
- it is expensive, because of the expensive water tight tank needed to maintain the water seal. Skill is required for construction of this tank.

A pour-flush toilet with an outlet to a soakaway (Fig. 7.18) is a technology which overcomes the problems of maintaining the water seal. In general, only self-topping aquaprivies should be used where a water seal is desired and where users have traditionally used bulky anal cleansing materials that would clog a pour-flush toilet. A nearby source of water is required to ensure that enough water is available to maintain the water seal.

7.9.2. Off-site water dependent systems

Among various off-site water dependent systems, the vault toilet is widely used. This system is extensively used in Japan, Korea and China.

Vault systems

The vault toilet system utilizes a water tight vault located either offset from or beneath a water seal device for storage of the excreta over a period between 2 weeks to 1 month (Fig. 7.19). These excreta later collected and transported to treatment plant.

Vault systems are suitable for use in densely populated urban areas where on-site sanitation systems cannot be used, where water-borne sewerage is too difficult and expensive to install, and where institutional ability to organize and maintain a collection system exists. Nightsoil collection systems can be easily matched to changing demands by increasing the number of collection vehicles and staff.

The low cost of installing affordable vaults, in comparison with water-borne sewerage means that these are affordable sanitation systems, at least in terms of the initial capital costs.

The required working volume of the vault can be calculated from the formula :

$$V=NQD/K$$

where

V is the required volume in liters,
N is the number of users,
Q is the average volume of excreta plus flushing water (liters per person per day),
D is the time between nightsoil collection (days), and
K is the vault volume under utilization factor.

The average nightsoil contribution (Q) is generally less than 10 liters per person per day. The factor K is introduced since the vault will normally be emptied before it is full. For well maintained and organized collection systems, K may be as high as 0.85 (World Bank, 1986), but often it may have to be as low as 0.5 which allows for twice the planned filling time.

The vault needs not be large. For example, for a family of 6 using 10 liters per capita daily with a pour-flush system that is being emptied every two weeks, and with K taken as 0.5, the required vault volume is only 1.68 cubic meters.

Collection vehicles : Vaults can be emptied manually but this is unhygienic because of the likely spillage and so, wherever possible, the emptying should be done mechanically. The usual type of vehicle is a truck-mounted tanker equipped with a vacuum pump. Smaller vehicles, which can even be hand- or animal-drawn can be used to serve vaults located off narrow lanes or alleyways. Pumping can be by hand-operated diaphragm pumps. These small tankers then bring the nightsoil to a transfer station for collection by larger vehicles.

Nightsoil treatment and disposal : The collected nightsoil can be handled in several ways. It can be treated in nightsoil or sewage treatment works, or in waste stabilization ponds. The nightsoil can be safely reused as a soil conditioner, after treatment through composting.

Organization : In most developing countries, organization will be the limiting factor with vault systems, so they should not be introduced unless sufficient institutional skills are available to run the system. A large labor force will have to be closely supervised to ensure that standards of hygiene are maintained, and that the service remains available to all users on an impartial basis.

Maintenance : The maintenance of the fleet of collection vehicles is a critical factor in the operation of cartage systems. There must be adequate workshop facilities and sufficiently trained mechanics to service the vehicles, but it is also very important that sufficient stocks of spare parts are available.

Advantages :

- Vaults can be conveniently located in the house.
- Use of the nightsoil in agriculture after treatment is possible.
- Initial costs are less than other wet sanitation systems having tanks, such as septic tanks or aquaprivies.
- Water requirements are minimized as the user is conscious of saving on vault emptying charges.
- The high degree of planning flexibility is inherent in the vault system.
- Hygienic to the users.

Disadvantages :

- The high degree of organization is required to run vault collection services efficiently and hygienically. Any breakdown of this service can lead to public health risk.
- There can be health risk to the collection workers unless mechanical equipment is used

for collection.

- Vault systems have high operating costs and so this system, although cheaper than sewerage, is more expensive than other on-site sanitation systems.
- This system is not designed to handle sullage.

7.9.3. On-site dry systems

There are many kinds of latrine which come under this category. Some of them are hygienic but many of them can pose serious health risk.

Conventional pit latrines

Conventional pit latrines (Fig. 7.20) are a common sanitation facility used in developing countries. Three components make up a pit latrine : a pit, a squatting plate with foundation, and a superstructure. Excreta is deposited in the pit, and when this fills, the superstructure and squatting plate are removed, and the pit is covered over with soil. A new pit is dug nearby. Details can be found in Art. 7.7.1.

Pit latrines generally smell badly and provide an ideal location for breeding insects. For these reasons, the pit latrine is unhygienic to the user. Other disadvantages of the pit latrine are the high frequency of superstructure collapse and the problem that children may refuse to use the latrine because they are afraid of falling into the pit.

Because of these disadvantages, it is recommended that the traditional pit latrine not be used, and those in existence be upgraded to a ventilated improved pit (VIP) latrine.

Ventilated improved pit (VIP) latrines

The VIP latrine is discussed in art. 7.7.

Borehole latrine

This latrine is similar to a pit latrine, except that the hole is bored with an auger (Fig. 7.21), resulting in depths up to 8 meters, and a diameter of about 0.4 meter (World Bank, 1986). This small volume causes a short latrine lifetime. To prevent the collapse or caving of the pit walls, sometimes linings are provided. In areas where the ground-water level is high, or which are subject to flooding, the latrine floor is elevated above the surrounding ground as in Fig.

7.22.This design is used in a WHO-aided project in Bangladesh (WHO, 1958). However, ventilation is impossible because of the depth and diameter of the hole, and this generates odor and insect problems. Groundwater pollution is probable because borehole depths generally result in penetration of the water table. Because of these disadvantages, the borehole latrine is not recommended.

Overhung latrine

This latrine technology is popular in parts of South Asia and Southeast Asia. The latrine consists of a platform with a squat hole built over a body of water, and a superstructure which provides privacy. Overhung latrines are used in both urban and rural situations where streams, canals, or tidal areas are used for excreta disposal. However, major health problems result from the overhung latrine system. The water receiving the wastes becomes heavily polluted, and the persons who use the water downstream for washing, drinking or cooking are exposed to the pathogens in the water. This technology is not recommended because it facilitates transmission of disease, as in most of the developing countries, a significant portion of the population usually use water from open water bodies in some form of their daily life.

ROEC

A variation of the VIP latrine is the Reed Odorless Earth Closet (ROEC). In the ROEC the excreta are deposited into the pit via a chute located at the base of the squat hole or seat (Fig. 7.23). The ROEC is fitted with a vent pipe to control odor and insect nuisance. This latrine is common in southern Africa. However, the major problem of the ROEC is that the chute is easily fouled with excreta, thereby providing a site for insect and odor nuisance. The chute has to be regularly cleaned with a long handled brush. Despite this disadvantage, there are several advantages of the ROEC. The pit is larger and thus has a longer life than the VIP. In addition, the pit can be easily emptied, so that the superstructure can be a permanent facility. Another advantage is that the pit is displaced, children have no fear of falling into it. Moreover, it is not possible to see the excreta in the pit, which encourage the use of the latrine.

Compost latrines

Household systems for composting nightsoil and other organic materials are used under a variety of conditions. They are successful in both developing and industrial countries when they receive a high degree of user care and attention. This is most likely to occur when there is an urgent need for fertilizer or when there is high degree of environmental concern. There are two types of systems, continuous and batch.

Continuous composting toilets are developments of a Swedish design known as a 'multrum' (Fig. 7.24). They are extremely sensitive to the degree of user care : the humus has to be removed at the correct rate, organic matter has to be added in the correct quantities, and only a minimum of liquid can be used. Even with the required sophisticated level of user care, short circuiting may still occur within the system, and viable excreted pathogens can be washed down into the humus chamber. The results of these field trials indicate that (Kalbermatten, et al, 1980) continuous composting toilets are presently not suitable for use in developing countries.

The most common type of composting latrines are the batch or double vault composters.

They are similar in many ways to alternating double-pit VIP latrines. They have two chambers or vaults which may be constructed either above or below ground and may have sealed or impermeable bases.

One vault is used until nearly full and the remaining space is filled with dry soil or organic matter, such as leaves or grass, and then it is sealed while the second vault is used. The vaults are usually designed to take at least one year to fill. The excreta in the sealed vaults are digested anaerobically for at least a year.

For efficient composting, the correct balance of nutrients must be present for the microbes which digest and degrade the material. The microbes need carbon for energy and nitrogen to form proteins for growth. To achieve suitable C:N ratios, it is necessary to add organic carbon in the form of leaves, grass or some other easily composted material. To reduce the acidity and odor of the compost and speed up the composting process, wood ass can be added regularly to the composter. Likewise urine should be separated to reduce nitrogen and moisture levels in the compost pile. For the same reason water should not be added to the pile.

If ash or organic matter is not added, the toilet acts as a VIP latrine, if it is not sealed, or as a vault toilet, if it is sealed.

The humus produced by a compost latrine that is functioning well will be a dark, friable and inoffensive material, rather like a good, moist organic soil.

Compost toilets can be upgraded to pour-flush toilets. The conversion to PF toilet is straightforward since, out of the two vaults, one can be used for excreta and other for sullage disposal. This conversion is especially attractive (indeed may be necessary) if the housing density increases substantially so that the land available to the householders on which they can reuse their excreta decreases and on-site sullage disposal is no longer possible.

Advantages :

- This type of latrines can be useful where there is a need for a soil conditioner. This is particularly important in tropical areas where nutrients are quickly leached from the soil. Compost latrines are most appropriate for use in areas where there is a tradition of using human excreta on the land.
- Compost toilets need no water for flushing because composting is most efficient if the material is moist but not wet. Thus, they are suitable where people prefers bulk anal cleansing materials.
- Compost latrines need not penetrate the subsoil and can therefore be built on rock.
- Compost latrines pose a low pollution risk, particularly if they are completely sealed units, so they can be used where it is important to prevent contamination of a vulnerable water supply.

Constraints :

- Compost latrines need organic waste to correct the carbon-nitrogen ratio of the excreta and provide the right conditions for composting. Thus, substantial amounts of biodegradable organic matter must be locally available.
- Compost latrines need care in their operation. If the correct measures are not taken, the contents of the latrine can easily become too wet and fly breeding will result.
- If the wastes are not stored for a long enough period of time, pathogenic organisms will persist in the compost, resulting in health risks for those handling it.
- A strong commitment to producing and using compost must be shown by the latrine's users. Thus, this type of latrine is not suitable where there is a reservation about using compost produced from nightsoil, or compost at all.

Case study 1 : African compost latrine

This type of compost latrines have been tried in several parts of Africa. Most of the latrines have been designed with permeable bases to allow excess fluids to soak away. No attempt has been made to exclude urine from the latrines. This is partly for cultural reasons, but also because of the prevalence of urinary schistosomiasis in parts of Africa.

Organic materials such as crop residues, leaves, grass or sawdust must be correct the balance of carbon to nitrogen and also to absorb liquids. Wood ash is a useful addition because it absorbs moisture and counteracts the acids produced during the composting process.

The required vault volume is given by (World Bank, 1986):

$$V_v = 1.33\ N\ R\ P$$

where

V_v = required vault volume

N = number of users

R = rate of filling (m^3/person/year)

P = emptying period (years)

The factor 1.33 is necessary to allow for the vaults to be sealed when the level of material reaches three-quarters of the height of the vault. The R is reported as about 0.1 – 0.15 m^3 per person per year (World Bank, 1986). The P is usually one year.

The latrines are usually constructed on a concrete base slab if they are above ground, with walls of concrete blocks or brickwork. If they have permeable bases, the walls must extend at least 200 mm (World Bank, 1986) below ground level (Fig. 7.25).

Cover slabs are usually made from reinforced concrete. Sometimes each vault has a separate slab, one which is plain with no holes and the other which has a squat hole. When it is time to seal a freshly filled vault and remove the compost from the other one, the slabs are changed around so that the one with the squat-hole is over the newly emptied vault. Alternatively each slab has a squat-hole, or a hole into which a seat unit fits; one is sealed with a cover or plug while the other is in use. This type usually has removable cover slabs to allow the compost to be removed.

Case study 2 : Vietnamese compost latrine

Double-vault batch composters have been used for many years in Vietnam where they are reported to have contributed to a great improvement in the health of farming communities. Prior to the introduction of the "double septic bin", as the design is known, untreated excreta were traditionally used in agriculture.

The latrines have two small vaults of only about 0.3 m^3 capacity (World Bank, 1986) and take between 45 to 60 days to fill. They are built entirely above ground on an impermeable concrete base. The walls are usually built from brick and concrete cover slabs with two squat-holes forming the top of the vaults and floor of the latrine. Two small doorways that are closed with timber hatches or removable brickwork in weak mortar are provided at the rear for removing the compost. Fig. 7.26 shows the dimension of the Vietnamese compost latrine.

Urine is not disposed of in the composter, but is drained away through a special channel in the squatting slab. This helps to keep the contents of the composter dry and to improve the carbon-to-nitrogen ratio of the excreta. To neutralize acids in the compost and to absorb liquids, wood ash is sprinkled on the fresh feces at each visit.

The urine is diluted and used immediately as a liquid fertilizer or it is disposed of in a soakaway. Very few diseases are spread by urine, but special precaution should be taken where urinary schistosomiasis is present, to prevent the urine from entering water bodies where the intermediate snail hosts are present.

The vault is sealed by cementing the cover in place with mud when it is about three-quarters full. The space above the excreta is filled with dry soil first.

In Vietnam, the vaults are kept sealed for about 45 days, which is not long enough at the low temperatures achieved to destroy all parasites and their eggs. However, the hazard from bacteria will be considerably reduced. Certainly the compost produced is much less hazardous than the raw excreta that was used before the introduction of compost latrines.

7.9.4. Off-site dry systems

In most cases, these type of latrines are not fully safe from hygienic point of view. There are many kinds of latrine which come under this category. It is generally recommended to upgrade these types of latrines to more safe systems.

Bucket latrines

The bucket latrine consists of a squatting plate or seat immediately above a bucket of 20–30 liters capacity, into which the feces and urine fall (Fig. 7.27) and which is removed for emptying and cleaning at frequent intervals. .

The bucket can be removed through a small door at the back of the latrine which usually faces onto a road or alleyway. The latrines may even be built into the house.

The design of the latrines is usually poor. As a result, they are not easy to wash and keep clean, and have no provision for split liquids to drain away. Generally the latrines smell very badly and are breeding sites for insects.

The most hygienic method of operating bucket latrines is to seal the used bucket with a clean lid when it is collected, and transport it to a depot for emptying. The used bucket is replaced with one that has been washed and disinfected at the depot. Using different colored buckets may be helpful in supervising a system.

If the latrine buckets are emptied at the latrine, usually into a large container or cart, then the system is likely to be very unhygienic because spillage normally occurs, and the buckets and carts are rarely, if ever, cleansed and disinfected.

Excreta collected in this system may be disposed of by a number of methods. One of the simple method is to bury in earth trenches. Anaerobic digestion is another alternative.Disposal directly into sewer is also used in many areas.

Due to the inherent health hazards the bucket latrine system is not recommended. They should be replaced in the long term by a more appropriate sanitation facility. Often the vault latrine is a viable alternative to the bucket system in high density areas.

Trench latrine or 'Feuillées'

In this type, very small and shallow pits are dug into the top layer of the ground. The excavated earth is piled loosely around the hole (Fig. 7.28). Each user is expected to throw a scoopful of loose earth over the faeces deposited. The urine usually falls outside the pit and drains away. After 100 to 150 droppings, it is thoroughly covered with an equal volume of earth. Under tropical conditions, the decomposition of faeces is completed in about eight weeks, and the resulting humus may be dug out and utilized as fertilizer. A new hole is dug at a distance away from the first pit and is used in the same manner. While the trench latrine is designed for temporary use only, sometimes they are used in the rural and semi urban areas.

The trench latrines offer serious disadvantages and health hazards for the communities as a whole. The most significant hazards include (a) soil pollution as worm (especially hookworm) have full access to surrounding grounds, (b) enormous fly breeding, (c) surface and ground water pollution, (d) easy access to and scattering of the excreta by rodents and insects. To these may be added the odor nuisance and unaesthetic view. On the credit side, it can only be said that they are easy and cheap to build. However, unless for temporary use, it is highly recommended not to use these type of latrines.

The long drop latrines

This latrine system is used in multistorey buildings. It comprises a shaft incorporated into the walls of the house, and a water-tight excreta chamber at the base of the shaft. A vent is provided to dissipate odors. The contents of the chamber can be removed manually, but care should be exercised in light of the health risks associated with fresh excreta. Mechanical removal will help to reduce this risk. The removed waste should undergo treatment by either composting or waste stabilization ponds. Figure 7.29 illustrates the long drop latrine. This variation is from Yemen, and it involves the separation of urine from excreta. The urine runs down the inside face of the wall of the house where it evaporates rapidly in he heat.

This is not a safe system and it is recommended that this latrine technology be upgraded to a pour-flush or vault system.

7.10 Septic tanks

This is an on-site water-borne sanitation system. A septic tank does not dispose of wastes, it only helps to separate and digest the solid matter. The liquid effluent flowing out of the tank remains to be disposed of, normally by a soakage pit or drainfield, and the sludge accumulating in the tank must be periodically removed.

A septic tank is a rectangular or cylindrical chamber, usually located just below ground level, that receives both excreta and flush water from toilets as well as other household wastewaters (or sullage). As shown in Fig. 7.30 settleable solids settle to the tank bottom, accumulate, and are then anaerobically digested. A scum of light-weight materials (including fats and greases) rises to the top. The clarified liquid flows through an outlet structure just below the floating scum layer and is normally treated through a soil absorption system. The effluent from a septic tank is an obnoxious liquid, containing high concentrations of organic matter, nutrients, and enteric microorganisms. It should not be discharged without treatment to surface drains, streams or lakes.

The effectiveness of the treatment depends on the local climate, especially on temperature. BOD may be reduced by 30 — 50% and total suspended solids (TSS) by 50 — 70% (WHO, 1982b).

Advantages

- The main advantage of septic tank systems is their flexibility and adaptability to a wide variety of individual household waste disposal requirements.
- Another advantage is that the septic tank has no moving parts and therefore, needs little mechanical maintenance.
- Septic tank system can be easily upgraded into small-bore or conventional sewer.

Disadvantages

- A major disadvantage of the system is its high cost. Septic tanks are more expensive than other on-site waste treatment systems and are generally only found in wealthy areas.
- The system requires a permeable subsoil structure so the effluent can be distributed. If the subsoil structure is too impermeable, the septic tank effluent can contaminate surface or groundwater, creating a public health hazard.
- Space for drainage fields is also required, and all drinking water withdraw point must be set away from the septic tank system.
- Septic tank systems also require piped water supply.

Design of septic tank

A septic tank should be designed to remove almost all settleable solids and to decompose organic matter anaerobically. To accomplish this, the tank must provide the followings.

1. Proper volume of septic tank to adequately retain the waste : For effective sedimentation of the sewage solids, the liquid retention time should be at least 24 hours. Two-thirds of the tank volume is normally reserved for the storage of accumulated sludge and scum, so that the size of the septic tank should be based on three days retention time. This ensures that at least one day of retention still remains just before each desludging operation.

2. Proper shape : A rectangular shape for a single compartment tank is most favoured with a length two to three times its width, and a depth of 1 to 2 meters (World Bank, 1986). The rectangular tank is better than a square tank. However, cylindrical tank is also possible.

3. Proper placement of inlet and outlet devices and adequate sludge and scum storage space to prevent the discharge of sludge and scum in the effluent : The inlet to a septic tank (Fig. 7.30)

can be a sanitary tee or an elbow with diameter greater than 10 cm (World Bank, 1986). Its vertical leg should extend to about 20% of the liquid depth. The outlet of a septic tank can also be a tee placed in such a way that the bottom of the horizontal leg is below the level of the inlet pipe. Its vertical leg must extend upto the top and bottom of the scum layer and to about 40% of the liquid depth. Manholes should be provided to serve as a means to inspect the septic tank and to empty the settled sludge. Those manholes should also be airtight to prevent odors from escaping.

4. Proper number of compartments : A two-compartment septic tank, as shown in Fig. 7.30, yields better performance than a single-compartment tank of equal capacity in reducing pollutants,

5. Proper ventilation : Since the digestion process is anaerobic, requiring no oxygen, no direct ventilation is necessary. However, provision should be made to permit the escape of the gases produced in the tank, through a ventilation pipe.

Installation of septic tank

The following points should be considered in the installation process.

- Septic tanks must be water-tight, structurally durable and stable. Reinforced concrete and ferrocement meet these requirements, but the tanks should be sealed for water-tightness after installation with bituminous coating or other materials with equivalent properties.
- Other materials include polyethylene and fiberglass which are light-weight, easily transported, and resistant to corrosion and decay.
- Steel is another material, however, it may get deteriorated despite a corrosion-resistant coating.
- The inlet and outlet pipes should be sealed with a bonding compound that adheres to both concrete and the pipes.
- After installation, the tank should be tested for water-tightness by filling it with water.
- The most important installation requirement is that the tank be on a level grade and at a depth that provides adequate gravity flow from the house, matching the invert elevation of the house sewer. It should also be easily accessible to facilitate inspection, maintenance, and sludge removal.

Treatment of septic tank effluent

There are various procedures for disposing septic tank effluent (Fig. 7.31).

a) Absorption fields and evapotranspiration beds :

Where site conditions are suitable and do not pose any threat to ground-water quality, subsurface soil absorption is usually the best method for disposing of septic tank effluent. As shown in Fig. 7.32, the effluent flows by gravity from the tank through a closed pipe and a distribution box into perforated pipes in trenches. Fig. 7.33 shows the detailed construction of a trench. It consists of open-jointed drainage tiles of 10 cm diameter laid on a 1 meter depth of crushed rocks or gravel and soil. Bacteria in the soil help purify the effluent.

The performance of a soil-absorption system depends on the ability of the soil. A proper site evaluation requires accurate measurements of the degree of slope, the position of groundwater table, the effective soil depth, and the depth of any bedrock or other impermeable materials. Perhaps the most important characteristic of the disposal field is its soil permeability. A percolation test is recommended to give a measure of soil permeability.

To test percolation (World Bank, 1986), at least three 150 mm diameter holes should be drilled to the depth of 5 m. These are then filled with water and left overnight saturating the soil. The next day the holes should be filled with water again to a depth of 300 mm. After 30 and 90 minutes the water levels are measured. The soil is considered to have sufficient percolative capacity if the level in each hole has dropped 15 mm/hour.

The design approach of absorption fields can be calculated (Kalbermatten, Julius, Gunnerson, & Mara, 1982) according to :

$$L = NQ / (2DI)$$

where

L = Trench length (m)
N = Number of users
Q = Wastewater flow (l/cap/day)
D = Effective depth of trench (m)
I = Design infiltration rate ($l/m^2/day$)

Design infiltration rate for the septic tank is usually taken as 10 $l/m^2/day$. This can be used until a more accurate figure is calculated from local experience.

The soil absorption system clogs up periodically, therefore overloading the system should be avoided in order to increase its operating life. Absorption fields must be located away from wells, streams, buildings and other objects. It is imperative that they located downstream from utilized water sources. In addition, the groundwater level during the wet season should be at least 1.2 meters below the trench bottom.

b) Evapotranspiration mounds :

In areas where the water table is near the surface or soil percolation is insufficient, an evapotranspiration mound or bed may be substituted for a drainfield. These should be located in areas not subject to flooding and on a sloping grade to facilitate gravity drainage of the system. Design criteria for these mounds depend on climate, soil type, and vegetation. Pilot studies are required to confirm or modify the suggested dimensions outlined in Fig. 7.34 (World Bank, 1986).

c) Soakaways :

Soakaways or soakage pits (Fig. 7.35) are recommended as alternatives when absorption trenches are impractical, where the pervious soil is deep, or where an impervious upper-layer is underlaid by a porous layer. The septic tank effluent flows through pit walls, made of open-jointed bricks and rocks, into the surrounding soil, and is then treated by bacteria present in the soil.

Typically, soakaways are 2 to 3.5 meters in diameter, and 3 to 6 meters deep (World Bank, 1986). Generally, an infiltration rate of 10 liters per square meter per day is used. However, it is to be noted that the bottom area of an soakaway normally becomes clogged in a short period of operation, and only its side wall areas remain effective in wastewater infiltration. Precast tanks with sidewall holes can be conveniently employed as absorption pits.

d) Disposal to nearby sewer :

This type of disposal is possible when a newly laid sewer line passes nearby an existing septic tank and when the land required for effluent treatment is no longer available.

Treatment and disposal of sludge

Sludge and scum must be removed from the tank when they occupy 2/3 tank capacity. This operation is usually carried out every 1 to 5 years. Sludge accumulates at a rate of 0.03 to 0.04 m^3/person/year, so given the number of users and the volume of the tank, the interval between successive desludging operations can be easily calculated. Because survival of pathogens is highly variable, sludge disposal should be done with caution. The most satisfactory method of sludge removal is to use a tanker lorry equipped with a pump and suction hose. When a tanker is unavailable, it can be removed manually. Anaerobic digestion of the septic tank sludge has been carried out in some tropical areas to produce methane for household uses, and the digested slurry can be used as a soil-conditioner or fertilizer for fish ponds. However, it is always better to inspect the effluent from septic tanks periodically to ensure neither scum nor suspended solids are leaving the system.

Modified septic tank :

The conventional septic tank works well in low-density areas (less than about 100 persons/ha) where the soil conditions are suitable (Cairncross & Feachem, 1983). However, at higher densities there is insufficient space for adequate drainfields. By modifying the design, it is possible to use septic tanks at higher densities, provided of course the soil is suitable for on-site disposal. The design modification is to give the septic tank three compartments (Fig. 7.36); the first receives only the cistern-flush toilet waste water which after settlement passes to the second compartment for further settlement and thence into a third compartment which also directly receives all the household sullage. The net result of having three compartments and initially separating the toilet waste water and the sullage is that the effluent can be expected to have a long term infiltration rate some two to three times greater than the effluent from a conventional septic tank, so that the drainfield can be two to three times smaller.

Thus the modified septic tank could be used at higher densities, at least 200 persons/ha and possibly 300 persons/ha. It is, therefore, possible to have modified septic tanks in areas with these densities instead of conventional sewerage system. If the soil conditions are not suitable for on-site disposal by a drainfield, then a small-bore sewerage system to receive the septic tank effluent should be considered.

7.11 Jokaso

"Jokaso" is the term for privately owned excreta / domestic wastewater treatment systems common in Japan. They are a favoured alternative used in individual houses, housing estates and public facilities where a public sewer system is not available and there is high demand for water carriage of excreta, which is not allowed in Japan if there is no treatment system. Jokaso systems range in size from single-family units to ones that serve over ten thousand people. Users get the benefit of having flush toilets even though they are not hooked up to public sewerage.

There are two types of Jokaso prevail in Japan. A simple nightsoil jokasoes ("Tandoku jokaso"), which treats water flushed human excreta exclusively, and combined jokasoes ("Gappei jokaso") which treats both human excreta and gray water. In case of simple Jokaso, gray water was directly discharged into the environment and often causes water pollution.

Jokaso systems help in raising the water carriage rate of excreta where a public sewage system is not available yet. Particularly in areas where a sewage system is not feasible because of scattered population, a jokaso system is the only way to have water carriage toilets.

In Japan, 66% of the population (Kitawaki, 1993) uses a water carriage system, and out of them, 27% of the total population use Jokaso system.

Inflow rates and BOD concentrations used in planning are 50 l/d/cap and 260 mg/l in simple nightsoil jokasoes, respectively, whereas 200 l/d/cap and 200 mg/l, respectively, for combined jokasoes. Requirement in BOD Removal Rates widely differs in accordance with sizes and environmental capacities. However, BOD removal can sometimes reaches upto 90%. Treated wastewater from jokaso is disinfected with hypochlorites before being discharged into public water bodies.

For small combined jokasoes, bio-film treatment system is preferred because they are less likely to be affected by flow rate fluctuation, which is common in small treatment plants. Design of large jokasoes, which often have sludge treatment facility as well, are of the same design as public sewage treatment plants. An example of small scale jokasoes is shown in Fig. 7.37.

However, Jokaso system requires energy input for aeration and requires maintenance by skilled persons. Desludging is done at least once or twice a year. Such maintenance frequencies depend on treatment methods and scale of jokaso.

In developing countries, jokaso systems seems to be not an appropriate technology for low income households. However, in public facilities, public toilets or sightseeing spots where water pollution control is crucial, Japanese Jokaso technology and experience could be very valuable. It goes without saying that education of operation / maintenance experts is a prerequisite for the successful use of jokaso systems in any country.

7.12 Small bore sewerage

Due to a variety of factors on-site sanitation systems often cannot be used, particularly in densely populated urban areas. Waterborne sewer systems are very suitable for serving these areas because they are able to dispose of both excreta and household wastewater (sullage) with an absolute minimum of health risk to the users.

In many developing countries, conventional sewer systems based on those used in the developed countries have been constructed. These systems have proved so expensive that many households cannot afford to pay the sewerage charges and often only a small proportion of premises have been connected to the systems, even after they have been in operation for many years.

Small-bore sewerage is a sanitation technology which has all the advantages of water-borne sewerage for the user, but these systems cost far less to construct than conventional ones.

There are three basic components to a small-bore sewer system (Fig. 7.38) :

a) *House connections* which collect all the household wastewater (excreta, washing water, etc),

b) *Interceptor tanks* which remove both the suspended and floating solids from the wastewater, and

c) *The small-bore sewer network* which consists of small diameter pipes collecting the settled wastewaters and discharging them into an existing sewerage system or treatment plant.

The interceptor tanks remove solids from the wastewater by allowing it to remain still while the heavy solids sink to form a sludge layer and lighter ones rise and form a scum blanket. The solids are digested anaerobically in the sludge layer. This sludge has to be removed, usually once every five to ten years (World Bank, 1986).

Since most of the solids are settled out in the interceptor tank, it is not necessary to ensure a self-cleaning velocity in the sewers as in conventional sewer systems. Because of this, the small-bore sewers can be much smaller in diameter and slope much less steeply than conventional sewers.

As will be seen from the system description above, the most important characteristic of small-bore sewers is that they are designed to handle only the liquid portion of domestic wastes.

Although the term 'small-bore sewers' has become commonly accepted, a more accurate description would be 'solid-free sewers' or 'effluent drains' (TAG, 1985).

Special advantages

Convenience : Small-bore sewer systems are as convenient to use and have all the advantages of conventional sewer systems.

Water requirements : Since the sewers are not required to carry solids, large quantities of water are not needed for solid transport. Thus, unlike conventional sewers, small-bore sewers can be employed without fear of blockages where domestic water consumption is low. Small-bore sewers are particularly suitable in newly developed areas where conventional sewerage is not affordable and users do not consume the quantities of water required to properly operate conventional systems. It requires no more water to operate than other on-site sanitation systems such as the pour-flush toilet.

Excavation cost : With the troublesome solids removed, the sewers do not need to be designed to maintain a minimum flow velocity for self-cleansing. Therefore, rather than being installed on a straight path with a uniform gradient, they may be laid with curvilinear alignment and a variable or inflective gradient. This reduces excavation costs, since the sewer can follow the natural topography more closely than conventional sewers.

Material cost : Peak flows which the small-bore sewers must be designed to handle are lower than those experienced with conventional sewers because the interceptor tanks provide some surge storage which attenuates peak flows. Therefore, the sewer and any pumping equipment can be reduced in size. In addition, expensive manholes can be replaced with much less costly flushing points since mechanical cleaning equipment is not necessary to maintain the sewers in a free-flowing condition.

Operation & maintenance : Small-bore sewerage is particularly appropriate where experience with conventional sewerage does not exist because the operation and maintenance of small-bore system requires minimal skills and resources. In contrast to conventional sewerage, small-bore sewers do not require skills beyond those required for on-site sanitation systems. Routine maintenance is limited to the removal of solids from each interceptor tank and flushing of the sewers every five years or so. Both of these duties can be performed by trained personnel with simple equipment.

Treatment requirements : Screening, grit removal, and primary sedimentation of treatment in anaerobic ponds are not needed at the treatment works since these unit processes are performed in the interceptor tanks.

Upgrading : Small-bore sewage offers the opportunity of upgrading on-site sanitation at moderate cost at such time that on-site sullage disposal is no longer possible. Many existing installation can be connected directly, without the need for constructing new interceptor tanks.

Costs : Although small-bore sewer systems are cheaper to install than conventional systems, on-site sanitation is usually cheaper still. However, on-site systems often cannot dispose of sullage water and this has become a major problem in many urban areas. Where existing sanitation systems are unable to handle volumes of sullage produced in a community, existing surface water drains become grossly polluted, creating ideal conditions for insect breeding and the spread of disease.

Disadvantages

The principal disadvantage of the small-bore sewer system is the need for periodic evacuation and disposal of solids from each interceptor tank in the system. Special precautions should be taken to prevent illegal connections to the system, since it is likely that interceptor tanks would not be installed in such connections, thereby introducing solids into a system which is not designed to handle solids. This could create serious operational problems.

Design and construction principles of interceptor tanks

The trouble-free operation of small-bore sewer networks depends above all on the correct design of the interceptor tanks. If solids are carried over it to the sewers, they may cause blockages.

The interceptor tank has to provide conditions for four actions to take place (World Bank, 1986) as shown in Fig. 7.39.

1. Sedimentation : a long enough detention time with suitable conditions for the solids to settle to the bottom or float to the surface,
2. Digestion : sufficient volume for the digestion of the solids to take place,
3. Sludge storage : sufficient volume for storage of the digested sludge between sludge removals,
4. Scum storage : sufficient volume for the scum blanket to accumulate.

Often, interceptor tanks are designed with two compartments. This is not usually appropriate for small wastewater flows from individual households, but is for interceptor tanks serving institutions such as hospitals or schools.

The design of interceptor tanks is based on the same principles as the design of septic tanks. For tanks serving a single household a detention time of 1 day is usual.

The volume required for the solids to separate from the liquids in the tank is given by (World Bank, 1986) :

V_s (liters) = T W N

where,

T = detention time (days)
W = wastewater flow (liter/capita/day), and
N = number of users.

The volume required for the anaerobic digestion of the sludge is a function of the volume of solids in the wastewater and the time needed for digestion to take place. The volume of fresh sludge (feces, toilet paper, etc.) is usually taken as 1 liter/person/day and the digestion time appropriate for tropical climate is usually assumed to be 50 days.

The volume required for digestion is given by :

V_d (liters) = 0.5 D N S

where,

D = digestion time (days), and
S = volume of fresh sludge (liters/person/day).

The factor 0.5 is introduced to allow for the average volume of the sludge as it passes through the digestion zone of the tank.

The volume needed for storing the digested sludge between desludging operations is given by :

V_a (liters) = 0.25 A S N

where,

A = accumulation period (days).

The accumulation period is the desludging period less the sludge digestion time, and the factor

0.25 is the assumed ratio of the volume of digested to fresh sludge.

No allowance is made for the volume of scum when calculating the effective volume of the tank.

The total required effective volume is the sum of the three volumes above.

The inlet and the outlet of the interceptor tank must be fitted with a 'sanitary tee'. This is a tee-shaped pipe which has one arm extending into the liquid below the scum layer and one arm extending above the scum into the air space in the top of the tank. On the inlet side the tee dissipates the energy of the wastewater as it enters the tank. This prevents settled solids becoming re-suspended and provides quiescent conditions for the solids to settle out. On the outlet side of the tank the tee prevents scum blocking the outlet and stops floating solids leaving the tank.

The level of the outlet should be at least 75 mm below that of the inlet (Fig. 7.40). This prevents wastewater 'backing up' in the inlet when the liquid level in the tank temporarily rises due to the surge of wastewater entering the tank. This surge storage is very useful because it reduces the peak wastewater flows that the small-bore sewers have to carry, and this helps to reduce the size of pipe needed in the sewer network.

Interceptor tanks are usually made of bricks or reinforced concrete. Prefabricated tanks can also be used.

The house connection has to handle feces and so needs to have steeper gradient than the small-bore sewers.

Small-bore sewer network

Like other water borne sewerage systems, small-bore sewer system is also provides drainage for entire areas. In most cases, the location and outlet of the interceptor tanks together with the local topography will establish the routes and necessary depths of the sewers. While it is desirable to serve every connection by gravity, the local terrain and costs of excavation may require that one or two pump stations be used. The pumping stations will be less expensive than those needed with conventional sewerage systems because specialized solids-handling pumps are not required.

In small-bore sewer network, some sections even have a negative or uphill gradient. There is no problem from the wastewater remaining in the dips when there is no flow because there are no solids to settle out and block the pipe. Conventional sewers are designed so that they never flow completely full of sewage but small-bore sewage systems can have sewage flowing through them under pressure. The only limit to the pressure head is that it must not rise above the interceptor tanks which connect into the sewer. If this occurs there would be a backflow of sewage into the tanks.

The most common material for small-bore sewers is PVC which is durable, has simple and leak-proof jointing, and is light and easy to lay. The minimum diameter should be 100 mm (TAG, 1985). However, vitrified clay pipes can also be used.

A limited number of access points inspecting and cleaning the sewer can be provided. Conventional manholes can be used at major junction, however simple vertical pipes with cover are more usual. These 'flushouts' allow cleaning of the system and clearing blockages, if any, with flexible rods.

Treatment

Waste stabilization ponds are generally the wastewater treatment option of choice in developing countries.

To design a series of ponds to treat small-bore sewerage effluent, one can conservatively assume BOD and fecal coliform reductions of 60% and 90% respectively in interceptor tanks in warm climates (World Bank, 1986). For this reason no anaerobic pond is required in the treatment process. The wastewater should be discharged into a facultative pond and thence into maturation ponds, the size and number of which are determined in the normal way by the required quality of the final effluent.

7.13 Conventional sewerage

Sewerage is the conventional means of wastewater collection in developed countries. The socio-cultural, economic and technical developments that have made sewerage appropriate in those countries must be examined before concluding that it will be appropriate in other countries. Significant differences in any of these conditions may preclude sewerage as a common approach.

Sewerage is a sanitation technology. Indeed the most compelling reason for installing any waste disposal technology is health. Control of human wastes, particularly feces, minimizes the occurrence of a large number of diseases, some of which cause death. Sewerage aids in control by rapidly conveying wastes away from the household.

However, sewerage is not a requisite for good sanitation and there are other low cost sanitation technologies as safe as conventional sewerage from health point of view. On the other hand, in a conventional sewerage system, if wastewaters are not treated prior to their discharge into receiving waters, the health risk to downstream drawers of water may be greatly increased; the extent depending upon distance, dilution and other factors.

In combination with full plumbing there must be suitable hygienic practices in the household. Good cooking, dishwashing, bathing, and infant feces handling practices must exist or diseases may be communicated whether or not sewerage is installed. A knowledge of hygiene will help protect an individual even in an environment without any waste control technologies. Therefore hygiene education is a fundamental component of sanitation.

There will always be wastewater from any household from bathing, dish and clothes washing. These wastes are known as sullage and present less of a health hazard compared to wastewater containing feces. However, there are many less expensive ways to control sullage than sewerage, particularly in low water usage households.

Aesthetics is another criterion on which to evaluate sanitation systems. Full plumbing and sewerage is very effective in controlling odors and other nuisances associated with wastes. Again, other sanitation systems can be as effective.

Technology selection

Conventional sewerage is practical and applicable to downtown, commercial, residential, and industrial areas which can afford them. This omits some 40 to 80% of the population of the developing countries living under less fortunate circumstances.

There are strong biases that favor selection of conventional sewer system over other alternatives. There are few reasons for that tendencies (World Bank, 1986).

1. Economics of scale favour sewerage system over other alternatives.
2. Reduced affordabilities and lower consumption patterns of future immigrants are grossly underestimated.

3. Financial rather than economic costs are too often used in the cost-effectiveness analysis. This understates the cost of foreign exchange, professional services and alternative uses of capital.

4. Private costs like house plumbing are often ignored in estimating overall costs of sewerage systems.

5. Project financing donor often favors selection of sophisticated technologies and expatriate engineering requirements.

6. Training and experience of engineer insists that there is no acceptable alternative to sewerage.

Indirect costs and benefits

There are some indirect costs and benefits of the conventional sewer system.

Private benefits include (World Bank, 1986) :

1. convenience of having a waterborne waste disposal unit in the home,
2. improved household hygiene,
3. reduced health hazards,
4. property value appreciation, and
5. reduction in space required for disposal of sewerage on the property by alternative means such as septic tanks.

External benefits include (World Bank, 1986) :

1. improvements in the urban environment by removal of the sight and smell of sewage at the soil surface and in canals,
2. benefits to public health,
3. reduced downstream river pollution,
4. increased potential for tourism,
5. introduction of new technologies with spin-off benefits of training, experience and employment generation,
6. institutional development, and
7. water pollution monitoring, legislation and enforcement programs usually initiated in parallel with major wastewater collection investments.

External costs include (World Bank, 1986) :

1. Flush water is required to operate the system. The volumes required to maintain self-cleaning velocities are substantial, and in many instances, marginal costs of providing this

water is high.

2. There may be a loss of the reuse potential of excreta. Sewage treatment plants are often included in early plans, but in view of the high costs, they are commonly reduced to primary treatment only or excluded entirely from the system and the sewage is dumped directly into the sea or river. The opportunity of reusing the nutrients and water in agriculture is waived.

3. The sewerage service may incur downstream costs in the long term.

4. With one area covered by sewerage, long term hidden cost is associated with increased demands and later sewage treatment requirements.

7.14 Sewerage Treatment

Sewage from water-borne sanitation systems must be treated before it is disposed of or reused, because it contains wastes which pollute the environment. This treatment has two objectives :

- to remove organic matter from the sewage which causes pollution,
- to remove pathogens (disease causing organisms) which cause serious health risks.

Sewerage treatment is highly recommended in conventional sewer system. Actually much of the benefits of the conventional sewer system can not be obtained with out proper treatment. Many other systems like septic tank, vault toilet and even bucket toilet also require some sort of treatment.

The most common treatment flow starts with primary treatment to remove big particles like sedimentation tank and grit chamber followed by main or secondary treatment which includes pond system, trickling filter, activated sludge, oxidation ditch, etc. Sometimes these can be followed by tertiary or advanced treatment like filtration, nutrient removal, etc. Finally the effluent must be disinfected by chlorination or ozonation.

The sewage treatment processes used in the industrial countries have frequently not been successful in developing countries. This is mainly due to the difficulty of maintaining the energy-intensive, complex machinery in working order. There are also problems in keeping up the supply of imported spare parts and in getting the foreign exchange to buy them.

Sewage treatment processes in developing countries should :

- be effective, low-cost and simple to construct and operate,
- need little imported equipment.

The most appropriate treatment process in the developing countries is probably the waste stabilization pond system.

7.15 Waste stabilization ponds

The hot climate of many developing countries provides ideal conditions for treating sewage by natural processes in ponds called waste stabilization ponds. Pond systems meet the criteria listed above and thus are well-suited for use in developing countries. By keeping raw sewage in a series of shallow ponds for two to three weeks, safe levels of BOD and pathogen removal can be achieved.

Advantages

- Waste stabilization pond systems are simple to build, reliable and easy to maintain.
- They are a low-cost process for treating sewage.
- They require little or no imported mechanical equipment.
- Pond systems provide pathogen removal, which is sometimes better than conventional treatment processes.
- The ponds give a consistent standard of treatment and are not sensitive to sudden load increases.

Disadvantages

- The only disadvantage is that waste stabilization ponds require a substantial amount of land. However, land price is quite low in developing countries compared to developed countries.

The pond system

The three types of waste stabilization ponds are anaerobic, facultative and maturation as shown in Fig. 7.41.

Anaerobic ponds

Anaerobic ponds are used to settle out and break down organic matter.

They are always placed first in a series of waste stabilization ponds. Two processes take place in anaerobic ponds :

- Solids in the incoming sewage settle to the bottom of the pond and form a layer of sludge.
- Anaerobic bacteria break down the organic matter in the sludge. This breakdown produces gas, which go to the atmosphere, and some soluble products, which pass into other ponds. This process causes a very low buildup of sludge in the anaerobic pond.

Facultative ponds

Facultative ponds are used for BOD and pathogen removal.

They can be the first pond in a series of treatment ponds or they can receive effluent from an anaerobic pond. In this pond :

- Some of the suspended solids settle to the bottom where they are digested anaerobically. This bottom layer is called the anaerobic layer. 30 % of the BOD reduction of the pond occurs in this layer.
- There is a layer above the anaerobic layer in which oxygen is present. Algae growing in this layer produce the oxygen by photosynthesis. The algae obtain the nutrients they require to survive from by-products of aerobic bacteria, which are also present in this layer. Aerobic bacteria require oxygen to survive and the bacteria get this in turn from algae as a by-product. The interdependence between the algae and aerobic bacteria is called symbiosis (Fig. 7.42).

Maturation ponds

Maturation ponds are used to upgrade the effluent from a facultative pond or from another maturation pond. They should not receive untreated wastewater. Maturation ponds are aerobic for their whole depth because of their low concentration of organic material and their high concentration of algae. The ponds are intended mainly for pathogen removal. The pathogenic organisms die off as the wastewater slowly passes through the maturation pond. The number of ponds required in the stabilization system depends on the required quality of the final effluent.

Pond design principles

Pre design considerations

There are factors which affect the size and layout of a pond system :

1. The volume of sewage to be treated.
2. The strength of the sewage to be treated.
3. The desired quality of the final effluent from the pond system.
4. Climate.

Before designing a pond system, the values of the first three factors have to be established.

The volume of sewage will depend first on the estimated population of the area to be served at the end of the design life of the system (which is usually assumed to be between thirty and fifty years), and secondly, the quantity of water each person is expected to use. This must take into account improvements in the water supply and higher standards of living, which will mean higher water consumption.

The 'strength' of sewage depends on its contents of organic material, and is measured by its BOD. To estimate the strength of the sewage to be treated, the total amount of BOD contributed per person in the population served is considered. This will vary according to diet and how much food waste is disposed of through the sewers, but in most developing countries it will be roughly 40 gm per person per day (World Bank, 1986). The strength of sewage will be the total BOD per person divided by the water consumption per person. Special consideration is needed for any industrial waste coming to the sewer system.

The third factor, the desired quality of the final effluent from the pond system will depend on the use to which the effluent will be put, or how it is to be disposed of. Three criteria are used to measure the quality of effluents : BOD is used as a measure of its content of organic matter; suspended solids (SS) is a measure of the amount of suspended solid material in the effluent; and the bacterial quality is usually expressed as the number of fecal coliform bacteria (FC) per 100 ml of effluent. In tropical countries, the amount of suspended solids is usually unimportant if the effluent is discharged into a water body because the effluents' suspended solids are largely algae and rivers already contain naturally high concentration of algae.

However, where the effluent is used for trickle irrigation, the suspended solids contents will be important. Suggested values of BOD and FC for various end uses for the effluent are given in

Table 7.2.

Table 7.2 Suggested effluent standards for irrigation and discharge

Method of reuse	BOD mg/l	Fecal Coliforms No/100ml
Irrigation of trees, cotton and other non-edible crops	60	50,000
Irrigation of citrus fruit trees, fodder crops and nuts	45	10,000
Irrigation of deciduous fruit trees, sugar cane, cooked vegetables and sports playing fields	35	1,000
Discharge to a receiving stream	25	5,000
Unrestricted crop irrigation, including parks and lawns	25	100

Source : (World Bank, 1983)

Preliminary treatment

Before sewage flows into the first pond in the series, it may be screened to remove rags and other large objects that will float and cause problems in the ponds. The screen can be mechanically raked, but manually raked screens have the advantage that they cannot break down and can be fabricated locally. The screenings should be buried or burned.

In tropical countries, sewage tends to contain a lot of grit and sand which is washed into sewers because people often use sand for cleaning kitchen utensils. The grit can be removed by passing the sewage along grit removal channels. If so, the grit should be regularly removed from these channels and buried. Alternatively a sump can be constructed below the inlet of the first pond. The sump stores the grit between desludging operations. The sump is easier to construct and maintain than the grit removal channel and is therefore recommended.

Anaerobic ponds

Anaerobic ponds are designed to receive BOD loadings of between 100 – 400 gm/m^3/d. The actual loading will depend on climate, with higher loadings possible at higher temperatures. The retention time will usually be in the range of 1 – 2 days and a rate of BOD removal of up to 80% (but normally about 60%) is possible under tropical conditions.

The design procedure for anaerobic ponds is based on the volumetric BOD loading, as mentioned earlier. This can be determined from the formula :

$$\lambda_V = \frac{L_i Q}{V}$$

where

λ_v = Volumetric BOD loading, gm/m^3/d

L_i = Influent BOD_5 Concentration, mg/l or gm/m^3

Q = Influent flow rate, m^3/d, and

V = Volume of pond, m^3.

Anaerobic ponds are between 2 and 4 meters deep, a depth which ensures anaerobic conditions and provides space for the storage of sludge which accumulates at a rate of 30 – 40 liters per person per year. Anaerobic ponds are desludged when they are full of sludge, usually every 2 – 5 years.

Two or more ponds are often arranged in parallel to allow one pond to be taken out of service for desludging. The sludge can be pumped out, but it is simpler to allow it to dry and then remove it by hand or by mechanized methods. If the sludge is well dried, it can be safely used as an agricultural soil conditioner.

Facultative ponds

Facultative ponds are usually 1.5 — 2.5 m deep. If they are deeper than 2.5 m, the anaerobic layer of the pond predominates. If the pond is less than .1.5 m deep, there will be problems with plants growing in the ponds. Detention time varies from 5 to 30 days.

Facultative ponds are usually designed by considering the maximum BOD load per unit area at which the pond will still have a substantial aerobic zone. Because the biological activity is dependent on temperature, the BOD loading can be increased at higher temperatures without increasing the risk of failure due to the pond becoming anaerobic. A commonly derived formula is :

$\lambda_s = 20\,T - 120$, kg/ha/d

where,

λ_s = BOD surface loading, and

T = the average ambient temperature of the coldest month in °C.

This formula was derived through correlation of possible BOD loadings (with ambient temperatures) in many successful ponds world-wide (World Bank, 1986).

If the facultative is the first in a series, a layer of sludge will slowly build up over the bottom of the pond. The rate of buildup will be much slower than with an anaerobic pond because the loading of raw sewage per square meter of pond area is much lower. Desludging is usually only carried out every 10 – 15 years or even more.

Nutrients and carbon dioxide, which are formed by the breaking down of organic material, are carried by upward mixing where they are used by the algae for growth and the formation of new cells. Wind is the main force which causes mixing, so ponds should not be sheltered from the wind. The height of the embankments surrounding the ponds should not be more than 0.5 m above the normal water level and solid fences should not be used near ponds.

Maturation ponds

The number and the size of maturation ponds in a system depend on the bacteriological quality that is required of the effluent. The number of fecal coliform bacteria per 100 ml of effluent can be estimated from the equation :

$$N_e = \frac{N_i}{1 + K_b t}$$

where

N_e = the number of FC/100ml of effluent

N_i = the number of FC/100ml of influent.

K_b = first order rate constant for bacteria removal, per day

t = retention time.

A safe estimate for the number of FC/100 ml for raw sewage entering a pond system would be 10^7 — 10^8 FC/100ml.

K_b is dependent on temperature and is obtained from the formula :

$K_b = 2.6\ (1.19)^{T-20}$

where T is the average temperature of the coldest month in °C.

The number of FC per 100 ml can be calculated for the effluent from each pond in the series, but the number can be found for the effluent from the last pond in a series from

$$N_e = \frac{N_i}{(1 + K_b t_1)(1 + K_b t_2)\ldots(1 + K_b t_n)^n}$$

where t_n is the retention time for the n th pond and n is the number of maturation ponds in series.

Maturation ponds are usually 1 — 1.5 m deep, and retention times are usually about 5 — 7 days per pond. If several ponds are used in series, they will be most efficient at removing bacteria if they all have same retention time.

Maturation ponds can be used as aquaculture ponds in which fish are grown. Reduced pathogens in the maturation ponds reduces the potential of disease transmission while extending the biological chain through fish lowers the algae and suspended solids content of the effluent.

Construction

The layout of the various ponds depends on the quantity and topography of the land available. A sample layout is in Fig. 7.43.

Embankments should be simple and cheap to build and, where possible rely on construction using homogenous soil with a clay or silt content. If the soils of the available site are not sufficiently impermeable, the embankments can be constructed with an impermeable clay core or a clay blanket on the inside of the embankment.

Where the permeability of the soil is so high that losses due to infiltration are likely to exceed local evaporation rates, a lining should be used. This may be impermeable soil with a high clay or silt content or plastic covered by a protective layer of soil.

The side slopes of the embankments will usually be about 1 : 3. The embankment crests should be wide enough for all vehicles to drive to all parts of the pond system, and should be approximately 0.5 m above pond level.

Interpond connections should be as simple as possible and should allow for flexible operation and expansion of the pond system.

Operation and maintenance

The maintenance of waste stabilization ponds is simple because they are a simple treatment system. A well maintained pond system will yield a good effluent quality with little labor.

Vegetation on embankments must be kept short by cutting or mowing because tall vegetation will shelter the ponds from wind. This will reduce the efficiency of the pond as wind is required to mix the layers of water in the pond. Plants in the pond and near the water's edge should be removed because they shade the ponds and encourage mosquito breeding. Lining part of the inner slopes with rocks or stones will help prevent aquatic plants from growing in shallow waters.

Algae control can be accompliced by growing fish in the maturation ponds. This will cut down on the relatively high suspended solids content which is associated with maturation and facultative ponds. High yields of protein from fish have been achieved using species such as crap and tilapia, and fish sales may offset some of the cost of sewage treatment.

Insect problems with ponds are generally associated with weeds emerging from the water surface. Ponds and pond edges must be kept clear of vegetation. Scum destruction will also help control insects. Screenings and removed grit should be buried upon removal from the system. Fish may be reared in facultative or maturation ponds because they feed on insect larvae.

If there is an odor nuisance then additional units may be added in parallel with anaerobic and/or facultative units to cut down on the possible problem of overloading. An increase of depth in anaerobic ponds may also remove the odor problem.

Monitoring

To make sure the pond system is operating correctly and is not being overloaded, several things have to be measured regularly.

The volume of sewage flowing into the ponds should be monitored by installing a Venturi or a parshall flume to measure the rate of flow. The rate of flow out of the final pond in the series can be measured more simply by installing a V-notch weir. The comparison between inlet and outlet flow gives an idea of the magnitude of evaporation and exfiltration as well as the dilution effect of rainfall.

To check the BOD loading on the ponds, regular test should be done with the samples from the sewage entering the works. The effluent should be tested as well to check that the desired effluent quality is being achieved and that the ponds are functioning correctly.

If the loading on a pond system is monitored, the operators can tell whether the design loading limit is being approached and so enable future expansion of the plant to be initiated in good time.

TABLE 11.II. Financial Requirements for Investment and Recurrent Cost per Household for Sanitation Technologies (1978, US Dollars)

Technology	Total investment cost	Monthly recurrent cost	Monthly water cost	Hypothetical total monthly cost*	Percentage of income of average low-income household**
Low-cost					
Pour-flush (PF) toilet	70.7	0.2	0.3	2.0	2
Pit latrine	123.0	—	—	2.6	3
Communal septic tank	355.2	0.3	0.6	8.3	9
Vacuum-truck cartage	107.3	1.6	—	3.8	4
Low-cost septic tank	204.5	0.4	0.5	5.2	6
Composting toilet	397.7	0.4	—	8.7	10
Bucket cartage	192.2	2.3	—	5.0	6
Medium-cost					
Sewered aquaprivy	570.4	2.0	0.9	10.0	11
Aquaprivy	1100.4	0.3	0.2	14.2	16
Japanese vacuum-truck cartage	709.9	5.0	—	13.8	15
High-cost					
Septic tank	1645.0	5.9	5.9	46.2	51
Sewerage	1478.6	5.1	5.7	41.7	46

*Assumes investment cost is financed by loans at 8 per cent over 5 years for low-cost systems, 10 years for medium-cost systems, and 20 years for high-cost systems.

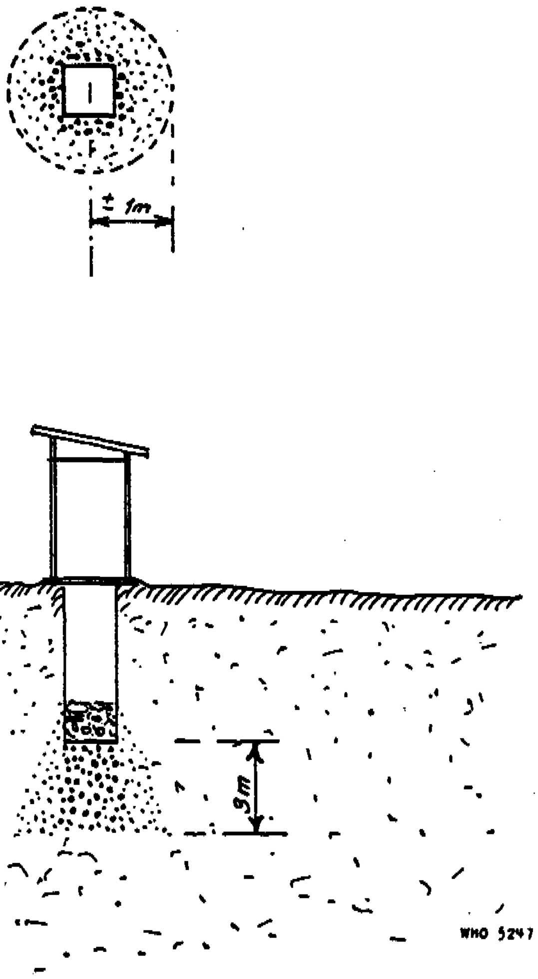
**Assumes an average annual income of US$ 180 per capita with six persons per household.

Source: Kalbermatten, J. M., Julius, D. S., and Gunnerson, C. G., 1980, World Bank Report Series on Appropriate Technology for Water Supply and Sanitation, Volume I, "Technical and economic options", Washington, D.C.[19].

Table 7.1 (IWES 83)

Note: Table 7.2 is within the text

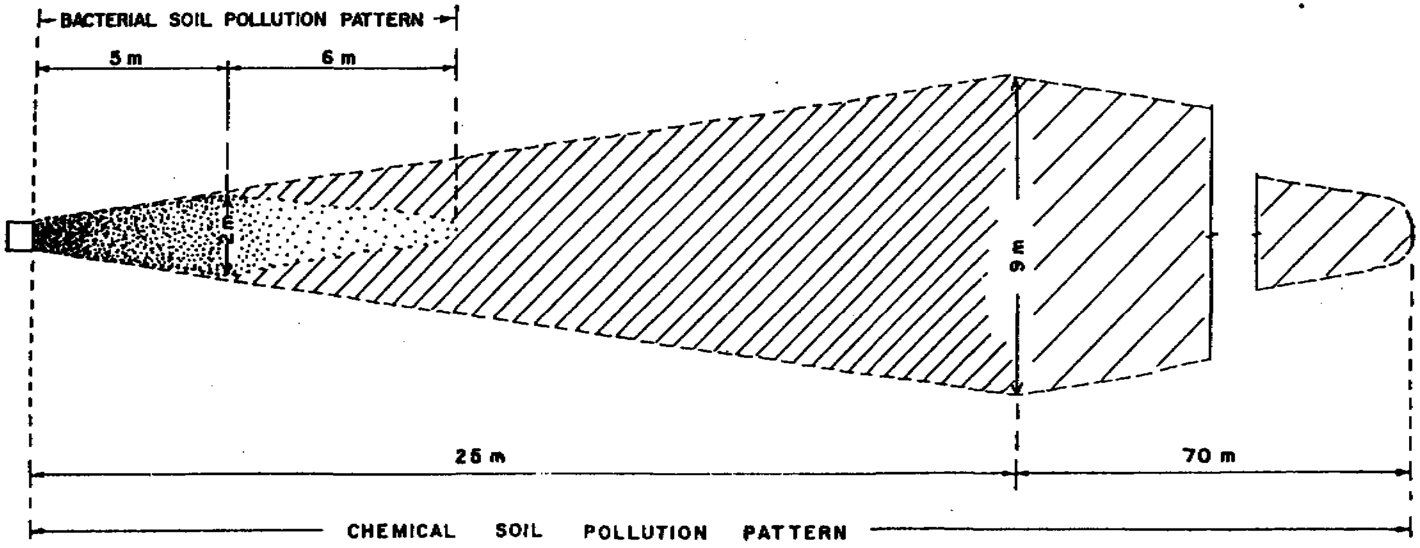
FIG. 4. MOVEMENT OF POLLUTION IN DRY SOIL

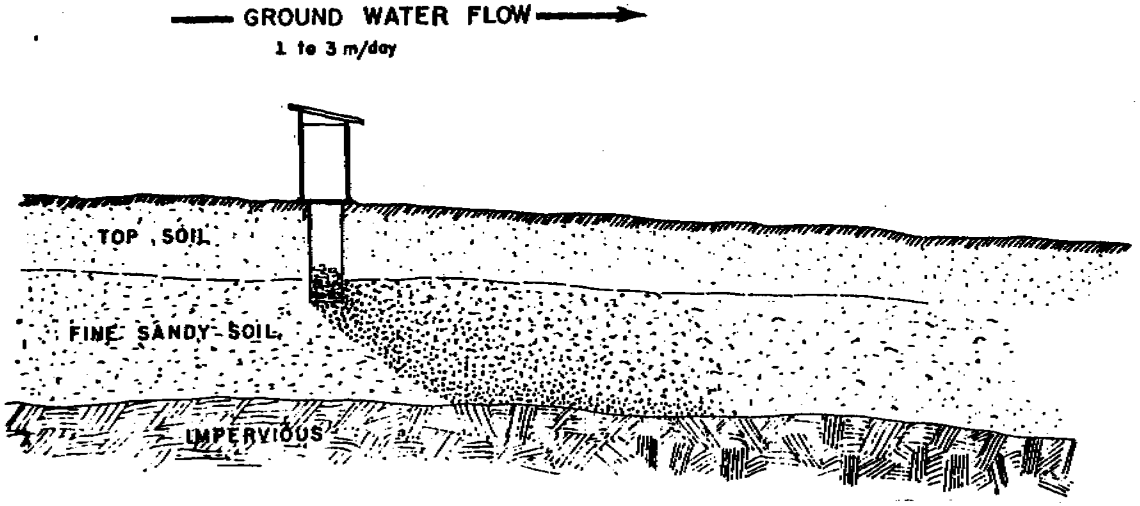


In dry soil there is relatively little migration of chemical and bacterial substances. Laterally there is practically no movement; and with excessive washing (not common in privies or septic tanks) the vertical penetration is only about 3 m (10 ft). Where the contamination does not enter the ground water, there is practically no danger of contaminating water supplies.

Fig 7.1 (WHO, 58)

FIG. 5. BACTERIAL AND CHEMICAL SOIL POLLUTION PATTERNS AND MAXIMUM MIGRATIONS *





The source of contamination in these studies was human excreta placed in a hole which penetrated the ground-water table. Samples positive for coliform organisms were picked up quite soon between 4 m and 6 m (13 ft and 19 ft) from the source of contamination. The area of contamination widened out to a width of approximately 2 m (7 ft) at a point about 5 m (16 ft) from the privy and tapered off at about 11 m (36 ft). Contamination did not move "upstream" or against the direction of flow of the ground water. After a few months the soil around the privy became clogged, and positive samples could be picked up at only 2 m to 3 m (7 ft to 10 ft) from the pit. In other words, the area of soil contamination had shrunk.

The chemical pollution pattern is similar in shape to that of bacterial pollution but extends to much greater distances.

From the point of view of sanitation, the interest is in the maximum migrations and the fact that the direction of migration is always that of the flow of ground water. In locating wells, it must be remembered that the water within the circle of influence of the well flows towards the well. No part of the area of chemical or bacterial contamination may be within reach of the circle of influence of the well.

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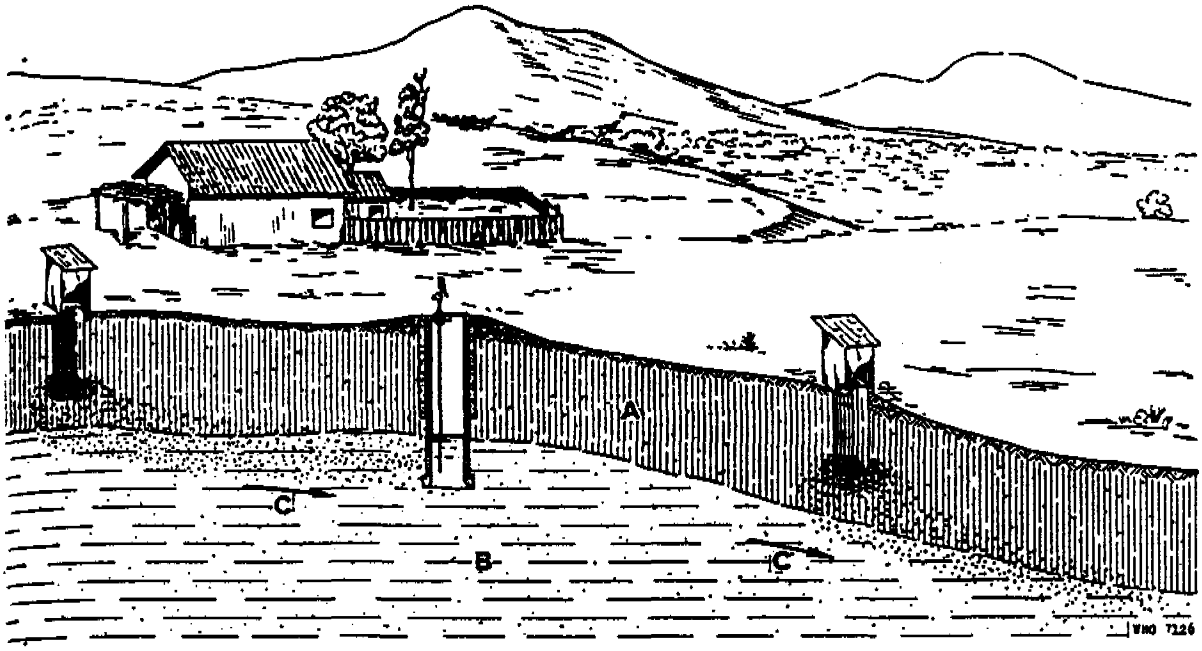
* Based on data from Caldwell & Parr [4, 5] and Dyer, Bhaskaran & Sekar.[10, 11]

Fig. 7.2 (WHO, 58)

FIG. 6. MOVEMENT OF POLLUTION IN UNDERGROUND WATER



A = Top soil B = Water-bearing formation C = Direction of ground-water flow

Fig 7.3 (WHO, 58)

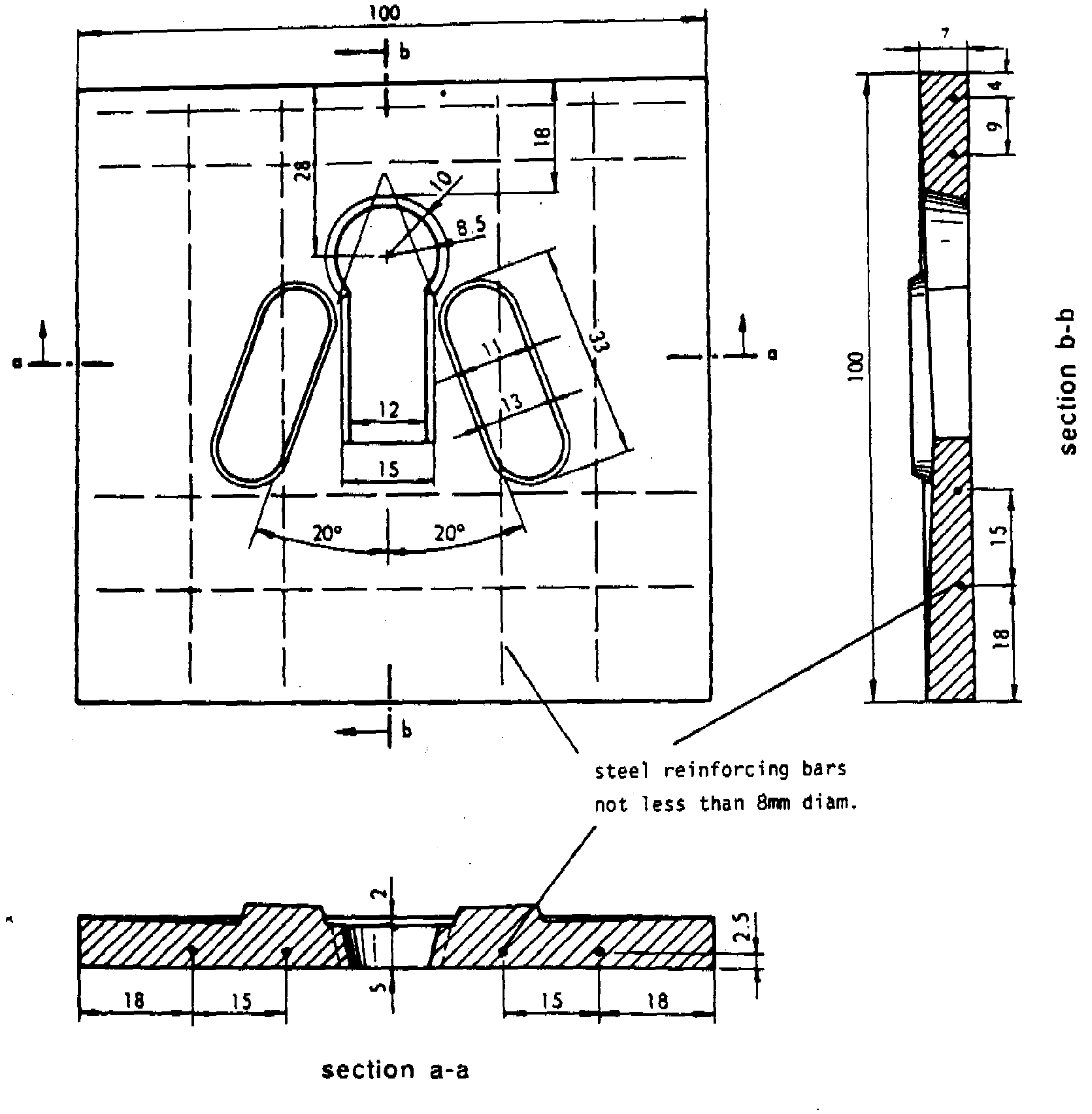


Figure 8.1 Square, reinforced, concrete squatting slab for a pit latrine (dimensions are in centimetres)
Source: From Wagner and Lanoix (1958)

Fig 7.4 (c &F, 93)

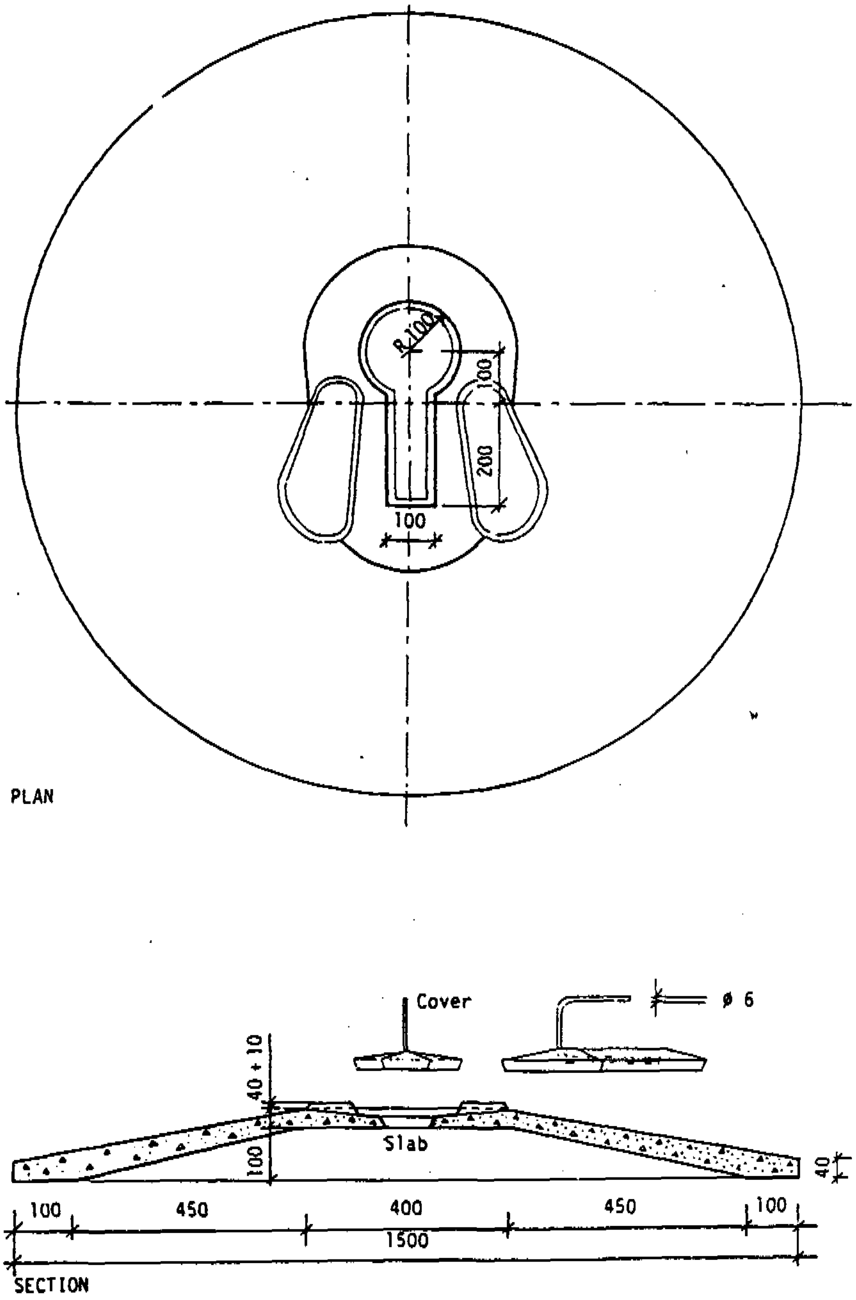


Figure 8.2 A round, conical, unreinforced concrete squatting slab developed in Mozambique (dimensions are in millimetres) (Drawings: B Brandberg)

Fig 7.5 (C &F, 93)

Figure 1: The Components of the Single-Pit VIP Latrine

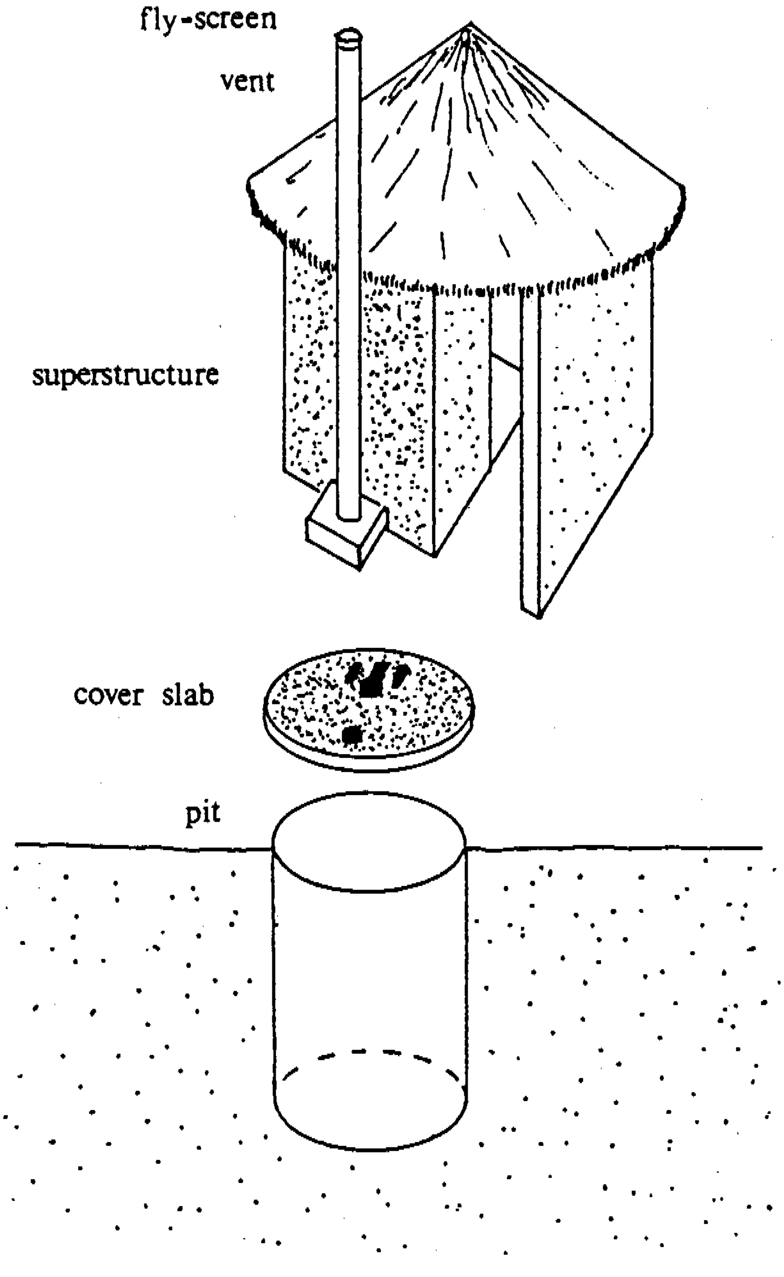


Fig 7. 6 (WB, 86)

Figure 3: Operation of a Single-Pit VIP Latrine

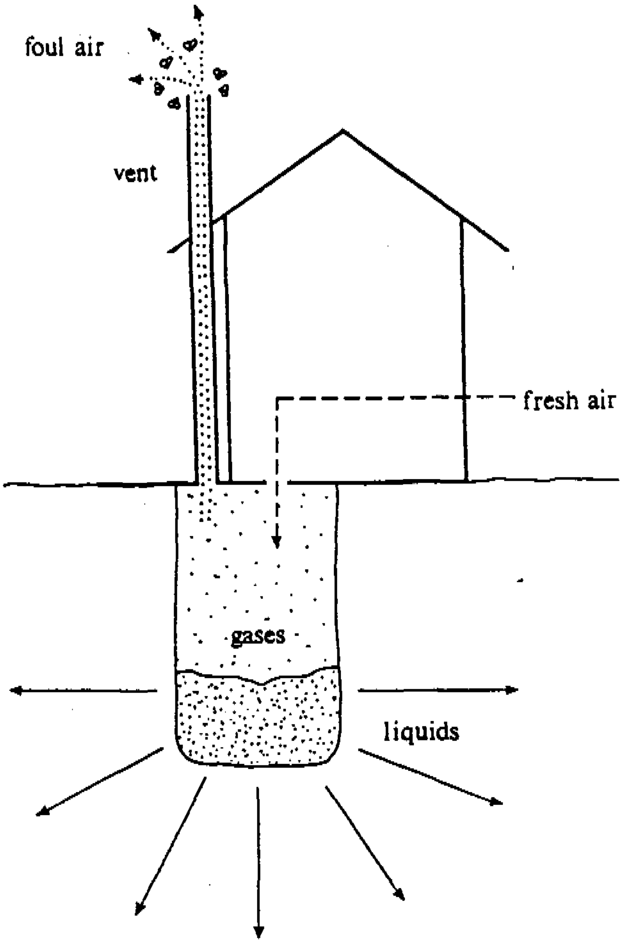


Fig 7.7 (WB, 86)

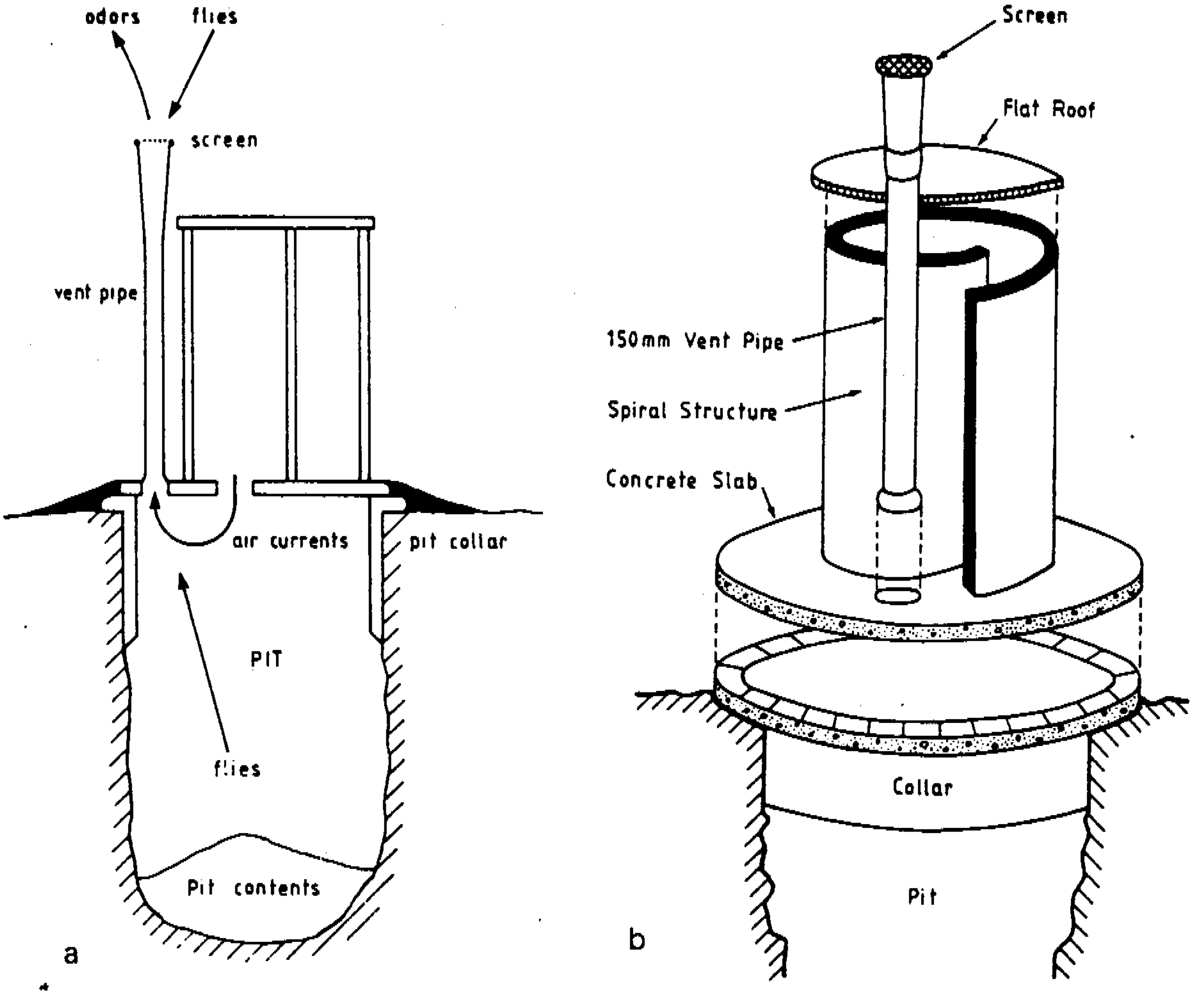
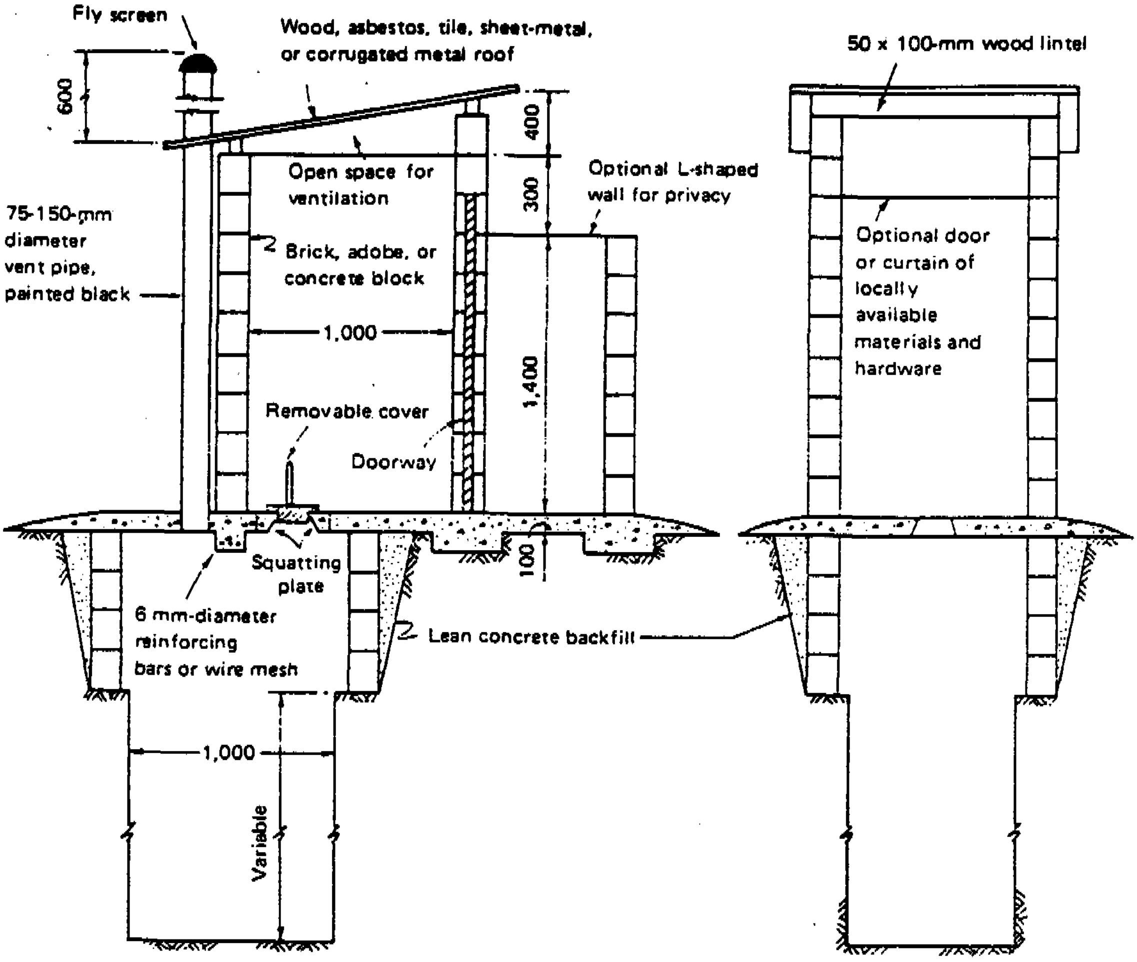


Figure 8.3 These pictures show VIP latrines as developed in Zimbabwe. (a) Schematic diagram of a VIP latrine (b) Exploded schematic diagram of a VIP latrine with a spiral, ferrocement superstructure (c) A VIP latrine with a spiral, ferrocement superstructure and an asbestos cement vent pipe (d) Exploded schematic diagram of a VIP latrine with a spiral, mud and wattle superstructure (e) A VIP latrine with a spiral, mud and wattle superstructure and a plastered reed vent pipe
Source: From Morgan and Mara (1982)

Fig 7·8 (C &F, 93)

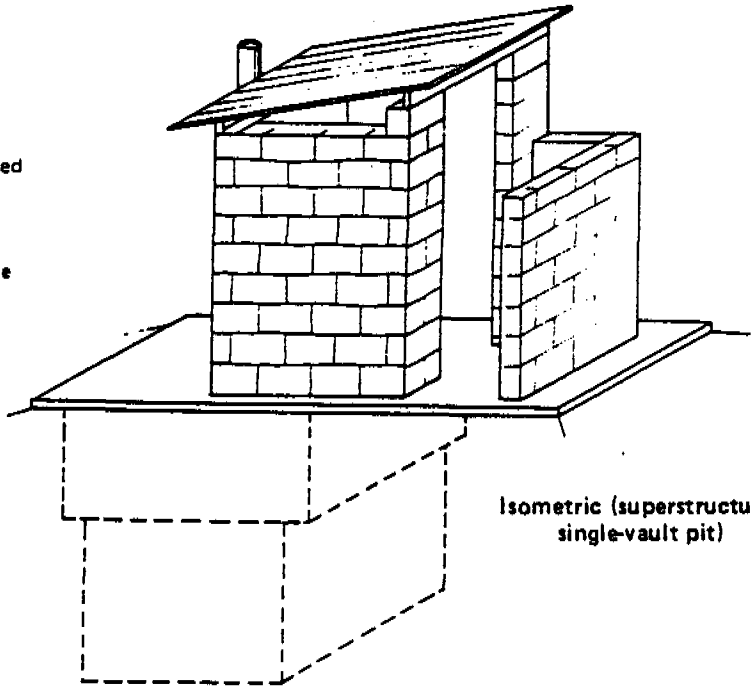
Figure 8-10 . Ventilated Improved Pit Latrine (measurements in millimeters) (millimeters)



Side view (section)

Front view (superstructure; L-shaped wall and vent not shown)

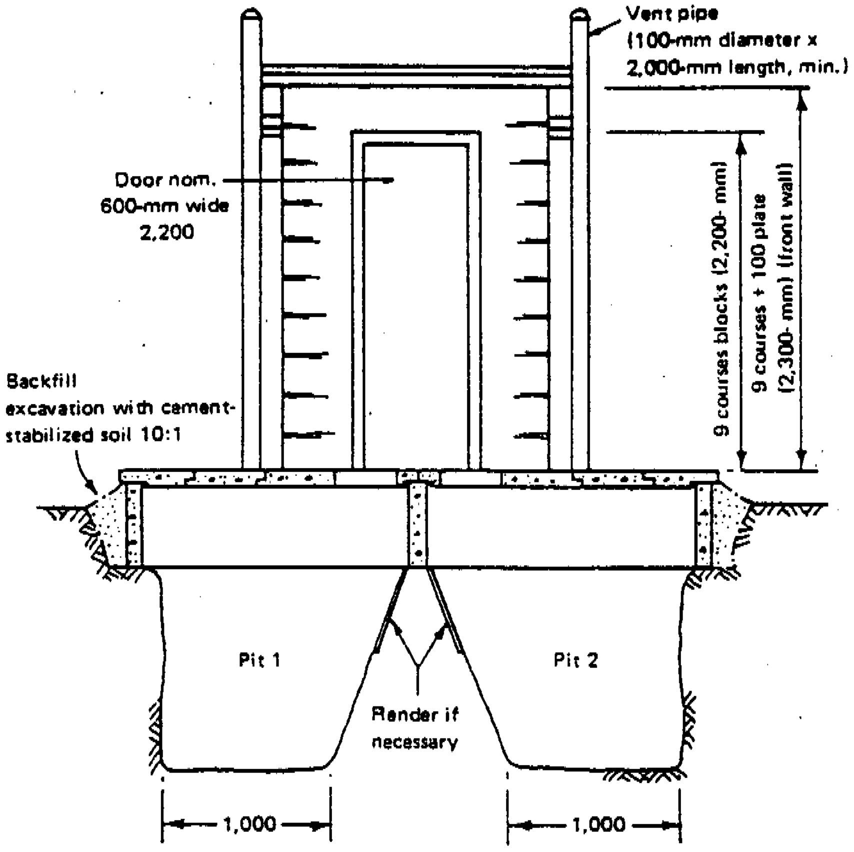
Note: Side view. Pedestal seat or bench may be substituted for squatting plate. An opening for desludging may be provided next to vent. Dimensions of the bricks or concrete blocks may vary according to local practice. Wooden beams, flooring, and siding may be substituted for concrete block walls and substructure.



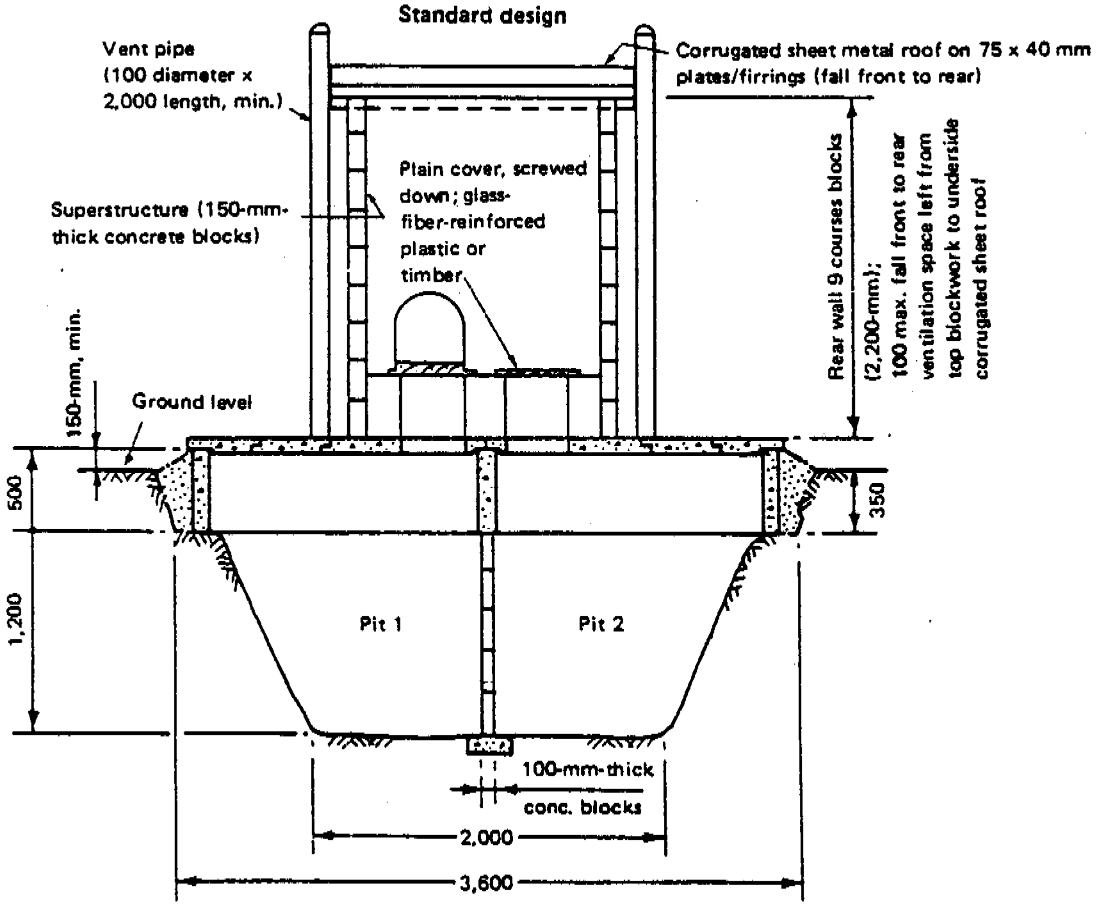
Isometric (superstructure; single-vault pit)

Fig 7.9 (Kalbermatten, 80)

Figure 8-11. Ventilated Improved Double-pit Latrine (millimeters)



Standard design



Optional design

Source: Adapted from R. Carroll (1979).

Fig 7.10 (Kalbermatten, 80)

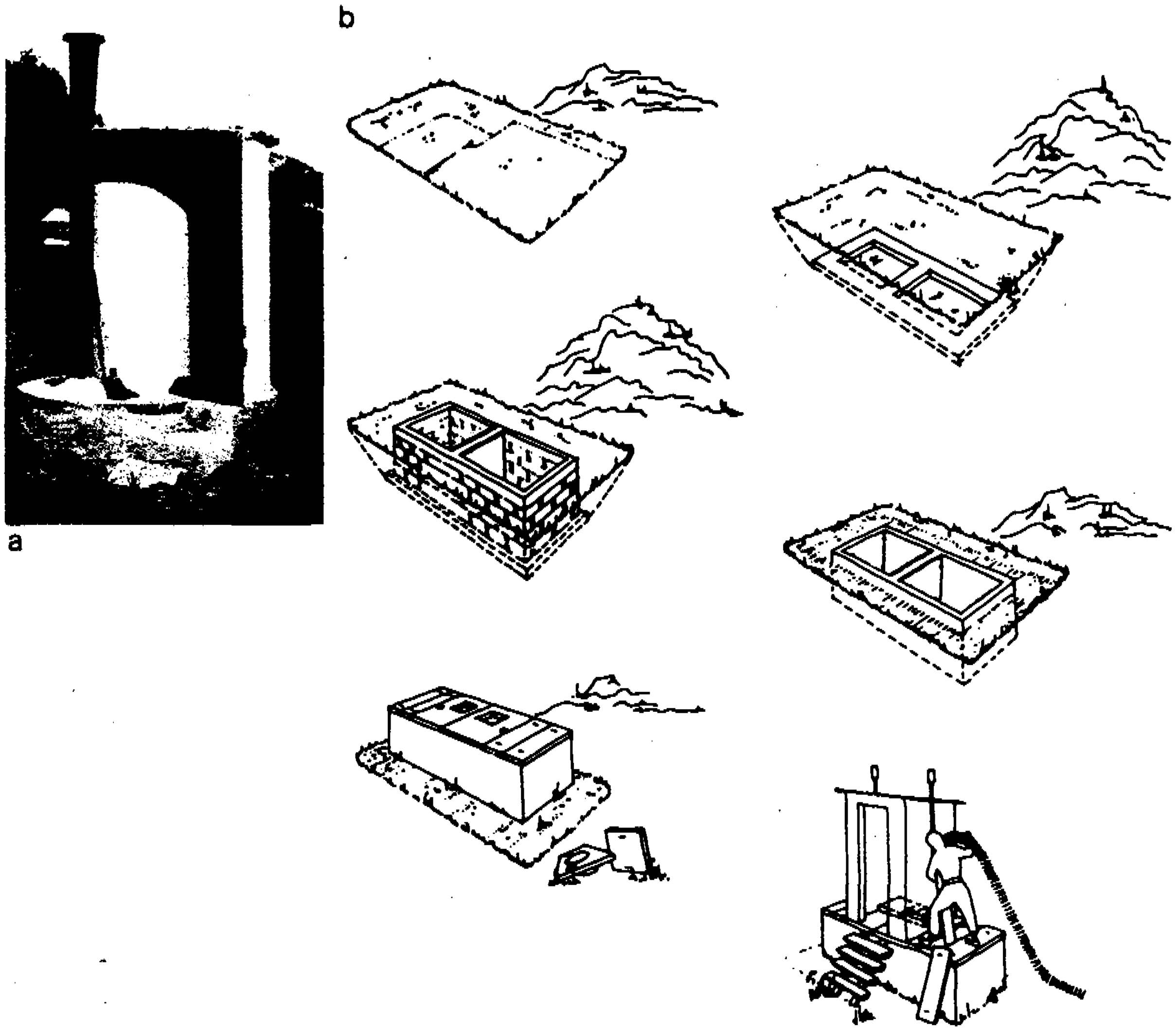


Figure 8.6 Built-up pit latrines. (a) A built-up VIP latrine in Zimbabwe in an area with high ground water table
Source: From Morgan and Mara (1982)
(b) Construction of a built-up, twin-pit, VIP latrine
Source: From Carroll (1980). Reproduced by permission of the controller, HMSO

Fig 7.11 (C & F, 93)

Figure 2: Dimensions of the Pour-Flush Pan and Waterseal[2]

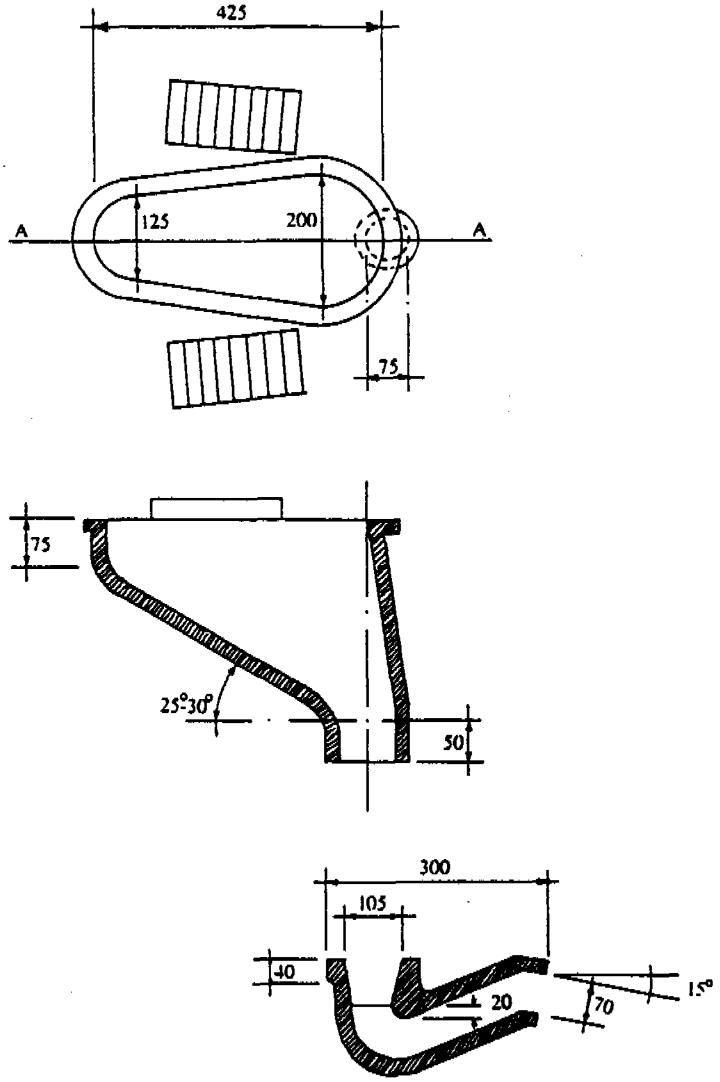
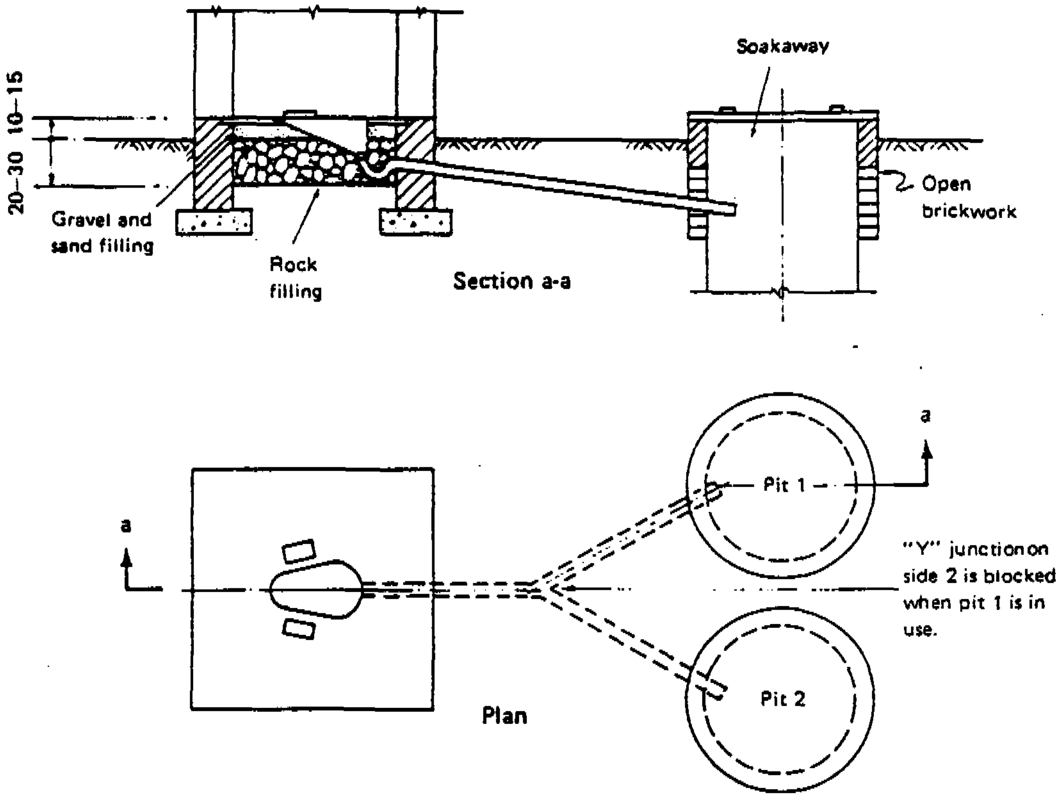
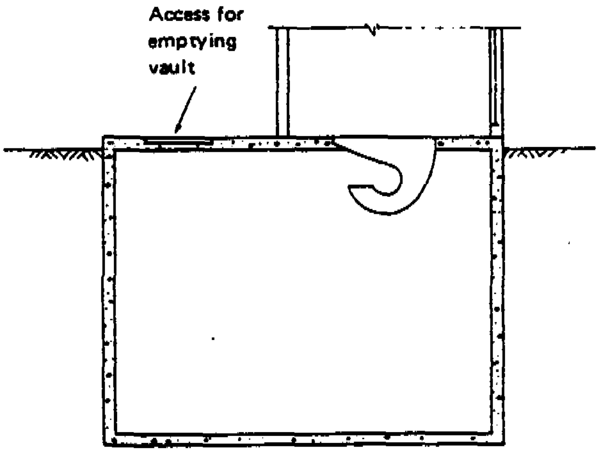


Fig 7.12 (WB, 86)

Figure 8-17. Alternative Designs for Pour-flush Toilets (millimeters)



Offset pit design



Direct discharge design

Note: In the offset pit design, the pit is placed at site of "Y" junction if only one pit is installed.

Fig 7.13 (Kalbermatten, 80)

Figure 1: The Components of a Pour-Flush Toilet

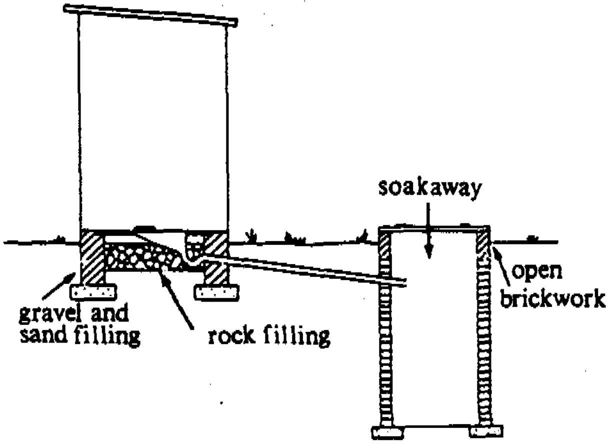


Fig 7.14 (WB, 86)

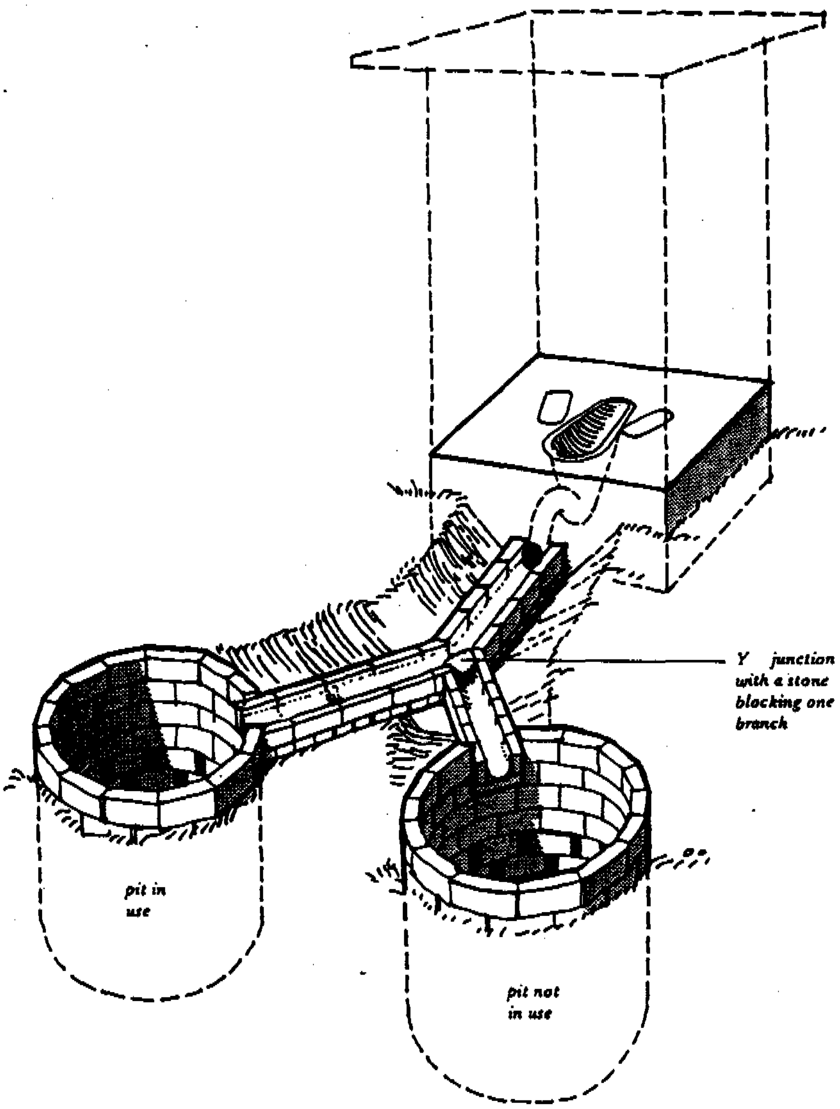


Figure 21 A pour-flush latrine with two pits. Drains and receptacles still to be covered

Fig 7.15 (Winblad & Kilama, 85)

Figure 1: The Aquaprivy[3]

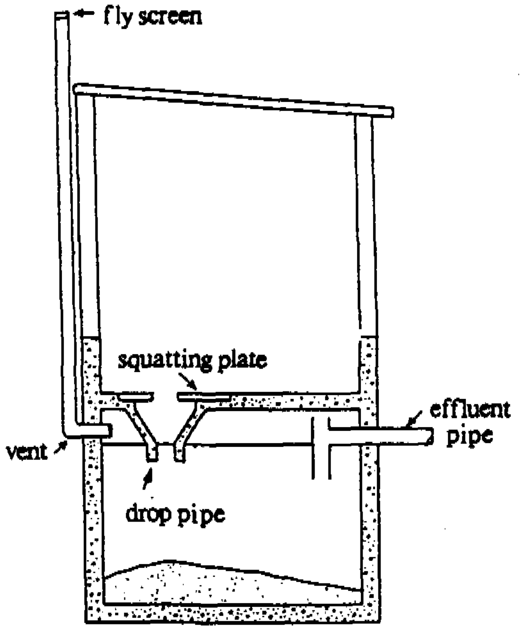


Fig 7.16 (WB, 86)

Figure 2: The Self-Topping Aquaprivy[5] (Dimensions in mm)

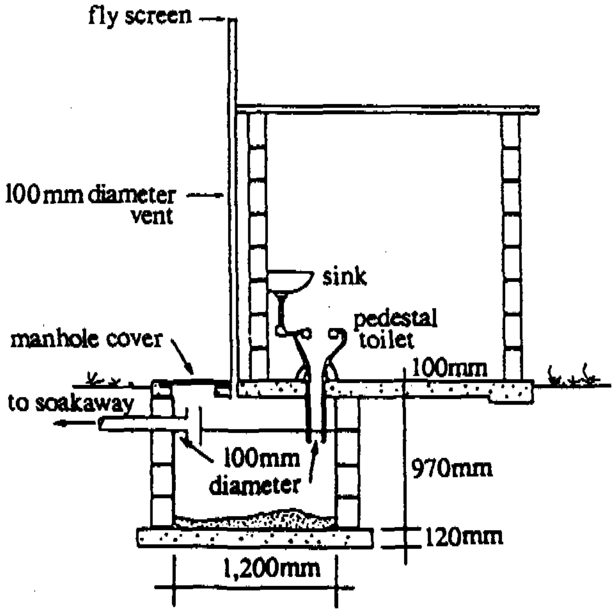
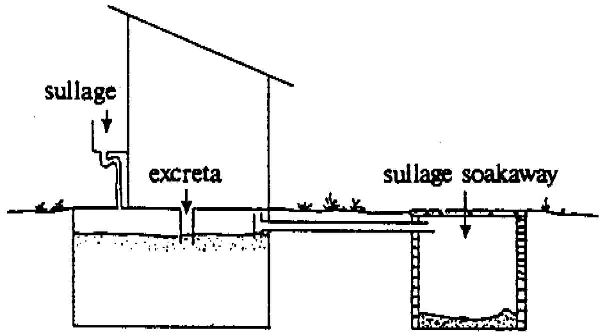
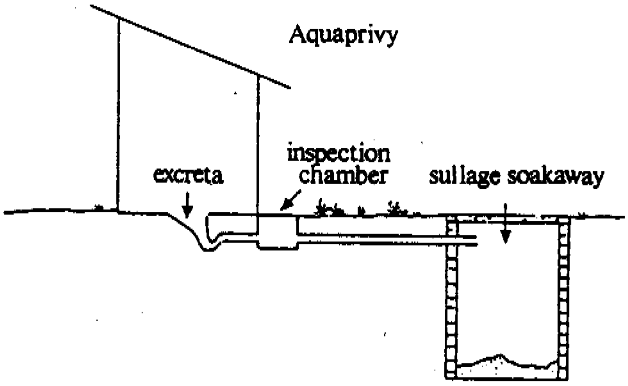


Fig 7.17 (WB, 86)

Figure 4: Comparison of Self-Topping Aquaprivy and Pour-Flush Connected to a Soakaway[3]



Aquaprivy



Pour flush toilet

Fig 7.18 (WB, 86)

Figure 5: The Vault Toilet[6]

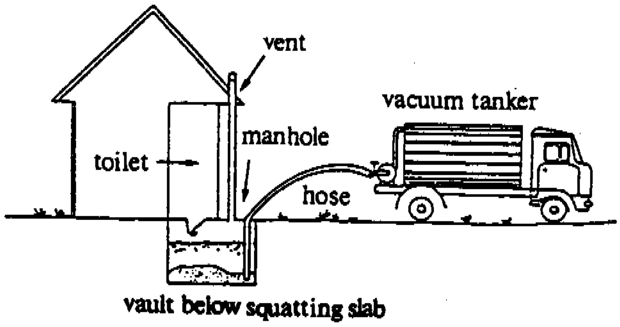
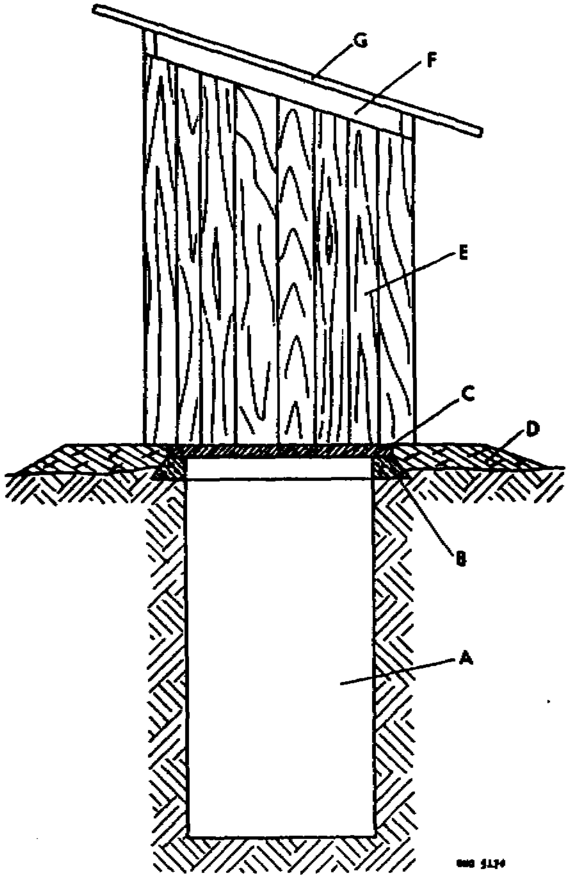


Fig 7.19 (WB, 86)

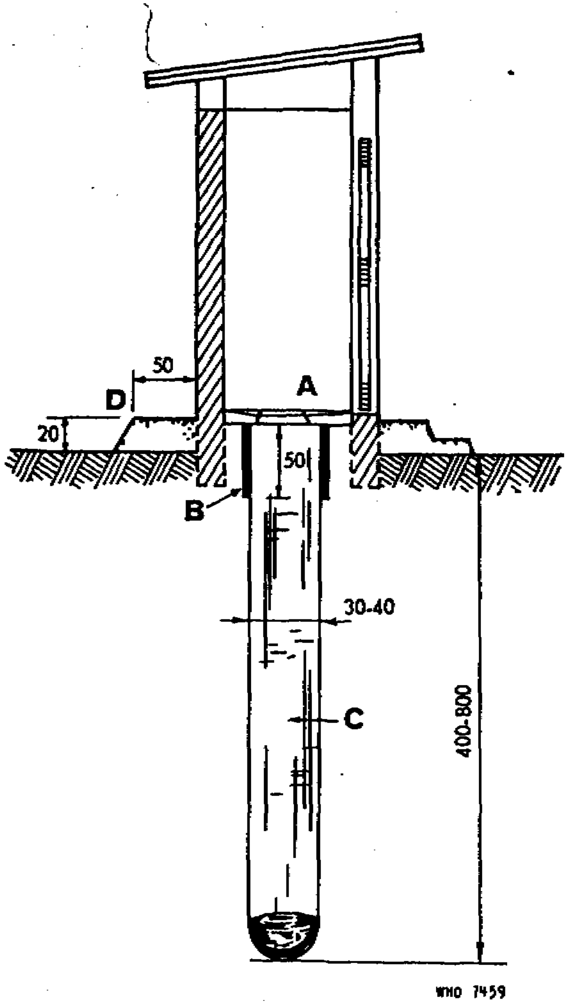
FIG. 10. VARIOUS PARTS OF A ~~SANITARY PRIVY~~ (conventional pit latrine)



A = Pit
B = Base
C = Floor
D = Mound
E = House, including door
F = Ventilation
G = Roof

Fig 7.20 (WHO, 58)

FIG. 51. TYPICAL BORED-HOLE LATRINE

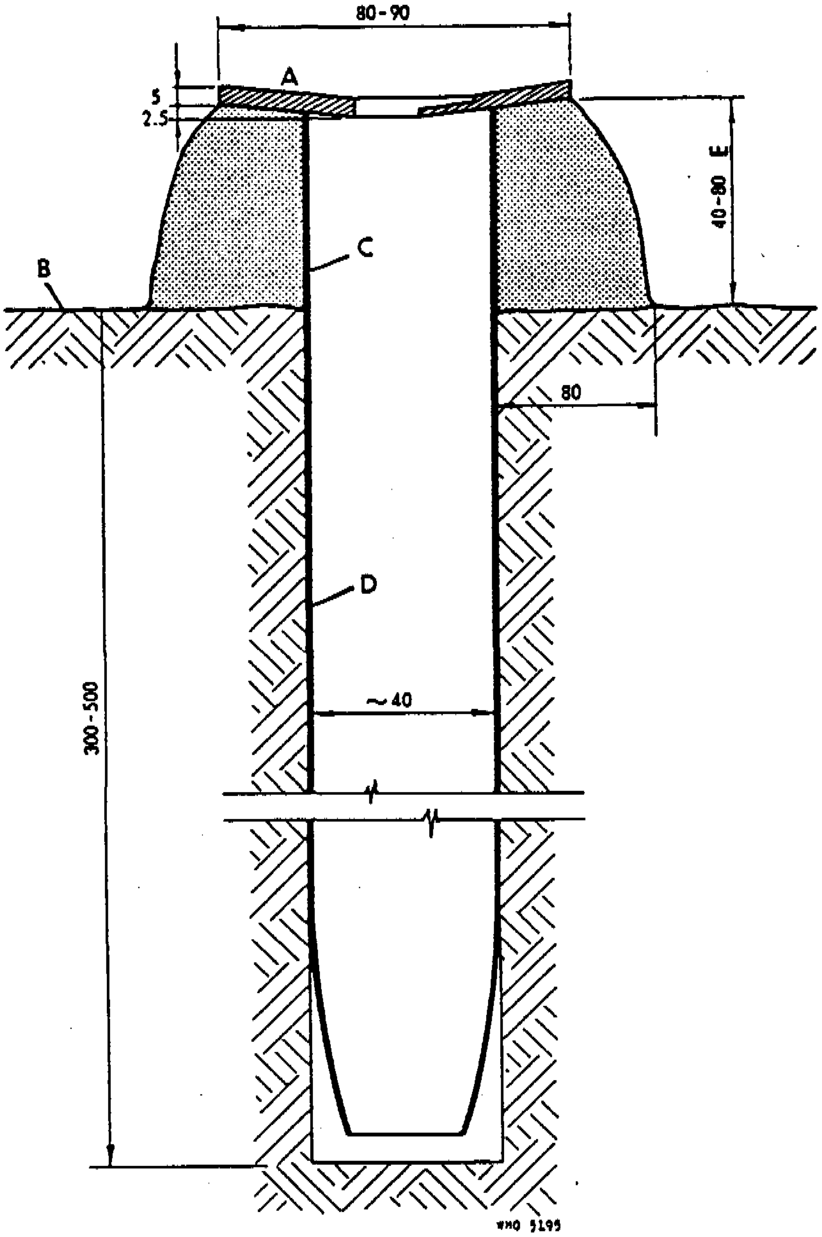


Measurements shown are in centimetres.

A = Squatting slab. Note sides sloping towards hole
B = Impervious clay-tile lining
C = Woven-bamboo lining
D = Earth mound, well tamped

Fig 7.21 (WHO, 58)

FIG. 52. BORED-HOLE LATRINE IN ALLUVIAL SOILS, SUITABLE FOR FLOOD PLAINS AND TIDAL AREAS *



* Built in East Pakistan. Measurements shown are in centimetres.

A = Round slab with slope to centre, as shown in Fig. 27
B = Original ground
C = Bamboo lining required in mound
D = Bamboo lining ful length if required
E = Tamped earth mound

Fig 7.22 (WHO, 58)

Figure 7: The Reed Odourless Earth Closet (ROEC)[5]

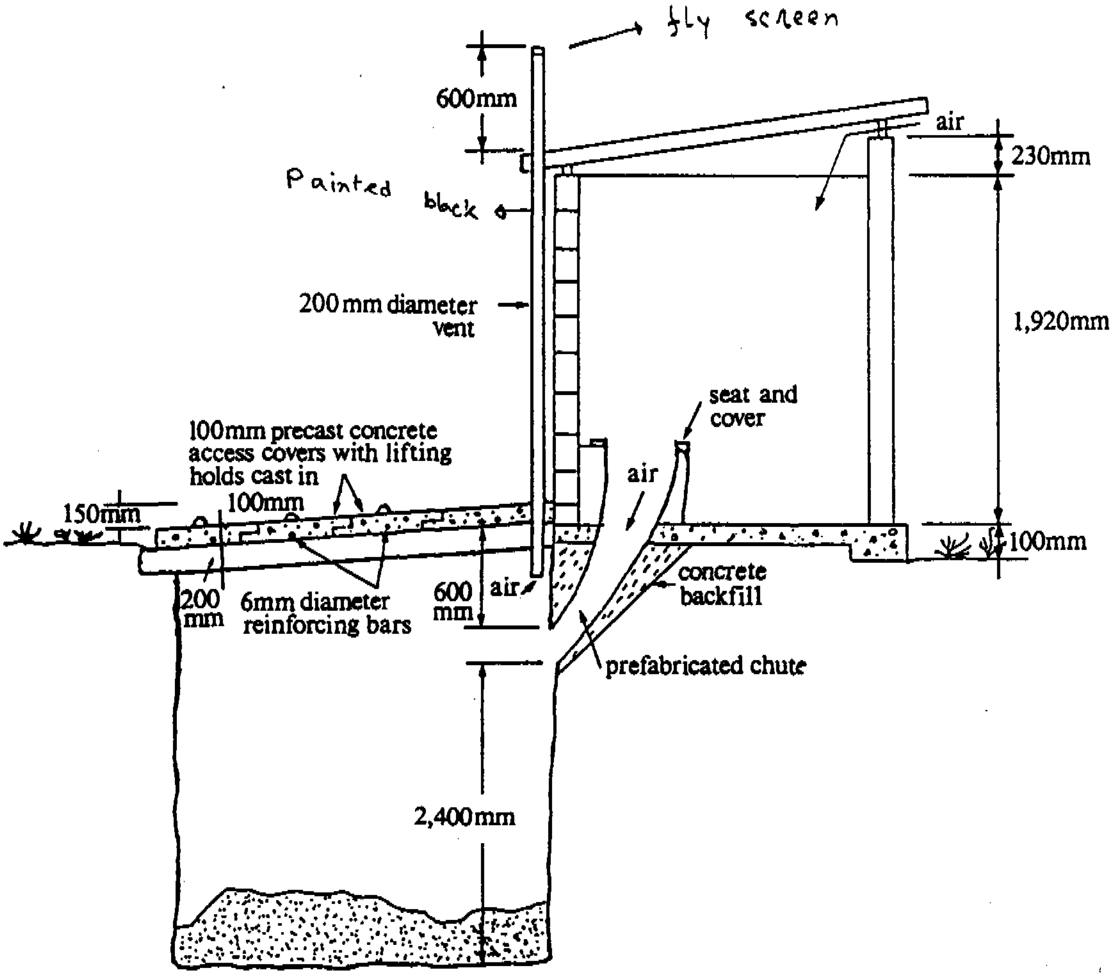
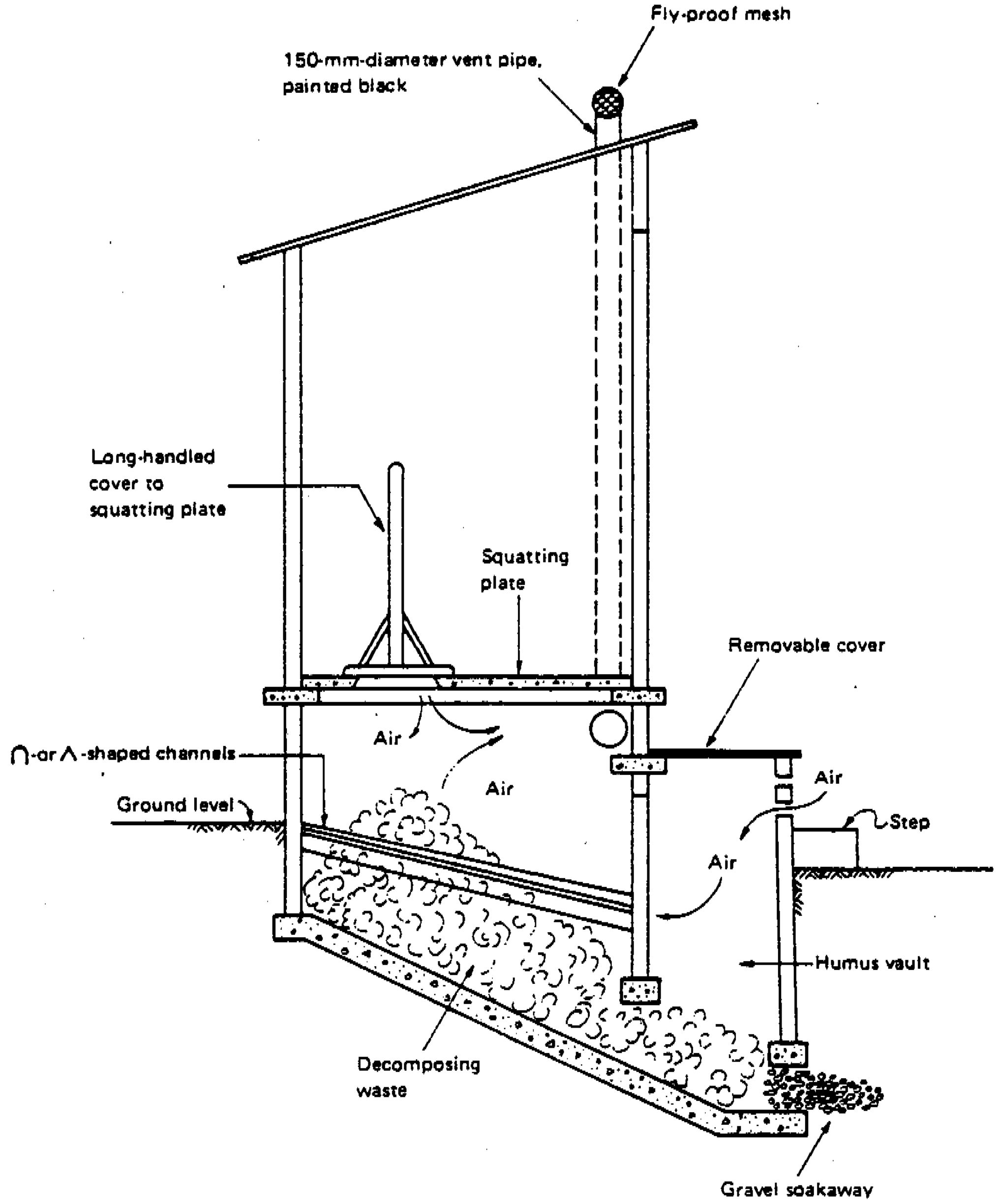


Fig 7.23 (WB, 86

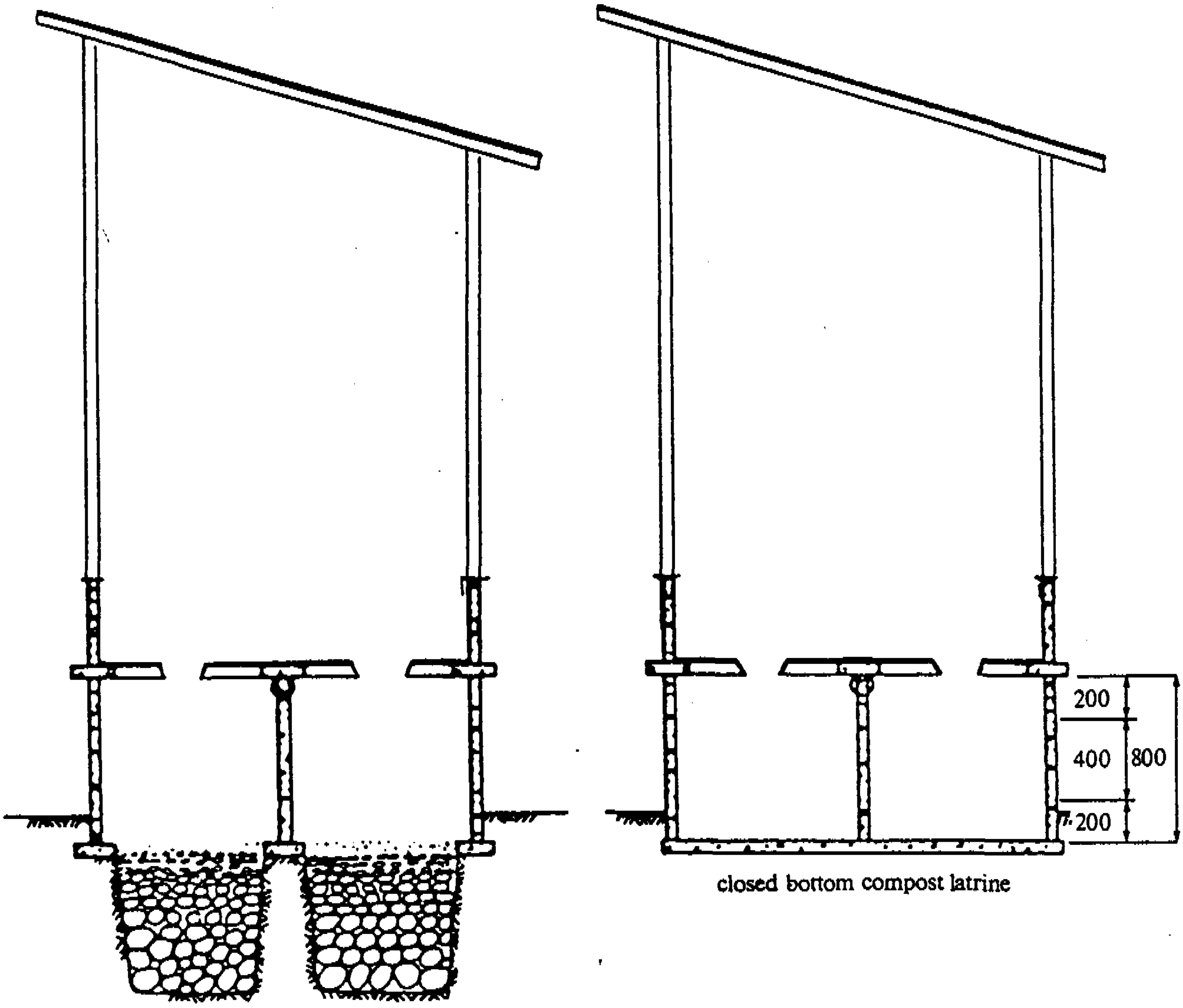
Figure 8-14. "Multrum" Continuous-composting Toilet



Source: Adapted from a drawing by U. Winblad.

Fig 7·24 (Kalbermatten, 80)

Figure 8: The African Batch Compost Latrine[7]



closed bottom compost latrine

open bottom compost latrine

Fig 7.25 (WB, 86)

Figure 9: The Vietnamese Compost Latrine[7]

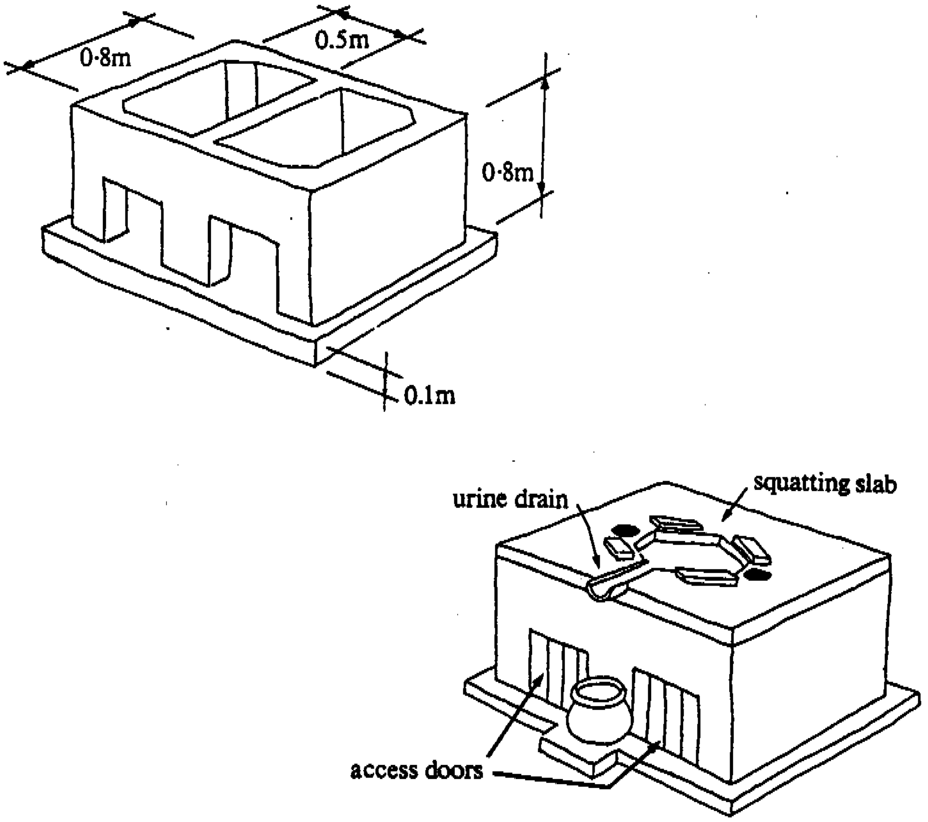
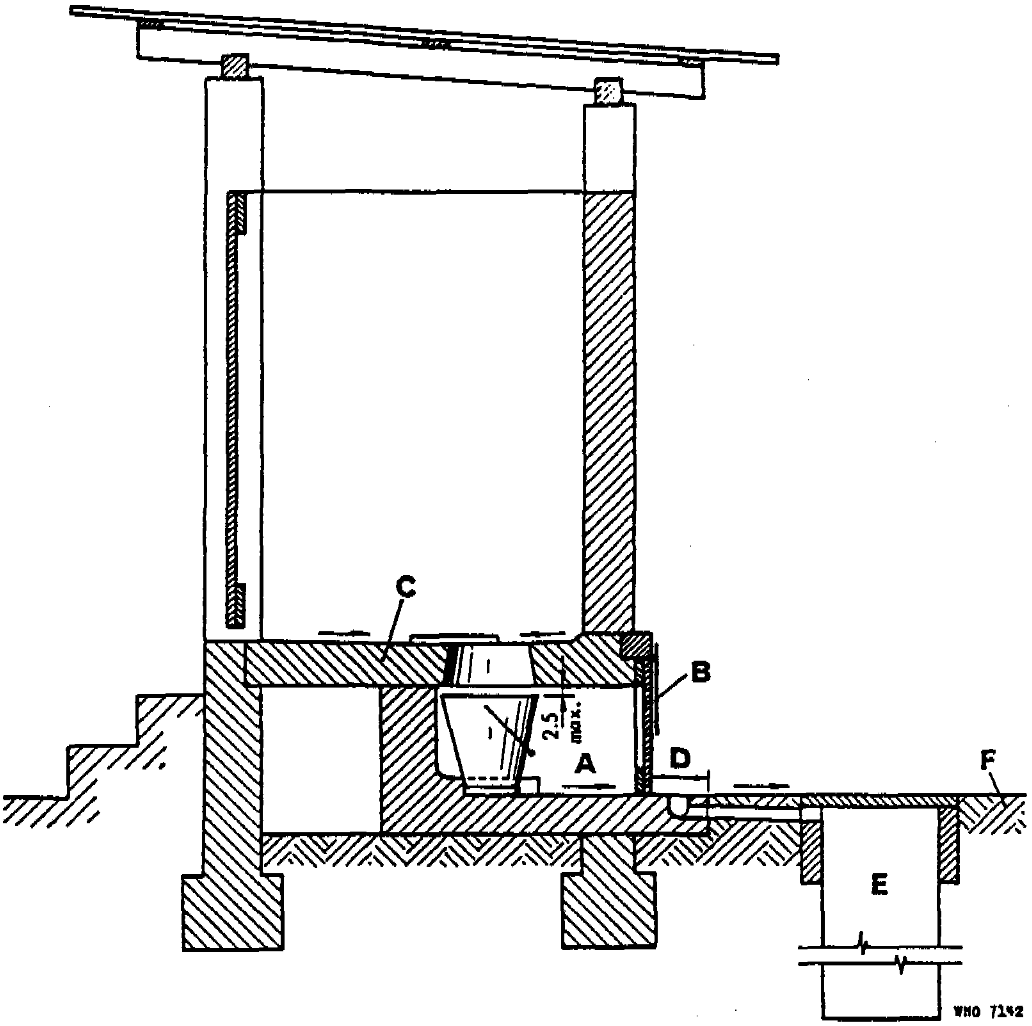


Fig 7.26 (WB, 86)

FIG. 57. THE BUCKET LATRINE

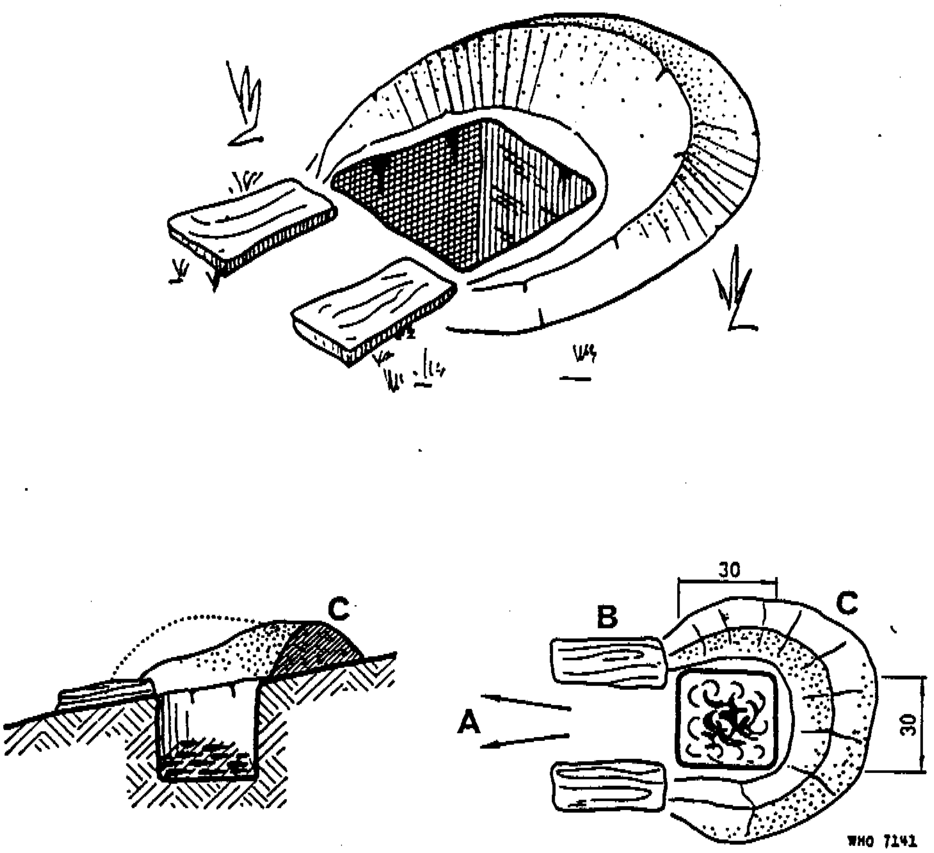


The measurement shown is in centimetres.

A = Collection chamber built of impervious material; note bucket
B = Fly-proof door
C = Elevated floor or slab
D = Paved surface and drain
E = Soakage pit or trench
F = Original ground-level

Fig 7.27 (WHO, 58)

FIG. 58. A "FEUILLÉE"



Measurements shown are in centimetres.

A = Flow of urine over the ground or in a furrow
B = Flat stones forming foot-rests
C = Loose earth used for covering faeces

Fig 7.28 (WHO, 58)

Figure 11: The Yemen Long Drop Latrine[7]

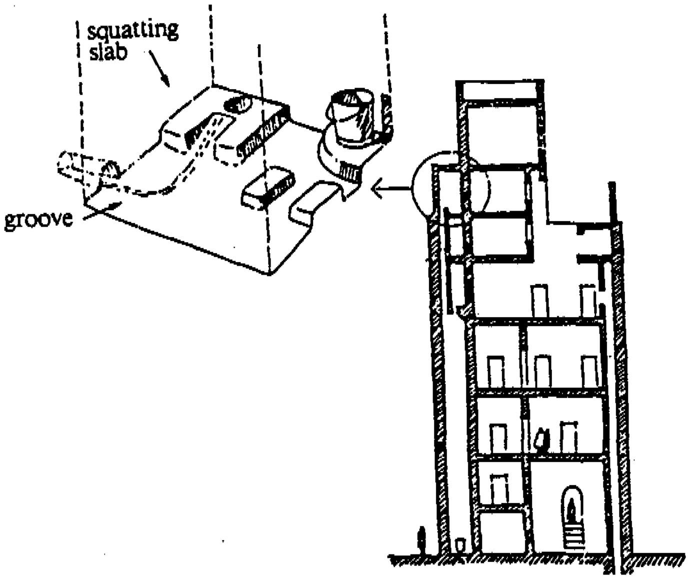


Fig 7.29 (WB, 86)

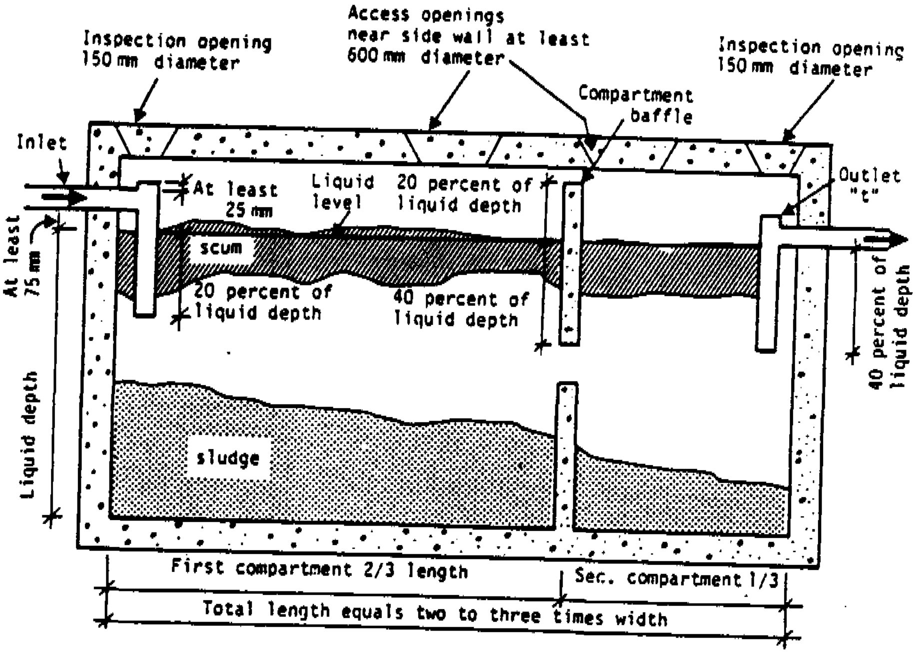
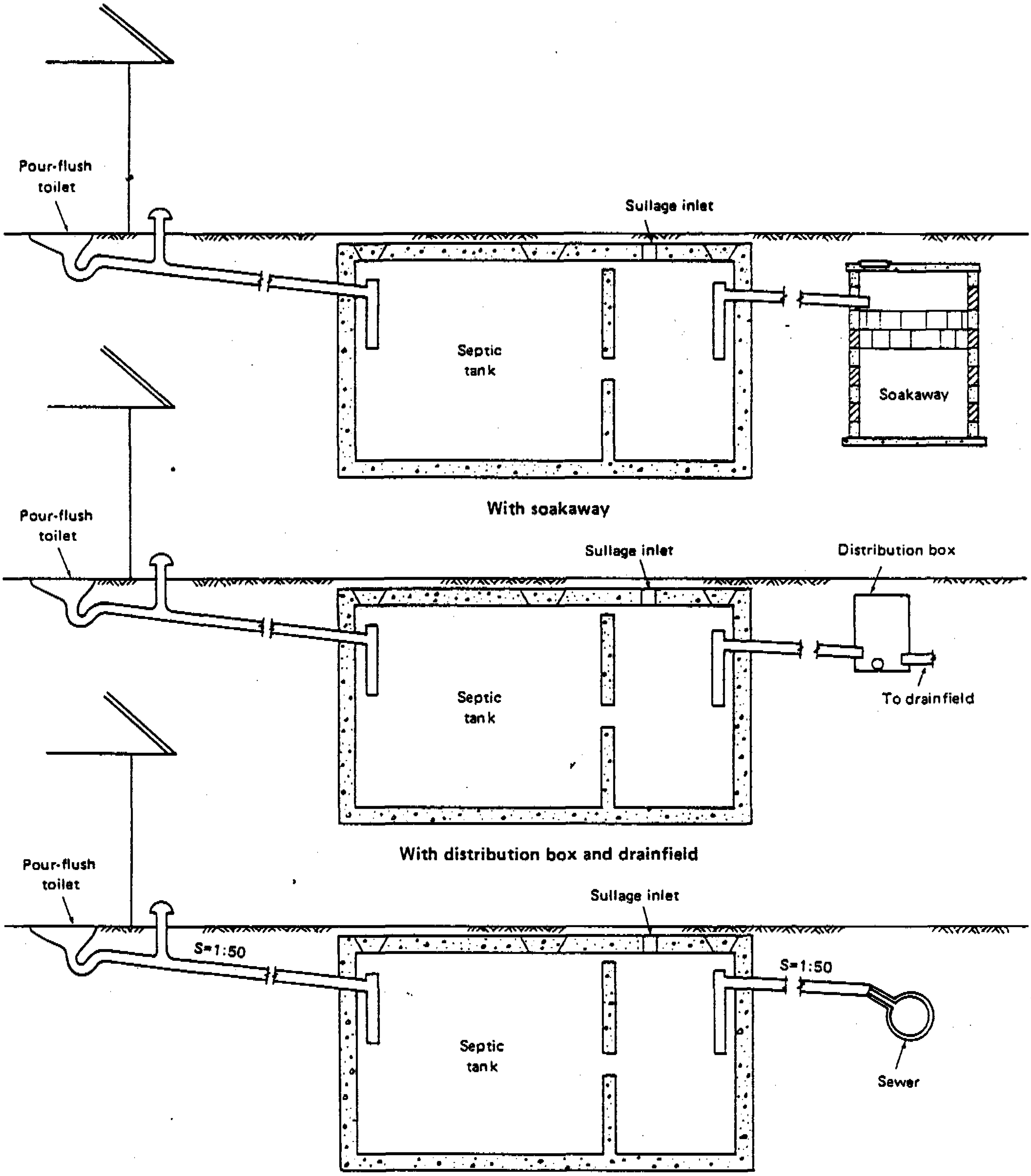


Figure 8.10 A conventional two-compartment septic tank. Note the deliberate absence of a ventilation pipe, which would favour mosquito breeding (Chapter 15). *Source*: After Kalbermatten *et al.* (1982)

Fig 7.30 (C8F, 93)

Figure 8–18 . Pour-flush Toilet — Septic-tank Systems



With soakaway

With distribution box and drainfield

With sewer

S, slope.

Note: See chapter 14 for details of septic tanks, soakaways, and drainfields.

Fig 7·21 (Kalbermatten, 80)

Figure 2: A Typical Septic Tank System[2]

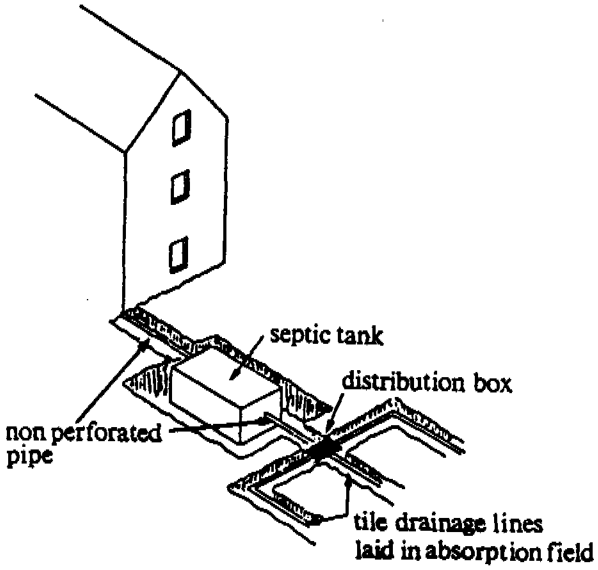


Fig 7·32 (WB, 86)

Figure 3: Disposal Trench and Tile Line

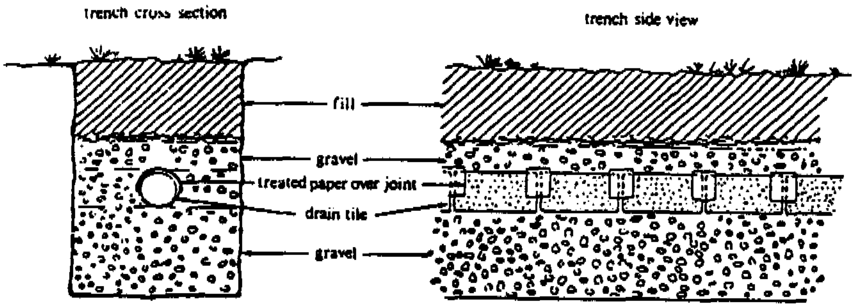
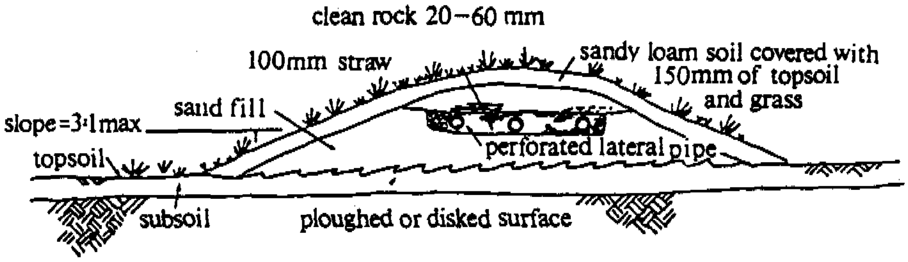
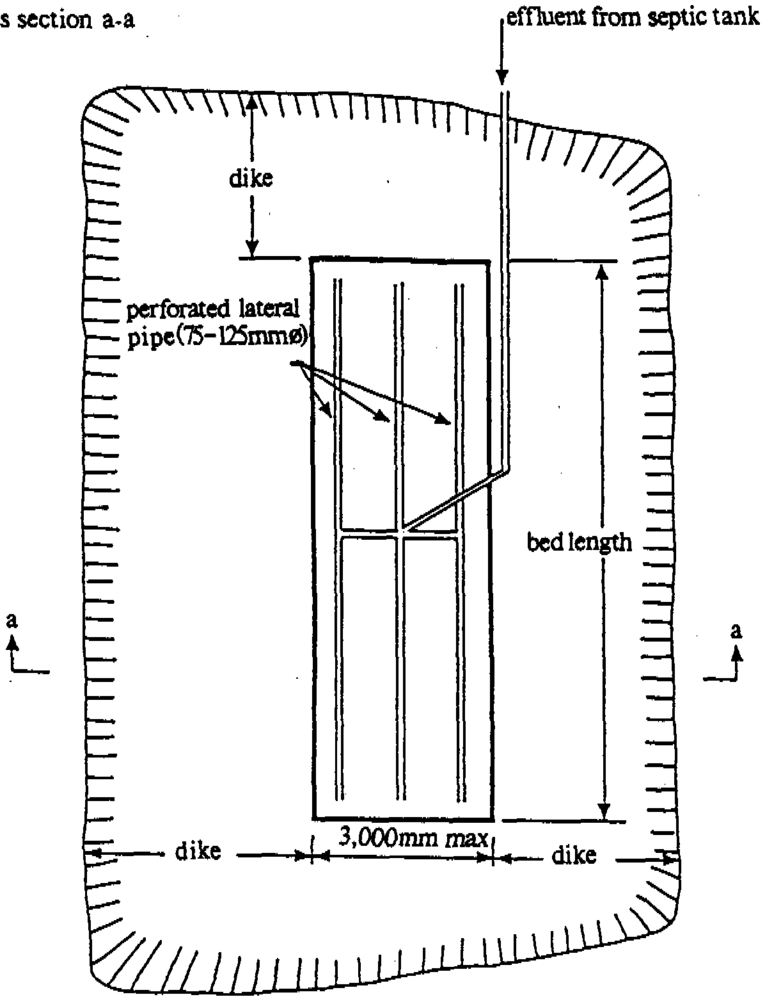


Fig. 7·33 (WB, 86)

Figure 4: The Evapotranspiration Mound[1]



Cross section a-a



Plan/top view

Fig 7.34 (WB, 86)

Figure 5: The Seepage Pit or Soakaway[4]

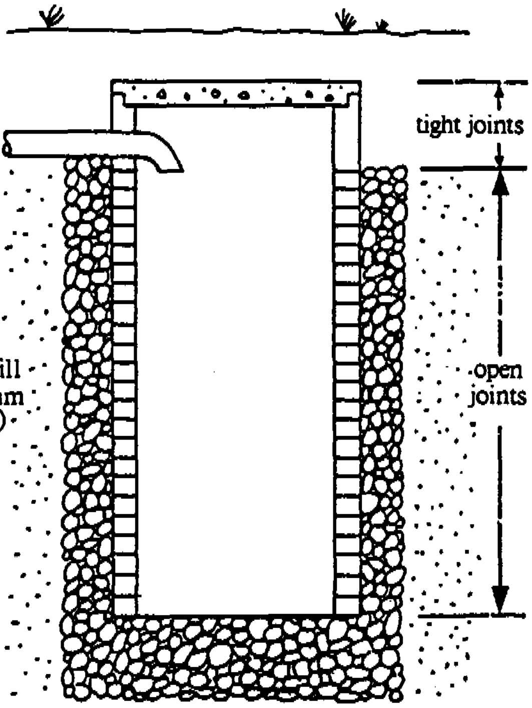


Fig 7.35 (WB, 86)

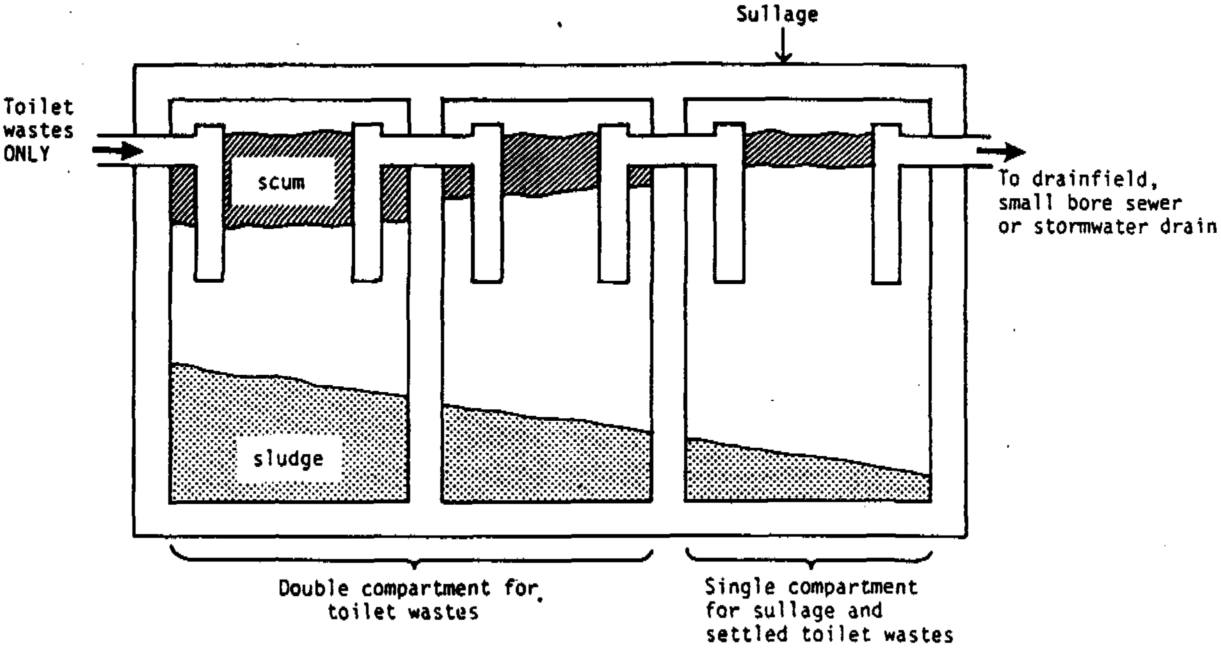


Figure 8.11 Three-compartment septic tank
Source: After Kalbermatten *et al.* (1982)

Fig 7.36 (C & F 93)

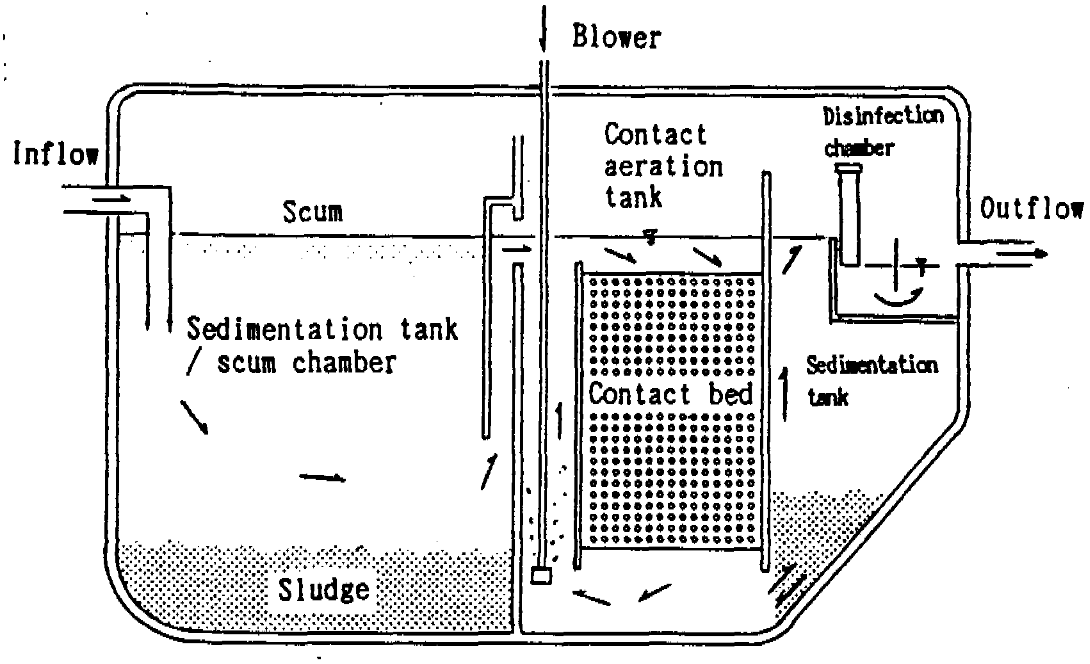


Fig. 1 Example of Small Jokaso with Contact Aeration and Sedimentation

Fig 7.37 (Kitawaki, 93)

Figure 1: Components of a Small-Bore Sewer System

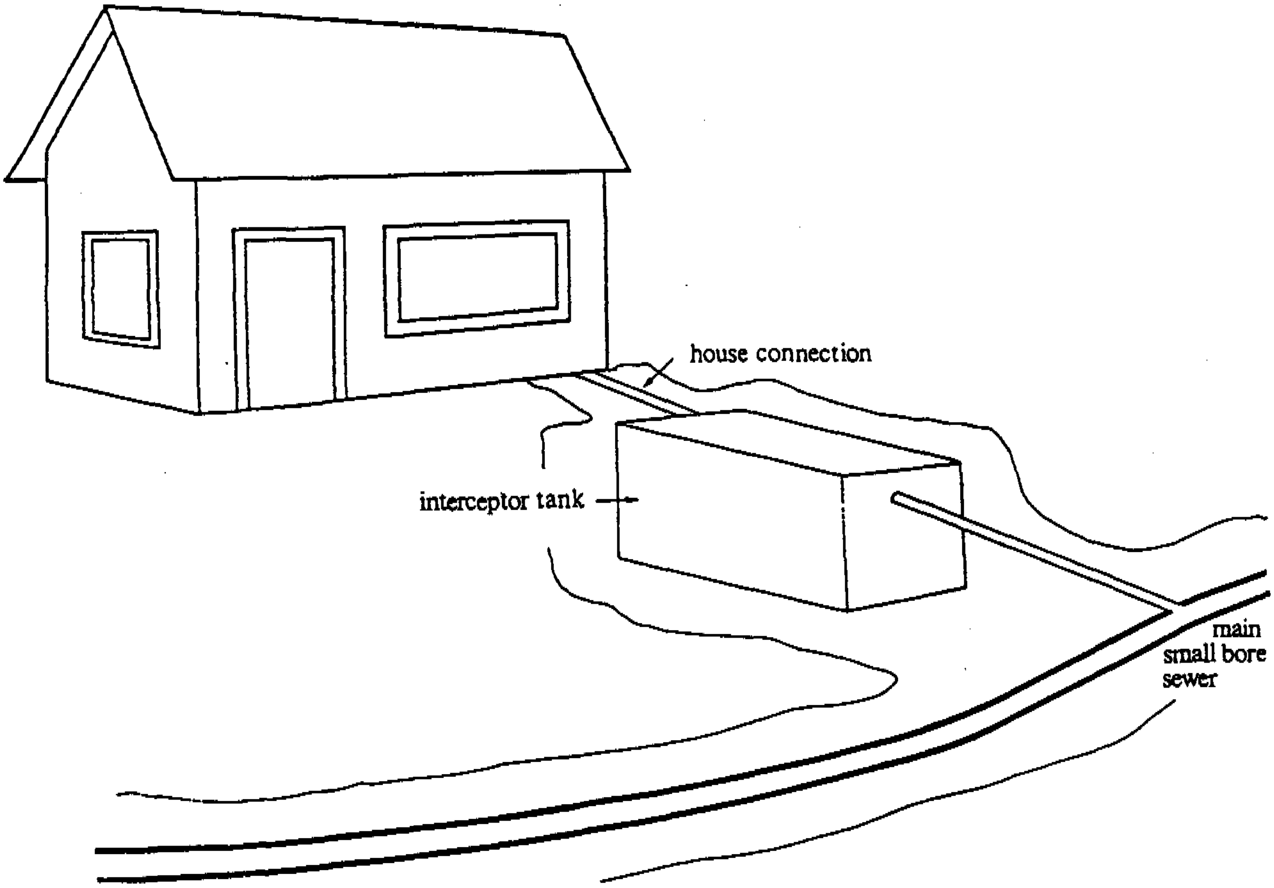


Fig 7.38 (WB, 86)

Figure 2: Functions of the Interceptor Tank

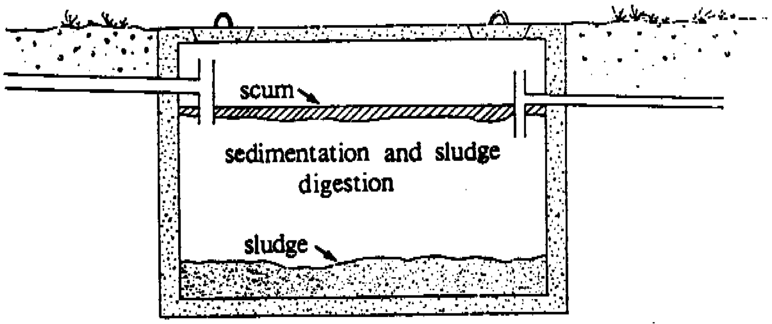


Fig 7. 39 (WB, 86)

Figure 3.: Placement of Inlet and Outlet in the Interceptor Tank

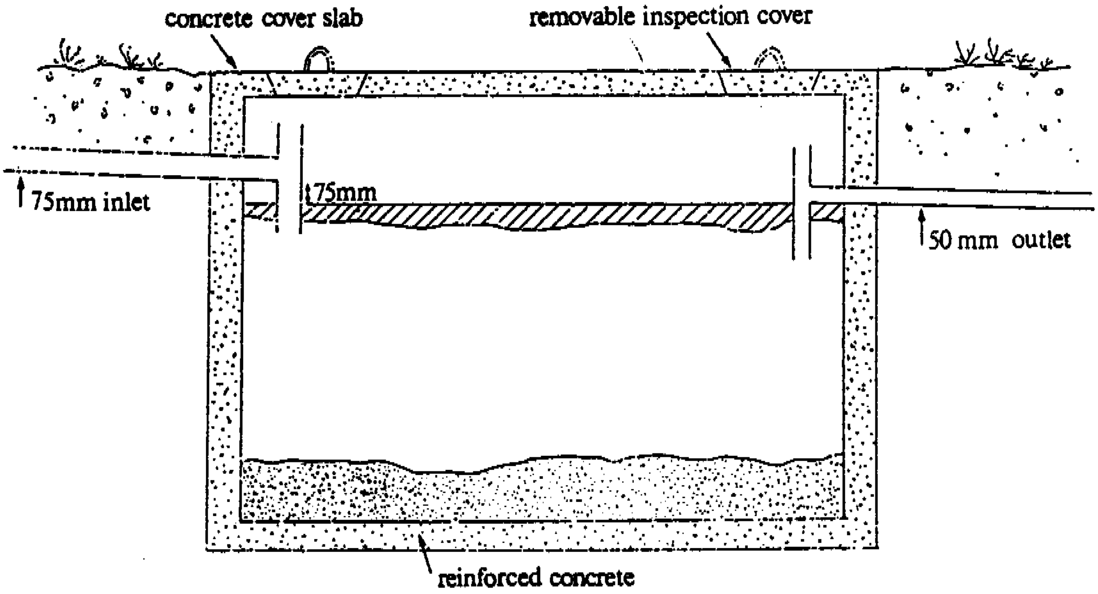


Fig 7.40 (WB, 86)

Figure 1: The Three Types of Waste Stabilization Ponds

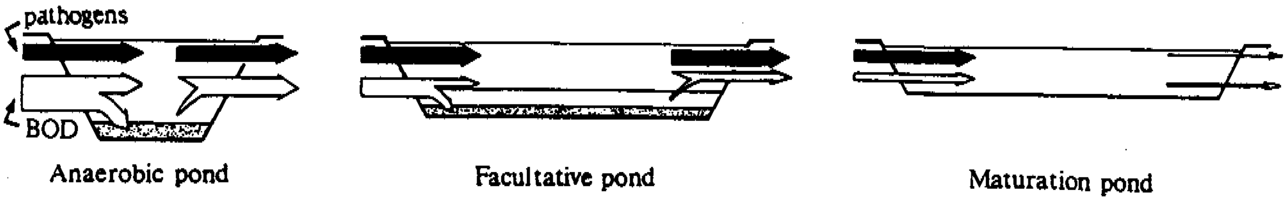


Fig 7.41 (WB, 86)

Figure 2: The Symbiotic Relationship between Algae and Bacteria

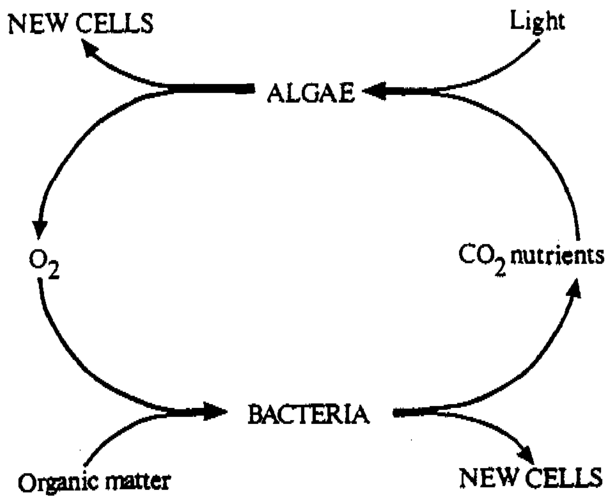


Fig 7.42 (WB, 86)

Figure 3: Example of a Waste Stabilization Pond Layout[1]

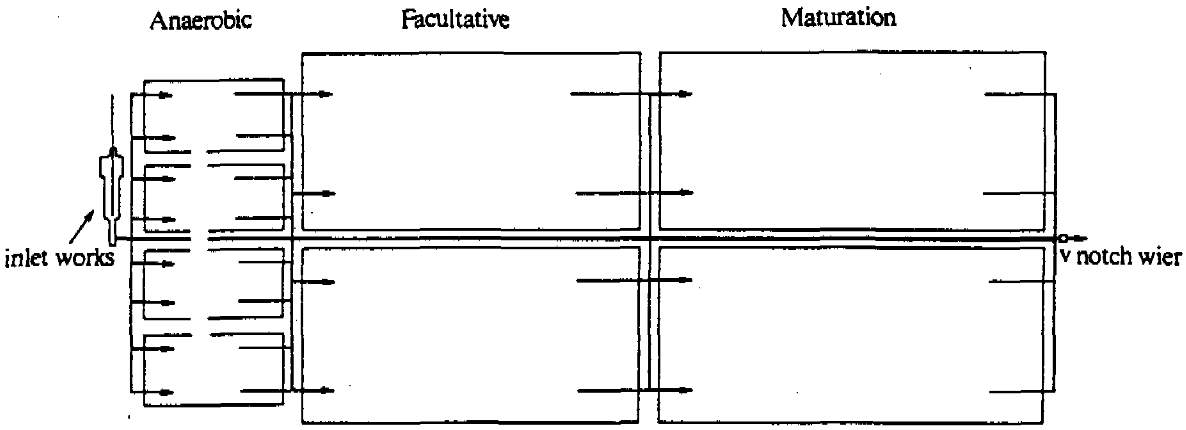


Fig 7.43 (WB, 86)

REFERENCES

Adeniyi, J.D., Brieger, W.R., et al, 1983 : "Guidelines for Health Promotion and Health Education in Community Water and Sanitation Programmes", University of Ibadan, Ibadan, Nigeria.

Adrianzen, T. & Graham,G.G., 1974 : "The High Cost of Being Poor : Water", in *Archives of environmental Health*, **28** : 312–315.

Assar, M., 1971 : "Guide to Sanitation in Natural Disasters", World Health Organization, Geneva.

Baars, J. K., 1957 : "Bulletin of World Health Organization, vol **16**, No. 727.

Barke, M. and O'Hare, G., 1991 : "The Third World : Diversity, Change and Interdependence", 2nd Edition, published by Longman Group, UK.

Blankwaardt, B., 1984 : "Hand Drilled Wells : a Manual on Siting, Design, Construction and Maintenance", TOOL Foundation, Amsterdam.

Blum, D. and Feachem, R. G., 1992 : "Measuring the Impact of Water Supply and Sanitation Investments on Diarrhoeal Diseases : Problems of Methodology", *International Journal of Epidemiology*, **12**, 357–365.

Brush, R.E., 1979 : "Wells Construction : Hand Dug and Hand drilled, Peace Crops, Washington, DC.

Cairncross, S., 1990 : "Water Supply and the Urban Poor", in *The poor die young : housing and health in Third World cities*, edited by Hardoy, J.E. et al., Earthscan publications, London, pp 109–126.

Cairncross, S. and Feachem, 1993 : "Environmental Health Engineering in the Tropics", 2nd edition, John Wiley & Sons, UK.

Cairncross, S. and Kinnear, J., 1991 : "Water Vending in Urban Sudan", *Water Resources Development*, **7**, 267–273.

Cairncross, Carruthers, Curtus, Feachem, Bradley and Baldwin, 1980 : "Evaluation for Village Water Supply Planning", John Wiley, London.

Charnock, G., 1984 : "Patna Project Pays Off", *World Water*, January, 1984.

Churchill, A., et al, 1987 : "Rural Water Supply and Sanitation : Time for a Change", World Bank Discussion Paper No 18, World Bank, Washington DC.

Cleasby, J.L., 1972 : "Filtration", in *Physicochemical Processes for Water Quality Control*, edited by Weber, W.J., John Wiley, new York.

DeMaeyer, E. and Adiels-Tegman, M., 1985 : "The Prevalence of Anaemia in the World", *World health Statistics Quarterly*, **38**, 302.

Doornkamp, J. C., 1982 : "The Physical Basis for Planning in the Third World I, II and III", *Third World Planning Review*, vol. 4(1), pp 11–30.

Esrey, S.A., et al., 1990 : "Health Benefits from Improvements in Water Supply and Sanitation : Survey and Analysis of the Literature on Selected Diseases". *WASH technical report No. 66*, USAID, Washington, DC.

FAO, 1977 : "Self-help Wells", Irrigation and drainage paper No. 30, Food and Agriculture Organization, Rome.

Feachem, R.G., Bradley, D.J., Garelick, H., & Mara, D.D., 1983 : "Sanitation and Disease : Health Aspects of Excreta and Wastewater Management" published for the World Bank by John Wiley & Sons.

Glossary, 1981 : "Glossary : Water and Wastewater Control Engineering", Prepared jointly by APHA, ASCE, AWWA, WPCF.

IDRC, 1981 : "Rural Water Supply in China", International Development Research Center, Ottawa.

IRC, 1979 : "Public Standpost Water Supplies : A Design Manual", Technical paper 14, International Reference Center for Community Water Supply and Sanitation, The Hague, The netherlands.

IRC, 1983 : "Small Community Water Supplies", Technical paper 18, International Reference Center for Community Water Supply and Sanitation, The Hague, The netherlands.

IRC, 1986 : "Renewable Energy Sources for Rural Water Supply", Technical paper 23, International Reference Center for Community Water Supply and Sanitation, The Hague, The netherlands.

IRC, 1987 : "Slow Sand Filtration for Community Water Supply", Technical paper 24, International Reference Center for Community Water Supply and Sanitation, The Hague, The netherlands.

IRC, 1992 : "Water Harvesting : A Guide for Planners and Project Managers", Technical paper 30, International Reference Center for Community Water Supply and Sanitation, The Hague, The netherlands.

Islam, A.K.M.Nurul, 1992 : "Impact of Greater Dhaka Flood Protection Embankment on Domestic Waste Disposal and Environment", a report submitted to the United Nations Center for Regional Development (UNCRD), Japan.

IWES, 1983 : "Water Practice Manuals, Part 3, Water Supply and Sanitation in Developing Countries", edited by Dangerfield, B.J., compiled and published by The Institution of Water Engineers and Scientists, London.

JWWA, 1990 : "Suido Shisetsu Sekkei Shishin : Kaisetsu" (in Japanese), Japan Water Works Association.

Kalbermatten, J.M., Julius,D.S., Mara., D.D., & Gunnerson, C.G., 1980 : "Appropriate Technology for Water Supply and Sanitation : A Review of the Technical and Economic Options", World Bank, Washington, USA.

Kalbermatten, J.M., Julius,D.S., Gunnerson, C.G. & Mara, D.D., 1982 : "Appropriate

Sanitation Alternatives : A Planning and Design Manual", World Bank, Washington, USA.

Kitawaki, H., 1993 : "Jokaso — Privately Owned Wastewater Treatment Plant", INTEP Newsletter, No. 1, Published by International Environmental Planning Center, Dept. of Urban Eng., The University of Tokyo, Japan.

L'Lvovich, M.I. & White, G.F., 1990 : "Use and Transformation of terrestrial water systems", in *The earth transformed by human action : global and regional changes in the biosphere over the past 300 years*, edited by, Turner, B.L., Cambridge University Press, Cambridge, UK.

Macdonald, O.J.S., 1952 : "Small Sewage Disposal systems", London.

Meigs, P., 1953 : "World Distribution of Arid and Semi-arid Homoclimates", *Reviews of Research on Arid Zone Hydrology*, pp 203–10, UNESCO Arid Zone Programme 1, UNESCO.

Morgan, M.T., 1993 : "Environmental Health", Published by Brown & Benchmark Publishers, USA, Australia, England.

Nigam, A., 1993 : "How to Improve Cost Effectiveness of Water and sanitation Programs", presented in a workshop entitled *Planning for health and socio-economic benefits from water and sanitation programmes*, organized by UNICEF, held in New York, USA.

OECD, 1995 : "Development Co-operation", Organization for Economic Co-operation and Development, Paris, France.

Pacey, A., 1977 : "Handpump Maintenance", Intermediate Technology Publications, London.

Pickford, J., 1977 : "Water Treatment in Developing Countries", in *Water, Wastes and Health in Hot Climates*, edited by Feachem, McGarry and Mara, published by John Wiley, London, pp 162–191.

Reed, A., 1989 : "The Developing World", 2nd Edition, published by Unwin Hyman Ltd., London, UK.

SABESP/CNEC, 1986 : "Master Plan for the Utilization of the Hydraulic Resources for the Sao Paulo Metropolitan Area", Sao Paulo, Brazil.

Saito, Masaru, 1980 : "Appropriate Technology for Development -- from the field of Japanese international cooperation", Diamond Corp., Japan. (in Japanese)

Salvato, J.A., 1992 : "Environmental Engineering and Sanitation", 4th ed., John Wiley & Sons, New York, USA.

Seager, J., 1990 : "The State of the Earth", published by Unwin Hyman Ltd., London, UK.

Sinnatamby, G, 1990 : "Low Cost Sanitation", in *The poor die young : housing and health in Third World cities*, edited by Hardoy, J.E. et al., Earthscan publications, London, pp 127–167.

Snyder, J.D. and Mason, M.H., 1982 : "The Magnitude of the Global Problem of Acute Diarrhoeal Disease : a Review of Active Surveillance Data", *WHO bulletin*, 60:605-613.

TAG, 1985 : "The Design of Small Bore Sewer Systems", by Otis and Mara for UNDP-WB Technology Advisory Group (TAG), TAG technical Note No. 14, published by The World Bank, Washington, USA.

Todaro, M.P., 1977 : "Economics for a Developing World", published by Longman, Hong Kong.

Trewartha, G. T., 1954 : "An Introduction to Climate", McGraw Hill, Inc.

Twort, A.C., Hoather, R.C. and Law, F.M., 1985 : "Water Supply" 3rd edition, Edward Arnold, london.

UNCHS, 1989 : "The Conservation of Drinking-water Supplies; Techniques for Low-income Settlements", United Nations Center for Human Settlements, Nairobi.

UNDP, 1984 : "Rural Water Supply Handpumps", *UNDP project management report No. 4*, World Bank-UNDP water and sanitation program, Washington, USA.

UNDP, 1991 : "Human Development Report, 1991", for United Nations Development Program, New York, USA, published by Oxford University Press.

UNDP, 1995 : "Human Development Report, 1995", for United Nations Development Program, New York, USA, published by Oxford University Press.

UNEP, 1986 : "The State of the Environment, 1986, Environment and Health", United Nations Environment Program, Nairobi, Kenya .

UNICEF & UNEP, 1990 : "Children and the Environment", United Nations Children's Fund and United Nations Environment Program.

UNICEF, 1988 : "Redirecting Adjustment Programmes Towards Growth and the Protection of the Poor : The Philippine Case", in *Adjustment with a human face, Vol. 2, Country case studies*, edited by Cornia, et al., Clarendon Press, Oxford, UK.

UNICEF, 1989 : "The State of the World's Children 1989", Oxford University Press, UK.

Wagner, and Lanoix, 1959 : "Water Supply for Rural Areas and Small Communities", WHO monograph No. 42, World Health Organization, Geneva.

Warford, J.J. & Julius, D.S., 1979 : "Water Rate policy : Lessons From Less Developed Countries", *Journal of American Water Works Association*, **77**, 199-203.

Watt, and Wood, 1977 : "Hand Dug Wells and Their Construction", Intermediate Technology Publications, London.

Watt, S.B., 1978 : "Ferrocement Water Tanks and Their Construction", Intermediate Technology Publications, London.

WCED, 1987 : "Our Common Future", for World Commission on Environment and Development, published by Oxford University Press, Oxford, UK.

White, G.F., et al., 1972 : "Drawers of Water : Domestic Water Use in East Africa", University of Chicago Press, Chicago.

Whittington, D., et al, 1989 : "The Value of Time Spent on Collecting Water; Some Estimates for Ukunda, Kenya", Report INU 46, World Bank, Washington, USA.

WHO, 1958 : "Excreta Disposal for Rural Areas and Small Communities", Wagner & Lanoix, WHO monograph series No. 39, World Health Organization, Geneva.

WHO, 1982 : "Rural Water Supplies", EURO Reports and Studies 87, World Health Organization, Regional Office for Europe, Copenhagen.

WHO, 1982b : "Appropriate Technology for the Treatment of Wastewaters for Small Rural Communities", EURO Reports and Studies 90, World Health Organization, Regional Office for Europe, Copenhagen.

WHO, 1983 : "Minimum Evaluation Procedure (MEP) for Water Supply and Sanitation Projects, World Health Organization, Geneva.

WHO, 1984 : "World Health Statistical Annual", World Health Organization, Geneva.

WHO, 1986 : "Intersectoral Action for Health", World Health Organization, Geneva.

WHO, 1987 : "Technology for Water Supply and Sanitation in Developing Countries" report of a WHO study group, Technical report series 742, World Health Organization, Geneva.

WHO, 1990 : "The Impact of Development Policies on Health", a review of the literature by Weil, Alicbusan, Wilson, Reich and Bradley, World Health Organization, Geneva.

WHO, 1990b : "Handbook of Financial Principles and Methods", a document by WHO working group on cost recovery, WHO/CWS/90.10, World Health Organization, Geneva.

WHO, 1991 : "Environmental Health in Urban Development", WHO technical report series 807, World Health Organization, Geneva.

WHO, 1992 : "Our Planet, Our Health", report of the WHO commission on Health and Environment, World Health Organization, Geneva.

WHO, 1995 : "The World Health Report, 1995", World Health Organization, Geneva.

Winblad, U. & Kilama, W., 1985 : "Sanitation Without Water", published by MacMillan Education Ltd., London, UK.

World bank, 1983 : "Notes on the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries", by Arthur, J., World Bank Technical Paper No. 7, The World Bank, Washington, USA.

World Bank, 1986 : "Information and Training for Low-cost Water Supply and Sanitation", a training module published by The world Bank, Washington, DC, USA.

World Bank, 1989 : "World Development Report 1989", The International Bank for Reconstruction and Development / The World Bank, Washington, USA.

World Bank, 1991 : "Urban Policy and Economic Development : an Agenda for the 1990s", The World Bank Group, Washington, USA.

World Bank, 1994 : "World Development Report 1994", The International Bank for Reconstruction and Development / The World Bank, Washington, USA.

World Bank, 1995 : "World Development Report 1995", The International Bank for Reconstruction and Development / The World Bank, Washington, USA.

World Resources Institute, 1988 : "World resources 1988–89", Basic Books, New York, USA.

World Resources Institute, 1990 : "World resources 1990–91", Oxford University Press, Oxford, UK.