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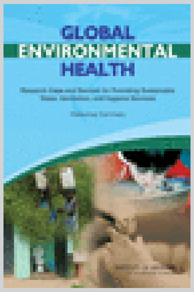

Global Environmental Health: Research Gaps and Barriers for Providing Sustainable Water, Sanitation, and Hygiene Services: Workshop Summary

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GLOBAL ENVIRONMENTAL HEALTH

Research Gaps and Barriers for Providing Sustainable Water, Sanitation, and Hygiene Services

Workshop Summary

Christine Coussens, *Rapporteur*

Roundtable on Environmental Health Sciences, Research, and Medicine

Board on Population Health and Public Health Practice

INSTITUTE OF MEDICINE
OF THE NATIONAL ACADEMIES

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The serpent has been a symbol of long life, healing, and knowledge among almost all cultures and religions since the beginning of recorded history. The serpent adopted as a logotype by the Institute of Medicine is a relief carving from ancient Greece, now held by the Staatliche Museen in Berlin.

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*"Knowing is not enough; we must apply.
Willing is not enough; we must do."*
—Goethe

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ROUNDTABLE ON ENVIRONMENTAL HEALTH SCIENCES, RESEARCH, AND MEDICINE

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Herman Ellis, Division of Public Health, State of Delaware
Jonathan Hall, The Hall Water Report
Roger Lewis, School of Public Health, Saint Louis University

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the final draft of the report before its release. The review of this report was overseen by **Melvin Worth, MD,** who was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the rapporteur and the institution.

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1

Workshop Introduction

The Roundtable on Environmental Health Sciences, Research, and Medicine of the Institute of Medicine (IOM) focuses on building partnerships and facilitating scientific discussions of ongoing and emerging issues in the field of environmental health. The roundtable illuminates scientific discussions to foster understanding among the public, academia, government, nongovernmental organizations, industry, and policy makers, but it does not make recommendations. A cornerstone of the approach is to air divergent views on sensitive and difficult issues in an atmosphere of respect and neutrality, in order to foster dialogue and strategic solutions.

This workshop summary was prepared for the roundtable membership in the name of the rapporteur and includes a collection of individually authored commentaries. The contents of the unattributed sections are based on the presentations and discussions that took place during the workshop. The workshop summary is organized in chapters as a topic-by-topic description of the presentations and discussions. The workshop agenda, as well as speaker information and a list of attendees, appears in the appendixes at the end of the summary.

The reader should be aware that the material presented here expresses the views and opinions of the individuals participating in the workshop and not the deliberations of a formally constituted IOM consensus study committee. These proceedings summarize only what participants stated in the workshop and are not intended to be an exhaustive exploration of the subject matter and should not be perceived as a consensus of the participants, nor the views of the roundtable, the Institute of Medicine, or its sponsors.

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Global Environmental Health: Research Gaps and Barriers for Providing Sustainable Water, Sanitation, and Hygiene Ser

LEARNING FROM THE PAST

Paul G. Rogers, J.D., Chair
Roundtable on Environmental Health Sciences, Research, and Medicine

The nation has made tremendous progress in the past 35 years in addressing its watersheds. Individuals, such as Rachel Carson, and meetings, such as the one in Rio de Janeiro in 1992, spurred individuals and organizations worldwide into action. Many people will remember when the Cuyahoga River caught fire in 1969. As *Time Magazine* reported the incident, “Some river. Chocolate Brown. Oily. Bubbling with subsurface gases. It oozes rather than flows. Anyone who falls into the river does not drown, he decays.” At the same time, the Federal Water Pollution Control Administration dryly noticed, “The lower Cuyahoga has no visible sign of life, not even low forms such as leeches, or sludge worms that usually thrive on wastes. It is also literally a fire hazard.”

The Cuyahoga River fire and other environmental decays of the water systems in the United States led to some of the landmark congressional legislation of the 1970s, such as the Clean Water Act, which helped to clean up the watersheds, and the Safe Drinking Water Act, which ensures that the drinking water is of high quality. These acts ensured that people in the United States will have water for recreation, drinking, and other activities.

The world that we live in is changing. In 1999, the world population surpassed 6 billion people. By the end of the last century, there was a shift in the demographics as more people were living in urban areas than rural areas, which stressed the world’s natural resources. Climate change is no longer an academic debate, but a growing public concern as the impacts of climate change on health are categorized. These effects may include water scarcity, heat waves, and other extreme weather events.

The need for water is vital not only to the United States, but also to all regions of the world. Many regions worldwide are water stressed, particularly those located near large megacities (Figure 1-1) but especially in Brazil, China, India, Mexico, Nigeria, the Philippines, Turkey, and the United States. The Southwest region of the United States, including fast-growing desert cities like Phoenix and Los Angeles, is already experiencing high levels of water stress. However, other regions, such as the South, with its extensive web of rivers, are not immune. For example, metropolitan Atlanta’s rapid transformation to a sprawling city of 4 million people and other rapidly growing areas are starting to tax the region’s water availability.

Current United Nations estimates suggest that there are about 300 potential conflicts over water around the world, arising from disagreements over river borders and the drawing of water from shared lakes and aquifers (Oatridge, 1998). Avoiding these conflicts means using limited resources smarter and looking at new ways to manage and protect water. This is a daunting task, and the solutions will not come from a single sector of the water community but will require differ-

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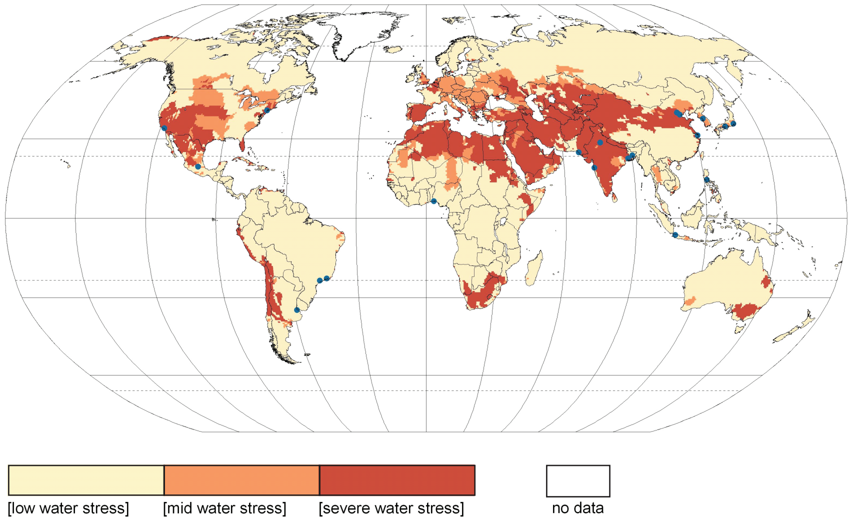

FIGURE 1-1 In 2000, the majority of the sixteen megacities were found along the coasts, within regions experiencing mild to severe water stress; this is particularly true for the cities located on the Asian continent. "Water stress" is a measure of the amount of pressure put on water resources and aquatic ecosystems by the users of these resources, including the various municipalities, industries, power plants and agricultural users that line the world's rivers. The map uses a conventional measure of water stress, the ratio of total annual water withdrawals divided by the estimated total water availability. This map is based on estimated water withdrawals for 1995, and water availability during the "climate normal" period (1961–1990).
SOURCE: Map prepared for the World Water Assessment Programme (WWAP) by the Center for Environmental Research, University of Kassel, 2002. For the water stress calculation: data from WaterGAP Version 2.1.D; Cosgrove and Rijsberman, 2000; Raskin et al., 1997. For the megacities: UN, 2002. Reprinted with permission.

ent expertise from engineers, health research and offices, economists, ecologists, and policy makers.

This two-day workshop held on October 17–18, 2007, in Washington, DC, follows up on previous workshops in 2003 and discusses how to provide people with access to drinking water in the context of sanitation and hygiene. The legislation of the 1970s started to show the value of water by providing protection. This workshop brings together people from various sectors of water services and from various countries to consider how to do this in a sustainable way.

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WORKSHOP OBJECTIVES

Jennie Ward Robinson, Ph.D., Executive Director
Institute for Public Health and Water Research

The issues surrounding water services are some of the most critical challenges facing not only the United States, but also the global community today. In September 2000, the United Nations developed the Millennium Declaration in order to accelerate democratization and securing peace, scale up development and poverty reduction, ensure environmental sustainability, and promote global partnerships. The eight identified goals provided a road map to reduce poverty and hunger, and to tackle ill-health, gender inequality, lack of education, lack of access to clean water, and environmental degradation by 2015. While these are challenging goals, various organizations have identified targets as steps to meet each goal. Targets, such as those identified by the Asian Bank, have been identified under all eight of these goals (see Box 1-1), and if water services around the globe are going to meet the Millennium Development Goals, then organizations cannot discuss water without considering the impact or the interrelationship of sanitation and hygiene. It is the convergence of these strategies that promotes healthy outcomes for both individuals and the environment. A holistic approach is needed. People need to step outside their traditional way of thinking to understand what happens beyond their sphere of experience to ensure water services and environmental health. One of the objectives of this workshop is to think about the interdependence of environmental health and human health as connected through water.

The World Health Organization (WHO) defines human health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO, 1948). The roundtable has built on this definition by looking at broad-reaching goals for environmental health, including establishing and maintaining a healthy, livable environment for humans and other species; promoting an environment that improves well-being and a high quality of mental health; and pleasing for a sustainable the environment to be sustainable for the future. At the same time, these health goals need to create a setting that can address population growth and permits manufacturing and agriculture to thrive.

The timing is right, as the world is under more stresses because of globalization, urbanization, population growth, and climate change. All of these factors have resulted in a stress on many natural resources—in particular water, not only for drinking water, but also for water services being used in agriculture, industry, and recreation. These different uses can be at odds with each other and may be a driving factor in water scarcities today.

A second challenge in addressing needs is that many organizations and agencies are trying to forge a path toward sustainable practices in water, but the various sectors utilizing and governing water services are not interconnected. More integration and a greater understanding of holistic approaches are needed. The current disparate action represents why it is important to find a solution and to

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BOX 1-1
Millennium Development Goals:
Asian Bank Water Supply and Sanitation Targets

MDG 1: Eradicate extreme poverty and hunger
- Providing more water for agriculture and irrigation will increase food production and will help alleviate the world's hunger.
- Improving water infrastructures and services will not only increase water provision but will also provide jobs to local communities and build capacities.
- Easy access to water will halve the proportion of people who suffer from hunger and whose income is less than $1 a day.

MDG 2: Achieve universal primary education

MDG 3: Promote gender equality and empower women
- Access to water supply will reduce the multiple burdens on women and girls, as they are the primary collectors, providers, users, and managers of water in the household.
- Easy access to water will give girls and boys more time to attend school.
- Better sanitation services will improve women's health.
- With their hands free from collecting water, women will have more time to participate in community decision making and have greater opportunities for livelihood improvement.

MDG 4: Reduce child mortality

MDG 5: Improve maternal health

MDG 6: Combat HIV/AIDS, malaria, and other diseases
- Better water quality and sanitation services will reduce children's and expectant mothers' susceptibility to diseases and generally improve health.
- The provision of safe water for drinking and medical purposes will prevent pregnancy and birth complications, and increase people's ability to combat HIV/AIDS, malaria, and other diseases.
- Better water management will reduce the incidence of waterborne diseases.

MDG 7: Ensure environmental sustainability

Better management of water resources will
- Lessen pollution and improve water conservation
- Ensure access to adequate and safe water and improved sanitation services for poor and poorly-serviced communities in rural and urban areas
- Improve the lives of people in slum areas
- Build capacity among communities organized around water supply provision

MDG 8: Develop a global partnership for development
- Where water problems serve as a constraint to development (e.g., water scarcity, salinity, disasters, etc.), improved water resources management and water supply and sanitation services can facilitate partnerships for global development.

SOURCE: Asian Development Bank. Water, Sanitation, and the Millennium Development Goals. Available at: http://www.adb.org/Water/Knowledge-Center/statistics/water-sanitation-mdgs.asp. Reprinted with permission.

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plan a way forward. A second objective of the workshop is thus to consider how planning, management, and interdisciplinary approaches—including technology, social behavioral issues, gender, health, environment, economic, and political aspects—can be integrated to arrive at sustainable solutions.

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Global Water Services: Short- and Long-Range Views

In many regions of the world, water services policies are fragmented. Many different agencies regulate the various aspects of water services, from those that protect the watersheds to those that regulate the water from the tap. The situation may also differ if one lives in a community with a small water technology or a large urban one with a community water services system. Currently, there is a movement toward sustainable water services that incorporate technological, economic, and social aspects in a holistic manner. This holistic approach moves beyond simple access to water to also consider sanitation and hygiene. This chapter looks at the short- and long-term views for water needs both in the United States and abroad.

THE NATIVE AMERICAN APPROACH TO SUSTAINABLE WATER: THE SEVENTH GENERATION CONCEPT

Cathy Abramson, Member
Tribal Board of Sault Tribe of Chippewa Indians

The preservation of the Great Lakes is a matter of great personal responsibility; the lakes have raised countless generations, with the hope that its safe and natural environment will continue to do the same for future generations. A tribe known as the Anishinaabe lived in the Great Lakes region for centuries, and, as recently as a few decades ago, fished and drank water directly from the lakes. Now, industrial contamination from steel and paper mills has caused long-term damage; however, it was the solid waste and trash washing up on the shore of Sugar Island that led the community to create a coalition of local tribes and First Nation groups to fight for their environment and way of life. The way of the tribes has always been to treat the earth in terms of sustainability for seven future generations. Participants are urged to use many modalities, from traditional heal-

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ing, to education, to science, to collaboration with others to push for a successful future for the seventh generation.

SUSTAINING PROGRESS FOR CLEAN AND SAFE WATER

Benjamin Grumbles, Assistant Administrator
U.S. Environmental Protection Agency

When it comes to water, Benjamin Franklin said it best, "we know the worth of water when the well runs dry." As issues of water quality and security coalesce with issues of water quantity, changing landscapes, and weather patterns, the value of water comes into question. Although there are many reasons to believe the current patterns of unlimited, high-quality water are impossible to maintain for the future, water prices remain artificially low, with most of the costs and risks remaining invisible to consumers. Adjusting water pricing to reflect the true costs involved is a major need. This will promote water conservation and improvements and at the same time prevent future costs from escalating in such a way that the well runs so dry or dirty. Prior approaches by U.S. Environmental Protection Agency (EPA) focused primarily on water quality, without considering the limitations or implications of water quantity. This approach is changing, with the EPA hoping to educate stakeholders and the public about the symbiotic relationship between quantity and quality. Challenges to be addressed and potential solutions to ensure the future availability of quality water have been outlined.

The Legacy of Clean Water: Gains in Health and the Environment

The 35th anniversary of the Clean Water Act in 2007 pointed to significant public health advances. For example, of the 230 million people served by wastewater treatment facilities in the United States, more than 98.5 percent are served by systems that provide secondary treatment. Furthermore, an estimated 31 million pounds of pollutants have been kept from waterways in the past 35 years as a direct result of the Clean Water Act and its amendments; the EPA is expanding its efforts to include the impacts of nonpoint sources (water pollution from diffuse sources) as the next step in removing toxic contaminants from water sources. The Safe Water Drinking Act of 1974 has led to nearly universal access to high-quality drinking water. Regulatory standards have been almost entirely achieved through scientific investigation into adverse environmental health impacts, emerging contaminants, and safe levels. In the past century, access to clean water has resulted in a three-quarters reduction in child mortality nearly half the total mortality reduction in major cities (Cutler and Miller, 2005), and a water delivery system admired throughout the world. Despite these gains, many challenges remain that threaten past accomplishments, with the potential to make future threats for adequate and safe water insurmountable.

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Challenges in Future Water Quality and Quantity

Major challenges exist to preserve future water security and quality. These include maintenance of current infrastructure, levels of water "nutrients," such as nitrogen and phosphorous, climate change impacts, such as sea level rise and storm intensity, and preservation of wetlands and coastal ecosystems. Many of these changes are compatible with the future needs and consequent actions of other sectors, such as energy, security, and urban planning. Whether these challenges will be surmounted with an uninterrupted water supply depends on current implementation of changes in policy and regulation.

Science has advanced to develop risk-based health standards under the Safe Drinking Water Act for 90 contaminants. The EPA has established a program to identify emerging and unregulated contaminants for future action. Furthermore, to achieve these goals, the EPA has implemented a multiple barrier approach to protect water from the source to the tap. In an ideal world, carrying out the multiple barrier approach would be easy, but the reality is that contaminations can come from a wide variety of sources. Technology is critical to the process of supplying safe drinking water. The same technology that allows for removal of contaminants also allows for detection of the remaining contaminants at lower concentrations. The challenge for those in the field is that there is considerable uncertainty about the potential effects of low-level contamination on public health. For the EPA, this is an area for further research.

Water Infrastructure: Asset or Emerging Threat

The United States has an approximately 1.6 million miles of water pipeline, which allows approximately the entire nation to have direct access to high-quality and regulated drinking water. Yet many of these pipes are over 100 years old or far past their intended period of use; thus there is an increasing possibility of the presence of pathogens in the pipes that pose risks for vulnerable populations, such as elderly or immunocompromised people. The EPA is currently very concerned about the viability, maintenance, and replacement of the existing pipes, and it estimates the cost to address these problems over the next 20 years at $224 billion. Further strategic planning is needed to increase the capacity of or consolidate the 53,000 water systems in use, of which approximately half serve 500 or fewer people. The public is generally unaware of these risks, a situation that poses an obstacle in terms of funding and widespread support for needed renovations.

The EPA is trying to be proactive with other federal, state, and local agencies, tribal governments, and nongovernmental organizations to help everyone understand the growing need for maintaining, sustaining, and increasing the capacity of these systems, both in the United States and abroad. At the same time, however, people are recognizing that a one-size-fits-all approach is not the right strategy. A 2002 EPA report focused on a strategy for achieving sustainability for water

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and wastewater infrastructure. As part of the improved management of these assets, the report embraced water efficiency, a watershed approach, and full-cost pricing—that is, spreading the cost over all users, with the heaviest users paying a greater share. Building in the cost will allow for maintenance of the system, prevent its reliance on federal taxpayer dollars, and encourage water conservation.

Agricultural Impacts: Nitrogen, Phosphorous, and Sediment

Large-scale impacts of nonpoint source pollution are also a source of concern. Agricultural impacts on water owing to nitrogen are analogous to carbon impacts on energy. Inadequate focus has been given to understanding the complete cycles of nitrogen and phosphorous throughout the environment. Globally, no doubt exists that significant effects on ecosystems and health will result. Recent reports on algae blooms, dead zones, and fish kills have raised concern that little is being done to regulate these nonpoint sources. Furthermore, sediment is associated with large-scale farming operations and loss of vegetation, which threatens to choke off much of the Mississippi River ecosystem. The National Research Council report (NRC, 2008) recommended the need for a more integrated and collaborative approach to focus on the nutrients and sediments in this watershed. It is a daunting task to remedy, as 31 states are part of the watershed and contribute to the nutrient loading. Although the focus of nitrification has been on point sources, recent efforts have concentrated on the nonpoint sources. To begin to address these issues, more regulatory, financial, scientific, and technological solutions are needed to address this problem as its short-term effects expand into larger impacts on biodiversity, water quality, and soil erosion.

Climate Change: Not Just an Energy Problem

As the impacts of climate change become well recognized, areas in addition to energy production and transportation are being investigated to reduce the impact of greenhouse gases. The EPA and the National Water Program, the Clean Air Act, the Safe Drinking Water Act, the Ocean Dumping Act, and programs for the protection of coastlines and wetlands are being reviewed for modifications to mitigate climate change. Particular areas of concern include sea level rise, increasing storm intensity, ocean chemistry, and invasive species. Increased efforts to protect coastal sites are needed as storms become more intense, resulting in coastal erosion and sea level rise; wetlands preservation is an important step in protecting coastal areas. The incursion of storms and the loss of coast may cause drinking water supplies to be contaminated with salt water. The impact of changing weather on water will undoubtedly be considerable—the recent drought in Atlanta is one example of the potential for regional or national conflicts about water rights and access.

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Paradoxically, climate change prevention through carbon sequestration may also risk contaminating drinking water; agencies are therefore creating guidelines to protect drinking water from injected carbon. Changes in acidity or the composition of global oceans are also affecting the ecosystem and the diversity of life. In addition, the introduction of invasive species leads to destruction of natural habitat and disruptions or die-offs throughout the food chain; currently, over 180 invasive species exist from the Gulf of Mexico to the Great Lakes to San Francisco Bay—from protozoa to large fish. Although guidelines exist to regulate ballast water dumping, the EPA is currently considering adding further restrictions on the dumping of ballast water into U.S. waters. These additions to the Clean Water Act would unify and strengthen the U.S. policy that reduces the introduction of aquatic invasive species.

Future Directions for U.S. Water Regulation

Much progress has been made in the area of water and environmental protection over the past few decades. The public has accepted the inseparable links between health, water, and regulatory and scientific environmental protection. Potential future threats still exist, such as problems in the water supply from personal care products, pesticides, and pharmaceutical products. New projects will examine the endocrine-disrupting chemicals and biosolids present in the influent waste stream traveling into wastewater treatment. Several government agencies plan to combine their efforts at multiple stages, from introduction into the waste stream to exposure to health impacts, in addition to creating new guidelines on disposal and water treatment for products disrupting endocrine function.

To reach a sustainable water infrastructure, implementation of full-cost pricing, such as charging users a fee based on water usage, would cover the cost of the water and its infrastructure construction and maintenance. Improvements in the sustainability of infrastructure and increased motivation by organizations and individuals to implement cost-saving efficiency measures would result. Cities should learn from prior mistakes and build on previous successes. For example, Pittsburgh's sewer overflow problems stem from having 50 local authorities managing sewer projects in the EPA's previous clean water efforts. Greening the watershed is key to efficiency and sustainability simultaneously and is an obvious priority in greening the water system. It protects the water supply and increases green space while protecting infrastructure. The future of water regulation and conservation is a collaborative, science-based approach that uses long-term outcomes with environmental health benefits.

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CREATING THE SANITARY CITY: WATER, WASTEWATER, AND HEALTH IN AMERICAN CITIES

Martin Melosi, Director
Center for Public History

While Fredrick Law Olmsted, one of the builders of New York's Central Park, called trees "the lung of the city," sanitation services can be thought of as the circulatory system of the city. Sanitation services are important vehicles for revealing contemporary environmental thought as it relates to urban life and city development. A look at the history of Western civilization's modern water and sewage systems from the 19th and 20th centuries provides insight into the policy issues facing water services today. Water services are linked inextricably to prevailing public health and ecological theories and practices of the time. These factors, in turn, determine the form and function of the implementation of water systems, and along with technology they can have far-reaching effects.

In 1842, British reformer Edwin Chadwick called it time to bring "the serpent's tail into the serpent's mouth." In essence, it was time for the water distribution systems that had been developing for decades to unite with sewer systems, which were virtually unheard of at that point. Although his ideas were blocked by plumbing interests, there is now a consensus that the distribution of water and the treatment and disposal of wastewater are inextricably linked. A growing push to more strongly link the engineering of these systems with environmental and health professional participation would benefit all three disciplines. A review of history shows how the sanitation system came to be, and how it closely correlates with cultural ideas and trends in health and medicine.

Miasmas and Mechanics: Early 19th-Century Water Management

The concept of sanitation was not recognized until several decades after the development of systems that transported water for local and domestic use. In 1800, 17 waterworks were operating in the United States, but no real city-wide sewer or wastewater facilities yet existed. The concept of sewage systems emerged in the 1830s with the development of the "sanitary idea" by Edwin Chadwick: filth, dirty conditions, and bad smells (miasmas), along with poverty, could lead to disease and health problems. This notion contrasted with previous ideas that health was determined by divine intervention. The miasmatic theory strongly influenced what became the first sanitary awakening in the United States between 1830 and 1880.

In the United States prior to this time, residents of cities suffered from a range of diseases and a series of problems that could not be corrected by public action because the prevailing attitudes of the time were that private citizens were ultimately responsible for their water and waste. And in that environment, it became increasingly difficult for communities that were experiencing popula-

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tion growth to address their health problems, because their ideas from a scientific point of view were absolutely incorrect. As a result, there was a growing need to move beyond individual responsibility for collecting water and disposing of wastewater toward an integrated system, since access to water was not only necessary for fire protection, but also a vital step in promoting public health in the community.

The first example of this shift was seen in 1801 with the completion of Philadelphia's public Fairmount Water Works, eventually drawing attention from all over the world as the first major water distribution system in the United States (Figure 2-1). The public became more accepting of the idea that disease could be combated through the import of clean water into the household. Owing to the availability of clean water, the use of unfiltered but fresh water for household purposes had a significant impact. This, however, was only a mechanistic or water transportation system, rather than an integrated drinking water delivery system with treatment technology. The design considered only the ease of transport and not the health and environmental issues of storage, filtration, and potential contamination. Thus the major problem was concerns of contamination at the water source and an inability to use much more than sensory means to test water quality.

This was the method of design of the modern water and sanitary system—a design with virtually no understanding of bacteriology, filtration, water testing, environmental protection, or disease. In addition, no interventions or systems were developed to deal with sewage and waste because, unlike the intrinsic value and revenue source of water supplies, the same could not be said of sewer services.

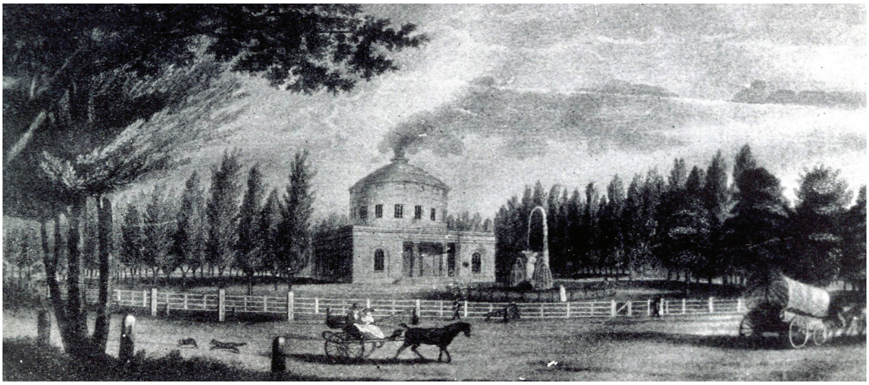

FIGURE 2-1 The Centre Square Pumping Station in Philadelphia in 1801 (early stage of the Fairmount Water Works).
SOURCE: Melosi, 2000. The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present. Baltimore: Johns Hopkins University Press.

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With no financial incentive, underground sewer systems did not begin until the late 19th century. As a result, most modern water and sanitation systems were developed independently in the United States and in much of the world, which put limitations on the creation of a unified water treatment system. One benefit of the shift to the miasmic view, however, was the concept of filtration; if filth could be removed from water, then it should be healthier to drink than unfiltered water. Filtration became available at the end of the 19th century and led to a rapid reduction in water-borne communicable disease and mortality.

Even in their earliest iterations, water systems had consequences, which were at times economical, political, and environmental. Rural and less populated areas were exploited in order to divert water toward and waste away from large urban areas. For example, the aqueduct that fed Los Angeles destroyed much of the economy of Owens Valley, from where the water had been diverted early in the 20th century. Battles continue to this day between jurisdictions over resources and where to divert waste.

Bacteriology: The Discovery of Germs and New Treatment Technology

As the miasmatic theory lost its vitality and science advanced, the bacteriological age commenced by the turn of the century. For the first time, there was a definitive and physical cause of disease that was plausibly linked to water. Since the causes were controllable on a large scale, public health exploded as a field, while a regard for public welfare increased immensely. Public health measures and large-scale public works were seen as appropriate responses. The developments of pharmaceuticals, immunization, and isolation for communicable diseases coincided with the bacteriological period, with health continuing to improve at an unparalleled pace. However, the work of engineers did not correlate with the work of public health or prevention medicine personnel, insofar as medicine increasingly focused on the individual and not the public at large. As a consequence, the sanitation and water systems became engineering issues, with public health officials assuming less of a role in the protection and treatment of water. Although there was some public health oversight in the planning of systems, a new institutional split developed that persists to this day.

The bacteriological period saw the construction of major public works projects for both water distribution and sanitation. They were supported financially by public agencies and were intended to be permanent; the permanent nature of theses projects led to future limitations and diminished adaptability. At the same time, filtration systems became more sophisticated, and treatment, such as chlorination, became more widespread. More attention was given to the problem of what to do with large volumes of water pumped into homes—what should its fate be? Septic tanks came into use at this time, along with other community-wide underground wastewater systems. There was also a strategic decision to move from a combined, single-pipe system to remove both wastewater and

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TABLE 2-1 Public Versus Private Ownership of Waterworks, 1830–1924

Year	# Works	Public	Private	% Public	% Private
1830	45	9	36	20	80
1840	65	23	42	35.4	64.6
1850	84	33	51	39.3	60.7
1860	137	57	80	41.7	58.3
1870	244	116	128	47.5	52.5
1880	599	293	306	48.9	51.1
1890	1879	806	1073	42.9	57.1
1896	3197[a]	1690	1490	52.9	46.6
1924	9850	6900	2950	70	30

[a]Includes 17 undocumented systems.
SOURCE: Melosi, 2000. The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present. Baltimore: Johns Hopkins University Press.

storm water toward a separate pipe for sanitary waste that came from homes and commercial establishments and another separate pipe for storm water. This was first implemented in Memphis, Tennessee, in 1880 after a series of infectious disease outbreaks. However, the system did not have an elaborated storm water apparatus, and the city still experienced flooding problems. Today, little debate exists in technical communities about the advantages of separate systems over combined systems.

The problem of pollution in waterways was still largely unrecognized at the turn of the 20th century, with a number of wastewater plants dumping directly into streams and lakes regardless of water treatment. Many engineers argued that, when phenol or other chemicals were released into the water, they acted as a disinfection agent and therefore helped to eliminate disease-carrying bacteria. Furthermore, if there was a proper dilution formula, then the industrial pollution problem was remedied by dumping the chemical into a large and fast-moving watercourse. However, this merely displaced the problems from inside the city to the natural environment and more rural areas. Battles between upstream and downstream cities intensified. The concept of pollution was changing, however, as the dangers of chemical and industrial contamination were recognized and pollution was no longer considered a biological problem. Water treatment continued to improve, and large public systems dominated the field (Table 2-1).

The New Ecology: Responding to New Technologies and Cultural Shifts

When the United States moved into the modern era after World War I, large-scale challenges from industrialization and other sources of pollution occurred. Ultimately, however, a more ecological approach to sanitary service delivery led to greater attention to incorporating environmental concerns into new projects

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and approaches to water. As the population spread into larger and more suburban areas, the costs associated with water treatment increased and the benefits were less apparent than in initial projects. Financial pressures also limited resources for new projects. By the 1930s, there was an increasing role of the federal government, not in the development of local water systems, but rather in the testing of particular problems and providing support. The federal government stepped in to create standards for systems, impacting health standards and delivery technologies. For the most part, however, water and wastewater systems in place today remain similar to their early incarnations. At the time, attitudes about medicine and health again shifted, as new medications and patient treatments became better understood. The strong focus on preventive medicine of the medical community was rapidly replaced by an interest in medical treatment of the diseased individual, a trend that is only beginning to be reversed today. Again the role of public health in water and sanitation diminished and remains relatively low in industrialized nations.

One of the disadvantages of a permanent, highly capitalized set of systems, such as in the United States and elsewhere, is their lack of resilience—the inability to address emerging problems. Following the postwar years, water pollution became complicated by nonpoint sources and groundwater contamination. These problems could not be addressed easily by means of large treatment plants located near a river. Such structures have proven to be essential in dealing with point pollution, but they could not necessarily address other forms of pollution.

In summary, the water and sanitation systems developed in the 19th and 20th centuries were strongly influenced by social norms and prevailing scientific theory. Little was known about the etiology of disease, the presence of pathogens in water, filtration or treatment, or environmental protection—and those aspects were not incorporated into early systems. Later advances still failed to amend the limitations of future systems, becoming larger and less adaptable. Public health played a decreasing role over time, whereas maintenance and replacement of water systems became the bigger issue as original infrastructure passed the century mark.

The future of water and sanitation requires a sustainable and adaptable system. The original design never regarded the need to address environmental contamination that was not from a point source. Historic trends are critical to the current situation, as the infrastructure and limitations owing to public health and cultural ideas of sanitation have shaped the current path, making it difficult to change direction. Nevertheless, optimism prevails as public opinion shifts back toward the value of preventive medicine and public health, the preservation of the environment, and investments in public infrastructure.

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3

The Technology Pillar of Sustainable Water: Technology, Economics, and Health

Approximately 1.1 billion people worldwide are currently without access to safe drinking water. Addressing this need in a sustainable way is one of the overarching challenges of the international community and may be the difference between security and instability, between opportunity and poverty. A cornerstone to approaching this challenge is the appropriate use of new and existing technology. This chapter captures the presentations from the workshop on how technology, water management, and community engagement can ensure human health.

MOVING TOWARD MEGACITIES: DECENTRALIZED SYSTEMS

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Many people have asserted that the 21st will be the century of water and there will be significant conflicts because of the lack of water. The fundamental assumption behind the idea of water scarcity that people make is that water is like oil: once you use it, it's gone. In fact, water can be used, recycled, and reused a number of times. For example, each drop of the Colorado River is used at least seven times. With better management practices, this number can increase.

In 2006, the United Nations Development Programme released a Human Development Report on water for the first time. The city named as having the best water supply and wastewater treatment was not in the United States, Europe, Australasia, or Japan—but was Singapore, a city with one of the lowest per capita water supplies.

Singapore has two agreements to bring water from Malaysia that are due to expire in 2011 and 2058. The Singaporeans have already given advanced notice to the Malaysian government that they do not want to renew their 2011 treaty. Their water delivery strategy has shifted from water procurement to managing

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the resource better. A central component to their plan is to use treated wastewater for drinking and to sell wastewater to the semiconductor industry. Using recycled water as drinking water can create a perception problem. However, there is a top-down commitment in Singapore, as the president and the prime minister drink the "new water" (i.e., recycled, domestic wastewater). In general, there is widespread acceptance because of the quality of the water, irrespective of religion.

There will not be a shortage in the availability of water unless there continues to be mismanagement of current resources. This can be true not only in all regions, but also in the world's megacities—cities with more than 10 million inhabitants. Currently in Delhi, the water board supplies water for three hours a day. Due to this inefficiency, each house or block of flats in Delhi is a mini-utility. They collect enough water to last for 24 hours by using underground storage tanks under each house or block of flats.

In Delhi, water consumption is 250 liters per capita per day; however, approximately 50 percent of this water is not accounted for. As in many regions in the world, 40–70 percent of the water pumped into the system never reaches the consumer (Biswas, 2006) because of leakage and pilferages. This is true not only in developing countries, but also developed countries. In 2006 Thames Water, one of the largest private water supply companies in the United Kingdom, lost 31 percent of its water before it reached the consumer. Singapore is the one bright beacon, with losses amounting to approximately 5 percent.

Furthermore, the water crisis is going to come, not from the shortage of water, but because of decades of negligence for water quality management. To illustrate: In 1976, during the International Water Supply and Sanitation Decade, the United Nations General Assembly approved the idea that access to water means access to water that is drinkable. In Delhi, however, each house or block of flats has had to set up such processes as reverse osmosis or a membrane system, because the filtration supplied is not sufficient to make the water drinkable. The intention of the Millennium Development Goals (MDGs) and the International Water Supply and Sanitation Decade is that people should receive water that is potable. They should not have to set up a mini-utility to ensure that their water is drinkable. MDGs state that, between 1990 and 2015, the number of people who do not have access to water should be reduced by 50 percent. Although there is a concerted effort to meet these goals, the fundamental question is whether the water that people are being supplied is drinkable. Or are small Delhi experiences being set up around the world?

Sanitation is another challenge for MDGs, which state that, between 1990 and 2015, the number of people without access to sanitation should be reduced by half. (Sanitation was not an original component of MDGs: it was added by the Johannesburg Declaration of 2002.) While this is a laudable goal and progress is being made to reach it, this is not the full story. From Mexico City to Delhi, from Manila to Nairobi, wastewater is collected from houses, but most of the time there

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is not even primary treatment of it. This untreated wastewater discharge simply transfers the problem from one place to another.

There is a lack of accurate numbers to answer the question of what percentage of people have access to sanitation and what percentage have access to sanitation and wastewater treatment. Solid statistics do not exist in this area. In Latin America, approximately 40–50 percent of people have access to sanitation, but approximately 11 percent have access to wastewater treatment and proper wastewater disposal. What this means is that places like Sao Paulo, Mexico City, Delhi, and others are either dumping their wastewater into the ocean, onto the ground, or into other bodies of water. The current situation of most urban centers in the developing world is that most of the water courses in and around the major cities are heavily polluted. The extent and the type of pollutants are not known, as there is a lack of information on water quality to holistically examine the water issue.

Financial issues and lack of expertise are not the largest challenge facing megacities; it is the need to improve management and harness the political will. Another problem is that there is inertia among the public. Some people accept the current standard as the status quo and do not push for necessary infrastructure and management improvements. The improvements may not necessarily need new knowledge generation, but rather knowledge synthesis. This approach would require a detailed understanding of what technologies or strategies work where and under which environmental and cultural conditions. For example, the city of Phnom Penh was losing 80 percent of its water in 1993. The Phnom Penh Water Supply Corporation was broke and had little staff or office space. In a time span of 14 years, the Phnom Penh Water Supply Corporation has become fully independent and now only loses approximately 8 percent of its water through better management of resources and synthesis of current knowledge. Delhi, Mumbai, and Nairobi have enough water. All they need is how to effectively use their current water resources. Kenya's second largest city, Mombasa, can support itself by the unaccounted for water of its major city, Nairobi.

The final point is pricing. Without full-cost pricing, there is no other way to supply clean water and wastewater treatment. In conclusion, the world does not have a problem with the lack of available water. There is enough science and management expertise, but its use is not being maximized. And if people do not use their current resources appropriately, even with access to all the water in the world, there will still be the same problem.

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OVERVIEW OF THE WATER SECTOR: POLICIES, INSTITUTIONAL ROLES, AND KEY ISSUES FOR UTILITY SERVICES DELIVERED IN GHANA

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Ghana is located in the western part of Africa, bordering the Ivory Coast, Togo, Burkina Faso, and the Gulf of Guinea. The country has a population of 22 million, with 57 percent rural and 43 percent urban inhabitants and a life expectancy of about 56 years. The gross domestic product per capita is approximately $400. In urban areas, 58 percent of the population receives some water services, and in rural areas and small towns, water coverage is 53 percent.

Water services are covered by a multitude of institutional arrangements in the government (see Figure 3-1). The Ministry of Water Resources, Works, and Housing administers policy, planning, and some aspects of financing. The Ministry of Finance covers some of the financial services. In addition, the Ghana Water Company, Ltd. (GWCL) oversees the urban water systems, and the Community Water and Sanitation Agency (CWSA) oversees the small town and rural systems and functions as a policy advisory body for the small town systems. Although the urban water supply is managed by the publicly owned utility company—the government and GWCL—the operations have been ceded to Aqua Vitra (AVRL).

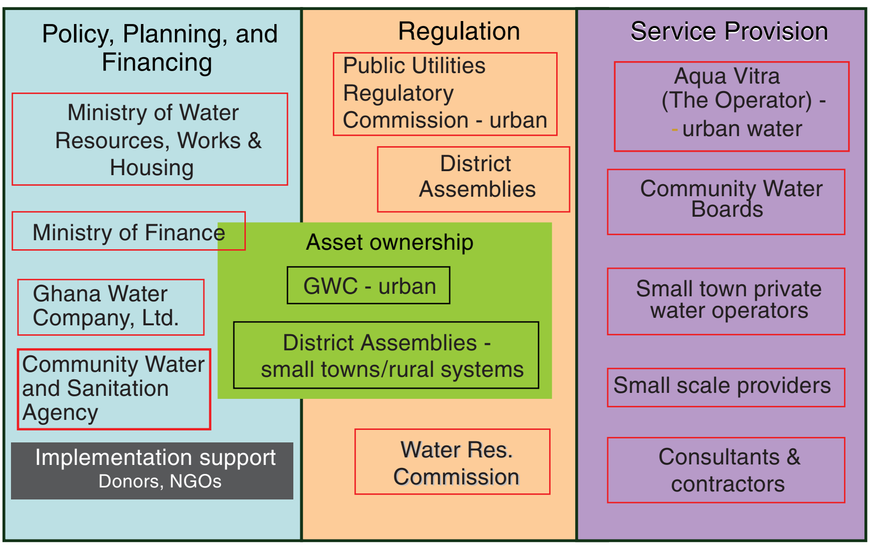

FIGURE 3-1 Institutional arrangement of agencies covering water services in the Ghanian Government.
SOURCE: E.K. Obutey.

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AVRL operates 87 systems in the 10 water regions. The remainder of the communities in the small towns and rural systems have established water boards and private operators with service contracts. Complementing the major agencies are several other government agencies that assist with regulatory affairs.

GWCL has approximately 364,000 billed customers. The nonrevenue water is 48.8 percent. The company has a daily average production of 580,000 cubic meters with an effective metering ratio of 47 percent. Tariffs alone do not cover the $1.5 billion needed to have an effective system, so the government is trying to mobilize investments.

Public Utilities Regulatory Commission of Ghana

The Public Utilities Regulatory Commission (PURC) of Ghana has produced three regulations since its inception in 1997: one to address the termination of service, one for a complaints procedure, and a third for the establishment of a customer service committee. For example, legislative instrument 1651 establishes the rules and regulations under which the company can terminate the services to a person. PURC has also published two important policy documents: the Social Policy Document for Water Regulations and the Urban Water Tariff Policy. Furthermore, by recognizing the large number of agencies involved in supplying fresh water, the commission has developed a Drinking Water Safety Plan to regulate water in a holistic manner—from the source to the consumer. Finally, the commission oversees three pilot projects to determine how to best serve the poor in society, with the goal to replicate these projects throughout the country.

National Development Goals

Recognizing the health and economic implications of ensuring adequate water services for the people of Ghana, the government laid out the National Development Goals in the Growth and Poverty Reduction Strategy II, a document that outlines strategies to accelerate water delivery in urban areas. As part of the goals, the government is seeking to establish PURC regional offices in all regions beyond the 10 currently served, mobilize new investments for urban water systems, extend distribution networks with an emphasis on the poor, and strengthen the management of the GWCL.

For the urban poor, there have been provisions of standpipes that allow some accessibility to water services, allowing people to draw water. The Growth and Poverty Reduction Strategy addressed the commission's transition to bring tariffs to cost recovery to make the operations of the urban water systems sustainable, at the same time assessing the lifeline tariff for poor urban households. In the transition, there was recognition that the tariffs had to be incrementally brought to the full-cost recovery level. Furthermore, the goals helped to direct state interventions in areas in which there is a marked gap in service delivery.

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National Water Policy

Currently, PURC has a draft National Water Policy with four broad principles. First, at its core, the policy establishes the fundamental human rights of all people, without discrimination, to have access to safe and adequate water to meet their basic human needs. Second, it states that water is a finite and vulnerable resource, with multiple uses. Third, it outlines the principle of solidarity—expressing profound human alliance to solve common problems related to water. Fourth, it meets social needs for water as a priority by recognizing the economic value of water and the goods and services it provides. As part of its strategy to ensure water, the policy has created an outreach program to educate the public to not waste water and established the Water Resources Commission to manage the water resource.

The key policy objectives for water resources management are to achieve sustainable use, while maintaining the biodiversity and the quality of the environment for future generations. The Water Resource Commission achieves this through protection, from the original source water all the way through the water delivery system. In the rural/small town water system, the overall objective of PURC is to improve the public health and economic well-being of rural and small town communities through water, sanitation, and hygiene education interventions. The specific objective includes the provision of basic water and sanitation services for communities that will contribute to the capital cost and ensure payment for normal operations and maintenance, at the same time being mindful of the need to ensure affordability, equity, and fairness for poor and vulnerable populations. The policy also sets out strategies to ensure sustainability through effective community ownership and management. There is a role for various forms of participation, and part of the strategy creates opportunities for the private sector to grow. For example, before the management contract with AVRL, the government considered several options. The current management contract runs for five years with the option of a five-year extension. If the extension does not happen, the operations will revert back to the government of Ghana.

Finally, the draft National Water Policy sets out to achieve financial sustainability through full-cost recovery. However, the policy is mindful of the need to apply cross-subsidies and design interventions to suit the supply and payment choices of the poor. The government cannot retrieve all the costs of running the company through the tariffs, so alternatives for investments are being explored.

Draft National Water Policy II

The draft National Water Policy II focuses on two key issues: equity and secondary and tertiary providers. The policy has a stated commitment to having an equitable amount of investment resources dedicated to extending services to low-income communities. Access to water services is a health issue, owing in particular to typhoid and Guinea worm infection. The government is looking at the

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best consortium investment to extend services to low-income areas, but they need to address the basic problem that individuals need to pay the connection fee.

In 2006, approximately 50.4 percent of rural water services was financed by the developing partners, and only 1.5 percent was supported by the government of Ghana. For the urban water supply, 34.7 percent was financed by the development partners, and approximately 1.7 percent was supported by the government. In order to meet the Millennium Development Goals, Ghana needs $820 million to meet the 2015 targets, an average $85 million a year. For the rural systems, the need is less—approximately $756 million. Figure 3-2 shows the commitment by the government of Ghana to reduce poverty in various sectors in 2003 and 2004. There has been a slight shift in funding toward feeder roads, agriculture, and rural electrification, away from water services, basic education, and primary health. So the challenge is how the country, with its multiple priorities, can address this major issue.

In summary, the government is faced with a number of key issues. Financing will continue to be a need, and the government is approaching this by identifying the needed investments and establishing roles for consumers, the government, and the development groups. The plans that are being drafted need to be equitable for all regions and socioeconomic groups, with increased commitment to the

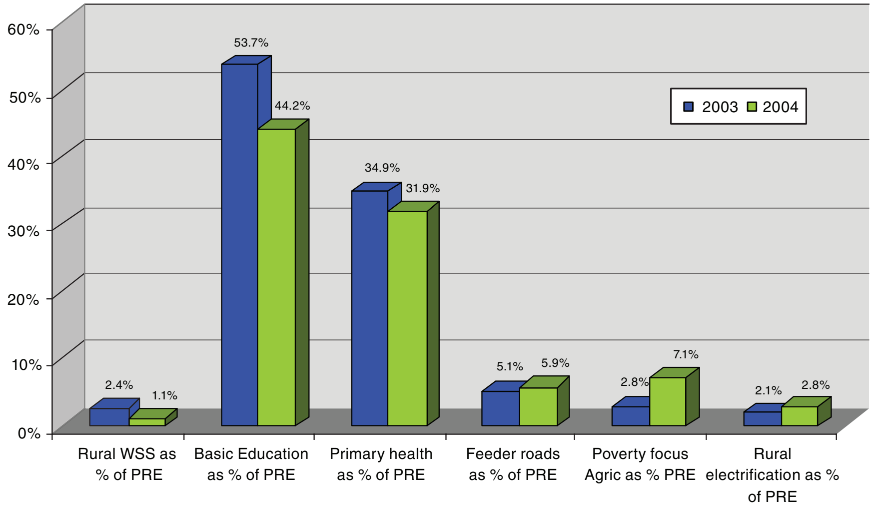

FIGURE 3-2 The percentage of money by sector allocated by the government of Ghana to reduce poverty in 2003 and 2004.
NOTE: PRE = poverty reduction expenditures; WSS = water supply and sanitation.
SOURCE: Derived from PURC, 2005; Ministry of Water Resources, Works, and Housing, 2007; IMF, The World Bank, 2005. Ghana: Poverty Reduction Strategy Paper Annual Progress Report by E.K. Obutey.

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underserved and the urban poor. Management plans will be important to interface between the urban and rural systems and for protecting natural resources. Finally, monitoring and evaluation need to be strengthened.

CLEAN DRINKING WATER: SOLVING THE ARSENIC CRISIS IN BANGLADESH THROUGH A SUSTAINABLE LOCAL FILTRATION TECHNOLOGY

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The U.S. Environmental Protection Agency (EPA), the World Health Organization (WHO), and the government of Bangladesh have standards for drinking water quality with regard to inorganic, organic, and microbial species. Drinking water should be free from pathogenic microbes and from toxic inorganic species, like arsenic. For many regions of the world, achieving this goal is a challenge. For example, the occurrence of toxic arsenic species in groundwater used for drinking is pervasive in the Indian Subcontinent, Southeast Asia, South America, Africa, Central America, and North America. The acceptable limit in potable water as set by the EPA is 10 parts per billion (or 10 micrograms per liter). A significant number of areas in the United States and around the world exceed this limit in their groundwater (Figure 3-3).

Bangladesh: The Challenge of Providing Potable Water

Bangladesh is a country of many rivers, but these waters are not potable because the surface waters are often polluted with high levels of pathogenic bacteria. For the past two decades, United Nations Children's Fund (UNICEF) and the World Bank have funded the installation of approximately 10 million tube wells to circumvent this problem. One well-known unintended consequence of this development is that 30 percent of these tube wells have water with high levels of arsenic. Drinking arsenic-contaminated water for a long time causes such illnesses as hyperkeratosis on the palms or feet, fatigue, and cancer of the bladder, skin, or other organs. The human liver degenerates at 800 parts per billion (ppb) of arsenic, but some experiments in mice suggest that degeneration can start as low as 10 ppb. A typical arsenicosis patient is shown in Figure 3-4. Naturally occurring arsenic in groundwater is now regarded as one of the most harmful public health crises in the world (Mukherjee et al., 2006).

More than 1 million people now have arsenic skin lesions (Smedley and Kinniburgh, 2002). Although the estimates for contamination vary, between 77 and 95 million people in Bangladesh are affected by high levels of arsenic in their drinking water. The problem is not uniformly distributed, but the local hot spots are densely populated. It is interesting to note that one tube well can have 50 ppb

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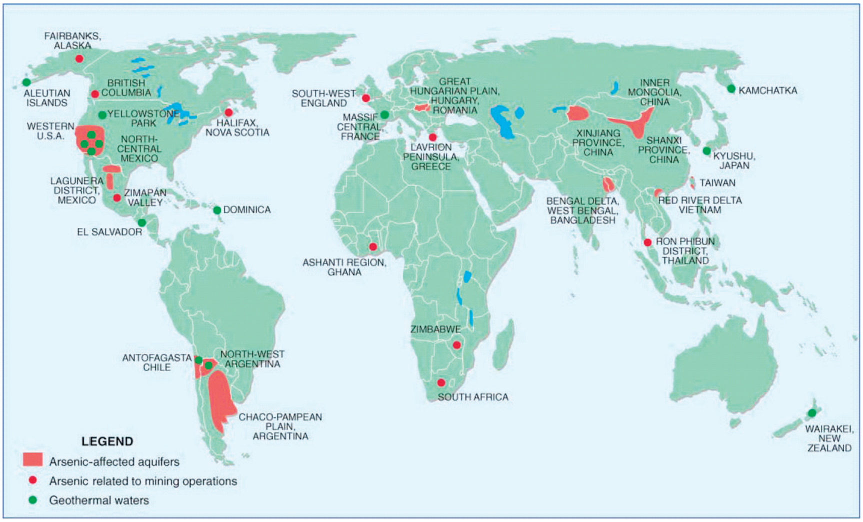

FIGURE 3-3 Arsenic in groundwater is a pervasive problem throughout the world. A significant number of locations exceeds the 10 parts per billion set by the U.S. EPA.
SOURCE: Smedley, P., and D.G. Kinniburgh, 2002. A review of the source, behaviour and distribution of arsenic in natural water. *Applied Geochemistry* 17(5):517-568. Reprinted with permission from Elsevier and British Geological Survey.

FIGURE 3-4 Arsenicosis patient showing hyperkeratosis on the palms.
SOURCE: A. Hussam.

and a tube well less than 100 feet away can have 170 ppb. In all, 16 percent of the deep tube wells in Bangladesh and India are contaminated. Scientists cannot accurately determine where to place tube wells to obtain arsenic-free water. The arsenic concentration also increases, albeit relatively slowly, as the age of the tube well increases. The initial draw from the tube wells can be deceptive—appearing to be of adequate quality, but with high concentrations of iron and arsenic. The water starts to become turbid through a process of oxidization and self-attenuation (Figure 3-5).

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FIGURE 3-5 Water that appears to be of high quality (right) upon initial draw from the tube well can contain high concentrations of iron and arsenic—the water starts to become turbid (left) through a process of oxidization and self-attenuation.
SOURCE: Hussam, 2008. Clean drinking water: Solving arsenic crisis through a sustainable local filtration technology. Global Environmental Health: Research Gaps and Barriers for Providing Sustainable Water, Sanitation, and Hygiene Services, Washington, DC.

The origin and distribution of arsenic in groundwater is still under study. However, early indications show that a biogeochemical reduction process mobilizes the arsenic in the ground into a form that is present in water. Current theory suggests that an anaerobic bacterium is consuming iron and organic matter present in the young geological formation; it is then using the iodine present in soil to convert and dislodge the stable form of arsenic into an unstable form called arsenite. Arsenite, the most toxic form of arsenic, is now in solution and contaminates the wells.

Toxicity of Arsenic Compounds in Decreasing Order

Strategies to Address the Problem

Because bringing water from the rivers miles away is not a plausible solution, scientists have been looking for more natural solutions to remove toxic forms

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of arsenic by understanding its chemistry and interaction with the environment. Surface water does not often contain arsenic, even when there is arsenic in the surrounding soil, because the soil absorbs the arsenic through a complex mineralization process with iron. Scientists have been trying to use zero-valent iron to absorb arsenic, similar to the method that soil mitigates arsenic.

One of the first systems used is a three-pitcher system to filter contaminated groundwater. The top pitcher contains sand at the top, cast-iron turnings in the middle, and sand at the bottom; this is the active filter to remove arsenic and other toxic species. The second pitcher is a sand-charcoal-sand-gravel filter, which removes residues from the first pitcher. The third pitcher is the collector for the filtered water. This system was tested in Nepal and in Bangladesh under a national environmental technology verification program for arsenic mitigation. It was demonstrated to produce high-quality water as defined by various government standards. This sustainable filtering system proved to be comparable in quality to commercially made filters containing active materials, such as microfine iron oxide, activated alumina, and hydrous cerium oxide in ion-exchange resins.

Later versions improved on the design to create a two-stage filtration system (Figure 3-6) of sand, composite iron matrix (CIM), and charcoal. This system has a flow of approximately 20–60 liters per hour, with the effluent water having less than 10 ppb of arsenic, which is below the EPA limit. As noted above, water contains two different arsenic species, As(III) and As(V), in which As(III) is 1,000 times more toxic. In this system, As(III) concentrations are removed to less than 2 ppb, which is below the detection limit of the measuring instruments and much below the toxicity level of 10 ppb.

The filter is guaranteed to work for five years, and its maintenance is extremely low. The only maintenance procedure is needed if there is soluble iron in the groundwater, usually more than 5 milligrams per liter, because the iron hydroxide precipitate might decrease the flow rate. The user needs to wash the precipitate off the sand and put the sand back into the system or use new sand. The cost of one filter is approximately \$35–\$40. Furthermore, these filters also produce water with significantly less manganese, iron, barium, and other inorganic species to make water potable to national standard. Building on the success of these first filters, there are plans to develop small filtration units in areas where arsenic is not a problem—for example, in Dhaka City, where the groundwater has high concentrations of iron, barium, calcium, and manganese, often resulting in nonpotable water.

This filter is built with an eye toward sustainability. It is a green filter, which means that the active material, composite iron matrix, is nontoxic. It can be disposed in the open, because it is converted into some minerals similar to what is naturally present in soil. At the end of the five-year filter life span, the CIM can be turned into metallic iron by a local blacksmith or it can be recycled into CIM by the manufacturer. The latter is a more attractive option because of the possible scarcity of iron in the future. Thus nothing is wasted. The use of the filters

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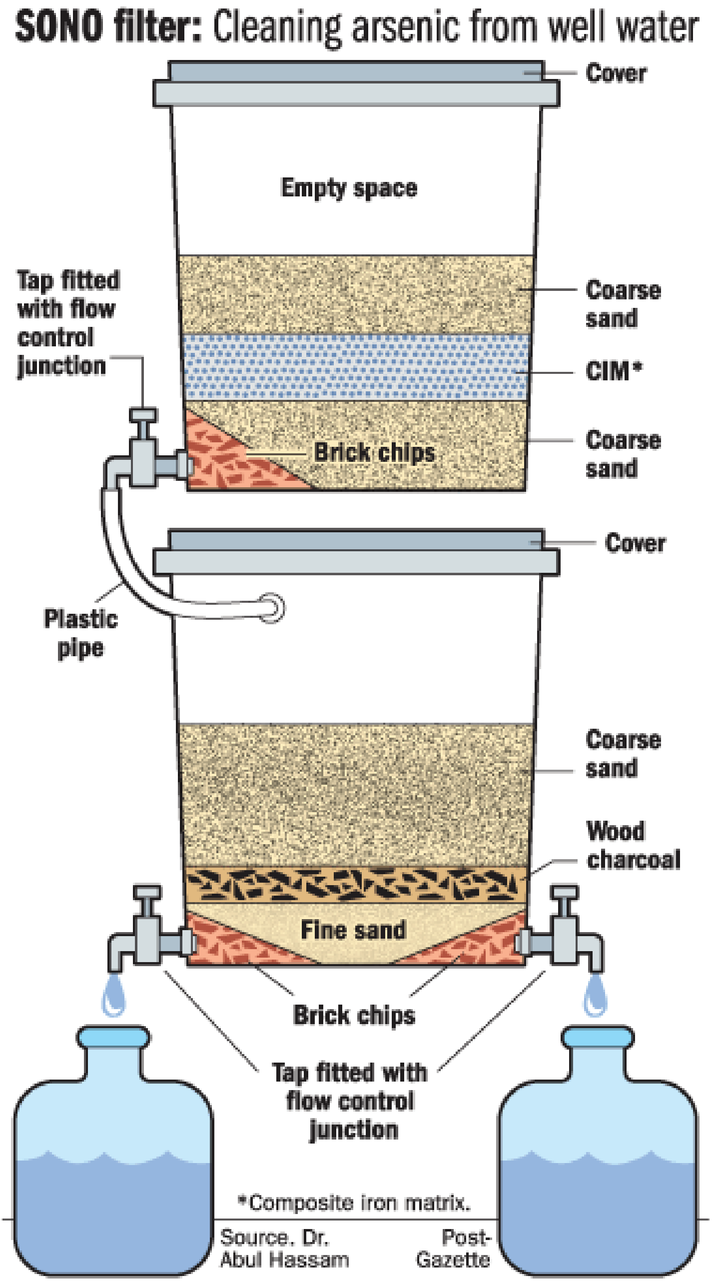

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is combined with community involvement to educate people about the dangers of arsenic and other contaminants and the usefulness of filtered water.

Approximately 42,000 filters have been distributed, serving more than 1 million people. The estimates are that close to 1 billion liters of water have been filtered at a low cost. Filtering also has the added benefit of decreasing the health risks of arsenic and its social consequences. Even if individuals have previously drunk water containing toxic levels of arsenic, after a couple of years of safe water use, the body burden of arsenic is decreased significantly. This will reduce the diseases rate of arsenicosis and consequently mortality from arsenic-induced cancers.

SMALL- TO MEDIUM-SIZED SYSTEMS: OPPORTUNITIES AND CHALLENGES

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Water systems in the United States are classified in various ways, such as by size, by ownership, and by the length of time that people are served (see Figure 3-7). For example, community systems serve at least 25 people or have 15 connections and serve water to people at least 60 days per year. Other types of systems are noncommunity, such as parks and churches; depending on the length of time they serve water, they might or might not be regulated under the Safe Drinking Water Act.

Community systems or small systems are ubiquitous in the United States and are found in very remote areas in the U.S. territories, rural regions of the United States, and the suburban counties around large metropolitan areas, including Washington, DC. Small systems that are located in high-income communities

FIGURE 3-6 Schematic illustration of the SONO filter that utilizes sustainable resources to produce 20–60 liters/hour. The only maintenance procedure is needed if there is soluble iron in the groundwater, usually more than 5 milligrams per liter, because the iron hydroxide precipitate might decrease the flow rate. The user needs to wash the precipitate off the sand and put the sand back into the system or use new sand.
SOURCE: Hussam, A., S. Ahamed, A.K. Munir. 2008. Arsenic filters for groundwater in Bangladesh: Toward a sustainable solution. *The Bridge: Technologies for Clean Water* 38(3):14-23; Ashraf, S. 2007. Fighting arsenic: News of chemistry professor's water filter is spreading around the world. Pittsburgh Post-Gazette. Copyright © *Pittsburgh-Post Gazette*, 2009, all rights reserved. Reprinted with permission.

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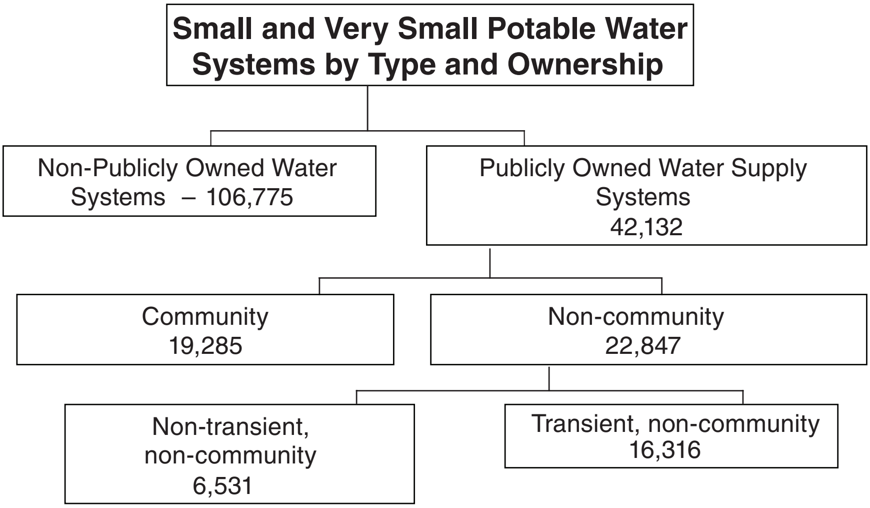

FIGURE 3-7 Regulatory classification of public water system systems in the United States based on ownership, size, and length of time that people are served.
SOURCE: Adapted from EPA (Environmental Protection Agency). 2003. Introduction to the public water system supervision program. http://www.epa.gov/watertrain/pdf/pwss.pdf.

are more sustainable, and the residents usually have an understanding of the relationship between water and health. However, in more remote areas, where people often have other social and economic problems, the residents often do not understand the water–health relationship. Some of these systems might become sustainable with effective capacity development among the users or the owners (citizens who live in the area), but others will require help from government and other groups.

Small- and medium-sized water systems range from serving communities, day care centers, mobile home parks, rural schools, factories, national parks, campgrounds, Native American reservations, and territories. The communities served by small systems are among the poorest and most remote in the United States and have limited access to infrastructure from the more settled areas. They are almost completely isolated from government decisions and, for that reason, there is little investment in the systems. It is difficult to address small systems from a regulatory perspective, as one size does not fit all in these regions. The systems serve different population demographics (ethnicity, education, and economic levels), have different governance (voluntary, contractors, employees), vary in the status of their infrastructure, and have different locations in the watershed.

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Puerto Rico

In Puerto Rico, there are currently about 300 systems inventoried, but anecdotal evidence from researchers in the field suggests that there are more not counted. These systems serve approximately 250,000–300,000 people and are regulated by the Puerto Rico Department of Health. Most of these systems are organized near agricultural areas. Their original purpose was to provide water for pasturage of animals and crop irrigation. As people located to these areas, they tapped into the systems. Two key challenges for small water systems put together by residents are the lack of either operational or administrative capacity. In addition, all the energy of the citizens is directed to ensuring delivery of water into the households. These systems might present a serious challenge to the island-wide water supervision, since some of these small systems have cross-connections with the water authority, and only a few systems (and fewer users) have the required protection to prevent contamination of the authority systems.

Small water systems are a problem not only in Puerto Rico, but also in many rural regions in the United States. However, Puerto Rico has fewer systems serving a growing number of individuals compared to states of similar size geographically or demographically. In fact, in Puerto Rico a lower percentage of the population is served by small water systems without health violations (27 percent in 2002) compared with Connecticut (96 percent), Colorado (99 percent), Alabama (96 percent), and Oregon (92 percent). These violations have significant health implications. In the tropics, the climate can bring additional stresses to the systems, as frequent heavy rains and floods will bring both microbial and chemical contaminants into the systems. Hepatitis E, cholera, malaria, and leptospirosis, are some of the most common disease outbreaks.

In these systems in Puerto Rico, like many places in the United States, people are essentially drinking water directly from the source. This untreated water exposes them to a variety of contaminants that are linked to disease outbreaks. Many of these health problems can be addressed cost effectively. In a recent study in Brazil, Carrizo (1995) found that every $4 invested in providing infrastructure for water results in a $10 decrease in medical services. A recent World Health Organization study found that, worldwide, every $1 invested in low-cost water and sanitation improvements resulted in $8 in health and productivity improvements (WHO, 2007).

Puerto Rican Water Pilot Study in Water

Regulations are only part of the solution to provide safe drinking water. In many countries, the regulations are goals, because the country and the people have many other pressing needs that take precedence. In order to understand if the health in communities served by small utilities differs from that in communities served by better operated utilities, a pilot study was initiated. A key component of this study was whether education could promote better health and water quality.

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Among a number of challenges to this program, one of the largest was the perception by the government that the population in these communities would not be interested or participate. Community engagement was an important component of the project, and one facet was to select or have the community select a representative. These individuals underwent one of two types of training, as either operator or administrator of small potable water systems. The operator training was 1 year in duration and consisted of at least 12 hours per week in the practical work in the communities. In the operator training, the modules included source protection, technical operation skills, and how various components of the system (source water, treatment, and distribution) related to each other. The administrator training was nine months in duration and included basic understanding of potable water system operation.

During the baseline period, the community was engaged in the planning of the system assessment and monitoring. The health-based targets were based on the project's Water Safety Framework. In addition, there were some independent surveillance studies.

The project was conducted in two different areas of Puerto Rico, although the results presented here are from Patillas, which is located in southwestern Puerto Rico. A cooperative of small systems was established, consisting of 8–10 small systems. The idea was to intervene in system operation, making some improvements, conduct a pathogen study, and complete a health assessment. Those studies were done before, during, and after the intervention.

The pathogen study focused on *Salmonella* and used a simple protocol in which 10 liters of water were filtered, and then the filters were divided among three laboratories (University of Delaware, Washington College, and the Center for Education, Conservation and Environmental Interpretation, Inter American University of Puerto Rico). These preliminary results showed that *Salmonella* was present 13 of 15 raw water and 22 of 37 distributed water samples. The occurrence of *Salmonella* was not significantly correlated with total coliform, fecal coliform, or *E. coli*. In the pilot program, there was a strong effect of education (training of the operators), with a significant decrease in *Salmonella* occurrence and diarrheal disease after the educational intervention. The decrease in diarrheal disease was stronger in both the elderly and children, and the preliminary results showed that 43 percent of diarrheal disease in the control communities was due to contaminated drinking water.

Furthermore, contrary to the initial perceptions, communities are willing to participate in strategies to improve their health and make their water supplies sustainable. Education and community commitment are key factors in reaching these goals. As evidence of this commitment, a follow-up case-cohort study showed that the reduction in the incidence of the diarrheal disease in communities with the intervention was maintained after 18 months, and the control systems without the intervention showed approximately the same incidence of diarrheal disease as the systems in the initial study before the intervention.

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THE USE OF TECHNOLOGIES: EXPOSURE (CROSS-CONTAMINATION), RISK ASSESSMENT, AND GUIDELINES

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Whereas the focus of various governments and nongovernmental organizations has been on whether people have access to a tap or a standpipe for water, a number of technology advances are of concern to health practitioners. Some of these technologies can result in exposure to pathogens through cross-contamination or growth within distribution systems, and others can have a more direct exposure pathway.

Opportunities to Rethink Water Services

Globally, both developed and developing governments and public utilities have a major problem from neglecting the water infrastructure. Some estimates suggest that at least 80 percent of the total cost of water and sanitation services is for infrastructure, the remaining 20 percent being for treatment. However, with an annual estimated shortfall in maintaining that infrastructure in the United States of some 20 billion dollars, some people in the water services field see an opportunity to rethink the current system as the aging infrastructure is renewed. This presentation highlights a number of opportunities.

One opportunity is to make water “fit-for-purpose” for which it is used. For example, at one end of the quality spectrum, advanced-treated wastewater in Singapore is returned to the source water reservoir, blended with other river water and conventionally treated at the waterworks, with approximately 10 percent being recycled water into the drinking water supply system. In Israel, Australia, Southern California, Florida, and Arizona treated domestic wastewater is used for irrigation, toilet flushing and clothes washing purposes, reducing the withdrawals of scarce river or groundwaters. In Australia (particularly Sydney, Melbourne, and Perth), which has been experiencing a 10-year drought, the government has mandated that all new housing have both a potable and a nonpotable water supply (i.e., the latter consisting of the appropriated-treated recycled wastewater from the community). In many parts of the world, recycled wastewater is treated to a level that is considered relatively safe for irrigation purposes. A fit-for-purpose system requires reservoirs for both potable and nonpotable waters, at the community and/or household level. Approximately 75 percent of domestic water is used for flushing toilets, garden irrigation, and clothes washing, which means that the non-potable water reservoirs will need to be of a sufficient size to accommodate the demand. Hence, fire fighting flow, the main determinator of the size of a water

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distribution system, should be via non-potable water, leaving opportunity for a smaller, better quality drinking water distribution system.

A second opportunity is to rethink wastewater disposal. Recognizing that the human body keeps urine and fecal materials separate and that urine is approximately less than 1 percent of the output into the sewerage system, there has been interest in separating urine flow from the fecal material as it exits the body. Not only is this separation viewed as sustainable, but the collected urine (yellow water) can be used as a fertilizer for agricultural purposes. About five companies, particularly in Scandinavia and Germany, make urine-diversion toilets for domestic use, and nongovernmental organizations (NGOs) have assisted in developing urine-diversion pit latrines that are self-financing (through the sale of yellow water) in southern China, Africa, and India.

Most pharmaceuticals, including endocrine-disrupting compounds are primarily excreted via urine, and using yellow water in agriculture prevents these compounds from entering the water supply. Furthermore, utilizing natural soil microbes to degrade these endocrine disruptors to agriculture may be far more economically feasible than treating the chemicals at a water treatment facility. Soil is a more reactive location, microbiologically speaking, to break down those compounds than in water. In a pilot study, looking at the uptake of some of these compounds into plants grown hydroponically and in soil, very low levels of endocrine disruptors were detected in the plants, which means that this method can be a potentially safe alternative.

In some "ecological villages," there has been an effort to focus, not on past water engineering marvels, such as huge dams, pipe systems, and aqueducts, but rather on how to supply sustainable water services to communities in the future. For example, the services needed in a house can be split into three types of source waters and three waste streams: black water from the toilet fecal flushings; grey water, the bulk of the water used in a household; and the yellow water, which is the urine stream. The black water could go directly to a composter or into a vacuum sewer to an energy-recovery plant. Grey water could be used for recycling or reuse either within the household or locally. The yellow water can be diverted as a fertilizer, as noted above either as a liquid for local use or as a solid precipitate for export.

A third opportunity builds on pilot programs in rural Philippines and Bhutan. Efforts have started there to create a clean-tech water supply system that only runs on solar energy. A further innovation is the use of a credit card device that can be recharged at the local city hall to activated local water dispenser in the community. In this example, the groundwater is chlorinated and distributed by gravity to dispensing areas, where people fill various containers. Although the standpipes are sources of good-quality potable water, the system can fail if it is not maintained safely by the user in the home.

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Exposure and Health

The majority of the large urban systems have pipe infrastructures that are prone to leaks. These leaks can be in the potable water infrastructure or the wastewater infrastructure, which can contaminate recreational areas, groundwater supplies, and other areas. On the water distribution side, cross-contamination/contaminant intrusions are one of the difficulties for even the "jewel" distribution systems. For example, every year in Sydney, cross-connections of non-potable are being detected in the potable water system, potentially impacting consumers. In other words, people are drinking the highly treated recycled water. While this water is treated to a level that is actually considered safe, cross-connections occur through illegal connections and are a warning to others contemplating this type of dual distribution system. A less well understood potential problem is the growth of pathogenic microbes in non-potable water systems, where higher nutrients and periods of stagnant flow may promote their growth.

WHO has developed guidelines for drinking water, recreational use, and water reuse, which are based on the risk assessment approach in Figure 3-8 and differs from the U.S. guidelines. WHO uses a health target based on some toler-

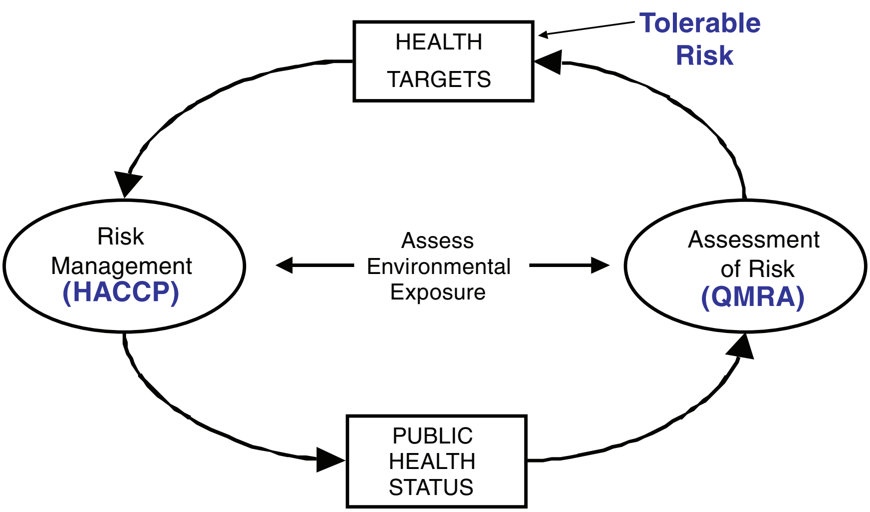

FIGURE 3-8 The World Health Organization's (WHO's) risk assessment approach guidelines for drinking water, recreational use, and water reuse. WHO uses a health target based on some tolerable level of risk, resulting in a risk management system that is primarily based on the Hazard Analysis Critical Control Point approach used in the food industry.
SOURCE: Fewtrell, L., and J. Bartram. 2001. Water Quality: Guidelines, Standards & Health Assessment of Risk and Risk Management for Water-Related Infectious Disease. World Health Organization. IWA Publishing. Reprinted with permission.

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able level of risk, resulting in a risk management system that is primarily based on the Hazard Analysis Critical Control Point approach used in the food industry; known now as the Water Safety Plan. On the basis of a person's exposure, an assessment of risk is determined.

The quantitative microbial risk assessment approach uses a framework (Figure 3-9) that is based on the chemical risk assessment framework developed by the National Research Council (1994). After describing the system and identifying the hazards in the system, this approach determines the exposure from the hazards, and dose-response models characterize the risk. The risk assessment approach is an iterative process, as more data specific to the location of interest are generated, to reduce uncertainties in risk estimates, and it is necessary to confirm with the stakeholders early on that all the agents of concern have been identified. The ultimate outcome is to help better manage the system by characterizing the risk.

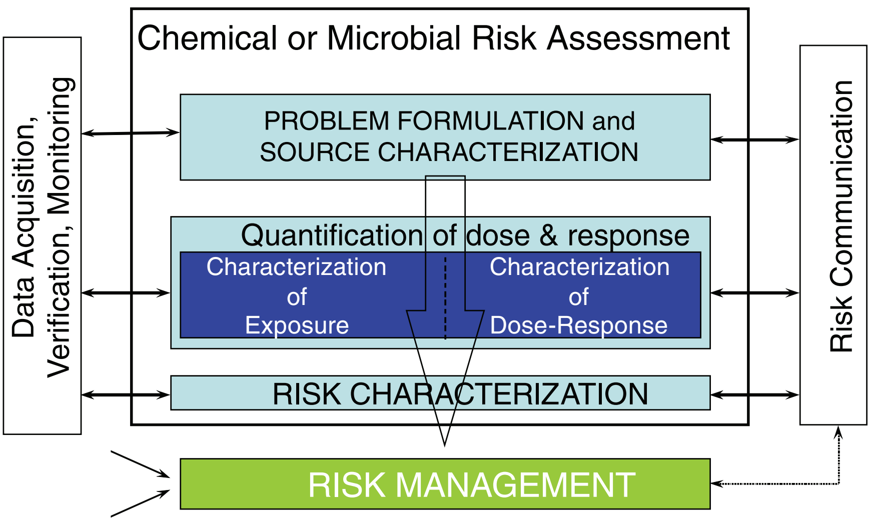

FIGURE 3-9 The quantitative microbial risk assessment framework is based on the chemical risk assessment framework developed by the National Research Council. This approach determines the exposure from the hazards, and dose-response models characterize the risk. The risk assessment approach is an iterative process, as more data specific to the location of interest are generated, and it is necessary to confirm with the stakeholders early on that all the agents of concern have been identified.
SOURCE: Adapted from NRC (National Research Council). 1983. Risk Assessment in the Federal Government: Managing the Process. Washington, DC: National Academy Press; NRC (National Research Council). 1994. Science and Judgment in Risk Assessment. Washington, DC: National Academy Press.

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The risk-based water guidelines have a number of ramifications, such as no longer focusing on end-point testing for specific maximum contaminant criteria. Water is treated to be "fit-for-purpose," which is based on the quality of the raw water and the tolerable burden/dose of hazards at the point of exposures. The risk-tolerance approach still needs a benchmark to determine the health target, which the U.S. EPA does not have. Instead, the EPA has used one infection per 10,000 per year in developing the surface water treatment rule in the late 1980s and the enhanced surface water treatment rule. WHO has developed with the disability-adjusted life year (DALY) benchmark as a common metric for health effects; using 1 DALY per 1 million people per year, which is equal to approximately 1 case of cancer per 100,00 people over a lifetime of 70 years (Murray and Lopez, 1996).

Quantitative microbial risk assessments have been undertaken in Australia for large-scale system for water systems, and qualitative assessments are now standard aids in prioritizing risk management actions. They help to focus on such issues as source water protection targets, treatment performance needs, effects of integrity losses, and a systems analysis approach. For some of the pathogens of interest, the maximum tolerable concentrations are below the detection limits of the current technology based on 1 DALY per 1 million people per year benchmark. So rather than focusing on largely undetectable pathogens in drinking water, the quantitative approach has the benefit of promoting the control of hazards of interest at their upstream sources as an important strategy to managing pathogens risks.

There are trade-offs in water services. For example, how does one compare an infection of cryptosporidiosis—a self-limiting diarrhea—to developing cancer from a disinfection by-product of treating water? Chlorination is ineffective against *Cryptosporidium*, but ozone is effective. However, ozone generates a number of disinfection by-products, such as bromate. WHO and the EPA classify bromate as a genotoxic carcinogen because it induced tumors in rat kidney, thyroid, and mesothelium and renal cancers in mice (Havelaar et al., 2000). As a common metric, DALYs can be used to determine the right balance between controlling cryptosporidiosis and addressing problems with disinfection by-products (Table 3-1).

Guidelines

The U.S. EPA currently has the National Primary Drinking Water Standards as a guideline of the maximum contaminant levels (MCLs) for various chemicals, by-products, or biological agents. The standards also list health goals, which may be lower or higher than the MCL—most importantly, they are unenforceable. For *Cryptosporidium*, there is no MCL for drinking water, because it would need to be below detection.

There has been a shift away from a strategy for regulating chemicals using

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TABLE 3-1 Balancing the Risks of Drinking Water Disinfection (Point Estimates Based on Median Values)

O_3 benefit for effect	*Cryptosporidium* Gastro gen pop	Gastro AIDS	Bromate Renal cancer	Total Reduction
Morbidity	500	0.33	–0.01	
Mortality	0.003	0.32	–0.006	
YLD	0.50	0.01	0.00	0.51
LYL	0.02	0.23	–0.06	0.19
DALY	0.52	0.24	–0.06	0.70

NOTE: LYL = life years lost; YLD = years lived with disability.
SOURCE: Derived from Havelaar, A.H., A.E. De Hollander, et al. 2000. Balancing the risks and benefits of drinking water disinfection: Disability adjusted life-years on the scale. *Environmental Health Perspectives* 108(4):315-321.

an analyte-by-analyte approach. WHO used the risk management approach first in the Annapolis Protocol (WHO, 1999), for recreational waters, then in their guidance for safe recreational water (WHO, 2003), third edition of the Drinking-Water Guidelines (WHO, 2004), and Wastewater Reuse, Volumes 2 and 3 (WHO, 2006a,b). All of these guidelines make use of an approach to a water safety plan that uses hazard analysis (Figure 3-10) and in particular, identifies hazardous

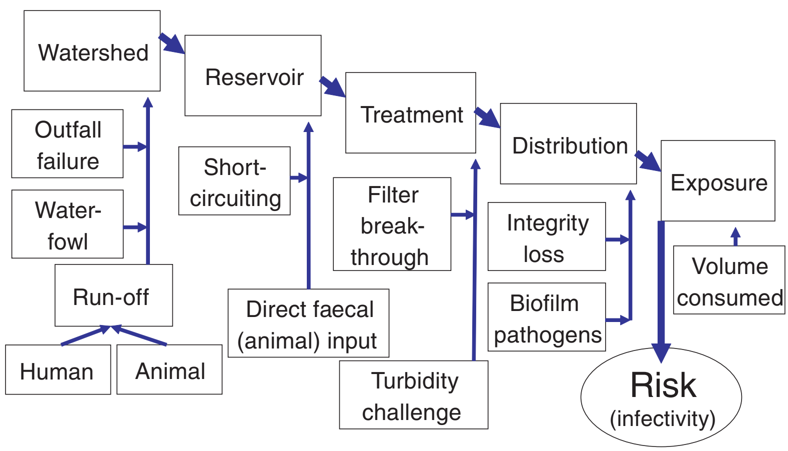

FIGURE 3-10 Systemwide hazard analysis and critical control point management of water. This approach uses system analysis, from the watershed to reservoirs, treatment, distribution, and finally exposure leading to potential infection. There are a number of opportunities to identify those hazards and hazardous events as well as the critical control points.
SOURCE: Ashbolt unpublished.

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events to manage. This approach is a system analysis, from the watershed to reservoirs, treatment, distribution, and finally exposure leading to potential infection. There are a number of opportunities to identify those hazards and hazardous events as well as the critical control points and target levels for management.

The European Union's Micro-Risk Project applied the source-to-customer Quality Management and Analysis System for 10 full-scale operational drinking water systems in Europe and one in Australia, focusing on six reference pathogens through various hazardous events. It became clear that much of the uncertainty in the estimate of infection probability came from what occurs in the distribution system. That study highlighted why there is uncertainty in detecting *E. coli* in distribution waters and trying to determine what it represents (e.g., sewage contamination, a bird in a reservoir, soil seepage). Figure 3-11 shows

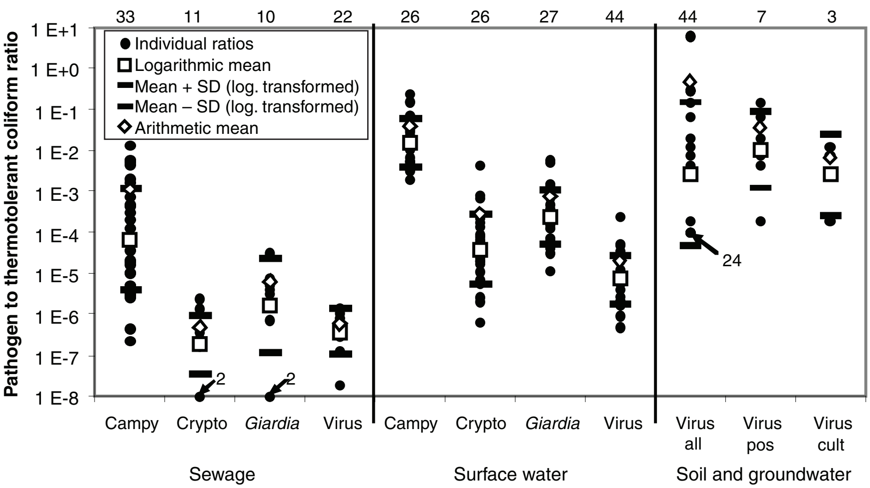

FIGURE 3-11 Pathogen to themotolerant coliform ratios in environmental samples collected from sewage, surface water, and groundwater. Campy = Camplobacter, Crypto = Cryptosporidium, virus cult = ratios of culturable enteric virus vs. themotolerant coliforms from data pairs in which thermotolerant coliforms were dectable; virus pos = ratios of both culturable enteric viruses and enteroviruses detactable with PCR vs. detectable thermotolerant coliform concentrations; virus all = all ratios (when themotolerant coliforms were not detectable, their concentration was estimated to be half the detection limit in order to be able to calculate a ratio). Two samples in sewage and 24 samples in soil or shallow groundwater did not contain detectable concentrations of pathogens and ratios were set to 1×10^8 and 1×10^4, respectively, for the purpose of presentation in this graph only (indicated with arrows), including calculations of means and standard deviations. The number of data pairs per pathogen is indicated over the graphs.

SOURCE: Van Lieverloo, J.H., E.J. Mirjam Blokker, et al. 2007. Quantitative microbial risk assessment of distributed drinking water using faecal indicator incidence and concentrations *Journal of Water and Health* 5(Suppl 1):131-149. Reprinted with permission.

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the relationship between *E. coli* and the pathogens from different sources, be it sewage, surface water or groundwater.

With various technologies, there are various types of exposures, and the guidelines, which have been heavily focused on end-point testing, have not necessarily helped in managing the situation. Newer approaches by WHO and the EPA are moving upstream for better management of the system. However, there is a need to further reduce the uncertainties, which include technical, social, and environmental uncertainties.

Major uncertainties in providing safe drinking water have been identified by the Quality Management and Analysis System, including short-duration system failures that lead to fecal pathogens in drinking water and distribution system intrusions that are likely to overwhelm the chorine disinfectant. In the United States, a number of agents have been attributed to drinking water outbreaks. *Legionella pneumophila*, which has been registered only since 2001, is probably the predominant water-borne pathogen now identified by the Centers for Disease Control and Prevention. However, a number of similar opportunistic bacterial pathogens exist, including *Mycobacterium avium, Burkolderia pseudomallei, Helicobacter pyloria*, and *Campylobacter jejuni*. From a research point of view, all of these opportunistic pathogens that may grow post water treatment in distribution systems, including some novel viruses called mini viruses, grow inside amoebae that naturally colonize biofilms in water after treatment in distribution systems, particularly inside building plumbing and hot water systems.

To conclude, sustainable water services need to consider the routes of pathogen exposure, including drinking, but also inhalation. When new technologies are developed and implemented—for example, recycled waters or water fit for purpose—their risks need to be assessed. As such, there needs to be an integrative assessment approach to address health that moves beyond traditional end-point assessments and includes all types of water exposures so resources are focused on the most important issues and locations for management.

APPROACHES TO SUSTAINABLILITY: GLOBAL WATER PARTNERSHIPS

Wayne Joseph, M.Sc., Chair
Global Water Partnership—Caribbean

Access to water supplies and drinking water cannot be discussed without considering water as a resource in totality. Water availability is a function of not only rainfall, but also the size of the land mass and population. For example, a small island with a low level of rainfall and a large population would be water stressed.

The Caribbean comprises the geographic area from Trinidad in the south to the Bahamas in the north. The annual rainfall varies across the region. Costa Rica has the largest annual rainfall in the region, with an average of 132.1 inches per

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year. In general, countries that are close to Costa Rica, are located on the mainland, or are close to the mainland tend to have the largest rainfalls. For a number of countries in the region, the annual per capita freshwater availability is below 1,000 cubic meters, which is the threshold for being considered water stressed.

To replenish aquifers and surface water sources, countries are very dependent on rainfall. However, climate variability is impacting water resources in the region because of changes in rainfall patterns. High-intensity, short-duration rainfall patterns are leading to runoff and flooding. Furthermore, these intense periods are followed by longer dry periods, resulting in reduced stream flows and a reduction in reservoir storage. Other changes are noticeable, such as the greater rainfall outside the conventional catchment areas and an increase in the frequency of extreme events. For example, two 50-year floods in Guyana within a two-year period have occurred. In addition, sea level rise, seawater surges during hurricane storms, and occasional flooding, as has occurred in the Bahamas, can cause aquifer contamination of the water supply.

Governance and Economics

Often multiple ministries in governments are responsible for water, and integrated water resources management is not practiced widely in the region. The result is that the programs of the various agencies may be slightly in conflict with one another. An integrated water system has to address the needs of the various sectors. In Trinidad and Tobago, both the agriculture and the tourism industries are reliant on fresh water and are negatively impacted by changing weather patterns as a result of climate change. For example, because the agricultural infrastructure cannot adequately incorporate the changes in the rainfall patterns, there is need for new infrastructure, including dams, wells, and associated sources, and for use of more efficient irrigation technologies, such as drip feed. The region needs to develop drought-resistant crops and to learn from other countries experiencing changing rainfall patterns.

Tourism also uses a significant volume of available fresh water for arriving cruise ships and hotels and for irrigation of golf courses. These industries can easily exceed the carrying capacity of the island. The demand has outstripped the supply, since industrialization and development as a result of tourism are happening at the same time. Currently, the water supply infrastructure is inadequate to provide the service levels that are expected by customers. For example, in Trinidad and Tobago, although development is occurring at a record pace, only 26 percent of the population receives a continuous water supply. The remainder of the population receives intermittent water supply.

The International Plant Protection Convention and local studies of the region have confirmed that the Caribbean is vulnerable to climate change. The agriculture, tourism, and health sectors will definitely be affected, so there is a need to quantify the extent of the impact of climate change on these economic sectors. Such an assessment will require a commitment to research, including the location

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and the extent of sea level rise throughout the country. It can provide a vulnerability map of the areas inundated with water to plan for effects on tourism and agriculture.

Current Water Challenges and Planning for the Future

One of the largest challenges is that water is not treated as an economic good. Some countries in the Caribbean have a metering policy in place, and other countries, such as Trinidad, do not. Even when metering is in place, tariffs are relatively low. Thus the current rating structure does not penalize wastage. In order to combat these challenges, the area is starting to recognize that water needs to be recycled to reduce the demand on the potable water supplies by moving toward an integrative water management approach that focuses on conservation. One of the essential features is the inclusion of reverse-osmosis filtration technology to treat sewage to a very high-quality standard for reuse.

Furthermore, as governments discuss strategies for mitigation of climate change, water resource management needs to be planned for extreme events, not based on historical data or trends. Such a strategy will encompass the design of larger storage reservoirs to accommodate long dry spells or short periods of higher intensity rainfall. Urban catchment areas need to collect and pump runoff from the catchment area to storage reservoirs, similar to the strategies being employed in Singapore.

Another strategy for the region, which is already being employed in Trinidad, is the use of desalinated technologies to produce potable water. Trinidad's desalination facility produces 24 million imperial gallons of water per day. It is expensive, but, for some countries, it is necessary.

Global Water Partnership

Through the development of the Global Water Partnership, the region is supporting an integrated, sustainable approach to water resources by working closely with the Caribbean Water and Wastewater Association, the United Nations Environmental Programme, the Integrated Watershed and Coastal Areas Management Program, and various nongovernmental organizations. The mission is to support countries in the sustainable management of their water resources. Currently, there are 40 partners from 16 different countries. The Global Water Partnership is committed to a participatory approach to development of water resources in the region and to treating water as a finite resource. Part of the outreach is at the ministerial level, to have top down support, although the organization believes that all stakeholders should be involved in the development of sustainable policies. Some examples of this approach include establishing a rainwater-harvesting model for poor rural communities in the Caribbean that can be easily adaptable to each island's specific needs.

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4

Panel Discussion: Coordination and Prioritization of Water Needs

DEFINITION OF SUSTAINABLE WATER SERVICES

A central theme of the workshop was the idea that water services should be sustainable. Paul Hunter of the University of East Anglia noted that, although most individuals can in principle agree to a broad definition of sustainable water services, there is a need for a more precise definition that defines the boundaries. Having a common definition allows researchers to define objectives and measure progress toward sustainability. At the same time, it allows for equity across groups, so that what is called sustainable in one region of the world would be defined the same way in other regions.

At its most basic level, sustainable water services will serve water needs over a long time by accounting for human, industrial, and ecosystem needs, offered Wayne Joseph of the Caribbean Global Water Partnership. However, those aspects are only part of what make a system sustainable. One needs to recognize that sustainability is not an end point, but a process or a continuum, suggested Nicholas Ashbolt from the U.S. Environmental Protection Agency (EPA). As the field plans for water services for current use and for future generations, decision makers need consider that future generations may have different purposes or uses for water that may make it more sustainable. Just as sustainability does not mean a specific time, its definition may change depending on an individual perspective, noted Stephanie Adrian from EPA. For example, the consumer may believe that sustainable water means being able to turn on a tap, to consume the water, and to know that the water will not cause illness from use. The provider, however, would want to ensure that the public has a lasting source of safe water that meets the regulatory requirements.

Technology is a central component to defining sustainable water services, according to some participants. Peggy Geimer from Arch Chemicals noted that sustainable water services provide a community not only with access to water, but also with access to mechanisms for disinfection and delivery of that water.

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She noted that these technologies need to be able to be used and maintained once the nongovernmental organizations, the companies, the researchers, or the governments leave. It is not a sustainable system if the technology is manufactured in some country a continent away, and the local users have no ability to obtain replacement parts. Jennie Ward Robinson of the Institute of Public Health and Water Research asserted that the water services have to be community owned and community based. The technology can be reliable, delivering water to a high standard, but if the people do not want it or cannot maintain it, and then it is not a viable sustainable solution. Any technology has to have longevity after the outside organizations or researchers leave. This means that local capabilities, capacity, and resources, including mechanisms for repairs and maintenance, must be in place. In the process of implementation, people in the water field need to think about the cultural, behavioral, and social factors that influence water usage—why people use water and what does its use mean in everyday life in that community. She further observed that, although it is appropriate for a solution to consider economic and social and health implications, the underpinning is to promote local ownership.

Cheryl Davis of the San Francisco Public Utilities Commission's Workforce Development Initiative expanded on the technology discussion by suggesting that sustainability analysis use a triple-bottom-line analytical framework. First, people using any technology need to be able to operate and maintain the system over the long term. At the same time, it needs to be economically viable. The second aspect of the triple bottom line is the environmental bottom line. For example, water utilities use energy, chemicals for treatment, and manage land. Water operations come at a cost to the environment. The third aspect of the triple bottom line is social. Social impacts include the water quality, communication with stakeholders, and the cultural and religious values associated with water. Cecilia Tortajada of the International Water Resources Association countered that sustainability has not been precisely defined, even though the concept was developed over 20 years ago. She asserted that individuals often imply a balance between economic, social, and environmental issues, although as yet the programs do not. There are trade-offs; for example, in Mexico with about 19–20 million people, large agricultural areas are irrigated with wastewater. These practices are not sustainable in either the developing or the developed world, yet the water is still provided in this way.

Hunter summed up this definition by drawing from the various presented viewpoints to suggest that the sustainability of water services is planning for the long term—how people provide clean water today should not interfere with the ability to provide clean water in 5, 20, or 100 years. He acknowledged that, most of the time, sustainability has been used in the environmental context—sustainability of the environment—but it is more than environmental sustainability. Water can be a commodity and a human right, two ideas that are not often captured in definitions of sustainability.

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PRIORITIES FOR ACHIEVING SUSTAINABLE WATER SERVICES

In the business community, people focus on commodity products and specialty products—and specialty products are more highly valued economically than commodity products. In this model, water is viewed as a commodity product, noted Geimer. If people want water to be valued at some point, it needs to be turned into a specialty product. As a first step, researchers need to identify what water means to a particular community. For example, will they cease to exist if there is no source of clean water for that community, or will there be cultural pressures on women if they don't have access to water at a common tap?

Davis noted that often there are trade-offs in water services. For example, in Mexico, using untreated wastewater for agriculture results in higher rates of water-borne illness in children. This creates a double bind given that families can die of starvation as a result of dry fields or because of increased rates of water-borne diseases. She noted that when the water supply and lack of water quality create inhumane, unsafe conditions, then water rights become a priority.

However, these trade-offs transcend human needs to also include environmental needs. Tortajada noted that when the environmental movement started, people recognized that there were minimum needs of water for flora and fauna to survive and for rivers to flow. These became the rights of the environment. When the discussion is about human rights, it becomes ideological. She further observed that many constitutions give priority to human consumption, so that many people recognize that humans need to take priority. Yet it can be difficult to separate the ideological from real needs. For example, when severe droughts occur, certain areas are selected for agriculture and irrigation. Keeping rights is also a consideration, whether they are basic needs—such as electricity, education, food, or water—or economic, social, or environmental ones. For example, in Spain, there has been an argument whether there should be transfer of water from north to south. The southern regions use it for irrigation to support their economic rights, and the northern regions use it to support the environment. These often conflicting rights become the challenge for managing water services.

STAKEHOLDER INVOLVEMENT

Many of the participants discussed what was needed for water interventions and policies. Ward Robinson noted that people in developed countries are trying to respond to an issue from their perspective—with their experiences, luxuries, education, and resources—and assume that these values are transferable to other regions of the world. She suggested that before asking what the priorities are, it is important to understand the context in which these priorities are set. This approach implies involving the community and using knowledge and resources within the community in order to have successful programs.

It is not just the public that needs to be involved in the process. Joseph noted there are three perspectives: civil society, groups, and government. It is

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important for any program for stakeholders to be involved through consensus building, public participation, and establishing proactive alliances. They need to be representative, gender sensitive, and participatory at the community, the regional, and the international levels. Davis concurred, noting that the water utilities also need to be involved. While utilities are subject to public interest, governmental regulations, and political factors, it may not be visible from the outside that utilities do have discretion (within limits) about how they operate and maintain their plants and design projects. At present, the water industry is focused on mechanical and economic concerns, but if the goal of groups is to incorporate environmental and social concerns into the water strategy, then the utilities need to be more engaged.

AN INTEGRATED APPROACH

The urban water sustainability framework, which was developed in Sweden and modified in Australia, has as a central component the expectations that stakeholders, including the public, are involved in identifying needs and priorities, noted Ashbolt. However, what is missing from the Australian and Swedish program is finding the right institutional homes within the government. This has been a worldwide problem, as most governments divide the responsibility of water among various agencies and locales. In order for water services to be sustainable, there needs to be an institutional home, noted Ashbolt. For example in the United States, the EPA says that its boundary stops at the customer's house. Joseph said further that countries need to learn from best practices. For example, in Singapore, they have moved from three main departments—to handle drainage that addresses storm overflow, wastewater, and drinking water—to an integrated public utilities board. The new model has the drainage department collect rainwater and pump it into reservoirs instead of out to sea. The wastewater department can treat the rainwater as a high-quality effluent. And the drinking water department can use an integrated water resources management strategy to meet the demand. Thus a truly integrated program would start upstream (at the watershed level) down to the household by looking holistically at the water system. Ashbolt suggested that this is one of the highest priorities for a more sustainable solution. Ward Robinson, echoing these comments, asserted that without a clearly defined line of research and investment in holistic water services, which are directly linked to public health outcomes at a national level, future societies will be paralyzed by current inaction.

CURRENT CHALLENGES FOR WATER SERVICES

Hunter noted that one of the malaises of Western society is that people are getting more interested in the process of managing something rather than achieving its goals. For example, in the academic setting, administrators may become

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more interested in whether teachers can teach document and deliver the process of teaching rather than whether they are good teachers. This is applicable to water delivery, as researchers and policy makers have focused on what they can measure instead of the objectives of delivering consistent, safe drinking water.

Adrian noted that the water community is constantly striving to look for a silver bullet to solve the world's water issues, but there isn't one. The result is that researchers and policy makers end up in a discussion about all the different issues involved and not making progress. She suggested that there needs to be a focus on empowering communities to do more for themselves and to address their particular challenges and characteristics. This does not mean that governments and aid organizations walk away, but rather that they offer tools and ways to help. The EPA has been promoting water safety plans—introduced in the World Health Organization guidelines for drinking water quality in 2004—as a framework to help empower communities to identify their greatest vulnerabilities and prioritize their investments.

Ward Robinson furthered this theme by suggesting that people are telling the water research community what they want, but researchers and planners are not always listening. For example, researchers bring interventions to developing countries, but after they leave, the filters are polished and put on the shelf. In the United States, people choose to buy bottled water to drink and use the water that utilities spend so much money and time sanitizing to water their lawns. She noted that this is a fundamental disconnect. The water community has the expertise and the technology, but the field does not take into account the community's will or even its willingness to pay. Hunter built on this idea that current approaches have been a linear process: you have a problem, you solve the problem, and you deliver the solution. However, a lot of the problems in water services are not amenable to that linearity in delivery and solution finding.

Davis suggested that the field is suffering from learned incapacity, which means that as people learn what to do, sometimes they become rigid and less able to learn the new thing they actually need to know right now. In the United States there is a bias toward centralization and high technology, with a great reliance on the short-term economic bottom line, without determining if communities can operate and maintain facilities long term. The move toward centralized systems may not work as the world faces climate change. Ward Robinson noted that it is the ideal time to revisit water services—allocation, storage, delivery, and cost recovery—to correct past mistakes and inaction and address future challenges. The opportunity is emerging to develop sustainable solutions that are built on best practices and worldwide knowledge.

EFFECTIVENESS, LONGEVITY, AND EVALUATION

Some of the largest impacts on developing country costs for water interventions are the premature failure and the inadequate longevity of the systems. Hunter

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questioned how to build systems with an eye toward longevity and effectiveness. The traditional strategy by many groups and organizations has been to focus on technology, but that is only one facet of planning and management, noted Tortajada. The primary reason that programs do not have longevity is because the field does not plan for it. However, this is only partially correct: Singapore is an achievement in terms of long-term planning and management within which technology is only one component, asserted Tortajada. Planning determines what the appropriate technology is and not vice versa. Once the plans are finalized, the overall system can be designed and implemented. Davis further noted that, even in the United States, with its fairly complex planning for capital projects, there is often a failure to plan for the operations and maintenance needs. The question is not necessarily the longevity of the technology if it received perfect maintenance, but what kind of maintenance will actually be provided. Planning for water systems needs to take into account the investments for maintenance and the local capacity to keep systems operational.

Changing water usage and demographics make it difficult to plan beyond a short time frame. What was appropriate for the demographics and conditions for a country 20 years ago is no longer the strategy needed today. The difficulty may be best illustrated by considering climate change—a threat that people are still trying to understand. For example, according to the Indian Meteorological Society, more than 80 percent of the annual rainfall for a city like Delhi occurs in fewer than 85 nonconsecutive hours. Without knowing how climate change will affect this skewed distribution of rain, it will be difficult to plan and manage water resources on a long-term basis, not only in India but also in all other monsoon countries of Asia. In other words managing water for plausible climate change scenarios of the future will require different policy responses in India, asserted Biswas.

The world is very heterogeneous, and the water field needs to recognize that one size does not fit all. In the United States, for example, policy makers and planners cannot use the Alaska experience in California—planning has to be uniquely focused on the area at hand. Biswas further noted that technological and management advances are now often coming from the field—combining local interest and expertise with available technology. Therefore, researchers need to understand the success stories at the local level, as do the policy makers. Currently, these stories are not well documented or evaluated, which means that communities cannot learn from the current body of interventions. One model will not work in all, or even most, situations. Accordingly, there is a need to have many good models, or a selection of good practices. This will allow a community to select from the available models and tailor appropriate solutions to their current and emerging needs.

Joseph added that all of the planning has to be placed in a cultural context, so that technologies are appropriate for a country or a region. For example, some cultures will not tolerate recycled wastewater coming into their homes at all, such as occurs in Singapore. While it is true that the planning needs to be sustainable—

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environmentally sound—it will not be successful unless it is accepted by the community. These perceptions may subtly change over time, but planning cannot rely on acceptance unless it comes from the community. Ward Robinson noted that future strategies in the water community need to consist of education, planning, management, and integration across technology, social behavior, gender, health, environment, economics, and politics. Biswas, however, argued that it is wrong to see countries like Singapore as a monolithic society; rather it is a rainbow society with Chinese, Malay, Indian, and Europeans, with strong Confucian, Islamic, Hindu, Christian, and Judaic beliefs. Singapore community accepted treated wastewater because its political leaders have a long-term vision, showed great political leadership by themselves using treated wastewater, and by providing all the relevant health-related information on reusing treated wastewater to the public. It will be a good case study to see how the public accepted the idea of using directly treated wastewater. All over the world, including the United States, communities often use, albeit indirectly, treated wastewater. They may not be aware of it, but they do.

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5

Achieving Water and Sanitation Services for Health in Developing Countries

Water-related efforts in the developing world are often balkanized and not sufficiently integrated to ensure sustainable water services. There can be different strategies to ensure access to safe water depending on the country and its social needs. The different strategies may have impacts on reaching the Millennium Development Goal of reducing by half the proportion of the population that lacks access to improved water and sanitation by 2015. This chapter focuses on presentations addressing the challenges in developing countries.

IMPROVING WATER AND SANITATION ACCESS IN DEVELOPING COUNTRIES: PROGRESS AND CHALLENGES

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Emory University

Water and sanitation concerns are of great magnitude: 1.1 billion individuals, approximately 17 percent of the world's population, are without improved water and more do not have access to safe drinking water, and 2.6 billion, approximately 41 percent, are without improved sanitation. Even worse, many of the world's school children attend a school without water or toilets. Not surprisingly, 40 percent of the world's school-age children have worm infections, predisposing them to cognitive and developmental problems. It is further estimated that 5,000 children die every day from diseases because of lack of safe drinking water, inadequate sanitation, and poor hygiene (WSSCC, 2004).

In many regions of the world, collecting water is primarily the responsibility of women. Women's lives are further impacted by lack of water and sanitation because they are responsible for the care of children, who are affected by diar-

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rheal disease. Women do not always have the financial resources to pay for water purchases, treatment, or new investments. However, it is not just access to water that is a problem. The lack of sanitation means that, in some places, women and girls must wait until nightfall to defecate, while in some nations more than 50 percent of girls drop out of school due to the lack of toilets. These disparities have additional implications for health, education, and human rights.

Thus women and children place a higher value on water and sanitation. A study showed that microcredit loans provided to women in Bangladesh increased the presence of latrines in their household from 9 to 26 percent over three years; the control group showed a slight decrease in latrine presence during the same time period (Husain, 1998). A group of schoolgirls in Kenya demonstrated that children are thinking about sanitation. When asked about the type of preferred sanitation, they provided a detailed drawing depicting the location and construction of a latrine for their school (Dickman, 2008). Much work must be done in order to reach a global goal of increasing access to improved sanitation in many parts of the world.

The Past and Future of Sanitation and Water Improvement Goals

The first collaborative international effort to create significant impacts on the global water and sanitation situation came from the First International Drinking Water Supply and Sanitation Decade (1981–1990) which ultimately met with limited success. However, new innovations exist that may lead to greater success in the second decade International Decade for Action: Water for Life (2005–2015), such as increases in public-private partnerships, investments by large corporations, and more community-based organizations and nongovernmental organizations that work on improving access to water and sanitation. A greater focus on microfinancing and local initiatives, along with new discussion of ecological sanitation and culturally appropriate initiatives, is led by empowered community members. Other trends include the consideration of global water scarcity in sustainable planning and a move from simple water quality monitoring to the development of a more holistic water safety plan approach by the World Health Organization (WHO) as well as greater use of various household water treatment approaches.

With regard to standards for improved water and sanitation, it is important to recognize that improved water is not necessarily safe drinking water. Improved water access includes household connections, public standpipes, rainwater collection, boreholes, and protected wells, but not water vendors, unprotected wells, unprotected springs, rivers or ponds, or tanker truck water. Improved sanitation includes connections to public sewers, septic systems, pour-flush and improved pit latrines, but not shared, traditional, or open pit latrines. Results have been mixed—between 1990 and 2002, the number of people with improved water gradually increased (Figure 5-1).

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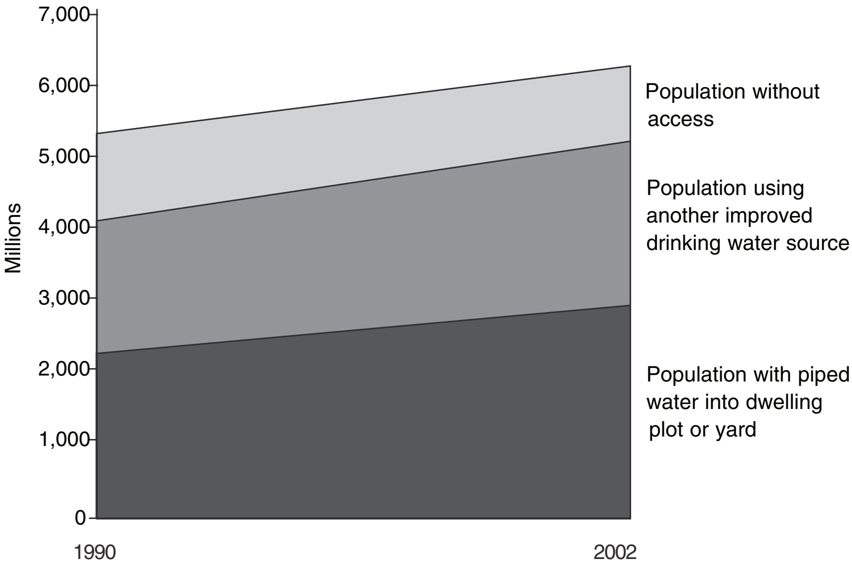

FIGURE 5-1 Trends in service levels for drinking water. Between 1990 and 2002, there has been a gradual increase in the number of people with access to improved water sources. However, the data does not show that the gains are partially offset by individuals who loss their access to improved drinking water sources.
SOURCE: UNICEF (United Nations Children's Fund) and WHO (World Health Organization). 2004. Joint monitoring programme for water supply and sanitation; meeting the MDG drinking water and sanitation target: A mid-term assessment of progress. Reprinted with permission.

For sanitation, large gains occurred in some areas and losses in others (Figure 5-2, UNICEF, 2004). Disparities exist between the rich and poor and are much greater in sanitation than water. The poor are half as likely to have water access and one-fourth as likely to have sanitation access. More than half of the 41 percent of worldwide population without improved sanitations live in India and China. Unmet needs are highest in sub-Saharan Africa (in Ethiopia, 94 percent of the country is without access to sanitation; in Chad, 92 percent; in Congo, 91 percent; in Eritrea, 91 percent; in Burkina Faso, 88 percent; in Guinea, 87 percent; in the Comoros, 77 percent) and Southeast Asia (in Cambodia, 84 percent) (UNICEF, 2004). In terms of access to improve water, coverage is lowest in Africa and Oceania (UNICEF, 2004).

What can be done about these large gaps in access to water and sanitation? The Millennium Development Goal Number Seven, outlined by the United Nations, includes reducing the proportion of those without improved water and sanitation by one-half worldwide by 2015 (DESA, 2008). Meeting this goal

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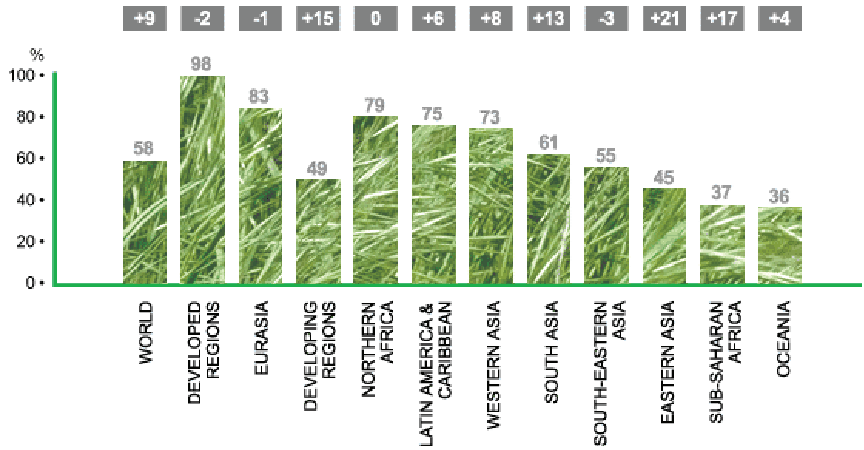

FIGURE 5-2 Coverage with improved sanitation by region in 2002. Fifty-eight percent of the world has access to improved sanitation; however, sub-Saharan African and regions in Oceania have the lowest rates of coverage.
SOURCE: UNICEF (United Nations Children's Fund) and WHO (World Health Organization). 2004. Joint monitoring programme for water supply and sanitation; meeting the MDG drinking water and sanitation target: A mid-term assessment of progress. Reprinted with permission.

requires that 50 people receive services for water and 65 receive sanitation per minute (Stockholm Environment Institute, 2005). Reaching these goals would cost an estimated $11.3 billion per year, according to a WHO study (Hutton and Haller, 2004). These goals may be reached by addressing four major challenges to achieve greater gains in the current Water and Sanitation Decade.

Major Challenges to Improved Access: Need for Evaluation, Accountability, Sustainability, and Capacity

First, we must understand, respond to, and promote consumer demand for water and sanitation services. Without identifying why and how users would like improved services and subsidizing improvements without user input, many projects risk being abandoned or misused. The new goal is to spur consumer demand and provide market-based approaches, such as microcredits or loans instead of grants, in those areas where individuals and communities desire improvements. Investment will then be more sustainable than a generic installation by an outside organization.

Second, there must be a move away from implementation without evaluation. Water and sanitation projects must include monitoring and evaluation com-

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ponents from inception through implementation and follow-up, and the metrics should reflect the need, design, implementation, use, impact, efficiency, and sustainability of the project/program. Agencies often measure success by the number of wells or latrines installed, rather than the quantity used or the number still operational five years later. The metrics of successful water and sanitation projects need to reflect actual use as well as promote accountability for keeping the services operational. Furthermore, the results of the monitoring and evaluation and lessons learned need to get back to the decision makers so that the findings can inform policy.

Third, there needs to be an emphasis on sustainability. There is a need for additional longitudinal research to identify approaches that are sustainable technically, financially, and environmentally. Technical sustainability has been an ongoing problem in water and sanitation projects in developing countries. Too often, a pump or other piece of equipment breaks and cannot be repaired. This problem can occur all along the scale of services from a pump at a borehole to a pump in a modern water or wastewater treatment plant.

Financial sustainability depends on local capacity to recover the true costs of water and sanitation system operation and maintenance without reliance on long-term financial aid from external donors. This includes consideration of community management models, transparency, and good governance practices. However, there can be tension between the need to recover the costs of water supply and sanitation development, operation, and maintenance and the principle that safe water and sanitation are basic human rights that should be provided to all. It is essential that these services be adequately valued since they are also linked to the protection of scarce natural resources. Environmental sustainability includes consideration of the available water resources that can be developed for drinking water as well as for industry and agriculture needs and also weighing the long-term feasibility of waterborne sewerage and wastewater treatment. In developing countries, most cities and towns that have a sewerage system do not have sewage treatment, and the consequences of continued discharge of raw sewage into the environment are serious, irreversible damage to the aquatic environment as well as health risks from exposure to pathogens entering the environment.

Finally, there needs to be investment in building human capacity in-country in order to be able to construct, operate, manage and maintain water and sanitation services.

Sustainable Infrastructure: Structure for the Future

In the United States, 20–30 percent of production water is lost, and older systems, with many pipes nearing the end of their planned lifetimes, may lose as much as 50 percent of their water (NRC, 2006). However, upgrading water distribution systems is costly and difficult to implement. Therefore, there may be increased exposures to pathogens from distribution system contamination. This

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contamination can occur through illegal tapping into the pipes, breaks in pipes, and leaks and loss of pressure due to power outages and other factors. This is a problem not just in the United States. Recent studies found that 30 percent of homes with indoor plumbing in Uzbekistan had no residual chlorine levels. The addition of home chlorination subsequently led to a 62 percent reduction in diarrheal disease (Semenza et al., 1998). This finding challenges the idea that piped water is generally safe and indicates that in some settings home treatment may be necessary in addition to improved water sources.

Water Scarcity: Increasing Need, Decreasing Supply

A new focus for WHO is the development of water safety plans, that include analysis of water needs and usage and evaluation of water safety and system factors that lead to problems. The plans also include remediation of deficient factors, from operator training to repairs. However, goals need to be taken into account. Given increasing water scarcity problems and limited resources, should the goal be to create potable drinking water in large quantities, or would it be more viable to provide a small supply of high quality drinking water and greater quantity of less pristine household water for other uses? Many parts of the world suffer from physical or economic water scarcity; that may indicate a need to change how we use and value water.

The number of countries that are classified as water-scarce or water-stressed is projected to increase from 31 in 1995 to 48 in 2025 and to reach 54 countries in 2050. At the same time, the number of people living under water-scarce or water-stressed conditions will increase from 460 million in 1995 to 4 billion in 2050 (Hinrichsen et al., 1997). The implications of this scarcity are serious for global stability, food security, and health. In addition, global use of water has rapidly increased in this century for agricultural, industrial, and municipal purposes (Figure 5-3).

An important question is how to incorporate water efficiency into water programming to address scarcity. One method is to look at behavior and lifestyle change, such as decreasing meat consumption and water waste. Another is to implement infrastructure improvements that repair leaks in water pipes—both to prevent loss as well as protect water quality, as discussed earlier. Finally, agriculture is the greatest water consumer; how can efficiency be improved in irrigation and land use?

Global trade of water-intensive products leads to virtual water flows (Figure 5-4). This is because different foods and diets have different water requirements. For example, a kilogram of beef requires 15 cubic meters of water, a kilogram of poultry requires 6.0 cubic meters of water, and a kilogram of cereal requires 1.5 cubic meters of water. The water footprints of industry and manufacturing also need to be considered. With regard to wastewater, toilet flushing alone can consume 50 liters of water per person per day (assuming 12 liters per

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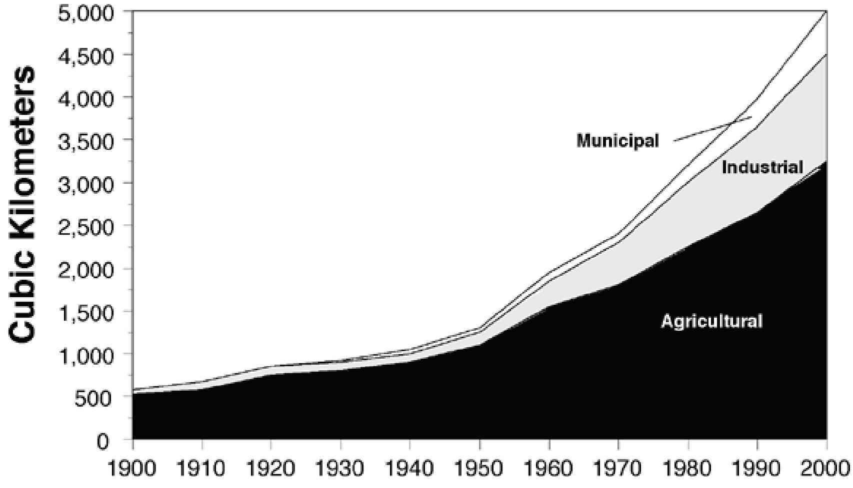

FIGURE 5-3 Global annual water withdrawal by sector, 1900–2000. Global water use has been rapidly increasing during the past century for all purposes—agricultural, industrial, and municipal. Agriculture use has had the largest increase.
SOURCE: Worldwatch Institute, *Imperiled Waters, Impoverished Future: The Decline of Freshwater Ecosystems*. www.worldwatch.org. Reprinted with permission.

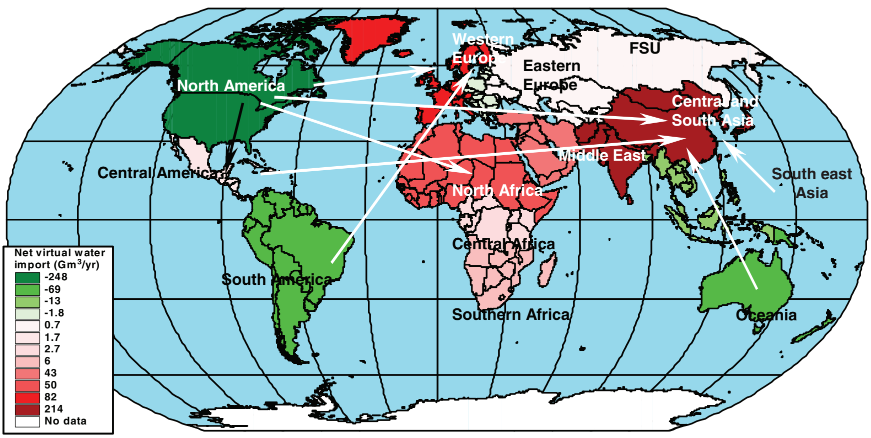

FIGURE 5-4 Virtual water balances of the 13 world regions, 1995–1999. The biggest net flows (> 20 Gm3/yr) as a result of the trade of water-intensive products are indicated with arrows.
SOURCE: Hoekstra, A.Y., and P.Q. Hung. 2002. Virtual water trade. A quantification of virtual water flows between nations in relation to international crop trade. The Netherlands: IHE Delft. Reprinted with permission.

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flush for a conventional toilet [4–6 liters per flush for a low-flush toilet] and 4 flushes per day). Perhaps it is time to stop using water for the purpose of sanitation, particularly in areas where water is limited.

Sanitation Improvements: Investing the Community in Their Health

There are vast unmet needs in sanitation, and the question remains as to why water is considered a human right, but sanitation is seen as a commodity. A survey of attitudes on sanitation in Benin and the Philippines revealed that most of the reasons that sanitation was considered desirable were based on comfort, privacy, and prestige, with health falling lower in terms of priorities (Cairncross, 2004). Leaders need to speak out about the sanitation crisis and be willing to publicly address the deficiencies and push funding toward parity. From 1990 to 2000, the total annual investment in sanitation in Africa, Asia, Latin America, and the Caribbean was $3.1 billion in comparison to a $12.5 billion annual investment in water during the same period (WHO-UNICEF-WSSCC, 2000).

Dry sanitation is an attractive option for many parts of the world because of the water scarcity costs described above and the complex infrastructure needs and costs associated with waterborne sewerage and wastewater treatment. Ecological toilets are toilets that do not use water for function, contain human excreta to prevent environmental contamination and disease transmission, promote the inactivation of microbial pathogens in excreta through high pH, desiccation, heat, and time, and recycle nutrients from human excreta (urine and feces) for agriculture to promote better crop production, home gardens and ultimately, improved nutrition. Most ecological toilets store excreta in an alternating, two-chamber system and separate the urine from the feces, thus allowing fecal waste to decompose to biosolids and collecting urine separately for use as fertilizer. Urine separation reduces odor and promotes more rapid desiccation of the feces. Desiccation can also be facilitated by adding absorptive material to the storage chamber or using a solar structure to dry and decompose the feces more quickly. One research project found a greatly increased yield of corn associated with increasing amounts of urine fertilizer, as urine has a chemical composition virtually identical to agricultural needs (Morgan, 2005).

Bolivia has the lowest sanitation coverage in Latin America and high rates of diarrheal disease (Franco, 2007). Recent surveys in communities with sanitation interventions by several nongovernmental organizations (NGOs) indicate that households with access to bathrooms (most of them with ecological sanitation) were more willing to pay for improved sanitation service than those without, and half of those without toilets were willing to pay for sanitation (Moe et al., unpublished) Regardless, most households surveyed reported that they would not have a bathroom if they had not received technical assistance (usually construction materials). Microcredit in this setting may be an ideal solution to meet such a need. A new project, funded by The World Bank Development Marketplace, has

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four strategies for improving access to sanitation in poor communities in Bolivia: (1) development of low-cost sanitation models, (2) examining and stimulating consumer demand, (3) creating small sanitation businesses to meet this demand, and (4) establishing microcredit systems to help finance sanitation purchases. This project addresses previously identified barriers to sanitation access and examines market-based approaches to improve access and sustainability.

Meeting Water and Sanitation Needs: Research and Evaluation

In summary, a number of challenges remain, including important research needs for sanitation. In the past, many water and sanitation intervention programs took their own designs and implemented them in areas with need. This led to some unsustainable, culturally inappropriate, or irrelevant installations that were not always effective. New concepts focus on smaller, community-based projects that are chosen by the household and implemented through microcredit. The major research areas mirror these approaches, leading to more social marketing research, health behavior research, technical and microbiological investigation, and health outcomes and impacts research. The future of sanitation improvement lies in trying new approaches—creative approaches to technology and delivery, greater dissemination of information on what works and what does not, providing greater training and building capacity in human resources, and greater political and financial commitment.

THE DRINKING WATER SUPPLY AND SANITATION IN LATIN AMERICA: MOVING TOWARD SUSTAINABILITY FOLLOWING TWO DECADES OF REFORMS

Andrei Jouravlev, Economic Affairs Officer
United Nations Economic Commission for Latin America and the Caribbean (ECLAC)[1]

Latin American and Caribbean countries have made great efforts to improve their population's access to drinking water supply and sanitation services. Although the situation varies considerably among countries, levels of coverage can generally be considered reasonable, with the possible exception of wastewater treatment.

Approximately 91 percent of the region's population has access to drinking water supply services, either through household connections or through easy access to a public source. With regard to sanitation services, only 51 percent of the regional population is connected to conventional sewerage systems, and

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another 26 percent use in situ sanitation systems. As a result, some 50 million people in the region lack access to drinking water supply services and approximately 130 million lack access to sanitation. The majority of those without access to services are poor and live in rural areas.

In many countries in the region, drinking water supply services are intermittent, even in extensive areas of the main cities. Owing to inadequate maintenance and poor commercial management, there are high levels of water losses in the drinking water supply systems of almost all the countries in the region. The proportion of the population covered by adequate systems of monitoring and control of drinking water quality is low in urban areas and insignificant in rural areas. However, the monitoring of drinking water quality and its disinfection has increased in most countries.

Wastewater from about 370 million people is discharged into recipient water bodies without any treatment, causing significant water pollution problems. The insufficient coverage and poor quality of services not only have negative impacts on the health of the population but also affect the environment, the economy, foreign trade, and the availability of water for various uses.

All these problems, together with the reappearance of cholera in the region at the beginning of the 1990s, have led the governments of Latin American and Caribbean countries to give high priority to the drinking water supply and sanitation sector. As a result, over the past two decades, this sector has been subject to extensive reforms in the majority of the region's countries. Despite the inevitable differences in a region that includes very different countries, there are many common trends in the reforms carried out, or under way, in the countries of the region:

- Modification of the institutional structure of the drinking water supply and sanitation sector. The reforms invariably include institutional separation of the functions of sectoral public policy making, economic regulation, and systems administration.
- Modifications to the industrial structure of the sector, with an emphasis on decentralization of service provision, in many cases to the municipal level.
- In many countries, policies have been adopted to ensure nonpolitical management of services by autonomous public agencies or local governments, in accordance with technical and commercial criteria. There is also a general interest in promoting private-sector participation.
- A desire to formulate new regulatory frameworks for the sector both to facilitate private participation and to bring about a significant improvement in the efficiency of public provision of services.
- The changes in the institutional and industrial structure of the sector have gone hand in hand with a requirement for services to be self-financing.

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Interest has also been shown in establishing sophisticated subsidy systems for low-income social groups.

In general terms, it may be said that the reforms relating to modification of the institutional and industrial structure of the sector, the formulation of new legal and regulatory frameworks, the setting up of the designated institutions and, in some cases, the transfer of services to the private sector, have made relatively rapid progress.

There are still significant lags, however, in reforms associated with tariff readjustments to levels that guarantee the self-financing of services, the creation of effective subsidy systems for the poor, implementation of the regulatory frameworks, and modification of the behavior of public service providers. As a result of these gaps, and also the macroeconomic instability and structural deficit of public finances, the reforms have not achieved the expected degree of success.

To understand the situation in Latin America and the Caribbean, one must also look at regional trends. Some countries have been much more successful than others. So the question remains as to what factors or drivers could help explain the different levels of progress. The variance among nations could not be explained by economic development alone, since only 0.35 of the coverage variation can be attributed to per capita gross domestic product (Figure 5-5). Extending the analysis to institutional quality, a much better predictor is found in terms of service coverage, 0.56, which increases even further when corruption is controlled. Thus such government priorities as budget allocations, good institutions, efficient public policies, and corruption control are important predictors of success.

The experience of the past two decades suggests some of the main priorities of the countries in the region in reforming the drinking water supply and sanitation sector:

- **Improving regulatory frameworks.** The regulatory frameworks adopted in the region are relatively weak, especially compared with the regulatory practices in countries with a long tradition of public utility services being provided by the private sector. The main priorities for improvement are (1) strengthening the professional, technical, and financial capacity of the regulatory entities and ensuring their independence and stability; (2) developing procedures for accessing the internal information of regulated companies, especially regulatory accounting and monitoring of purchasing and contracts with associated companies; (3) promoting the participation of consumers and civil society in general in the regulatory process; (4) improving arbitration mechanisms and dispute resolution procedures; (5) strengthening regulatory frameworks, for both public and private service providers, based on the notions of fair and reasonable rate of return, good faith, due diligence, and duty of efficiency; and (6) conducting a critical

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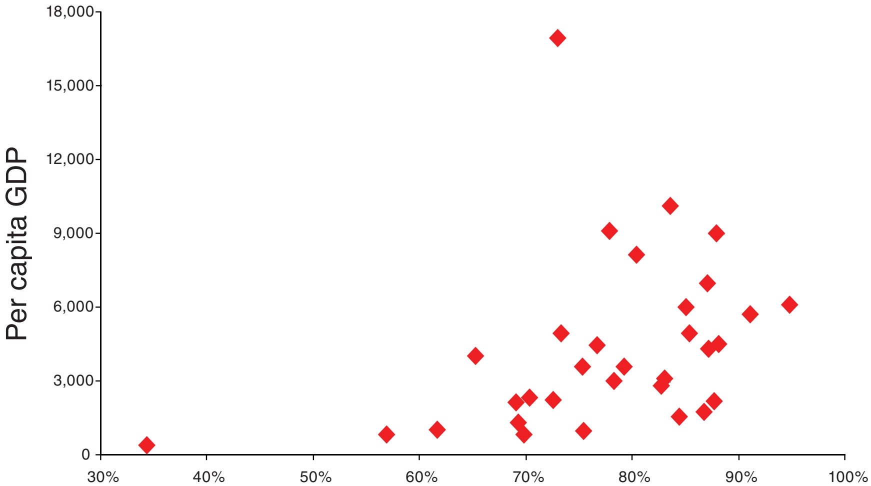

FIGURE 5-5 Coverage of sanitation and access to drinking water can not be explained by economic development alone as there is a low correlation (.35) between percent covered and per capita GDP.
SOURCES: Derived from ECLAC (Economic Commission for Latin America and the Caribbean). 2005. Per capita gross domestic product (GDP), at constant market prices. Statistical yearbook for Latin America and the Caribbean. Santiago, Chile (http://www.eclac.cl/publicaciones/xml/4/28074/LCG2332B_contenido.pdf); UNICEF (United Nations Children's Fund) and WHO (World Health Organization). 2007. Joint Monitoring Programme (JMP) for water supply and sanitation. Retrieved September 2007 from http://www.wssinfo.org/en/welcome.html.

analysis of available options for service provision and structuring them in such a way that they do not become a burden on the economy or the citizens, or ultimately a regressive factor that hinders socioeconomic development. Other important tasks include adapting regulatory practices to the specific characteristics of public service providers and deepening the analysis of the effects of international investment protection agreements on the national capacity for regulating public utility services. With regard to international arbitration tribunals, the reasons for concern include the secret nature of their procedures, the lack of obligatory precedent, the absence of principles of public interest, and the fact that these tribunals are ad hoc bodies comprised of members paid by the parties involved.

- **Creating subsidy systems for low-income groups.** The financing of drinking water supply and sanitation services has been and remains a critical unresolved problem in most of the region's countries. Given that the rate adjustments needed to achieve self-financing are limited by the

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low payment capacity of large groups of the population, the creation of effective subsidy systems, which should be based as far as practicable on direct and focused compensation mechanisms and should avoid cross-subsidies, is a prerequisite to reverse the chronic lack of finances in the sector. In many countries, the state needs to recover its traditional role of financing investment, particularly for the purposes of extending coverage to low-income groups and rural areas.

- **Consolidating horizontal industrial structure.** Many of the decentralizing reforms have left the sector with a highly fragmented and inefficient industrial structure. It is made up of numerous service providers, without real possibilities for achieving economies of scale or economic viability, and is the responsibility of local bodies that lack the necessary resources to deal effectively with the complexity of the processes involved in providing drinking water supply and sanitation services. Most countries clearly need to consolidate the sector's industrial structure by achieving a happy medium between the excessive centralization of the 1960s and 1970s and the extreme fragmentation of the 1980s and 1990s. Regulatory frameworks should therefore offer incentives for such consolidation and provide the means of achieving it.

The experience of the past decade has also demonstrated the need to harmonize macroeconomic and sectoral policies in order to strengthen trends toward sustainability in service provision, as well as to ensure a rigorous sequencing over time of economic, social, and environmental goals.

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6

The Environmental Pillar of Sustainable Water: Ecological Services

Across the globe, increased demand and water mismanagement have put stress on water services. As a result, there has been a growing societal recognition of the need to look at sustainable solutions that allow for everyone to have access to clean water. There is growing recognition of the importance of ecological services (benefits arising from the ecological functions of healthy ecosystems) as part of a management strategy in new approaches. Ecological services imply that nature can also play a role in providing safe drinking water. Whether through source water protection or natural filtration, the environment can work in concert with technology to provide water in a reasonable, sustainable fashion.

DRINKING WATER VALUATION: CHALLENGES, APPROACHES, AND OPPORTUNITIES

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Brock University

The value of water and the importance of having the public recognize the true value of water are of great relevance to the goals of achieving sustainability and efficiency in water supply systems. Investigating how people value water and how to elicit these beliefs and behavior in order to improve water use and cost recovery can be understood by outlining challenges to the valuation of water, approaches to valuation, and opportunities to make gains in water systems and societal attitudes about the former. While workshops such as this one will not be able to solve the challenges, bringing together scientists from diverse areas to discuss water issues creates opportunities to bring about crosscutting solutions.

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Challenges to Valuing Water: What to Value, Water Competition, and Willingness to Pay

The first challenge in estimating the value of water to the consumer and society is to determine which qualities, amounts, and uses to include. Human health is an obvious value, as are general household and industrial and agricultural uses. Water is used for many valued activities, which fall into three categories: (1) direct, including household consumption, waste disposal, and recreation as well as industrial and agricultural input use in production processes or as a method of eliminating waste; (2) indirect, including hygiene, ecosystem maintenance, flood protection, and aesthetics; and (3) nonuse, including the values people place on the existence of bodies of water, such as the Great Lakes. One framework for water valuation is the Total Economic Valuation Framework, which was used in Canada to quantify the value of Canada's natural resources, including water. The focus of these remarks is on drinking water as it directly affects human health.

Drinking water has two main dimensions that affect health: quantity and quality. Water quality is a critical component in value for consumers and directly links to health. Economists use a willingness to pay (WTP) approach in order to value drinking water quality. By enumerating a number of components of quality, they then have survey respondents reveal their values through a series of tasks designed to elicit trade-offs made across different aspects of water quality. This is a difficult problem for water, as it may be difficult for consumers to separate out components of water quality, and there are no competitive markets to allow market comparisons. The lack of a market to equilibrate between the supply and the demand for water is problematic, in that many people have no concept of their consumption levels or the quality of water they consume. Even more complicating is the fact that value may differ significantly in different contexts.

In Canada, the metering of household water consumption is not universal. Approximately two-thirds of households are metered, which results in many individuals not knowing how much water they use and therefore having little understanding of the value of water. A similar situation exists in the United States. An exacerbating factor in both countries is that the pricing structure designed by water utilities generally is intended as a cost-recovery exercise relating to administrative costs and past infrastructure cost recovery. Thus individual households can in theory use very large volumes of water, but be charged only a minimal administrative cost. Furthermore, current pricing structures do not generally cover infrastructure renewal or innovation. Overconsumption and ignorance of the amount of water usage arise from the lack of understanding that water is scarce. Current pricing structures encourage the perception that water is not scarce, which results in a reference bias, in which water becomes a free good and its value is zero. Because there is no feedback mechanism, such as volumetric pricing, people have the tendency to overconsume.

Similarly for the industrial sector, the pricing structure is such that the cost of one more unit of water is so small that firms are discouraged from adopting

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conservation efforts or efficient use. Of course, the cost to society is far more than nothing, and reform of water provision is needed to reflect these costs. Engineering has come to focus on production to meet the demand rather than prioritizing other needs, such as safety and sustainability. The alternative is that water is managed through conservation pricing as a way to acknowledge that the supply of water is not inexhaustible. Finally, sustainable action must commence prior to when supplies run dry and the demand for water can be modulated through price.

When it comes to valuation, most people struggle to quantify what constitutes water of high quality. Focus groups defined good-quality water by the absence of contaminants, such as color, odor, and taste. Economically, this is a conundrum that may be addressed by turning these negatives into positives, such as health benefits and reliability (i.e., the water will be there when the tap is turned on). Another challenge in quality is helping the consumer make linkages between their own water use and ecosystem services (conservation and environmental consequences). The solution to this disconnect is education of the public on the impact of water quality and quantity.

The Real Value of Water: Economic Approaches

Markets will not be able to reveal the disparate values for different components of water, as their approach is based on giving every unit of the item in question a homogeneous value, which is not the case for water. Because of this market failure, economists turn to nonmarket valuation approaches, both indirect and direct. The indirect method relies on the assumption that the value of water can be revealed through examination of the values of related goods and services that are bought and sold in a market. In terms of finding water values related to health, indirect methods include the cost of illness (COI) approach, which infers the value of water to promoting good health with reference to treatment costs associated with illness or to lost wages due to illness, and the averting behavior (AB) approach, whereby consumers spend money to self-protect in order to reduce the perceived risk of ill health from poor quality water. For example, in a water valuation study of 1,600 Canadians, individuals were found to spend about $180 Canadian per household per year on bottled water. This can be viewed as a form of averting behavior, since many individuals reported doing so for health reasons. Further questioning revealed that, for just over 50 percent of the individuals surveyed, bottled water was considered safer than tap water (Dupont et al., 2008) despite less regulation and testing. Expenditures on in-home filtration systems were of a similar order of magnitude ($189 per household per year). Given that the average household pays on the order of $500 a year to purchase tap water from public utilities, these expenditures represent a significant increase. Since these expenditures tend not to be in reference to the purchase of specific benefits but instead are related to

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preferences and beliefs, it is difficult to use these values solely for the purposes of obtaining health benefits from good-quality water. The second approach used by economists to obtain nonmarket values, direct methods of valuation, can be constructed to provide more detailed and accurate values.

The direct valuation method constructs a simulated market setting for consumers to state choices that reveal the relative value of one level of quality of an attribute compared with another. This may be a better method for obtaining consumer-related water values, because individuals can clearly conceptualize an increase in the cost of their water bill as a trade-off. In a survey done in Canada, consumers chose between different water management programs that involved different levels of chlorination, resulting in decreases in microbial contamination at the cost of increasing bladder cancer cases and vice versa. Visual and numeric estimations of risk were used to describe the relative risks in the different scenarios. Two methods of estimating willingness to pay were used in a survey done in 2004; the contingent valuation method (CVM), in which the entire package is priced, and the choice experiment (CE) method, in which individual components are priced by consumers. Individuals were, on average, willing to pay increased water bills in order to see reductions in either one or both health risks, with the average annual willingness to pay for a reduction in the risk of a cancer death of $10 and a willingness to pay of $13 for a reduction in the risk of a microbial death. Lower willingness-to-pay values were obtained for reductions in illnesses that were not fatal (Adamowicz et al., 2007).

Opportunities to Bring the Value of Water Closer to the True Value

The status quo value of water cannot remain close to zero if societies are ever to encourage its sustainable use. There exists a need to increase the price that users pay for water to include not only the full cost of infrastructure renewal and upkeep but also a component relating to the cost of environmental conservation. More research is needed to explore how consumers and industries value or fail to recognize the value of water and to examine how these beliefs can be challenged to refute false perceptions and, most importantly, to improve water conservation so that future generations do not see the day when the well runs dry.

IMPACTS OF DEMOGRAPHIC CHANGES AND WATER MANAGEMENT POLICIES ON FRESHWATER RESOURCES

Jill Boberg, Ph.D., Consultant

The assumption that all water scarcity can be summarized in a single number must be challenged. Instead, the factors influencing water scarcity are more complex and require scaling for different sectors. The discussion should be restructured to address demographics and water management and more clearly

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outline water supply issues. The limitations of these data are the inaccuracies and problematic measurement of supply and demand as well as changeable demographic forecasts. Forecasts tend to change because of variation in human behavior as much as change in environment. Because of variation in local distribution, analysts tend to aggregate multiple, heterogeneous local groups into water data. Although this shortcut occurs because of limited information, it is, in fact, critical to water management, which by necessity will occur on a local level.

Water Supply and Demand: The Bigger Picture

Despite a general focus on domestic water consumption, this use of water represents only 10 percent of worldwide consumption, with 20 percent for industrial use and the remaining 70 percent for agricultural use. However, there is often wide variation in this breakdown, depending on the economy and the location. There is a framework for examining the factors that impact water management. The water supply, on one side, and water demand, on the other, are both modified by intervening factors. Water supply consists simply of water resources and water quality services. Water demand consists of the important demographic factors that are expected to predict use and need. Also of consideration is the importance of intervening factors, which tend to be neglected in water management estimates.

World Demographics: A Picture of Water Demand

Demographics are broken down into several categories: population size, number of households, urbanization, population distribution, migration, and mortality. Population size is a critical factor, as population growth is a strong predictor of future resource need. Fertility rates are widely disparate among levels of global development, which will drive future water needs strongly. A potential mitigating factor is declining growth rates; as fertility rates converge in different world economies, predictions of growth become more complex. Regardless, the median numbers indicate that overall there will continue to be an increase in growth and a need to adjust water management accordingly. Of all the demographic inputs, population size is the one most consistently taken into account; yet the other implications for water demand are important.

With growth, increase in the number of households is an expected trend; however, this increase is disproportionate to numbers of individuals. As multigenerational households decrease, and the number of children per family decreases along with increasing independence of young adults and divorce rates, there is a greater increase in households. The number of households has a strong influence on domestic water rates, leading to more water usage for static needs as well as a decrease in the cost-effectiveness of water conservation and efficiency. It also leads to increasing sprawl and other environmental impacts, such as urbanization, again driving up domestic use. Number of households is gaining interest in the

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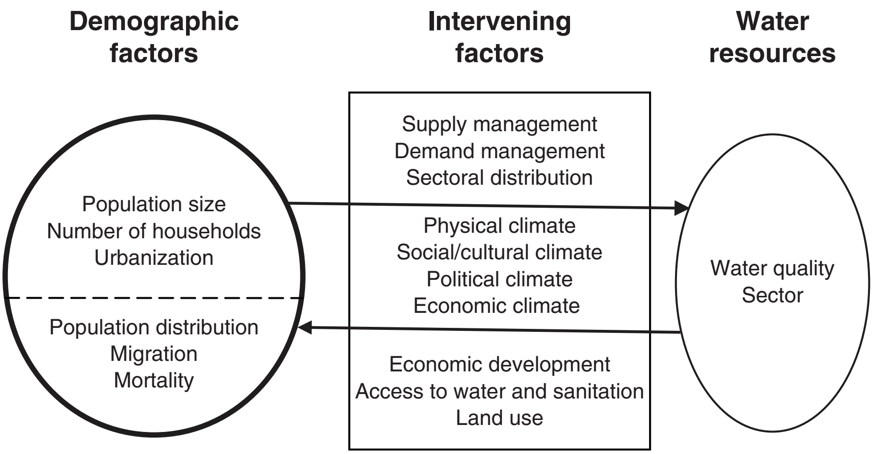

FIGURE 6-1 Water supply and water demand (demographics factors) impact water management. However, both water resources and demographic factors are modified by a number of intervening factors that are often neglected in water management estimates.
SOURCE: Boberg, 2005. Liquid Assets: How Demographic Changes and Water Management Policies Affect Freshwater Resources, RAND Corporation. Reprinted with permission.

water management sector, with ongoing studies to determine whether number of households might be more important than population size in predicting water use (Figure 6-1).

Urbanization and Agriculture: Challenges to Water Management

Rapidly increasing rates of urbanization should also be expected to alter water consumption. The proportion of urban and rural dwellers in the world is expected to be equal in 2030, with growth concentration increasing in urban centers after that. Despite the fact that urban areas are currently less than half of the world population, they already account for 60 percent of world's freshwater withdrawals (O'Meara, 1999). Because water in urban centers is piped rather than directly withdrawn, it generally leads to increased use per person. Urban centers are more likely to use water-based sanitation, which is a very high use of water; for example, in India, when adding water-based sanitation, water use increased threefold.

Industrial use of water is higher in urban areas, as is the predominance of convenience foods, which are very water-intensive to produce. Because of the population density in urban centers, there tends to be a large, negative environmental impact on the surrounding area. In addition, urban areas are quite prone to water shortages, even in areas that are relatively water secure, owing to large

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demand and environmental disruption, leading to lower water supply or quality in the periurban area (O'Meara, 1999).

Agricultural water use must be addressed in water management. A major concern for water quality is groundwater contamination with pesticide and fertilizer runoff. Protection of groundwater, however, is an achievable and necessary endeavor for large urban centers. For example, New York City has ensured a clean water supply through watershed protection in its region. Watershed protection can be achieved through maintenance and replacement of forest or natural land cover in the watershed and reforestation when necessary.

Equity and Access: Providing a Fair Share of Water Resources

Another challenge of urbanization is the provision of equal access to water resources for everyone in the region. Poor and migrant populations tend to cluster on the city outskirts, where there is no formal access to water or sanitation (Lenzen, 2002). Even when service is provided, agencies sometimes struggle to keep up with demand of these populations. This scarcity of water and sanitation services coincides with other shortages, such as fuel and housing. Paradoxically, this leads to increased fertility rates, as each child can provide a marginal benefit to the household of another person to search for water, food, and other resources. This increased fertility of marginalized poor populations only exacerbates scarcity and reduces the opportunities to improve the financial situation of the household (Dasgupta, 2000). Furthermore, the individuals in these circumstances are vulnerable to disease and death because of their lack of access to clean water and sanitation. These influences create a feedback loop that leads to more children, more poverty, and more scarcity.

Water resources are important to refugees and migrants, but water scarcity is itself a cause of migration. Individuals who move because of resource constraints or environmental disasters are known as environmental refugees. Thus, migration and changing demographics lead to such conditions as scarcity or pollution, which in turn lead to migration and environmental refugees. Although in ancient times migrants often moved to locations with rich stores of water, this is not the case more recently, and scarcity is supplanting demand as a motivator for migration.

Economic Development: A Confounder of Water Management

An intervening factor that strongly affects levels of water use is development status. The more industrialized a nation is, the larger the per capita water use, with the most developed nations using twice as much water per person as the least developed (World Bank, 2002). In theory, this trend makes some sense, as more developed nations have more industry and thus more industrial use. Industrialized nations are more likely to use water for removing or dilut-

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ing pollutants and carrying waste. As previously mentioned, the industrialized nation lifestyle leads to increased use of convenience foods, with more intense water needs. Interestingly, agricultural use as a percentage decreases the more industrialized a nation becomes (Food and Agriculture Organization, 2003). The major division comes as a nation moves from lower middle to upper middle levels of industrialization, with large-scale changes from efficient agricultural practices to water-based sanitation and expanded industrial use. This trend seen in nations is also seen among individuals by income. The wealthy use far more water than the poor owing to higher consumption, sanitation uses, and increased access to water.

In summary, water supply and demand are complex, and water management is a difficult area with significant methodological needs and research gaps. Many demographic factors—population size, number of households, urbanization, population distribution, migration, and mortality—interact with culture, the physical environment, economics, politics, and management to modulate demand. Again, it is important to look at local water economies and needs rather than large-scale, national, or regional networks. Caution should be taken in areas in which natural water scarcity and poverty of economic resources interact, as these are virtually insurmountable barriers for management. Otherwise, water management is achievable if demographic and supply limitations are considered with efficiency and watershed protection in mind. Sustainable water management will not accommodate a one-size-fits-all type of solution. A comprehensive plan informed by local data on demographics and unique intervening factors should be sufficient to prevent water scarcity and maintain quality.

THE SUSTAINABILITY OF DRINKING WATER: SOME THOUGHTS FROM A MIDWESTERN PERSPECTIVE

D. Peter Richards, Ph.D., Senior Research Scientist
National Center for Water Quality Research, Heidelberg College

The Midwest of the United States has a formidable role in water management and sustainability. The Midwest is a large region, from the central to the eastern United States, the heart of which surrounds the Great Lakes. The watershed of the Great Lakes includes parts of New York, Pennsylvania, Ohio, Indiana, Illinois, Wisconsin, Minnesota, and all of Michigan. The region has a temperate climate and a moderate amount of rainfall, 60–120 cm per year on average, depending on location, enough so that agricultural operations generally do not employ irrigation. The southern parts of the region are largely agricultural, producing corn, soybeans, wheat, and barley, with some animal farming, and the northern portion is largely forested and rural.

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The Great Lakes and Sustainable Water Use

The Great Lakes are the largest freshwater source in the world with the exception of the polar ice caps, containing 84 percent of North America's and 21 percent of the world's freshwater (http://www.epa.gov/glnpo/statsrefs.html). The lakes hold approximately 22,600 km^3 of water (http://www.epa.gov/glnpo/statsrefs.html). Approximately 25 million people obtain their water from sources within the Great Lakes watershed. Still, with so much water, sustainability would not seem to be an issue.

The water in the region is the envy of all the surrounding regions, but particularly the Southwest United States, which is perpetually water-scarce. As pressure mounted from outside sources, regional concern grew about protection of the Great Lakes as a water supply and as an ecosystem. Regional government leaders from Canada and the United States came together to develop the Great Lakes Water Resources Compact, signed into law October 3, 2008, that severely restricted the export of significant quantities of water from the watershed. It provides possible exceptions for communities bordering the watershed, provided the water is used for a drinking water supply, no adequate alternative source is available, and the majority of the water is returned to the basin after use.

This protective action leads to the question, how much water can be used from the region without compromising its sustainability? What does sustainability mean in this context?

Sustainability must be understood in the context not of the total amount of water, but of the rate at which it is replenished by rainfall and snowmelt within the watershed. The Great Lakes are like a bathtub with water coming in one end and flowing out of the other. Divert too much water, and the lake levels will go down, an unacceptable outcome. In this sense, the maximum sustainable export of water from the Great Lakes is represented by the water that actually leaves the lake system naturally via outflow down the St. Lawrence River. But the St. Lawrence River also has ecosystems that need to be protected, and that have evolved in the context of nearly constant discharge of water. One might be able to reduce that discharge by perhaps 5–10 percent without harming those ecosystems. But this is only about 0.05 percent of the total volume of the Great Lakes. If sustainability is considered in an appropriate way, the Great Lakes have much less to offer the outside world than it would appear from their size.

Sustainability and Water Quality

Sustainability is mainly a question of water quantity and the demands placed on it, but water quality also influences sustainability. For example, Lake Erie is generally a very high quality drinking water source. The most important threat to Lake Erie as a water supply at present is the increasing loads of phosphorus entering the lake from agricultural sources. These phosphorus loads result in large blooms of cyanobacteria like Microcystis and Lingbya, which can lead to

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the release of toxic substances that impact human health. While phosphorus itself does not degrade the quality of the water as a drinking water source, it sets into motion a chain of ecological events that lead to reductions in water quality and possibly in sustainability, or at least in treatment costs for drinking water.

In the major Lake Erie tributaries, water quality is impacted by pesticides, nutrients, and the emerging contaminants of concern known as pharmaceuticals and personal care products. A significant amount of research has been done on pesticides in the region. Herbicides may present a chronic health risk, but the impact of insecticides is negligible. In general, the concentration of herbicides present in the water rarely reach the maximum containment level (MCL) levels on an annual average basis, but may exceed these levels in the summer months. More information is needed to determine the impact of pharmaceuticals and personal care products on the local ecosystems. The most significant water quality problem is nitrate nitrogen, which is present seasonally in major agricultural rivers like the Maumeee and Sandusky Rivers in concentrations up to 2.5 times as great as the MCL of 10 mg/L. Nitrate in high concentrations become a drinking water management issue, as nitrogen must be diluted to below the MCL with untainted water sources. High nitrate levels are most common in summer; in one instance, the concentration of nitrate exceeded the MCL for 41 consecutive days in May and June (NCWQR, unpublished data). Given this current situation, the demand for corn for ethanol becomes a major threat to water quality: more corn means more fertilizer, which means higher nitrate concentrations in these tributaries.

Groundwater Contamination in the Midwest

Although most people in the Midwest obtain their water from public water supply systems, many residents in rural regions still get their water from household wells. Because these wells are private, testing for water quality is not required, and they are thus susceptible to unknown contamination. For this reason, the National Center for Water Quality Research (NCWQR) operates a voluntary water testing program for private wells. This program has tested 55,000 wells over the past 15 years. Because private wells are generally more vulnerable to contamination than municipal wells, lower quality water was expected; however, more than 80 percent of wells have ideal water quality, with only 3 percent exceeding safe nitrate levels and only 0.1 percent exceeding atrazine limits. Factors that are predictors of contamination include older wells, those in sandy or karst terrain, those near barns or fields, and shallow or dug wells. Other, natural and locally prevalent contaminants of the water supply include iron, hydrogen sulfide, and less frequently radon and arsenic. More households are now "contaminated" with arsenic, not due to increasing concentrations, but rather due to a recent decrease in the MCL from 50 ppb to 10 ppb. The recent trend is away from groundwater sources and toward local municipal supplies, mostly surface-

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water based, which will reduce stress on groundwater supplies and increase the stress on surface water.

Sustainability or Carrying Capacity?

I believe we need to change the way we understand sustainability. At present, "sustainability" is mostly about having enough good quality water in the future to meet our needs (i.e., increasing the supply to meet growing demands). We need instead to think of sustainability as synonymous with "carrying capacity," which suggests modifying our demands to meet the available supply. The supply of water is largely static, though it can be increased somewhat by better sanitation and by expensive measures such as desalination. The way to sustainability is through more efficient and effective use and reuse of the water available to us, more than through continually seeking new sources.

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7

The Social Pillar of Sustainable Water: Health Research Gaps

Diarrheal diseases impact many people worldwide and are a barrier for achieving health goals as outlined by various organizations. Technology alone cannot provide access to clean water, as social factors such as behavior, health, and culture can work either in concert or against even the best designed implementation strategies. Some in the water field suggest that interventions and water services programs in the United States and abroad need to take these social factors into account and also need to include the communities in the design, implementation, and evaluation of these programs. This chapter looks at these social factors to consider how they work with technology and economic factors to ensure water services.

WATER AND HEALTH: THE GLOBAL PICTURE OF RISK OF WATER-BORNE DISEASE AND CHRONIC DISEASE

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Water-associated diseases are described by the World Health Organization (WHO) in terms of four categories: water-borne, water-washed, water-based, and water-related. A fifth category—water-carried (water-travelled)—has been proposed to include diseases spread by people travelling to collect water (Santaniello-Newton and Hunter, 2000). The global burden of these diseases is staggering. Each year, there are 4–8 billion episodes of diarrheal disease. It is particularly tragic due to its preventable nature given that 80 percent of diarrheal disease is attributed to unsafe water supply, inadequate sanitation, and lack of hygiene. Including diarrheal disease, schistosomiasis, trachoma, ascariasis, trichariosis, and hookworm disease, the burden of disease from water, sanitation, and

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hygiene accounts for 4 percent of worldwide deaths and 5.7 percent of worldwide disability-adjusted life years (DALYs) per year (Prüss et al., 2002). Rather than expensive technological solutions designed without local input, there is a need for low-tech, community-based interventions; these interventions have achieved excellent results in health and hygiene, as well as a potential for economic and social benefits.

Water-Borne Disease: A Worldwide Epidemic

Water-borne diseases are caused by ingestion of water contaminated with human or animal feces and urine containing pathogens, including cholera, typhoid, amoebic dysentery, campylobacter, salmonella, cryptosporidium, among others. The transmission of these diseases is almost exclusively through diarrhea. Although in healthy, adult patients of more developed countries, it is generally of limited severity and short duration; in vulnerable patients of developing nations, it can be devastating. Worldwide, 1.8 million people die annually from diarrheal disease, 90 percent of whom are children. A WHO analysis looked at relative risks of disease given six different water and sanitation paradigms, from the ideal situation to one without access to clean water or improved sanitation. WHO found that risk increased as fewer had access to services, without piped water, without sanitation services, and little management of the water supply. In the worst-case scenario, the relative risk was 11-fold for diarrheal disease, yet the highly penetrant, water-based systems of developed nations still carried a relative risk of 2.5 from the ideal scenario (Table 7-1).

Room for Improvement: Simple Interventions in More Developed Settings

In developed nations, problems with water distribution systems are significant sources of disease. One-third of outbreaks of gastrointestinal illness in Europe are related to problems with the distribution system (Risebro et al., 2007). Cryptosporidium was associated with many outbreaks because of the inadequate removal during water treatment. As a result, most systems have been improved or removed from service. Major problems in distribution leading to outbreaks include construction or repair complications, low pressure, and damaged or outdated water mains. In the United Kingdom, low water pressure was found to be the strongest association with self-reported diarrheal disease, which could represent 10–15 percent of cases (Hunter et al., 2005).

In developing countries, the problem of distribution is more complex and severe, with many large outbreaks occurring as a result of distribution problems. The risks depend on the system. In the Sudan, for example, some communities use large community water pots into which individuals dip their hands, leading to very high fecal contamination. In Vietnam, some households are able to capture rainwater through roof guttering but many poorer households have roofs made

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TABLE 7-1 World Health Organization Analysis of Relative Risks of Disease Related to Water and Sanitation Access

Scenario	Description	Min RR	Realistic RR
I	Ideal situation, corresponding to the absence of transmission of diarrheal disease through water, sanitation, and hygiene.	1	1
II	Population having access to piped water in-house where more than 98% of the population is served by those services; generally corresponds to regulated water supply and full sanitation coverage, with partial treatment of sewage and is typical in developed countries.	2.5	2.5
III	Piped water in-house and improved sanitation services in countries where less than 98% of the population is served by water supply and sanitation services, and where water supply is likely not to be routinely controlled.	2.5	4.5
IV	Population having access to improved water supply and improved sanitation in countries where less than 98% of the population is served by water supply and sanitation services and where water supply is likely not to be routinely controlled.	3.8	6.9
V	Population having access to improved water supply but not served with improved sanitation in countries which are not extensively covered by those services.	4.8	8.7
VI	Population not served with improved water supply and no improved sanitation in countries which are not extensively cover by those services (less than 98% coverage), and where water supply is not likely to be routinely controlled.	6.1	11.0

SOURCE: Prüss, A., D. Kay, L. Fewtrell, and J. Bartram. 2002. Estimating the burden of disease from water, sanitation, and hygiene at a global level. *Environmental Health Perspectives* 110:537-542. Reprinted with permission.

of plastic sheets or branches, making collecting pristine rainwater impossible. Sometimes problems may be because of human action. In a recent visit to Africa, the speaker came across a women drinking directly from a stream in which cattle were also standing. A month earlier the village where she lived had a serviceable water supply, but workmen who were contracted to improve the supply started by destroying it and then left and had not returned to complete the work.

People who have been accustomed to high-quality water are at much higher risk when suddenly exposed to unclean water because of lack of immunity or when their drinking water systems fail (Hunter et al., 2009). Some settings

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have multiple modes of transmission, such as a fish ponds being used both as a latrine and as a source of food. Extreme events are also catalysts for outbreaks of diarrheal disease, particularly cholera, which spikes during yearly flooding in Bangladesh.

Water-Washed, Water-Borne, and Water-Related Disease: Infection by Contact or Vector

Water-washed diseases are those that can be transmitted through poor personal hygiene and skin or eye contact with contaminated water. Pathogens include trachoma, flea, lice, and tick-borne diseases. WHO includes scabies on this list, even though it does not meet the formal definition of water-washed but refers to the fact that many around the world use the term "scabies" in a general way to refer to itching disease.

Water-borne diseases are contracted from parasites found in intermediate water organisms, such as schistosomiasis and helminth infections. An example is dracunculiasis, in which a parasitic worm enters the skin and grows to a meter's length inside the body. The traditional treatment is to pull the worm out an inch or two per day to avoid breaking the worm internally which causes a painful inflammatory reaction.

Water-related diseases are caused by insect vectors that breed in water. They include some lethal and highly morbid diseases, such as malaria, dengue fever, filariasis, onchocerciasis, trypanosomosis, and yellow fever. Parasitic intestinal disease often becomes chronic and impacts individuals for extended periods. Water traffic can also be the basis for spread of other infectious diseases; for example, in a refugee camp in Ethiopia, meningitis broke out and spread along the paths that individuals used to carry water. It was controlled only by a massive immunization campaign and ultimately sickened 291 and killed 43 (Santaniello-Newton and Hunter, 2000).

Chronic Diseases and Water: Chemical Contamination

Chronic disease caused by water with chemical toxicity from contamination and metabolic risk from lack of water-carried nutrients should be noted. Earlier presentations discussed the impact of arsenic filtration in Bangladesh and the impact of fluoride supplementation. Research on chemical contamination of water is a major need, as few correlations have been demonstrated other than chlorination and bladder cancer. Examples of this kind of problem are fishermen wading in a stream filled with drainage from the local dump, an unprotected pile of trash washing unknown concentrations of dioxin and household wastes into the water that people drink and eat from. Again, the need to use these clearly sullied water sources is greater among the most disenfranchised and poor populations, leading to increasing health disparities.

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Musculoskeletal Disease: The Underestimated Weight of Water

Musculoskeletal disease has a high and poorly recognized burden in developing countries, falling within the top 15 of worldwide disease burdens and not including the significant burden of lower back pain. Lower back pain is poorly quantified in developed and developing countries alike, with no data available on the impact of carrying water on back pain and musculoskeletal disease. The effect of carrying heavy loads of water long distances on child development is unknown; although in developed countries there is a known correlation between heavy backpacks and low back pain in children. There is also the potential for a significant improvement in pregnancy and delivery in terms of reducing spinal problems.

Conclusions: The Time Is Now for Improved, Not Perfect Water

Standards should not be held too high and risk missing the benefits of simple interventions and education to reduce acute and chronic disease related to water. The most important step to take is the first one. The incremental benefits decrease with additional and complex interventions, especially those undertaken without the input of the community or addressing patterns of water use and needs. Examples are a shiny filtration unit being used for gardening and a water tap having been damaged by placing heavy water jugs on them prior to hoisting them onto women's heads for carrying purposes. There is a need for sustainable interventions, because short-term interventions that lapse back to previous exposures will be more likely to lead to disease (Hunter et al., 2009). It is clear that the benefits of improved water could be much more significant than just the reduction of diarrhea, with both productivity and social aspects. Drinking water is essential to health, and contaminated water has a myriad of harms other than diarrhea, which is a major source of worldwide disease alone. The rapid provision of high-quality drinking water will not miraculously appear in the near future, but this should not be a deterrent to using community-based, evidence-supported, simple interventions to achieve rapid improvements in health.

PRELIMINARY OVERVIEW OF CURRENT RESEARCH AND POSSIBLE RESEARCH PRIORITIES: SMALL COMMUNITY DRINKING WATER SUPPLIES

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Boil water advisories are an effective mechanism to reduce burden of illness as long as the people in the affected communities abide by them. In Canada, there are approximately 1,200 to 1,500 boil water advisories in place at any one time across the country, impacting approximately 200,000 to 300,000 people. With few

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exceptions, the vast majorities of these advisories in Canada and most developed countries are in small communities. Recognizing that fact, the question needs to be asked how we should approach the issue of addressing these challenges to the safety of drinking water in small communities.

In Canada, we have set up a consortium involving industry, government regulators, nongovernmental organizations (NGOs) and academia to not only define the challenges faced by small systems, but to also identify solutions and develop strategies to address these. At the same time, it is important to build on and contribute to the work done internationally. The World Health Organization's Network on Small Community Water Supply Management is actively engaged on developing tools and strategies for small systems, in both developed and developing countries.

Clearly, it is important to identify where research efforts should focus to most effectively reduce the burden of illness from unsafe drinking water in both developed and developing countries, and how to successfully promote and support this research and the transfer of knowledge.

Context

The burden of illness from water, sanitation, and hygiene total approximately four percent of world deaths (Prüss et al., 2002). Health care costs to treat these health-related effects on unsafe drinking water are approximately $7 billion per year, which results in $63 billion per year in time lost (Hutton and Haller, 2004). The advantage of improving the supply of drinking water can translate into significant economic benefits for a developing country. Sachs (2001) estimated a 3.7 percent annual average growth by developing countries with improved water and sanitation versus 0.1 percent for those without these improvements.

The WHO Small Community Water Supply Management Network was established in 2003 as a coordinated global response for the safety of drinking water in developed and developing countries. Its target was to help meet the Millennium Development Goal of reducing the number of people without access to safe drinking water by a half by 2015. The Network is focused on developing better management tools (e.g., water safety plans), and determining best management practices that are community driven and applied. Other central components include better communication and education, capacity building in the local community, knowledge transfer (research and technology), and advocacy.

As part of this work, the WHO Network has undertaken to identify research priorities as a basis for addressing research gaps and determining investment opportunities which could result in significant health benefits.

As a first step, a preliminary assessment of the state of research on small water systems was conducted. This assessment must now move beyond categorizing the broad research needs to focus specifically on research that could most effectively reduce the burden of illness globally.

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The research agenda will also concentrate on promoting and supporting the transfer of research into real world settings. As noted many times during this workshop, transferring research knowledge is a pressing need globally to meet the Millennium Development Goals. One challenge, which at the same time reflects the need for a research network, is that we often follow the traditional but impractical approach of every jurisdiction or every country developing their own solution to a given problem. For example, there are currently 15 risk assessment tools to identify the risks in the drinking water system from source to tap. There is a need to evaluate the necessary components of research that can be transferred to other areas of the world, but at the same time communication of this research is essential, in order to prevent duplication and promote optimization of efforts.

Overview of Research

In a simplistic way, risks and barriers to improving small community drinking water supplies can be used to set research priorities. The risks range from the source water to the tap. Source water risks include availability, which has become more important with awareness of climate change; water usage; watershed vulnerability; and pollutants from microbiological and chemical exposures. At the tap, these risks include the infrastructure vulnerabilities from the collection from the watershed, treatment technology, distribution, and operation and maintenance of the system. Barriers, including capacity (financial, people, and knowledge) and socioeconomic factors (culture, governance, and business models), can stop effective action to address these risks in both developed and developing countries.

The focus for the WHO Small Community Network is to identify areas where more research would contribute to the goal of safe drinking water by identifying gaps and priorities and strategically implementing mechanisms to direct and guide research, and deliver and/or fund projects. As a starting point, the research that has been done in the drinking water, defined broadly, can be used to identify the research needs for small community water supplies, while recognizing the unique challenges in the small community. This focus needs to be done in the appropriate context by recognizing that one size does not fit all—the importance of understanding and adapting to different cultures, and socioeconomic and political conditions. Thus, a range of solutions need to be identified as many factors will affect whether and how research can be applied to any one community. We can arbitrarily define the core components of a targeted research program as follows:

- Health-based research
- Treatment technology
- Source water protection
- Capacity and socioeconomic research

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Health-Based Research

Health-based research related to burden of illness has made significant contributions to advancing technology and solutions to ensure safer water supplies. Health risk assessments are key drivers and need to be undertaken in addressing the safety of drinking water, including drinking water for small community water supplies. The research to better understand the health risks related to both pathogens and chemicals in drinking water is not directly linked to the size of the water system. Significant advances in the understanding of the range of health effects have been made: There is a growing body of information on acute and chronic illnesses, an increased focus on disinfection byproducts, and risks to reproductive and developmental health effects, to name a few. Additional research will have benefits in helping to determine appropriate remediation strategies.

Potential areas for more work in developing countries include having the capacity and support for better surveillance and monitoring of acute and chronic illnesses. In all countries, and especially in developing countries, it will be important to conduct comparative risk analysis before making new policy decisions. For example, in Bangladesh and Croatia, the surface water had microbial contamination, which resulted in a decision to switch to ground water sources. The result is that 50–60 percent of the population is now exposed to very high levels of arsenic (WHO, 2000). In summary, health-based research is not a limiting factor in improving the safety of drinking water in small communities, or communities lacking resources and capacity.

Infrastructure and Technology

Most of the existing technology and research for water treatment is applicable to large community systems and for systems in developed countries; for example, the use of ozone, ultraviolet, membranes technology, remote monitoring (Supervised Control and Data Acquisition). While engineering solutions do exist for small community systems, the cost and infrastructure capacity prevent wide-scale application or adequate maintenance—sustainability of these systems continues to be a challenge. In recent years, there has been a movement toward distributed systems for small communities; however, this approach is probably useful in some contexts and not in others.

Across the world, communities need reliable, robust, and resilient systems. We need additional research in many areas to reach this goal, including more affordable, operator-friendly treatment technologies for the full range of contaminants. The traditional focus has been on microbiology, especially for small systems, but technologies need to also address the inorganic contaminants, such as arsenic. In addition, communities have moved toward centralized drinking water systems, but in natural disasters, a distributed system provides a greater likelihood of continuity of service. However, governments have not been investing in understanding how a distributed system can work for small community systems.

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Multi-barrier systems will be important, but the transfer of knowledge should include understanding of how the integrated system will function with other essential components, including energy. Especially in the small communities, energy solutions, whether it is a "turnkey" package, wind power, dams, waste, should ensure continuity of service. Finally, there is a need for affordable monitoring and testing tools to more quickly assess the health impacts related to drinking water contamination.

Source Water Protection

Key to the multi-barrier approach is the need to protect source water. This is challenging because local and regional protection of watersheds needs to be a part of the planning. The extent of the protection will depend on the size of the watershed and other local factors. Local factors include capacity, knowledge, resources, and decision-making authority available to the community. In general, developed countries are doing more work on watershed management and source water protection; and knowledge transfer to the developing countries has been limited.

Socio-Economics and Capacity

Socio-economic factors in both developed and developing countries need to be considered in small community systems. As discussed earlier, there is sufficient evidence that safe drinking water protects health, reduces burden of illness, avoids boil water advisories; yet it's very difficult to get communities to actually invest and value water as a resource. Additional work on cost-benefit analysis is, therefore, an important component of advancing safe drinking water in small communities. We must better understand the cultural challenges, and social and economic barriers to help guide investment which will lead to sustainable improvements.

In order for governments, NGOs, and researchers to help communities, they need to engage the community as a partner and focus on community-driven research. Furthermore, cultural and traditional issues can affect efforts in this area and they need to be understood and respected. One example of how culture can effect decision making is the painted pump story—a village with a blue pump. Originally, it was painted red, which indicated that the water was non-potable. However, there is a social stigma to having a red pump in your village which can, for example, affect the marriageability of your daughters and sons. The villagers went out at night and painted the red pump blue. While this was not a good solution, scientists, policy makers, and NGOs need to recognize that socioeconomic issues need to be considered and addressed if the world is going to achieve safer drinking water.

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Knowledge Transfer

There is strong pressure in the academic community to conduct and publish research, but less on ensuring that the results of the research are picked up and applied broadly. Transfer of research directly or indirectly to the end-user is obviously essential to improving safety in small community water supplies. And yet, in a global context, there is not a good mechanism for the community of researchers to share their information and work together more collaboratively. There are a number of opportunities to break down these barriers through optimizing the application of research results to stakeholders, end users, and communities. By building broad-based networks to share information, researchers can build collaboration and be involved in setting priorities.

Policy

Most countries have regulations, guidelines, and policies to guide the provision of safe drinking water; however, there are significant variations in design, application, and enforceability. Regulations and policies that are valued indicate a level of commitment by government and communities to take action and try to meet the requirements. Once again, these policies and regulations are not necessarily tailored for small systems. Even if the regulations are for small systems, they cannot be met because of the following:

- The treatment is inadequate or lacking
- Operation and maintenance are not supported
- Monitoring and testing can be particularly onerous for small communities
- Inadequate laboratory access affects ability to receive timely sampling results

Recognizing this inherent problem in small systems, there is a need for evaluation of best approaches to ensuring safe drinking water in small water systems that is country or regionally based.

Conclusion

This has been a very preliminary and limited overview of research priorities related to improving the safety of small community water supplies. Clearly, the focus needs to be on helping to support developing countries, and tailoring research to meet their needs. It is suggested that one of the first priorities for the community of scientists and policy makers is the identification of research gaps and research priorities for small community water supplies, which reflects the need for a better understanding of the social, economic, and governance factors that must be addressed in supporting wise investment and sustainable solutions. At the same time, the research community should be able to take advantage of

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the wealth of existing research, and find opportunities to transfer this knowledge through better evaluation of current systems or refocusing research results for the end users. It will not be a "one-size-fits-all approach," and we need to focus on incremental improvement and steps toward reaching the Millennium Development Goals.

INTEGRATING WATER, SANITATION, AND HYGIENE

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The challenge of meetings that focus on water is that the meeting is not just about water. In fact, it is a meeting about water, sanitation, and hygiene. These areas are intertwined and dependent on each other, so that any program needs to consider all three aspects in order to have a successful health intervention. However, researchers do not know if there is a hierarchical approach to providing safe drinking water. They do not know how water, sanitation, and hygiene are related, or if there is a hierarchy for improving health. In other words, they do not know if emphasizing drinking water is more important than sanitation to ensuring health outcomes, or vice versa.

Learning from Hurricane Mitch

Hurricane Mitch made landfall in Central America in October 1988 and affected four countries: Nicaragua, Honduras, El Salvador, and Guatemala. It was a category 5 storm with sustained winds over 200 mph—the fourth strongest Atlantic hurricane in history to that point. Due to the fact that the storm was slow moving, Hurricane Mitch dropped historic amounts of rainfall in Nicaragua and Honduras. Some estimates suggest that Tegucigalpa, the capital of Honduras, experienced at least 20 inches of rain in one day, but the actual number may be as high as 36 inches. In Honduras alone, approximately 10,000 people were killed and 90 percent of the infrastructure was destroyed, including the majority of the bridges in the country (USAID, 1999). The landscape changes that were brought about by Hurricane Mitch were estimated to be the equivalent of 50,000 years of change in normal geological time.

As part of the response, the American Red Cross started a water and sanitation and hygiene intervention program in 110 communities in all 4 countries. The interventions benefited approximately 75,765 people and were individually tailored to the conditions in each country. As part of the evaluation process to determine needs of each region, the Centers for Disease Control and Prevention (CDC) assisted the Red Cross by looking at environmental health inputs—access to water, access to sanitation, and hygiene (hand washing) education—in 800

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households. The output measure was the number of cases of diarrheal disease in children under age 13, with a goal of a 25 percent decrease in childhood diarrhea. The water interventions varied from shallow groundwater wells to deep-drilled wells, and the sanitation interventions varied from simple pit latrines to composting desiccation latrines (Figure 7-1). In order to evaluate whether a composting latrine is working, it needs to be individually inspected. The hygiene test was a rigorous evaluation of hand washing by scoring people as they wash their hands. As discussed many times during the workshop, there was a significant community involvement, such as input of community labor and input into the type of system (intervention) for each community. From these results, the Red Cross and the CDC evaluated the combination of these inputs.

A qualitative evaluation of the Chiquimula area in Guatemala found that the community met the goals for access to water, access to sanitation, and hygiene education, and there was a corresponding decrease in childhood diarrhea. Conversely, in Las Pozas, El Salvador, there was a good water intervention with a drilled well that used gravity to provide water to the community. However, the installed composting latrines were not used properly, and hygiene was ineffective. So, although the community had a good-quality water intervention, they did not meet the health outcome goal. Interestingly, in Segovia, Nicaragua, they met

FIGURE 7-1 Examples of pit latrines and composting desiccating toilets from various water interventions. Left figure: Side of double vault composting latrine in Guatemala not in use, sealed with concrete cap. Right figure: Side of double vault composting in Guatemala in use, with toilet seat installed.
SOURCE: Photos by R. Gelting.

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the sanitation and hygiene goals, but the community did not meet the water goal owing to local politics. In contrast to the El Salvador program, the community met the health output goal even without a successful water intervention.

From a qualitative analysis, it appeared that hygiene practice had the largest impact in these projects, followed by sanitation, and then water interventions. With further data acquisition, quantitative and univariate analysis was possible. None of these interventions by itself had a statistically significant impact on health; however, a multivariate analysis of all three interventions resulted in a statistically significant effect of the interaction of water intervention, sanitation intervention, and hygiene practice. It is interesting that single interventions did not have a measurable statistical impact, but the combination of the three interventions had an impact on childhood diarrhea. The intervention interaction is in direct contrast to some of the research literature. The impact of the integrated approach did not have a greater effect than the single intervention, including several meta-analyses (Esrey et al., 1990).

It is unclear from the Hurricane Mitch work, why there is a disparity between these interventions and the research literature. From my experience in the Peace Corps, often there was a disparity in the field with what was occurring and what was reported. For much of the work in rural communities, the program was called an integrated intervention, but the focus was very heavily on water. Water systems were designed and constructed, but the sanitation varied from community to community. Similarly, hygiene education would vary because the water intervention was the focus.

This problem is not unique to low-income countries. Building water systems is an objective toward the goal of improving health, and equal time needs to be devoted for sanitation and hygiene measures. The Red Cross program was designed as an integrated program from the ground up: water, sanitation, and hygiene. Secondly, there is more data about water interventions than about sanitation, and even less information is available about hygiene and health education interventions. Incidentally, the funding follows a similar pattern. Most of the funding is allocated for water intervention, less for sanitation, and even less for hygiene and health education. The funding may also be a factor in some of these analyses.

One other difference about the Red Cross project is noteworthy. It was evaluated as an integrated program from the beginning, and the data availability was designed so that all three interventions were measured. This approach raises the question of whether incremental interventions versus integrated interventions are more effective. There is some evidence in the literature (Fewtrell, 2005) that incremental interventions focused on one element of water, sanitation, or hygiene, are more effective—or not less effective—than integrated interventions, but researchers do not have an understanding of why. More work is therefore needed to understand the effectiveness of the three interventions separately and together. If water interventions are not as effective, then further analyses may

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have funding implications to determine if more emphasis should be put on these other interventions as well.

WATER AND HEALTH: THE GLOBAL PICTURE OF RISK OF WATER-BORNE AND CHRONIC DISEASE

Peggye Dilworth Anderson, Ph.D., Professor,
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Culture through shared-beliefs, religion, and myths influences the acceptance of new ideas and influences how people address chronic diseases, changing environmental conditions, and other aspects of their lives. World Water Day 2006 (UNESCO, 2006) recognized this issue by focusing on water and culture interdependence, noting

> The importance of water in our everyday lives cannot be overestimated. Although it is ever-present, it is also ever-changing. Indeed, the ways in which water is perceived and managed are determined by cultural traditions, which are themselves determined by factors as diverse as geographical location, access to water and economic history. . . .
>
> Water is not perceived the same way in Africa as it is in Asia or in Australia as it is in the Amazon. The role that water plays in shaping the lives of people can be seen in the huge variety of water-related religious practices, spiritual beliefs, myths, legends, and management practices throughout the world.

Understanding these factors as part of public health and from a sociological perspective should be a part of the strategies for intervention by public health practitioners.

What Is Culture?

From a sociological perspective, one can define culture a number of ways, and each definition helps to define various borders for what can appear to be a borderless discipline. Culture is shared among an identifiable segment of a population (Rohner, 1984) and is often influenced by individual characteristics, such as gender and age (Goodenough, 1981). However, culture can be most precisely defined as a set of shared symbols, beliefs, and customs that shape individual and group behavior (Goodenough, 1999). Furthermore, it provides guidelines for speaking, doing, and evaluating one's actions and reactions in life (Goodenough, 1999). In 2002, the Institute of Medicine further modified this definition, stating that culture is socially constructed and learned, not genetically transmitted.

In essence culture is not static, but rather dynamic. Culture is not an end point; it is a process. Culture can change and become socially reconstructed on

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the basis of the political, economic, and religious factors that are impinging on the cultural group or individual within the culture. In other words, culture includes values and beliefs, customs, norms, and symbols, and the influence of these factors can change over time and in intensity among individuals and groups. The influence of culture is multifaceted by

- shaping how people perceive and interpret their environment,
- influencing how people structure their community and social life,
- determining what is perceived as a priority in the community, and
- serving as both an enabler and a barrier to acceptance of new ideas and interventions.

What is occurring locally can shape what the scientific community can do in influencing and impacting people in a particular society.

Culture and Public Health Interventions

Often culture can be seen as a barrier in the process of implementing public health interventions; however, culture does not have to be a barrier. Individuals in the community do not see themselves as a barrier. These barriers are often labeled as such by the investigators or donor community because they are not able to implement their plans as designed. The indigenous people perceive their actions as practices, traditions, norms, and values and not barriers. Investigators need to recognize, respect, and work within the cultural framework when designing the collection and use of water in the family household. Central to this process is the dialogue with the local community.

Culture involves more than understanding the spoken language, as one has to understand the nuances of the language—colloquialisms. Words are symbolic of behaviors that a person from outside the culture may easily miss, but they can have a profound impact on the acceptance or the rejection of the intervention. Community values may be moral, ideological, or social and may influence what the community deems a priority. Furthermore, components of culture, such as community values, the construction of health, stigma and taboo, patterns of authority, trusted sources of information, religion and spirituality, gender norms and roles, social structures, daily activities, and language and communication, can influence the acceptance of a new idea or intervention.

Cultures understand and define the concept of health differently. For example, a community may define health as the absence of disease or as a state of well-being. Stigma and taboo may influence whether an affected group may be wiling to discuss a topic or participate in an intervention. Furthermore, religion and spirituality can influence health beliefs and practices. This is especially true for water, as it plays a key role in many religions. It is considered symbolic in most religions, considered a cleanser and purifier, and used in spiritual rituals.

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Trust is an important part of this process. Who is regarded as a credible source of information varies across cultures and may include medical providers, traditional healers, family members, friends, religious leaders, and political leaders. In many communities there is often the blending of folk wisdom and experience with formal education, which together provide a stronger sense of the culture. Finally, there is often a trust barrier with outsiders that needs to be overcome. As a first step, researchers need to understand the patterns of authorities—the first contact in a community. This first contact may not be the person with the greatest amount of measurable power, but it may be the person with the greatest level of influence and authority in the system. Understanding the patterns of authority can help to determine who the community gatekeepers are, so that community members may be more likely to accept interventions when promoted by people in authoritative roles.

In conclusion, successful interventions will not only recognize but also understand the local culture. Researchers should not see culture as a barrier, but rather as an opportunity to ensure the sustainability of their interventions. Recognizing the importance of water and culture and their intersection opens opportunities to begin to address the Millennium Development Goals.

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Panel Discussion: Moving Forward

There is a fundamental disconnect between intervention programs and the translation of research into community action. The questions become what are the research needs to achieve the most sustainable water solutions and how to put these pieces together. Panelists started the discussion with a listing of research needs and strategies for improving sustainable water services:

- Evaluation of water, sanitation, and hygiene interventions. Christine Moe of Emory University noted there has been an emphasis on implementation of interventions, but comprehensive evaluations are often neglected. As people debate sustainable practices in water services, there is a need to understand what elements of the intervention were the determining factors for the success or failure of the intervention (see next section).
- Global climate and its implication for water use. As the environment is changing, one cannot necessarily assume that the current models or practices will remain relevant, noted Peter Richards of Heidelberg College.
- Real-time monitoring. For example, real-time bacterial tests that would inform the public whether the beach is safe today, not two days ago, noted Richards. Ideally, the monitoring would include information about the origin of the outbreak—whether the *E. coli* comes from Canada geese, deer, or people.
- Holistic approaches to implementing water services. Joseph Jacangelo of MWH and Johns Hopkins University noted that, for many programs, especially in developing countries, there is a need for a more holistic program that incorporates technology, education, and behavior. There are plenty of projects in which the engineering aspects were well designed but the project failed, because there wasn't an educational aspect or a behavioral change orientation. This is true not only for developing countries, but also in the United States. Water reuse is a good example of well-engineered

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programs that have failed because of poor educational and communication components.

- Integration of social, behavioral, and communication components in water services interventions. Phyllis Nsiah-Kumi of Northwestern University noted that at the beginning of any intervention is the need to understand the community's knowledge, attitudes, and beliefs about the problem in question. The incorporation of these factors needs to be used as the central foundation, so that the water field can teach the community about available solutions and why these solutions are important to health.
- A water-centered focus. Diane Dupont of Brock University noted that if the research interest is in water and water services, then water needs to be in the center diagram. From there, the field needs to develop the linkages from water to all of the different aspects that might relate to it. This change in focus may address the unintended consequences that can prevent the project from being a success. Thus, before the start of the project, it is important to think about what the ramifications may be.

EVALUATION OF INTERVENTIONS

During the workshop, a number of individuals alluded to the need for evaluation, and the panel explored best practices or effective matrices for measuring success. Dupont started with the idea that assessment of previous experience is the creation of a knowledge base on sustainable water services. Once the knowledge base is created, anyone can access it, and it is hard to recover the costs of maintaining it. What is needed is an agency or an organization to act as a central clearinghouse, where information is readily available for researchers to use. However, without a strong evaluation program, the knowledge base is incomplete, subject to bias, and exists only with the researchers in the field.

Paul Hunter of the University of East Anglia noted that one of the problems with evaluation is determining the appropriate objectives. A number of nongovernmental organizations use targets, such as the number of wells sunk. However, whether or not those wells are effective, are poisoned with arsenic, or improve the health of the population are more difficult matrixes to evaluate. It is not only the providers, but also many of the funders, who do not adequately think through the evaluations. Hunter noted that, even major institutions such as at the World Bank, can give the impression that they are more concerned with whether or not funds are dispersed than with whether projects achieve worthwhile outcomes, such as meeting health goals. Therefore, there needs to be more discussion, when money is given, to very clearly define the objectives about what needs to be done, and what the health aims are. Hunter stressed that money should be given out with the proviso that the intervention achieved its goals, not just that the work has been done.

Richard Gelting of the Centers for Disease Control and Prevention expanded

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on this idea by noting that people in the multilateral lending institutions are evaluated on money spent, and people at implementing institutions are evaluated on the number of taps installed. The question is how to approach those incentives, so that they are more in line with the ultimate goal. He further noted that the goals often become "the number of pipes in the ground." This is not the goal, but rather an objective used to get to the ultimate goal of improving public health. There is a need to focus on the goals and not on the intermediate steps or objectives. Jacangelo further suggested that putting pipes in the ground is a tactic from which to accomplish an objective or a goal. There is a well-developed science of program evaluation, and water researchers in the field need to learn from these scientists, noted Moe. If researchers are going to change the outcome of interest, then they need to invest time to determine how to measure it.

Finally, Moe noted that public health practitioners need to think broadly about health goals when providing safe drinking water, to include not only diarrhea or weight and height, but also well-being. For example, when practitioners look at the gender effects of the impact of water and sanitation on women, it's more than health. It is quality of life, well-being, and opportunities to do other activities, such as get an education and earn income. Improving literacy can be just as important as decreasing the rate of diarrheal disease.

Barriers to Evaluation

There is an inherent conflict with resource allocation that may be one of the largest barriers for incomplete evaluation, noted Moe. For example, a nongovernmental organization may feel compelled to spend its funds on implementing a solution in another community that does not have access to safe drinking water instead of evaluating a current strategy. The danger in this approach is that scientists, as noted above, may not understand which components are vital to the success of the intervention strategy and which components are not necessary. If implementing agencies spent the money and the resources on evaluation, then they would have evidence of success, and it would inform the strategies for future interventions.

The timing of an evaluation can be an additional barrier. For example, Moe noted that she had been asked to evaluate a program after a nongovernmental organization had built 3,000 units of a particular intervention. She noted that it is hard to correct a problem or an intervention strategy when there is already an investment in 3,000 of an item. It therefore becomes a balancing act to put in place a certain number of implementations to provide statistical power for evaluation, but not wait too long after spending these resources on a strategy that is ineffective. However, Moe asserted, the main problem is that monitoring and evaluation is an afterthought and not an integral part of an intervention strategy. Until funders recognize the importance of measuring the right objectives and invest money in this area, more cohesive programs are not feasible.

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COMMUNITY-BASED EVALUATION AND PARTICIPATION

A central theme during the discussion was the role of the community in providing water services, and this is the cornerstone of sustainability. With that spirit, one participant noted that evaluations need to be community based and not just consist of the research community evaluating the intervention. Metrics that are important to the community need to be reflected in the evaluation tool. Moe added that this underscores the need to have in-country partners who understand the culture. She said this is critical to the success of the project.

However, community engagement is important throughout the intervention. Peggye Dilworth Anderson of the University of North Carolina at Chapel Hill noted that when practitioners go into communities, their academic training is not enough. They need to have some model or framework as how to best approach community members by understanding their literacy and education levels. Working with indigenous people requires the use of advisory committees made up of the individuals that one wants to serve and having the gatekeepers involved up front. She noted that when she goes into a community, she does not use the word "intervention," but rather programs or projects—words that resonate with the community. The community then becomes a part of framing the aims, the research questions, and the evaluation process.

Bringing in a developing country perspective, Eric Kofi Obutey of the Ghana Public Utilities Regulatory Commission noted that, in Ghana, there is an abundance of researchers conducting survey research, but these surveys do not always result in changes in the community. While these researchers are well intended, if the community does not see a benefit, it is less likely to participate. There is thus a need to ensure that the research translates into policy making and recommendations in the communities studied. Vincent Nathan of the City of Detroit Department of Environmental Affairs noted that policy relies on research and community support. The community can influence that political process, but it needs to be involved.

Anderson noted that community research is an iterative process, that communities shape and reshape the interpretation of the results. Sometimes researchers have a rigid perspective on the outcome, but using the community-based participatory model may mean tweaking the aims and the questions as the process continues. Nathan agreed and suggested that the community say at the very beginning whether or not they want to do something and then decide whether it is acceptable and whether it is going to be sustainable.

Finally, Obutey noted that it is also important to change the perception of the study team. In most community work, there is certainly a concept of *us* and *them*, even as people try to do more community-based research. There is still the sense that the researchers "came to our neighborhood and did these things and asked us all these questions, and they left and we don't know what happened, and we didn't get any of the money." In these circumstances, the community feels taken advantage of. This calls for a new collective in which community members,

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the private sector, and academic institutions participate equally. This has to happen at all levels and from the beginning. This type of collective form can shape effective community programs, establish an effective evaluation, and ultimately shape policy to establish other programs that continue in the community long after the grant funding period. This type of project is difficult because it can take 6–8 months for a community to decide if they really want to participate in a program. And then once they decide they want to participate, the community may have a different plan, and it takes time to retool a program that has already been approved by a funding agency. This added time becomes a barrier for researchers who have established grants with deadlines and timelines. Some participants suggested that further discussion was needed to resolve how community engagement could be covered under a funding structure.

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Thinking About New Visions of Water Services

Jeanne Bailey, Public Affairs Officer, Fairfax Water

My remarks are neither as the public affairs officer for Fairfax Water nor as the chair of the Water and Health Work Group for the American Water Works Association, but as someone who has spent 20+ years in the drinking water business. From a 60,000 foot perspective, a number of issues, including climate change and the current regulatory paradigm, have dominated and continue to dominate the national thinking.

CLIMATE CHANGE

Turn on a radio or a television set and the weather announcements concerning weather and water have a recurring theme: there is no rain, there has been no rain, and we have no idea when rain will occur. The National Climate Data Center is reporting that 43 percent of the contiguous United States is in a drought. Atlanta, Georgia, has declared that it has less than 90 days of drinking water supply left as of October 2007 and the Washington Metropolitan Region is at a record of 34 days without measurable rain as of October 2007. The weather patterns are changing; longer, dryer periods are followed by intense wetter periods. The result is that there will be challenges locally, nationally, and globally to take advantage of the precipitation in shorter periods of time. People need to think regionally about the best solutions, including aquifer storage and recovery, building additional reservoirs, or using seawater. One of these ideas may not be the right solution, but the time to have these discussions is now, in order to anticipate the crisis and not react when the utilities cannot provide water.

From a local utilities perspective, the current drought is a temporary issue. When it rains customers will have forgotten their concerns and will consider reseeding their lawns, possibly installing a hot tub or a pool. Most importantly, there will not be the support to increase water rates to support future water source development. However, a local utility has a responsibility to plan for water

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resources well beyond their current careers, to take care of their grandchildren's grandchildren. As entities concerned with global sustainability, local utilities need to be concerned about how to improve government thinking at the highest levels. There needs to be integration in how the utilities' plans will affect the changes in how local, regional, and national governments will address these issues. Until society is able to look beyond the methods and begin to strategize about the larger impact, there will be little effect on true global sustainability.

REGULATORY PERSPECTIVE

Fairfax Water provides water services for approximately 1.5 million people and is a critical point in the public health system through the delivery of safe, reliable, affordable drinking water for one of out every five Virginians. This water is used for baby formula and bathing, as well as sanitation and hygiene for the region. The utilities play an important role in public health, yet there is a vast chasm between the public health, medical, and water resource treatment and delivery systems.

When the U.S. Environmental Protection Agency was formed in 1970, it provided an essential and vital role in the protection of the environment, the air, wastewater, and many other vital resources. In 1974, Congress passed its first approach to protecting drinking water in the form of the Safe Drinking Water Act. Until this point, there had been a close marriage between water and public health in the form of the U.S. Public Health Service, but after this time, there was a shift. The shifting paradigm begs the question if the current regulatory framework is working. This workshop has been about global sustainability—looking for the best solutions of today's water and sanitation problems. Many people in the field (academia, government, nongovernmental organizations, and industry) spend their time and resources looking for the most affordable ways to implement incremental risk reduction to what are, by global comparison, pristine water and wastewater systems. The question remains if enough has been done to protect public health and the waters of the United States and can we move on to a global standard. There may be room for refinement.

This is not a condemnation of the Environmental Protection Agency or the current regulatory framework. But perhaps a change is needed in how one looks at who regulates what. The services of environmental health officers and the Commissioned Corps ensure public health and safety in a variety of domestic and international roles, such as epidemiological surveillance, disease prevention, industrial hygiene, education, and emergency preparedness. During natural disasters and other emergencies, environmental health officers protect the public from environmental threats and help communities recover. However, is this the best use of the limited resources available to be able to solve the larger problems of global sustainability? It is not only money that is limited, but also people and water. J.B. Manion, the former executive director of the American Waterworks Association,

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once said, "We are all of us water beings on a water planet. Water is life. Without it, all living things die. Our dependence on water is absolute. Our psyches know this and signal us in myriad ways of water's elemental importance and significance. That is why we love the water and remember experiences associated with it. Of the earth's vast resources, only a small fraction is fresh and drinkable. A small subset of individuals among the approximately 6 billion on this earth have been charged with the task of ensuring that everyone has a reliable source of safe water. Supplying potable water is an essential activity, a great responsibility, and a vocation of distinction."

As we conclude the workshop, my challenge to you is to go back to your offices and programs with the ideas that you have worked on for the past two days and plan strategically, whatever your task, whatever your research agenda, and ask a series of questions: Have you included all the players? Are you reaching high enough? Are you truly looking for the global solution? Each of us has the opportunity, the responsibility, to look at the larger platform. Each of us holds the solution to the future in our current actions. Each of us shares in this vocation of distinction.

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Breakout Group: Meeting Goals for Water, Sanitation, and Hygiene

With the understanding that robust discussions from all participants are difficult in an agenda-rich meeting, a final discussion continued on the third day to highlight research gaps, barriers, and challenges in providing global water sustainability. The group also noted what the workshop failed to capture and what should be included in future discussions.

STANDARDIZATION OF EVALUATION

The lack of a standardized mechanism to evaluate projects continues to be one of the most challenging barriers to overcome in providing sustainable water, according to some participants. Current evaluation practices monitor programmatic goals, such as the duration of the project, the number of wells, and financial goals (e.g., the number of projects funded or the amount of money dispersed). However, asserted some participants, programmatic monitoring misses the objectives of the funding: the need for safe drinking water. A better strategy would be to monitor whether interventions, activities, and programs have actually achieved their primary objectives. Participants noted that while these monitoring strategies are more difficult to implement, the monitoring of mortality and morbidity reduction in relation to water sustainability and hygiene is essential to improving sustainable water services. Mawuna Gardesey of the Delaware Division of Public Health observed that, in addition to meeting the primary objectives of supplying safe drinking water, an intervention-centered strategy will inform best practices and interventions that can be tailored to fit individual communities. For example, monitoring can provide insight into what is an effective balance between drinking water, sanitation, and hygiene interventions. However, Vincent Nathan of the City of Detroit Department of Environmental Affairs asserted that monitoring alone is not enough. The community needs to be engaged in the evaluation. He noted that while donors are primarily interested in the evaluation of programs and monetary

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allocation, community evaluation can provide workable knowledge for future projects and create a better sense of community ownership. In the end, Jennie Ward Robinson of the Institute for Public Health and Water Research noted that community-centered approaches coupled with intervention strategies are necessary if the global community is going to reach the Millennium Development Goals for water. She asserted that current evaluation strategies are not aligned with the goals and misguide program allocations.

BRIDGING THE GAP BETWEEN RESEARCH AND POLICY

Currently, some participants noted that there is a gap between research on sustainability and policy for implementing sustainable water services. The lack of evaluation and evidence-based science was identified as one of the main challenges in bridging the gap between research and policy. Nathan noted that the lack of evaluation fails to provide the facts, data, and evidence needed to further future policy, and, if there is not a commitment to remedy this situation, the policies developed will not be strategic. However, some participants noted that policy should be also community and population driven. Policy makers are ultimately moved by their constituents' needs and demands. Ward Robinson asserted that policy actions also need to be tied to evidence-based education of the policy makers. Furthermore, any policy development needs to incorporate a three-pronged approach (research, education, and community engagement) if effective policies are to be formulated. For water services, she noted that these three approaches need to happen in parallel so that water services plans are appropriate for the community, fiscally sound, and sustainable.

AN ABSENCE OF LEADERSHIP AT THE NATIONAL LEVEL

A third barrier identified by members of the group was the absence of leadership at the national level. Currently, researchers and agencies are not in a position to share lessons learned and best practices in a coordinated effort owing to a lack of a national clearinghouse for water practices. A national organization could synthesize the science and create an accessible database for all agencies and nongovernmental organizations, noted some participants. With a national database, future agencies and organizations can investigate what technologies are currently working and under what conditions. This will make better use of the funds and prevent overlap (continuation) of research. Ward Robinson further suggested that the clearinghouse would also serve to coordinate the efforts of donors. Ideally, she suggested, this clearinghouse would allow for policy makers, potential donors, and experts in the field to elicit information on current interventions under way, as well as who is working in particular research areas and geographical regions. Accessing this information, she noted, will allow for

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substantive decisions, funding, determination of the next research project, and identification of best practices.

AN INTERDISCIPLINARY APPROACH

Some participants identified an interdisciplinary approach as a need in providing sustainable water services. The problem starts early in professionals' training, during their education. University degree programs have strict curricula that do not allow for the multidisciplinary education needed to address these multifaceted problems, noted one participant. After graduation, the separation of disciplines continues. In most developed countries, the delivery of water and sanitation is relegated to engineers, and hygiene is overseen by public health professionals—there is not a lot of cross talk. One participant mentioned her concern that the current disconnect between disciplines in the U.S. education system is being transferred to these developing countries. We have social scientists educating communities on the value of water and engineers educating others on how to maintain the wells, but there is still no holistic approach to educating entire social groups and communities. This is problematic as groups are trying to reach target drinking water goals, noted one participant.

THE COMMUNITY AGENDA

Communities are not monolithic around the world, yet we try to solve the world's water problems as if they were, asserted one participant. Finding the balance between the goals of researchers and scientists with the wants of a community has been a struggle for many employed in water sustainability and can lead to a failed water intervention strategy. Sustainable water, hygiene, and sanitation may not be as highly valued in some communities as it is in the United States, noted some participants. These communities are content with their current water situation, regardless of how clean the water is or how far they must walk to retrieve it. Without a community's desire for water programs, researchers and scientists will be unable to create a long-term sustainable water infrastructure. For example, Paul Hunter of the University of East Anglia spoke of his experience in South Africa when a community's main priority was their desire for mobile telephone masts, while the researchers were concerned with ensuring a readily supply of potable water. These sometimes nonbasic needs took priority in the community for a variety of reasons that may not be obvious to the researcher. To remedy the situation, a commercial company was engaged to provide mobile telephone masts, which in turn created more business for them. Hunter noted that this example illustrates the need for compromise between researchers and the community. Supplying the community with what they desire (in exchange for what they need) contributes to the awareness of the importance of clean water and is supportive of program implementation. The stakeholders must work together

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to set up an agenda for a community, and that agenda must be based on both the goals of the researchers and the needs of the community.

BUILDING COMMUNITY INVOLVEMENT AND EDUCATIONAL CAPACITY

A theme echoed repeatedly by participants throughout the workshop was the need to appropriately engage the community, encourage ownership of the project, and provide the education to local community members to ensure sustainability of the program. While this is a well-understood need for any successful program, it has continued to be one of the biggest challenges to overcome, noted many participants.

The problem is twofold. Developing countries and communities without financial stability are most likely to be willing to accept money or water programs from any donor offering help. Similarly, institutions are not educating the donors on best practices, in turn potentially hurting the communities more than helping. Without the proper education, donors' decisions may not garner the expected or desired outcome, resulting in poorly utilized funds, time, and resources. Many donors require that, in exchange for funding from their company, the recipients must agree to use their technology and buy directly from them for the life of the well. This type of funding hinders the region's efforts in creating a sustainable national utility, asserted one participant. What becomes visible too often, noted Ward Robinson, are poorly managed or maintained equipment, as training and resources for repairs may not be indigenous to the local community. Thus the education of the community and the use of local labor, skills, and resources have been identified as one of the best ways to help to create community ownership and longevity of programs. And yet funding programs are not designed with a long-term outlook, asserted Ward Robinson. Often the time frame of the program is 3–6 months, but the continuity after the funding is not considered.

One way to address this barrier is to have interdisciplinary education for community members to ensure the project's sustainability after sponsors leave, noted one participant. This community engagement will ensure that people are equipped with the proper skill set needed to create long-term sustainability and capacity. Ward Robinson felt that too few donors are currently utilizing an existing trusted institutional system to further the educational and technical capacity of the local community. This investment in resources could be used to increase the longevity of the project, as they would be educating the youth, who would in turn educate their parents and future children.

The discussion also focused on creating an educational capacity in a country, so that citizens could implement similar water programs in other communities. This strategy would end the need for nongovernmental organizations to establish prolonged residence in the local community by shifting the power to the individual communities and in addition begin to build and strengthen a national

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utility. A participant gave examples of how this process is being used in some communities. Nongovernmental organizations create water resource community building groups, which work to educate key members in the community to lead the maintenance and sustainability of the project after the outside group leaves. They also work to educate community members and create regional experts who can work throughout the region as experts on water. These local water experts will help create national ownership of new program implementations. The advantage of this approach is to increase the efficiency of intervention strategies. As programs are tailored for individual communities, researchers spend large amounts of time and resources learning about individual community cultures, modifying each program to fit societal needs. By creating a national utility led by a group of educated locals, implementation time will be reduced, as the locals will already be aware and understanding of the cultural differences. They will also be able to gain community trust and create community support faster than foreign scientists and researchers, noted some participants.

Finally, many participants agreed that nongovernmental organizations are able to make large change at the community level, but they find it difficult to bring national attention or change in regard to water. Some of these countries do not have stable national governments to impede the implementation of these programs. The community by community approach is therefore most feasible. Communities are many times more stable and less volatile than many national governments. In some regions of the world, water projects have been implemented at a national level only to have the country overturned and dismantled after years of resources investment into the programs. By focusing on the community, not only does it ensure continuity of ownership of the program, but also the communities provide stability, even during a disruption of the national government.

THE ROLE OF DONORS

Many times donors' personal interest in their investment return can create barriers in the ability to develop a comprehensive, sustainable program on the national level, noted some participants. Ward Robinson commented that providing safe drinking water is a hot philanthropic effort, with many potential donors looking for opportunities to invest money in programs. However, this influx of money brings technological challenges when donors do not fund technology that can be used interchangeably. When multiple individual communities in the same region or country receive different technology, the national government is unable to provide adequate maintenance and funding for long-term sustainability. Donors need to be educated on the need to fund interchangeable technology that can operate with other products, so the national government can develop a national utility with cohesive technology, asserted one participant.

A second challenge with donors is the role of businesses in providing sustainable water services. There is a sometimes-negative stereotype of working

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with large, for-profit corporations that has proven to be a challenge for many nongovernmental organizations and nonprofits to overcome. Many times possible funding opportunities go untapped for fear of the negative connotation that groups believe will be used against them for working with large corporations, asserted one participant. Instead, there is a need to educate corporations on their ability to provide social influence and to create a return in funding sustainable communities. Participants voiced the need to bring donors together in dialogue with agencies in order to discover the philanthropic and business opportunities that water sustainability projects can supply. By including donors in the dialogue and educating them on the needs of communities, some participants believe that donors would become more tolerant for the program designs, nuances, and ad hoc requests that emerge while executing a project.

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Appendix A

Workshop Agenda

GLOBAL ENVIRONMENTAL HEALTH:
RESEARCH GAPS AND BARRIERS FOR PROVIDING SUSTAINABLE WATER, SANITATION, AND HYGIENE SERVICES

Sponsored by
Roundtable on Environmental Health Sciences, Research, and Medicine

October 17, 2007

9:00 a.m. **Welcome**
Paul G. Rogers, J.D.
Chair, Roundtable on Environmental Health Sciences, Research, and Medicine
Partner, Hogan & Hartson

9:10 a.m. **Workshop Objectives**
Jennie Ward-Robinson, Ph.D.
Executive Director, Institute for Public Health and Water Research

SESSION I: GLOBAL WATER SERVICES:
SHORT- AND LONG-RANGE VIEWS

Session Goal: To develop a global overview of water by understanding human and ecological stresses on our ability to deliver water; to define sustainable water; and identify barriers to sustainability.

Moderator: Cathy Abramson, Member, Tribal Board, Sault Tribe of Chippewa Indians

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9:30 a.m. **The Native American Approach to Sustainable Water: The Seventh Generation Concept**
Cathy Abramson
Member, Tribal Board, Sault Tribe of Chippewa Indians

9:35 a.m. **Pure and Plentiful: The Origins of Urban Water Supply Systems**
Martin Melosi, Ph.D.
Distinguished University Professor of History, University of Houston

10:00 a.m. **Sustaining Progress for Clean and Safe Water**
Benjamin Grumbles, J.D.
Assistant Administrator for Water, Environmental Protection Agency

10:25 a.m. **Discussion** (initial Q&A about the presentations, followed by discussion of these topics with panel and audience members)
What is a definition of sustainable water system?

10:45 a.m. **Break**

SESSION II: THE TECHNOLOGY PILLAR OF SUSTAINABLE WATER: TECHNOLOGY, ECONOMICS, AND HEALTH

Session Goal: To understand how the technology sector will develop strategies to address water needs in a variety of settings—from developing to developed regions, and from rural to megacities, and to integrate this knowledge in a sustainable fashion to ensure health.

Moderator: Yank Coble, M.D., Distinguished Professor and Director of the Center for Global Health and Medical Diplomacy, University of North Florida and Clinical Professor of Medicine, University of Florida

11:05 a.m. **Moving Toward Megacities: Decentralized Systems**
Asit K. Biswas, Sc.D.
President & Academician, Third World Centre for Water Management

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11:30 a.m.	**Overview of the Water Sector: Policies, Institutional Roles, and Key Issues for Utility Services Delivered in Ghana** Eric Kofi Obutey, M.B.A. Economist and Manager, Public Utilities Regulatory Commission, Ghana
11:55 a.m.	**Discussion**
12:20 p.m.	**Lunch**
1:00 p.m.	**Clean Drinking Water: Solving the Arsenic Crisis Through a Sustainable Local Filtration Technology** Abul Hussam, Ph.D. Professor, George Mason University
1:25 p.m.	**Small- to Medium-Sized Systems: Opportunities and Challenges** Graciela Ramirez-Toro, Ph.D. Center for Environmental Education, Conservation and Research (CECIA), San German Campus, Inter American University of Puerto Rico (IAUPR)
1:50 p.m.	**The Use of Technologies: Exposure (Cross-Contamination), Risk Assessment, and Guidelines** Nick Ashbolt, Ph.D. Senior Research Microbiologist, National Exposure Research Laboratory, U.S. EPA
2:15 p.m.	**Approaches to Sustainability: Global Water Partnerships** Wayne Joseph, M.Sc. Chair, Global Water Partnership—Caribbean
2:40 p.m.	**Discussion** (initial Q&A about the presentations, followed by discussion of these topics with panel and audience members) How can we ensure sustainability as we implement water technologies? How do we resolve the tensions between technology and social issues in an economic setting? What is the role of environmental health as technologies are implemented or refined?
3:20 p.m.	**Break**

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PANEL DISCUSSION:
COORDINATION AND PRIORITIZATION OF WATER NEEDS

3:35 p.m.

What are our priorities for achieving sustainable water services?
How can we identify solutions and prioritize according to what technology is suited for a given region?
How do we have better coordination across NGOs, governments, and researchers to facilitate the delivery of safe water for health without duplicating activities?
How do we ensure that technological solutions have longevity and are evaluated for effectiveness?
How can better access to data and tracking of water-borne diseases be achieved?

Moderator: Paul Hunter, M.D., M.B.A., Clinical Professor, University of East Anglia

Jennie Ward-Robinson, Ph.D., Executive Director of the Institute for Public Health and Water Research
Stephanie Adrian, M.P.H., International Water Programs Manager, U.S. Environmental Protection Agency
Cheryl K. Davis, Manager, San Francisco Public Utilities Commission's Workforce Development Initiative
Cecilia Tortajada, Ph.D., President, International Water Resources Association
Peggy Geimer, M.D., Corporate Medical Director, Arch Chemicals, Inc.
Wayne Joseph, **M.Sc.,** Chair, Global Water Partnership—Caribbean

5:00 p.m. **Adjourn for the Evening**

October 18, 2007

8:30 a.m. **Welcome Back**

8:35 a.m. **Improving Water and Sanitation Access in Developing Countries: Progress and Challenges**
Christine Moe, Ph.D.
Eugene J. Gangarosa Professor of Safe Water and Sanitation
Director, Center for Global Safe Water at Emory University, Hubert Department of Global Health, Rollins School of Public Health at Emory University

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9:15 a.m. **Water Supply and Sanitation in Latin America: Moving Toward Sustainability Following Two Decades of Reforms**
Andrei Jouravlev
Economic Affairs Officer, United Nations Economic Commission for Latin America and the Caribbean

9:50 a.m. **Discussion** (initial Q&A about the presentations, followed by discussion of these topics with panel and audience members)
What are the short-term and long-term needs to reach a sustainable water system both in developing and developed countries?
What are the challenges for sustainable water from the regional government and global perspectives?

10:10 a.m. **Break**

SESSION III: THE ENVIRONMENTAL PILLAR OF SUSTAINABLE WATER: ECOLOGICAL SERVICES

Session Goals: To understand the role of the environment in the delivery of safe drinking water through ecological services, and to illuminate discussion on the tensions between the built environment, ecological health, and water.

Moderator: Howard Frumkin, M.D., Dr.P.H., Director, National Center for Environmental Health, CDC

10:35 a.m. **Drinking Water Valuation: Challenges, Approaches, and Opportunities**
Diane Dupont, Ph.D.
Professor of Economics, Brock University

11:00 a.m. **Impacts of Demographic Changes and Water Management Policies on Freshwater Resources**
Jill Boberg, Ph.D.
Consultant

11:25 a.m. **Sustainability of Drinking Water: Some Thoughts from a Midwestern Perspective**
R. Peter Richards, Ph.D.
Senior Research Scientist, National Center for Water Quality Research, Heidelberg College

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11:50 a.m. **Discussion** (initial Q&A about the presentations, followed by discussion of these topics with panel and audience members)
How do we account for the (monetary) value of ecology in providing drinking water?
How do we strike a balance between the competing interests for water in society when many countries and many agencies within a country govern various aspects of water usage?
How do we integrate ecology into a sustainable water plan?
What are the opportunities to integrate knowledge of political will, cultural and behavioral factors, and demographic trends to obtain more sustainable water services?

12:20 p.m. **Lunch**

SESSION IV: THE SOCIAL PILLAR OF SUSTAINABLE WATER: HEALTH RESEARCH GAPS

Session Goal: To understand the linkage between water services, chronic diseases, and water-borne diseases. To identify how to integrate water, sanitation, and hygiene into a sustainable water delivery system.

Moderator: Carol Henry, Ph.D., Vice President for Industry Performance Programs, American Chemistry Council

1:05 p.m. **Water and Health: A Global Picture of Risk and Impact on Chronic Illnesses**
Paul Hunter, M.D., M.B.A.
Professor, University of East Anglia

1:45 p.m. **The Interdependency of Water, Sanitation, and Hygiene (Hierarchical Approach)**
Richard Gelting, Ph.D., P.E.
National Center for Environmental Health, Centers for Disease Control and Prevention

2:10 p.m. ***"Preliminary"* Overview of Current Research and *Possible* Research Priorities: Small-Community Drinking Water Supplies**
John Cooper, Ph.D.
Director of the Water, Air and Climate Change Bureau, Health Canada

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2:35 p.m. **Discussion with Audience:** (initial Q&A about the presentations, followed by discussion of these topics with panel and audience members)
How do we determine acceptable risk levels (population vs. personal risk levels)?
What are the research gaps for understanding the interdependency of water, sanitation, and hygiene?
What is the economic burden of water-borne diseases and how can cooperation among governments begin to address this?

3:00 p.m. **Break**

THE HUMAN DIMENSION OF WATER SERVICES

3:15 p.m. **Cultural Influences and Acceptance of New Ideas**
Peggye Dilworth Anderson, Ph.D.
Professor, University of North Carolina at Chapel Hill

PANEL DISCUSSION: MOVING FORWARD

3:40 p.m.
The moderator will lead a discussion with the panel members and the audience to identify the following:

1. What are the research needs to achieve more sustainable water solutions?
2. How can we draw on the successes of case studies and learn from the barriers to implement safe water systems more effectively?
3. How do we facilitate collaboration amongst experts in the water field so that sectors (e.g., financial, technological, ecological, social, and public health) are integrated in their approaches?
4. How can risk-based, evidence-based frameworks be used more effectively to attain sustainable water solutions in the social and political landscapes?

Moderator: Vincent R. Nathan, M.D., Director, Department of Environmental Affairs, City of Detroit

Christine Moe, Ph.D., Eugene J. Gangarosa Professor of Safe Water and Sanitation Director, Center for Global Safe Water at Emory University, Hubert Department of Global Health, Rollins School of Public Health at Emory University
Diane Dupont, Ph.D., Professor of Economics, Brock University

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R. Peter Richards, Ph.D., Senior Research Scientist, National Center for Water Quality Research, Heidelberg College
Phyllis Nsiah-Kumi, M.D., Northwestern University Feinberg School of Medicine, Division of General Internal Medicine
Joe G. Jacangelo, Ph.D., Vice President and National Technical Director, National Technology Group, MWH

CLOSING

4:30 p.m. **Thinking About New Visions of Water Services**
Jeanne Bailey
Public Affairs Officer, Fairfax Water, Chair, Water Health Work Group, American Water Works Association

4:45 p.m. **Adjourn**

October 19, 2007

BREAKOUT SESSION FOLLOWING: GLOBAL ENVIRONMENTAL HEALTH: RESEARCH GAPS AND BARRIERS FOR PROVIDING SUSTAINABLE WATER, SANITATION, AND HYGIENE SERVICES

Session Goal: To follow-up in a small breakout on the previous two-day meeting to capture additional information about challenges in many countries including Africa and Latin America. The format will be on discussion and will not rely on presentations. This breakout session is open to all participants from the workshop.

8:30 a.m. **Welcome and Introduction of participants**
Jennie Ward-Robinson, Ph.D.
Executive Director, Institute for Public Health and Water Research

8:40 a.m. **Discussion: Review of the Workshop—The Challenges for Africa, Latin America, and Other Countries**
This discussion will help to frame the specific research needs and topics that are important to these regions that may bear additional discussion.

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10:30 a.m. **What Are the Priorities for Developing Countries in Reaching Sustainable Water Services?**
This discussion will focus on highlighting the developing countries perspectives on water services and discuss research needs, challenges of coordination with other organizations, and implementation needs.

12:00 p.m. **Adjourn with Lunch Provided**

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Appendix B

Speakers and Panelists

Cathy Abramson
Director
Sault Tribe of Chippewa Indians

Stephanie Adrian
International Water Programs Manager
U.S. Environmental Protection Agency

Nicholas Ashbolt
Senior Microbiologist
U.S. Environmental Protection Agency

Jeanne Bailey
Public Affairs Officer
Fairfax Water

Asit K. Biswas
President
Third World Centre for Water Management

Jill Boberg
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John Cooper
Director
Health Canada

Cheryl Davis
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San Francisco Public Utilies Commission

Peggye Dilworth Anderson
Professor
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Dianne Dupont
Professor
Brock University

Peggy Geimer
Corporate Medical Director
Arch Chemical, Inc.

Richard Gelting
Environmental Engineering
Centers for Disease Control and Prevention

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Benjamin Grumbles
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Paul Hunter
Professor
University of East Anglia

Abul Hussam
Professor
George Mason University

Joseph Jacangelo
Vice President and National Technology Director
MWH Americas, Inc.

Wayne Joseph
General Manager Operations
Water & Sewerage Authority

Andrei Jouravlev
Economic Affairs Officer
United Nations

Martin Melosi
Distinguished Professor
University of Houston

Christine Moe
Associate Professor
Emory University

Vincent Nathan
Former Director of Environmental Affairs
City of Detroit

Phyllis Nsiah-Kumi
Assistant Professor
University of Nebraska Medical Center

Eric Obutey
Manager
Public Utilities Regulatory Commission, Ghana

Graciela Ramirez-Toro
Director
Inter American University of Puerto Rico

R. Peter Richards
Senior Research Scientist
Heidelberg College

Paul Rogers
Partner
Hogan & Hartson

Cecilia Tortajada
Vice President
Third World Centre for Water Management

Jennie Ward-Robinson
Executive Director
Institute of Public Health and Water Research

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Appendix C

Workshop Participants

J.P. Ahluwalia
Johns Hopkins Bloomberg School of Public Health

Erin Anderson
Health and Human Services

Marci Balge
Partner
NewFields

Trisha Bergmann
American Association for the Advancement of Science/U.S. Environmental Protection Agency

Rebecca Blank
American Association for the Advancement of Science, Science and Technology Policy Fellow
U.S. Environmental Protection Agency

Sarah Bronko
Senior Program Assistant
Board on Global Health
Institute of Medicine

Eileen Choffnes
Scholar
Forum on Microbial Threats
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Margaret Chu
Biochemist
National Center for Environmental Assessment, Office of Research and Development
U.S. Environmental Protection Agency

Chelsea Clouatre
Department of Health and Human Services

Charles Darr
Environmental Health Fellow
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Richard Davis
Analyst
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Health and Social Services
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George Washington University

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Health Safety Environment & Energy
U.S. Public Health Commissioned Corps

J. Stephen Fries
Sci & Tech Policy Fellow
American Association for the Advancement of Science/U.S. Environmental Protection Agency

Mawuna Gardesey

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Park Ranger
National Mall and Memorial Parks
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Jose Mansen
Legal & Regulatory Specialist
Engineering
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Lia Marshall
Immunization
Pan American Health Organization

Myrtle McCulloch
Asst. Professor of Nutrition
International Health
Georgetown University, School of Nursing and Health Studies

Jeff Moeller
Senior Program Director
Water Environment Research Foundation

Matt Moy
American Medical Student Association

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Lola Olabode
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Water Environment Research Foundation

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Lisa Patel
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Johns Hopkins School of Medicine

Janet Phoenix
Director of Policy Research
National Research Center for Women & Families

Lisa Ragain
The George Washington University
Center for Risk Science and Public Health

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Environmental Scientific Instruments

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National Association of County and City Health Officials

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