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An SAB Report: Safe Drinking Water

Future Trends and Challenges

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

March 29, 1995

EPA-SAB-DWC-95-002

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

Subject: Safe Drinking Water: Future Trends and Challenges

Dear Ms. Browner:

As part of the Futures Project of the Science Advisory Board (SAB), the Drinking Water Committee (DWC) has examined trends and issues likely to affect the future availability and quality of drinking water in the U.S. The primary goal of this exercise has been to develop recommendations for strategies that would better enable the Agency and the Nation to face the challenges posed by those trends in the next few decades.

This report is the result of the Committee's deliberations. In brief, the Committee identified four broad trends that can be expected to seriously impact the future of drinking water in the U.S.: a) increased population growth resulting in declining underground water tables and increasingly contaminated water sources; b) increased public demand for cleaner drinking water; c) a changing profile of chemical and microbial contaminants of concern in drinking water; and, d) the resulting pressures to fundamentally change the manner in which drinking water is produced. Based upon an analysis of these trends, the Committee agreed upon five major recommendations, which are summarized later in this letter.

Although the U.S. is a relatively water-abundant country, and its population growth is modest, current population trends are nonetheless sufficient to severely strain water resources over time, particularly on a regional basis. One of the most serious problems in the U.S. will be the continuing decline of groundwater tables, on which approximately 50% of the U.S. population depends for drinking water. This decline is often related to agricultural uses and practices, it is particularly serious in the western U.S., and is often accompanied by increased contamination (e.g., by nitrates and toxic chemicals).

For surface waters, nonpoint sources of pollution will become the dominant threat. Industrial point source contamination will continue to be an important concern for both underground and surface waters, but the development of effective regulatory strategies to control industrial discharges will continue to reduce the relative importance of this source of pollution in the coming decades.

Increasing demands on renewable water resources will demand tough decisions regarding the allocation of water resources. Competition between uses will increase, and greater cooperation will be required between states and localities that comprise individual watersheds. In order to address these conflicts, it will be necessary to modify the current state water allocation systems so that they become more responsive to the trends in resource availability and use, and particularly to facilitate increased conservation and reuse of water. Also, the infrastructure of many U.S. water supply systems is old and in need of replacement, and many small and inefficient water supply systems will need to be consolidated into larger systems.

Coupled with the increased pressures on water resources, there has been a growing perception by the public that many drinking water supplies are contaminated repeatedly, and this perception is likely to continue unabated in the next decades. Increased demands for clean public water supplies also arise from the discovery of new information on health effects (e.g., arsenic and lead) and from a declining tolerance on the part of the public to "accept" any health risks. There are also growing expectations for the protection of virgin natural resources that inevitably reduce the pool of resources available to supply drinking water needs.

The chemical contaminants of primary concern in drinking water today, and in the foreseeable future, arise from the chemical treatment of water whose goal is to remove the risk of microbiological hazards. Many of these contaminants can be measured at concentrations that are so low that they exceed the ability of scientists to accurately estimate their human health effects. At the same time, recent outbreaks of waterborne infectious disease have focused attention on the shortcomings of current methods of water treatment, which often do not adequately eliminate hazardous microorganisms from treated waters. These incidents also highlight the need to be extremely careful when modifying water treatment systems in a manner that may give rise to new infectious disease risks.

The most difficult challenges to the production and delivery of safe drinking water in the next decades, therefore, will be in the areas of evaluating and minimizing the competing risks from chemical and microbiological contaminants that occur in water at very low concentrations. Significant advances in toxicology and epidemiology will be needed to overcome current gaps in scientific knowledge, including the development of better methods for extrapolation of animal data to humans and better dose-response models. In addition, it will be necessary to develop methods to compare microbial to chemical risks such that decisions can be made that result in minimizing both types of risk.

The Committee examined the trends briefly described above, and their likely impacts on the country's ability to provide safe drinking water in the future. As a result, the Committee agreed upon five major recommendations, as follows:

1. *Improve the existing systems of management of renewable water resources*, including prevention of further water supply deterioration, better management of land-use and forestry practices, wetland protection and extension, and implementation of water recycling and conservation practices to improve efficiencies of water use.
2. *Support the consolidation of small distribution systems* to improve the overall quality of water and provide the necessary revenue to implement treatment technologies now available to the larger systems.
3. *Support changes in treatment technologies* to respond to the changing profiles of contaminants of concern.
4. *Greatly accelerate research to spur advances in risk assessment methodologies for both chemical and microbiological contaminants of water* to be able to more effectively guide large public investments for changes in drinking water treatment plants that may be necessary.
5. *Establish a surveillance or alert system to detect waterborne pathogens* that may arise from changes and consolidation in water treatment and distribution systems in the next decades.

The attached report discusses these and other issues in more detail. We trust that the identification of trends and challenges in the drinking water arena and the accompanying recommendations, will be useful as you exercise your important responsibilities in the future.

Sincerely,

Dr. Genevieve M. Matanoski, Chair
Executive Committee
Science Advisory Board

Dr. Raymond C. Loehr, Chair
Environmental Futures Committee
Science Advisory Board

Dr. Verne A. Ray, Chair
Drinking Water Committee
Science Advisory Board

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An SAB Report: Safe Drinking Water

Future Trends and Challenges

An Environmental Futures Report

by the

Drinking Water Committee of the Science Advisory Board

Notice

Seven reports were produced from the Environmental Futures Project of the SAB. The titles are listed below:

(1) Environmental Futures Committee EPA-SAB-EC-95-007

[Title: "Beyond the Horizon: Protecting the Future with Foresight," prepared by the Environmental Futures Committee of the Science Advisory Board's Executive Committee.]

(2) Environmental Futures Committee EPA-SAB-EC-95-007A

[Title: Futures Methods and Issues, Technical Annex to the Report entitled "Beyond the Horizon: Protecting the Future with Foresight," prepared by the Environmental Futures Committee of the Science Advisory Board's Executive Committee.]

(3) Drinking Water Committee EPA-SAB-DWC-95-002

[Title: " Safe Drinking Water: Future Trends and Challenges," prepared by the Drinking Water Committee, Science Advisory Board.]

(4) Ecological Processes and Effects Committee EPA-SAB-EPEC-95-003

[Title: "Ecosystem Management: Imperative for a Dynamic World," prepared by the Ecological Processes and Effects Committee, Science Advisory Board.]

(5) Environmental Engineering Committee EPA-SAB-EEC-95-004

[Title: "Review of Environmental Engineering Futures Issues," prepared by the Environmental Engineering Committee, Science Advisory Board.]

(6) Indoor Air Quality and Total Human Exposure Committee EPA-SAB-IAQC-95-005

[Title: "Human Exposure Assessment: A Guide to Risk Ranking, Risk Reduction and Research Planning," prepared by the Indoor Air Quality and Total Human Exposure Committee, Science Advisory Board.]

(7) Radiation Advisory Committee EPA-SAB-RAC-95-006

[Title: "Report on Future Issues and Challenges in the Study of Environmental Radiation, with a Focus Toward Future Institutional Readiness by the Environmental Protection Agency," prepared by the Radiation Environmental Futures Subcommittee of the Radiation Advisory Committee, Science Advisory Board.]

Single copies of any of these reports may be requested and obtained from the SAB, Committee Evaluation and Support Staff (1400), 401 M Street, SW, Washington, DC 20460 or by FAX (202) 260-1889.

Abstract

The Environmental Futures Committee (EFC) of the SAB carried out a year-long study to examine how future developments will affect planning and decision-making for health and environmental quality. In addition to an overarching "Futures" report by the Executive Committee of the SAB, several standing committees prepared equivalent reports in their areas of expertise. This report reflects the perspective of the SAB's Drinking Water Committee.

Emphasizing the fact that freshwater resources are finite, the report first describes major trends in the availability and quality of drinking water resources in the U.S. The major uses of water are described, followed by a discussion of four broad factors that will most seriously impact the future of water quality in the U.S.: a) increased population growth resulting in declining underground water tables and contaminated water sources; b) increased public demand for cleaner drinking water; c) a changing profile of chemical and microbial contaminants of concern in drinking water; and d) pressures to fundamentally change the manner in which drinking water is produced.

The report examines the major challenges that arise from the factors above and makes recommendations in five areas: a) substantial improvement in the management of water resources, with emphasis on pollution prevention, recycling, conservation and reallocation of water resources; b) greatly accelerated research to spur advances in risk assessment methodologies for both chemical and microbial contaminants of water; c) support for changes in treatment technologies; d) support for the consolidation of small distribution systems; and, e) establishment of a surveillance or alert system for emerging waterborne pathogens.

Key Words: Drinking water, future trends, chemical contaminants, microbiological contaminants, risk assessment, surveillance, water treatment.

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Contents

Page

1. Executive Summary

The Environmental Futures Committee (EFC) of the Science Advisory Board (SAB) carried out a year-long study to examine how future developments will affect planning and future decision-making for health and environmental quality. In addition to an overarching "Futures" report by the Executive Committee of the SAB (EPA-SAB EC-95-007), several standing committees of the SAB prepared a report on these themes in their areas of expertise.

This report reflects the perspective of the SAB's Drinking Water Committee (DWC). Its primary goals were to identify the major trends in drinking water resources and water uses in the next 5-20 years, to gauge their likely consequences, and to recommend strategies that would permit the Agency and the Nation to face the challenges posed by those trends most effectively.

The amount of freshwater available is finite and humans everywhere must rely on renewable supplies. For the U.S., present and future requirements for safe drinking water will be governed primarily by population size and patterns of use of this finite resource. Population growth places severe demands on drinking water resources through greater absolute amounts of water needed to support essential human needs (i.e, drinking water, food supply, power supply), greater per capita demands that accompany a rising standard of living and the nature of modern urban society, and increased contamination burdens from the rising use of finite water resources to support human activities. Although the U.S. is a relatively water-abundant country, and its population growth modest, current population trends are sufficient to strain water resources over time, particularly on a regional basis.

One of the most pervasive and serious problems of the future is the decline of ground-water tables, on which approximately 50% of the U.S. population depends for drinking water. This decline is often related to agricultural uses and practices and is particularly serious in the western U.S. Much recent evidence also points to serious contamination of many underground waters as a result of human activities (e.g., by nitrates and toxic chemicals), even under optimal conditions of regulation and technological control.

Industrial development will continue to be an important focus of concern as a principal source of water contamination (both underground and surface), although the development of effective regulatory strategies to control industrial discharges (point sources) has reduced the relative importance of this source of pollution in the last decades. In the near and long-term nonpoint sources of water pollution will loom as the greater threat to surface water resources.

Coupled with the increased pressures on water resources, there has been a growing and increasingly vocal perception by the public that many drinking water supplies are contaminated, and this trend is likely to continue unabated in the next decades. Increased demands for clean public water supplies also arise from the discovery of new information on health effects (e.g., arsenic and lead), from a declining tolerance on the part of the public to "accept" any health effects, and from the continually increased ability of analytical procedures to detect substances in water at lower levels of concentration. There are also growing expectations for environmental protection that increasingly demand the protection of the best natural resources, rather than their increased use, thus reducing the quantity of resources available to supply drinking water needs, forcing the use of resources of lower quality, and increasingly calling upon the principle of recycling.

All the trends discussed above tend to generate demands for stricter drinking water standards. The substances that have been regulated, however, have often been selected without an adequate evaluation of the *true occurrence* of those chemicals as contaminants in water.

The chemical contaminants of primary concern in drinking water today, and in the foreseeable future, arise from the chemical treatment of water whose goal is to remove the risk of microbiological hazards. Many of these contaminants can be measured at increasingly lower concentrations, often exceeding the ability of scientists to accurately estimate the human health effects of such low levels of exposure. At the same time, recent outbreaks of waterborne infectious disease have focused attention on the shortcomings of current methods of water treatment, which often do not adequately eliminate or reduce hazardous microorganisms from treated waters. These incidents also highlight the need to be extremely careful when modifying water treatment systems in a manner that may give rise to new infectious disease risks.

Increasing demands on renewable water resources have created a need to make tough decisions on how water resources will be allocated. Competition between uses such as drinking water, agriculture, fish and wildlife habitats, and hydroelectric power will increase and greater cooperation will be required between states and localities that comprise an area of a given watershed. In order to address these conflicts, it will be necessary to modify the current State water allocation systems so that they become more responsive to the trends in resource availability and use described earlier, and particularly to facilitate increased conservation and reuse of water. Also, the infrastructure of many U.S.

water supply systems is old and in need of replacement. Distribution systems, particularly, will need replacement on an ever increasing basis throughout the nation. Finally, many areas of the U.S. are supplied by small and often inefficient water supply systems that will need to be replaced and consolidated into larger systems.

The most difficult challenges to the production and delivery of safe drinking water in the next decades will be in the areas of evaluating and minimizing the competing risks from chemical and microbiological contaminants that occur in water at very low concentrations. Significant advances in toxicology and epidemiology will be needed to overcome current gaps in scientific knowledge, including the development of a solid biological basis for extrapolation of animal data to humans, the development of dose-response models that account for differences in metabolism and pharmacokinetics for each chemical, the elucidation of the mechanism by which each chemical produces its effects and the identification of any intrinsic differences in these mechanisms in animals and humans. In addition, the recognition that the barriers traditionally used to reduce microbial hazards gives rise to chemical hazards has focused attention on the fact that there are currently no well developed and validated methods to compare microbial to chemical risks. Without such methods, it is difficult to make decisions that minimize both types of risk.

A number of likely trends in treatment and distribution technology are arising as a result of the growing pressures on drinking water supplies. These include improved filtration for the elimination of microorganisms, the use of disinfectants other than chlorine, and developments in membrane treatments. The use of alternative technologies to produce drinking water may also come into its own in the longer term, particularly desalination of sea water, which is today prohibitively expensive.

The Committee recommended: a) improvements in the existing systems of management of renewable water resources in order to improve quality and increase quantity; b) substantial acceleration in the research to spur advances in risk assessment methodologies for both chemical and microbiological contaminants of water; c) support for changes in treatment technologies, especially with regard to disinfection; d) support for the consolidation of small, inefficient water systems; and, e) the establishment of a surveillance system for emerging waterborne pathogens.

2. Introduction

2.1 Background and Charge of Futures Project

Increasing rates of economic, technological, and societal change are rapidly transforming the manner in which government, industry, and consumers grapple with environmental problems and opportunities. A clear understanding of the dynamics of these changes and the factors that will drive health and environmental developments and concerns in the decades ahead is critical to the development of policy responses that are preventive, focused, and effective. To assist the Agency in preparing for such future developments in a rapidly changing world, the Assistant Administrator for the Office of Policy, Planning and Evaluation (OPPE) at EPA, David Gardiner, and EPA Administrator Carol Browner asked the SAB to carry out a study addressing future environmental and human health problems.

The EFC of the SAB was formed to carry out a year-long study to examine how future developments will affect planning and future decision making designed to improve health and environmental quality. The principal objectives of the project were to:

a) identify and assess the short- and long-term impacts of economic, societal, and technological developments that may affect future health and environmental quality;

b) investigate methodologies that may guide the planning efforts of government, industry, and consumers to anticipate potential adverse health and environmental impacts from human activities; and

c) select a few key trends to examine with a given methodology and develop recommendations for assuming future challenges posed by those trends.

The outcome of this project is an overall report by the SAB's EFC, together with individual reports by several of the 10 standing committees of the Board, each focusing on future issues in their areas of expertise. While the deliberations leading to the individual committee reports played a role in the overall Futures report of the SAB, they were also designed to serve as more detailed independent looks at the future in their respective areas. This report reflects the perspective of the DWC.

2.2 Goals and Methodology

The primary goals of the report were to identify the major trends in drinking water resources and water uses in the next 5-20 years, to gauge the likely consequences of those trends, and to recommend strategies that would permit the Agency and the Nation to face those future challenges most effectively.

From the beginning, the Committee explicitly chose to engage in a relatively informal discussion process to meet these goals and develop its report. Because of constraints of time and expertise, they did not systematically investigate the possible use of formal methodologies for futures work of this type.

Specifically, the DWC initially identified a list of "drivers," or factors that in the opinion of the Committee were likely to dominate developments in the drinking water arena in the next 5-20 years. A summary of this initial list of factors can be found in Appendix A. The list was discussed at length, refined, and the "drivers" were then ranked in importance to provide a framework for the Committee's report. The organization and contents of the report reflect the choices made through this informal methodology.

2.3 Contents of the Report

Following this Introduction, Chapter 3 describes the major trends in the availability and quality of water resources for drinking water in the U.S. This includes a description of the current patterns and trends in water use in the U.S., the major factors likely to affect the quality of underground and surface water resources in the near and mid-term, the reasons for an increased demand in the quality of water, and the resulting trend for stricter standards and their likely consequences on treatment and distribution systems. Chapter 4 examines the implications of these trends in three broad areas that are critical to the future effective management of water resources; namely, the need for reallocation of water resources, including the need for more conservation and reuse; the need for a substantially improved scientific basis for the assessment of both chemical and microbiological risks of drinking water contaminants; and the likely developments and changes in treatment and distribution technology. Finally, Chapter 5 makes a number of recommendations for the nearer and longer term, based on the analysis developed in the entire document.

3. Drinking Water Resources: Major Trends in Availability and Quality[1]

3.1 Water Resources are Finite

The amount of freshwater available is finite, and humans everywhere must rely on renewable supplies. For the U.S. population and the world, present and future requirements for safe drinking water will be governed primarily by population size and patterns of use of this finite resource. Renewable water comes as rain or other precipitation whose fate may be to seep into the ground, collect in rivers and lakes, evaporate directly to the atmosphere, or flow back into the sea from which it is then again drawn by the sun's energy. In order for this natural hydrologic cycle to be sustainable, water cannot be taken from reservoirs and other sources faster than it is replenished. There is essentially no more freshwater on the planet today than there was thousands of years ago. Water availability calculations indicate a practical upper limit for the world's available renewable freshwater (estimated as 9,000-14,000 km^3 per year). Not all of it is available for direct human uses, however, as it is evident that a substantial proportion of this amount is also needed to sustain natural ecosystems.

In sharp contrast with the reality of a finite water supply is the enormous recent increase in world population. World population doubled between 1940 and 1990, from 2.3 billion to 5.3 billion human beings, and the per capita use of water also doubled from 400 to 800 cubic meters (m^3) per person per year. It is unlikely that such a future quadrupling of total use could be sustained again.

Freshwater availability is determined by climate, including precipitation and evaporative demand (determined primarily by average temperature). Further, water availability can vary widely from season to season and year to year. Among the greatest single influences on freshwater availability is the number of people taking from a given resource. Population growth not only increases direct demands for water, but it also produces disturbances of the water cycle. Greater needs for energy and food are often accompanied by trends such as deforestation and destructive land use practices. Also, higher standards of living and high density population areas boost demand for finite regional sources of freshwater (Engleman and LeRoy, 1993). A comparison by water resource regions indicates that coastal regions of the U.S. (New England, Mid-Atlantic, South-Atlantic-Gulf, Pacific Northwest, California) accounted for nearly one-half of the total water withdrawn in the U.S. in 1990. In the U.S., each individual is estimated to use more than 700 liters/day, or 185 gallons for domestic purposes.

A country whose annual renewable freshwater availability exceeds about 1700 m^3 per person will suffer only occasional or local water problems (Falkenmark and Widstrand, 1993). Below this threshold countries begin to experience periodic or regular water stress. When freshwater availability falls below 1000 m^3 per person per year, countries experience chronic water scarcity. In the U.S. the total annual renewable freshwater available is estimated at roughly 2,500,000 million m^3. In 1955 a population of 165 million had a per capita water availability of 14,900 m^3. By 1990, with a population of 250 million, the figure was reduced to 9,900 m^3, a drop of 33.6% in 35 years. While this figure suggests that the U.S. can still be considered a water-abundant country, the recent rapid decline in per capita availability does not instill confidence for our future. Further, regional scarcity of renewable water, such as that experienced in California in 1987-1992, can produce devastating results to ecosystems and water quality. Increasing populations in urban areas and arid sections of the country intensify shortages of water when drought conditions occur. This will only be aggravated in future years with continuing population growth.

3.2 Patterns of Water Use in the U.S.

Before examining future trends in the availability of water, it is instructive to briefly review the major uses of water in the U.S. The U.S. Geological Survey (USGS) conducts an authoritative survey of water use in the U.S. in 21 water-resource areas that encompass each state, Puerto Rico, the U.S. Virgin Islands, and the District of Columbia. The following quote from the 1990 survey provides a succinct picture of U.S. water uses:

> "Water withdrawals in the U.S. during 1990 were estimated to average 408,000 million gallons per day (M gal/d) of freshwater and saline water for off stream uses[2]--2% more than the 1985 estimate. Total freshwater withdrawals were an estimated

[1] This section is derived mostly from two publications: U.S. Geological Survey (USGS) Circular 1081 on the estimated uses of water in the U.S. in 1990 (these circulars are prepared at 5-year intervals by USGS) and *Sustaining Water: Population and the Future of Renewable Water Supplies* by Population Action International (1993).

[2] Off stream use - water withdrawn or diverted from a ground or surface water source for public-water supply, industry, livestock, thermoelectric power generation, and other uses. Sometimes called off-channel use or withdrawal.

339,000 M gal/d during 1990, about the same as during 1985. Average per capita use for all off stream uses was 1,620 gallons per day (gal/d) of freshwater and saline water combined and 1,340 gal/d of freshwater. Off stream water-use categories as used in the USGS Circular 1081 are classified as public supply, domestic, commercial, irrigation, livestock, industrial, mining, and thermoelectric power. During 1990 public-supply withdrawals were an estimated 35,800 M gal/d, and self-supplied withdrawals were estimated as follows: domestic, 3,390 M gal/d; commercial, 2,390 M gal/d; irrigation, 137,000 M gal/d; livestock, 4,500 M gal/d; industrial, 22,600 M gal/d, of which 3,270 M gal/d was saline water; mining, 4,960 M gal/d, of which 1,650 M gal/d was saline; and thermoelectric power, 195,000 M gal/d, of which 64,500 M gal/d was saline."

More detailed information from the USGS survey can be found in Solley et al. (1990). In 1990, freshwater withdrawals in the U.S. were 339,000 M gal/d. The four largest use categories were agricultural irrigation (40.4%), thermoelectric facilities (38.6%), public supplies (11.4%), and industrial uses (5.7%). Future management and conservation initiatives in these four use areas, which comprise 96% of freshwater uses, are the most likely to have favorable impacts in the availability of water.

3.3 Major Trends and Their Impacts on Future Water Quality

What factors will most seriously impact the future of water quality in the U.S.? Four broad factors can be identified: a) increased population growth resulting in declining underground water tables and contaminated water sources in general; b) increased public demand for cleaner drinking water, which will manifest itself in many different ways; c) a changing profile of contaminants of concern in drinking water; and d) the resulting pressures to fundamentally change the manner in which drinking water is produced (i.e., lower use of chlorine-containing compounds by industry in general, and in drinking water in particular). The salient aspects of each of these factors is discussed in this section, in terms of both the near term (5 years) and the long term (20 years).

3.3.1 Population Growth

Population growth places multiple and often severe demands on drinking water resources, as anyone who has resided in a growth state like California can easily understand. These demands arise from the greater absolute amounts of water needed to support essential human needs (i.e., drinking water, food supply, power supply), greater per capita demands that accompany a rising standard of living and the nature of modern urban society, and increased contamination burdens from the rising use of the water to support myriad human activities. Although the growth of population in the U.S. has slowed and is nowhere comparable to the rapid pace of the developing world, the U.S. rate of growth is sufficient to strain water resources over time, particularly when the heterogeneous distribution of population growth is considered.

The availability of freshwater to meet growing demands depends upon its regeneration rate. For surface water sources, such as rivers, it has been estimated that the rate of regeneration is about 18 days, whereas for large lakes and deep aquifers it can span thousands of years. Depending upon the type of hydrogeological formation, ground-water replenishment may take days to millennia (Engelman and LeRoy, 1993). In the U.S. the available sources of renewable water and the issues associated with its use and regeneration vary considerably across different regions. The growing use rate of this resource, however, may soon begin to challenge or exceed the ability for nature to replenish it.

3.3.1.1 Ground-Water Availability

One of the most pervasive and serious problems of the future is the decline of ground-water tables. This is particularly important because approximately 50% of the U.S. population currently depends on underground sources for its drinking water (Borrelli, 1988). The decline in availability of potable underground water is often related to agricultural uses and practices. This phenomenon is especially true for the western United States, where current trends suggest a severe shortage of ground water as a source of acceptable source of potable water in the future.

Some of the unsustainable ground-water use involves "fossil" aquifers, i.e., underground reservoirs that have held water hundreds or thousands of years and that receive little replenishment from rainfall today. These aquifers are essentially nonrenewable. An example is the large and important aquifer system in the High Plains (the Ogallala formation) that stretches from southern South Dakota to northwest Texas. It has been undergoing depletion for several decades principally from its heavy use in agriculture. The High Plains aquifer supplies about 30% of the ground water used for irrigation in the U.S. The most severe depletion has occurred in northwest Texas, where heavy pumping for irrigation began expanding rapidly in the 40s. As of 1990, 24% of the Texas portion of the Ogallala had been depleted, a loss equal to nearly six years of the entire state's water use for all purposes (Brown, 1993). In addition, pumping costs have risen and irrigation has become uneconomical in northwest Texas (Brown, 1993).

The continued long-term pumping of underground water in the Sacramento and San Joaquin Valleys of California is another example of a regional trend towards depletion of ground-water resources. In this area of the country, intensive pumping for agricultural, industrial, and domestic use is leading to intrusion of salt water from the Pacific Ocean, thereby reducing the water's suitability for drinking in future years.

Ironically, technological advances in irrigation have also tended to facilitate large population shifts to arid areas, thus placing increased pressures on their poor or limited water resources, especially underground sources. These areas were largely inaccessible as large urban habitats until recently. Also, climatic modelers have been cautiously predicting that the earth will gradually warm in the years ahead, producing gradual changes in climatic patterns. For instance, the middle of North America may slowly grow arid (Milbrath, 1994). As a result, will extreme weather conditions cause population shifts? If so, the consequence may also be important shifts in the geographical patterns of consumption of drinking water, with resulting impacts on the future patterns of regional water scarcity problems.

3.3.1.2 Ground-Water Contamination

In addition to depletion of ground-water resources, much recent evidence points to serious contamination of many underground waters as a result of human activities (e.g., agriculture, industry, transportation). Increased population tends to increase these activities and the resulting contamination, even under optimal conditions of regulation and technological control. Results from surveys by the USGS and state agencies of 100,000 wells indicate that for the past 25 years underground sources have become increasingly polluted by nitrates and other toxic chemicals. Nitrates from fertilizer use on agricultural crops is common. Excessive nitrates in wells in areas as diverse as Nebraska, Iowa, and California's Sacramento Valley have been reported. The Geological Survey stated that the "Current trends suggest that nitrate accumulations in ground water of the U.S. will continue to increase in the future" (Borrelli, 1988). Evidence has also mounted regarding contamination of underground aquifers by organic solvents and other hazardous substances from past waste disposal practices, underground storage tanks, landfills, and other sources.

3.3.1.3 Surface Water Availability

Surface water availability is also under severe strain in major areas of the country. A study by the National Academy of Sciences suggests that water volume in northern California rivers and the Colorado River will decline by as much as 60% in the future. In the next couple of decades this would leave much of the West with severe shortages of water. The frequency of droughts and the danger of major fires would increase substantially in southern California. The forests throughout much of the West and upper Midwest would experience similar incineration (Borrelli, 1988).

On the Atlantic Coast, tide gauges have documented a rise in sea level of nearly a foot over the past century. Models predict that the level will have risen by another foot in low-lying coastal regions of the country in 2030, and by as much as three feet in 2100. Besides coastal erosion, other threats posed by a one-to-three-foot rise in sea level include increased salinity of drinking water and saline intrusion into river deltas and estuaries, which would imperil fisheries (Borrelli, 1988).

The most easily accessible sources of renewable freshwater (rivers, streams, lakes, and aquifers) already have been developed for the three major uses discussed in Chapter 2. Remaining sources of untapped freshwater supplies available for mobilization in the U.S. are few, and the cost for developing less accessible sources will be high. Also, the transport of water from one river basin to another such as in the western U.S. is costly (Engleman and LeRoy, 1993).

3.3.1.4 Surface Water Contamination

Industrial development has been and continues to be an important focus of concern as a principal source of water contamination (both underground and surface). Yet industrial development continues to be an important social goal of virtually every country in the world, including the U.S., and such development increases with absolute increases in population and with the increased demand for manufactured goods that accompanies rising standards of living. In the last decades, the development of effective regulatory strategies to control industrial discharges (point sources) has progressively reduced the relative importance of this source of pollution. Yet increasingly tighter controls in industrial pollution and pollution prevention incentives will still be needed and implemented in the future. The second law of thermodynamics tells us, however, that this battle can only be won through the expenditure of increasing amounts of energy.

Nonpoint sources of water pollution, on the other hand, have been assuming increasing importance as major sources of water contamination. In the near and long term, this source of pollution will loom as the greater threat to surface water resources. The earlier discussion described agricultural runoffs as important nonpoint sources affecting underground waters, but agriculture runoffs also severely impact surface waters, while increased population density in urban areas are a major source of runoff contamination by heavy metals, organic chemicals, and other potential chemical hazards.

In summary, increased population is resulting in declining underground water tables and contaminated water sources in general. These trends are tangible indications of unsustainable water use that are increasingly placing water budgets in the U.S. badly out of balance (Brown, 1993).

3.3.2 Increased Demand for Clean Water

3.3.2.1 Increased Public Awareness and Expectations

In the last decade, there has been a growing perception by the public that many drinking water supplies are contaminated, and this trend is likely to continue unabated in the next decades. A clear sign of this public perception has been a marked rise in the use of bottled water throughout the country. A complete discussion of the reasons for this perception is beyond the scope of this report, but it is clear that many of the trends in contamination of surface and underground waters described in the earlier section were important determinants of this public attitude. Recent outbreaks of protozoal, viral, and bacterial disease and occasional requirements for boiling of water from public sources have also increased awareness by the public of the fragile nature of the barrier between safe and contaminated water supplies.

3.3.2.2 New Knowledge and Lower Detection Levels

Increased demands for clean public water supplies also arise from the discovery of new information on health effects (the effects of arsenic and lead are current examples with direct relevance to water), from a declining tolerance on the part of the public to "accept" any health effects, and from the continually increased ability of analytical procedures to detect substances in water at lower levels of concentration. The latter trend already often exceeds the ability of scientists to accurately understand and estimate the human health effects of such low levels of exposure.

3.3.2.3 Increased Demand for Protection of Virgin Resources

A subtle but important trend in the next decades will also be that growing expectations for environmental protection will increasingly demand the protection of the best natural resources, rather than their increased use. This will reduce the quantity of resources available to supply drinking water needs, force the use of resources of lower quality, and increasingly call upon the principle of recycling to find ways to make the recycled resources do the job once done with "virgin" resources.

For example, the Owens River Aqueduct, which supplied 80% of the water to Los Angeles a few years ago, supplies a much smaller fraction of the city's water today, mostly because of agreements designed to protect Mono Lake. The state water project has had its yield substantially reduced in order to protect certain species in the San Francisco-San Joaquin Delta. The result is not only water conservation, water marking, reduced agricultural supplies, and more traditional wastewater reclamation, but serious consideration of water supplies for drinking that would not have been considered in the past. For example, the Metropolitan Water District of Southern California is seriously studying sea water desalting and the city of San Diego is now considering a project involving "indirect potable reuse." The indirect potable reuse concept includes applying advanced water treatment to filtered, disinfected secondary effluent and discharging it into a reservoir that serves as a part of the supply to the city's drinking water treatment plant. Both of these alternatives involve the use of sources of water of originally much poorer quality than those that have traditionally been used. EPA's current regulations are not designed with water sources of this quality in mind.

3.3.2.4 Trend for Stricter Standards

All the trends discussed above tend to generate demands for stricter drinking water standards. If properly channeled, these demands will help to minimize any detrimental public health impacts of changes in the manner drinking water is obtained and treated in the future. There are, however, several troubling patterns in the regulatory arena that could undercut the potential benefits of future standards.

First, the selection of contaminants to regulate in drinking water too often has been driven by the identification of those chemicals that are used in larger volumes on a national scale, or those chemicals that are perceived as "problems" in the environment, independent of the *true occurrence* of those chemicals as contaminants in water. For example, rulemaking has been pursued for many persistent pesticides, PCBs, and dioxins, yet these chemicals are rarely, if ever, found in drinking water, because of their physical/chemical characteristics. This type of priority-setting can be very wasteful of the limited resources of the EPA and the regulated communities.

Secondly, the importance of devising adequate regulatory strategies will increase dramatically as the proportion of reused or wastewaters increases in drinking water systems as a result of diminishing supplies. The character of wastewaters will vary by geographical area, because nonpoint sources of contamination such as storm water runoff, pesticides that are mobile in soils, and nitrates will vary by regions. An effective regulatory strategy will require the flexibility to take into account these regional variations.

3.3.2.5 Consolidation of Existing Water Supply Systems

The infrastructure of many U.S. water supply systems is old and in need of replacement. Distribution systems, particularly, will need replacement on an ever increasing basis in a significant proportion of towns and cities. Also, many areas of the U.S. are supplied by small and often inefficient water supply systems. In the next few years, it is very likely that the need for massive replacement of many systems, combined with the demands for stricter drinking water standards described above, will result in the consolidation of many small systems. Mechanisms to encourage such consolidation have already been a part of legislative proposals for the reauthorization of the Safe Drinking Water Act and the debates surrounding it. Appropriate consolidation of small systems should improve the overall quality of water and provide increased revenues to implement water treatment technologies now available only to larger systems. Larger, consolidated distribution systems, should also have a substantial beneficial effect on water quality.

3.3.3 Changing Profile of Contaminants of Concern

For most of this century and throughout the world, the major public health goal in the treatment of water prior to its use for drinking has been to reduce or eliminate the probability of microbial contamination and thus to prevent waterborne infectious diseases. The most economical and proven treatment of water for this purpose involves the use of reactive chemicals, (particularly different forms of chlorine, although other chemicals have been used also).

Many of these chemicals, however, have been discovered to give rise to a variety of by-products when they are used to disinfect natural waters, and a growing number of these *disinfection by-products* are now identified as potential health hazards to water consumers. For example, there is substantive epidemiologic and/or toxicological evidence to suggest that certain by-products of chlorine and ozone, two common treatment chemicals, may pose risks of cancer and perhaps other health effects. The *degree* of risks posed by the concentrations of these chemicals that are actually found in drinking waters, however, are the subject of considerable controversy. These potentially hazardous by-products arise from chemical interactions between the natural organic contaminants of all water sources, particularly surface waters, and the very reactive nature of the treatment chemicals. Thus, ironically, the chemical contaminants of primary concern in drinking water today, and in the foreseeable future, arise from the chemical treatment of water whose goal is to remove the risk of microbiological hazards.

The following two sections discuss the major factors affecting the changing profile of chemical and microbial contaminants of concern in the drinking water arena.

3.3.3.1 Chemical Contaminants

There are two major and somewhat overlapping sources of chemical contaminants of concern in drinking water in the U.S. These are hazardous by-products generated by the treatment processes, as described briefly above, and the contaminants from multiple leaching processes from natural and man-made surfaces that contact water from the source to the consumer. With some exceptions, natural contaminants in source waters, even surface waters, are not typically the most serious chemical contamination problem. The U.S. fortunately has had sufficiently plentiful water resources to allow most sources of drinking water to be selected with minimum possibility of chemical and microbial contamination.

The evaluation of the risks arising from disinfection by-products is complicated by the increased ability to detect these by-products in treated waters, an ability that often outstrips the scientific information and knowledge available to support accurate and useful risk assessments for them. In other words, the current state of scientific knowledge often falls short of what is needed to assess the magnitude of the hazards posed by these by-products, certainly the degree of understanding sufficient to design policies that can minimize chemical risks without raising the competing risks of waterborne infection. This critical difficulty in grappling with the risks of water contaminants is discussed in more detail in the next chapter.

3.3.3.2 Microbiological Contaminants

The microbiological side of the drinking water treatment scenario is equally critical, however. As the use of traditional or new chemical treatments is modified to reduce the generation of hazardous by-products, there is a need to maintain the efficacy of water treatment plants to minimize the threat of waterborne disease.

Quite aside from the traditional concern for the disinfection goals of water treatment plants, a number of recent outbreaks of waterborne infectious disease (e.g., cholera, and those attributed to *Cryptosporidium*, *Giardia*, *E. coli 0157:H7* and *Legionella*) have focused attention on the shortcomings of current filtration and disinfection components of water treatment. Although much more scientific data are needed to draw an accurate picture of the threats posed by these organisms in U.S. water supplies, it is clear that, at least in some instances, traditional treatment methods may not adequately eliminate some of these and possibly other hazardous microorganisms (e.g., viruses) from treated waters.

In addition, it is likely that the prevalence of many waterborne diseases, including those mentioned above, are woefully underestimated. Several of these diseases may be having sizable public health impacts because of the large numbers of people they affect. Also, while most of these infectious disease threats are unlikely to pose fatal hazards to healthy individuals, some may be having severe impacts on more sensitive, weaker, or immunocompromised individuals. For example, it is projected that from 1980 to 2020, the number of individuals over 65 will double from 25 to 50 million. Likewise, the number of immunocompromised individuals is a relatively new and severe problem, magnified by the current AIDS epidemic and escalated by cancer chemotherapy and organ transplant patients. Not only are these groups of individuals more susceptible to infection by waterborne or water-based microorganisms, but they face a significantly greater risk of severe disease and mortality from infection than healthy individuals. Thus, the risk of water-associated illness in the U.S. is likely to increase in the coming decades. Climate change may also affect the evolution of new pathogens and their spread through the environment.

Another area of concern to microbiologists is the possibility that the profile of microorganisms that grow in water distribution systems could change to a mix of new and/or more resistant threats to human health. There are at least two reasons for this concern. First, changes in water treatment *practices* that are triggered by the need to reduce exposure to toxic disinfection by-products may create new niches for unrecognized, opportunistic or antibiotic-resistant pathogens to grow to numbers that increase the risk of illness in exposed populations. Secondly, the likely overhaul of many water distribution systems in the next decades with new materials (e.g., plastic pipes) may also change the habitat sufficiently for new or modified microorganisms to flourish.

4. Future Challenges and Strategies in Management of Water Resources

As described earlier, it can be anticipated that source waters for the production of drinking water will degrade significantly over a 20-year period, as population increases and the competition for varying uses of water become more intense. These trends will pose challenges and require new strategies in the assessment of risks from water contaminants, as well as in the areas of water resource management, treatment, and distribution. In brief, these challenges will be, first, a need to reexamine the character of existing water allocation systems, shifting their focus from the development of abundant water resources, to one of increasing conservation and reuse of those resources. Secondly, there will be demands to substantially improve the scientific basis of the evaluation of the competing and changing risks of chemical and microbiological contamination of drinking water. Thirdly, there will also be a need to use the results of the improved scientific knowledge to design treatment and distribution systems that minimize these risks in a cost-efficient manner.

4.1 Water Management

4.1.1 Water Resource Allocation Systems

Increasing demands on renewable water resources due to increasing population pressure and other factors have created a need to make tough decisions on how these water resources will be allocated. Competition between uses such as drinking water, agriculture, fish and wildlife habitats, and hydroelectric power will increase and greater cooperation will be required between states and localities that comprise an area of a given watershed. For example, competition for water resources on the Columbia-Snake River system in the Pacific Northwest, where river-blocking dams have caused problems with the salmon fisheries, has resulted in several options, all with potentially severe consequences. These include a lowering of the Snake River for four months to natural levels or a drawdown of the Lower Granite Dam for four months a year. Both would impact fisheries viability, electric power generation, agriculture, recreational uses, rights of Indian tribes, and modification of a watershed affecting irrigation for southern Idaho. This example also points to the need for a major program of watershed management that includes restoration of watersheds, wetland protection and extension, stabilization of aquatic and terrestrial areas and provision for safe drinking water.

In order to address these conflicts, it will be necessary to modify the current state water allocation systems so that they become more responsive to the trends described in the earlier chapter, and particularly to facilitate increased conservation and reuse of water. The current state allocation systems were typically established in the last century, during an era of abundant water resources and a need for their development. They have allocated all the available water, and then some, to uses such as irrigation, ranching, and mining. Existing mechanisms to adjust water allocations to the new realities, such as those of the Snake River System, are woefully inadequate, and it is necessary to adapt existing policies to reflect the change from the past era of development of abundant untapped resources to an era of management of shrinking available resources.

Any substantial changes in water allocation systems would be complex and politically difficult to accomplish, however, as they would have substantial and widespread impact, particularly throughout the West (Borrelli, 1988).

4.1.2 Reuse and Conservation

As a result of decreasing and deteriorating water resources, it will also become increasingly necessary to reuse nontraditional sources of water for potable purposes. Reuse of water will extend to the use of surface waters of less dependable quality. There will also be pressures for the *direct* recycling of wastewater to treatment plants whose product will go directly to potable water systems, bypassing any intermediate discharges into water bodies and the consequent partial natural cleaning processes. While this is not qualitatively different from current practices--most surface water has been "used" at some point in the past--the need for faster reuse cycles will greatly intensify with increased competition for available supplies of freshwater. The intensity of this need will vary geographically, but in degree rather than substance.

Finally, as high quality drinking water supplies decrease, it also will be necessary to apply water conservation practices more widely and consistently, e.g., lining of irrigation canals, installation of more efficient plumbing, and consideration of reallocation of water rights. Conservation will cause big changes in drinking water systems, however. Lowered demand for water will mean slower flows and longer residence times in existing distribution systems, with attendant quality problems (disinfectant residuals, regrowth, corrosion, etc.). Also, because of the fixed costs inherent in water utility operations, water rates per unit volume will have to be higher in order to raise the necessary revenue. Although not in the purview of the DWC, the impact of water conservation on the wastewater collection system and treatment plant will also need to be addressed.

The necessary changes in water reuse and conservation will require public acceptance, and it will be necessary to educate the public on the various issues facing our society so that the modified water management strategies can be properly appreciated and successfully implemented.

4.2 Risk Assessment of Water Contaminants

4.2.1 Chemical Contaminants

The health impacts of drinking water contaminants depend on the nature of individual chemicals and their concentrations in drinking water as it is consumed. These concentrations are typically very low, and the current state of scientific knowledge is often inadequate to accurately estimate potential health risks that may arise from the resulting low exposures. The most difficult challenges to the production and delivery of safe drinking water in the next decades, therefore, will be in the areas of evaluating and minimizing the competing risks from chemical and microbiological contaminants that occur in water at very low concentrations. Significant advances in toxicology and epidemiology will be needed to overcome current gaps in scientific knowledge.

In general, it will be necessary to establish a solid biological basis for extrapolation of animal data to humans for a relatively select number of chemicals of most immediate interest, i.e., disinfection by-products. The dose-response models developed from this effort would explicitly consider differences in metabolism and pharmacokinetics for each chemical, the mechanism by which each chemical produces its effects and any intrinsic differences in these mechanisms in animals and humans. Much of the human data will have to be developed using *in vitro* techniques that have been validated by *in vivo/in vitro* comparisons in several species of experimental animals. In addition to addressing the questions of direct relevance to drinking water, these efforts will have the long-term benefit of establishing principles that will be applicable to the evaluation of other chemicals in a much more cost-effective way. In turn, this approach will provide a much more credible means of dealing with complex mixtures of chemicals that are more typical of actual human exposure.

The development of more biologically based risk assessment tools may also change the evaluation of which adverse effects of chemicals are considered to be most important. For example, the risks estimated to arise from carcinogens that act by cytotoxic rather than genotoxic mechanisms will probably decrease significantly. As calculations of carcinogenic risk become more biologically based and thus more realistic, the impact of other effects that are classically treated as threshold phenomena (e.g., developmental toxicities) will become more prominent in regulation. Moreover, it is also possible that the definition of appropriate safety factors may be found inadequate as knowledge of those mechanisms that are responsible for such effects are better defined.

Finally, to support the regulation of disinfection by-products, the EPA is currently relying on sizable estimates of cancer risks attributable to the chlorination of drinking water from the scientific literature (Morris et al., 1992). Some scientists, however, are skeptical of these estimates, for numerous reasons (Bull and Kopfler, 1991). In addition, many important by-products of chlorination that have not been toxicologically characterized are produced by other means of disinfection, so that shifts away from chlorination to other methods of disinfection may not successfully reduce carcinogenic risks.

4.2.2 Microbiological Contaminants

A somewhat different problem exists with risk assessment for infectious agents. Classically, an estimated degree of risk has not been explicitly used with microbial agents. Rather, the effort has depended upon hazard identification and then installation of general methods of treatment that provide a series of barriers that reduce or prevent exposure in a dependable way. The recent recognition that the barriers traditionally used to reduce microbial hazards give rise to chemical hazards has focused attention on the shortcomings of the available methods to compare microbial to chemical risks such that decisions can be made that result in minimizing both types of risk.

While the methods for quantifying risks from environmental exposure to infectious agents are inadequate, they have one distinct advantage over the estimation of risks from chemical agents, in that in many cases there is no need to do interspecies extrapolations. Most of the agents that are of concern have been clearly shown to produce human disease, and frequently information is known about how likely infection is likely to give rise to morbidity and mortality (Haas, 1993). Moreover, there has been work to actually document the economic impact in known cases, and this provides some basis for estimating impact for unreported cases as well (Payment, 1993). What is generally not known are actual levels of exposure, the infectious dose for many of the agents, and how these factors might vary in their impact with susceptible populations.

4.2.3 Strategies to Address Risk Assessment Needs

What strategies are available to better address the uncertainties in characterizing and comparing chemical and microbiological risks? The most important strategy in the near and midterm must be to ensure that sufficient research efforts are implemented to address the current gaps in toxicologic and epidemiologic knowledge for both types of contaminants. Research activities in these two areas must be concurrent and coordinated by the development of methodologies that can effectively compare the disparate risks of waterborne disease and chemical contamination.

The problems posed by disinfection by-products can be addressed appropriately only after considerably more data are available to a) verify the currently available epidemiologic findings; b) establish that the by-products responsible for the effect are decreased by other forms of treatment; and c) that other treatments do not give rise to by-products of comparable health concern.

Unfortunately, the critically needed advances in risk assessment methodologies, as described above, have not been a priority of regulatory activities to date, and current levels of publicly funded research are insufficient to address these needs. If allowed to continue, this trend will have very damaging consequences.

If sufficient investment in this type of research is not made, it will be very difficult to articulate directions for the truly large investments that will be needed to improve drinking water treatment and distribution systems and accommodate anticipated population increases over the next two decades. Many current distribution systems are more than 100 years old and due for replacement or major repairs. To a lesser extent, many treatment plants are also due for replacement in the U.S. Treatment plants must consider a productive lifetime of at least 25-50 years, and local authorities will find it increasingly difficult to obtain financial resources in the face of scientific uncertainty about potential risks and uncertain standards that could make sizable investments obsolete in a few years. Moreover, regulation of chemicals whose risks cannot be clearly documented with scientific evidence will tend to undermine public confidence in the process for setting drinking water standards.

4.3 Design of Treatment and Distribution Systems

The combined pressures of population and growing demands for cleaner drinking water were discussed in Chapter 3. The critical need for a solid scientific basis to address the consequences of these pressures and to guide investments in water treatment facilities over the next two decades was discussed above. Despite the gaps in scientific knowledge, however, a number of likely trends in treatment and distribution technology are already arising as a result of these pressures. The more likely technological developments in the near and midterm are discussed in Section 4.3.1 below. Treatment changes in the more distant future are discussed in Section 4.3.2.

4.3.1 Technology Changes in the Near Term

The primary goals for changes in treatment and distribution systems in the next decade will be to improve microbial safety, control corrosivity, and lower concentrations of disinfection by-products. Unfortunately, these goals are somewhat in conflict. For example, disinfection is improved at low pH and in the presence of higher concentrations of disinfectants. In contrast, low pH aggravates corrosivity and high concentrations of disinfectant create more disinfection by-products.

Treatment changes will be required to improve filtration such that it will remove some of the more difficult to inactivate microorganisms such as *Giardia* and *Cryptosporidum*. This will allow disinfection using lower concentrations of disinfectants. Disinfection by-products will be controlled through the removal of precursors by improving coagulation, or adding adsorption, oxidation, or membranes as unit processes beyond "conventional" treatment. This will allow the use of lower concentrations of disinfectant to provide adequate disinfection and the use of high pH to meet the requirements of the "lead and copper" rule.

Two common disinfectants do not use chlorine or chlorine-containing products, ozone and ultraviolet radiation. Both will probably be employed more frequently. Because neither produces a disinfectant residual for distribution system protection, however, a small amount of chlorine or chlorine-based material will continue to be needed to maintain protection of the public. Another approach to biofilm control in distribution systems involves the removal of biodegradable organic matter in the treatment plant. This will lower the demand for biocide in the distribution system, thus saving on the use of chlorine and its compounds.

The final area of near-term changes relates to improvement of ground-water quality. Many ground waters have been contaminated by solvents and other organic compounds. As clean-up and restoration activities increase, the challenge to the water utilities may ease somewhat, although there will be increased pressures from growing runoff (nonpoint) sources of contamination.

Of course, the development of technology makes higher environmental standards and higher standards of living possible, at least, if the energy to drive our technological processes become more available in the future. Technological development is the only hope we have for resolving the seeming conflict between our goal of having more people living better while trying to reduce the adverse impact we have on the environment at the same time.

In summary, the most important foreseeable developments in the technology area in the near and midterm are the following:

a) Membrane treatment as a substitute for both conventional filtration and primary disinfection using oxidants.

b) Membrane treatment as a more effective means of removing natural and synthetic organics from drinking water.

c) The elimination of metallic materials in distribution systems and consumer plumbing.

d) The development of methods for stabilizing water in distribution systems that do not depend on maintenance of a residual oxidant in the distribution system.

e) The development of additional strategies to protect membrane disinfected water from contamination during distribution (cross connection control, higher pressure standards, etc.).

f) The development of methods for real-time assessment of microbiological contaminants and/or particulates, including a number of important pathogens.

g) The development of more sophisticated methods for maintaining high water quality during storage in large distribution system reservoirs.

4.3.2 *Technology Changes in the Next 20 Years*

Treatment changes in the more distant future (20 years) are far more difficult to discuss. The treatment technologies that are selected to minimize chemical and microbiological hazards will be decided by the results of the accelerated scientific research in risk assessment recommended in Section 4.1.2 above. Unit processes not yet developed will be competing with conventional treatments for future use.

Moreover, developments in two other areas also will undoubtedly occur, however, both of which will influence drinking water: pollution prevention technology and conservation.

The movement by industry, agriculture, and municipal water and wastewater treatment plants to lower the quantities of their residuals and to recycle them will cause long-range improvements in source water quality. This improvement will lower the pressure on water utilities to continually increase the aggressiveness of treatment to prevent health risks and allow more attention to the production of a quality product, pleasant to the consumer in every way.

Conservation, which was discussed in Section 4.1.2, will also result in changes in cost and quality of drinking water systems, as well as in potential detrimental impacts on wastewater collection system and treatment plants.

Another strategy that will become increasingly available in the next decades will be the use of alternative technologies to produce drinking water. Desalination of sea water, a theoretically sustainable source of freshwater, is one example. It is high in capital and energy costs, generally several times more than water supplied by conventional means. The current major constraint of desalination is the need to use fossil fuels, with their finite supply and contribution to air pollution. Future energy technologies have the potential of being clean, inexhaustible and inexpensive, and therefore may make the pursuit and application of alternative technologies feasible.

The new energy technologies are typically high-tech, industrialized power generation ranging from nuclear fission and nuclear fusion to the large-scale capture of solar energy. For nuclear fission, the answer is breeder reactors to generate power and atomic fuel, although few experts now see this as an option beyond the year 2025 (Garbarino, 1992). For nuclear fusion the key is to find a way to transform globally abundant hydrogen into usable energy. Ohkawa, vice president for fusion power research at Gulf's General Atomic Company, says that research programs could lead to construction of an experimental fusion reactor within a decade (Garbarino, 1992). Cetron (1994) has predicted that fusion reactors producing "clean" nuclear energy will appear after 2010; by 2030 they will be a major source of power. He also predicts that ocean-wave power plants will produce both electricity and freshwater for island communities.

A final observation concerns the effect of technophobia or fear of technology. Technology, particularly chemistry, will continue to be a mystery to the public and, as a result, the public will continue to put pressure on the EPA and on Congress to find-fail safe solutions to problems where only judgments of relative risk can be made. Attempts to balance risk and cost will continue to be viewed as an effort to avoid environmental responsibility. Congress will continue to be frustrated with progress in regulation. Only if the Administration works closely and effectively with Congress, the industry, and the public will a sensible outcome occur.

A wise person once said, "Predictions are always difficult, particularly when they are about the future." Thus, looking five years ahead is risky, but less uncertain, as some of the forces currently in motion will come to fruition in that time frame. A 20-year time line is much more difficult because of unexpected surprises. Looking back 20 years, trihalomethanes were just being discovered, and their impact was totally unpredictable.

5. Conclusions and Recommendations

The major challenges facing the future provision of safe drinking water in the U.S. will be the increased demands on finite water resources and the need to minimize the risks posed by both chemical and microbiological contaminants. These challenges have implications for changes in the management of water resources and for changes that are made to existing drinking water treatment and distribution systems. The Committee's major recommendations in these areas are:

a) **Improve the existing systems of management of renewable water resources.** Greater emphasis must be given to improving the management of existing renewable water supplies. A national management program should include 1) prevention of further water supply deterioration, including pollution prevention and better management of land-use and forestry practices; 2) improvement of our ability to capture a larger proportion of renewable water supplies, including wetland protection and extension; and 3) implementation of water recycling and conservation practices to improve efficiencies of water use, including lining of irrigation canals, installation of more efficient plumbing, and consideration of reallocation of water rights.

b) **Greatly accelerate research to spur advances in risk assessment methodologies for both chemical and microbiological contaminants of water.** Modifications of current water disinfection treatments to minimize chemical risks in the drinking water supply must consider the magnitude of microbial risks that may be introduced as a result of the changes, as well as the creation of other disinfection by-products. To do this effectively, substantial research into risk assessment methodology for both chemical and microbial risks is urgently needed. This research must emphasize a more biologically based risk assessment process in order to determine what adverse effects of chemicals are most important. Without the understanding that will come about from such research, large public investments for changes in drinking water treatment plants may be made on an inadequate and possibly incorrect scientific basis.

c) **Support changes in treatment technologies.** The trends that were discussed in the earlier sections of this report will cause the concepts of water treatment and distribution to change in the future, both in the near term (5 years) and the longer term (20 years or more).

   In treatment systems, technological developments that will need to be improved and implemented will include membrane treatment as a substitute for both conventional filtration and primary disinfection using oxidants. Membrane treatment will also be considered as a more effective means of removing natural and synthetic organics from drinking water. In addition, methods will need to be developed for stabilizing water in distribution systems that do not depend on maintenance of a residual oxidant in the distribution system.

   There will also arise new strategies to ensure adequate future water supplies, particularly improvements in the economic efficiency of desalination of sea water. However, such a process will require a cheaper source of power or energy. New energy technologies ranging from nuclear fission and nuclear fusion to the large-scale capturing of solar energy may develop to the point of making desalination more economically feasible.

d) **Support the consolidation of small distribution systems.** A greater consolidation of small systems should occur that will improve the overall quality of water and provide the necessary revenue to implement treatment technologies now available to the larger systems. The drive toward consolidation should take advantage of the replacement of distribution systems that will be necessary in the near future in many communities.

e) **Establish a surveillance or alert system for emerging waterborne pathogens.** The almost certain changes in water treatment and distribution systems in the next decades and the increased consolidation into larger and large systems for efficiency of control and delivery of water poses the very real danger of the generation and transmission to large populations of heretofore unknown microorganisms that may pose serious disease threats. A surveillance or alert system to detect these threats early should be put in place.

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Appendix A
List of Factors That Formed the Initial Basis of the Committee's Discussion

1. Water supply/demand issues.
2. Environmental protection vs. human uses/needs.
3. Economics, cost of water.
4. Costs to states and communities of regulatory "overload."
5. Use of bottled water, contamination and regulation.
6. Reuse of water.
7. Increase in immunocompromised individuals and resistant organisms.
8. Aging of water system infrastructures.
9. Use of water as garbage disposal vehicle.
10. Ground-water contamination.
11. Use of membrane technology for water purification.
12. Use of salt water, desalination.
13. Dual systems of water delivery (potable, nonpotable).
14. Population shifts and dynamics.
15. Limits on construction and development.
16. Possible shifts away from large urban concentrations.
17. Possible trends towards greater population density with increasing transportation fuel costs.
18. Source protection as a trend.
19. Greater use of networks, as for electrical systems, to shift water resources around country.
20. Use of cisterns and rainwater and solar disinfection.
21. Decreased use of pesticides.
22. Possible increased use of tilled land.
23. Increased demands on water supply if any efforts to re-industrialize.

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