BASIC ENVIRONMENTAL HEALTH

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6

WATER AND SANITATION

LEARNING OBJECTIVES

After studying this chapter you will be able to do the following:

- discuss the importance of clean water as a determinant of health and discuss the nature and extent of waterborne diseases
- list the major sources of water contamination
- discuss how drinking-water criteria are developed
- outline the various approaches to prevention of water-related environmental health problems and the debates associated with implementation strategies

CHAPTER CONTENTS

WHY WATER IS ESSENTIAL

Water (or liquids based on water) is essential for basic survival (see Chapter 1). When a person has nothing else to drink, even poor-quality water must be consumed to stave off death through dehydration. The relief may only be temporary since contaminated water can spread disease and cause poisoning. People and animals drink water but they also bathe in it and depend on it to grow crops. Every person on earth requires about 2 liters of clean drinking water each day, which amounts to 12 million m^3/day for the world's population. Animal consumption is considerably larger, but animals do not require the same quality of water needed for human consumption. Most of the world's fresh water is used for irrigation: 70% of fresh water is used daily. As the world population increases, the demand for drinking water and irrigation will grow. Water is also used in the generation of hydroelectric and thermoelectric power. Dammed reservoirs provide the gravity-driven force that turns turbines to produce electricity (energize dynamos). Water also acts as a coolant for nuclear and coal/oil power stations. Industry uses significant amounts of water, particularly in the production of paper, petroleum, chemicals, and primary metals. Attempts have been made in these industries to cut back on water consumption through reuse of water, as well as through new processing methods. Water is used for the transportation of goods and people, as a means of recreation through swimming and boating, and as a natural habitat for many forms of fish and wildlife. Seawater is also used to produce salt. The quality requirements for different water uses vary and the impact on water quality varies with the type of use (see Box 6.1).

This chapter will emphasize the health hazards related to contaminated drinking water and lack of proper sanitation. Lack of good-quality water is a key problem in economic development in many parts of the world. In dry parts of the world, lack of water sources is complicated by the poor quality of what is available. The term *water privation diseases* comprises those health problems that occur because of lack of water.

WATER QUALITY, SANITATION, AND HEALTH

Communicable Diseases Associated with Water

Bacteria, viruses, and parasites can spread by water and cause disease. These agents of disease are called *pathogens*. Most of these diseases are considered communicable because they can spread from one person to another via contaminated water or other vectors. The water is a vehicle for spread of the pathogens and other environmental health hazards. The most common diseases of this type are diarrheal diseases, such as cholera, typhoid, paratyphoid, salmonella, giardiasis, and cryptosporidiosis (Box 6.2; see Chapter 2). The minimal infectious dose (the number of bacteria required to make a person ill) is much lower for cholera than for the other diseases, so cholera can spread even via water that looks reasonably clean. The feces of an ill person with cholera or carrier contain large numbers of pathogenic organisms and the contamination of drinking water by feces creates the opportunity for spread of the disease to another person. Many of the communicable diseases that spread via water can also spread via food (see Chapter 7). Successful prevention would have to address both exposure routes. A person does not even need to drink the water to get diseases associated with it. In schistosomiasis, a parasitic tropical disease, for instance, the parasite enters the human body through the skin and causes disease after being transported inside the body to the target organs—the gut and the urinary bladder (Box 6.2).

BOX 6.1

Water Use and Water Quality

Uses affecting water quality:

- Municipal — sewage discharge, storm water run-off
- Agricultural — manure disposal, agrochemicals, drainage water discharge
- Industrial — wastewater effluents, cooling water discharge, acid mine drainage

Uses limited by water quality:

- Municipal — drinking, domestic and public uses
- Agricultural — domestic farm supply, livestock watering, irrigation
- Industrial — food and other processing, boiler feeding, cooling, mining
- Recreational — swimming and other water-contact sports, aesthetic enjoyment, fishing
- Aquatic life — aquatic and wildlife, fish, swamp and wetland habitat, aquaculture

Uses less or not at all affected by water quality, and with usually less impact on water quality:

- Commercial — hydropower generation, navigation
- Recreational — boating, landscape watering

Source: WHO/UNEP, 1989.

A flowing body of water partially cleans itself. Dissolved oxygen, clay and soil particles, and living organisms in the water all play an important role in the process. Flowing water can dilute, oxidize, and remove pathogens as long as its capacity is not exceeded and sufficient time elapses before water is withdrawn downstream for human use. When the population density of a given area places intense pressure on water resources, this self-purifying capability of water is exceeded. Bodies of water that have their natural flowing properties removed, as, for example, through damming, are much less able to cleanse themselves.

According to *Agenda 21*, the United Nations Program of Action from the Rio Conference in 1992 (UN, 1993), 80% of all diseases and over one-third of deaths in developing countries are caused by consumption of contaminated water. As much as one-tenth of every person's productive time is sacrificed to water-related diseases (UN, 1993). An estimated 1.4 billion people still do not have access to safe drinking water and 2.9 billion do not have access to adequate sanitation (UN 1997), and according to the World Resources Institute (WRI, 1998) this inadequate access to water and sanitation contribute to 2.5 million childhood deaths each year from diarrhea. Most pathogens come from animal or human feces, a result of insanitary excreta disposal. Inadequate water supply plays an equally important role in the spread of disease. Most diseases that are water-

BOX 6.2

Three Diseases Associated with Water

Cryptosporidiosis is a diarrheal disease caused by the protozoan *Cryptosporidium parvum.* As a result of a number of waterborne outbreaks of cryptosporidiosis in developed countries in the last 5 to 10 years (such as one in Milwaukee, Wisconsin, USA, in 1993, in which 400,000 people fell ill and 100 died), there has been renewed interest in the epidemiology of this emerging infectious disease. While much is still not known about this microorganism, waterborne transmission and person-to-person transmission may play an important role. For most healthy persons, infection leads to self-limiting watery diarrhea with or without nausea, vomiting, and abdominal cramping. Symptoms may last 1 to 2 weeks. However, immunocompromised people, those with AIDS, on immunosuppressant drugs, or vulnerable otherwise, may not be able to fight the infection. Cryptosporidiosis may represent a lethal disease to this population.

Schistosomiasis, otherwise known as *snail fever,* or *bilharzia,* is an infection caused by a blood fluke (trematode). Major species infecting humans include *Schistosoma mansoni, S. japonicum,* and *S. haematobium.* Infection is acquired by contact with water containing cercariae, the free-swimming larval form that has developed in snails. The cercariae burrow into the skin of susceptible hosts, enter the bloodstream, migrate to the liver, and ultimately reside in veins of the abdominal cavity. The adult male and female worms can reside in the mesenteric or vesical veins of the host for many years. Signs and symptoms are to a certain degree related to the species of infecting worm, but may include bloody urine, abdominal pain, or diarrhea. The larvae of certain schistosomes of birds and mammals may penetrate the human skin and cause a dermatitis, sometimes known as *swimmers itch.* These schistosomes, however, do not mature in humans and therefore do not cause serious disease.

Giardiasis is a protozoan infection caused principally by *Giardia lamblia, G. intestinalis,* or *G. duodenalis.* While often asymptomatic, infection may cause abdominal cramping, diarrhea, fatigue, and weight loss. Infection may be acquired by ingestion of fecally contaminated food or water, or by hand-to-mouth transfer of cysts from the feces of infected people. See Chapter 7 for additional information.

Sources: Meinhardt et al., 1996; Benenson, 1995.

borne may also be transmitted by person-to-person contact, aerosols, and food intake; thus, a reservoir of the bacteria is maintained in the people carrying the disease and a sick individual may contaminate water or food supplies and thus continue disease transmission (WHO, 1993a). Some people get infected but do not get the disease symptoms. These people may become carriers of the disease. One of the most famous carriers, known as "Typhoid Mary," lived in New York (Federspiel, 1983). An Irish immigrant who was infected with typhoid around 1900 but did not become ill herself. Instead she became a carrier of the disease because the bacteria lodged permanently in her gallbladder and constantly passed into her gastrointestinal tract. Mary, a kind and well-liked woman, repeatedly took jobs as a food preparer because she did not believe that she could spread disease. By the time she was put in permanent custody by public health authorities in 1915, she had infected at least 47 people and three had died. At the time, it has been estimated that there were at least 200 such carriers in New York City alone!

Most diseases associated with water are caused by pathogens. These diseases are traditionally classified according to the nature of the pathogen. However, such a classification is not very useful for prevention. As explained in *Our Planet, Our Health* (WHO, 1992a), a more useful way of classifying these diseases is according to the various aspects of the environment that human intervention can alter, hence this classification will be used here.

Waterborne Diseases These arise from the contamination of water by human or animal feces or urine infected by pathogenic viruses or bacteria, which are directly transmitted when the water is drunk or used in the preparation of food. Cholera (see Box 6.3), typhoid, and cryptosporidiosis are typical examples of waterborne diseases.

Water-Privation Diseases This category of diseases is affected more by the quantity of water rather than by quality. These diseases spread through direct contact with infected people or materials contaminated with the infectious agent. Infrequent washing and inadequate personal hygiene are the main factors in these types of diseases, such as certain types of diarrheal diseases, helminths, and skin and eye infections.

Water-Based Diseases In these diseases, water provides the habitat for intermediate host organisms in which some parasites pass part of their life cycle. These parasites are later the cause of disease in people as their infective larval forms in fresh water find their way back to humans, either by boring through wet skin or by being ingested with water plants, minute water crustacea, or raw or inadequately cooked fish. Schistosomiasis is an example of a water-based disease.

Water-Related Diseases Water may provide a habitat for insect vectors of water-related diseases. Mosquitoes breed in water and the adult mosquitoes may transmit parasite diseases, such as malaria, and virus infections, such as dengue, yellow fever, and Japanese encephalitis.

Water-Dispersed Infections The disease categories listed above are primarily problems in developing countries. A fifth category of diseases associated with water is emerging in developed countries—infections whose pathogens can proliferate in freshwater and enter the body through the respiratory tract. Some freshwater amoebae that are not usually pathogenic can proliferate in warm water, and if they enter the host in large numbers, they can invade the body along the olfactory tracts and cause fatal meningitis. These bacteria can be dispersed as aerosols from air-conditioning systems; an example of this type of disease is Legionella (WHO, 1992a).

BOX 6.3

Latin American Cholera Epidemic

Cholera is one of humankind's oldest diseases and one of the best-known waterborne diseases. Drinking water that has been contaminated at the source or during storage is the most common source of infection. Any foods that have been taken from contaminated water (fish, shellfish) or washed with it (fruit, vegetables) are also important sources of infection. Severe diarrhea and vomiting are the main symptoms of cholera. The diarrhea is so severe and rapid that patients suffer severe loss of liquid. The main treatment is therefore intravenous or oral liquid rehydration, which prevents the patient from becoming fatally dehydrated. About 90% of cholera cases are mild and difficult to distinguish clinically from other types of acute diarrhea.

The first cholera epidemic in Latin America since the turn of the century began in Peru and quickly spread to a number of neighboring Latin American countries, spreading as far north as the United States. Peru was hardest hit by the disease with a total of close to 300,000 cases reported by January 1992. The spread of disease during the initial period, by February 1992, and by March 1993, is shown in Figure 6.1.

In assessing what had led to the devastating cholera outbreak in Peru, a number of factors were identified: (*a*) urban water supplies were operated on an intermittent basis and thus subject to contamination from leaks, back siphoning, and

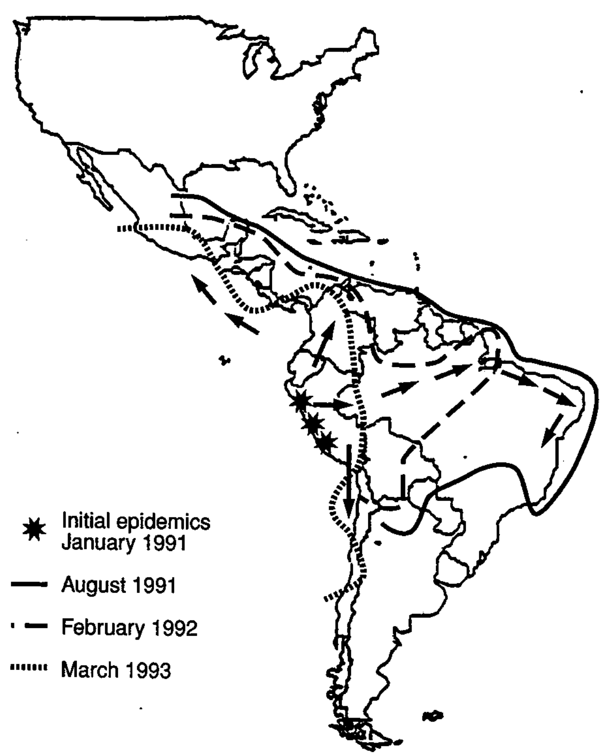

Figure 6.1 Geographic extent of the Latin American cholera epidemic over time. From Hug and Colwell, 1996, with permission.

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cross connections; (*b*) most households had inadequate hygiene practices related to water storage; (*c*) in periurban areas most households were not connected to the piped water or sewage systems; (*d*) organized garbage and solid waste storage, collection, and disposal were nonexistent in the periurban areas and inadequate in many of areas of the central city; and (*e*) among the poor, fundamental health and sanitation practices were often not applied. A WHO document released following the outbreak outlined a number of guidelines for controlling cholera. These include providing a safe water supply, properly disposing of human waste and educating communities about how to prepare safe water at home (WHO, 1993b).

Chemical and Radioactive Constituents of Water

Some chemical substances dissolved in water as a result of natural processes may be essential ingredients of dietary intake, and some may be dangerous to health when they occur above certain concentrations. Others have both properties simultaneously. To assess the health impact of all of these substances, the Global Environment Monitoring System (GEMS), discussed further in Drinking-Water Supply and Monitoring (below), classifies chemicals in drinking water into three typical categories:

1. Substances (various metals, nitrates, cyanides) that exert an acute and/or chronic toxicity when consumed. As the concentration of these substances in the drinking water increases, so does the severity of the health problem; below a certain threshold concentration, however, there are no observable health effects.

2. Genotoxic substances (synthetic organics, many chlorinated microorganics, some pesticides, and arsenic) that cause adverse health effects such as carcinogenicity, mutagenicity, and birth defects. There is no threshold level for these substances that would be considered safe, since any amount ingested contributes to an increase in risk.

3. Essential elements (fluoride, iodine, selenium) that are a mandatory part of dietary intake to sustain human health. Deficiencies or high concentrations of these elements cause a variety of adverse health effects (WHO/UNEP, 1989).

Some chemicals present in water are of particular importance with regard to their effect on human health. These include arsenic, fluoride, iodine, and nitrates.

Arsenic Arsenic is naturally present in all lead, copper, and gold ores. Groundwater enriched through the weathering of arsenic-bearing minerals is generally the most important source of arsenic in drinking water. There are several geological areas in Asia, North America, and Latin America where dermatological effects were the first manifestation of groundwater enrichment of arsenic. At chronic poisoning levels, various effects are observed, such as vascular disease, liver disease, skin lesions, skin cancer, and neurological disorders.

Fluoride Fluoride is naturally present in some foods as well as in water, but for the most part, it is the amount provided by drinking water that determines the daily intake. Since fluoride is an important component in bone and tooth structure, it is considered an essential element. It is also a toxic chemical. Only a relatively narrow range of fluoride concentrations in drinking water provides optimal conditions. Too-low levels of fluoride increase the incidence of dental caries whereas elevated levels cause mottling of the teeth as well as skeletal fluorosis. Fluoride is added to drinking water in some countries to improve dental health.

Iodine Water is one of the main sources of dietary intake of iodine. In areas where there is very low concentration of groundwater iodine, resident populations suffer from iodine deficiencies resulting in an enlargement of the thyroid gland (goiter) and, in severe cases, mental retardation and cretinism.

Nitrates Excessive and widespread application of nitrogenous fertilizers and manure spraying are the main sources of elevated nitrate concentrations in groundwater. High levels of nitrates in drinking water are of concern because they may lead to serious, even fatal consequences in infants below 6 months of age. Nitrates are reduced to nitrites and, once absorbed, combine with hemoglobin to form methaemoglobin, which is unable to bind with oxygen and therefore transport it from the lungs to the tissues (WHO/UNEP, 1989). The nitrate concentration in selected river systems is shown in Figure 6.2 (WHO, 1992a). With time there is an apparent increase in concentration in many of these rivers.

Other Aspects of Water Quality

Color The color of drinking water is usually due to the presence of colored organic matter associated with the humus fraction of soil. Color is influenced by the presence of iron (usually rusty brown) and other metals—this may be caused

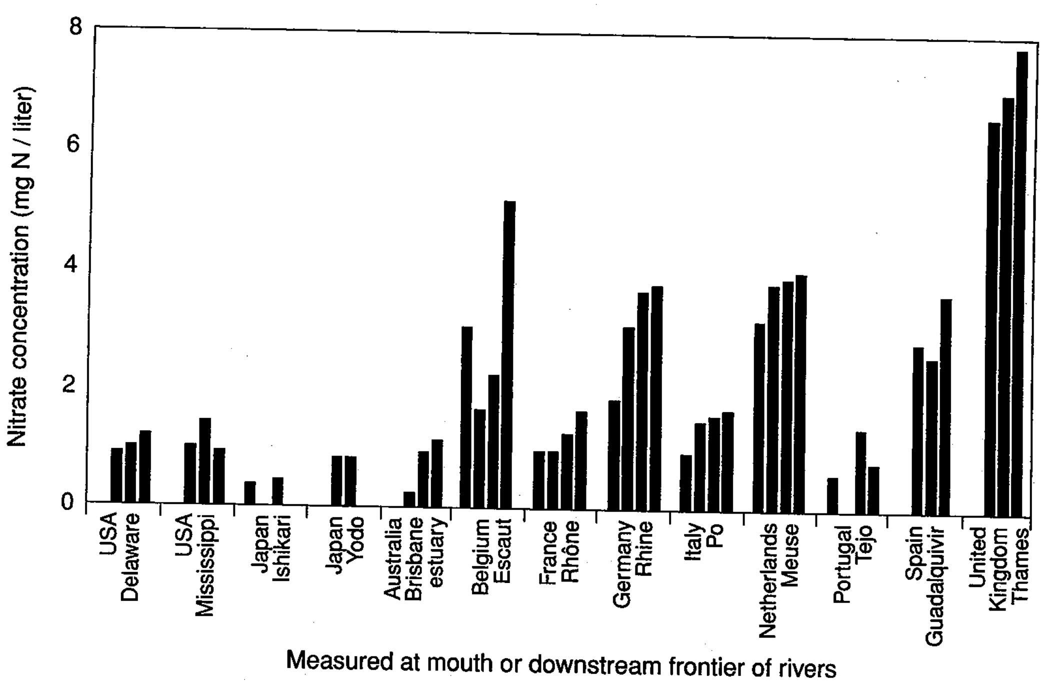

Figure 6.2 Nitrate concentrations in selected rivers: 1970, 1975, 1980, and late 1980s. From WHO, 1992a, with permission.

by natural impurities or may be a signal of corrosion products. It may also result from the contamination of the source with industrial effluents, which could indicate a hazardous situation.

Taste and Odor Taste and odor originate from natural and biological sources, from contamination by chemicals, or as a side effect of water disinfection. Taste and odor may develop during storage and/or distribution. Any deviations in taste and odor may indicate some sort of pollution or malfunction with the storage or distribution systems.

Temperature The temperature at which water is consumed is very much a matter of personal preference. Generally, cool water is more palatable than warm water. High-temperature water enhances the growth of microorganisms and may increase taste, odor, color and corrosion problems.

Turbidity Turbidity in water is caused by particulate matter that may be present as a consequence of inadequate treatment or the presence of inorganic particulate matter in some groundwater. High turbidity levels can protect microorganisms from the effects of disinfection and can stimulate bacterial growth.

Although deviations in the physical characteristics of drinking water may be harmless, any significant changes over time should be investigated, as these may indicate potentially hazardous situations.

ADEQUACY OF FRESHWATER SUPPLY TO MEET THE WORLD'S NEEDS

Adequacy of Supply

Freshwater quality and quantity are inextricably linked. There is sufficient freshwater worldwide to meet human demands at present and in the foreseeable future, but because of uneven distribution of groundwater, surface water, and rainfall, many arid and semi-arid parts of the world lack reliable sources. Of all the world's water, 97% is in oceans or lakes. Of the remaining 2.53%, by far the largest part, 69%, is in the form of snow and ice. The available liquid fresh surface water upon which most communities depend accounts for only 0.008 (2.53% × 0.34) (see Fig. 6.3).

Sources of freshwater include rivers, lakes, and groundwater. The last three centuries have witnessed a significant growth in the volume of water being withdrawn from these sources, an increase of more than 35 times compared to a sevenfold increase of the population. In recent decades, there has been a further increase in water withdrawal, with the highest rates of growth occurring in developing countries. The main increase in water withdrawal is for agricultural purposes (see Fig. 6.4).

Access to water is at least as important a problem for health as water contamination. Water is distributed very unevenly around the world and those areas with less access have had much greater problems with hygiene and quality of water. The tropics and the mid-level of the Northern Hemisphere has much more potential freshwater available than other parts of the world.

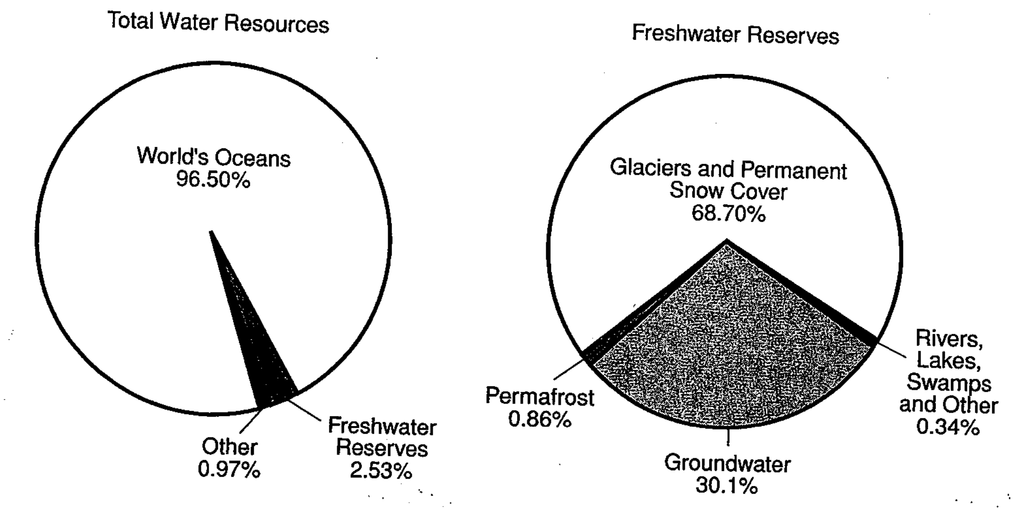

Figure 6.3 Global total water and freshwater reserves. From Shiklomanov, 1993, with permission.

Countries are not simply water-rich or water-poor; there is wide variation within many countries. Calculations based on the level of precipitation per unit of area, for example, are very misleading. Users of water upstream may affect the quality of water available to users downstream. Many countries draw water for sources that come from the territory of other countries, e.g., as Egypt does with the Nile, and The Netherlands does with the Rhine. In the case of Egypt, river inflow provides 50 times more water than does rainfall. The intensity with which local river runoff is used may be a more revealing indicator of water scarcity.

Global Trends

The issue of water scarcity carries many political, legal, and economic implications. Many of the important water basins of the world are shared by more than one country, as in the Great Lakes of Africa and the Aral Sea. The Aral is badly depleted and contaminated on both the Kazakhstan and Uzbekistan sides. It draws

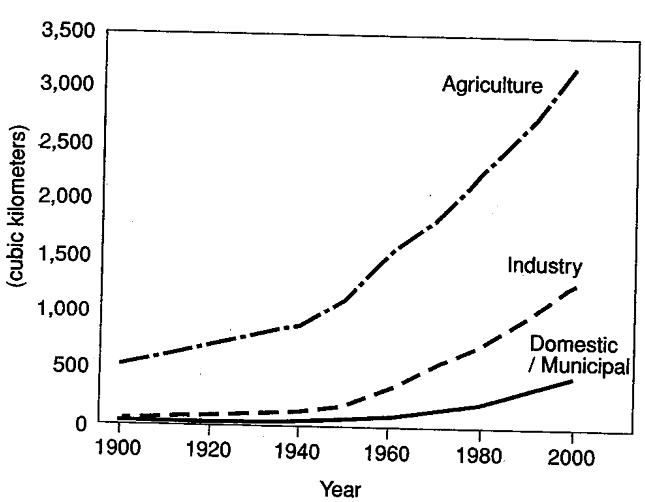

Figure 6.4 Global water withdrawal by sector, 1900–2000. From Shiklomanov, 1993, with permission.

its water from Turkmenistan, Tajikistan, and Kyrgistan and was heavily affected during the days of the Soviet Union by economic decision to benefit Russia. The significance that countries attach to their water resources is reflected in the existence of over 2000 treaties relating to water basins, such as the Great Lakes Compact between Canada and the United States. The first modern treaty on joint environmental management was conducted over the Baltic. In many areas of the world, agreements on sharing water resources are inadequate or do not exist. An example is the Nile Waters Agreement of 1959, an Egyptian and Sudanese attempt to distribute the flow of that river that did not take into account the requirements and demands of upstream countries like Ethiopia. Turkey's construction of a system of dams on the Euphrates River is expected to reduce inflow of water to Iraq to as little as 10% of normal flow (WRI, 1994).

Conflict over shared water resources is a reality in many parts of the world. Attempts in Ethiopia to enhance the flow of the White Nile by building a canal to bypass the Sued (a large swamp in Southern Sudan) was one factor that began the civil war in The Sudan. Dispute over control of the headwater of the Jordan River (a basin shared by Syria, Jordan, Lebanon, and Israel) and the possibility that the river might be diverted into the Israeli National Water Carrier helped to spark the 1967 Arab–Israeli war. Danger of conflict continues due to the competing demands for surface and groundwater in the Jordan River basin. Water sharing agreements are expected to be a key issue in any future Middle East peace agreement. When Solvakia and Hungary had a dispute over damming the Danube River, the matter went to the International Court of Justice.

One area that has been seriously affected by water use for irrigation is the Aral Sea river basin. The large-scale cotton-growing projects established in the 1950s eventually used such large quantities of the water in the rivers Amu-Darja and Sur-Darja that the influx of water into the sea was less than the evaporation. The size of the Aral Sea has therefore gradually shrunk and this has seriously affected the living environment, the economy, and the health of the region around this landlocked sea.

Many international development projects have inadvertently affected water resources and have thereby had a negative impact on both the environment and the health of the communities they were trying to assist. This has occurred even though the projects were intended to enhance socioeconomic conditions and the quality of life. Large dams and water reservoirs that were built in Asia and Africa for irrigation or hydropower in the 1960s and 1970s have led to disastrous consequences, with increases in the cases of schistosomiasis, malaria, and Japanese encephalitis. Such projects have even led to the introduction of new diseases in an area, as in the case of intestinal schistosomiasis introduced into the Senegal River delta following the construction of the Diama dam.

Determining Quality of Fresh Water

The quality and quantity of water tend to be closely linked. Where water is scarce, the quality often tends to be poor and the effects of pollution have an even greater impact because there are no alternatives. Over centuries and particularly over the last few decades, the natural quality of water in rivers, lakes, and aquifers has been altered by the impact of various human activities and water uses. Most pollution problems involving water have evolved gradually over time before they became apparent and measurable. The four most important sources of water pollution worldwide are sewage, industrial effluents, storm and urban runoff, and agricultural runoff.

In many developing countries the problem of water pollution has become similar to that in developed countries. In the past, pollution in developing countries resulted primarily from domestic sewage. While sewage remains a source of pollution, the increasing use of pesticides for agriculture and the production of toxic wastes from industry have increased the complexity of water contamination issues. Currently, in some developing countries water pollution is due to domestic sewerage systems or specific pollutants from industry and it is significantly worse than in industrialized countries where there has been a longer history of pollution control activities. Any efforts at the international level to distribute water equitably need to be matched by efforts to combat the pollution of the various water bodies.

Indirect pollution of water from air is also an important factor in water pollution. *Acidification* is due to long-distance air pollution from industry and motor vehicle traffic (see Box 6.4). *Eutrophication* is due to overloading by nutrients (e.g., nitrates and phosphates) from agricultural fertilizers.

Sudden growth of microorganisms in water is called a *bloom.* Blooms of Cyanobacteria (blue-green algae) occur in lakes and reservoirs used for potable supply and can produce different types of toxins. Adverse health effects are known to be caused by these toxins in drinking water and especially in watering holes for livestock. The increased incidence of toxic algae blooms is sometimes the result of pollution, particularly sewage and agricultural runoff, although such blooms can occur naturally in shallow, nutrient-rich bodies of water. There are insufficient data at the present time to form recommended guidelines, but there is a clear need to protect impounded surface-water source from discharges of nutrient-rich effluents.

The problem of maintaining good water quality is particularly acute in urban areas in developing countries. This effort is hampered by two factors: failure to enforce pollution controls at the main point sources and inadequacy of sanitation systems and of garbage collection and disposal. Box 6.5 gives some examples of water pollution in different cities in the developing world.

DRINKING-WATER QUALITY CRITERIA

The WHO *Guidelines for Drinking Water Quality* (WHO, 1993d) are comprehensive in scope and intended to be used as a basis for the development of national standards. Through use of the WHO Guidelines, each country can develop its own standards based on a risk-benefit approach. Standards that are too stringent may have the effect of reducing or limiting available water supplies in some parts of the world. The Guidelines are therefore designed to be realistic, adaptable, and advisory. The overriding priorities in the Guidelines are (in priority order):

1. An adequate supply of water
2. An adequate supply of microbiologically safe water
3. An adequate supply of microbiologically safe water that meets the guidelines for chemical parameters.

BOX 6.4

Water Pollution Related to Development

ACIDIFICATION

Acidification of surface and some groundwater is a slow process that is principally caused by increased atmospheric deposition of inorganic acids. Atmospheric deposition in the form of acid rain occurs worldwide through the chemical reaction of rainwater with sulfur and nitrogen oxides, ions from coal/oil burning, and motor vehicle traffic pollution to air. Increased acidic deposition in some susceptible areas has reduced the pH of lakes so that they no longer support fish or animal life. In addition, the release of metals into lakes and streams from acidified soils presents possible risks to human health and to fish in the lakes.

EUTROPHICATION

Eutrophication can be a natural phenomenon in lakes over long periods of time through which organic material gradually accumulates in the lake basin during the geological history of the lake. Added nutrients such as phosphorus and nitrogen serve to accelerate eutrophication and make it abnormal and destructive to the lake. Increased concentration of these nutrients has been attributed to the discharge of wastewater into lakes, the use of fertilizers, and changes in land use that increase runoff. Eutrophication is an established problem in many lakes and reservoirs in highly populated industrialized countries and is probably the most pervasive water quality problem on a global scale. One of the results of eutrophication is algal bloom, which produces large increases in algae in the water of the lake, some of them producing toxins. Eventually the lake suffering from eutrophication will get clogged up with weeds and become a swamp or peatmarsh.

DIRECT DISCHARGE

Direct discharge of pollutants into water is usually controlled by regulations, although it certainly still occurs. Effluent from a plant may carry waste and the byproducts of industrial processes. Runoff from the plant site may carry chemical contaminant, including oil, into drains and then into waterways. Holding ponds are often used to impound the discharge and to partly decontaminate it before release. Thermal pollution is a special type of discharge in which warm water heats the piercing waters and may cause a situation similar to eutrophication. It is often a problem downstream from power plants.

Source: UNEP, 1993.

Many organisms present in drinking-water supplies have no real health significance but may affect the appearance, taste, and/or odor of the water. These organisms may also be important indicators of defective water treatment and distribution systems.

Frequent monitoring for fecal indicator organisms is an old method of assessing water quality but remains the most sensitive way of assessing the hygienic quality of water. Fecal bacteria that have been chosen as indicator organ-

BOX 6.5

Some Examples of Water Pollution in Selected Cities in Developing Countries

ALEXANDRIA, EGYPT

Most industries in Alexandria discharge untreated liquid wastes into the sea or into Lake Maryut. In the past decade, fish production in Lake Maryut declined by some 80% because of the direct discharge of industrial and domestic effluents. The lake has also ceased to be a prime recreational site because of its poor condition. Similar environmental degradation is taking place along the seafront due to the discharge of untreated wastewater from poorly located sewage pipe outfalls. The paper, textile, and food industries contribute most to the organic load.

BOGOTA, COLOMBIA

The Tunjuelito, a tributary of the Bogota River, is highly polluted. Many tanneries and plastic-processing plants pour untreated wastes into it and the dissolved oxygen in the water is almost depleted. The wastes include heavy metals such as lead and cadmium. Other rivers are not so heavily polluted with chemical wastes but receive large volumes of untreated sewage.

KARACHI, PAKISTAN

The Lyan River, which runs through Karachi, Pakistan's largest industrial city, is an open drain, from both the chemical and the microbiological points of view, for a mixture of raw sewage and untreated industrial effluents. Most industrial effluents come from an industrial estate with some 300 major industries and almost three times as many small units. Three-fifths of the units are textile mills. Most other industries in Karachi also discharge untreated effluent into the nearest water body.

SHANGHAI, CHINA

Some 3.4 m^3 of industrial and domestic waste pour into the Suzhou Creek and the Huangpu River, which flows through the heart of the city. Less than 5% of the city's wastewater is treated, and these rivers have become the main open sewers for the city. Most of the waste is industrial since few houses possess flush toilets. The Huangpu has essentially been dead since 1980. The normally high water table also means that a variety of toxins from industrial plants and local rivers find their way into groundwater and contaminate wells, which also contribute to the water supply.

Source: WHO, 1992a.

isms are present in high numbers in the feces of humans and warm-blooded animals and are readily detectable by simple methods. They do not grow in water itself. The major indicator organisms of fecal pollution are *Escherichia coli*, thermotolerant and other coliform bacteria, the fecal streptococci and sulfite-reducing clostridia. No water intended for human consumption should contain

TABLE 6.1

BACTERIOLOGICAL QUALITY OF DRINKING WATER (WHO GUIDELINES)

Organisms	*Guideline*
ALL WATER INTENDED FOR DRINKING	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample
TREATED WATER ENTERING DISTRIBUTION SYSTEM	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample
Total coliform bacteria	Must not be detectable in any 100 ml sample
TREATED WATER IN DISTRIBUTION SYSTEM	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample
Total coliform bacteria	Must not be detectable in any 100 ml sample. In the case of large supplies where sufficient samples are examined, must not be present in 95% of samples taken throughout any 12-month period

Source: WHO, 1993d.

E. coli in any 100 ml sample. taken. Treated water should not contain total coliform bacteria in any 100 ml sample (Table 6.1). The indicators may or may not be associated with the disease themselves. For example, most *E. coli* do not cause human disease, although some do. The presence of *E. coli*, however, is a reliable indicator of potential contamination by pathogens.

Monitoring Contaminants

It is not practical or necessary to monitor water for all possible chemical contaminants and pathogens. While it is possible to detect the presence of many pathogens in water, the methods of isolation and enumeration are often complex and time consuming. Therefore, rather than monitoring water for every possible pathogen, the more logical approach is to detect organisms normally present in the feces of humans and other warm-blooded animals as indicators of fecal pollution (see Table 6.1). The strategy that works is one that (*a*) identifies episodes of contamination that might carry a significant risk and (*b*) closely monitors a few specific contaminants (such as arsenic) that could cause serious trouble.

The WHO has identified contaminants that are potentially hazardous to human health and those detected relatively frequently and in relatively high concentrations in drinking water. Certain indicator organisms and some 128 chemical contaminants can now be assessed through comparison with guideline values. *The Guidelines for Drinking Water Quality* (WHO, 1993d) apply the following principles:

- A *guideline value* represents a concentration of a constituent that does not result in any significant risk to the health of the consumer over a lifetime of consumption, usually assessed to be at least 70 years.

- Water that meets the criteria defined by the *Guidelines for Drinking Water Quality* is considered to be suitable for human consumption and for all usual domestic purposes, including personal hygiene. However, water of a higher quality may be required for some special purposes, such as renal dialysis. The Guidelines are not necessarily protective for these special applications.
- When a guideline value is exceeded, this should be a signal that something has gone wrong in the protection system. It should trigger certain actions: (*a*) to investigate the cause with a view to taking remedial action, (*b*) to consult with and seek advice from the authority responsible for public health, and (*c*) to take steps to ensure that the break in the system will not happen again.
- Although the guideline values describe a quality of water that is acceptable for lifelong consumption, they should be considered a minimum for acceptability. Guideline values should not be regarded as a target that is sufficient and that does not require improvement. The quality of drinking water should under no circumstances be degraded to the recommended level from a better level. Indeed, a continuous effort should be made to maintain drinking-water quality at the highest possible level.
- Short-term deviations above the guideline values do not necessarily mean that the water is unsuitable for consumption. The amount by which, and the period for which, a particular guideline value can be exceeded without affecting public health depends upon the specific substance involved and the degree of the deviation.
- It is recommended that when a guideline value is exceeded, the surveillance agency (usually the authority responsible for public health) should be consulted for advice on suitable action. The significance of an excess level may depend in part on the total intake of the substance from all sources, taking into account the intake of the substance from sources other than drinking water (for chemical constituents), the toxicity of the substance, the likelihood and nature of any adverse effects, the practicability of remedial measures, and similar factors.
- In developing national drinking-water standards based on these guideline values, it is necessary to take into account a variety of geographical, socioeconomic, dietary, and other conditions affecting potential exposure. This may lead to national standards that differ from the guideline values.
- In the case of radioactive substances, screening values for total alpha and total beta activity are given, based on a reference level of dose.

Microbiological Standards

Most of the disease agents that contaminate water and food are biological and come from animal or human feces. The contaminants come in the form of pathogenic bacteria, viruses, protozoa or parasites. Those that can be transmitted via the fecal-oral route by drinking water are listed in Table 6.2, together with a summary of their health significance and main properties. These pathogens present a serious risk of disease whenever they are present in drinking water. Many of these pathogens are also a hazard in food (these are described further in Chapter 7) and include *Salmonella spp.*, *Shigella spp.*, pathogenic *E. coli*, *Vibrio cholerae*, *Yersinia enterocolitica*, *Campylobacter jejuni*, *C. coli*, the viruses listed in Table 6.2, and the parasites *Giardia*, *Cryptosporidium*, *Entamoeba histolytica*, and *Dracunculus*

TABLE 6.2

WATERBORNE PATHOGENS

Pathogen	Health Significance	Persistence in Water Supplies	Resistance to Chlorine	Relative Infective Dose	Important Animal Reservoir
BACTERIA					
Campylobacter jejuni, C. coli	High	Moderate	Low	Moderate	Yes
Pathogenic *E. coli*	High	Moderate	Low	High	Yes
Salmonella typhi	High	Moderate	Low	High	No
Other salmonellae	High	Long	Low	High	Yes
Shigella spp.	High	Short	Low	Moderate	No
Vibrio cholerae	High	Short	Low	High	No
Yersinia enterocolitica	High	Long	Low	High(?)	Yes
Pseudomonas aeruginosa	Moderate	May multiply	Moderate	High(?)	No
Aeromonas spp.	Moderate	May multiply	Low	High(?)	No
VIRUSES					
Adenoviruses	High	?	Moderate	Low	No
Enteroviruses	High	Long	Moderate	Low	No
Hepatitis A	High	?	Moderate	Low	No
Enterically transmitted non-A, non-B hepatitis viruses, hepatitis E	High	?	?	Low	No
Norwalk virus	High	?	?	Moderate	No(?)
Rotavirus	High	?	?	Moderate	No(?)
Small round viruses	Moderate	?	?	Low(?)	No
PROTOZOA					
Entamoeba histolytica	High	Moderate	High	Low	No
Giardia intestinalis	High	Moderate	High	Low	Yes
Cryptosporidium parvum	High	Long	High	Low	Yes
HELMINTHS					
Dracunculus medinensis	High	Moderate	Moderate	Low	Yes

Source: WHO, 1993d.

medinensis. Most of these pathogens are distributed through water worldwide, however, outbreaks of cholera and infection by the guinea worm *D. medinensis* are regional. Other pathogens are accorded moderate priority in Table 6.2 or not listed because they are of lower pathogenicity. These parasites often cause disease opportunistically in persons with low or impaired immune systems, for example, in elderly people or people with AIDS.

Acceptable Daily Intake and Guideline Values for Chemicals

How are the risks of different chemicals determined? There are two principal sources of information on health effects resulting from exposure to chemicals that can be used to develop guidelines. The first is to be found in studies on human populations, studies that are often limited by a lack of quantitative information on the concentrations to which people are exposed. The second is found in toxicity studies on laboratory animals and is the source that is used most often (see Chapter 3). In the WHO's *Guidelines for Drinking Water Quality* (WHO, 1993d), the following formulas are used to determine tolerable intake of various chemicals, and these should be consulted for an in-depth discussion of the formula derivations. The formulas presented below refer specifically to drinking water, but they use terminology similar to that used for other topics in risk assessment (Chapter 3).

For most kinds of toxic chemicals studied, there is a dose below which no adverse effects have been observed. For such chemicals an *acceptable daily intake* (ADI) can be derived as follows:

threshold values

$$ADI = \frac{\text{NOAEL or LOAEL}}{UF}$$

where: NOAEL = no-observed-adverse-effect level, LOAEL = lowest-observed-adverse-effect level, and UF = uncertainty factor.

The *guideline value* (GV) is then derived from the ADI as follows:

$$GV = \frac{ADI \times bw \times P}{C}$$

where bw = body weight (60 kg for adults, 10 kg for children, 5 kg for infants), P = fraction of the ADI allocated to drinking water, and C = daily drinking-water consumption (2 liters for adults, 1 liter for children 0.75 liters for infants).

- The ADI is an estimate of the amount of a substance in food or drinking water, expressed on a body weight basis, that can be ingested daily over a lifetime without appreciable health risk.
- The proposed ADIs are regarded as tolerable throughout life; they are not set with such precision that they cannot be exceeded for short periods of time. Short-term exposure to levels exceeding the ADI is not a cause for concern, provided the individual's intake averaged over longer periods of time does not exceed the ADI.
- It is impossible to make generalizations concerning the length of time during which intakes in excess of the ADI would be toxicologically detrimental. The induction of detrimental effects will depend upon factors that vary from contaminant to contaminant. The biological half-life of the contaminant, the nature of the toxicity, and the amount by which the exposure exceeds the ADI are all crucial.
- The large uncertainty factors generally involved in establishing an ADI also serve to provide assurance that exposure exceeding the ADI for short time periods is unlikely to result in any deleterious effects upon health. However, consideration should be given to the potentially acute toxic effects that are not normally considered in the assessment of an ADI.
- The GV is generally rounded to one significant figure to reflect the uncertainty in animal toxicity data and exposure assumptions made. More than one sig-

nificant figure is used for GVs only when extensive information on toxicity and exposure provides greater certainty.

As noted earlier, carcinogens, which are generally genotoxic chemicals, have no detectable threshold for consumption and consequently may be harmful at any level of exposure. The development of an ADI for these chemicals is therefore inappropriate, as was discussed in Chapter 2. The initiating event in the process of chemical carcinogenesis is the induction of a mutation in the genetic material (DNA) of somatic cells. There are carcinogens, however, that are capable of producing tumors without genotoxic activity, but through an indirect mechanism. It is generally believed that a threshold dose exists for these nongenotoxic carcinogens, but in most cases this threshold has not been determined.

non-threshold chemical

For carcinogens for which there is convincing evidence to suggest a nongenotoxic mechanism, guideline values are calculated using an ADI approach. In the case of genotoxic carcinogens, guideline values were determined by means of a mathematical model, and the guideline values are presented as the concentration in drinking water associated with an estimated excess lifetime cancer risk of 10^{-5} (one additional cancer case per 100,000 of the population ingesting drinking water containing the substance at the guideline value for 70 years).

DRINKING-WATER SUPPLY AND MONITORING

The Source

Proper selection and protection of water sources are critical for the provision of safe water. It is always better to protect water from contamination than to treat it after it has been contaminated. Before determining that a source of water will be used as a drinking-water supply, it is important to ensure that the quality of the water is satisfactory or treatable and that the quantity available is sufficient to meet continuing water demands. Seasonal variations and potential growth of the community must be taken into account to ensure that there are no shortages. Sources of groundwater such as springs and wells should be sited and constructed so they are protected from surface drainage and flooding. Areas of groundwater abstraction should be fenced in and kept clear of garbage.

The protection of surface water is more problematic. Surface water such as streams, rivers, and lakes are more vulnerable to pollution. The water source should be protected from human activities. If possible, the source should be isolated and there should be control over polluting activities in the area, such as dumping of hazardous wastes, mining, and agricultural use of fertilizers and pesticides. Recreational activities should be limited so that they are not likely to introduce contamination. While it may be possible to protect a reservoir from major human activity, this may be more difficult to enforce in the case of a river. Often it is necessary to accept existing uses of a lake or river and design treatment accordingly.

In areas where drinking water is collected from roofs it is important to avoid contamination from paint on the roof or in the storage tanks. In addition, an increase in air pollution may add to poor-quality roof water.

BOX 6.6

GEMS/Water

The United Nations Environment Program's Earthwatch office and the Global Environment Monitoring System (GEMS), in association with the WHO, UNESCO, and the World Meteorological Organization, have developed a global water quality monitoring network, called GEMS/Water. Initiated in 1977, the network includes 344 monitoring stations—240 river stations, 43 lake stations, and 61 groundwater stations. Rivers such as the Rhine, the Nile, and the Ganges, and lakes, from Lake Tai in China to the North American Great Lakes, are routinely sampled and analyzed. Groundwater, crucial for drinking-water supplies, is sampled in Africa and the Middle East, particularly in areas where no perennial rivers flow. More than 50 water variables are measured, providing information on the suitability of water for human consumption, and for agricultural, commercial, and industrial uses. All data are stored and processed at the GEMS/Water global data bank at the National Water Research Institute in Canada, and summaries of the data are published every 3 years. In 1990, the GEMS/Water Program broadened its scope to include not only monitoring but data interpretation, assessment of critical water quality issues, and management option analysis.

Whereas guideline values have been set for drinking water itself, no firm requirements can be formulated for the source of such water (WHO/UNEP, 1989). Water quality monitoring, however, is in place in several countries through the GEMS project (Box 6.6).

Drinking water can also be produced from seawater through desalination. This is common in countries with little rainfall and large oil supplies, e.g., Bahrain and Curaçao. The process of removal of salt from seawater involves boiling, distillation, or reverse osmosis, all technologies with high energy requirements.

Treatment of Drinking Water

Proper treatment of drinking water protects the consumer from health risks associated with biological or chemical hazards in the water. The quality of the original source of water determines the extent of treatment required. The number of people served by a particular drinking-water supply also influences the treatment process. If the water comes from a source serving only one or a few households, the treatment may take place at the site of consumption rather than at the source or in the distribution system, which is the rule for large population supplies. Water purification filters and disinfecting tablets can be used at the household end. It is even better to protect the household source, such as a well, so that the water can be used directly with minimal treatment or handling.

The most common treatment methods include (*a*) pretreatment in reservoirs; (*b*) coagulation, flocculation, and sedimentation; (*c*) filtration; and (*d*) disinfection (see Box 6.7 and Fig. 6.5). Details of these methods are given in the WHO's

BOX 6.7

Water Treatment and Chlorination By-Products

A typical water treatment facility, as may be found in large cities in Canada, is shown in Figure 6.5. After water is drawn from a source, large debris is removed via a screen. A disinfectant is then added to reduce bacteria. The process of coagulation, flocculation, sedimentation, and filtration constitutes the treatment process. Through coagulation and flocculation particulate impurities are removed; adding a coagulant causes the particles to clump, whereas flocculation is a slow stirring process during which the particles gather together to form larger particles. Sedimentation is used to remove suspended solids that have been preconditioned by the coagulation–flocculation process, following which a filter completes the process of removing suspended solids. Sometimes a disinfectant is added before the distribution of treated water.

Trihalomethanes (THMs) result from the reaction of chlorine with organic precursors during the water treatment process. Several ecological studies have examined the relationship between THMs and cancer. These studies have generally suggested that there is an association between THMs and cancer of the bladder and colon. Some of the studies have also reported that incidence of cancers of the rectum, stomach, breast, lung, pancreas, and kidney and non-Hodgkin's disease may increase in association with THMs. Some case–control studies have also suggested significant associations for cancers of the bladder, colon and rectum. The sum of the available evidence points to a small increased risk of some cancers associated with consuming water with high levels of THMs.

Characteristics of the treatment process affect the amount of chlorine compounds and organic precursors in treated water. The stage at which disinfection is performed is important in determining the THM level, since other treatment procedures will affect the level of organic precursors available to react with chlorine. For example, when chlorine compounds are added before any treatment, the largest levels of THMs result. This effect is tempered by using activated carbon later in the process, as it has the potential to remove volatile organic compounds. The amount of chlorine by-products in treated water can also be reduced with dechlorination.

It is important to recognize that disinfection is an important component of water treatment. While measures should be followed to reduce cancer risk to a minimum, the health risks associated with failing to chlorodisinfect water far exceed the risks of chlorination, according to current knowledge.

Source: Marrett and King, 1995.

Guidelines document (WHO, 1993d). One of the basic elements of the treatment methods is sedimentation of larger particles in reservoirs, where special screens can further reduce the amount of organic matter in the water. Predisinfection with chlorine compounds can also be used in this process if the water is known to be polluted by sewage. In the coagulation step, aluminium or iron compounds are added, which react with impurities in the water to cause flocculation (creation of slimy particles, called *flocs*, in the water). These flocs will attach to bacteria and other remaining organic material in the water, and the flocs can be sep-

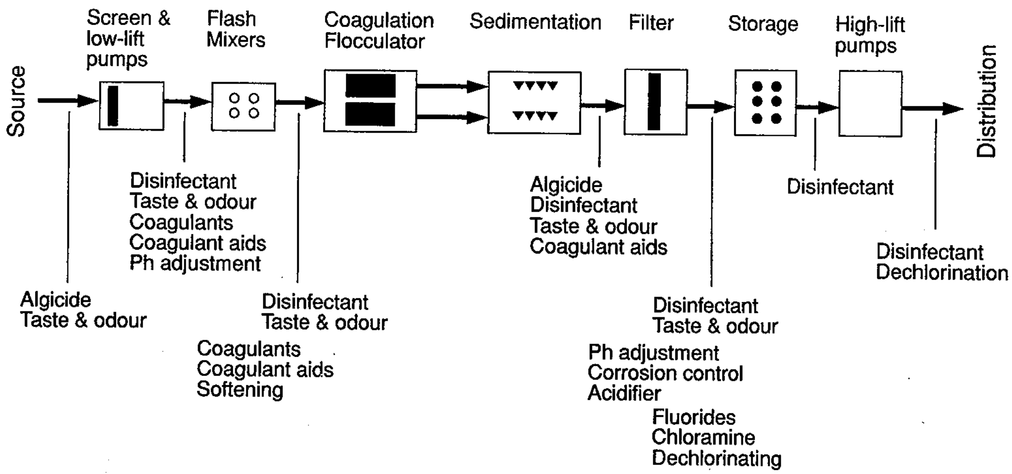

Figure 6.5 Diagram of a water treatment process. From Marrett and King, 1995, with permission.

arated from the water by sedimentation or flotation. To ensure that all flocs and most bacteria are removed from the water, the next step includes filtration in sand. The longer distance of sand the water filters through, the more efficient the filtration. Normally, bacterial counts can be reduced by a factor of about 1000 by a suitable sand filter.

Even after thorough sand filtration, some bacteria and viruses may remain, so a final disinfection is extremely important. The most commonly used methods involve the addition of chlorine or hypochlorite to the water. Disinfection can also be achieved with chloramines, chlorine dioxide, ozone, and ultraviolet (UV) radiation. The latter method has been applied in small-scale solar-powered disinfection units, and this may be the method of choice for remote areas with much sunlight. The chlorination process makes it possible to maintain a certain level of free residual chlorine in the water during its transport through the distribution system. This reduces the buildup of bacterial and algae growth inside the pipes, and it maintains some protection from contamination of the water during transport. In large population supply systems, the water source is often prone to contamination and the storage and distribution systems can be contaminated. Chlorine is preferred because it continues to act downstream. In Box 6.7 chlorination of drinking water is discussed further.

In some countries, fluoridation of drinking water is as an approach to increase the daily intake of fluoride to levels that prevent caries in teeth. This practice has been controversial because excessive intake of fluoride can have detrimental health effects and can discolor teeth (see Chemical and Radioactive Constituents of Water, above). Individual intake is difficult to control. Fluoride in toothpaste provides significant exposure for people who use such toothpaste. The fluoridation of water supplies is nonetheless promoted as an essential intervention for preventive oral health.

Distribution and Storage

Where high-quality piped water is readily available in the home, monitoring of water quality can be done directly at the time of use. According to the WHO's

Guidelines, these conditions are "globally the exception rather than the rule" (WHO, 1993d). Many people worldwide collect water away from the point of use or store water in unsanitary conditions in their homes. In cases where an adequate supply is present, contamination may occur in household storage tanks if they are not property installed and maintained. Contamination can also occur during distribution of water from the source to the household, through the use of dirty containers and/or coverings. Contamination of water in the home may be the most important source of microbiological contamination throughout the world. Educational initiatives on the subject of water handling and the promotion of storage tank maintenance can reduce this risk to human health.

Place of Use

As discussed in Chapter 4, Factors Affecting the Perception and Acceptance of Risk, many organisms present in water have no real health significance but may be important indicators of other problems with either the water supply or the water distribution system. Consumers cannot usually assess the safety of their water systems themselves but their attitude toward their water supply and water suppliers will certainly be affected by what they can perceive themselves. The provision of water that is not only safe but physically acceptable is important to a community (see Other Aspects of Water Quality, above).

Heat kills bacteria and protozoa and destroys viruses. Boiling water is a very effective means of treating water for biological contamination but it is ineffective for controlling chemical contamination. It is also very expensive, especially where fuel is in scarce supply. Water can also be filtered at the place of use. For small volumes, disinfection chemicals can be used to treat highly contaminated water. Small-scale systems based on solar UV radiation as a disinfectant have been developed.

SANITATION

Throughout this chapter numerous references have been made to sewage, excreta, or fecal contamination. The prevalence of waterborne diseases resulting from this type of contamination raises the obvious question of what can be done to improve sanitation. In the 1970s, international agencies began to look at alternative low-cost sanitation technologies for rural and low to medium-density urban settlements. There are now over 20 different excreta disposal systems that offer varying degrees of convenience and protection. One such system, the ventilated improved pit (VIP) latrine, is outlined in Box 6.8 and Figure 6.6. Larger-scale sewage systems for urban areas are described in the section Wastewater Treatment and Reuse, below. Concerted efforts during the 1980s brought improved water and sanitation services to many of the world's poorest people. Although the target of the International Drinking Water Supply and Sanitation Decade (IDWSSD), discussed in the last section of this chapter, was to provide safe drinking water and sanitation to underserved urban and rural communities by 1990, the progress of the decade was not enough.

Most urban centers in Africa and Asia have no sewage system at all, including many cities with a million or more inhabitants (WHO, 1992a). In 1994 at

BOX 6.8

Ventilated Improved Pit Latrine

A ventilated improved pit latrine (VIP) is an improved version of the traditional pit latrine. The main difference between a VIP and a pit latrine is that a VIP has a vent pipe with a fly screen at the top. The vent pipe and fly screen together have two effects: increased ventilation and fly control. The vent pipe creates a flow of fresh air through the cubicle and pit. As wind blows over the top of the vent pipe, it sucks air up the pipe and out of the pit. Fresh air is then drawn from outside, through the cubicle, and down into the pit. The toilet itself is therefore odorless (see Fig. 6.6a). Flies approaching the latrine are attracted to the odors coming from the pipe, but cannot pass the screen to enter the pit. Flies escaping from the pit are attracted to the light coming down the pipe, but are trapped by the screen and cannot leave. Thus far fewer flies are attracted to and able to breed in the toilet (see Fig. 6.6b).

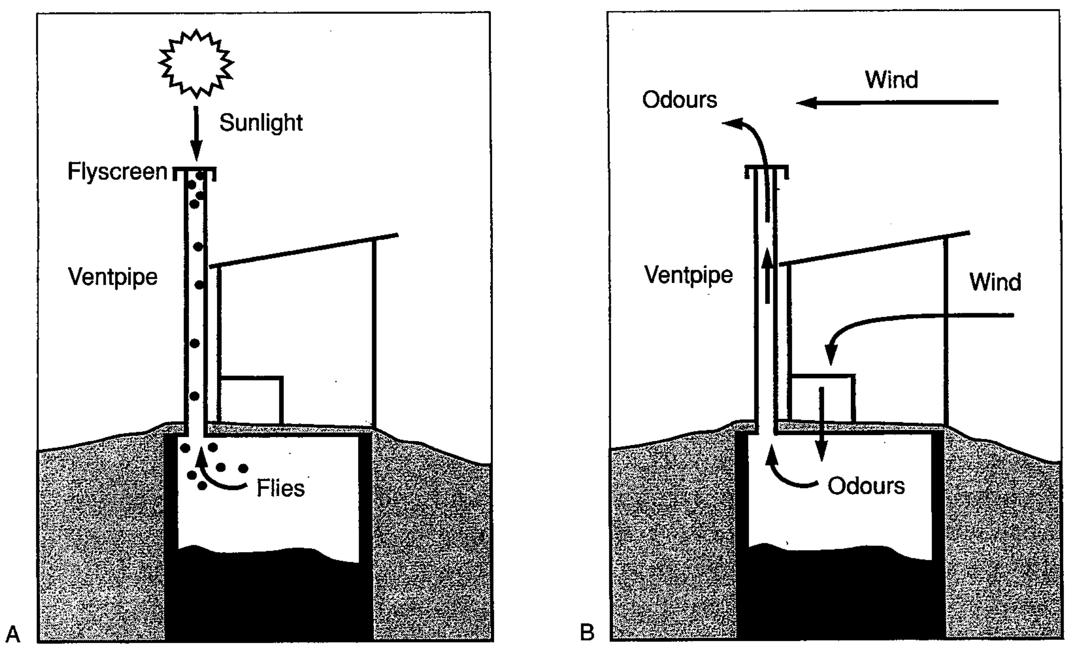

FIGURE 6.6 Ventilated improved pit (VIP) latrine. In addition to the vent pipe and fly-screen, the following are other important features of a VIP toilet: (*1*) Apart from the holes for the vent pipe and the toilet seat, the pit should be completely sealed by the slab to prevent odors (**B**) and flies (**A**) from escaping. (*2*) In soft ground the pit should be lined, to prevent the toilet from collapsing. If the ground is solid, it may only be necessary to line the top part of the pit. (*3*) The superstructure interior must be shaded (i.e., light must not be allowed to enter it directly), as this attracts flies from the pit. (*4*) The toilet must be well maintained and kept clean for it to work properly. Contributed by D. Carter, The MVULA Trust.

TABLE 6.3

URBAN WATER AND SANITATION COVERAGE BY REGION, 1994

Service	Africa (%)	Asia and Pacific (%)	Middle East (%)	Latin America (%)
WATER				
Population covered	68.9	80.9	71.8	91.4
Served by house connection	65	48.4	89.7	92
Served by public standpost	26	24	9.3	3.3
Served by other	9	27.6	0	4.7
SANITATION				
Population covered	53.2	69.8	60.5	79.8
Served by house connection to sewer/septic system	53.0	42.7	100.0	91.2
Pour-flush latrine	3.0	43.1	0	2.1
Ventilated improved pit latrine	13.6	2.7	0	0.9
Simple pit latrine	22.4	8.5	0	5.4
Other	2.6	3.0	0	0.4

Reproduced from WRI/UNEP/UNDP/World Bank, 1996, with permission.

least 220 million people still lacked an easily accessible source of potable water (see Table 6.3) (WRI, 1996). Figures for water supply and sanitation often understate the problem because they do not take into account the quantity of water needed by a household for proper hygienic practices. Moreover, figures given for clean water sources or adequate sanitation facilities in a community may also conceal some problems. If people have to wait in long lines for their water, they often reduce their water consumption below what is needed for good health (WHO, 1992a). People who have to walk long distances to use a latrine may end up defecating where it is most convenient to save effort. Improving sanitation will only work if other factors such as personal hygiene and adequate water supply are addressed simultaneously. Improving access to water and sanitation facilities alone can reduce the incidence of diarrheal disease by at least 20% (WRI, 1996).

As noted in *Our Planet Our Health* (WHO, 1992a), capital costs alone are not a sufficient basis for determining the cost of a system because 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 considered unaffordable. Most low-cost sanitation alternatives come within this range, even for the poorest of communities. Table 6.4 outlines typical sanitation facilities and their costs. Costs are a crucial factor in the choice of sanitation systems, but a number of other determinants such as settlement and population density, ground conditions, and social and cultural practices will also play a role.

TABLE 6.4

CAPITAL COSTS OF SANITATION SYSTEMS (1990 PRICES)

Type of System	*Cost (U.S. $) per Household (1990)*
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

Reproduced from WHO, 1992a, with permission.

CONTROL OF WATER POLLUTION

Domestic sewage, stormwater runoff, and industrial wastes have all been mentioned in this chapter as significant contributors to water quality degradation. A few decades ago, it was considered economically acceptable to turn over some water courses entirely to waste disposal, with other water bodies being reserved for drinking water. However, this is no longer acceptable practice. The increase of population density in urban areas, the concern for environmental protection, the greater understanding of the links between the environment and health, and a better assessment of the economic damage of water pollution have all served to motivate an improvement in pollution control practices (Hespanol and Helmer, 1993).

As highlighted in Box 6.5, many of the rivers that flow through the developing world's major cities are little more than open sewers. Untreated industrial and municipal wastes add pollution loads far beyond the rivers' self-purifying capacities. While these rivers and other surface water bodies are highly visible signs of pollution, less visible but equally dangerous is the contamination taking place in groundwater. The attraction of groundwater as a supply source has led to overexploitation. This in turn has led to a number of quality problems. As the natural water table falls, saline water is drawn in to replace the fresh water. Seepage through the soil can contaminate groundwater with pathogens from sewage, as well as a wide variety of potentially toxic compounds dumped by industry. Improvements in sanitation, wastewater treatment and reuse, and in the regulation of industrial pollution need to be priority areas for controlling the pollution of both surface and groundwater sources.

Industrial Pollution

Industrial wastes degrade water quality when proper disposal methods are not in place. The water may become so polluted that it is not fit for other uses. Many factories in developing countries have been built without effective waste treatment and disposal systems, since costs would increase production costs and accordingly reduce a product's competitiveness on the international market. Industrial wastes, especially those containing heavy metals and organic chemicals, may leave a particularly severe impact due to their persistence, their harmful effects at low concentrations, and their ability to enter the food chain (Hespanol and Helmer, 1993).

Agenda 21 recognizes that "gross chemical contamination, with grave damage to human health . . . and the environment, has in recent times been continuing within some of the world's most important industrial areas. Restoration will require major investment and development of new techniques" (UN, 1993). In every country there must be an appropriate legislative framework developed to support a public administration that can issue and enforce regulations and responsibilities, and develop control policies.

Wastewater Treatment and Reuse

Treatment Wastewater treatment accounts for the largest part of the costs associated with urban sanitation. The level of wastewater treatment established should be consistent with the characteristics of the receiving waters to which the effluents will be discharged after treatment or according to reuse practices. When choosing a treatment system decision makers have to take into account the availability of forms, equipment, and expertise. The system must also be adapted to local climatic conditions, particularly where there is flooding, to support water treatment locally.

There are three levels of wastewater treatment: primary, secondary, and tertiary. In *primary treatment,* sewage is held in settling tanks and solid materials are allowed to settle out of the water. Bacterial action digests organic materials and the sludge that remains is dried and disposed of. Excess sludge from biological treatment plants can be composted to produce a stable biomass that is free of pathogens and can be applied to agricultural land as a soil conditioner. In *secondary treatment,* further degradation of wastewater organics is accomplished by bacteria in an oxygen-rich environment, created by blowing or shipping air into the wastewater. *Tertiary treatment* involves chemical separation of phosphates and nitrates and in some cases further action by bacteria in ponds or through filtration.

The most common tertiary treatment systems used in both developing and industrialized countries are based on processes such as the following:

- stabilization ponds
- activated sludge
- trickling filters and towers
- aerated lagoons
- upflow anaerobic sludge blanket reactors (UASBR).

still 2° treatment

The choice of treatment depends on such factors as land availability, power requirements, and availability of skilled operators. The UASBRs have low power and land requirements. Stabilization ponds require large amounts of land but are simple and inexpensive to operate. Activated sludge plants require considerable amounts of power as well as skilled operation.

Wastewater is a valuable resource that plays an important role in the management of water resources (WHO, 1980b). Worldwide, water withdrawal for irrigation accounts for nearly 70% of all use. By using wastewater for irrigation, particularly in arid or semi-arid parts of the world, high-quality water currently being used for agriculture could instead be made available for drinking. Reuse of wastewater for irrigation of crops may help to increase food production while improving health and social conditions. The use of wastewater for irrigation or aquaculture can prevent problems associated with the discharge of untreated or partially treated wastewater into rivers and lakes. Additionally, by reducing the dependence on groundwater for irrigation, the use of wastewater helps to diminish the problems of saltwater intrusion into aquifers. Wastewater can be used particularly effectively in forestry and thus be of aid to arid developing areas or countries suffering from deforestation.

If wastewater used in irrigation is not carefully controlled, health problems may result. The following integrated safeguard measures can be used to protect the health of people who may be at risk from wastewater use systems:

- *Wastewater treatment,* to ensure that the wastewater applied to crops has low levels of pathogenic organisms
- *Wastewater application techniques,* such as drip irrigation, that avoid wastewater coming into contact with the edible parts of crops
- *Crop selection,* to limit the use of wastewater for irrigating crops that are not consumed directly (industrial and fodder crops) or that grow well above the ground (tomatoes and chili), or crops not eaten raw (potatoes)
- *Human exposure control,* by advising farm workers, crop handlers, and consumers of potential hazards through programs of health education, by immunizations, by providing treatment and adequate medical facilities to treat diarrheal diseases

RECREATIONAL WATER QUALITY GUIDELINES

Recreational uses of water include swimming, boating and diving. Although water quality for these uses does not have to be as stringent as for drinking water, there must be some controls to prevent contamination and waterborne diseases from recreational water uses. Recreational water quality is becoming an increasingly important issue because of the economic importance of tourism around the globe. Recreational water quality guidelines have mostly been the concern of developed countries. Although acceptable levels of microorganisms and contaminants will vary from country to country, the method of assessing the water quality is fairly standardized among developed countries. The recommended levels given here are from the *Guidelines for Canadian Recreational Water Quality* (Health Canada, 1992). Several aspects of recreational water are examined: presence of pathogens and physical and chemical characteristics.

Indicator organisms are often used for determining the presence of pathogens. These organisms are not toxic in and of themselves but reflect the levels of pathogenic organisms that are probably present in the water. Several organisms lend themselves to this task, depending on the resources available to the tester and the nature of the body of water. In freshwater, fecal coliforms are often measured, but there is some debate about the strength of the correlation between their levels and the risk of disease. It is recommended that levels not exceed 200 fecal coliform/100 ml over a 5-day period. Fecal coliforms are not useful in salt water. Fecal streptococci may be a better choice for both fresh- and saltwater, but at present the methods available for determining their levels are more expensive. Other pathogenic organisms should be measured when there is epidemiological evidence that pathogens are present in a particular body or area of water.

Recreational water quality is also dependent on physical and chemical characteristics. Although water temperature is an important quality aesthetically, and for comfort, humans can tolerate a wide range of temperatures. The optimum for swimming is in the range 18°–25°C. Prolonged submersion into colder or hotter water may lead to some of the physical effects discussed in Chapter 2. Acidic and alkaline pH levels are also a consideration but are not extreme enough to affect humans adversely. The recommended range is between 6.5 and 8.5. Turbidity is important in determining water quality because the presence of pathogens is significantly higher in sediment than in surface water. The maximum suggested level is 50 *nephelometric turbidity units* (NTU). Color and clarity can also be important qualities, but they vary so dramatically among different areas of water, depending on the contaminant, that guidelines are difficult to establish. Oil and grease should not be visible, either on the surface or shore, and no odor should be detectable. Both organic and inorganic contaminants vary dramatically and therefore should be measured and the health risk assessed on an individual basis. Although recreational water does not require the same level of protection as drinking water, proximity to sources of pollutants should also be considered.

ENSURING A SAFE AND SUFFICIENT WATER SUPPLY

The Water Decade, 1981–1990

Drinking-water supply has been a top priority of the United Nations. The United Nations Conference on Human Settlements held in Vancouver in 1976 and the Mar del Plata Action Plan (Mar. del Plata, Argentina March, 1977) set the stage for the launching of the International Drinking Water Supply and Sanitation Decade

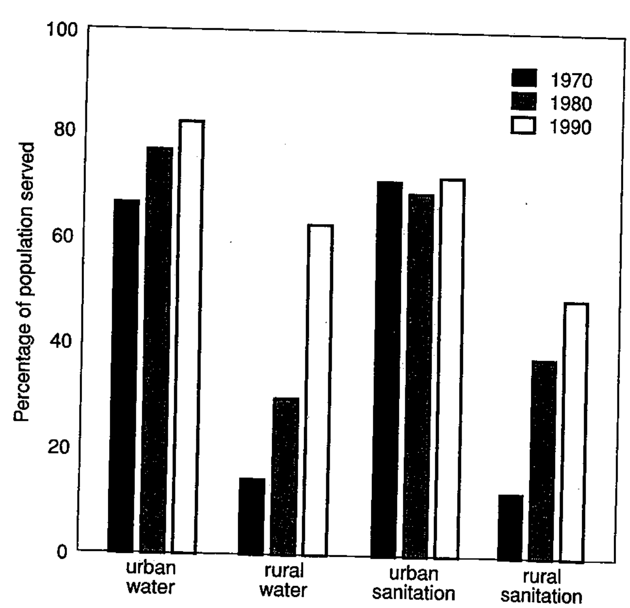

Figure 6.7 Water supply and sanitation access in developing countries. From UNEP, 1992a, with permission.

BOX 6.9

The Mvula Trust: A Community-Centered Approach to Improving Water and Sanitation Services

South Africa had a long history of racial discrimination and inequality. The country had its first democratic elections in 1994. South Africa was left with a huge legacy of inequalities, among them unequal environmental conditions. The challenge of providing the entire country's population with a basic and sustainable level of water supply and sanitation service is enormous. The Mvula Trust is a nongovernmental organization (NGO) dedicated to improving water supply and sanitation services to disadvantaged, poor, and marginalized rural communities. It provides funds mainly to villages that are remote and have low incomes. Local government structures in South Africa are very new, with little capacity to maintain service infrastructure. Overcoming these difficulties to achieve sustainability requires innovative approaches to all aspects of project design and implementation. The technologies installed must be easy for the community to maintain, and they must be affordable. However, the most important element in sustainability is that the community must have a sense of ownership and responsibility for the scheme. For this reason a community-centred approach to project design and implementation is essential. The Mvula Trust has developed an approach based on the following principles.

DEMAND DRIVEN

The Trust only responds to requests for assistance from communities. It does not search for projects, nor does it respond to proposals from consultants unless they are in support of a community application. Without effective, genuine demand for the service and for the level at which it is to be installed, there is unlikely to be a commitment to the smooth implementation of the project and, more importantly, to the maintenance of the scheme.

CONCEPT OF OWNERSHIP

The Trust approach stresses community ownership of the process and the product of the project. The Trust only enters into a contract with the association representing the community, which is then expected to open a bank account, procure materials, employ labor, pay consultants, and set up a tariff collection system.

COMMUNITY IS THE CLIENT

In order for the community to take an active interest in the ongoing maintenance of the scheme, it is essential that the facilities effectively serve their needs. Key decisions regarding the design of the system and the implementation of the project must therefore be made by the community, within a set of clear guidelines, such as the policies of the funding agency. Without this, there is a risk that an inappropriate system will be installed.

COST SHARING

The principle of paying for services is basic to the South African government's reconstruction and development program, which the Trust supports. The Trust expects the community to start contributing cash to a special fund as soon as the pro-

(*continued*)

(*continued*)

ject starts. The process through which the association must go to raise the contributions to this fund sets a precedent for the collection of operation and maintenance fees.

CAPACITY BUILDING

A key element in promoting sustainability is to develop the skills needed to take responsibility for the scheme. All Trust-funded projects have a large training component, and the community is given the opportunity to put their training into practice during the course of the project. This develops a strong sense of self-reliance needed to run the project after completion.

The government Department of Water Affairs and the Trust have entered into an innovative agreement. The Trust receives most of its funding from the Department but it is allowed to be separately accountable for public funds. This enables it to retain a flexible NGO structure that can implement rapid, demand-driven processes to support community empowerment.

Contributed by I. Wilson, Mvula Trust.

(IDWSSD, 1981–1990) by the General Assembly of the United Nations in 1980. The main objective of the Decade was to substantially improve the standards and levels of services in drinking-water supply and sanitation by the year 1990.

According to *Saving Our Planet* (UNEP, 1992a), the percentage of the population in urban areas of developing countries with access to safe drinking water increased from 67% in 1970 to 82% in 1990, but access to sanitation services hardly improved at all. In rural areas improvements were more dramatic, with the percentage of people having clean water rising from 14% to 63% and those with access to sanitation services rising from 11% to 49% (see Fig. 6.7). Even so, at the end of the Decade there were still one billion people without a safe water supply and almost 1.8 billion without adequate sanitation. The rate of progress achieved during the Decade would be insufficient to reach the ultimate objective of sanitation for all by the end of the century. The slow progress of achieving the goals of the IDWSSD has been attributed to several factors, including population growth, rural–urban migration, the unfavorable world economic situation, and the debt burden of developing countries. The debt burden has been a major obstacle to investment in infrastructure (UNEP, 1992a).

As discussed in *Our Planet, Our Health* (WHO, 1992a), there are a number of lessons to be learned from the Decade, some of which are outlined below:

- The ability of communities to run and maintain their own sanitation and water systems needs to be strengthened.
- There needs to be greater emphasis on the connections between improvements in water and sanitation and improvements in hygiene and primary health care.
- It is important to involve local populations in decisions regarding design, costs, and management of projects.
- Disease risk and socioeconomic conditions must be considered in the design and delivery of water and sanitation services.

Many development programs have tried to incorporate these lessons into their various projects. The Rural Water Supply and Sanitation Project in Ghana's Volta Region is one example of this approach; many examples are provided in the various international agency publications cited in this chapter. The efforts of the Mvula Trust in South Africa are described in Box 6.9.

Water Resources Management

Consumers, suppliers, industry, and governments all have a role to play in ensuring a safe and sustainable water supply. Leakage is one of the main reasons for the shortfall in capacity of many cities' water supplies. This is particularly true of urban centers in developing countries where typically 30% of the water is treated and pumped into the water supply but as much as 60% is lost on its way. The leakage rate in the United States and Europe is typically around 12%. Proper maintenance of the distribution system is an important way to cut back on water waste. *Pressure* provides the force that moves water through a pipe. When pressure cannot be kept at an adequate level, water cannot be delivered where it is needed and contaminated water outside the pipe can seep into the clean water inside the pipe through leaks. Maintaining adequate pressure requires careful maintenance of pumps and energy to run them. As indicated earlier, governments have an important role to play in the management of water resources, particularly where it relates to pollution control, through appropriate legislative frameworks.

The use of economic devices is also a powerful means of promoting efficient environmental protection and the rational use of water resources by all users, including households, municipalities, industry, and farmers. Public awareness of pricing structures that reflect the real cost of water supply encourages more efficient use of water. Of all natural resources, water is most likely to be consumed at a lower price than the cost to deliver it, as the costs of water utilities are rarely fully recouped from consumers. The most widely known basic principle in this category, the *polluter-pays principle*, is Principle 16 in *Agenda 21* and reads as follows:

> National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment.
>
> Source: UN, 1993.

Economic instruments used to put this principle into practice include effluent charges, subsidies to pollution control works, financial enforcement incentives, tax rebates, and budgetary and fiscal mechanisms. Financial incentives that assist polluters to protect the environment, although not universally accepted, are in widespread use. Grants, low-interest loans, and tax credits are incentives given to encourage remedial measures. Financial assistance can be a powerful instrument in environmental protection programs, particularly in developing countries (Hespanol and Helmer, 1993).

Significant progress cannot be made in ensuring water supply and protection without a strong commitment at the governmental level, as large expenditures for infrastructure are required. Some actions can be taken at an *individual* level, however. Water wastage is common in many homes in developed countries. Only 5% of household water consumption in North America is for drinking and cooking; the rest is consumed through toilet flushing (40%), showering/bathing (30%), laundry/dishwashing (20%), and other uses (5%). Most of this water has been treated to a level that is safe to drink, which requires an enormous amount of additional resources. When a lot of treated water is used for purposes that do not require treatment, such as flushing toilets, water and treatment costs are raised. Since it is not generally practical or safe (there is a potential hazard if treated and untreated water lines get crossed) to have a second distribution system for untreated water, the only solution is to minimize the waste.

Study Questions

1. What factors need to be considered to develop an effective strategy to improve sanitation in a rural community of a developing country? Of an urban community?

2. A number of initiatives and suggestions for better management of water resources have been discussed in this chapter. Try to develop other initiatives that could be used to promote water conservation. These could be economic, social, legal, or physical in nature. Think about how these may be implemented.

3. Make a list of ten tips to reduce water consumption in a community affected by water shortage.